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Preface

This Post-Congress Report is an important completion to the Congress Report, which had been published for the 14th IABSE Congress in New Delhi, 1-6 March 1992. It contains keynote lectures and contributions to the daily themes and to sessions dealing with the Congress' general theme "Civilisation through Civil Engineering". Many new ideas and solutions had been proposed and important knowledge exchanged which will lead to progress in all fields. These themes will remain, for years to come, a "challenge" for all structural engineers.

Once more, I wish to congratulate the Organizers of the 14th IABSE Congress on their success. In particular, I wish to thank the Indian National Group of IABSE, Messrs Ninan Koshi, Chairman, and S.P. Chakrabarti, Secretary, as well as Dr. T.N. Subba Rao, Chairman of the Scientific Committee and Vice-President of IABSE. My words of thanks also go to the many volunteers who worked behind the scenes, especially to Mr. Krishan Kant, Deputy Secretary of the Congress.

Further, I wish to thank all authors of contributions, all Committee members and participants of the Congress. I am looking forward to seeing you at the 15th Congress of IABSE 1996 in Copenhagen.

Zurich, May 1992

Prof. Hans von Gunten
President of IABSE

Préface

Ce Rapport Post-Congrès est un complément essentiel au Rapport du Congrès publié à l'occasion du 14e Congrès de l'AIPC à la Nouvelle Delhi, du 1 au 6 mars 1992. L'ouvrage présente des exposés magistraux et des contributions aux thèmes quotidiens et aux séances du Congrés "Le génie civil au service de la civilisation". De nombreuses idées et des solutions originales ont été présentées et discutées à l'occasion du Congrés; il en résultera des progrés. Ces thèmes restent néanmoins des défis à l'ingénieur des structures pour les années à venir.

Il m'est agréable de féliciter et d'exprimer mes sentiments de reconnaissance aux Organisateurs de notre 14e Congrés. Je tiens à remercier le Groupe Indien de l'AIPC et, plus particulièrement, Messieurs Ninan Koshi, son président, et S.P Chakrabarti, son secrétaire; ainsi que M. le Dr. T.N. Subba Rao, Président du Comité Scientifique et Vice Président de l'AIPC. De nombreux volontaires ont oeuvré en coulisses et je les remercie également, en mentionnant spécialement M. Krishnan Kant, dévoué Secrétaire adjoint du Congrés.

A tous les auteurs de contributions, à tous les membres des comités de l'AIPC et aux participants, j'exprime ma grande satisfaction pour ce magnifique Congrés et leur donne rendez-vous à Copenhague en 1996 pour le 15e Congrés de l'AIPC.

Zurich, mai 1992

Prof. Hans von Gunten
Président de l'AIPC

Vorwort

Dieser Schlussbericht ist eine wichtige Ergänzung zum Kongress-bericht, der anlässlich des 14. IVBH Kongresses in Neu Delhi, 1.-6, März 1992, veröffentlicht worden ist. Er enthält Einführungsvorträge und Beiträge die sich den Tagesthemen und Sitzungen, in Bezug auf das Kongressthema "Leben durch Bauen" widmen. Zahlreiche neue Ideen und Lösungsvorchläge wurddem vorgeschlagen und beratgen. Es dürfte zu Fortschritten in allen Bereichen führen. Dennoch bleiben diese Themen auch in Zukunft für jeden Bauingenieur "Herausforderungen".

Gerne möchte ich an dieser Stelle den Organisatoren des 14. IVBH Kongresses noch einmal herzlich zu ihrem Erfolg gratulieren. Im Speziellen möchte ich der Indischen Gruppe der IVBH, den Herren Ninan Koshi, Präsident, und S.P. Chakrabarti, Sekretär, sowie Herrn Dr. T.N. Subba Rao, Vorsitzender des Wissenschaftlichen Komitees und Vize-Präsident der IVBH, für ihren Einsatz danken. Die zahlreichen Mitarbeiter, die hinter den Kulissen gewirkt haben, verdienen unseren besonderen Dank, ebenso wie Hr. Krishan Kant, Stellvertretender Generalsekretär des Kongresses.

Mein Dank gebührt auch allen Autoren, allen Komiteemitgliedern und Teilnehmern des Kongresses. Gerne möchte ich abschliessend meine Zufriedenheit über diesen erfolgreichen Kongress ausdrücken und freue mich auf ein Wiedersehen am 15. IVBH Kongress 1996 in Kopenhagen.

Zürich, im Mai 1992

Prof. Dr. Hans von Gunten
Präsident der IVBH

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Opening Ceremony of the 14th IABSE Congress

Cérémonie d'ouverture du 14e Congrès de l'AIPC

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Welcome Address

Discours de bienvenue

Wilkommensansprache

NINAN KOSHI
Chairman, Organising Committee and
Chairman,
Indian National Group of IABSE
NEW DELHI, India

1. Hon'ble Minister for Surface Transport, Mr. Tytler
2. President, IABSE, Prof. Von Gunten
3. Secretary, Ministry of Surface Transport, Mr. Abraham
4. Secretary, Department of Posts, Mr. S.P. Gulati
5. Secretary ING, Mr. S.P. Chakrabarti
6. Distinguished Guests, Delegates to the Congress, Ladies and Gentlemen

It is a matter of great privilege and pleasure for me as Chairman of the Indian National Group and of the Organising Committee to extend a hearty welcome to all of you on the occasion of the inauguration of the 14th Congress of the International Association for Bridge and Structural Engineering.

It was a great moment for the Indian National Group when its bid to host the 14th Congress of the IABSE was accepted by the Parent Body in 1988. Since then we have been preparing for the Congress and we are extremly happy to see the culmination of our efforts today at this inauguration ceremony which is graced by so many distinguished guests and delegates from India and abroad.

The IABSE is the most reputed international body dealing with multi-disciplinary aspects of structural engineering. The Congress of the IABSE attended by a galaxy of loading luminaries of the bridge and structural engineering profession affords an unique opportunity for exchange of views at the professional level, cross fertilization of ideas and opening of new vistas.

India has a history of excellence in building structures dating back over many thousands of years. The many ancient monuments and edifices which can be seen even today bear witness to this magnificent structural heritage. They examplify the theme of this Congress which is 'Civilisation through Civil Engineering' or the vital role of structures in the orderly growth of civilisation. I am sure many of our delegates from abroad who may be going on the post-Congress tours will get an opportunity of seeing some of these historic structures as well as some of the more modern structures which signify India's march towards progress and development.

In conclusion I wish to once again welcome and express my thanks to all our distinguished guests and especially to all the delegates who have come from far and wide to enrich and enliven the deliberations of this Congress with their valuable participation. We hope your discussion will be fruitful, that your stay will be comfortable and that you will carry back with you pleasant memories of this Congress, this historic city and this country.

Inaugural Address.

Discours d'ouverture

Eröffnungsansprache

JAGDISH TYTLER
Honourable Minister of State for Surface Transport
Government of India, New Delhi

Distinguished delegates.
Ladies and Gentlemen,

It gives me great pleasure to be amongst the eminent bridge and structural engineers of the world who have assembled here for the 14th Congress of the International Association for Bridge and Structural Engineering being organised by the Indian National Group of the IABSE under the patronage of Government of India, Ministry of Surface Transport (Roads Wing) and State Governments.

The theme of the congress is **"Civilisation through Civil Engineering"**, which aims at highlighting the all embracing nature of civil engineering in shaping and improving the built environment for the benefit of society. From the primitive society to the present industrial age, it is civil engineering technology which is producing the basic infrastructure for development and growth. It is, therefore, very appropriate that the Fourteenth Congress of the IABSE should focus attention on the close relationship between civilisation and engineering.

As we know the United Nations have proclaimed the nineties as the "International Decade for Natural Disaster Reduction" India and many other developing countries are highly prone to natural disasters such as earthquakes, land slides, floods, cyclones and tidal waves which cause immense damage to life and property every year. The recent devastating earthquake which rocked the Uttar Kashi region of northern India comes to mind. I am happy to know that eminent structural engineers will investigate in this Congress various ways and means of mitigating such natural disasters so as to reduce loss of life, damage to property and economic and social disruption.

Environmental pollution, thanks to the rapid pace of industrialisation in the world, is another important issue which is of great concern to humanity. Large scale urbanisation, de-forestation, discharge of industrial effluents in the rivers and indiscriminate use of hydrocarobons are some of the harmful effects of industrialisation which are creating ecological imbalance. It is, therefore, apropriate that the Congress will be examining the environmental impact of civil engineering projects and providing suitable guidelines. It is also heartening to know that special emphasis is being given to large scale technical exploitation of renewable energy like solar energy and the contribution that the civil engineer can make to this cause.

A large and efficient highway network is essential for economic development for which we are all striving. Our transportation needs are growing by leaps and bounds and improved technology and quicker methods of construction are required to meet the demand. Bridge structures form a vital part of any road network and their construction maintenance and upkeep are of great importance in keeping the arteries of communication open. For bridging the very wide Indian rivers, specific solutions with long span structures will be required. Apart from this, there will also be very heavy bridging activity in this country in the years to come. I am sure the bridge engineers of this country will make full use of this opportunity to interact with their counterparts from abroad and bring themselves uptodate with the latest thinking in these areas.

I note with appreciation the fact that one of the sessions of this congress is being devoted in discussing world trends in financing of projects. This is indeed a very topical subject and I am sure all countries whether developed or developing are facing the same problem of finding enough resources to expand and develop their transportation infrastructure. In this regard the need for going in for new and unconventional sources of financing other than that provided by Government is now quite well recognised. I hope the deliberations in this regard will lead to some practical conclusion which can be immediately put to use for successful implementation of projects.

The Indian National Group of the IABSE, ever since it was set up in 1957, has been playing a leading role as a forum for exchange of ideas and dissemination of the latest technical information regarding bridges and structures. It has been one of the most active National Groups of the IABSE and has been extremely successful in holding many international seminars on very important and topical subjects in structural engineering whose published proceedings have become work of refrenence for structural engineers of the country. The holding of this 14th Congress of the IABSE in India is indeed a feather in the cap of the Indian National Group. I have no doubt that the group will go from strength to strength in its endeavours to serve the engineering profession in this country.

I am told that this is the first time that the Congress of the IABSE is being held in a developing country in Asia. I am sure that the technical discussions of the congress will not only be stimulating and rewarding but would also be extremely beneficial for the bridge and structural engineers of the country.

I would like to offer my sincere thanks to the Indian National Group of IABSE for giving me this opportunity to be here today and share my views with you. I wish you a happy stay in this historic city and success in your deliberations.

With these words, I declare this Congress Open.

Opening Address

Discours d'ouverture

Eröffnungsansprache

Prof. HANS VON GUNTEN
President of IABSE
Président de l'AIPC
Prasident der IVBH

Ladies and Gentlemen,
Dear colleagues,

It is a great honour and pleasure for me to welcome all of you here in New Delhi on behalf of the International Association for Bridge and Structural Engineering.

In the first place, let me address our hosts, our Indian friends who have organized this Congress. It is, for all of us, a most remarkable event that we have the opportunity to gather in your marvellous country. We are impressed by your great hospitality and aware that a number of interesting days lie ahead to which we look forward with anticipation and we are sure that we will always remember them with pleasure. For all this, my dear friends from India, I would like to extend to you my utmost appreciation and heartfelt thanks.

I would like, in particular, to greet the ladies who enlighten through their presence the social programme of the Congress. Accompanying persons are always welcome at our events and without them their charming presence would be really missed.

The identity of the International Association for Bridge and Structural Engineering is dependent not only on the quantity but also on the quality of the participants. The numerous authors of contributions, the session chairmen and the members of the Scientific Committee guarantee the high standard of our Association. We would like to express our most sincere thanks and appreciation.

Associations such as ours are being confronted with some tough gales, with a heavy recession worldwide and increasing unemployment. We are not at a stage where we have to fight for our survival, but serious consideration has to be given to IABSE's future. Many of our members are indeed experiencing great difficulties in paying their membership fees. I appeal to some of our National Groups to initiate sponsorship, for a limited period of time, of collective membership fees. In this day and age, affluent countries could do their share to reduce the North-South gap. Furthermore, the Executive and Administrative Committees are faced with an increasing lack of moral fibre in payment attitude which costs thousands of francs annually to the Association, thus a threat to our own funds. We are quite willing to talk about codes of ethics and to philosophize on these but we should not forget to abide by our declarations.

Sehr geehrte Damen und Herren,
werte Kolleginnen und Kollegen,

Im Namen der Internationalen Vereiningung für Brückenbau und Hochbau, ist es mir eine grosse Ehre und besondere Freude, Sie alle in Neu Delhi willkommen zu heissen.

Lassen Sie mich bitte zuerst unsere indischene Freunde ansprechen, welche diesen Kongress vorbereitet haben: Es ist eine bemerkenswerte Tatsache und eine grosse Chance für uns alle, uns in Ihrem wunderschönen Land zu treffen. Ihre gross Gastfreundschaft beeindruckt uns sehr. Interessante Tage liegen vor uns und wir werden sie mit Freude in Erinnerung behalten. Für all dies möchte ich Ihnen, liebe Freunde aus Indien, gratulieren und herzlichst danken.

Insbesondere möchte ich die Damen begrüssen, die durch Ihre Anwesenheit die Tatigkeiten des Gesellschaftlichen Programms erleuchten. Die Begleitpersonen sind an unseren Veranstaltungen willkommen und wir möchten keinesfalls ihre Anwesenheit und ihren Charme vermissen.

Der Ruf der Internationalen Vereinigung für Brückenbau und Hochbau resultiert aus der Anzahl und der Qualität der Teilnehmer. Die vielen Autoren von den Beiträgen, die Sitzungsvorsitzenden, sowie die Mitglieder des wissenschaftlichen Komitees sorgen für das hohe Niveau unserer Vereinigung. Ich bin Ihnen sehr dankbar.

Ein rauher Wind weht Vereinigungen wie der unseren ins Gesicht. Weltweit stellt sich eine grosse Rezession ein, Arbeitslosigkeit macht sich breit. Nicht dass wir einen Kampf ums Ueberleben fechten, doch müssen wir uns ernsthaft Gedanken zur Zukunft der IVBH machen. Viele unserer Mitglieder haben tatsächlich grosse Mühe, die Mitgliederbeiträge zu entrichten, und ich apelliere an unsere nationalen Gruppen, für solche Länder und Hochschulen zeitlich begrenzte Kollektivmitgliedschaften im Sinne einer Patenschaft zu übernehmen. Dadurch würden die reichen Länder einen sinnvollen Beitrag zur Verminderung des Nord-Süd-Gefälles leisten. Daneben stellen wir im Vorstand und in der Geschäftsleitung eine zunehmende Verwilderung der Zahlungsmoral fest, die unsere Vereinigung jährlich Tausende von Franken kostet und unsere Substanz gefährdet. Wir sind gerne bereit, von hehren ethischen Zielen zu sprechen und darüber zu philosophieren. Vergessen wir aber nicht, von uns selbst auch entsprechede Taten zu verlangen!

Mesdames, Messieurs
Chers collègues,

Au nom de l'Association Internationale des Ponts et Charpentes, j'ai l'honneur et le plaisir de vous souhaiter la bienvenue à la Nouvelle Delhi.

Permettez que je m'adresse d'abord à nos hôtes indiens, organisateurs de ce Congrès. C'est pour nous tous un évènement remarquable que de pouvoir se réunir dans votre merveilleux pays. Votre grande hospitalité nous impressionne et nous savons que des jours intéressants s'annoncent à nous. Nous nous préparons à vivre ces journées avec curiosité et nous sommes sûrs que nous en emporterons un souvenir plaisant. Pour toutes ces expériences à venir, chers amis de l'Inde, je désire vous exprimer ma gratitude et mes chaleureus remerciements.

Je désire, en particulier, saluer les dames qui illuminent par leur présence les activités du programme social de Congrés. Les personnes accompagnantes sont les bienvenues à nos manifestations et nous ne voudrions en aucun cas manquer leur présence et leur charme.

L'image de l'Association Internationale des Ponts et Charpentes est le résultant du nombre et de la qualité des participants. Les nombreux auteurs de contributions, les présidents de séance et les membres du Comité Scientifique sont les garants du haut niveau de notre Association. Qu'ils acceptent notre reconnaissance et l'expression de nos sincéres remerciements.

Un vent rude souffle à la face d'associations telles que la nôtre. Une grande récession s'installe dans le monde entier, le chômage croît. Nous n'en sommes pas à combattre pour notre survie, mais il y a lieu de nous poser de sérieuses questions pour l'avenir de l'AIPC. De nombreux membres de l'AIPC ont en effet des difficultés considérables à régler leurs cotisations. J'en appelle à certains de nos groupes nationaux, lesquels pourraient parrainer, pour une période limitée, quelques membres collectifs. De cette maière, les pays riches pourraient entreprendre une action utile pour réduire l'écart entre le Nord et le Sud. Nous devons constater, au sein des Comités Exécutif et Administratif, une tendance désastreuse dans le paiement des cotisations qui entraîne chaque année des pertes de milliers de francs et qui diminuent dangereusement les fonds propres de l'Association. Nous sommes volontiers disposés à parler de régles d'éthique et de philosopher sur la question. Mais n'oublions pas de joindre le geste à la parole!

Plenary Session 1

New Horizons in Structural Engineering

Nouvelles frontières dans les constructions de génie civil

Herausforderungen an den konstruktiven Ingenieurbau

Organizer:	Michel Virlogeux, France
Chairman:	D.W. Quinion UK

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Civil Engineering and Water Conservation

Génie civil et protection des eaux

Bauingenieurwesen und Wasserschutz

Thierry CHAMBOLLE
Vice-Pres.
Lyonnaise des Eaux-Dumez
Nanterre, France

Thierry Chambolle, born 1939, graduated from the Ecole Polytechnique, the Ecole Nationale des Ponts et Chaussées and the Institut des Sciences Politiques in Paris. Initially Manager of several French ports, subsequently Manager of Water Pollution Prevention and Major Risks Representative at the Ministry of the Environment. In 1988 Thierry Chambolle became a director of the company Lyonnaise des Eaux, and since September 1991, he is Vice-President responsible for Technology, the Environment and General Communication for the group Lyonnaise des Eaux-Dumez.

SUMMARY

The author tackles the problem of the impact of civil engineering structures on rivers and groundwater. Having mentioned the principal characteristics of aquatic areas and of water resources on the earth, he goes on to discuss firstly the case of those structures serving no particular hydraulic purpose, such as transport infrastructures, and then that of hydraulic structures. The effects of these structures as a whole are very diverse and sometimes difficult to foresee. It is important to take these effects into account right from the start at the time when the structures are conceived, in order to avoid ecological obstacles and elevated costs at the time of realisation and subsequently of operation.

RÉSUMÉ

L'auteur aborde le problème de l'impact des ouvrages de génie civil sur les eaux. Après avoir rappelé les principales caractéristiques des milieux aquatiques et des ressources en eau sur cette planète il évoque successivement le cas des ouvrages sans finalité hydraulique particulière, comme les infrastructures de transport et le cas des ouvrages hydrauliques. Les effets de l'ensemble de ces ouvrages sont très divers et parfois difficiles à prévoir. Il importe d'en tenir compte dès la conception des ouvrages pour éviter les blocages d'origine écologique et les surcoûts au moment de la réalisation, puis de l'exploitation.

ZUSAMMENFASSUNG

Der Verfasser behandelt Auswirkungen von Baumassnahmen auf Gewässer. Mit Blick auf die Wesensmerkmale der Wasserumwelt und -vorkommen der Erde stellt sich der Verfasser die Frage von hydraulischen Bauwerken und von jenen ohne bestimmte hydraulische Nutzung, wie zum Beispiel die Transportinfrastruktur. Die Auswirkungen der Gesamtheit dieser Bauwerke sind sehr verschieden und manchmal kaum vorherzusagen. Von der Konzeption an müssen solche Folgen in Betracht gezogen werden, damit Hindernisse aus ökologischen Beweggründen und Zusatzkosten zum Zeitpunkt der Realisierung und des späteren Betriebes vermieden werden können.

The Role of Civil Engineering in Protecting Water Resources

Mr. President, Ladies and Gentlemen,

Allow me to begin by telling you how honored I am to be speaking for the first time to the AIPC (IABSE, IVBH). Although originally trained as a highway engineer, I have spent a large part of my career working for the environment, and more particularly in the field of water resources. In my company, Lyonnaise des Eaux-Dumez, which includes such well known civil engineering companies as GTM and Dumez, there are several people -- like F. Lemperière and J. P. Teyssandier of GTM and B. Raspaud of Dumez -- that are much more competent than I in the field of civil engineering structures.

But since we're talking about protecting water resources, they preferred that I take the podium. They helped me prepare this presentation, so in fact I'm speaking in their name, and I'd like to thank them publicly for their help.

I hope you don't mind if I take a personal tone with you. I'll be talking more about my experience, rather than my rather limited knowledge of this field.

My first job was building roads and bridges, and I had learned in school that their most important enemy was water. I built my first road, a pretty small affair, in Martinique, over terrain that was very sensitive to water. My first concern was to prevent water -- and there's a lot of it on the island -- from ruining a road that I was very proud of.

A little later, as an engineer in Bayonne on the Atlantic coast of France, I was in charge of monitoring an old bridge, whose pilings had been undermined by the river on both sides, so that they were sort of perched on top of huge piles of sand and gravel.

So you can see that what I had learned in school was true: **water is the civil engineer's greatest enemy.**

After ten years as a highway engineer, I served as Director of Water Resources and Pollution Prevention at the French Ministry of the Environment. This was a complete change of view for me, and I had to admit that **the civil engineer could be water's greatest enemy.**

My position was unique and full of contradictions. As the person in charge of protecting France's water, I had to make sure that the large infrastructure builders, like Electricité de France or Compagnie Nationale du Rhône, did not harm the environment and the quality of water resources. As the person in charge of flood and drought control, I was encouraging the construction of barrages to combat these disasters.

I think all civil engineers are feeling this contradiction today. They are working to improve water management, but they are often accused of helping to spoil water and destroy nature.

This introduction has already been too long, but I think it was necessary to us to understand each other.

I'd now like to talk to you about water and its role in human society, but also -- and perhaps most of all -- its role in our ecosystems. I'll also mention the many dangers that threaten our water resources.

I'd then like to discuss the problems specific to infrastructure projects, both those that are not involved with water resources, such as bridges and roads, and those that are designed to improve water management, such as dams and dikes.

1. WATER AND WATER PROBLEMS WORLDWIDE

We'd need a whole book -- or maybe several -- to do this subject justice, so for now, I'd like to mention briefly some of the key ideas concerning water and water-related issues.

The Blue Planet

It's not for nothing that Earth is called the Blue Planet. One of our most distinguishing features is an abundance of water -- some 1.4 quintillion cubic meters of it worldwide. Fresh water only amounts to 2.5 percent of this total. The water cycle uses around 500 trillion cubic meters, of which 110 to 120 trillion actually concern the land masses. These figures may not mean much to you, but on a per capita basis, we're talking about an average of 20,000 cubic meters of water a year -- which is a lot.

A wide diversity

The extreme diversity of terrain, weather, seasons and population densities means that water is unequally available worldwide. Per capita resources range from over 100,000 cubic meters a year in very wet, lightly populated countries, like Iceland, Canada and the Congo, to less than 1,000 cubic meters a year in such dry countries as Saudi Arabia, Israel and Libya, or even less than 100 cubic meters a year in a few extreme cases like Malta or the Bahamas.

All water is not available as a resource

Around sixty percent of water evaporates into the atmosphere, while the rest can rarely be found where we need it when we need it. Around 28 trillion cubic meters flow uncontrolled down the world's rivers every year -- although this can decline to as low as 12 trillion. Of this amount, six trillion cubic meters are held behind dams or in reservoirs, and only seven percent, or two trillion, is controlled.

Future imbalances

In the future, the unfair distribution of water resources is going to be further skewed by demographics. By the year 2020, water will inevitably grow increasingly scarce in Africa and Southern Asia.

A major role in the economy

Water is an important economic force in all civilizations. It plays a major role in farming, of course -- you need nearly 1,000 square meters of water a year per irrigated crop to feed one person -- but also in energy, industry and city life. You need 60 to 400 cubic meters to make a ton of cardboard, up to 1,000 cubic meters for a ton of paper, 12 to 50 cubic meters per person per year in the country, 150 in Paris, 500 in New York.

An even greater role in the environment

Water has physically or chemically sculpted the very face of our planet, through erosion, transport and sedimentation; water also washes the planet clean every day. Water makes our landscapes; the level and amount of groundwater determines the type and abundance of vegetation. And naturally water is responsible for biocenosis -- the community of biologically integrated and interdependent plant and animals.

Rivers cannot be separated from the land environment. The ecology of river systems is primarily an ecology of imbalance. On a planetary scale, river-scapes are highly varied, and to understand their dynamics, you need a planetary vision.

Endangered water

In every country, in every region, water can be threatened just as much by excessive use as by pollutants, both concentrated (from industry and cities) and dispersed (from farms and rural communities).

Some countries, where demand has reached or outstripped supply, are in a critical situation. But in many others, where demand doesn't exceed 25 percent of total resources, there are already many local or temporary shortages. Water tables are shrinking, rivers are drying up and wetlands are disappearing.

In all of the industrialized nations, rivers and underground water are suffering serious damage from oxydizable wastes (from cities and industries), nutrients (from cities and farms) and toxic wastes (from industries and farms). Throughout Europe, a good percentage of underground water has been polluted by nitrate and pesticide runoff, making their use as drinking water questionable.

The vast world movement that has formed to protect the ozone layer, prevent changes in the climate, preserve the Antarctic, and limit destruction of the forests cannot ignore fundamental role of water in all its forms, and must make a commitment to protecting this valuable resource -- even as we use it wisely -- for the very future of our planet.

2. THE IMPACT OF CIVIL ENGINEERING STRUCTURES

In this sensitive environment, civil engineering works have an impact that can remain fairly limited or be very powerful and decisive, depending on their type, use and size.

We'll be talking about three types of works :

- Structures without any particular relationship to water
- Small water-related structures
- Large water-related projects

2.1 Structures without any particular relationship to water

This is mainly transportation infrastructure, such as bridges, roads and railroads.

They can affect water in many ways. Because they cross natural drainage areas, they can have an impact on water flows, especially during peak periods, and on water table levels. Their waterproof surfaces increase the accumulation rate. Washing runoff can spread traffic pollutants to the environment.

In the case of a traffic or railway accident, toxic substances may be spilled into the surrounding environment. Roadway products, such as deicing salts, or maintenance products, such as weed-killers, can contaminate groundwater. Side effects can be observed in quarries, extraction and dump areas.

Let's look at the example of a bridge runoff. Traditionally, floor plate runoff used to be caught in side drainage channels and directly discharged into the environment via gully holes or drainpipes.

Today, large bridges are equipped with special facilities to catch and treat runoff before it is returned to the environment. These facilities include :

- Side drainage channels.
- Screened gully holes across the cantilevering.
- A drainage network composed of a main drainage basin located along the bridge's center axis, generally inside the precast segments, and of side drainpipes crossing the web and connecting the gully hole to the main basin.
- Downspouts located along or inside the river bank abutments, equipped with water tanks that follow plate/abutment shifts.
- A sand-catcher/oil trap located upstream from disposal.

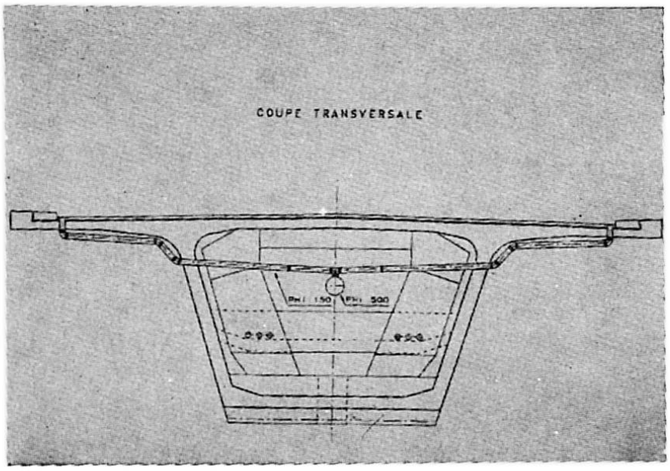

Fig. 1 Cross section

These facilities are being used on both road and rail bridges.
A second example concerns the restoration of groundwater flows. Here I'll be talking about the St-Cyr-Boulevard Périphérique Nord covered drainage channel in Lyon, which cuts across the thalweg of the Rivières brook.

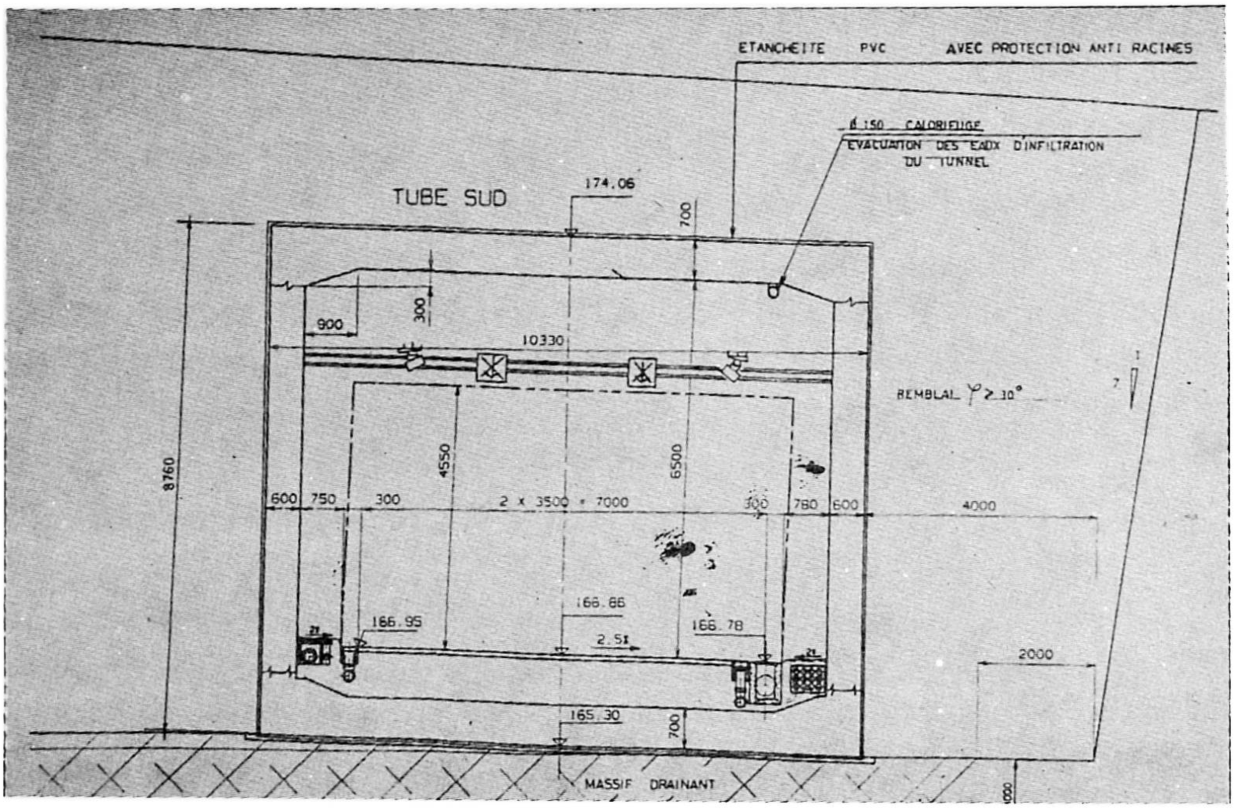

Fig. 2 Special Equipment (for large bridges) to catch and treat run-off before it is returned to the environment

To maintain groundwater flow at all times and prevent blockage by the frames, which descend almost to bedrock and are placed perpendicular to the main groundwater flow, it was decided to build a thick draining layer under the frames. The layer is highly permeable, allowing around 10^2 meters/second flowthrough.

Now let's look at a linear structure like a road. Pollution can come from a number of sources:

- The erosion of unplanted soil and embankments, which can have many negative effects, such as embankment washout or destruction, filling of drainage systems or pollution of receiving watercourses.
- Construction equipment (motor oil or washing runoff).
- Pollution spills.
- Deicing salts.
- Chronic pollutants (dust, lead, zinc, hydrocarbons).

I'd like to use the example of the A-36 Motorway as it crosses Mulhouse. This highway crosses the secure protection zone around the city's catchment fields. This is why it is so highly protected, as shown in the attached drawing. It is built on an embankment, but to prevent any vehicles from exiting accidently, it is protected by high berms on either side. Rainwater is collected by a sewage network and deposited in settling tanks and reservoirs that can store toxic substances as needed. Naturally, rainwater is disposed of upstream and far from the catchment fields. Lastly, a waterproof coating has been applied under the road and the berm embankments to prevent any seepage into the motorway embankment.

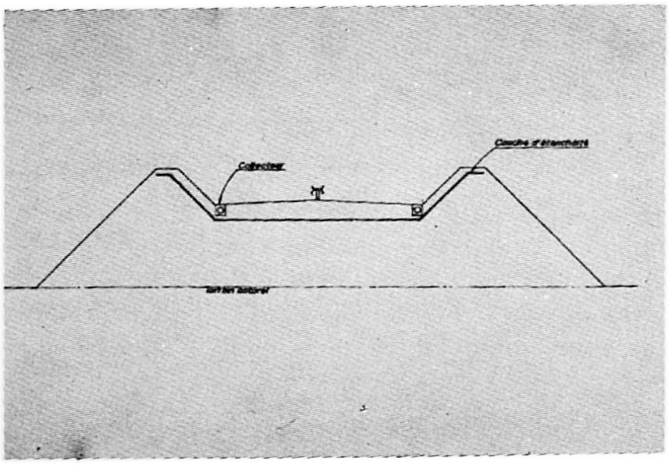

Fig. 3 Protections of the Mulhouse "Catchment fields" (A 36 Mortorway)

J. M. Bernard, who works for SETRA, the French Roads and Highways Technical Engineering Agency, has briefly described the measures to be taken:

"Highway authorities have a number of ways to limit the impact of roads on water resources when they design infrastructure. During the environmental impact study, it is important to prepare a full and accurate initial description. The different types of water resources (groundwater, watercourses, etc.) should be located, their current and future use identified and their exposure to road pollution determined.

The most important step is determining the route, since routing the road away from recharge areas is the only real way to guarantee water quality. This is because, while some of the pollution will be caught by the sewage system, the rest will be discharged into the surrounding environment and cannot be controlled by the protective or regulatory devices installed in the sewage system.

Lastly, the installation of protective or regulatory devices limits the contamination of the environment by runoff. Some forms of pollution are hard to manage, however. This is the case of salts which dissolve in water and are thus impossible to screen out. These devices should designed to reflect the type of pollution they are expected to treat (suspended solids, hydrocarbons, etc.) and their maintenance and management requirements.

In addition to the problems of water quality mentioned above, roads also have an impact on surface runoff and on groundwater. A road's impact on water resources and water environments should be studied in a comprehensive way. Solutions exist and each case deserves special attention to avoid upsetting the delicate balance of nature."

Let me add that it is possible, in cities and suburbs, to adjust construction methods to allow the use of roads made of thick open-grain asphalt as storm reservoirs. In this case, the road can actually be a solution to a rainwater management problem.

2.2 Small water-related structures

These are the small or medium-sized barrages or diversion cuts that only have limited influence over the entire water basin. Their impact on water is well known. The first examples of this type of structure were built around 5,000 years ago. These were often simple dikes built to create artificial ponds recharged by seasonal rains. Then dams appeared. It seems that the oldest dam still in existence was built by the Mongols in the thirteenth century in Kbar, near Qum, Iran. It is 26 meters high, 55 meters long and five meters thick, and already looks like a road. Since that time, many dams have been built over the centuries, especially in India. In 1990, there were 36,138 dams over fifteen meters high in the seventy-one countries that are members of the International Commission on Large Dams. But the total number of barrages, dikes and dams is much higher, probably over 500,000. These structures are fairly commonplace, and their impact on water is not new. In the earliest times, this impact was the reason why they were built -- to store water for drinking or irrigation, to control floods or to generate electric power. It is only recently that we have begun to study their side or unintended effects.

In the late seventies, the International Commission on Large Dams, fully aware of the importance of environmental issues and public sensitivity to them, created a technical committee to deal specifically with this subject. The commission published a report in 1980, but they realized later that it was too technical for the general public to understand easily. In 1981, therefore, they published a brochure entitled *Dams and the Environment: A Success Story*. The title makes you wonder and even sounds funny when you consider all of the problems encountered by many dam projects in different parts of the world.

The report and the general public brochure deal with the many environmental problems raised by dams:

- Crossing the dam (migrating fish)
- Sediments (accumulation and disposal)
- Discharges (heat, turbidity, water oxygenation)
- Weather effects
- Eutrophication
- Plants and animals
- Changes in groundwater for lowland dams
- Flooding risks due to landslides or earthquakes.

All of these problems and their solutions are well known. The International Committee's bulletins have discussed them many times (notably in 1985). It would be pretentious and time-consuming to talk about them here, before an audience that is well aware of these difficulties and their solutions.

Nevertheless, a dam can profoundly modify the environment, at least locally, and it is becoming harder and harder to get people to accept one "in their backyard", no matter what technical solutions are implemented. In many countries, you need to plan for a compensation program, with not only economic and social measures, but also a whole series of ecological measures, such as reconstituting biotopes, creating reservoirs, and implementing systems to collect and treat wastewater upstream to avoid problems with eutrophication or water quality.

In some densely populated countries, these measures are still not enough to prevent environmentalist opposition, and other solutions have to be found. Examples include creating groundwater reservoirs by artificially recharging the water table, building waterproof underground walls or raising existing dams.

The first solution, already used in France to build drinking water reservoirs, requires very good understanding of groundwater regimes and the use of waterproof underground wall construction techniques, that have been mastered by companies like Bachy and Solétanche.

An innovative technique recently developed to increase the capacity of existing dams is the Hydroplus process, designed and implemented by GTM.

With most high dams and hydroelectric complexes, retained water levels are regulated by sluice gates that let flood waters through. But with the vast majority of lower dams, flood waters flow over a spillway that is a few dozen meters wide and unequipped with any sluicegate control. At flood crest, the spill can rise to around a meter deep, but sometimes exceeds five meters.

The dams are designed for peak flood water levels, but are used only to retain water below the spillway level. This means that there is a great deal of reservoir capacity going to waste. Lost capacity can amount to over twenty percent of the total volume on an average non-sluicegate equipped dam.

One safe, cost-effective way of raising the spillway is to build overspill fusegates that remain submerged for moderate overspill, trigger part of their fuses to rise slightly for the higher waters that come every fifty years or so, and trigger all of the fuse and rise to full height for exceptional flood levels. This solution is very economical.

Every year around the world, the lack of such systems causes us to lose around fifty billion cubic meters of water, much of which could be saved at low cost and relatively quickly through a system of overspill fusegates.

This system can be adapted to most existing free spillways, but can also present major advantages for future dams.

2.3 Large water related projects

The impact of large multi-purpose water-related projects on water regimes and quality is even harder to forecast. And the ways of reducing that impact are even more difficult and unpredictable.

As I said above, the ecology of river systems is an ecology of imbalance. The engineer intervenes in a complex, constantly changing system to substitute a new system that is also in imbalance and will undergo its own process of change.

It is not enough to compare the post-construction state to the initial state. Comparisons have to be made between the different stages of the initial system (without the proposed development) and between these same successive stages in the event the development is carried out. Since it is highly uncertain how each of these stages will evolve, you can imagine how difficult it is to compare them, especially when you have to convince sceptical inhabitants who will not necessarily benefit directly from the project.

All of the major development projects like the Aswan Dam or the reclamation of the Zuider Zee have had unexpected consequences.

The Aswan Dam had many positive effects, but the reduction in silt flows also had a serious negative impact. The river's banks and bed eroded, the delta 1,000 km downstream eroded, fish reproduction declined and salt concentrations rose.

In the Zuider Zee, the improvement in flood control and the development of new polderland also caused the disappearance of biotopes and related species, as well as water eutrophization.

Thus, engineers who prepare large development projects and who analyze their predictable impact on water and the environment have a very difficult task. So do the political authorities who have to take the decision to develop and convince the surrounding population that it is a good idea. If you doubt this, just think about the Bangladesh flood control system. This project offers a number of alternative solutions, such as nearby dikes and distant dikes, but in all cases it means a radical transformation of the local economy and lifestyles, notably in their relationship to water. There is already a great deal of controversy about the future consequences and disadvantages of the different solutions.

I was personally involved in the development of a large French river, the Loire, which is full of history and famous for its beautiful scenery and dramatic floods. The first attempts at flood control date from the twelfth century, when levees were built along its banks.

An initial project prepared in the seventies to develop the water resources needed to cool nuclear power plants and irrigate farmlands proposed the construction of not less than twelve dams. A critical analysis by a blue-ribbon commission of experts reduced the project to five dams -- three for flood control, of which one was already built, and two for low water support, of which one was already partially built.

Environmentalist opposition has caused the number of new dams to be cut to two, with, in addition, the raising of an existing dam and the construction of close set protection dikes.

All of these changes were the subject of major controversy both in France and internationally.

In conclusion, nobody would think of denying the importance of civil engineering works designed to meet new demand for transportation, to enhance the value of our water resources and to protect lives from natural disasters. But these structures cannot be built to the detriment of the environment and of water quality.

We must be aware of the fact that, once a project has aroused environmentalist opposion, it then becomes very difficult to prevent the construction process from grinding to a complete halt : either the project has to be abandoned altogether or those involved must reckon with considerably elevated costs to finance the necessary modifications to the original project. This being the case, it is imperative that we ensure that environmental issues are taken into consideration from the very beginning of each project.

In the past, civil engineers have sometimes underestimated the psychological or factual impact of what they built. As a result, they have sometimes incited feelings of hostility on the part of inhabitants and sometimes of elected officials. They need to act to regain the people's trust.

In closing, I'd like to quote Michel Virlogeux, of the Association Française Pour la Construction:

"Engineers (i.e. all of us) need to learn modesty and should analyze the long-term impact of their actions, particularly on water resources."

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Preservation of Newly Built and Historical Buildings

Conservation des bâtiments historiques et récents

Bewahrung historischer und neuzeitlicher Bauwerke

Giorgio CROCI
Prof. of Civil Eng.
University of Rome
Rome, Italy

Giorgio Croci, born 1936, has carried out important research, studies and projects for the strengthening and restoration of historical buildings. The Colosseum and Senatorio Palace in Rome, the Ducale Palaces in Modena and Genova, the Castle of Spoleto, the Basilicas of S. Francis of Assisi and S. Ignatio de Loyola in Spain, represent some examples of his activity.

SUMMARY

This paper deals with the preservation of existing buildings. The main problem is the evaluation of the safety level, taking into account the crack patterns, the deterioration of materials, etc. As a result of this analysis, decisions can be taken about the opportunity and the criteria for intervention. The paper illustrates some cases, referring especially to historical buildings in Italy and Spain.

RÈSUME

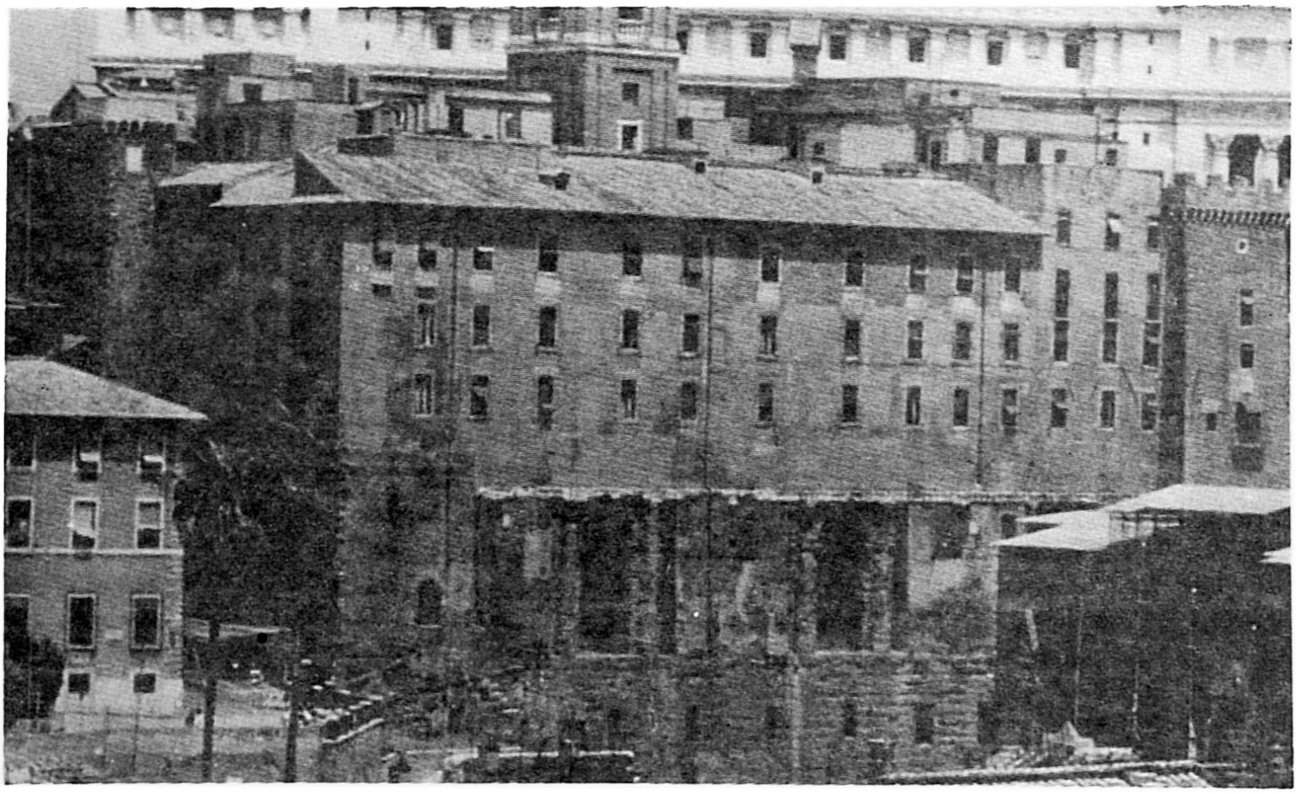
L'article traite de la conservation de bâtiments existants. Le problème principal concerne l'évaluation du niveau de sécurité, prenant en compte l'évolution des fissures, la détérioration des matériaux, etc. Cette analyse permet de prendre des décisions sur l'opportunité d'une intervention, et sur les caractéristiques de celle-ci. Des exemples de bâtiments historiques en Italie et en Espagne illustrent l'article.

ZUSAMMENFASSUNG

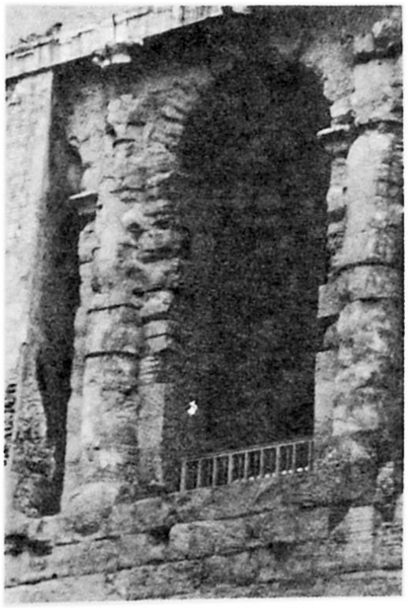
Der Artikel handelt von der Bewahrung vorhandener Bauwerke. Der Schwerpunkt liegt dabei auf der Berechnung der Standsicherheit unter Berücksichtigung des Rissbildes, der Baustoffverwitterung usw. Diese Analyse erlaubt Entscheidungen bezüglich Eingriffsmöglichkeiten und Alarmgrenzwerten. Beispiele für historische Bauwerke in Italien und Spanien erläutern den Artikel.

1. INTRODUCTION

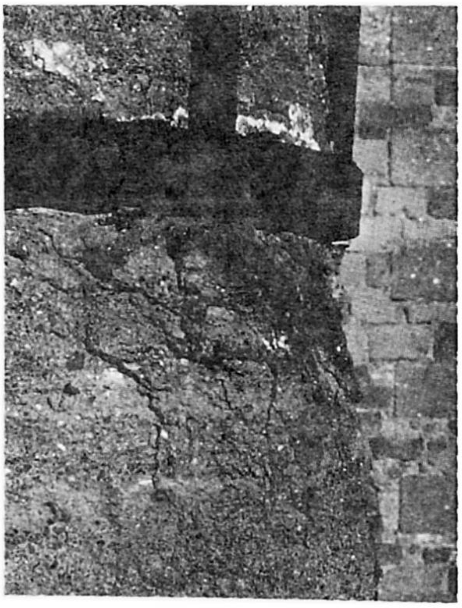
The first point to examine in the preservation of a structure is the analysis of the deterioration of the materials. This deterioration in the oldest buildings is linked not only to the chemical and physical phenomena, but also to the countless alterations, that, as in the case of Palazzo Senatorio in Capidoglio, Rome, (fig. 1) have occurred during the centuries (fig. 2), sometime stressed by incorret reinforcements (fig. 3).



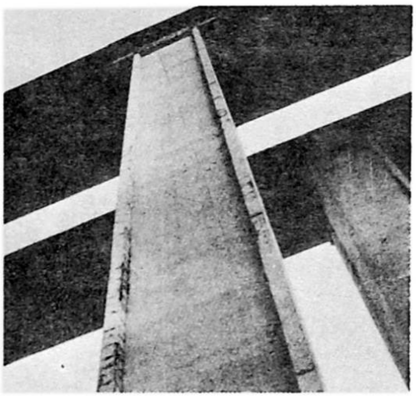
Pic.1: General view of Palazzo Senatorio and Tabularium in Campidoglio from the side of the Roman Forum



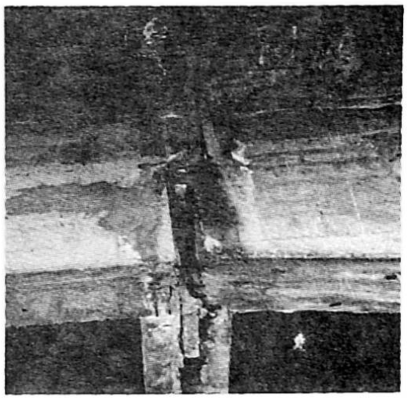
Pic.2: Alterations and deteriorations of Palazzo Senatorio



Pic.3:Effect on the columns of Tabularium

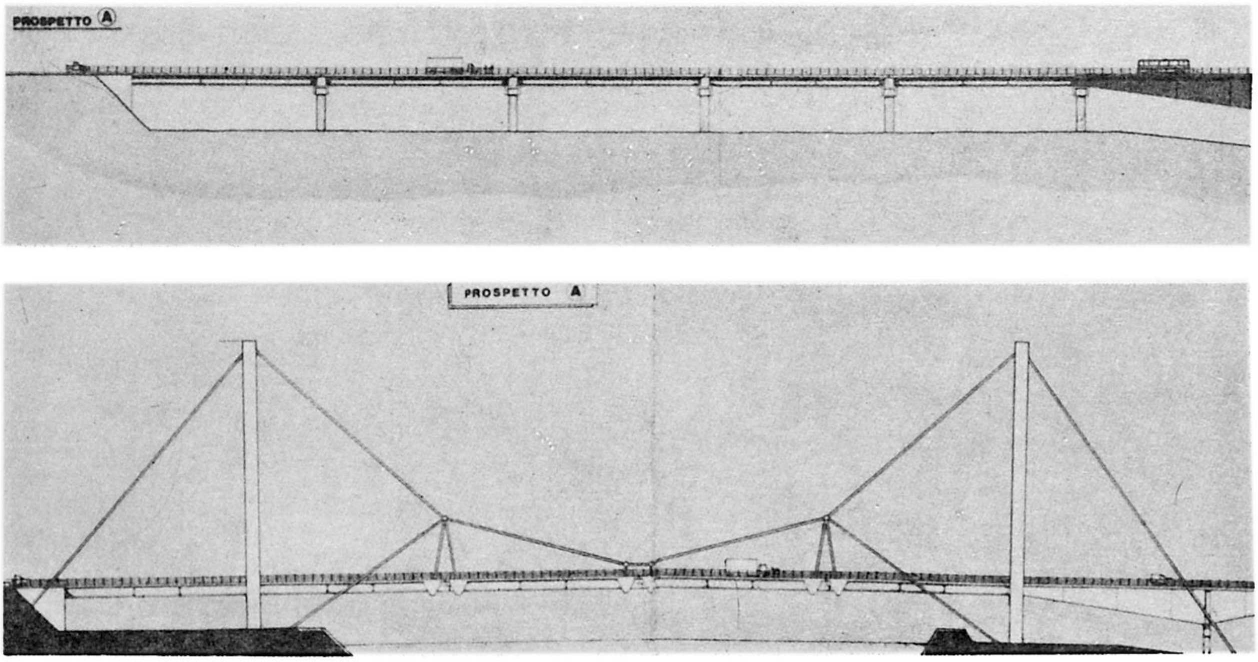


Pic.4: Concrete motorway bridge



Pic.5: Deterioration in a bridge deck

For newly built constructions, unluckily, the situation is often worse, despite the support offered by science and modern technology. It is not uncommon to find in some bridges (fig. 4) high levels of deterioration due to lack of maintenance, insufficient protection of the steel, bad quality concrete, imperfect design of details. (fig. 5) Repairing and strengthening will be an important activity for the future.
The second point to consider is the assessment of the structural capacity. This evaluation, which will be examined in the following paragraphs, related to historical buildings, is often very difficult and always delicate, because it involves the decisions and criteria of interventions. Structural interventions, however, are not only related to insufficient bearing capacity. In some cases, new requirements can suggest a substantial change in the original behaviour; this is the case, for example, of a bridge (fig. 6) where it was decided to remove the pillars, substituting the support of the beams with cable, transforming in this way the old structure, to a new suspended bridge (fig. 7), satisfying the need for a free area below.



Pic.6,7: The same bridge before and after the substitution of the pillars with cables

2. THE ASSESSMENT OF THE RESIDUAL CAPACITY

The evaluation of the safety level, expecially for historical buildings is not an easy task and, as a general rule, it is necessary to follow simultaneously three different routes or criteria.

The safety assessment, should thus result from the synthesis of the best information obtainble from the following different approaches:

I - historical survey (historic-critic method) which consists of the systematic reading and interpreting of historic documents;

II - in situ observations (or empirical-qualitative method), often with the support of investigations and monitoring systems, which consists of the survev of the crack patern, the quality of materials, and so on;

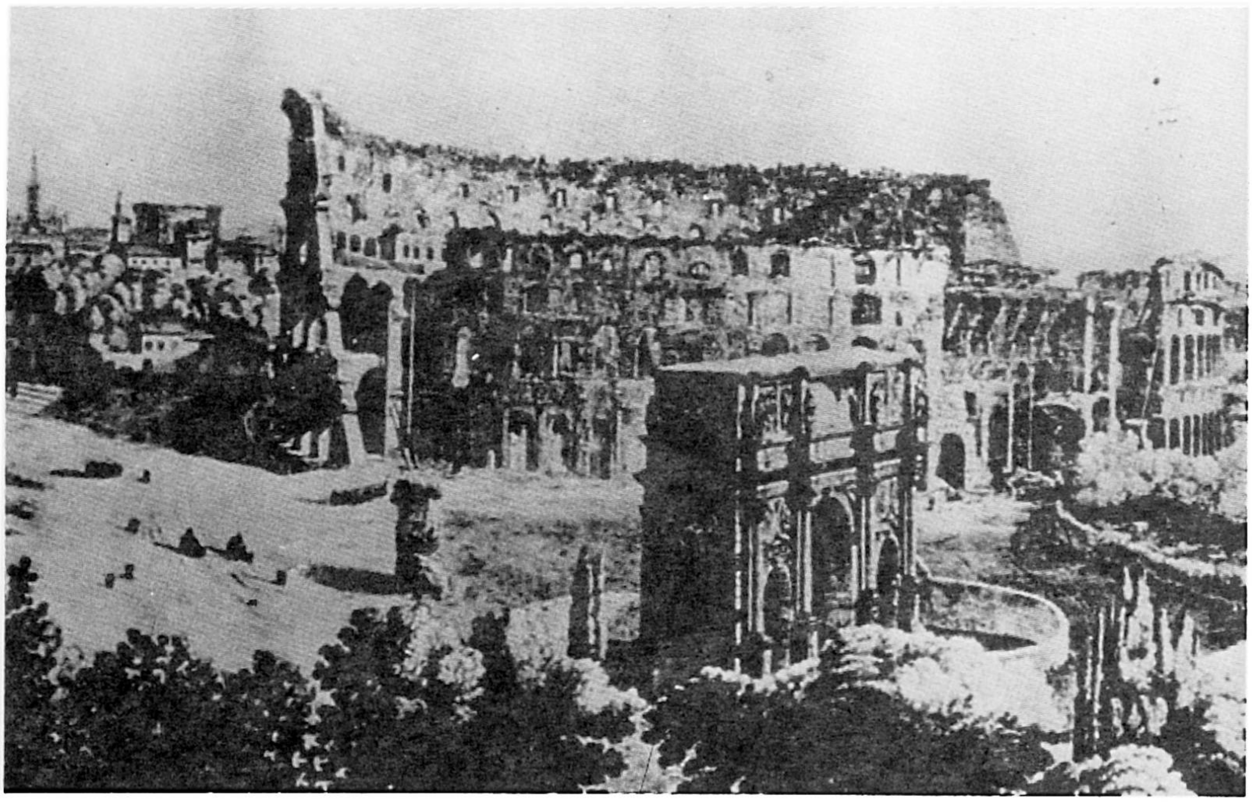
III - structural analysis (theorical quantitative method), that is an abstraction of the reality, reducing the complexity of the Monument's behaviour to simplified mathematical schemes.

The study of COLOSSEUM can be seen as a significant example of this methodology, following a continuous feed-back process.

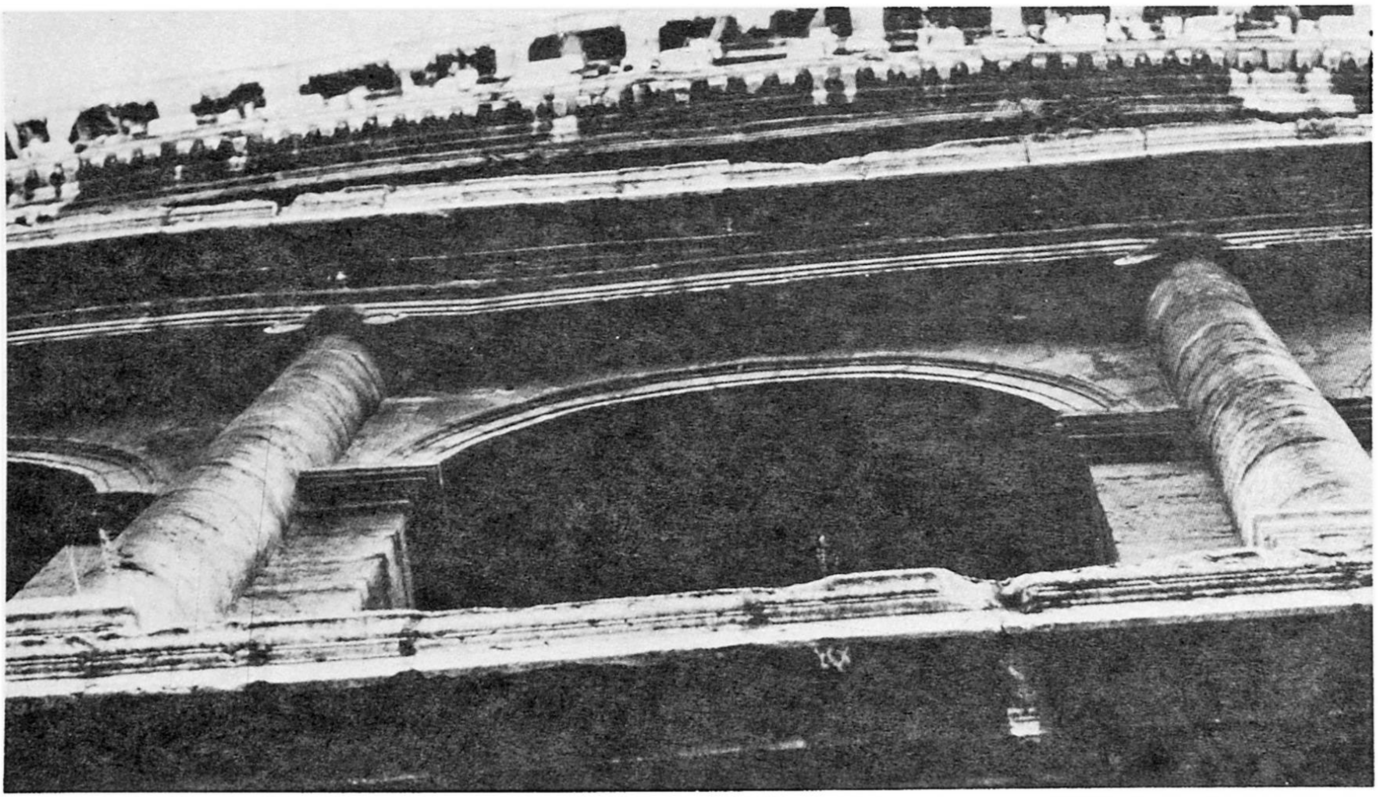
The historical survey has pointed out the role of the earthquake in the failure and collapses that have been occurred in 443, 801, 1347, 1703 (fig. 8).

As a initial result of the historical survey there appears to be a discrepancy between the quantity of crumbled portions, as seen today, and the description of historical collapses related to the earthquakes that have been recorded

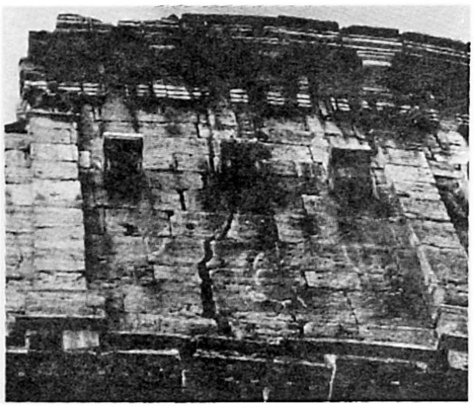
We will see later the mechanical behaviour which has caused spontaneus collapses a long time after the earthquakes have occurred. The second congitive process, the in situ survey, shows sinusoidal deformations of the external wall, (fig. 9) clearly due to the seismic effect, and considerable out of plumb.



Pic.8: the Collosseum in the XVIIIth Century

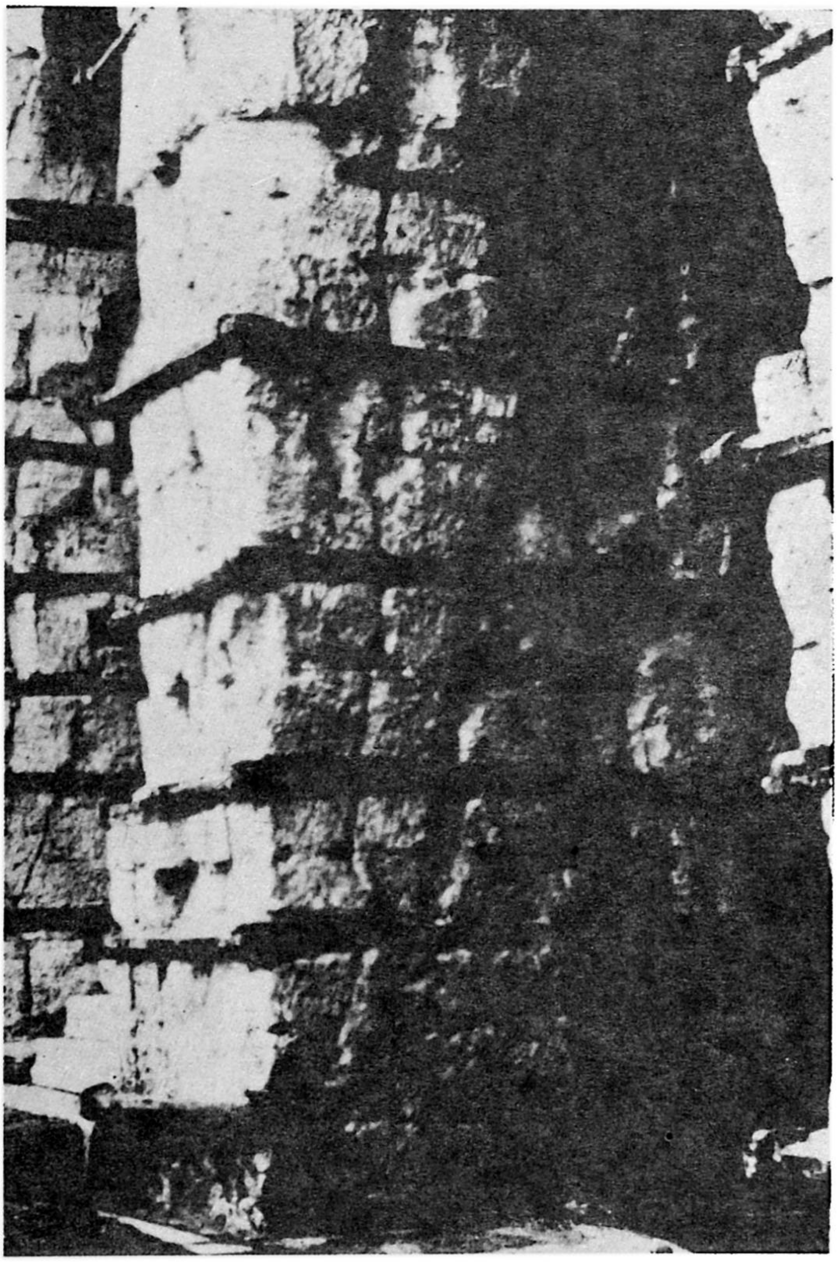


Pic.9: Sinusoidal deformations of the external wall showing the signs of the earthquake



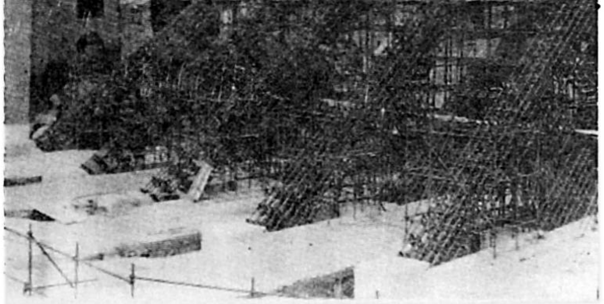
Pic.10,11: Displacements and discontinuities in the structure of Collosseum

Consequences of this outward movement are relative displacement of the blocks (fig. 10) and discontinuity between the outer elliptical structure and the radial masonry (fig. 11).
The corresponding increase of the stress level has been the cause of the worrying signs of collapse present in some pillars ten years ago (fig. 12). This occurred in such fast evolution that the pillars had to be shored urgently (fig. 13).
We will see later why the Colosseum arrived at a situation of collapse two centuries after the last important earthquake, without apparent motivation.
The third criterion, the mathematic analysis (fig. 14), has shown that the foundation dishomogeneties caused a different amplification of the seismic action and have been the cause of the wellknown assymmetric collapse of Colosseum.
The mathematical analysis has also shown the importance of the dissipative behaviour under dynamic actions linked to the dry friction coefficent between the blocks.

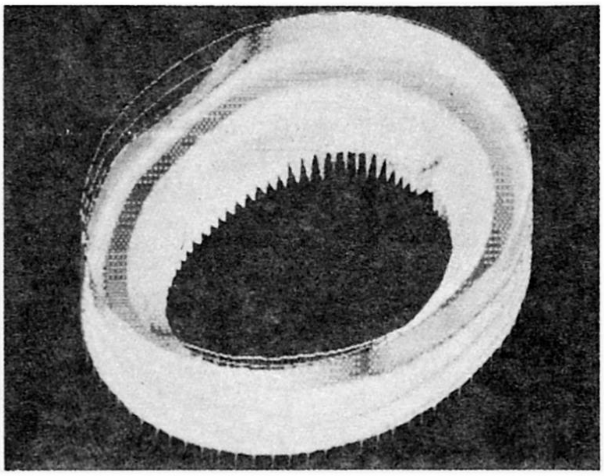


Pic.12: Warrying signs of collapse in some pillars of Collosseum 1979

On the basis of all the information obtained (historical survey, in situ observation and mathematic analysis), we can try to explain what has happened: due to the seismic actions the cylindrical outer surface suffered a loss in shape, with an increase of the elliptical length that caused out of plumb. The increase in the stress level caused the first collapse; at the same time the adjacent structural elements were left weaker because of the lack of circumferential continuity.
Once the stability had been in such a way compromised then, even weaker earthquakes, slow decay and deterioration of materials, the pushing of iced water in the small fractures caused by the high stress levels, ... generated, years, or even centuries after, the "spontaneous failures". A situation of this kind occurred, (I was witness to it), in 1979.



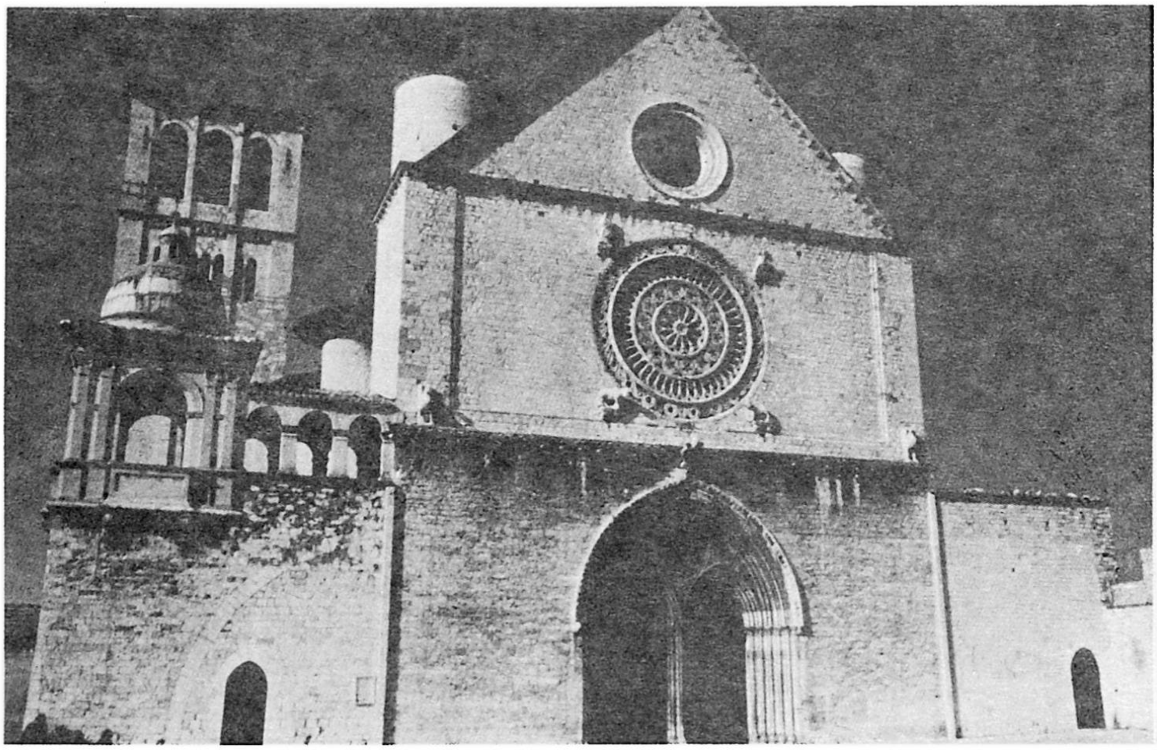
Pic.13: Shoring put in place in 1979



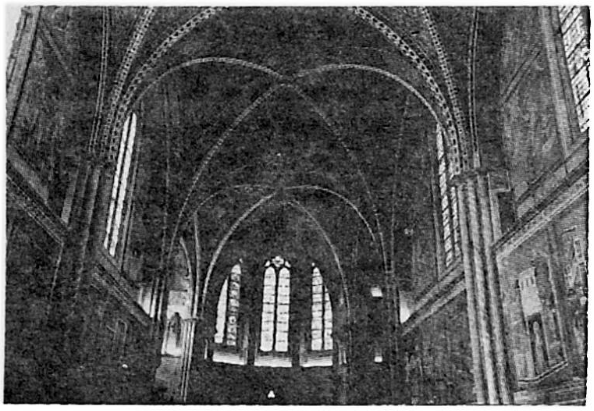
Pic.14: Mathematical model

3. INTERVENTIONS IN MONUMENTS RELATED TO EARTHQUAKE EFFECTS

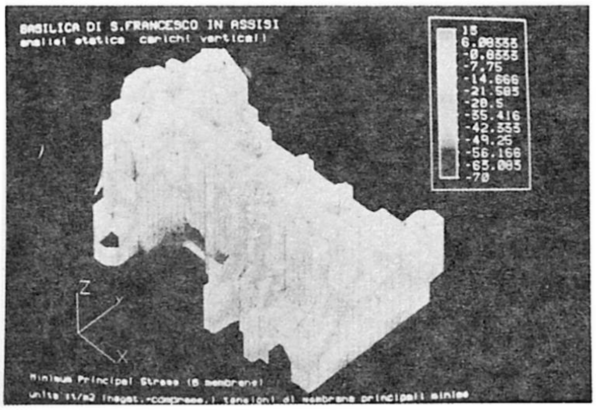
The earthquake has been also the main cause of damages in the Basilica of S. Francis of Assisi (fig. 15). Many signs are visible, the cracks in the central columns of the large windows and the damages that in the centuries have effected Giotto frescos (fig. 16).
The mathematical model shows the general stress distribution (fig. 17). In the wall that supports the Giotto frescos we can see in further detail the tensile stresses in the inner surface, and the compression stress in the outer surface, corresponding to bending moments; these stresses change sign many times during the sinusoidal seismic action, causing the cracks that we have observed. In order to reduce these effects, a steel trussed beam will be placed over the internal cornice (fig. 18, 19). This beam is connected to the masonry by oleodynamic dampers in a position to allow thermal deformations, but to react rigidly under the effect of dynamic impulse due to the seismic action.



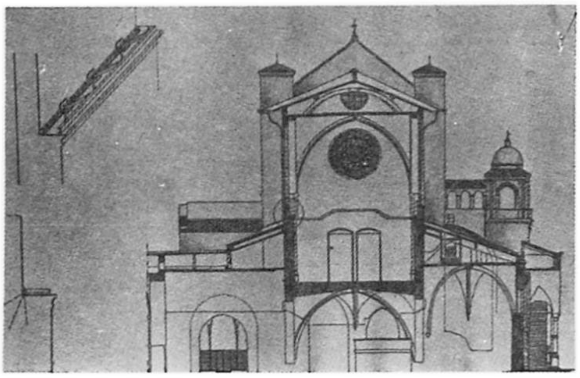
Pic.15: The Basilica of St. Francis in Assisi

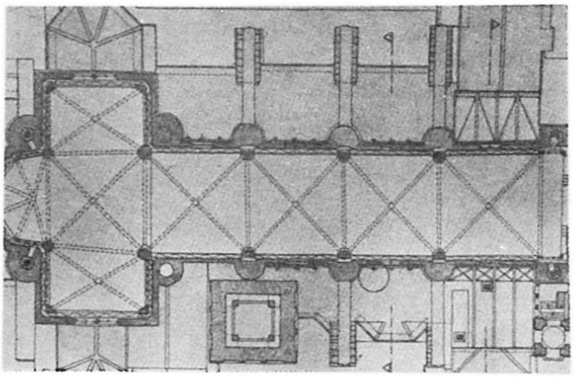


Pic.16: Damages in the Giotto frescos



Pic.17: Mathematical models of Basilica of St. Francis in Assisi

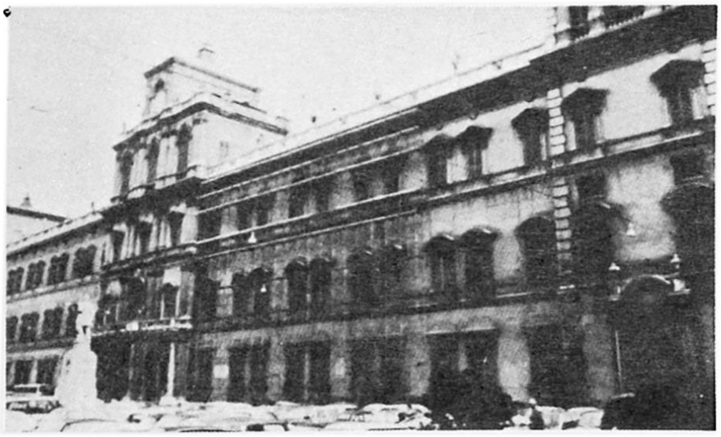




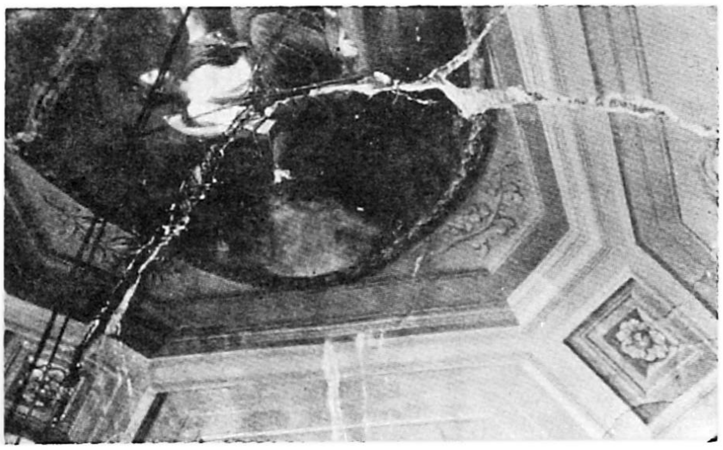
Pic.18,19: Steel trussed beam placed the internal cornice of Basilica of St. Francis in Assisi

4. INTERVENTIONS IN MONUMENTS RELATED TO SOIL PROBLEMS

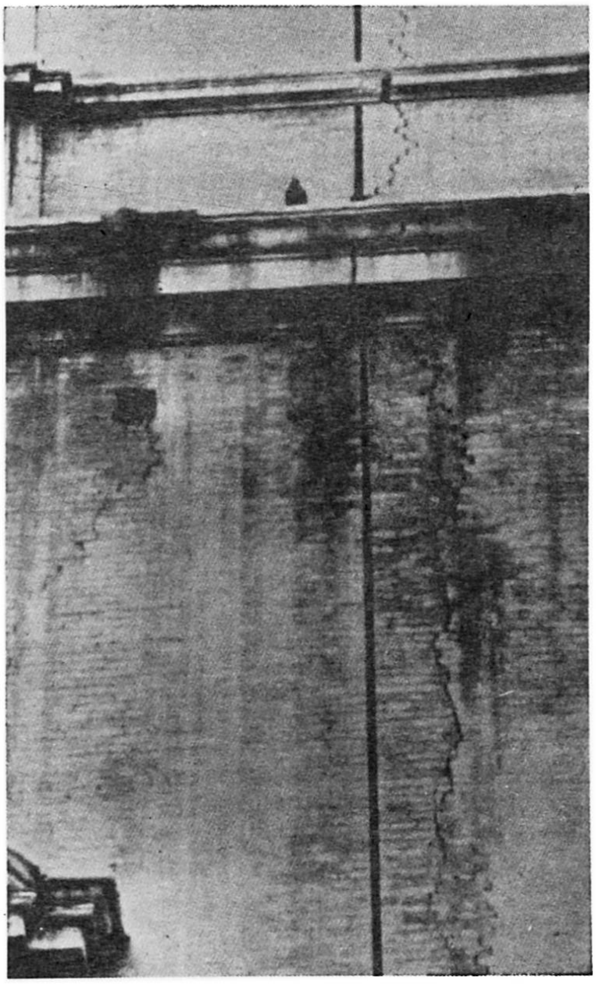
Soil deformations represent a further group of phenomena that often effect old buildings. The solution is not only in improving the bearing capacity of the foundations (underpinning, ...) or in strengthening the building as a whole. It is often better to use different solutions: in the Ducal Palace of Modena (fig. 20), where important cracks due to soil rettlements effect the walls, floors and vaults (fig. 21), we have proposed to make joints (fig. 22), to allow differential settlements to occur without inducing significant stresses in parts of the Palace.



Pic.20:Ducal Palace of Modena

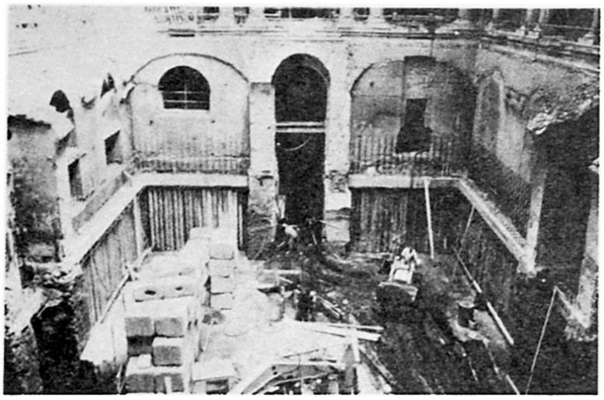


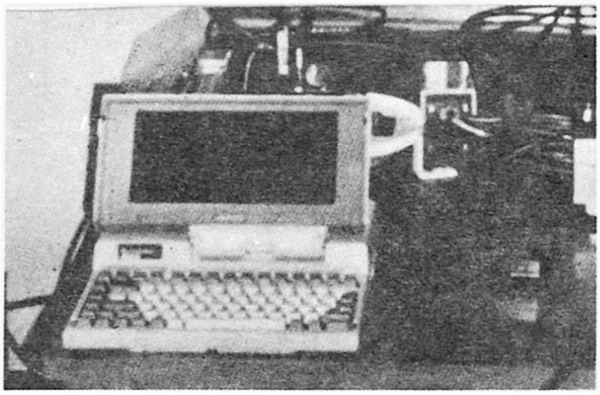
Pic.21: Cracks in the voults of Ducal Palace of Modena



Pic.22: Joints realized by cutting the walls, following the main crack pattern

In other situations the repairs to foundations are related to the buildings current needs.
This is the case of Palazzo di Istituto Massimo in Rome, where it was necessary to make important excavation works to obtain new space for a permanent museum, containing old coins of the Roman Empire (fig. 23); a monitoring system has been set up in order to control the settlements of the foundations and, if necessary, to take corrective measures (fig. 24).

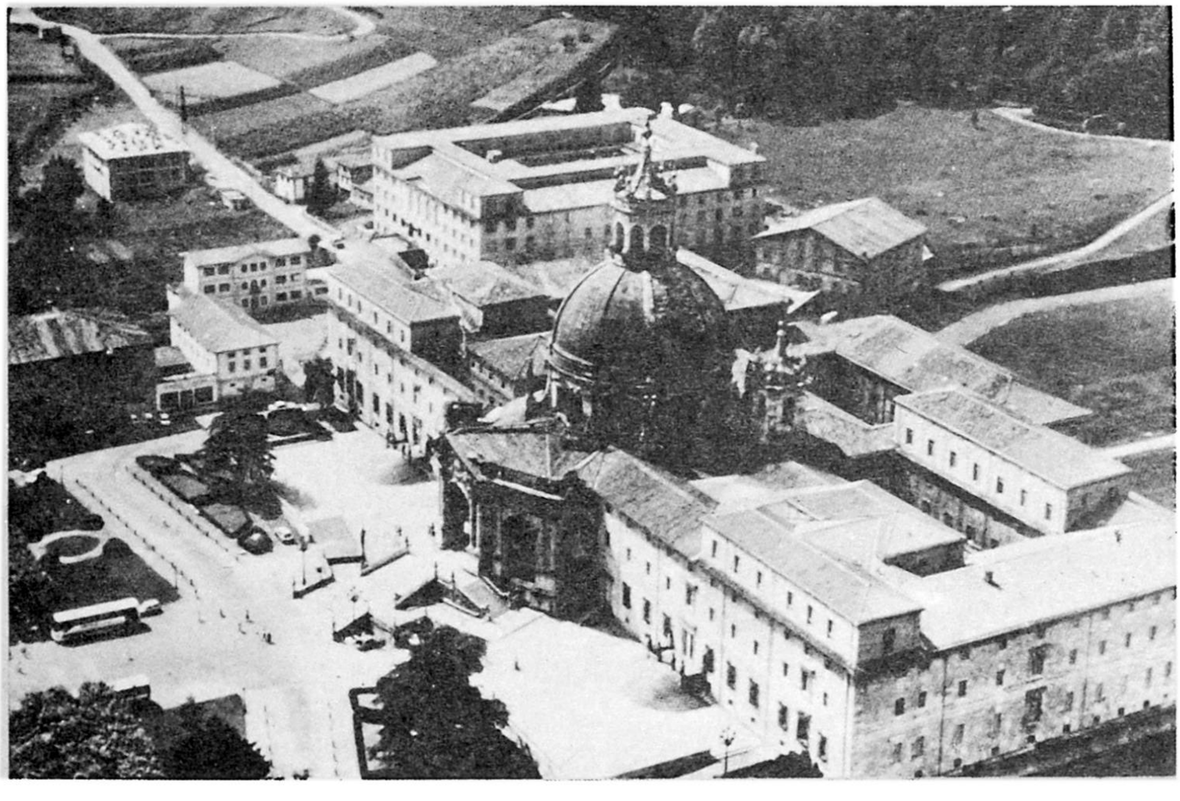




Pic.23,24: Excavation works under the foundation and monitoring system

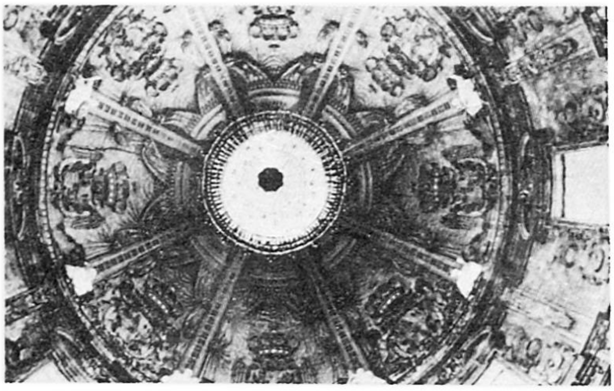
5. INTERVENTIONS IN MONUMENTS RELATED TO IMPERFECTIONS IN THE ORIGINAL CONCEPTION

A third category of problems are due to the direct forces, namely the dead load. In the Basilica of S. Ignatio de Loyola in Spain (fig. 25), this has been the cause of important cracks that effect the dome (fig. 26).

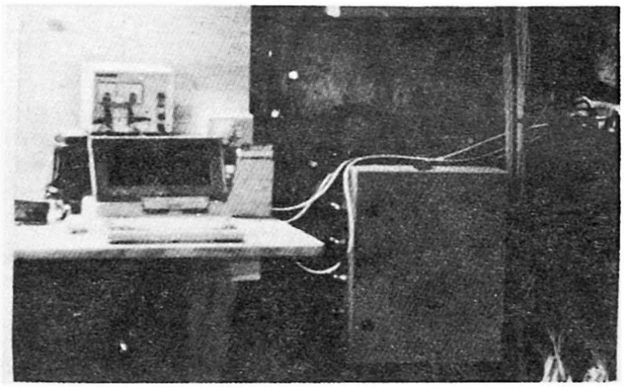


Pic.25: Basilica of St. Ignatio de Loyola in Spain

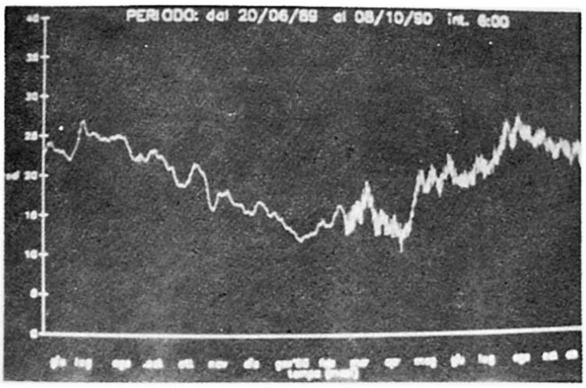
A monitoring system has been installed (fig. 27) to assess the evolutionary character of the phenomena; the results show the dependence on temperature and a low trend of the width of cracks to increase (fig. 28, 29).



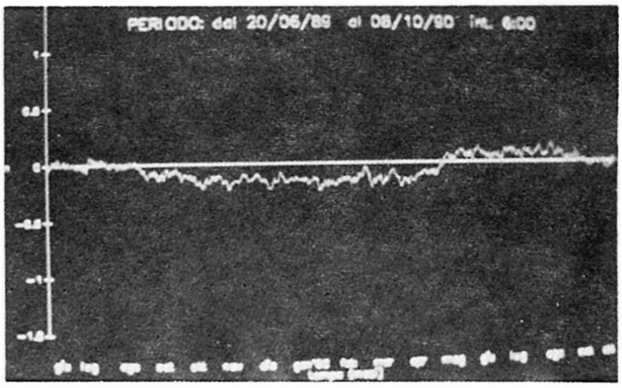
Pic.26: Cracks on the dome



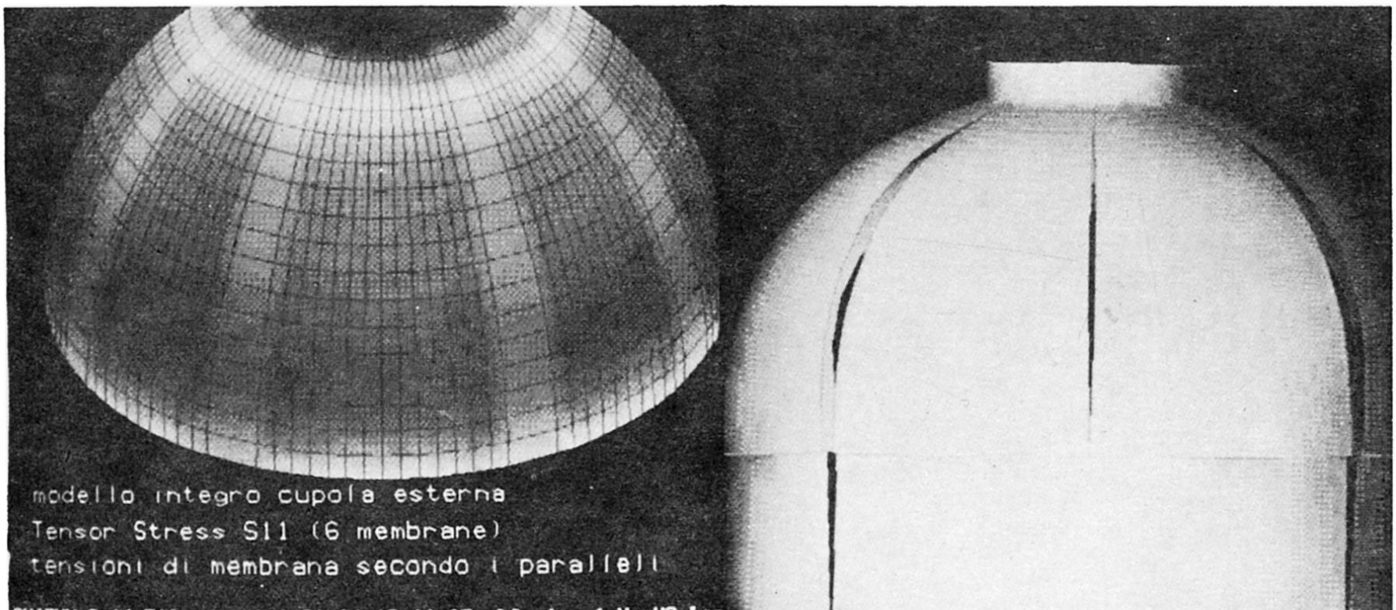
Pic.27: Monitoring system



Pic.28: Diagram of temperature evolution

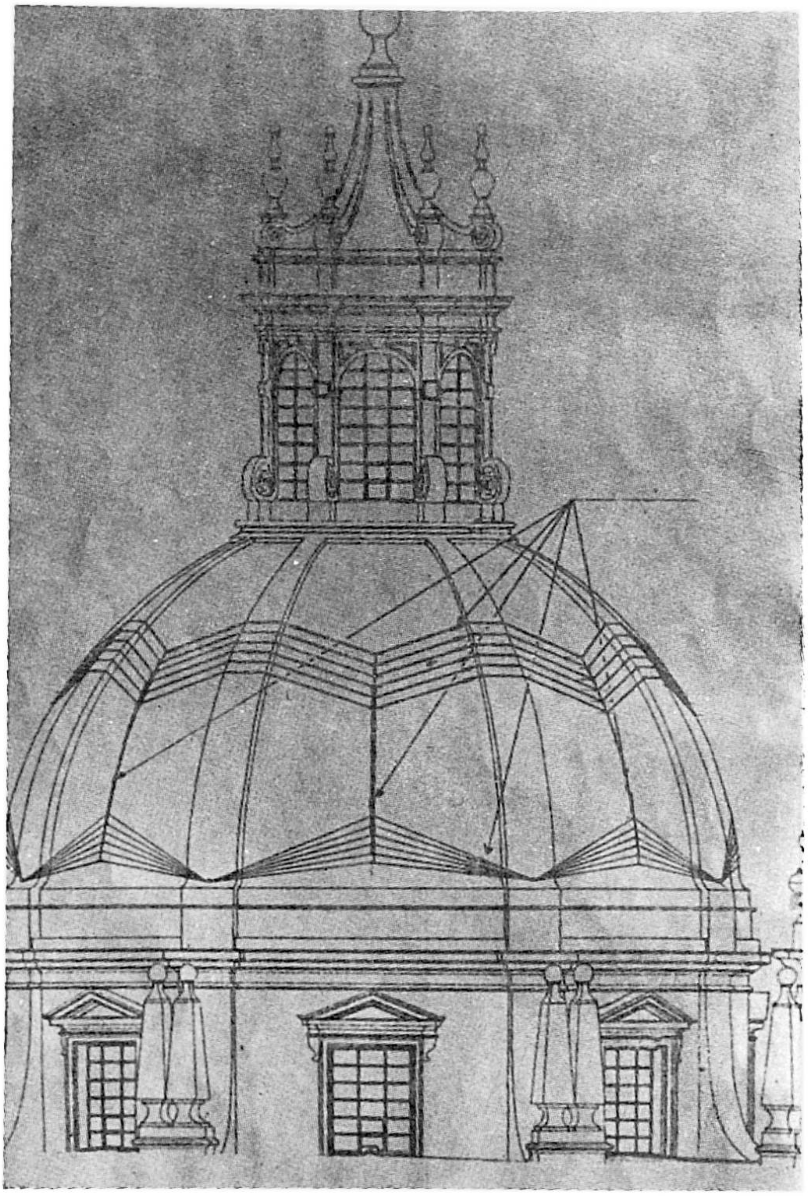


Pic.29: Diagram of crack evolution

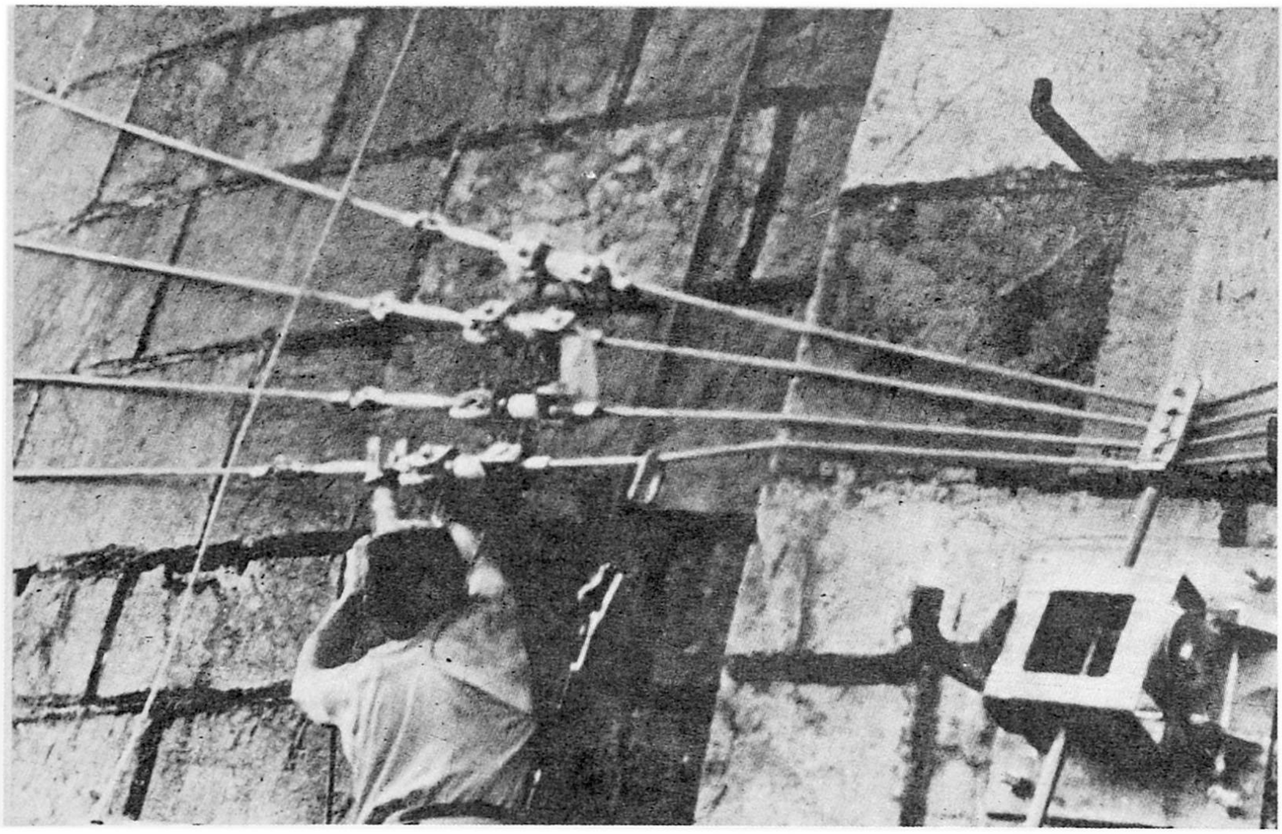


Pic.30 : Mathematical model of the dome

A preliminary mathematical model (fig. 30) shows that the shape of the dome, bein quite hemispherical, is the cause of important tensile stresses in the parallels and, consequently it has led to the crack pattern that we have observed.
A second mathematical model, taking in account the discontinuites represented by the cracks, has shown that now the equilibrium is assured only by important bending momentes in the meridians, represented by tensile stress and compression stress, on the inner and outer surface of the dome.
In this situation the margin of safety is very low.
The reinforcement that we proposed consisted of prestressed cables of the same kind usually employed to sustain the masts of sailing boats (figg. 31, 32). The advantages of this solution are economy and durability.
The stainless steel cables have been put in place by "escaladores" (fig. 33) and the phase of pretensioning has been monitored (fig. 34).

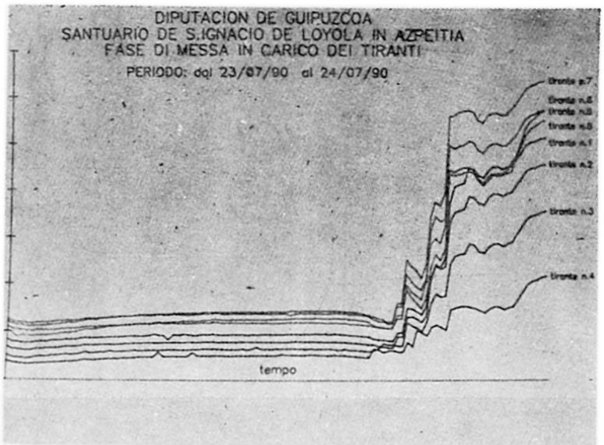


Pic.31: Prestressed cables for the reinforcement of the dome



Pic.32: The cables for the reinforcement of the dome

Pic.33: The operations to place the cables



Pic.34: Monitoring of the phases of prestressing

Engineer's Role in Shaping Civilization

Rôle de l'ingénieur dans l'évolution de la civilisation

Die Rolle des Ingenieurs bei der Gestaltung der Zivilisation

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SUMMARY

Engineers have played a vital and driving role in the evolution of civilization as we know it today. Tracing the thread from prehistoric times to the visions of the future, one becomes aware of the awesome responsibility the engineer has to his fellow man.

RESUME

Les ingénieurs ont joué un rôle essentiel et prédominant dans l'évolution de la civilisation actuelle. En parcourant l'histoire, des temps préhistoriques aux visions futures, l'on peut voir facilement la responsabilité impressionnante de l'ingénieur vis-à-vis de la société.

ZUSAMMENFASSUNG

In der Entwicklung der Zivilisation, wie wir sie heute kennen, haben Ingenieure eine lebenswichtige und treibende Rolle gespielt. Folgt man dem Faden von prähistorischen Zeiten zu den Visionen von morgen, so sieht man mit Ehrfurcht die Verantwortung des Ingenieurs gegenüber seinem Mitmenschen.

"... the bridge is more than an embodiment of the scientific knowledge of physical laws. It is equally a monument to the moral qualities of the human soul. It could never have been built by mere knowledge and scientific skill alone. It required, in addition, the infinite patience and unwearied courage by which results are achieved."

With these words, the Honorable Abram S. Hewitt, on May 24, 1883 expressed humanity's indebtedness to the builders of the Brooklyn Bridge.

If today Hewitt's words sound overly poetic and soaring, it may indeed be due to the changes in oratorical style that have occurred over the past century, but it is also due in part to our own loss of perspective and appreciation for the driving force that engineering works have been in shaping the physical world, society, and the basic human condition that we take for granted.

We have come to accept the fantastic as commonplace, the incredible feats of engineering achievement as the expected. But it was not long ago that the engineer was seen as a heroic leader of humanity, whose mission was to "subdue" the earth, as the Bible says God ordered man to do. Walt Whitman, the great American poet, expressed this thought in his lines;

> Lo, soul, seest thou not God's purpose from the first?
>
> The earth to be spann'd, connected by network,
>
> The races, neighbors, to marry and be given in marriage,
>
> The oceans to be cross'd, the distance brought near,
>
> The lands to be welded together.

What defines engineering and when did it begin? Some engineers, tongue-in-cheek, claim that it is the second oldest profession. This view may be valid if we allow latitude in the use of the term "profession." For when did we become civilized and in turn begin classifying individuals as doers of specific tasks? It was not when humans first gathered together to live in groups for the common good, because lower forms of life such as wolves, lions, even insects, preceded humans with this "societal lifestyle" (bees and ants seem to be more adept at it than we humans are, even today). It was not when humans developed the ability to communicate with each other, because again, many lower life forms do that. It can be argued very convincingly that civilization began when mankind broke free of the bounds set by its natural environment and began to shape its own world. It appears that this was an inevitable result of the physical evolution of man, as it is the human spirit, that exists for the sake of bettering itself, that has ultimately defined the species.

So we began to build. It doubtless began with primitive dwellings to deal with the weather, and primitive bridges of logs and stones connecting primitive highways cleared of brush to provide transportation to sources of food and water. It may have been very early in this evolutionary process that some individuals emerged as builders, while others were more suited for hunting, farming, etc.

As population centers grew, shortages of space and food undoubtedly led to rivalries between groups (an inherent but unfortunate characteristic of the human spirit) and defense and aggression became a more important concern of the builders. The most ancient ruins of civilized settlements generally bear one prominent feature in common, that of a system of fortifications in the form of protective walls or embankments. When man learned to protect his territory by building structures to thwart rival groups from taking what they wanted it became mutually advantageous for different societal groups to learn the concept of trade and commerce. This required transporting people and goods from one place to another and organized building of roads and bridges was born. Archaeological discoveries reveal that primitive man was remarkably industrious and creative in such civil works, even thousands of years before recorded history.

Until relatively recent times the word "engineer" had a military connotation. The empire of the Romans was based on military strength, but this strength was primarily a product of their highly developed skills in engineering. "All roads lead to Rome," the saying goes, and throughout its reign, this was literally true of the roads of the Roman Empire. In order to maintain its rule over the many settlements that were so remote from its capital, the Empire built roads and bridges, barrelling straight through from city to city to create an unhindered way for its legions of soldiers. The subjects of the Empire knew very well where the end of the road was.

But this formidable system of great roads also caused the intermingling of knowledge and cultures from the diverse peoples throughout much of the old world, and accelerated the evolution of civilization. Individual societies were no longer left to develop in isolation and mankind grew closer to becoming a singular, collective, whole. Eventually, through this exchange of knowledge more and more societies found the means and will to create important civil works for the betterment of their lives. Human intellect steadily moved toward higher ideals and philosophies and the recognition that society's reason for being is to work toward the common benefit of all.

While today we do not usually think of the engineer in terms of the governing segment of society, in ancient times the leaders were those who could direct the building of public and military works. The word "Pontiff", which today refers to the Pope of the Roman Catholic Church, originally meant "Bridge Builder," an interesting clue to the leadership role the engineer has played in history. It was recognized that society could only be sustained and improved when people did not have to struggle merely to survive. The construction of dwellings, systems to provide adequate water and sanitation, and reliable transportation routes were absolute necessities if civilization was to continue its course. The engineer was thus very powerful and influential in ancient times.

As this process of evolution continued, the human mind delved deeper into an understanding of the physical world. Science and mathematics progressed in the relentless pursuit of the technology that humanity demands, eventually leading to the industrial revolution of the 19th century. Engineering was freed from its military limitation and became a profession dedicated to building machines, structures, and highways for civilian purposes as well.

It was during this time that industrial machinery increased our ability to manufacture all nature of goods in mass quantities, making them available to a much broader segment of the population. The invention of electrical power generation and incandescent lights changed forever the way humans lived. As the industrial and commerce centers of the world grew steadily larger, so did the concentration of people needed to keep the machinery running.

These developments are what shaped the modern cities of the world. New York, as a glowing example, became overcrowded and began to overflow its geographical boundaries. The development of taller buildings was seen as a partial answer to packing more people and more industrial space within its confines. In 1849, James Bogardus built a factory framed entirely of cast iron, the first such use of the material, although it had been known to man for thousands of years. The practical height of conventional brick, stone, and concrete buildings was five or six stories due to the massive walls and foundations that were required to bear the weight. But with the innovative use of iron, and later steel, previously unimagined heights were now possible. The invention in 1854 of Elisha Otis's "safety hoister," or safe elevator made the skyscraper not only possible, but practical as well. An increasing boldness and a spirit of rivalry drove American engineers to build even taller buildings, and by 1890 the Pulitzer Building, on Manhattan's Park Row, held the world's record at 106 meters.
These furious advances in the construction of buildings were accompanied by still other advances in engineering that illustrate the old saw that "necessity is the mother of invention." The need to supply water to the teaming population led to the construction of the Croton Reservoir and Aqueduct, itself a major engineering achievement completed in 1842. Where 70 years earlier the city's sewage was being removed by lines of slaves carrying tubs to the river, over 150 km of underground sewer pipes were doing the job by the late 1850's (today, the system totals almost 10,000 km). The need to transport the city's workers to and from their homes in nearby rural Brooklyn set the stage for John Roebling to design his masterpiece Brooklyn Bridge which, using steel wire in its cables for the first time, was the prototype for modern long-span suspension bridges.

One cannot over emphasize the importance of transportation in the proliferation of civilized society worldwide. The construction of canals, railroads, and highways, with their requisite bridges and tunnels, was a key factor in shaping today's world. It is self-evident that the exploration, settlement and industrialization of larger geographical areas depend on transporting people and things. As we observe the new order of a more unified world taking shape there are monumental transportation projects underway as the first and necessary step to make the future possible.

Great Britain and France will soon be joined by a tunnel beneath the English Channel, one of the greatest civil engineering achievements in history and a milestone of cooperation between an international alliance of engineers and builders. There are numerous bridge building projects underway in Asia and Europe that will change civilization forever. The Great Belt Link, which is now under construction will permanently unify the three major land masses of Denmark, and will be accomplished through the combined efforts of Engineers and Contractors from several European countries as well as the United States. While this project also contains one of the world's greatest tunnels, the East Bridge, with the world's longest span to date, will be yet another "monument to the moral qualities of the human soul," created by the engineer. A bridge from Denmark to Sweden is the planned next step. Japan's Honshu-Shikoku project will similarly unify its major islands. In Italy, plans are being developed to bridge the Straits of Messina, the deep and treacherous waterway that separates Sicily from the mainland. Its proposed main span of over 3,000 meters will double that of even the Great Belt Bridge.

With our steady advances in technology and physical achievements has come a heightened awareness of a not so obvious responsibility of the engineer of today and the future. We realized only recently that our machinery and construction projects have been insidiously damaging the world we inhabit, and had we chosen to ignore the evidence, we would have engineered our own destruction. We have thankfully become markedly more environmentally aware, and have begun to install checks and balances to control the impact that our creations will have on the Earth's fragile ecosystem. We have seen in some quarters a complete turnaround in our attitude toward harnessing nature. In the United States, a telling example is the changing charter of the U.S. Army Corps of Engineers. The Corps dates back to the early 1800's and is charged primarily with protecting and developing the country's inland waterways to provide for transportation and adequate water supply. To this end, it fervently proceeded with massive dredging, damming and wetlands reclamation projects. Within the past thirty or forty years we have begun to learn how important wetlands are in the ecological balance of the environment, by moderating the climate, providing natural pollution control, and supporting the life cycles of a multitude of living organisms. For what was seen as disregard of these vital natural systems, the work of the Corps came under severe criticism in the 1960's, and in 1972 the U.S. Congress, with ironic brilliance, gave the Corps responsibility for protecting all of the nation's wetlands. Taking its new responsibility in earnest, the Corps now wreaks havoc on those developers who would potentially damage estuaries and swamps.

Hopefully, we have realized in time that our technology must be used carefully lest we destroy our own Mother Earth. The depletion of the ozone layer, the spectre of global warming, disastrous nuclear power plant accidents, and the visible destruction of plant and animal life throughout the world's lands and oceans are feedbacks from the engineer's work that are now redefining the engineer's role for the future. We obviously should not stop building dams to supply water to needy humanity, or rail and highway systems that bring better living conditions to undeveloped parts of the world. We have no choice but to continue building, but we must do it with an eye toward the larger scheme of things and balance the immediate human needs with the long term needs of our partner in survival; Nature.

We will continue to envision and execute great works to improve our lives and to gradually unify the peoples of the world. The shaping of the world by major engineering works is not over by any means, as some might believe.

Developing nations are moving rapidly toward industrialization and construction of infrastructure by importing and developing technology to meet their particular needs. India, for example, already has a well developed rail system that is the envy of its neighbors, and there is a national move toward increased industrialization and export of goods that will bring in the capital needed for further development. Major public works in water supply and power generation have already begun to move the country toward improved living conditions.

It is expected that major civil engineering works will eventually take place in the independent states of the former Soviet Union, where an abundance of recognized engineering skill and advanced technology will no doubt flourish with an infusion of investment from the outside world. The vast resources of these states can be tapped once a viable transportation system has been built. Russia is already revamping its civilian communication systems to do business with the rest of the world.

There is talk of bridging the Straits of Gibraltar and connecting the Aleutian Islands with Siberia. These bold visions are typical of the human spirit's natural drive to create that has brought us this far. We are witnessing blinding advances in computer aided design technology and the development of new engineering materials. The use of plastics, fibers and ceramics that developed through the space program may yield profound advances in future structures. E-Glass and Kevlar fibers, for example, have been manufactured with a tensile strength nearly two times that of modern bridge wire, opening the possibility that we may someday build superspan suspension bridges that will dwarf even the proposed Messina crossing. Advances in concrete making have yielded compressive strengths three to four times that of conventional concrete, allowing us to design more daring and more economical structures.

We will be forever occupied in repairing, maintaining, and upgrading our existing infrastructure. Well over one billion U.S. dollars will ultimately be spent on rehabilitating New York's four East River Bridges alone. We are developing ways to extend the life of these aging structures by refurbishing suspension cables and replacing roadways with more durable materials. We are strengthening the creations of our predecessors to make them capable of meeting modern demands of traffic and economical maintenance.

Major upgradings of our transportations systems will require innovative ways to increase the capacity of existing structures. The Tagus River Bridge in Lisbon, for example, is about to be retrofitted to carry rail traffic on a new second deck, as is San Francisco's famous Golden Gate Bridge.

As engineers, we can surely take pride in our profession, and we must surely never lose sight of the awesome responsibility that civilization has assigned us. It is a responsibility to the past and to the present, but even more so to the future generations. It is a responsibility to leave them with a world that is better than the one we entered.

In The Sons of Martha, a poem of tribute to the engineering profession, Rudyard Kipling eloquently portrays the engineer's place in society. This stanza from the poem is my favorite:

They do not preach that their God will rouse them a little before the nuts work loose.

They do not teach that his pity allows them to leave their work when they damn-well choose.

As in the thronged and the lighted ways, so in the dark and the desert they stand.

Wary and watchful all their days, that their brethren's days may be long in the land.

Reflections on the Development of Structural Engineering

Réflexions sur le développement de l'ingénierie des structures

Ueberlegungen über die Entwicklungen im Konstruktiven Ingenicurbau

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SUMMARY

"New horizons in structural engineering" — may first evoke the thought of innovative new structures to be built in the future. For this reason recent realizations of outstanding structures are briefly presented as an indication of potential new developments in this field. However, the challenge we face today, which is to create a viable environment for everybody, is much more of economical, social and political than of purely technical nature. Thus, it seems imperative that the IABSE and other international engineering organisations enhance their influence in decision-making bodies.

RESUME

Le sujet "Nouvelles frontières dans les constructions de génie civil" pourrait au premier abord nous faire penser à des perspectives nouvelles et innovatives dans les constructions. Les récentes évolutions de certaines constructions exceptionnnelles, évoquées brièvement, permettront de tirer profit pour de potentielles, nouvelles applications. Toutefois, le défi posé, soit de créer et de conserver un environnement viable pour l'humanité, est surtout une tâche de nature économique, sociale et politique, et ne pouvant pas uniquement être résolue au niveau technique. Pour cette raison, il est primordial que l'AIPC et d'autres organisations internationales d'ingénieurs gagnent de l'influence dans la phase de décision pour de nouveaux projets.

ZUSAMMENFASSUNG

Beim Thema "Herausforderungen an den konstruktiven Ingenieurbau" mag man zunächst unwillkürlich an neue, bahnbrechende Bauten denken, die in Zukunft realisiert werden könnten. Daher wird zunächst die jüngste Entwicklung hervorragender Bauwerke kurz aufgezeigt, in der Absicht, Schlüsse für potentielle, neue Anwendungen zu ziehen. Allerdings ist die Herausforderung unserer Zeit, das heisst der Menschheit eine lebenswerte Umwelt zu schaffen oder zu erhalten, vielmehr eine wirtschaftliche, soziale und politische Aufgabe, die mit technischen Mitteln alleine nicht gelöst werden kann. Daher sollte sich die IVBH und andere internationale Ingenieur-Organisationen darum bemühen, bei Entscheidungs-Prozessen für neue Entwicklungen vermehrt Einfluss zu gewinnen.

1. PRELIMINARY REMARKS

It is indeed laudable that an important international organisation such as IABSE devotes a whole congress to pressing problems of the future of mankind, rather than to treat technical topics only. There can be little doubt that civil engineers could and should play a more important rôle in the quest to create a viable environment for everybody. It seems however somewhat doubtful if this can be achieved by fabulous innovations or - as the title of this session suggests - by striving for new horizons in structural engineering, at least if this is interpreted as referring to technical progress only.

The challenge we face today is much more of economical, social and political, rather than of purely technical nature. If we only compare the beauty and cultural harmony of ancient towns with modern cities which look very much the same throughout the world, one realizes that even for a technically relatively simple problem, such as the one of providing adequate housing for the evergrowing world population, no convincing solution has yet been found, in spite of the many earnest, albeit sometimes questionable attempts made in this respect.

Even though the high spirited endeavour to improve "civilization through civil engineering" will be extremely difficult to achieve, it seems certainly worthwhile to make attempts in this direction.

2. OUTSTANDING STRUCTURES

When referring to "new horizons in structural engineering", one is indeed inclined to think first of ever larger, higher and more gigantic structures. As suggested in the introduction, this is hardly one of the most pressing issues of the future of mankind. As a matter of fact, the precarious world situation would not greatly change if the Strait of Gibraltar - to cite just one example - could be crossed by an enormous bridge or a tunnel rather than, as so far, by ferry boats. However, since the theme of this session implies such notions and since the topic is indeed very interesting from an engineering standpoint, we shall have a brief look at the recent development of outstanding structures, and in particular of bridges.

Among the most gigantic ones count certainly modern off-shore structures which go to ever greater depth of several hundred meters below sea level. Immense technical progress have been made in this field, if one thinks only of the sliding formworks employed, comprising a developed and accumulated circumference of up to 2 km to be continuously lifted in uniform manner (Fig. 1). The experience gained from such pioneer work will certainly sooner or later be adopted for bridge foundations in deep seas.

As for very high towers, sometimes deemed necessary, to broadcast Media Programs to the last corner of the world, they do not cause unsurmountable technical problems. However, one may rightly question if the flood of sensational and often useless information contributes to the improvement of our civilisation and thus justifies such investments.

Another matter is the one km high chimneys envisaged for the thermo-solar energy plants. Technologically this can certainly be realized if only the political and financial problems can be overcome.

There can be little doubt that, especially in the field of bridge construction, enormous progress has been achieved in the more recent past. This pertains somewhat less to spectacular new systems or concepts of bridges, but much more to advanced construction and erection procedures. Compared with the general costs of living, bridges have indeed become relatively cheap and can be built in extremely short time.

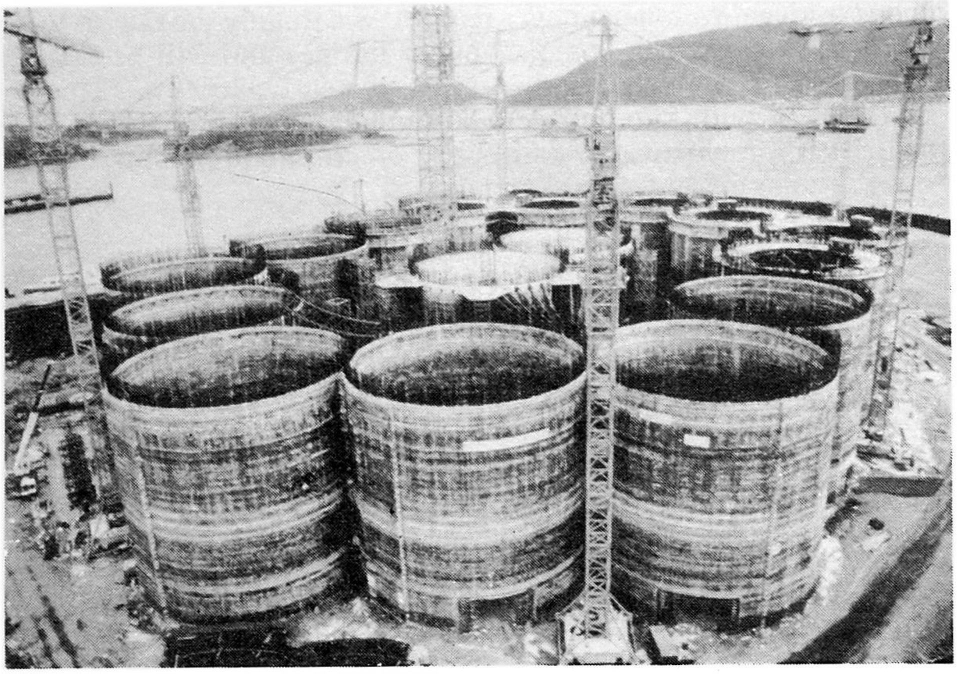

Fig. 1

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As an example, the remarkable Pont de Ré in France, which links the off-shore island with the continent, may be cited. The whole 2930 m long bridge was constructed by the cantilever style method in a record time of only 20 months for a unit price of less than 1000 US$ per meter square (Fig. 2).

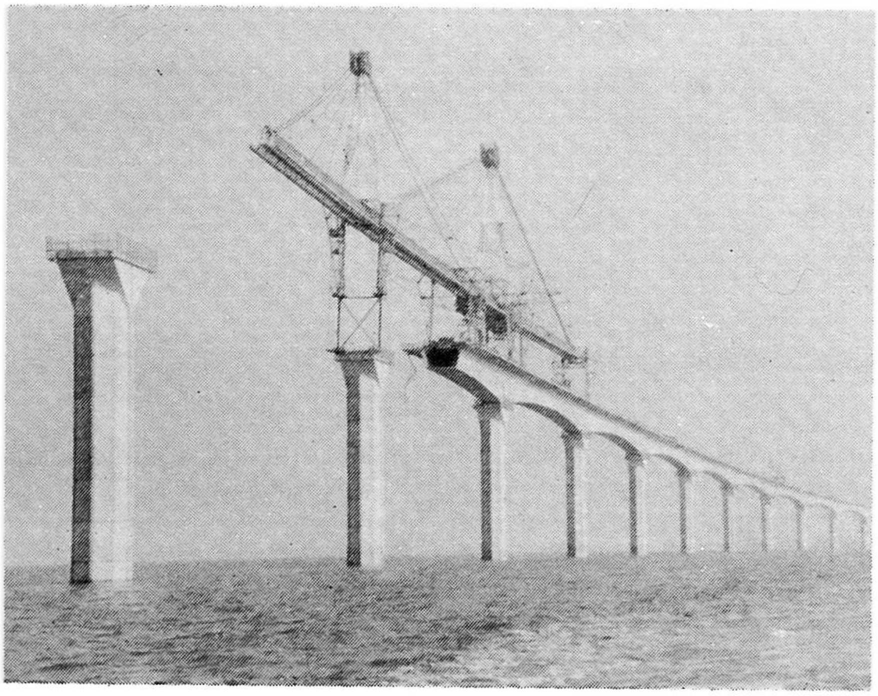


Fig. 2

The most ambitious bridge development ever realized is certainly the one of the Honsu-Shikoku crossing, which comprises some 20 major bridges and will be completed in 1998 by the Akashi-Kaikyo Bridge with a span of nearly 2000 m. This gigantic endeavour carried out in only two decades, unthinkable in former times, was only possible due to the very sophisticated and heavy erection equipments the Japanese engineers had developed to this end (Fig. 3 and 4).

Fig. 3

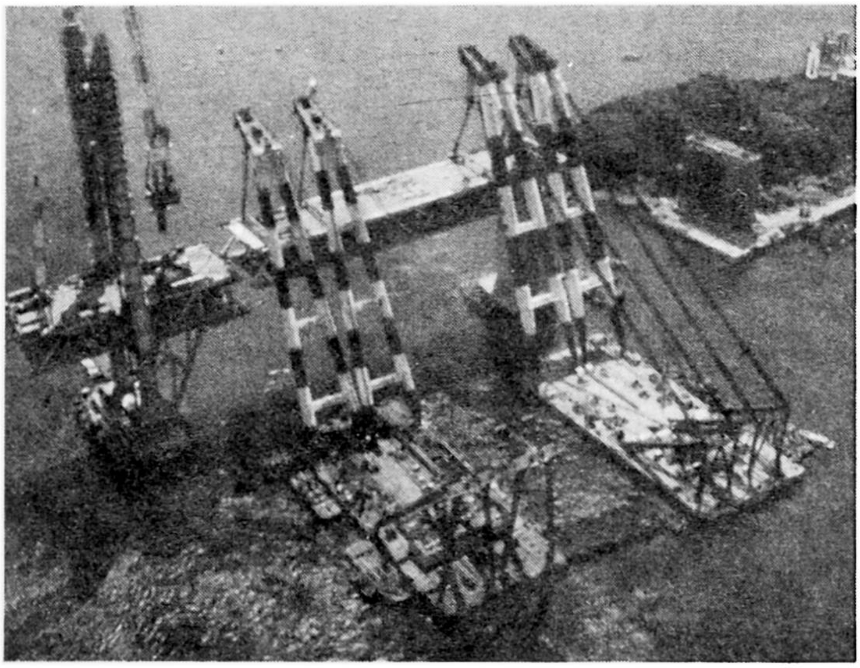


Fig. 4

Since in this paper it is intended to analyse the actual trends critically, it may be allowed to state that our admiration for this enormous undertaking would even be greater if the aspects of aesthetical harmony would have been given as much attention as to the unquestionable epochal technical achievements.

The pre-eminence of construction methods becomes also clearly evident in the case of arch bridges. Big labour-intensive falseworks as used in the past are not anymore envisageable economically. Thus arch bridges are nowadays built by skillful combinations of cantilever methods, incremental launching or even sliding formworks (Fig. 5 and 6).

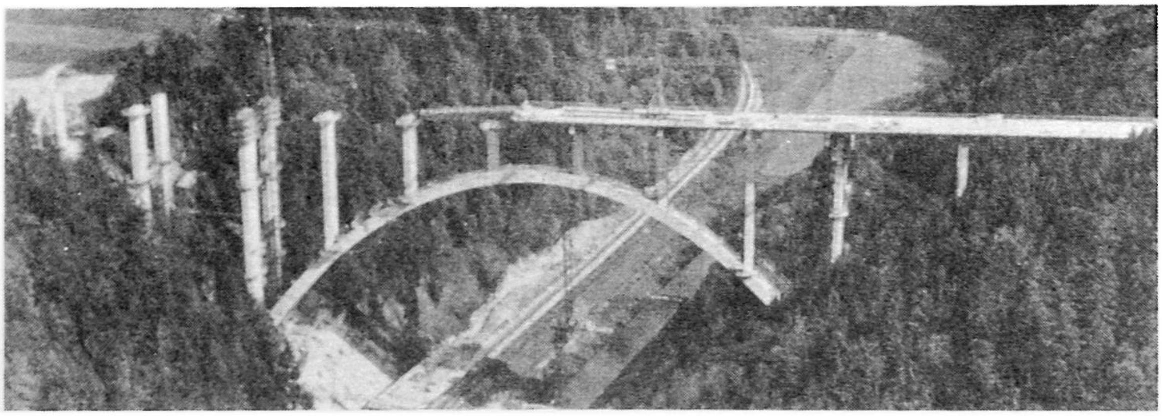


Fig. 5

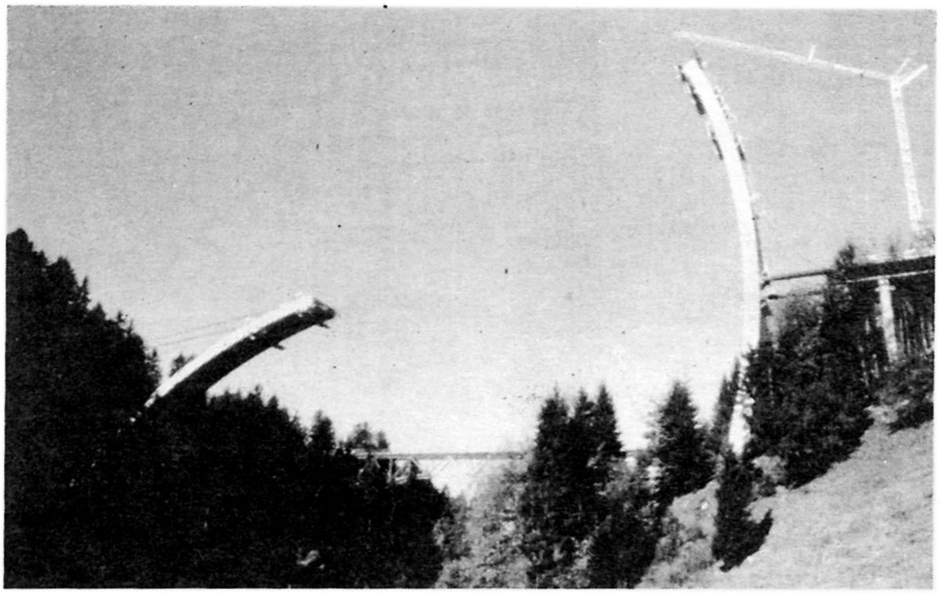


Fig. 6

Erection speed and economy can greatly be enhanced by prefabrication combined with external prestressing. In the case of the Sylan-Bridge in France prefabricated match-cast truss segments were assembled on a huge launching beam and tied together by external prestressing calbes (Fig. 7).

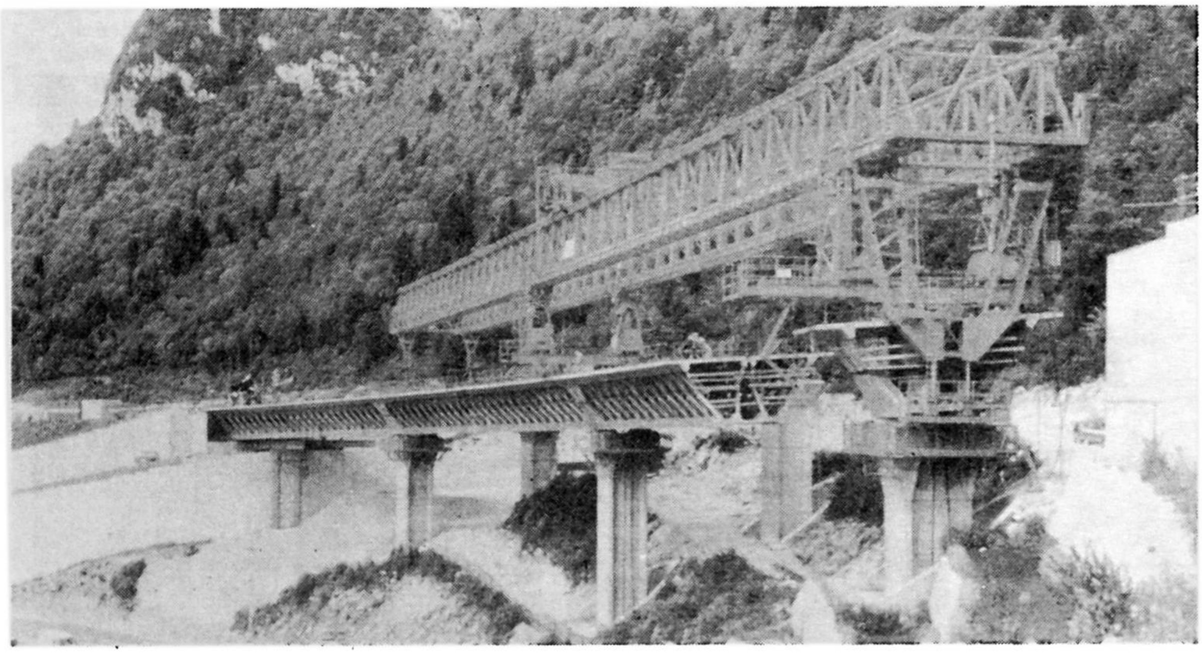


Fig. 7

The spectacular, worldwide success of cable stayed bridges is to a large extent due to the comparatively simple and economical erection procedure normally by the cantilever-method. It would lead too far to retrace this remarkable devlopment here in detail. Just two recent oustanding projects shall be mentioned: the recently inaugurated Skarnesund-Bridge in Norway (Fig. 8) has a record span of 530 m, which is all the more remarkable considering its width of only 13 m corresponding to a daring transverse slenderness ratio 1/40. Its fully satisfactory aerodynamical stability was achieved by an adequately shaped, rigid concrete box section.

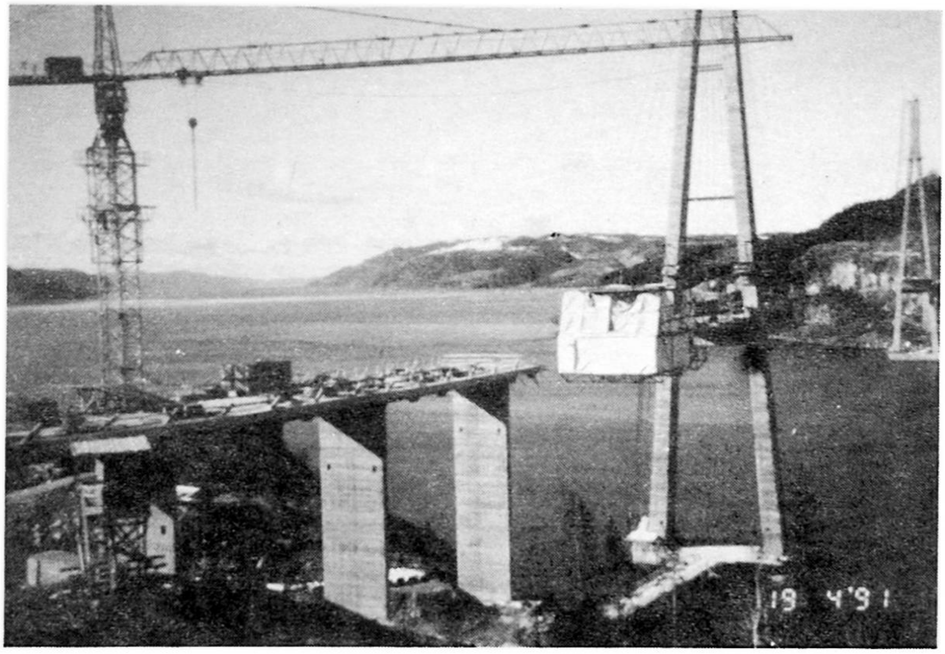


Fig. 8

The Normandy Bridge actually under construction will have an even greater span of 865 m (Fig. 9). There had been some quite heated arguments on whether or not it is prudent and feasible to extend the range of application of cable stayed bridges to such large spans. On the account of the experience gained from the Starnesund Bridge, the answer is clearly positive. As might be known, Prof. Leonhardt and his Italian partners have proposed to cross the Strait of Messina by a 1800 m span cable-stayed bridge (Fig. 10), which could undoubtedly be built, but which was not deemed acceptable, mainly for navigational and geotechnical reasons.

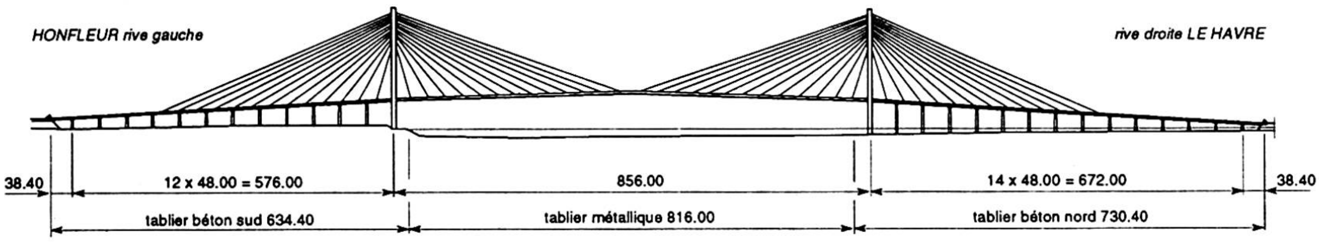


Fig. 9

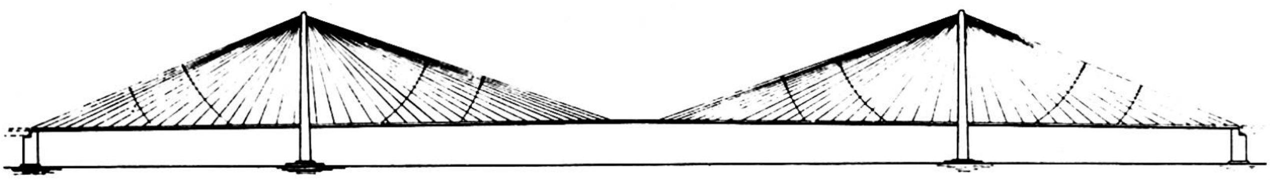


Fig. 10

On the other hand, the very thought that new types of cables made out of carbon fibers will enable us to build a bridge over the Strait of Gibraltar with a central span of over 8 km belongs for the foreseeable future to the world of pure fantasy. It would be all but impossible to erect and stabilise 4 km long free cantilevers. However, the advantage that such cables are about four times lighter than steel cables could be potentially of interest for future but somewhat more modest applications.

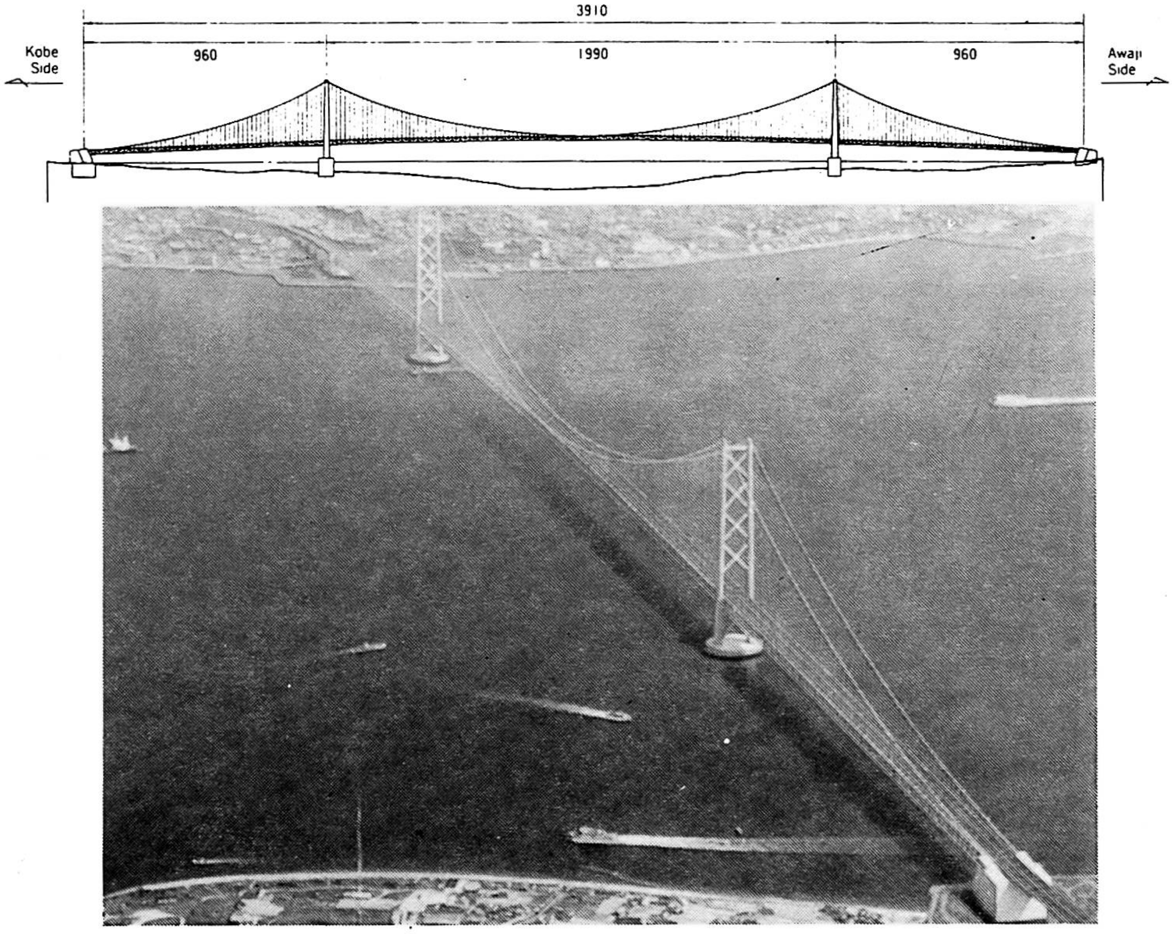


Fig. 11

Fig. 12

For the time being very large spans will probably remain the domain of suspension bridges with steel cables. At any rate the two largest projects in view pertain to this category, namely the Akashi-Bridge in Japan acutally under construction with a span of 1990 m (Fig. 11) and the Messina Strait-Crossing with an even more daring central span of 3300 m (Fig. 12).

3. ON INNOVATION AND ORIGINALITY

The theme "new horizons in structural engineering" might also evoke notions of revolutionary innovations, which - if they ever come true - can hardly be foreseen. If we indulge in some objective modesty, we have to admit that in spite of all the spectacular technical progress we witnessed in the recent past, there were rather few fundamental innovations. The last major break-through, the invention of prestressing by Jackson, dates already one century back and it took another 50 years to develop it to its present standard.

It is indeed true that a great many interesting new developments have taken place, such as for example very high strength (or high performance) concrete, composite materials, carbon - and glass-fibers etc., however none of these taken as such seems at least at present to open radically new horizons in structural engineering.

One may deplore this fact but the gun powder cannot be reinvented every so often and we have also to bear in mind that the most glorious periods of human civilisation were usually brought about by utmost perfection of the cultural inheritance rather than by sudden technical innovation.

In our opinion, innovation at all price should not be an end in itself, all the more since the search of ostentatious originality bears sometimes rather dubious fruit, as for example the palace shown in figure 13 which is in reality a low-rent apartment building.

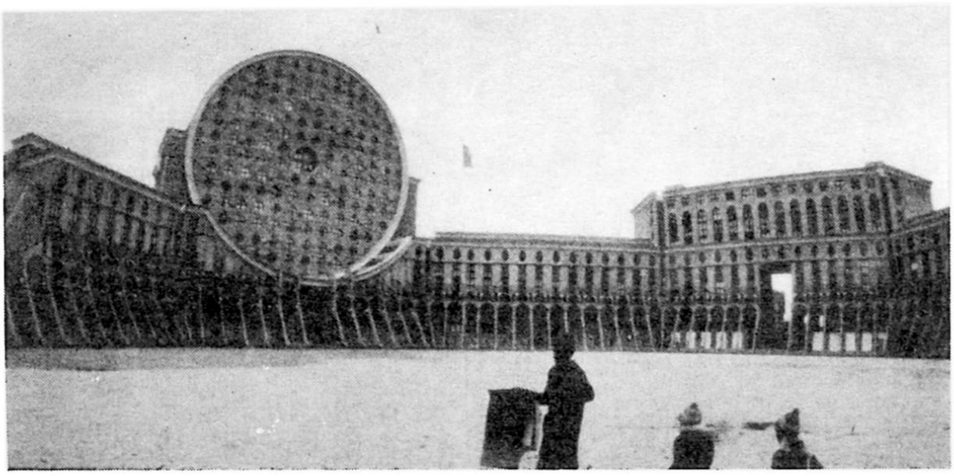


Fig. 13

4. ON THE ROLE OF STRUCTURAL ENGINEERS

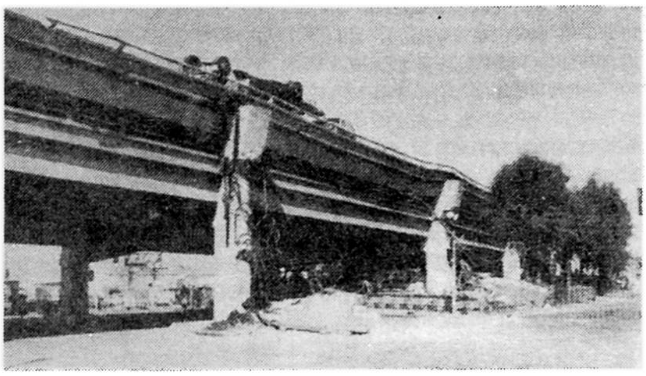
In many parts of the world, especially in industrialized countries, the reputation and status of engineers is not anymore as high as it used to be in the past and certainly not what it should rightly be in accordance with the great responsability they have to shoulder, in particular if anything goes wrong in the building process.

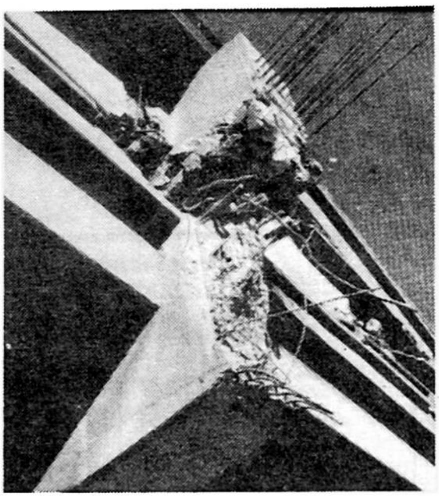
Among others this decline in the public recognition of the decisive rôle of the engineers is for example demonstrated by the fact that even for bridge competitions, it has become fashionable to assign the task of the conceptual design to architects rather than to engineers.

Indeed many reasons exist for this deplorable situation which are beyond our control. However, the engineers have also to shoulder some blame in this respect.

The excessive preoccupation of many scientists with setting up ever more detailed codes and specifications hardly contributes to the image of engineers as creative designers. It is a small wonder that architects consider the latter as mere interpreters of these intricate documents and more often than not call upon engineers only to dimension structures already conceptually designed by them.

On the whole the ever growing narrow specialization and in particular the unfortunate drifting apart of theory and practice have very detrimental effects on our profession. The most basic law in engineering that is the one of equilibrium, should also be observed in education; however it is nowadays grossly violated at many universities in favour of a onesided emphasis on theoretical science with no or only marginal reference to practical application. One striking example is the collapse of the double-deck highway bridge (fig. 14) during the 1989 Loma Priesta Earthquake in San Francisco, which was mainly due to bad detailing. This seems all the more incredible since in the very same region there are several first rate universities with the world's foremost specialists in seismic engineering, computer science and management. Unfortunately all the profound knowledge accumulated there evidently did not in this case find its way to practical design and construction.





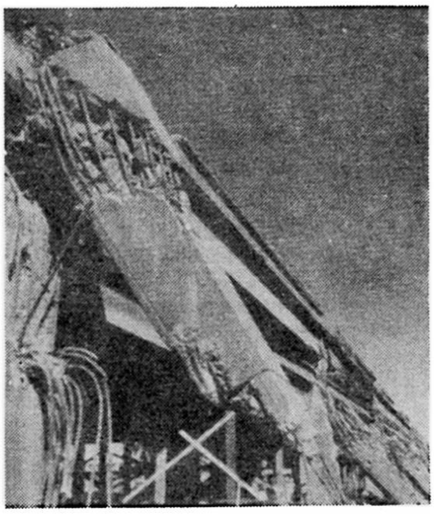


Fig. 14

Civilization through civil engineering cannot, however, be brought about by learned discussions but only by practical achievements, which necessitates also a more active participation of our profession in the decision making political process.

In our opinion the IABSE should spare no effort in helping to improve the image and rôle of civil engineering in our society. There must somewhere be a forum which actively defends the interests of our profession.

This is admittedly more easily said than done, but the importance of this urgent task warrants such an endeavour by the IABSE, preferably in close collaboration with other international organizations.

Plenary Session 2

Structural Contribution to Natural Disaster Reduction

Contribution du génie civil à la réduction des catastrophes naturelles

Beitrag des Bauwesens zur Verminderung von Naturkatastrophen

Organizer: Johan Blaauwendraad, The Netherlands

Chairman — S.S. Chakrabarti India

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Natural Disaster Reduction through Structural Quality

Réduction des catastrophes naturelles grâce à une meilleure qualifé des structures

Verringerung von Naturgefahren durch bessere Bauqualität

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Alan G. Davenport attained his B.A. and M.A. in Mechanical Sciences from Cambridge Univ. England, in 1954 and 1958 respectively, his M.A.Sc. in Civil Eng. from the Univ. of Toronto in 1957, and Ph.D. in Civil Eng. from the Univ. of Bristol in 1961. Appointed to the Eng. Faculty of the Univ. of Western Ontario, London, ON in 1961, he is now a Professor and founding Director of the Boundary Layer Wind Tunnel Laboratory since its establishment in 1965. He is currently Chairman of the Canadian Committee for the International Decade for Natural Disaster Reduction. Author of some 200 papers and recipient of a number of awards.

SUMMARY

The paper discusses the role the structural engineer can play in reducing natural disasters. The paper examines the strategies for disaster reduction and the obstacles that must be faced. The paper suggests that the control of quality must be a high priority in hazard resistant construction and suggests ways how this might be improved.

RÉSUMÉ

Cet article présente le rôle que peut jouer l'ingénieur civil dans la réduction des catastrophes naturelles et il examine les stratégies à envisager et les obstacles à surmonter pour y parvenir. Il envisage de donner un rôle prioritaire au contrôle de la qualité des constructions devant résister aux risques envisagés et il suggère des moyens pour l'atteindre.

ZUSAMMENFASSUNG

Es wird die Frage nach dem Beitrag des konstruktiv tätigen Bauingenieurs bei der Linderung von Naturkatastrophen aufgeworfen, nach Strategien des Vorgehens und zu erwartenden Hindernissen. Der Verfasser vertritt die These, dass der Qualitätssicherung beim Bau widerstandsfähiger Tragwerke hohe Priorität zukommen muss, und schlägt Wege zu deren Verbesserung vor.

THE PROSPECTS OF NATURAL DISASTER REDUCTION THROUGH IMPROVEMENTS OF STRUCTURAL QUALITY

1.0 INTRODUCTION

Over the past 20 years the costs of natural disasters have escalated significantly. The number of catastrophes, as defined by the reinsurance industry, has nearly quadrupled. The World Bank has similar estimates for the increase in the costs of post-disaster reconstruction. The losses to smaller nations are often well in excess of their GNP and their development is seriously impeded.

It is these concerns and the needless waste involved which has inspired the declaration of the 1990's as the International Decade for Natural Disaster Reduction. The goal of the Decade is to reduce the losses of life and property from disasters due to various natural hazards including earthquakes, wind storms, tsunamis, floods, landslides, volcanic eruptions, wild fires, grasshopper and locust infestation.

Natural disasters are not a new problem and in fact are as old as the hills. Human history and mythology is steeped in the dread of catastrophes as far back as biblical times. At some times in our history, peoples' responses have been fatalistic and disasters regarded as "Acts of God". In some quarters this is still the case. But fortunately this is not the only view. While the natural events themselves may be inevitable and will continue, the disasters which result must be regarded largely as "Acts of Mankind" or more exactly, the failure of mankind to take prudent action when collectively in possession of the knowledge to do so. We are, indeed, "masters of our destiny".

In our progress to civilization, the concern for natural disasters and the development of counter-measures has been a powerful and persistent incentive. In fact it has been contended that the capacity to deal with natural disasters has been and is a critical measure of the advancement of our civilization. To come through a severe natural disaster is a test of the technical capacity to mitigate the disaster, the social capacity to take appropriate humanitarian action as a community, and the political capacity to prepare for the emergency and maintain law and order at a time when there is panic and confusion.

These capacities are still a critical test of our own civilization. It is appropriate that it was the United Nations that passed the international resolution expressing our collective international intent to reduce natural disasters. It is not the intent, however, that the United Nations will take on the task by itself. It could not, the task is too great.

The task must be accomplished first through individual countries developing a national plan of action, and the internal institutions for emergency preparedness and disaster planning; second, through collective bilateral and multilateral action, and third through the involvement of various sectors of society which have a stake in the outcome and ability to influence events. This last group includes the engineering profession, scientists, and technologist; the financial community, involving investors and insurers; as well as industry,and many important non-governmental organizations involved with emergency preparedness,

It is important to find where the weaknesses are in the way that we do things at present, find out what more can be done, and make changes. This is the challenge.

At present, the increasing threat of natural disasters, in spite of our increased knowledge is ominous. It is due to several causes. First, the increase in population and increase in size and numbers of large cities. This increases the "target area" for the disasters to strike. Second, because of the increasing scarcity of land, settlement is occuring on land such as coastal regions and floodplains, which are more vulnerable to natural disasters; and third because of the increasing cost and complexity of the infra-structure of modern life.

We are steadily becoming more vulnerable. The nature of the vulnerability is different in different countries. In India and Bangladesh, threatened by cyclones in the Bay of Bengal, there is the tragic threat to human life and the destruction of a fragile economy. In Tokyo or San Francisco, threatened by major earthquakes, there is not only a threat to life but also a different kind of danger from the economic shock wave which may follow as the insurance companies sell stocks to pay claims reaching, perhaps, many tens of billions of dollars.

Civil engineers, and in particular structural engineers, have a vitally important contribution to make in reducing these natural diasters. The evidence is that a major cause of earthquake and windstorm disasters is structural failure; the other major cause being inundation by the storm surge accompanying tropical cyclones, coastal erosion and river flooding. The skills and knowledge of civil engineers are key to the prevention of both these causes of disaster. Their skills are needed in the prevention of these disasters and reconstruction after the disaster has struck

There are indications that much more can be done.

This paper first discusses the general approaches to disaster mitigation and the role played by civil engineers. We illustrate the evolution of a natural disaster by considering the structural damage due to recent hurricanes in the Caribbean. We conclude with some suggestions for tasks for structural engineers to consider.

2.0 DISASTER MITIGATION: THE MAIN LINES OF DEFENCE

To appreciate the potential civil engineering role, it is worth considering the three main lines of defence in mitigating disasters - prevention, reduction of the impact, and recovery.

TABLE 1. MEASURES FOR DISASTER MITIGATION
***** major, ** significant, * minor**

First Line of Denfence: Prevention		Civil Engineering Involvement
Hazard risk assessment	***	Estimation of extreme winds, seismicity and floods;
Planning	**	definition of hazard prone areas;
Prevention	***	design of hazard resistant construction; inspection and maintenance; geotechnical site evaluation of slopes; shore protection and flood prediction.
Second Line of Defence: Reduction of Impact		
Emergency preparedness		
Warnings	*	Flood, landslide warnings;
Dissemination		
Evacuation		
Shelter	*	Evaluation of safety an design of shelters;
Search and Rescue		
Third Line of Defence: Recovery		
Relief (food, medical and other aid)		
Post-disaster assistance	**	Re-establishing utilities; evaluation of damaged buildings and other facilities;
Reconstruction	***	Redesign, restoration and rehabilitation of damaged buildings and other facilities

The first line of defence is prevention. This involves assessing of the risk of the hazard occurring; planning and siting of settlements so that the effect of the hazard is minimized; and construction of buildings, structures, and protective works (sea walls, dykes, etc.) which are hazard resistant.

The second line of defence is reducing the impact of the hazard. This includes the development of warning systems, the dissemination of the warnings to the public, evacuation and shelter, as well as search and rescue.

The third of defence is recovery. This embraces relief operations, post disaster assistance and ultimately reconstruction.

Clearly, the measures higher in the disaster-recovery cycle have greater leverage in reducing the potential disaster. However the humanitarian response following a disaster is such that more resources are usually given to measures lower down the list. The purpose of the International Decade for Natural Disaster Reduction is to reverse this trend, by putting greater emphasis on prevention, without jeopardizing relief and reconstruction.

Civil engineers and structural engineers have an important role in most phases of these defences but particularly in the prevention phase and the reconstruction. Table 1 indicates the degree of involvement.

3.0 HURRICANE GILBERT

The transformation of a natural hazard into a natural disaster is apparent from the following example of hurricane Gilbert. This storm was described as the "hurricane of the century" and was the most severe storm to strike Jamaica since Hurricane Charlie in 1954. The losses were over $2.2 B, in excess of the annual GDP of the island.

Sustained wind speeds at 10 m height near the coast were estimated to be about 40 m/s with gusts up to about 60 m/s, similar to the "design speeds" in the codes for Jamaica. All regions of the island were affected. The influence of terrain roughness and topography would have modified these approach wind speeds at the coast where they would be higher on hill crests and lower in the lee of hills.

The damage (and its consequences) can be summarized as follows.

Roughly 130,000 or 25% of the houses suffered significant damage. These ranged from simple "chattel" houses, housing estates built through government agencies, and the larger more expensive houses particularly those on the hill crests surrounding Kingston. Without roofs, water damage from the torrential rains crippled the capacity of families to recover. Damage was mainly to roofing.

Significant damage was reported to ten hospitals. This left the community without the facilities to treat those injured in the storm, and they faced afterwards the replacement of the structure, supplies and costly medical equipment.

Schools, and churches and other buildings designated and used a refuges, were badly damaged even when people were sheltering in them. 500 of the 580 schools in the island were damaged or destroyed.

Other essential structures destroyed included communication towers and buildings. Early in the storm, the roof of the main international telephone exchange was damaged, the switching equipment drenched, and communications overseas were cut off. This confused reporting of conditions and delayed the despatch of relief and supplies.

Internally, communications were cut by the failure of the 300 ft. tower on St. Catherines Peak carrying the main microwave repeaters for the island. Towers at the police headquarters in Kingston, and the military base at Newcastle were destroyed interfering with the essential military and police communications. Towers at most radio and television stations on the island were also damaged, preventing broadcast of warnings and bulletins.

The Mona Campus of the University of the West Indies lost roofs from the Administration buildings, the Law school, the Performing Arts Centre and the student residence. The losses included the Law and various library collections, valuable research results and a long delay in the academic year.

Utilities, such as power and water were interrupted for many days - weeks inland. Although the main high voltage distribution network on the island, carried on steel towers survived intact, 50% of the wooden utility poles were destroyed both by wind and fallen trees and branches. Water supply was interrupted in many regions, in one instance due to the collapse of a roof over a reservoir.

There was extensive damage to industrial buildings throughout the island. Principally these were older buildings but there were numerous examples of newer buildings as well. The loss of these structures had a direct impact on the productivity of the economy and jeopardised the income of the workers.

The tourist industry, the island's largest foreign currency earner, was seriously affected. Photographs in the foreign press of hotels without their roofs caused vacationers to switch their bookings.

Although damage to larger office buildings in down town Kingston was relatively light, there was extensive glass breakage, and water damage was consequently serious. One insurance company lost the records on its policyholders.

Losses to agriculture contributed significantly to the measure of the disaster. As well as very heavy crop damage - to bananas, citrus, sugar, coffee and coconut palms, there was widespread damage to storage sheds, and chicken houses (the occupants of which were decimated). Jamaicans who were accustomed to being self reliant for food, were suddenly dependent on imports.

The heavy rainfall which accompanied the storm washed out roads and bridges and once again compromised the efforts at relief and slowed down recovery.

The following conclusions can be made on the disaster due to hurricane Gilbert.

- The disaster was primarily due to the failure of buildings and disruptions in its aftermath.
- The intensity of the storm itself closely matched the design wind considered in the standards prepared for use in Jamaica (CUBIC and Jamaican Building Code). If buildings had been designed to withstand these winds with the appropriate safety factors, and built accordingly, very little damage might have occurred.
- The marginal costs of building to these standards would have been nominal.
- Most of the building failures appeared to be the result of inadequate quality control.
- There was evidently a lack of guidance and appropriate standards for roofing. This applied in particular to the thicknesses and fasteners needed for aluminium and galvanized steel sheet, and the use of adequate attachment of the rafters to the walls.

On the positive side there were examples of the proper functioning of well built structures.

- Most block masonry walls were reinforced. This prevented wall collapse even after the roof had gone and reduced fatalities. The practice was learnt in part over 50 years ago following a severe earthquake.
- "Hurricane straps" used to hold down the roof rafters to walls worked well when used.
- Traditional style, steep hipped roofs, with short eves, planting beneath the sheeting performed noticeably better than flat, gabled roofs, with lattice and corrugated sheeting.

- A significant number of pre-engineered metal buildings erected throughout the island performed without significant damage. They were designed and built to the standards; the trades erecting the buildings were trained and inspection was thorough.

Other important factors which help the recovery included:

- excellent advanced weather warnings, giving time to bring in supplies and board up windows;
- relatively high insurance coverage (about 99% reinsured in hard currency) allowing early financing of repairs and;
- generous supply of foreign aid and funds for reconstruction.

The capability of buildings and structures to survive is also a key determinant in the severity of a earthquake disaster. This latter was illustrated in two earthquakes of comparable intensity at the site - Armenia and Loma Prieta. The loss of life, which was tens of thousands in the former case versus a little more than a hundred in the latter, reflected the general use of modern building codes in the design of structures in San Francisco.

The paramount question is how hazard resistant construction can be achieved more widely?

4.0 SOME OBSTACLES

To consider the obstacles to hazard resistant construction it is necessary to recognize that the construction process is awkward and often involves a number of people with separate responsibilities and influence on the outcome. They include the owner who will take responsibility for the use and maintenance of the structure once it is designed and built; the investor (owner, government, bank or aid agency) who wishes to see a return on his investment; the insurer, who protects the investor by insuring the structure against natural disaster; the design professional who contracts with the owner to design the structure; the contractor who builds it; the materials suppliers; and finally a government regulatory body that sets standards, prescribes a code of practice and inspects the construction for compliance with the code.

In most countries the "construction industry" tends to have a loosely knit, fragmented structure, particularly in developing countries.

Skills and trades are sometimes migrant, poorly trained and inexperienced in some "newer" technologies. Experienced job site superintendents are hard to find, preferring to "retire" to more regular occupations instead of the "roller-coaster" of the construction industry cycles. Unlike the manufacturing industry, construction deals mostly with "one off" products, and instead of the controlled environment of a factory, contends with variable site and weather conditions.

Bidding practices are competitive and financial risks are high. There are incentives to cut corners and disincentives to careful inspection of workmanship.

Regulatory practices concerning disaster resistant construction have important deficiencies in most jurisdictions. In developing countries codes and standards pose problems. Often they are hard to get, reflect conditions in countries which are quite remote, and are unenforced. Loading and materials standards are sometimes mismatched. "New" technologies (roofing materials, for example, introduced for economic reasons to replace "traditional" approaches) are sometimes marketed without adequate technical information.

Many countries in which disasters occur are poorer countries. Owners may be very short of funds and resources and may not be particularly concerned about a threat which last occurred a generation ago. This short term perspective also prevails amongst more sophisticated owners and investors. There are hopeful signs that this is changing.

In many communities the perception of disasters is accompanied by a fatalism which inhibits special efforts to confront the hazard; there may be gaps in understanding about what can be done.

When funds are stretched to the limit, maintenance becomes a low priority. A recent practice in some UNDP construction projects to incorporate a special maintenance fund in the initial capital grant may be a useful approach. At the same time there has been a reluctance for aid agencies to interfere in decisions which are considered to be prerogative of the country receiving the aid. Their influence on hazard resistance has similarly been restrained.

While the owner and investor protect their investment through insurance, local insurance companies usually reinsure the bulk of their disaster coverage overseas. This spreads the risk of these infrequent events and provides for hard currency payments when and if the losses arise. Because of this indirect relationship between the insured party and the reinsurer, the latter has very little direct knowledge of any structure or its hazard resistance. The local insurer, carrying a small fraction of the risk, tends to lump the risk with other hazards such as fire.

Historically the insurance industry has had a strong influence on the standards of marine safety, with shipping and off-shore oil construction. However the influence of insurance in improving the disaster resistance of on-shore construction has been slight. Proposals for premium incentives for disaster rated construction are however now under study. This is timely in view of recent bad disaster insurance experience (a fivefold increase in the number of "catastrophic" events in the past twenty years) and the reluctance of reinsurance companies to provide coverage.

5.0 WHAT STRUCTURAL ENGINEERS CAN DO?

The following are a number of actions which the structural engineering profession is particularly well qualified to take.

5.1 Risk Assessment

a. Develop regional risk maps. Risk mapping should give the magnitude of key structural loads such as earthquake peak ground acceleration and maximum wind speed (or velocity pressure), for specific levels of annual risk. Such procedures are now established for most important structural loads. In some cases the basic meteorological or other geophysical data may be lacking. In these cases synthetic methods may be assumed to estimate the data that is lacking. One example of the latter is the "Monte Carlo" simulation of hurricane winds.

b. Develop maps of local site hazards and allow for these hazards in assessing the loads. These include soft soils which selectively amplify certain frequency bands in the earthquake shock spectrum at bedrock; land subject to flooding; and topography which causes "speed-up" of the wind, near hill crests.

c. In particular 'balanced risk' approaches to safety for strategically important structures such as hospitals, major bridges, etc. should be encouraged. In this the risk levels of the design loads are chosen so that the marginal costs of increasing the resistance of the structure are balanced by the decrease in the expected costs of failure.

5.2 Siting and planning

Use this information on hazard risks in the siting of structures and settlements. The information of risks should if possible be integrated into the assessment of insurance risks.

5.3 Hazard Resistant Construction

A major reason for the failure to achieve adequate hazard resistant construction has been found to be inadequte quality control in the construction process. Hazard resistant construction should therefore be thought of as part of the overall approach to quality control in the industry. The steps that should be taken to assist in achieving this are:

a. Within selected jurisdictions, investigate the quality control measures available to the construction industry together with a critique of their effectiveness. The study should address such issues as materials supply and distribution, design and specification processes, construction, training, regulation and inspection. These questions should be asked at the level of the housing owner/builder, design and/or construction by national companies and international companies. The enquiry should evaluate the influence on the quality of construction of insurance, financial institutions, aid agencies, government, industry as well as the public.

b. As a result of this investigation recommendations for action should be developed which will improve hazard resistance as part of a total quality approach to construction. The following interlocking objectives should be part of this broader approach to hazard resistance:

   - to improve the awareness of industry, the public and government of the value of hazard resistant construction and its proper maintenance;
   - to improve the performance of new and existing structures providing essential services during a disaster; and
   - to improve the job quality in construction; and
   - to improve the productivity and profitability of the construction industry.

c. Increase the awareness of the importance of hazard resistant construction in key sectors of society which can influence the quality of the construction process. Within the scope of these objectives, several initiatives might be productive.

   - Make the aid agencies, banking and insurance industries aware of the importance of hazard resistance and study ways for their direct involvement in the quality assurance process;
   - Make various industries - the tourist and manufacturing industries in particular - aware of the cost-benefit advantage of hazard resistant construction so that they will act as pace setters in encouraging other sectors to follow.

- Make government aware of the importance of ensuring the serviceability of essential service buildings and structures during and after the disaster. Ensure that such buildings reflect a "balanced risk" approach to safety in which the safety factor reflects the uncertainties and the strategic importance of the building.

- Consider the appointment of a "hazard resistance auditor" to verify and assist with hazard resistant construction. This person would be available to government in certifying public buildings for hazard resistance, the insurance companies and to individual investors.

d. A number of technical issues deserve detailed study. The following is a selction:

- Adaptation of traditional designs which functioned well to current techniques. One example is the use of hip roofs. These roofs are traditional in some areas and can carry over 50% more wind load than a gable roof with the same amount of material.

- The strengthening of old buildings through the use of "strong materials" and other means.

- The development of procedures and criteria for the assessment of the hazard resistance of existing buildings and structures, including the certification of disaster shelters.

- Incentive mechanisms for use by the insurance industry to raise the hazard resistance of construction.

- Approaches for industry to include disaster resistance of buildings as part of the overall plant safety.

- The development of user friendly codes and standards which foster the use of both new and traditional methods.

- Establishment of better plans for reconstruction which avoid the repetition of previous defects.

- Expansion of the engineering study of collective disasters, involving many structures, as opposed to the more usual concern for individual structures.

To achieve a significant reduction in natural disasters in accordance with the IDNDR, civil engineers should be prepared to take a leadership role particularly in improving hazard resistant construction as well as the protection against floods and landslides.

A Total Quality Control approach should be taken to the construction industry in order to improve the effectiveness of the industry and the delivery of hazard resistant construction.

River Training Works on Indian Bridges

Ouvrages de régulation des rivières à proximité des ponts en Inde

Flussregulierung zur Sicherung indischer Brücken

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SUMMARY

India's mightiest rivers have unusually large widths with meandering tendencies and absence of stable banks, posing enormous problems in siting of bridges across them and protecting the approaches from river attack. A solution has been found by constricting the width of flow of the river by providing artificial earthen banks suitably armoured. The paper discusses various aspects of planning, design and construction of these river training works along with some case studies.

RESUME

Les fleuves de l'Inde sont souvent imposants et extrêmement larges. En l'absence de rives stables, ils auraient tendance à quitter leurs lits. Il en résulte des problèmes énormes pour l'implantation de ponts et pour leur protection. Une solution consiste à contrôler la largeur du courant en réalisant des rives artificielles en terre, efficacement renforcées. L'article traite divers aspects de la conception, du projet et de la construction de ces ouvrages de régulation des rivières, à l'aide de quelques exemples.

ZUSAMMENFASSUNG

Wegen ihrer ungewöhnlichen Breite und Neigung zum Mäandrieren ausserhalb fester Ufer stellen die mächtigen, indischen Ströme enorme Probleme bei der Wahl von Brückenstandorten und dem Schutz der Zufahrten. Eine Lösung wurde in künstlichen, bewehrten Dämmen gefunden, die den Flusslauf eingrenzen. Der Beitrag behandelt einige Aspekte aus Planung, Entwurf und Bau solcher Regulierungsbauwerke anhand von Fallbeispielen.

1. INTRODUCTION

1.1 The geographical disposition of the Indian sub-continent is unique. It is bounded by the high mountains of Himalayas in the North and the peninsula region in the South. It has staggeringly diverse geographical features in terms of terrain, soil and climatic conditions and consequently there are wide variations in the behaviour of its rivers also. While in the southern part of India, known as Deccan Plateau, the rivers have carved deep channels through predominantly rocky strata and stable banks, the rivers in the northern part of the country known as Indo-Gangetic plain flow through deep alluvial deposits and have undefined and unstable banks in most regions. Also, these rivers have meandering behaviour, swinging several kilometres from one side to the other, over the years. The maximum width over which the river meanders during high floods is knwon as the 'khadir' width of the river. An unique example of such meandering behaviour is that of Kosi river which has shifted its course by about 112 Kms. between the years 1736 to 1964. In this movement, about 7700 sq. km. of land in India and approximately 1300 sq. km. in Nepal have been laid waste as a result of sand deposition. For such rivers in the Indo-Gangetic plain, where the width of 'khadir' is much more than the active channel, bridges would have to be constructed across the full 'khadir' width as otherwise there is a danger of these being outflanked. The cost of such long bridges would be prohibitive and, therefore, it becomes necessary to constrict the width of the river by training it.

1.2 In the early days, Indian engineers used the method of providing retired embankments or a series of spurs along the banks on the upstream of the bridge site to train the alluvial rivers. These, however, did not prove to be effective because the spurs attracted eddies and got damaged in high floods, entailing high maintenance cost. An improvement on the system of providing spurs was tried by provision of a pair of long parabolic earth embankments with a comb of spurs running out at right angles. This also proved to be inadequate and expensive for maintenance. Further improvement in river training work was made by constricting the width of the river by providing a pair of embankments, called guide bunds, so that the river flow could be made axial through the bridge. The provision of guide bunds in lieu of spurs proved to be successful and was a landmark in the field of river control and training for construction of bridges. Since then construction of bridges across alluvial rivers in India are accompanied with river control and training measures by providing guide bunds as developed by Bell and improved upon by Spring. The system has proved to be technically sound and cost effective

2. GUIDE BUNDS

2.1 Guide bunds may be defined as artificial earthen embankments constructed in the river bed whose main functions are firstly to train the river and induce it to flow axially through the constricted width of the bridge and secondly to protect the approach embankments from river attack. Guidelines for fixing the salient features and configuration of the guide bund system (Figure 1)required for efficient training of the river have been established and are as follows:

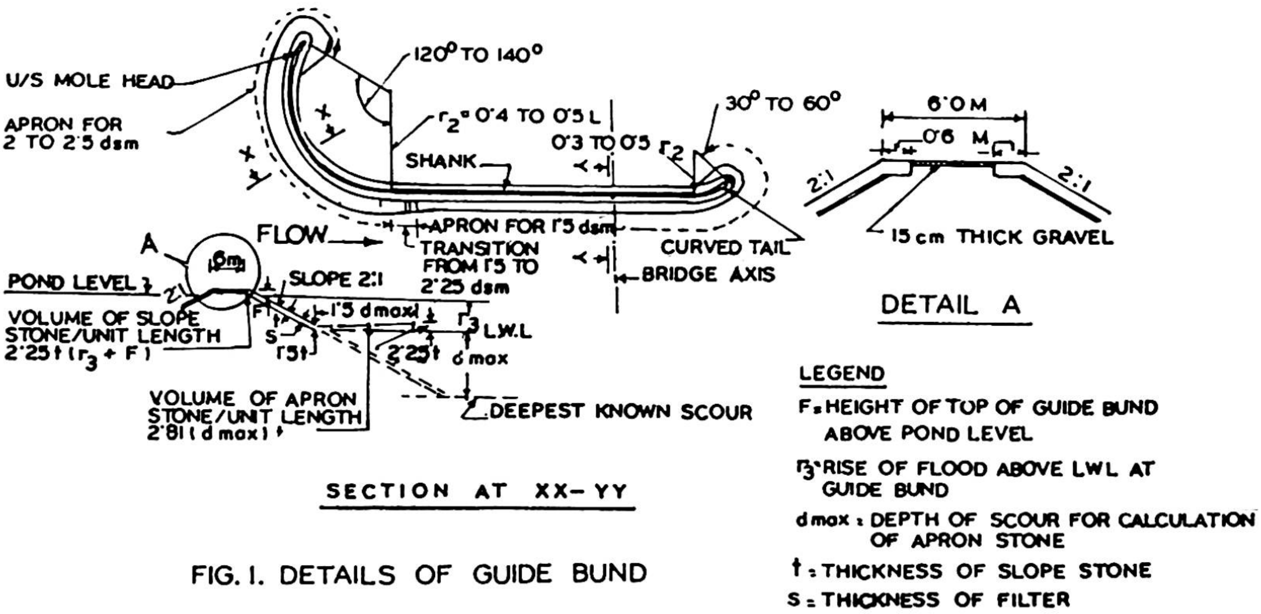

FIG. 1. DETAILS OF GUIDE BUND

2.2 <u>Constriction of width of river:</u> This is decided on the basis of stable channel flow condition, known as regime flow condition, which can carry the maximum discharge of the river. Lacey made observations on several alluvial rivers in India and suggested that the regime width at the highest flood level depends on the discharge and the angle of internal friction of the bed material. He gave an empirical formula for regime width W as:

$$W = C\sqrt{Q}$$

Where W= Regime width in metres

Q= maximum discharge in m^3/sec.

C= A constant, usually taken as 4.8 for regime channels but varying from 4.5 to 6.3 depending upon local conditions of channel flow.

This formula has been found to give quite satisfactory results.

The clear waterway at HFL (High Flood Level) between the guide bunds is fixed as at least equal to Lacey's regime width(W). The constriction ratio may be defined as Total khadir width at bridge site divided by the Regime width or actual waterway provided.

The total length of the bridge (L) is fixed as clear waterway plus the obstructions due to piers.

2.3 <u>Length of Guide Bunds on upstream (u/s)side:</u> The length of guide bunds has to be fixed from two important considerations, namely, the maximum obliquity of the current and permissible limit of embayment of the main channel of the river near the approach embankment behind the guide bund(Figure 2). It is generally fixed on the basis of the radius of the sharpest loop, which the river is capable of taking as shown by the data of the acute loops formed by the river in the past.

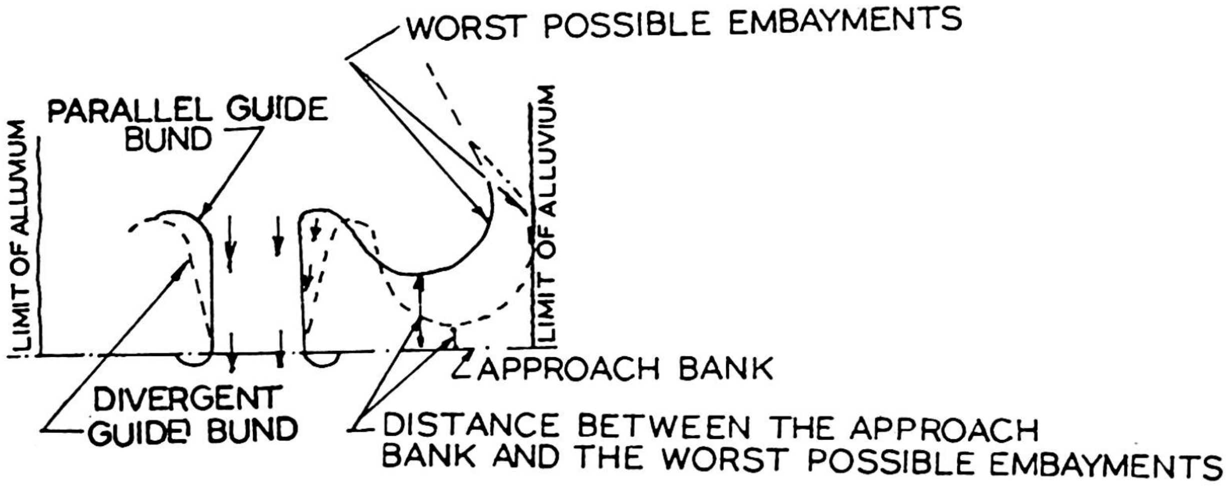

FIG. 2. EMBAYMENT

If survey plans do not indicate the presence of the sharpest loops it may be derived from a mathematical model. After having determined the radius of the sharpest loop the single or double loops are laid out on a survey plan showing the alignment of the approach embankment and high banks. It is ensured that the distance between the anticipated sharpest loop and approach embankment is not less than L/3 where L is the length of the bridge. The upstream length of the guide bund is usually kept as 1.0 L to 1.5L. Guide bunds are generally effective in protecting the approach banks beyond the abutments on either side for a length upto 3 times the length of the guide bunds. Where the constriction is large and the length of the approach banks are greater than three times the length of guide bunds, additional training/protective measures are required to be taken.

2.4 Length of Guide Bund on downstream (d/s)side: On the downstream side of the bridge, the river tries to fan out to regain its natural width. Here the function of the guide bund is to ensure that the river does not attack the approach embankent in the process of regaining its normal width. A length of 0.2 L for the downstream portion of the bund is generally found to be satisfactory.

2.5 Radius and angle of sweep of u/s curved mole head
The radius of curvature of upstream mole head should be such as not to cause intense eddies which may be formed due to constriction of flow. The greater the radius and flatter the curve the less is the possibility of eddy formation. This, however, increases the cost. For proper functioning of the guide bund, radius of upstream mole head is generally kept as 0.4 to 0.5 times the length of the bridge(L). It is usually kept between 150 m. to 600 m. The angle of sweep of the upstream mole head is generally between 120° to 140°.

2.6 Radius and angle of sweep of d/s curved tail: Radius of curvature is generally kept as o.3 to 0.5 times the radius of upstream mole head. Angle of sweep varies from 30° to 60°.

2.7 Top Width: The top width is generally kept as 6 m. to permit passage of vehicles for carriage of materials and inspection.

2.8 Free Board: The free board is measured from the pond level behind the guide bund after taking into account the afflux, kinetic energy head and water slope. The minimum free board is generally kept as 1.5 m to 1.8m.

2.9 Side Slope: Side slope of guide bund is generally determined from consideration of stability of the embankment and hydraulic gradient. Generally a side slope of 2(H):1(V) is considered appropriate for predominently cohesionless materials.

2.10 Slope Protection: The river side slope is protected against erosion by pitching with stones/concrete slabs. The pitching is extended upto the top of the guide bund and tucked in for a width of atleast 0.6m at the top.

2.11 Rear Slopes of Guide Bunds: Rear slopes are also protected against wave splash by provision of 0.3-0.6 m thick cover of clayey or silty earth and turfing. Where moderate to heavy wave action is expected, stone pitching is laid upto a height of 1 m above the rear pond level.

2.12 Pitching on the river side: For the design of pitching on the river side, the factors to be taken into consideration are size/weight of the individual stone, its shape and gradation and thickness and type of filter underneath. The predominant flow characteristic which affects the stability of the pitching is velocity along the guide bund. Other factors like obliquity of flow, eddy action and waves are indeterminate and may be accounted for by providing adequate margin of safety.

2.12.1 The size of stones required on the sloping face of the guide bunds to withstand erosive action of flow may be mathematically worked out from the following equation:

$$d=Kv^2$$

Where

K=a constant, usually taken as 0.0282 for a slope of 2:1 and 0.0216 for a slope of 3:1

d=mean diameter of stone in metres

v=mean design velocity in metre/sec.

However, no stone weighing less than 40 kg. is used in order to prevent stones being carried away by river current. Where the required size of stones are not economically available, cement concrete blocks or stones in wire crates are used.

2.12.2 The thickness of pitching (t) in metres is determined from the following formula:

$$t=0.06Q^{1/3}$$

Where Q= design discharge in m^3/sec.

The thickness of stone pitching is subject to an upper limit of 1.0 m and a lower limit of 0.3 m.

2.12.3 Quarry stone is preferable to round boulders as the latter roll off easily. Angular stones are preferred as they fit into each other and have good inter-locking characteristics.

2.12.4 The stones for pitching are hand placed with the principal bedding plane normal to the slope. The pattern of laying is such that the joints are broken and voids are kept to a minimum by packing with spalls.

2.13 Filter: Filter is provided just below the stone pitching and generally consists of gravel, stone over burnt brick ballast or coarse sand. Provision of filter is necessary to prevent the escape of underlying base material of embankment through the voids of stone pitching/cement concrete blocks as well as to allow free movement of water without creating any uplift head on the pitching when subjected to attack of flowing water and wave action. In order to achieve this requirement, the following criteria are adopted to fix the size of filter material:

$$\frac{D\ 15\ (\text{Filter})}{D\ 85\ (\text{Base})} < 5$$

$$4 < \frac{D\ 15\ (\text{Filter})}{D\ 15\ (\text{Base})} < 20$$

$$\frac{D\ 50\ (\text{Filter})}{D.50\ (\text{Base})} < 25$$

Where D 15 is the size of that sieve which allows 15 percent by weight of the filter material to pass through it, D 50 and D 85 have similar meaning. The filter is compacted firmly. The thickness of filter is generally of the order of 150 to 200 mm.

2.14 Launching Apron

Launching apron is provided to protect the bund from the scouring action of the river. It is formed as a flexible pitching of the river bed, generally placed at low water level (LWL) in continuation of the slope pitching. The stone in the apron is designed to launch along the slope of the expected scour hole so as to provide a strong layer that may prevent further scouring of river bed material and undermining of the guide bund. The apron, when fully launched, is assumed to take a slope of 2(H):1(V) in case of loose boulders or stones and 1.5(H):1(V) in the case of cement concrete blocks or stones in wire crates. The size and shape of apron and the size of stone depends upon the depth of expected scour.

The extent of scour at different portions of the guide bund are adopted as under:

Location	Maximum scour depth to be adopted
Upstream curved mole head of guide bund	2 to 2.5 dsm
Straight reach of guide bund including tail of the downstream of guide bund.	1.5 dsm

where, dsm is the mean depth of scour measured below highest flood level (HFL) .

2.14.1 Width of launching apron generally kept as equal to 1.5 d max where d max is the maximum anticipated scour depth in metres below low water level. The thickness of launching apron at inner and outer ends are kept as 1.5 t and 2.25 t respectively as shown in Figure 1, where t is the thickness of slope pitching.

2.14.2 It may be mentioned that an apron may fail to provide protection to the guide bund if the river bed contains high percentage of silt or clay or where the angle of repose of the bed material is steeper than that of stone as in such a case the apron may not launch properly.

2.15 General considerations

2.15.1 Usually guide bunds are constructed in pairs to guide the river flow between them. Their relative disposition could be parallel, divergent or convergent, depending on river behaviour at the location. (Fig.3)

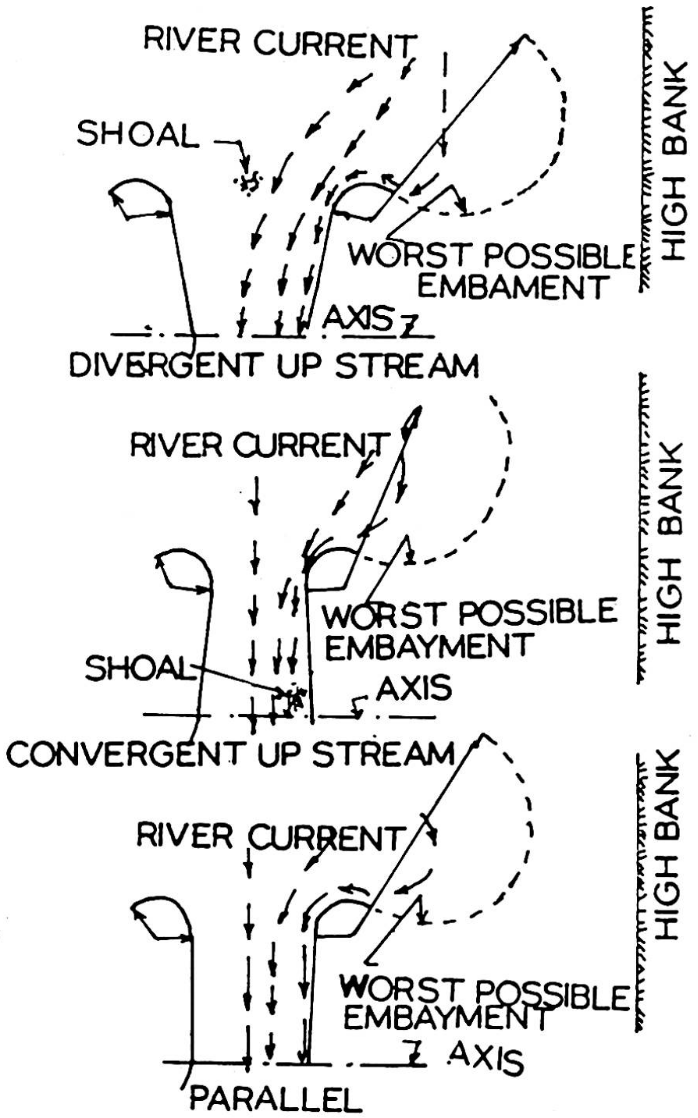

FIG. 3. DIFFERENT FORMS GUIDE BUNDS

2.15.2 Parallel guide bunds with suitable curved heads have been found to give uniform flow from the head of the guide bund to the axis of the bridge and so these are generally preferred.

2.15.3 Divergent guide bunds exercise an attracting influence on flow and they are used where the river has formed a loop and the approaching flow is oblique. However, they have a tendency of shoal formation at centre due to larger waterway between the downstream curved heads. They require a longer length in comparison to parallel guide bunds for the same degree of protection to approach embankemnt.

2.15.4 Convergent guide bunds have a disadvantage of excessive attack and heavy scour at the head and shoaling all along the shank rendering the end bays inactive. These are to be avoided as far as possible.

2.15.5 At certain locations, it may be possible to obtain a firm and stable bank on one side. In such cases only one guide bund on the other side needs to be provided. Obviously the cost of river training is reduced in such cases. This factor influences site selection of bridges, wherein the possibility of having a firm and stable bank in the vicinity of the site is a definite advantage.

2.15.6 Actual siting of a guide bund, however, requires a great deal of understanding of river behaviour. For this, river flow data is required to be studied to find out the most stable section in which the river has been flowing over a number of years. Based on physical site survey and the hydraulic behaviour of the river and the guidelines for the design, as mentioned above, a tentative design of guide bunds and their locations are fixed. Invariably, these are then tested in a model for their performance. We have a number of institutions, where facility for model testing on river behaviour is available. The flow pattern through the guide bund at different stages of discharge is studied in the model. It may be mentioned that in alluvial rivers, directions of river flow may sometime change at lower stages of discharge due to formation of shoals etc. but at design discharge level, flow may be parallel to the guide bund.

2.15.7 The configuration of the bund or the location may have to be slightly modified during model tests so that the flow is more or less axial and uniform between the guide bunds at all stages of discharge. The final configuration as confirmed from the model tests is adopted for execution.

3. CASE STUDIES:

3.1 Brahmaputra bridge near Tezpur

3.1.1 Planning & Design: Bridging Brahmaputra river, one of the major rivers of India has remained a real challenge to engineers especially on account of its hydrology and braided flow pattern. The river has defined banks only in its upper reaches i.e. in Tibet. Once it enters India it flows as a moving ocean from May to October, having flood plain width of 14 to 18 Kms. at most locations. The river carrying an annual runoff of 3,81,000,000,000 cum. also has a high silt load of approximately 0.102% transporting nearly 400 million tons of silt every year, causing wide ranging changes in the flow pattern.

Near Tezpur the river has a khadir width of approximately 5 kms. but the flood spill water extends far beyond this. The river is controlled on the north by Bhomoraguri hill and has a major tributary meeting it about 5 Kms. upstream on the north. These features have resulted in migration of the river to the south and there has been an active channel on the south side during the floods. Considering the facts that (a)any development in south channel may cause severe erosion of the south marginal bund and the river might outflank the bridge (b) large width may result in formation of shoals/islands at the bridge axis, and (c) development of concentration of flow in some bays may cause excessive scour, it was decided to construct a major guide bund on the south side. (Refer Fig. 4)

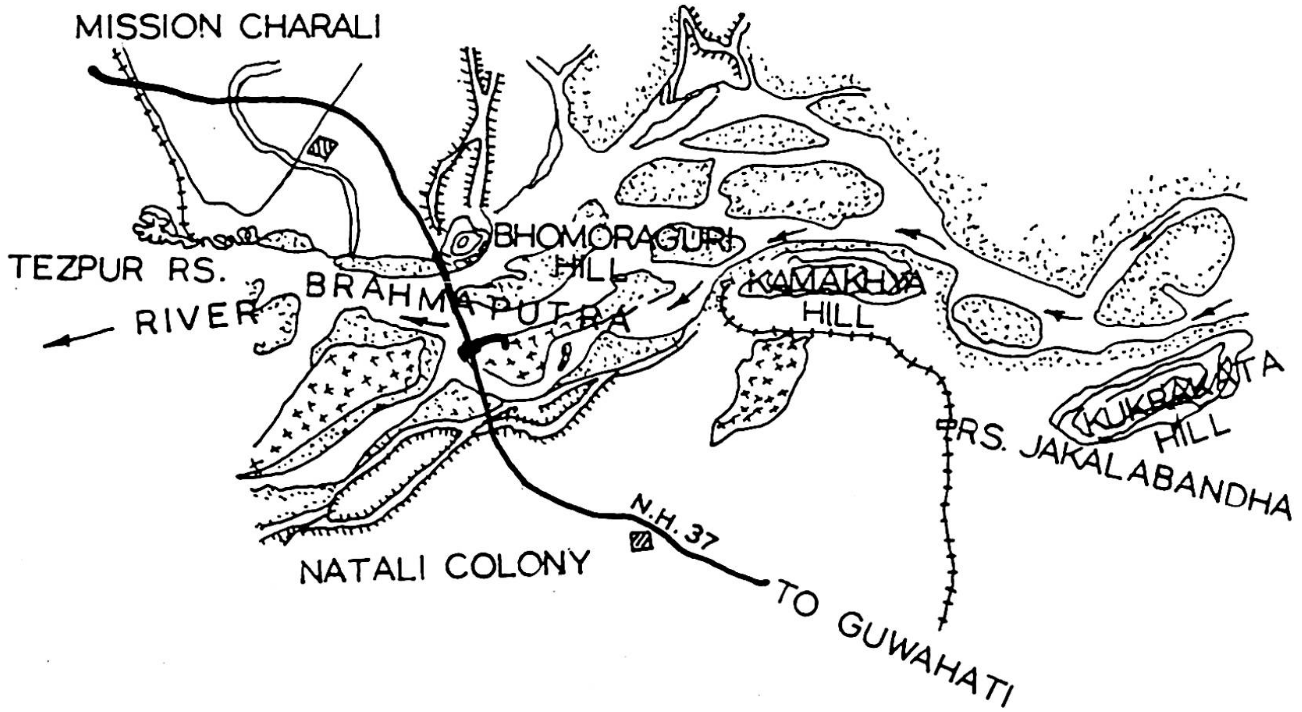

FIG. 4. LOCATION PLAN OF TEZPUR BRIDGE

This guide bund being the first on river Brahmaputra needed extensive studies for understanding its impact over the existing marginal bunds, road approach to the bridge and concentration of discharge, if any, for design of bridge foundations and most important of all, its impact over river flow condition with special reference to Tezpur town on the downstream.

Hydraulic model studies were carried out by U.P. Irrigation Research Institute, Roorkee. For the model studies, about 25 Km on upstream side and 10 Km on downstream side were surveyed in detail in respect of river cross sections, presence of firm points etc. Initially seven proposals with different alternatives of location, length and angle of guide bund were tested in the model and subsequently during the currency of work, additional model studies were required to be carried out due to changes in the river geometry.

Technical features of guide bund as constructed are as detailed below:(Also ref. Figure 5)

Discharge:	92,278m^3/Sec.
Max. Velocity:	4 m/Sec.
Type	Elliptical with equation $\frac{x^2}{(1200)^2} + \frac{y^2}{(560)^2} = 1$
Length	2000 m
Max. Scour depth below LWL	
(a) at the u/s shank	36.24 m
(b) at the mole head	52.27 m
Apron Width	
(a) at the u/s shank	54.50 m
(b) at the mole head	78.50 m
Apron material	Man size boulder (40-60 Kg.) placed in GI wire crates.
Apron thickness	Approx 3 m.
Slope pitching	1.5 m thick with 0.3 m of filter medium
Side slopes	River side 1:2.5 rear side 1:3
Top width	9.0 m.

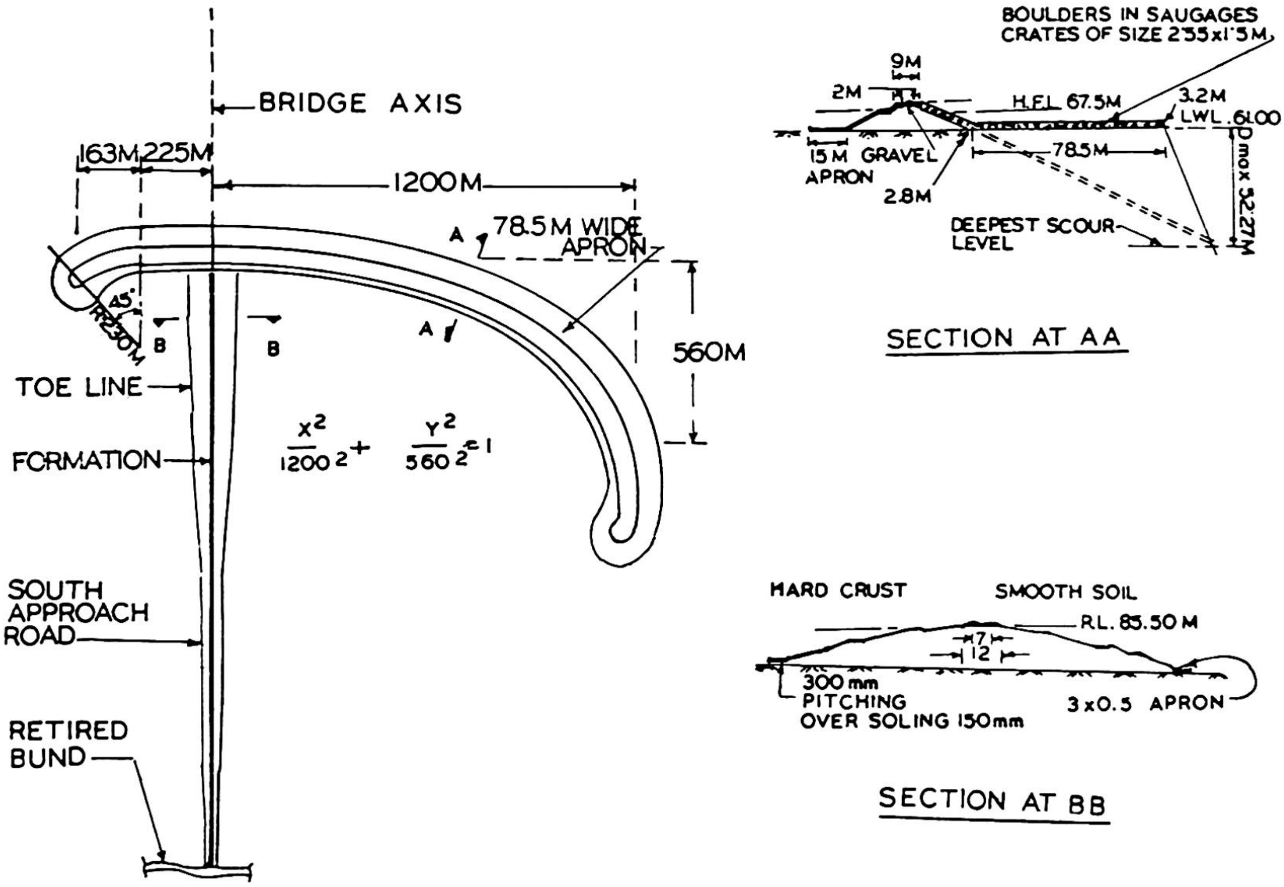

FIG. 5. GUIDE BUND DETAILS OF TEZPUR BRIDGE.

Since the khadir is very wide length of guide bund fixed according to the criteria does not provide enough protection to the approach embankment. It has been observed that the approach embankment is attacked by a single or double loop formation between the khadir edge and the guide bund (Fig. 6). In view of this it was necessary to study the river geometry on the upstream side particuarly in the vicinity of the hillock or permanent point in the left bank and also take into account the radius of the worst embayment for deciding the length of guide bund.

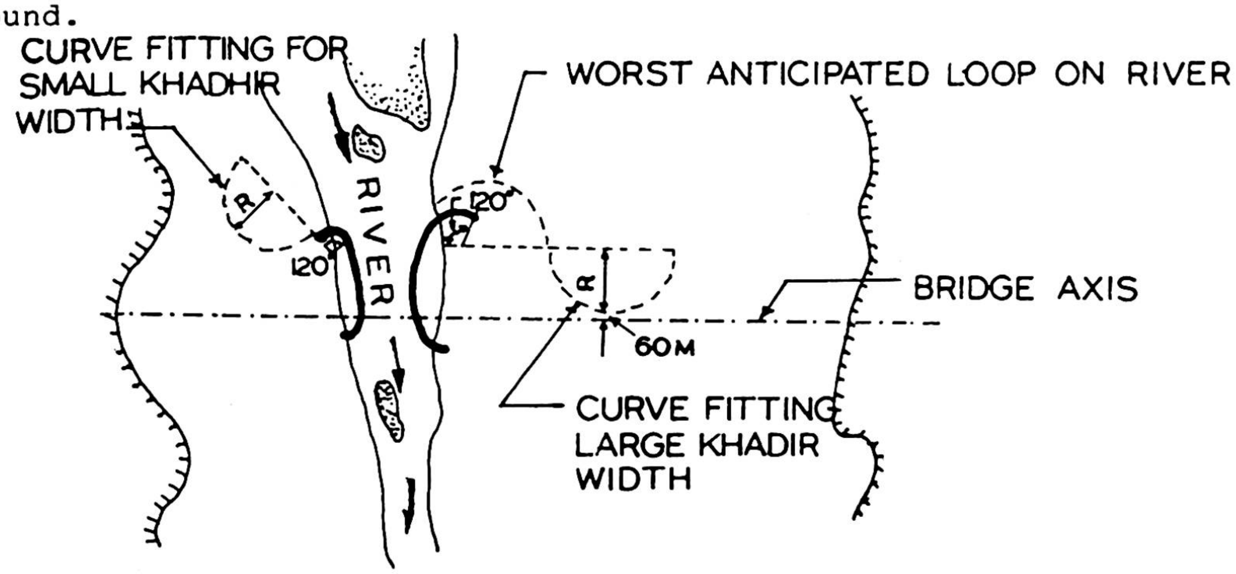

FIG. 6. DESIGN OF GUIDE BUND FROM LOOP CONSIDERATION

The road approach length 1.7 Km lies in the river khadir and has a risk of river forming embayment after leaving the tail end of the guide bund thereby, endangering the approach bank. Therefore, a series of boulder spurs were provided which helped in keeping the river course away from the approach bank.

3.1.2 Construction

Construction of guide bund and approach in river khadir requi detailed planning and construction strategy as the bulk of the work has to be completed in a short time i.e before floods set in. This problem gets further compounded in the case of Brahmaputra river where working period is restricted between November to April. Tezpur guide bund involved execution of about 1.9 million cum. of earthwork and 0.75 million cum. of stone work. Completion upto safe level which is HFL plus free board, required completion of 80% of earthwork and 95% of boulder work in 4½ months. This necssitated very high level of mechanisation. Some of the landmarks of construction were:

- it took 3 years to collect 0.75 million cum of boulders from hill face quarries and just 110 days to lay them in crates, pitching etc.
- average daily progress of earthwork was 12000 cum and of boulders 7000 cum respectively.
- nearly 12 Km of haul roads were developed for movement of earth-moving equipments.

Construction of guide bund became more difficult on account of development of active south channel. A series of river training works like permeable spurs etc. had to be provided to reduce the discharge in this channel. Inspite of these works it was required to close the channel in the month of November for carrying across the construction equipment.

Guide bund and approach has been provided with a well designed drainage arrangement and sufficient stock of reserve boulders has been kept at site to meet any emergency. During the monsoon regular patrolling is done to assess any damage and immediate measures are taken to rectify the same. So far behaviour of guide bund, development of embayment etc. has remained in conformity with the model study results and is expected to remain the same in future too.

3.2 <u>Bramhaputra Bridge at Jogighopa</u>

3.2.1 From hydraulic constructions, the river is stable at Jogighopa due to presence of two hills namely Jogighopa on the

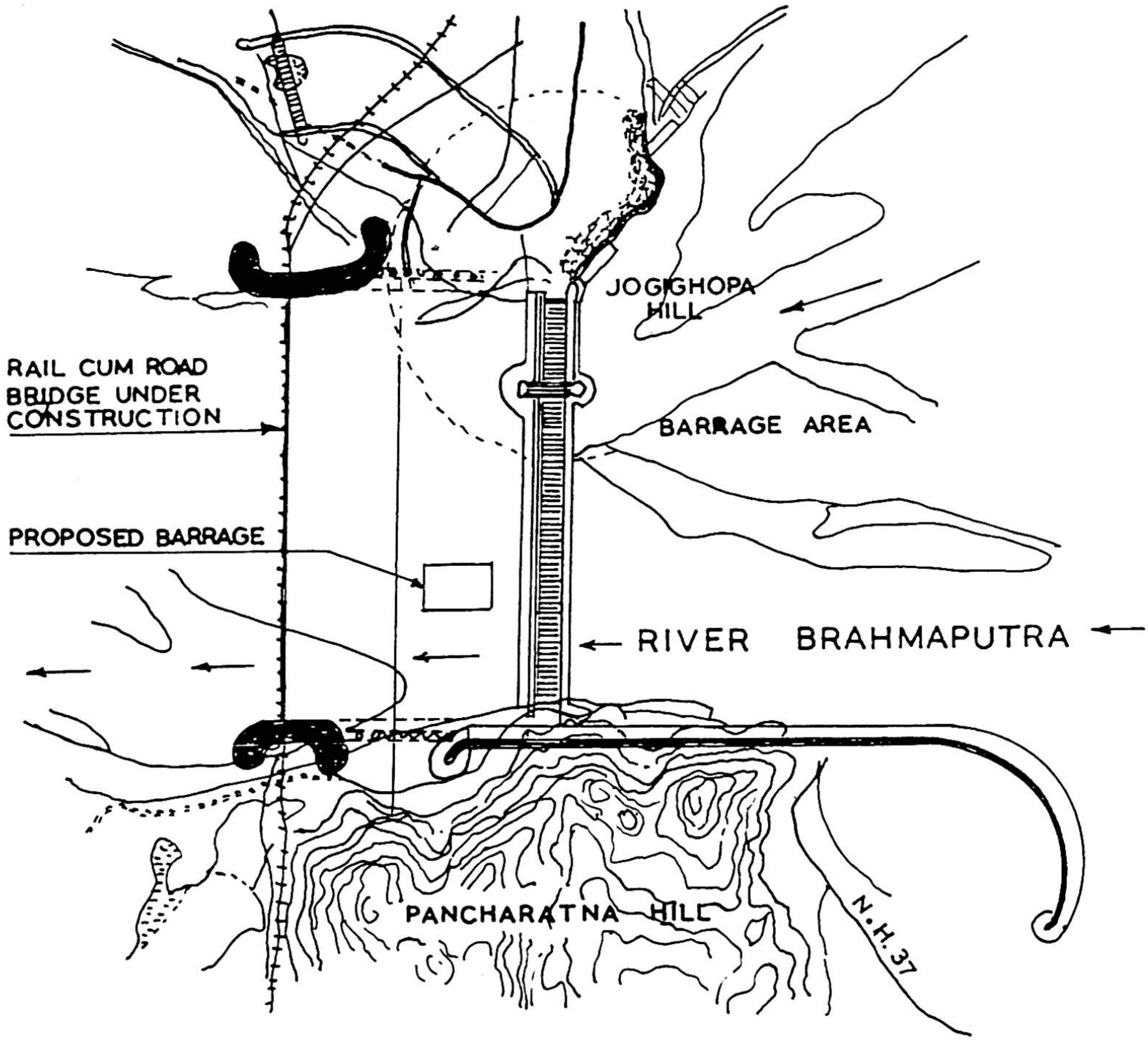

FIG. 7. LOCATION PLAN OF JOGIGHOPA BRIDGE (UNDER CONSTRUCTION)

north and Pancharatna on the south(figure 7). However, this stability is limited to a very small area between the hill noses where the site of the future barrage is located. Immediately after leaving the nose of the Jogighopa hill the river has a tendency to sway towards the north and horizontal control is necessary for any structure to be constructed on the downstream of the proposed barrage. Jogighopa rail-cum-road bridge is sited at 1350 m downstream of the barrage axis. In between, the proposed barrage and the bridge axis, an inland port is to be developed. Combination of the requirements of these multiple structures namely barrage, port facilities and rail-cum-road bridge needed extensive hydraulic model studies for designing length and shape of river training works. A number of combinations (figure 8) were tried out by the research station, with the following terms of reference

- to confirm the bridge waterway from hydraulic behaviour.

- to have final indication of discharge intensities along the bridge.

- to confirm whether there is any probability of increase in the maximum scour around piers on account of port facilities.

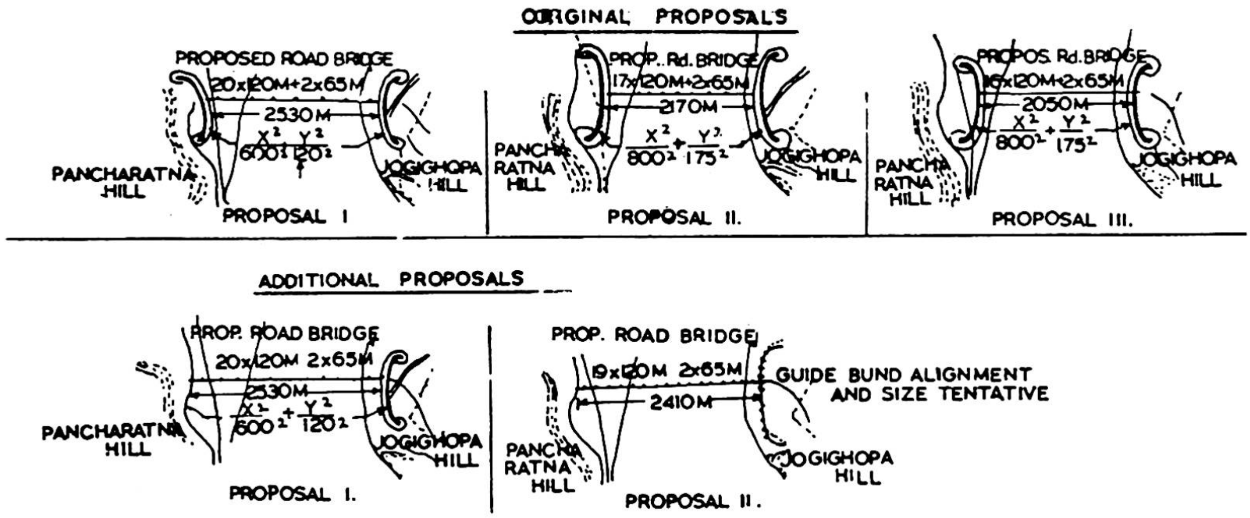

FIG. 8. ALTERNATIVE CONFIGURATIONS OF GUIDE BUNDS FOR JOGIGHOPA BRIDGE.

3.2.2 Model studies indicated that though the river has fairly uniform/stable flow conditions at the location, it is important to provide horizontal control with well designed guide bunds on either side.

3.2.3 Since on the north bank, port facilities are to be developed, a shorter guide bund of 450 m length has been designed. Model studies have also confirmed that due to the two control points, namely, Jogighopa hill and north guide bund in close vicinity, the river does not have any probability of developing full embayment and thus endangering the safety of rail/road approach to the bridge. Both the guide bunds have also been located in line with the planned guide bunds of the barrage so that there is a stable flow condition immediately down stream of barrage. At Jogighopa, south guide bund has been completed in 1990-91 and work on the north guide bund started in Nov. 1991 is expected to be completed by April, 1992. Construction of these bunds is highly mechanised and involved extensive logistic support. Important technical features of Jogighopa guide bunds are as showing in figure 9.

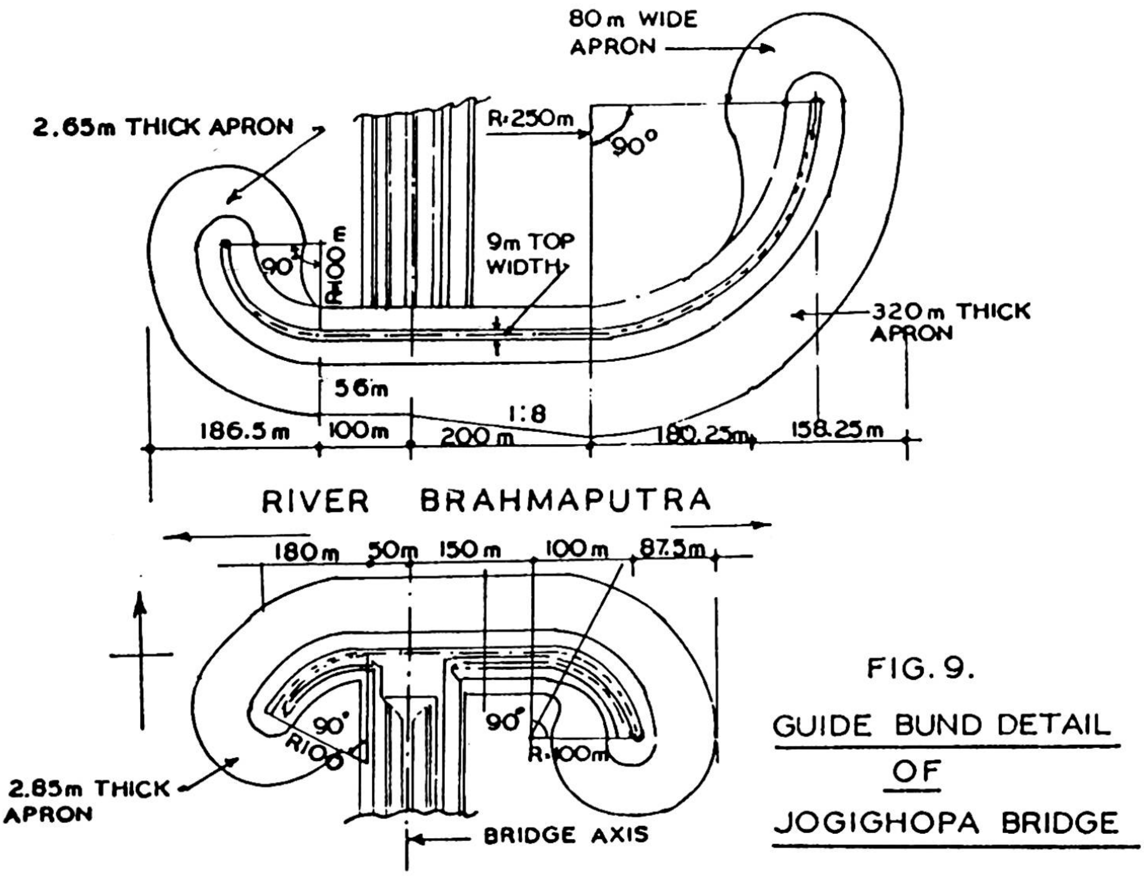

FIG. 9.
GUIDE BUND DETAIL
OF
JOGIGHOPA BRIDGE

3.3 Yamuna bridge at Karnal.

3.3.1 The river Yamuna rises in the Himalayas and flows in a south easterly direction for a distance of about 900 Kms before it joins the river Ganges at Allahabad. A bridge across this river is under construction near Karnal in the State of Haryana. Model studies for the various alternative sites have been carried out before the present site where the khadir width is 2.5 km. was adopted. The design discharge of 16000 cu. m/sec was based on the highest flood discharge of the year 1978 and the overall length of the bridge was kept as 600 m.

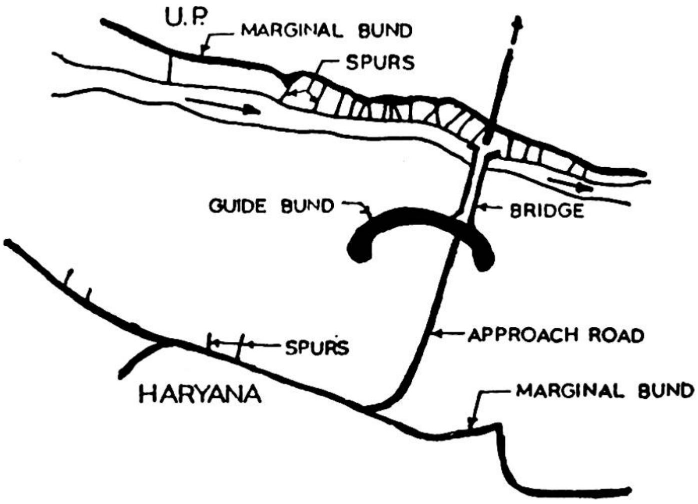

FIG.10. LAYOUT PLAN OF YAMUNA BRIDGE AT KARNAL

3.3.2 It was decided that the marginal embankment and spurs on the left hand side would be raised and strengthened and no guide bund would be provided on that side. On the right hand side an ellipitical guide bund with straight lengths of 400 m and 87 m on the upstream and downstream respectively was provided. The radii of curvature and angles of sweep were respectively 215 m and 90° on the upstream side of guide bund and 90 m and 45° on the downstream side. (Fig. 10)

3.3.3 For the past many years the river was flowing with its main channel hugging the left bank. However, during the floods of 1988 when the work on the foundations of the bridge was already in progress, the river suddenly changed course, shifted by more than 1200 m towards the right and started flowing behind the location of the proposed guide bund. The question of increasing the length of the bridge to cover the new channel of the river was then considered, but it was finally decided to train the river and go ahead with the construction of the guide bund at its originally proposed location (refer Fig. 11)

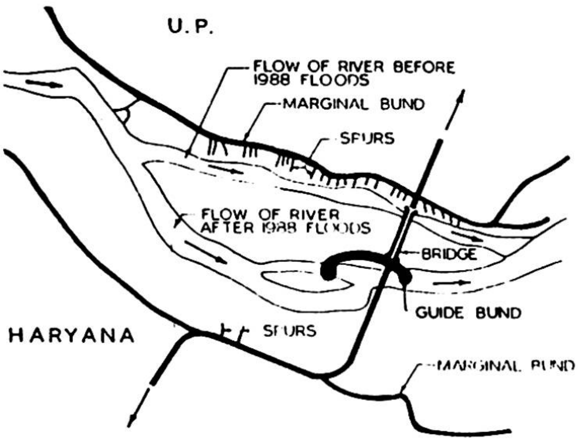

FIG. 11. POSITION OF FLOW OF RIVER BEFORE AND AFTER 1988 FLOODS

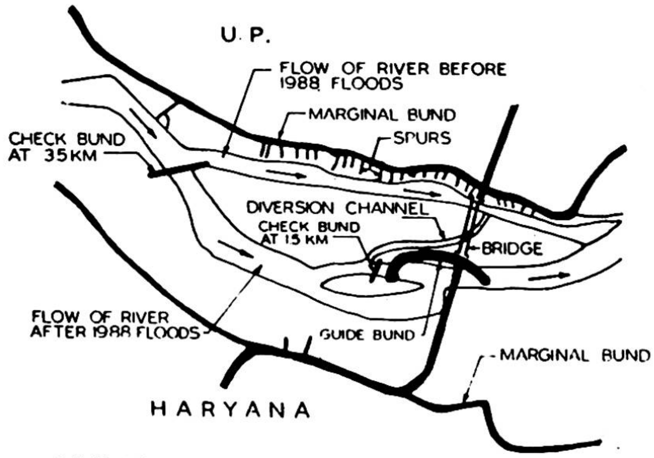

FIG. 12 REMEDIAL MEASURES ADOPTED TO DIVERT THE FLOW OF RIVER

3.3.4 During the dry period, a diversion channel was cut in the bed of the river to guide the dry weather flow under the bridge. To achieve this, the flow in the main channel was blocked by construction of a 'check bund' or embankment. The first such 'check bund' constructed about 3.5 Kms. upstream of the bridge site was not successful in diverting the flow and a second check bund about 1.5 Kms. upstream of the bridge site had to be constructed. (refer Fig. 12)

3.3.5 This proved entirely successful in diverting and channelising the flow under the bridge. Thereafter the work of the guide bund and the connecting approach embankment was taken up on a war footing and completed in phases before the advent of the next floods. The behaviour of the river has been well controlled since then and the work on the bridge is now proceeding according to schedule.

Earthquake Hazard Mitigation in New and Existing Structures

Réduction du danger dans les structures exposées aux séismes

Reduzierte Erdbebengefahr bei neuen und alten Tragwerken

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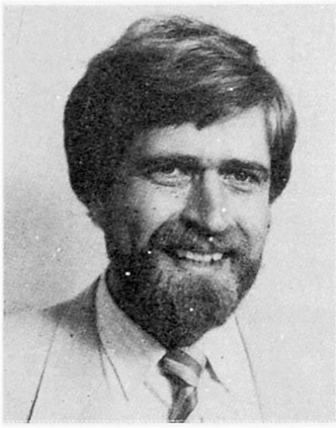

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SUMMARY

The unpredictable and devastating nature of earthquakes and the socio-economic consequences resulting from the failure of man-made structures emphasize the responsibility of the civil engineering profession with every major seismic event. Failures of civil structural systems in past earthquakes have shown that structural earthquake hazards exist around the world independent of the level of technical, cultural, social or economic development, and that earthquake hazard mitigation is a problem which needs to be addressed globally. Fundamental steps towards a rational and comprehensive structural systems design approach for earthquake hazard mitigation are outlined.

RÉSUMÉ

La nature imprévisible et dévastatrice des tremblements de terre et les conséquences socio-économiques résultant de la défaillance de structures anciennes et nouvelles mettent en relief la responsabilité des ingénieurs civils, chaque fois que se produit un séisme. Les ruptures de systèmes structuraux des bâtiments, survenues au cours de tremblements de terre récents et anciens, ont montré que les dangers dus aux séismes et encourus par les structures existent partout dans le monde, indépendamment du niveau de développement technique, culturel, social ou économique. De plus, la réduction du danger des tremblements de terre est un problème qu'il faut aborder globalement. Cet article esquisse les étapes fondamentales à effectuer vers une méthode rationnelle et globale de calcul des systèmes structuraux dans la réduction du danger aux séismes.

ZUSAMMENFASSUNG

Die Unvorhersagbarkeit und Zerstörungskraft von Erdbeben sowie die sozio-ökonomischen Folgen des Versagen von Menschen errichteter Bauwerke führen mit jedem Erdbeben die Verantwortung des Bauingenieurberufs neu vor Augen. Die Versagensfälle der Vergangenheit haben gezeigt, dass die bauliche Gefährdung weltweit ohne Ansehen des technischen, kulturellen, sozialen oder wirtschaftlichen Entwicklungsstands existiert und entsprechend angegangen werden muss. Der Beitrag umreisst die fundamentalen Schritte zu einem rationalen und umfassenden Entwurfskonzept für Tragwerke mit reduzierter Anfälligkeit auf Erdbeben.

1. INTRODUCTION

Earthquakes around the world have repeatedly demonstrated, and will continue to demonstrate, the vulnerability of man-made structural systems to seismic input. Major earthquakes in recent years such as Mexico 1985, Armenia 1988, Loma Prieta (San Francisco) 1989, Philippines 1990 and Costa Rica 1991 have shown, with their devastating consequences in terms of loss of life, loss and interruption of regional infrastructure and damage to public and private property, that a global need for structural earthquake hazard mitigation exists independent of technical, cultural, social or economic development levels.

The civil and structural engineering challenge and obligation to mitigate seismic structural hazards has to concentrate on two major areas, namely (1) the design of new structural systems and (2) the assessment and retrofit of existing structures to withstand probable earthquakes within defined performance criteria. For new structural design in seismic zones, deformation based performance limit states have to replace force driven conventional design criteria, and performance specifications for individual structures have to reflect not only structural properties but, equally importantly, consequences of partial or complete failure if a meaningful earthquake hazard mitigation is to be achieved. The seismic rehabilitation of existing structural systems has to be based on the latest research findings due to the just recently evolving nature of retrofitting knowledge and basic retrofitting technology, preceded by a realistic seismic performance assessment of the as-built and the retrofitted structures. Both new seismic design and seismic retrofit have to evaluate structural systems and component behavior differently from conventional gravity and live load design principles which are mostly force driven and based on lower bound strength principles. Since the unpredictable earthquake load case typically develops and exceeds the inherent strength of a structural system, seismic design must ensure that (1) the structure can perform inelastically through the formation of defined mechanisms, (2) the mechanisms are of a ductile nature which ensures large inelastic deformations and energy absorption without significant loss of capacity and (3) the safety margin to other non-ductile or brittle mechanisms forming in individual components is clearly established. Only if these deformation and capacity criteria are clearly established and adhered to, can the structure be expected to survive an earthquake which exceeds the structural elastic capacity.

In the following, ideas and principles are summarized which form the basis for a rational comprehensive seismic design approach, and evolving procedures are outlined for the increasingly important seismic retrofit of existing and aging structural systems. Even though the principles presented are equally applicable to building, bridge and lifeline structures, the examples will concentrate on bridge structures damaged during the 1989 Loma Prieta earthquake due to the extensive nature of available as-built structural and research data. A general overview is provided on seismic structural problems followed by a discussion of their mitigation through new design and relevant assessment and retrofit measures for existing structural systems based on the latest research data.

2. SEISMIC STRUCTURAL PROBLEMS

Earthquakes show their devastating nature through damaged and collapsed man-made structural systems which in turn are responsible for loss of life, damage to regional infrastructure, and interruption of associated essential services. The three categories of structures supporting our socioeconomic systems are buildings, bridges and lifelines, and all three are equally affected by major seismic events.

The partial or complete collapse of buildings is typically a major source of earthquake related casualties, and can be attributed to various problem areas ranging from conceptual systems selection and design to the construction, usage and maintenance. Major earthquakes in China and Armenia with heavy building failures suggest problems with the selected structural system, i.e. unreinforced masonry or the structural systems connection detailing of prefabricated reinforced concrete buildings, respectively. Additional system problems frequently encountered in seismic building failures are pounding effects of adjacent structures, soft stories, irregular geometry with significant stiffness changes in the horizontal and vertical directions, and inadequate footing performance. However, to label certain building systems as inherently unsafe has been proven wrong by the performance of similar systems in other earthquakes and by in-depth structural systems research. It is not an inherent fault with the selected structural system but rather an inadequate understanding of seismic input, seismic structural systems response and appropriate mitigating design principles.

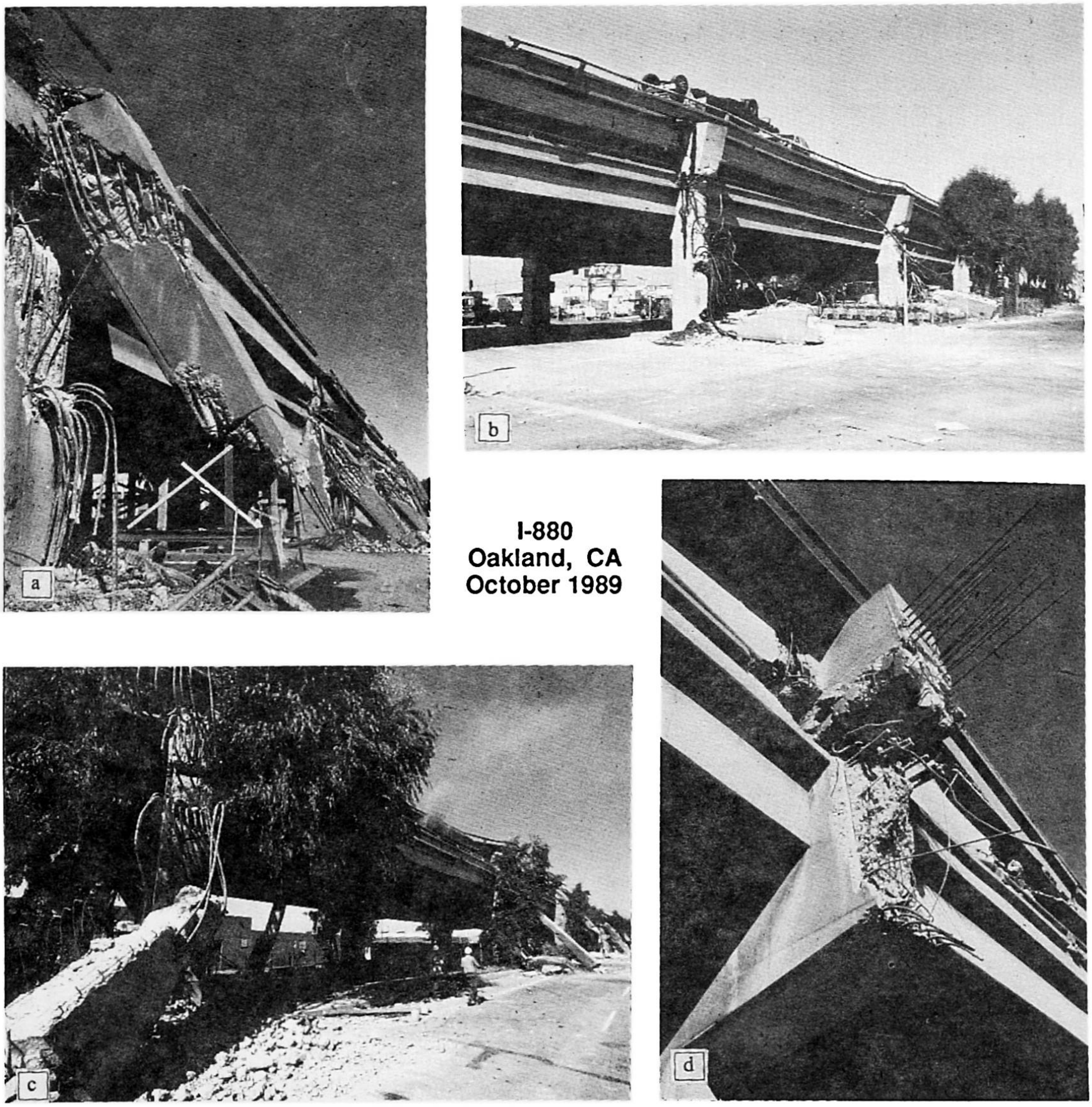

FIG 1. Bridge Damage During the 1989 Loma Prieta Earthquake

Bridge damage and/or collapse is noticed mostly due to its impact on traffic circulation patterns following a major earthquake. Quite often, it is the bridges most needed for post-earthquake search and rescue and relief operations which are collapsed or have to be closed. The duration of closure directly impacts the economic post-earthquake recovery of the affected region. Again, while many seismic bridge problems (see Fig. 1) can be associated with the choice of the structural system, the earthquake hazard also could have been mitigated by appropriate design and detailing measures. [1]. Primary seismic problems in bridge structures include foundation and footing problems (e.g. liquefaction), expansion joint and seating problems due to lack of seat width and/or force constraint across the joint, inadequate member capacities in flexure and/or shear, lack of redundancy in the structural system to allow alternate load paths, and the detailing of joints between primary structural members such as footing/column connections, column/cap beam and cap beam/superstructure connections.

Loss of lifelines can be devastating both immediately during the seismic event, i.e. rupture of water reservoirs and dams, or following the earthquake in the form of fire danger from ruptured gas lines, disrupted water supplies to extinguish fires and epidemic sanitary and health problems from interrupted fresh and waste water systems.

Since the forces resulting from an earthquake in our manmade structural systems are unpredictable due to the unknown time, duration, epicentral location, magnitude, and dynamic characteristics, it is virtually impossible to design for these forces in a deterministic manner. Also, to design for the probable or most credible force levels elastically to prevent seismic structural damage is in most cases technically difficult and economically and aesthetically prohibitive. Thus, mitigation efforts have to assume that the structure will be loaded beyond the inherent force capacity and that inelastic action and damage will occur. However, this inelastic action can be controlled to occur in a ductile mode with known mechanisms at predetermined locations which still allow the system to deform and dissipate seismic energy without losing its critical function of sustaining gravity loads [2]. As part of a comprehensive seismic hazard mitigation design approach, not only the performance of the structural system but also the hazard in the form of ground motion and soil conditions and the consequences of structural failure in the form of potential loss of life and economic impact have to be evaluated in assessing the seismic risk of our manmade structures. In the following, some of these principles are outlined using bridge design examples, both for new designs and retrofit of existing structures.

3. SEISMIC EARTHQUAKE HAZARD MITIGATION

A comprehensive seismic structural hazard design approach should include the components of (1) Risk Assessment, (2) Equivalent Seismic Load Input, (3) Component Assessment and/or Design (4) Systems Evaluation, (5) Final Design or Retrofit. These components are schematically outlined in Fig. 2.

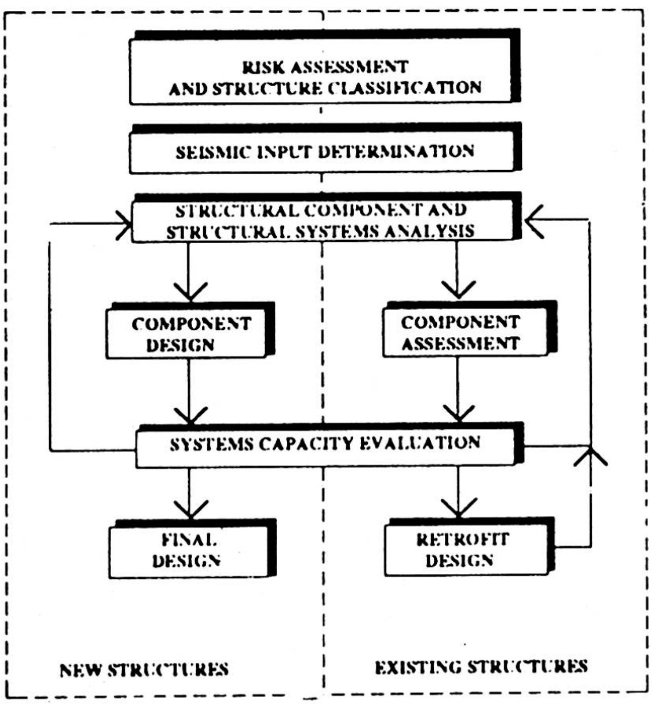

FIG 2. Seismic Design Process

The seismic risk assessment for a structure should involve the three principal components of hazard, structure and consequence. The hazard component reflects the probabilistic seismic input in terms of magnitude, probability of occurrence and soil/geological characteristics of the most probable seismic ground excitation. The structure component should address structural performance characteristics in terms of redundancy, detailing for inelastic action and critical geometry. Finally, the consequence component should address the importance of the structure and provide input on potential for loss of life consequences of failure or closure of the structure under evaluation. These three categories can be combined in a cumulative or multiplicative weighted risk algorithm to determine an estimate of the seismic risk for the structure. As an example of a risk assessment algorithm Fig. 3 shows the component and category tree structure currently used by

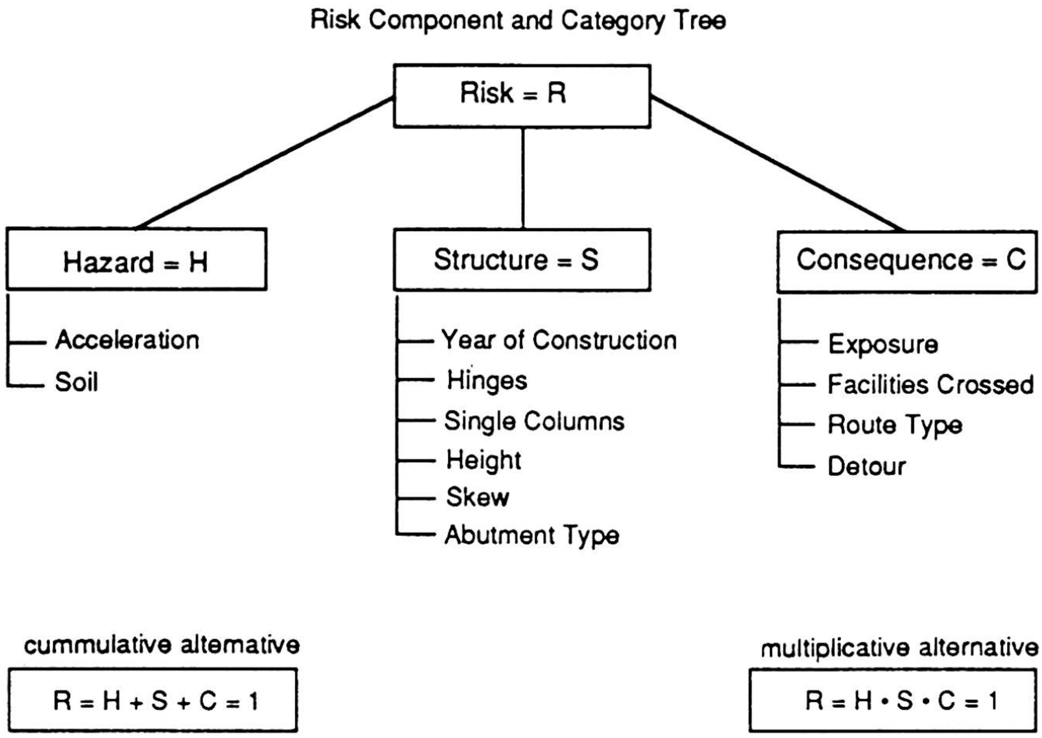

FIG 3. Seismic Risk Assessment Algorithm

California Department of Transportation (Caltrans) to assess the seismic retrofit priorities of over 24,000 bridge structures in California [3]. This risk evaluation can now be used to determine critical design limit states for the structural system and guidelines on how these design limit states should be achieved.

In the design phase of new structures or retrofits, design limit states should address the expected performance level and state of the structure during and after the earthquake, and should be directly tied to the structural importance and risk priority derived above. The essential seismic design limit state for any structural system is the collapse limit state defined as the state of structure at which gravity loads can no longer be supported. All structural systems should be designed to avoid this limit state but depending on the importance or risk level additional, more stringent design limit states should be added. A damage control limit state which prevents collapse but allows repairable damage of various degrees to occur could be formulated based on the importance of the structure and the consequences of a prolonged shutdown. Finally, essential facilities or structures servicing or leading to them should be designed based on serviceability limit states which would allow limited inelastic action resulting in minor damage and in uninterrupted and continued safe operation of the structure. One way to meet descriptive design limit states performance criteria as outlined above is to limit the inelastic structural response of the system since increased inelastic response is directly tied to increased damage levels. For example, inelastic structural response can be quantified by displacement ductility levels of the complete system, as sketched out on Fig. 4, where an idealized bilinear elasto-plastic approximation of the actual load-deformation relationship of the center of mass of the system defines the yield displacement level $\mu = 1$ (at $\Delta = \Delta_y$) and subsequent damage or ductility levels μ ($\Delta = \mu\Delta_y$) as multiples of the yield displacement. For long period structures, the equivalent elastic deformations are approximately equal to the actual (inelastic) deformations which allows a reduction of the equivalent elastic forces to the idealized plastic capacity level, i.e. the elastic force reduction factor $R = \mu$. For shorter period structures an "equal energy" approach can be used to define the relationship between R and μ.

The derived elastic force reduction can now be used to establish an appropriate deterministic load input for the structural system in the form of acceleration response spectra which determine equivalent static seismic loads on the system.

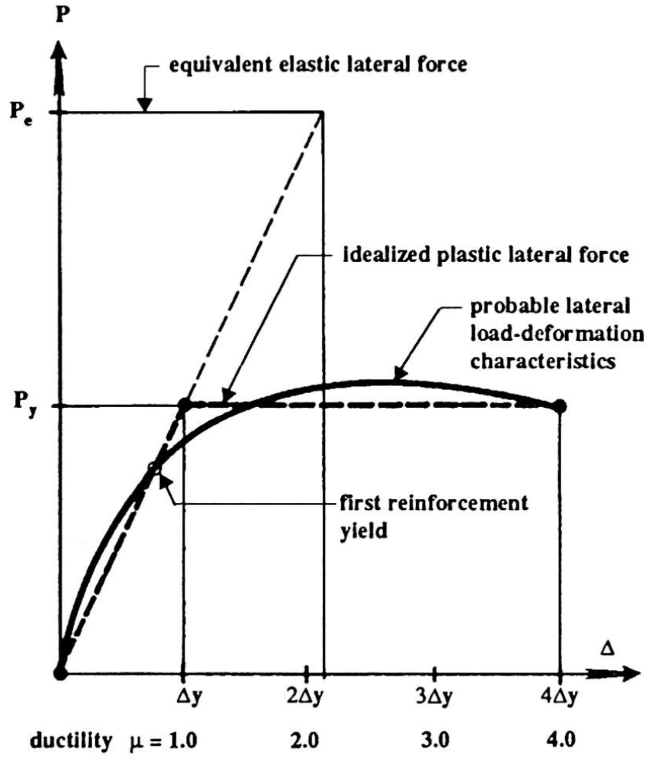

FIG 4. Load Deflection Behavior and Equivalent Elastic Forces

The actual member design for new structures and the assessment of actual member capacities for existing structures requires an evaluation of the most probable capacities of the component, i.e. a best estimate of the actual strength and deformation characteristics. Since in an inelastic design the earthquake will mobilize the inherent strength, a key design consideration has to be the formation of ductile mechanisms (not brittle shear or anchorage failures) which allow the structure to deform inelastically without significant loss of capacity. This design approach requires realistic capacity checks and comparisons of local mechanisms within each element and of adjacent joints, connections and members to ensure a global ductile systems mechanism. This capacity design concept was introduced by Park and Paulay [2] and finds increasing acceptance as one of the most powerful design tools in earthquake hazard mitigation. The same capacity based approach can also be applied to assess the seismic vulnerability of existing structures and to design, if necessary, appropriate retrofit concepts.

Based on this outlined design philosophy, new or existing structural systems can be designed, assessed, and or retrofitted, to allow various levels of inelastic deformation and damage as defined by the specified performance design limit states. An example of this capacity based approach is provided in the following example of a bridge assessment for one of the bridge structures damaged during the 1989 Loma Prieta earthquake.

4. ASSESSMENT OF EXISTING STRUCTURES

The key component in a comprehensive capacity based seismic design approach is the correct assessment of the component and systems behavior under combined gravity and seismic loads. Some of the principles involved in this assessment phase are outlined below in the examples of outrigger bents severely damaged during the 1989 Loma Prieta earthquake.

The realistic assessment of the component capacities and critical mechanisms of an existing bridge structure is based on the following steps:

1. Determine the most probable material properties; For existing concrete structures the actual concrete strength has significantly increased with time over the nominal design strength f'_c and reinforcement typically features higher yield than the specified nominal grade. Unless material tests on the existing structure are performed, assumptions of a 50% increase in concrete strength and a 10% increase in reinforcement yield strength are reasonable, i.e. $f'_c = 1.5\ f'_{c,design}$ and $f_y = 1.1\ f_{y,design}$.

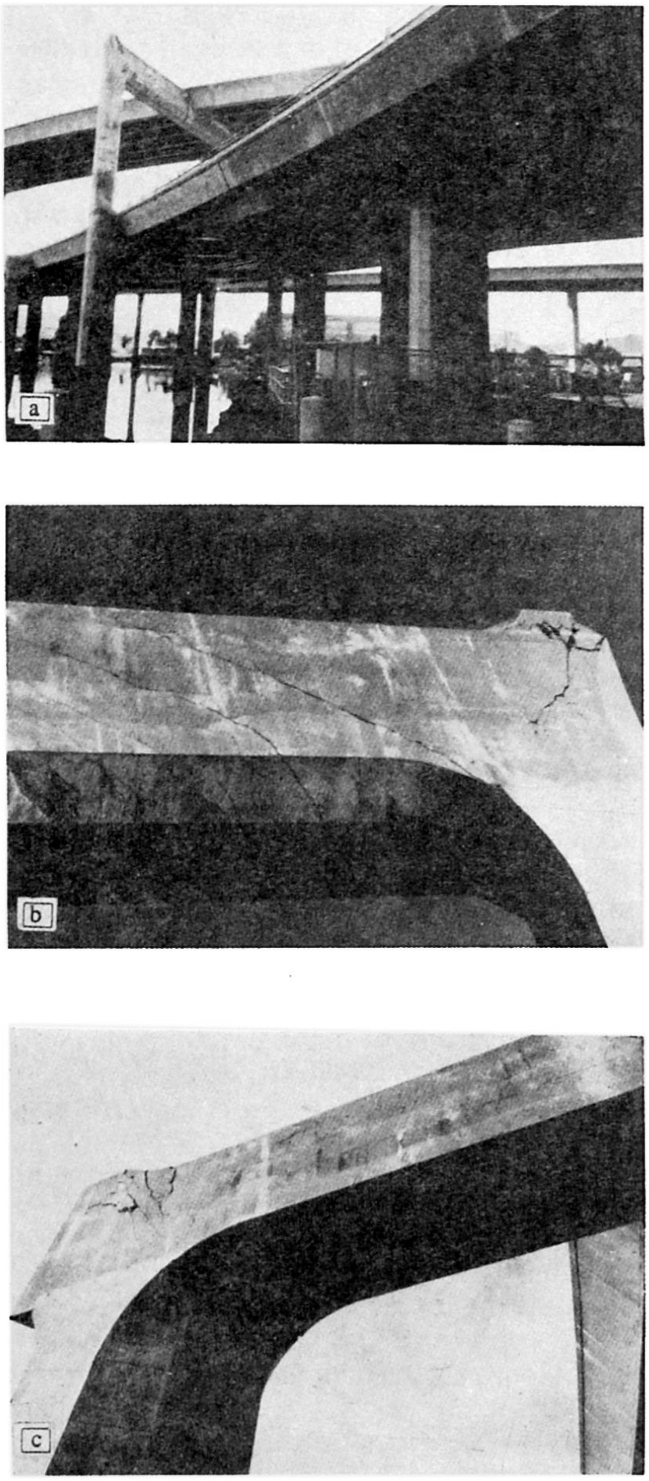

FIG 5. Earthquake Damage, Loma Prieta 89, China Basin Viaduct

2. Flexural capacities for the individual beam and column members are determined using above material properties and section analysis techniques which are based on a realistic concrete stress-strain relationship including axial load, confinement effects, and strain hardening. Flexural member capacities need to be adjusted where inadequate development length of the main reinforcement (see Fig. 1d) or lap splices with insufficient lap length or confinement limit the full capacity development under fully reversed cyclic loads. Detailed guidelines on the proper assessment of reinforcement development were proposed by Priestley [4].

3. The probable member shear capacities are determined, using a model which accounts for degrading concrete contributions with increasing ductility demand, truss action for stirrup reinforcement, and axial load effects from gravity loads or prestress as outlined by Priestley [4].

4. To determine the critical member mechanism, the plastic shear demand Vp of the member is determined based on full flexural plastic hinging and compared with the actual member shear capacity V_n. If $V_n > V_p$ a ductile flexural member failure mechanism can be expected. If $V_p > V_n$ the member might fail in a brittle shear mode prior to reaching its full flexural mechanism.

5. A combined gravity and earthquake (static lateral load) analysis of the complete gravity load support system or bent (beam - column assemblage) is now performed as a stepwise linear elastic event scaling procedure to determine the sequential formation of critical member mechanisms all the way to the critical systems collapse mode.

6. From the final global collapse mechanism, critical lateral load level and corresponding internal forces can now be determined. A check on joint shear in beam-column and column-footing connections and on footing capacities has to be performed with the obtained internal collapse loads based on capacity design principles [2] to ensure that no other degrading or brittle mechanisms develop in connecting or adjacent elements. If these capacity checks show deficiencies in the joints or adjacent members, appropriate systems load and deformation capacity reductions based on the expected level of cyclic degradation, see Priestley [4], have to be made.

7. The derived lateral load and expected deformation capacity for the structural system can now be compared to the required seismic load demand and the associated deformation or ductility design limit state as outlined in Fig. 2 to determine appropriate retrofit measures, as summarized by Priestley and Seible [5].

A general overview of the first outrigger bent on I-280 (China Basin Viaduct, San Francisco) is shown on Fig. 5a and damage patterns encountered during the earthquake are depicted in Figs. 5b and c. The as-built reinforcement details of the bent cap and columns are depicted in Fig. 6 and moment capacities and demands in the cap beam for separate and combined gravity and seismic loading are shown in Fig. 7.Following the outlined procedure, the bridge bent, shown in Figs. 5 to 7, was assessed [1]. Cap beam capacities were found well below corresponding column capacities and were thus critical for the overall seismic assessment. Member shear capacities were found to exceed flexural plastic shears. A unit lateral (seismic) load was applied to the bridge bent model and scaled to levels E_I and E_{II} where combined seismic and gravity loads form sequential mechanisms in the cap beam as shown in Fig. 7.

Lateral response force levels of $\vec{E} = 0.63$ g and $\overleftarrow{E} = 0.69$ g in the two directions, respectively, were found to cause complete global flexural mechanisms to develop. Particularly under loading to the right, see Figs. 6 and 7, the termination of negative or top reinforcement at a distance of 6.1 m from the column centerline is cause for the onset of a negative moment crack which propagates toward the column in shear aided by the lack of cap beam shear reinforcement in this region, see Fig. 6. A wide flexural-shear crack was observed in this region, as predicted, see Fig. 5c.

Joint shear cracking was calculated for both joints at lateral force levels less than those corresponding to the first flexural hinge formation. Approximate values corresponding to a joint shear stress of $0.33\sqrt{f'_c}$ MPa are $\vec{E} = 0.45$ g; and $\overleftarrow{E} = 0.40$ g, respectively. Thus, significant joint shear stress, as seen in Figs. 5b and c, can be expected. While the level of cracking visible in the positive knee joint moment regions of the bent cap beam indicated that the cap did not reach first flexural hinge formation, the shear stresses in the joints were high enough to cause joint failure. Hence the response accelerations appear to have exceeded 0.4 g in each direction. However, since both cap beam and joint mechanisms form at very similar lateral load levels and the distress pattern in the cap beam also reflects the reinforcement inadequacies, no repair or retrofit measure but rather complete replacement of the entire bent was recommended [1].

The second outrigger bent assessment example from the 89 Loma Prieta earthquake was performed for bent #38 on the I-980 southbound connector in Oakland, CA. Reinforcement details and dimensions of the critical knee joint are shown in Fig. 8. Based on capacity checks for both cap beam and columns, as outlined above, and from subsequent sequential failure mechanism analyses [1], the joint shear stress levels in the knee joint at the collapse limit state were found to be in excess of $0.5\sqrt{f'_c}$ and $0.35\sqrt{f'_c}$ [MPa] for closing and opening knee joint moments, respectively. Thus, joint shear damage can be expected prior to the development of any flexural ductile beam or column mechanism as demonstrated by the encountered distress patterns during the Loma Prieta earthquake, depicted in Fig. 9. Since existing beam and column capacities and reinforcement detailing were satisfactory to allow limited ductile performance, repair and retrofitting of the joint was performed by complete removal of the joint concrete, added joint shear reinforcement and an increased joint size.

While the above capacity based assessment examples were performed for existing bridge structures, similar capacity based procedures should also be employed in new structural systems design, see Fig. 2, to ensure ductile structural systems which allow seismic energy dissipation through well defined and appropriately detailed ductile mechanisms.

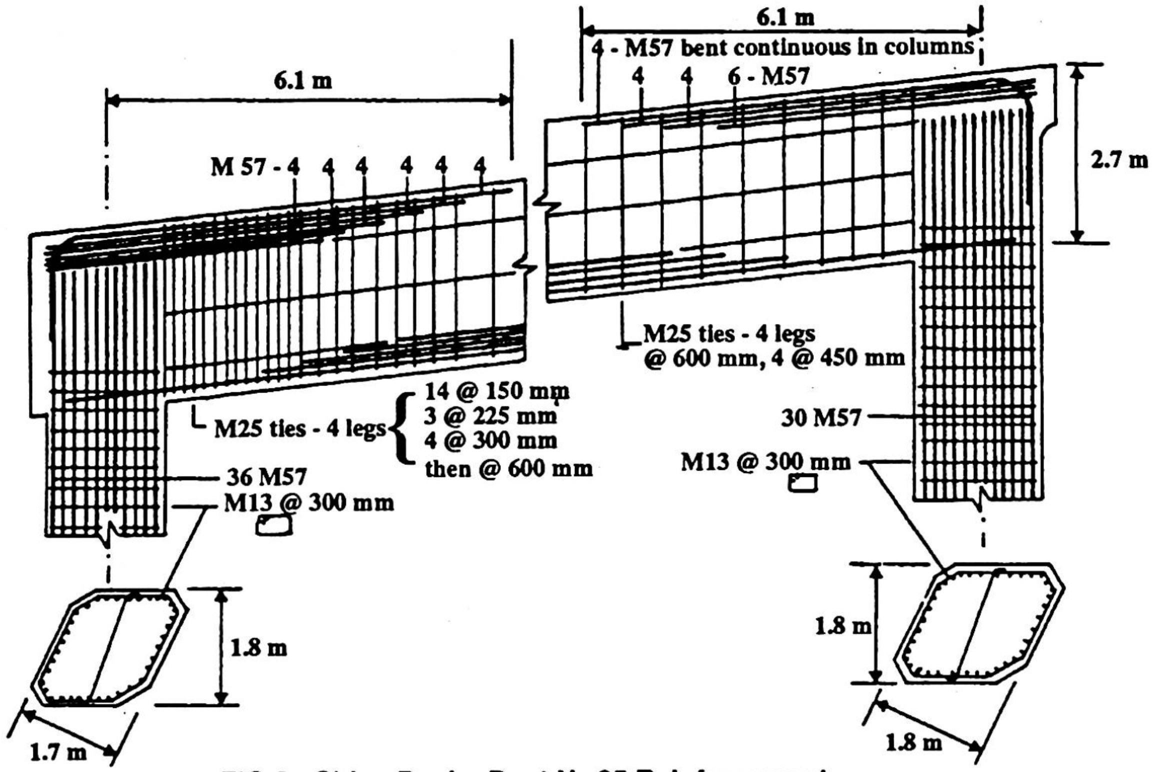

FIG 6. China Basin, Bent N_1-35 Reinforcement

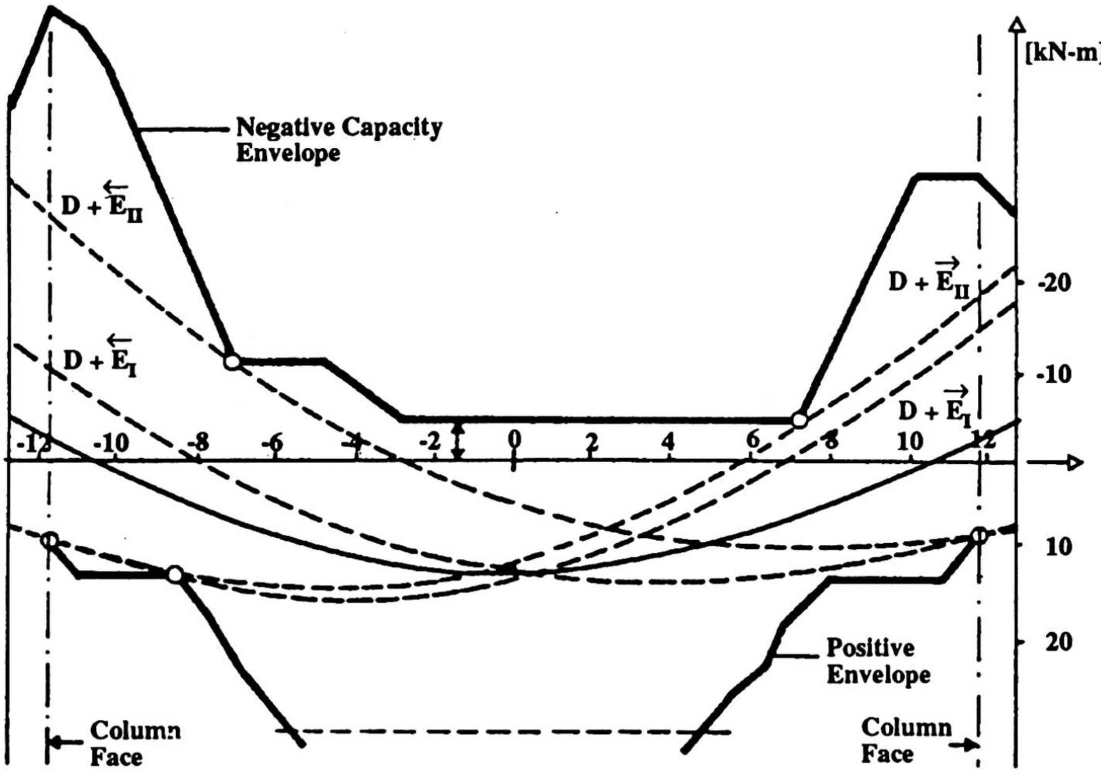

FIG 7. China Basin, Bent N_1-35, Moment Capacities and Demand

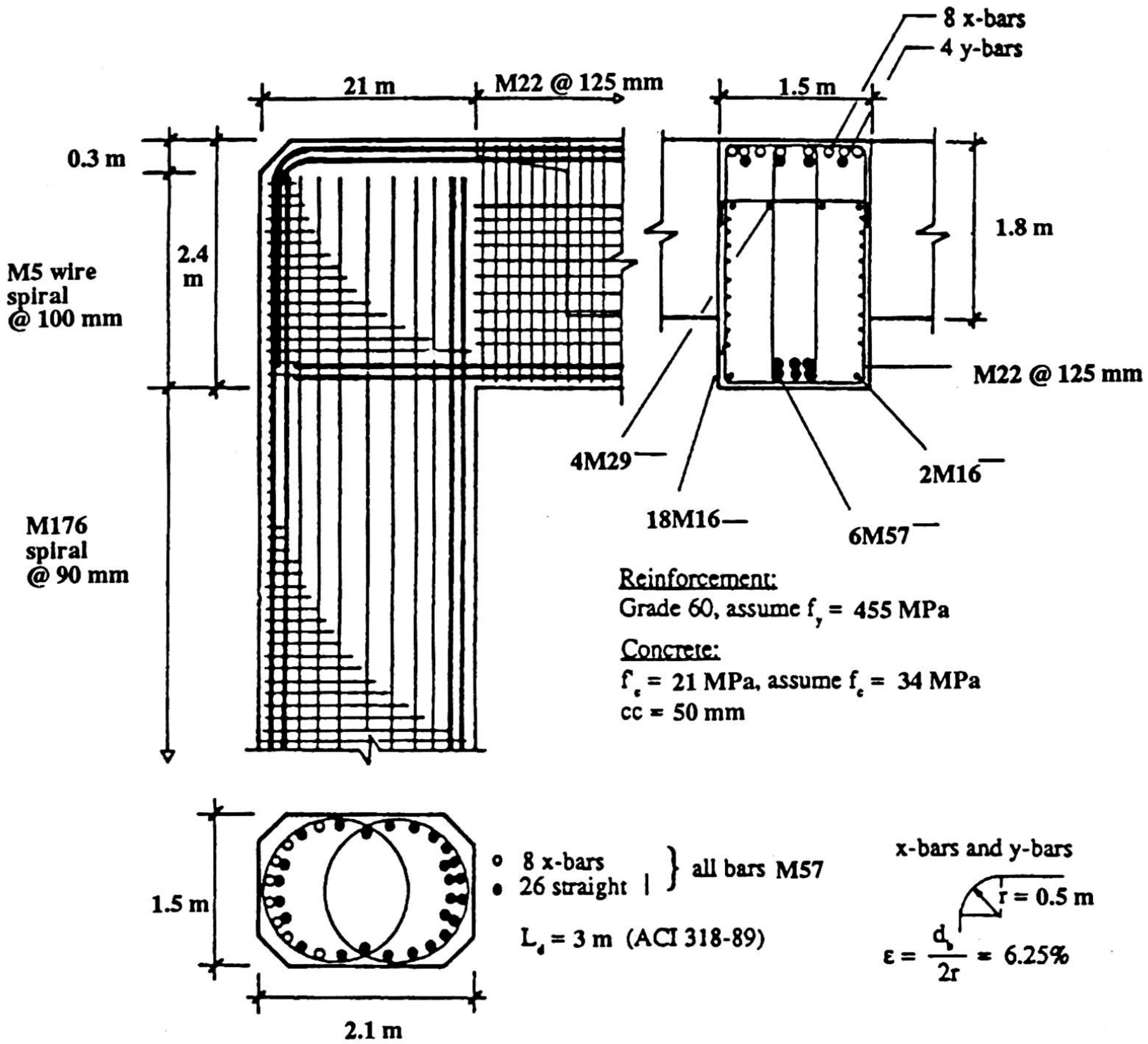

FIG 8. I-980, Bent #38 Reinforcement Details

5. CONCLUSIONS

To mitigate earthquake hazards arising from new or existing structural systems, a comprehensive seismic design and assessment approach is needed which accounts for seismic risk of the structure in terms of importance, consequence of failure, and probability of occurrence of the seismic design event. This seismic risk evaluation needs subsequentially to be employed to define expected structural performance levels in the form of descriptive performance design limit states on one hand, and in determining appropriate design guidelines on the other hand. The deterministic portion of the seismic design process should be based on a capacity philosophy where local and global structural failure mechanisms are determined based on realistic or most probable materials and performance characteristics. The goal is to design a retrofit for the development of ductile well confined (flexural) plastic hinge mechanisms which will allow the structure to deform inelastically without significant lateral capacity deterioration. Capacities of adjacent members, connections and joints, have to be designed with sufficient margin to ensure flexural plastic hinge development considering axial load effects, concrete overstrength, confinement effects and actual reinforcement strength including strain hardening. Seismic structural design based on the above principles will allow a comprehensive and rational seismic structural hazard mitigation process.

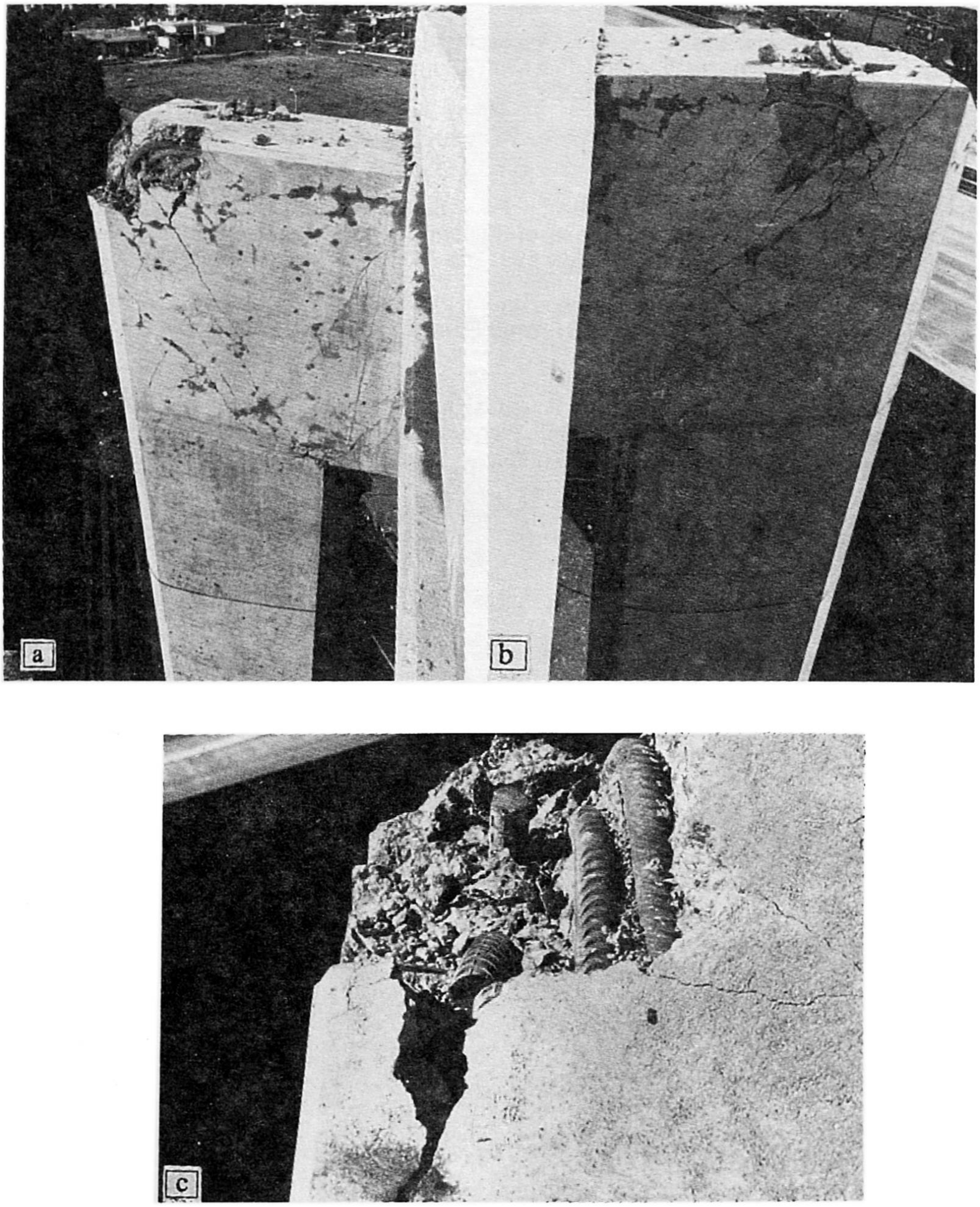

FIG 9. I-980 Oakland, CA, Encountered Damage Patterns

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Plenary Session 3

Impact of Structures on the Environment

Impact des structures sur l'environnement

Auswirkungen von Bauwerken auf die Umwelt

Organizer:	Jean-Claude Badoux, Switzerland
Chairman:	N. Gimsing Denmark

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Creativity in Changing Delta Duch Ecosystem Management

Gestion contrôlée de l'écosystème aux Pays-Bas

Ökologische Steuerung in den Niederlanden

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Henk Saeijs, born 1935, received his PhD in biology in 1982 at the University of Leiden, with the thesis 'Changing Estuaries'. For eleven years he was director of the Environmental Department of the Delta Project Organisation. For six years he was the driving force behind the modernisation of water management in his country. After two years of directorship at the Directorate North-Sea, he became responsible for the management of the complex, new, wet and dry infrastructure of the south-west part of the Netherlands.

SUMMARY

Experience gained this century with two very complex hydrological engineering projects in the Netherlands, resulted in a new so called 'integrated water-system management' approach, treating of symptoms developed, towards controlled ecosystem management, resulting in a new way of living with water. Examples illustrate what lessons can be learned; how new management concepts developed; and what applications are possible. The main message is to emphasize the positive role man can play in wetlands.

RÉSUMÉ

L'expérience acquise au cours de ce siècle, grâce a deux projets d'ingénierie hydraulique très complexes réalisés aux Pays-Bas, a débouché sur une approche de gestion de système intégrée. Le rapport présente les solutions apportées aux problèms rencontrés au cours de la mise en place de la gestion contrôlée de l'écosystème, qui a débouché sur une nouvelle manière de gérer l'eau. Il expose les enseignements qui ont pu être tirés, de nouvelles notions de gestion et les applications possibles. Le rapport met l'accent sur le rôle positif que l'homme peut jouer dans les zones humides et marécageuses.

ZUSAMMENFASSUNG

Die in diesem Jahrhundert in den Niederlanden bei zwei komplizierten Wasserbaugrossprojekten gesammelten Erfahrungen resultierten in einem grundlegend neuen Konzept, dem sog. integrierten Systemmanagement. Statt wie bisher gewissermaßen nur die Symptome zu behandeln, entwickelte man Verfahren zur Kontrolle der Gewässer als Ökosysteme, eine neue Art des Umgangs mit dem Wasser. An Beispielen wird gezeigt, welche Lektionen man gelernt hat, wie die neuen Konzepte entwickelt wurden und wie sie angewandt werden können Vor allem ist deutlich geworden, daß der Mensch in wasserreichen Gebieten eine positive Rolle spielen kann.

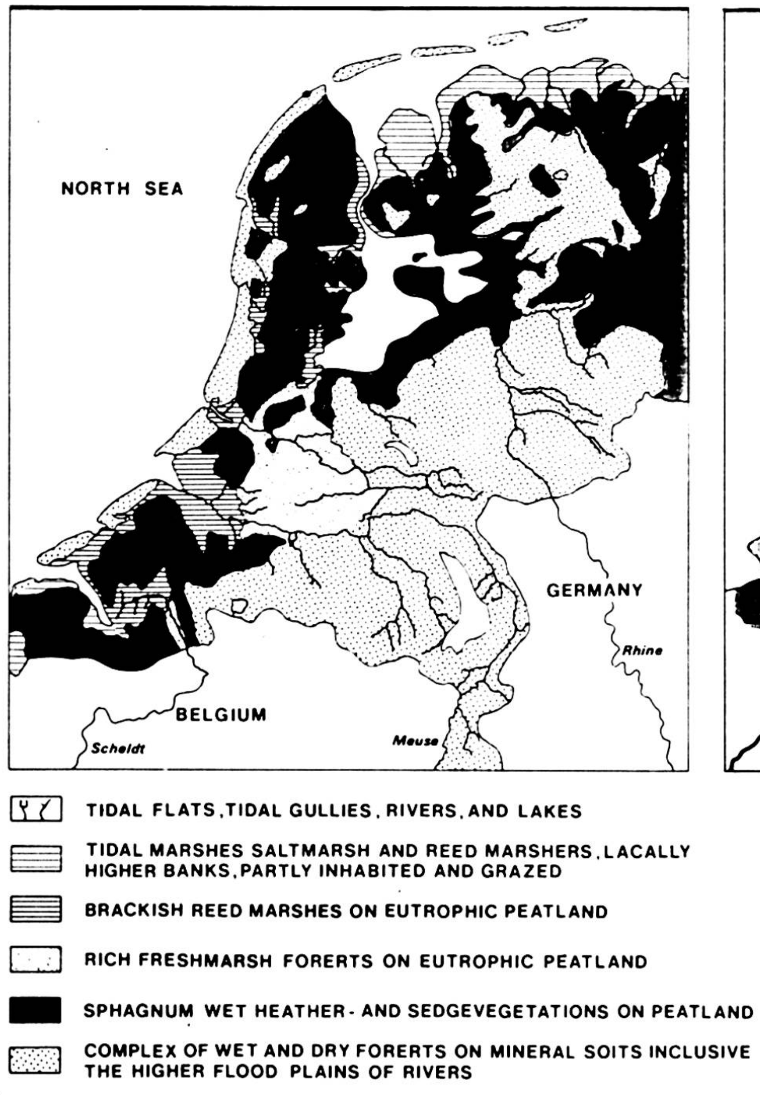
1. INTRODUCTION

The Dutch can be characterized by the expression 'God created man, but the Dutch created their own land'. Two thousand years of conditioning behavior became the 'art of a nation' [1]. In the twentieth century however hydraulic engineering threatens to become a curse instead of a blessing. In the last decennia spectacular developments took place, resulting in a new way of living with water. Coöperation instead of competition between technologists, economists and ecologists resulted in the new socalled 'integrated- watersystem-management' approach. Treating of symptoms developed towards controlled ecosystem management. With some examples is illustrated what lessons can be learned, from 2000 years of living with water, how new design and management concepts developed in the last decennia and what applications are possible.

2. LESSONS FROM 2000 YEARS OF TRIAL AND ERROR

2.1 From an ad hoc to a systematic approach

The Netherlands is situated at the end of four important European river systems, the Rhine, Meuse, Scheldt and Ems. So most of the Netherlands is actually a riverdelta, (fig.1). A part of the country (40%) is situated above sealevel. There it is too dry in summer and too wet in winter.



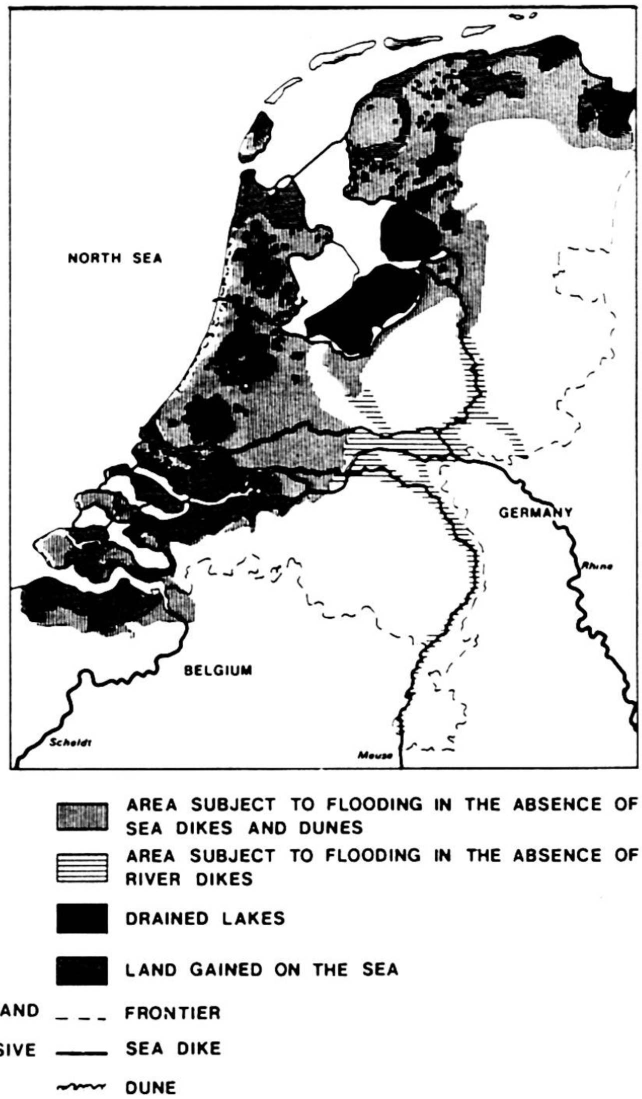


Fig. 1 A reconstruction of the ecological situation of the Netherlands in Roman times [5].

Fig.2 The Netherlands, 20th centu ry. The polders in down stream flat areas are made by draining lakes or by re claiming coastal embankments.

The major part of the nation however (60%), is situated below sealevel and exists as a result of human action and dedication (Fig.2). In the coarse of 2000 years, hydraulic engineering activities changed in character [2,3a,4]; from small-scale to large-scale; from defensive to offensive; from short-term to long-term; from specific to multifunctional; from conflict to harmony; and from stemming the tides to controlling them. Local coastal engineering measures, from the 1st-11th century; turned into well-organized dike building programmes, from the 12th century; into land-reclamation from inland lakes, from the 16th century; and into large-scale and complex transformations in the 20th century (Fig.2). A universal pattern developed, illustrating that wherever in the world authorities are dealing with water, sooner or later they will be confronted with the following coherent range: *The area* to be managed (river-basin, river, lake etc.); *the interests* associated with this area; *the potentials* of the ecosystems involved; *the machinery* necessary to ensure people's behavior (laws etc.) and to control the processes of the system (sluices, barrages, dams, pumps, models etc.); *the organization* responsible for functional management and *the financial means.*

2.2 'Divide et impera', compartmentalization.

In the Netherlands, the twentieth century has been characterized by large-scale operations such as the Zuiderzee- [5,6]) and the Deltaproject [3b,7,8]. Action was necessary otherwise a large part of the country would have been eroded away.
The aims of the Zuiderzeeproject (5000 km2) were; safety, land-reclamation and storage- and control of freshwater. The project involved dividing the area up into thirteen sections or 'compartments', separated by dikes and dams; four polders and ine lakes (Fig.3). The aims of the Deltaproject (4000 km2) were; safety, storage- and control of freshwater and to combat salinization. Seven estuaries were divided up in twelve compartments, among which nowadays are salt-, and freshwater lakes and a tidal controlled estuary [9,10,11] (Fig.4).

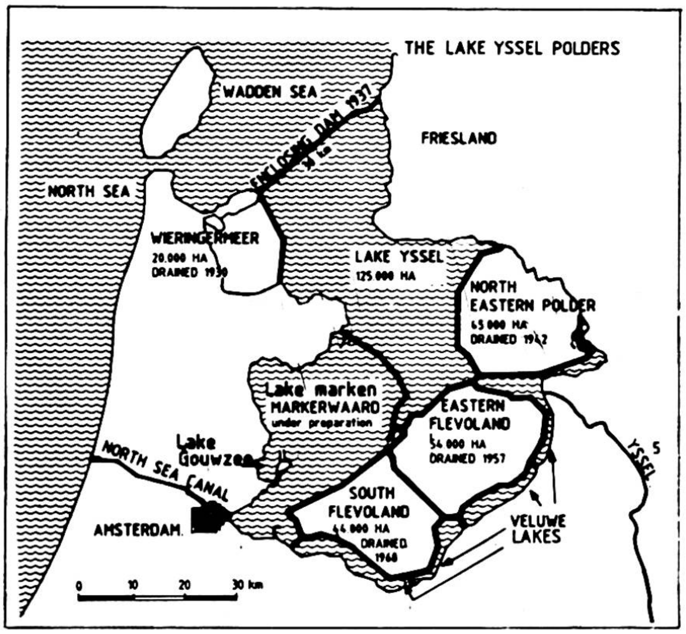


Fig.3 The location of the Zuiderzeeproject in the Netherlands. The stage of execution in 1989, with the compartments, segregated by dikes.

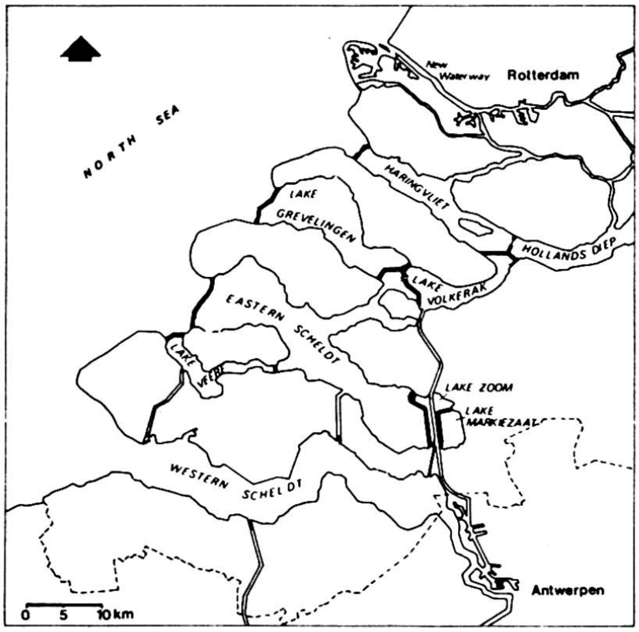


Fig.4 The location of the Deltaregion of SW-Netherlands, with the compartments segregated by dikes. The figure refers to the situation as it is now after completion of the Deltaworks in 1987.

Compartmentalization (to divide an area in compartments, in one way or another, for example by dams, isolated from each other) meant, that the compartments could be developed in stages. By dividing the area into compartments, it has proved to be possible to control elementary forces of nature and to facilitate the choice of particular (different) types of environment. We are talking here of; *The strategy of 'divide et impera'.* If the differences in environment between the original tidal estuaries (Fig.1.), are contrasted with the current, chosen and developed, environments of the polders and fresh- and saltwater lakes (Fig.2), then it is clear that the process of creating a compartmentalized region, has set new ecological conditions, with changes in landscape and utilization of the region. A lesson is, that the ecological impact of compartmentalization, the following choices of type of environment and the institution and management of the new system, have important ecological, economical and social potentials!

2.3 'Waterreclamatión', an alternative for 'landreclamation'

Let us have a quick look at the Zuiderzeeproject. Although the main emphasis was originally on agriculture (Wieringermeer, 1930), this was soon broadened to include urbanization (Noord-Oostpolder, 1942) and recreation, landscape and nature conservation (Flevopolders, 1957 & 1968).
By the time that work was ready to start on the Flevopolders, ecology had begun to assume greater importance in construction, planning, management and decision making. As a result in the seventieth another significant change took place; the creation of new marshlands, instead of reclaiming them. After defining certain environmental conditions (waterlevel, residencetime, nutrients etc.), the new environment has effectively been left to nature. Management is limited to controlling important environmental boundary conditions and only intervenes, when developments evidently go in the wrong direction. By applying the same basic principle, with different conditions, it is possible to allow other types of environment to develop! The 'Markerwaard' (until now Lake Marken), would actually form the fifth polder. After reassessing whether to proceed with land reclamation work in Lake Marken it has been decided to choose for the watersystem. This represents a second significant change in traditional (Dutch) thinking; the conditioning of terrestrial systems is now no longer considered to have sole importance, just as fresh-watersystems are also being seen as valuable alternatives. This trend is actively being pursued in the Delta-area, but with the inclusion of additional new elements such as salt waters and controlled tidal systems. 'Landreclamation' developed into land- and..'water- reclamation'.

2.4 The purifying effect of a range

The fact that using the possibilities afforded by the aquatic infrastructure allows a new ecological perspective to be developed, is illustrated with the following example.
The river Yssel, which mainly contains water from the river Rhine, flows into Lake Ketel (Fig.3). The majority of the sediments it carries, which are contaminated with pollutants, settle in Lake Ketel. This accumulation of toxic sludge in the Ysseldelta has polluted the lakebed severely. However as a result, the quality of the water that flows on, into Lake Yssel, has undergone considerable improvement. Further improvements in quality are also occurring in Lake Yssel due to physical/ chemical/ biological processes, that are taking place. Since Lake Marken receives its water from Lake Yssel, in addition to supplies of rainwater, this lake derives substantial benefits from its location and relative position in the compartmentalization system. Lake Gouwzee is even more favorably placed in this respect. It is not surprising, that this was the first in this series of lakes, where abundant submerges vegetation was found again, after it had disappeared, as a result of eutrification. In these situations it is of course important that such 'gains' are not frustrated by local sources of pollution. Two interesting management strategies can be identified: *The strategy of concentrating problems in particular areas and the strategy of interconnected surface waters.* The first strategy is really an emergency measure. As long as upstream prevention cannot be guaranteed, the downstream distribution of pollutants can be considerably reduced, by regulating the flow of noxious substances. This strategy is translated now into operational options. Studies are going on to optimize the sediment-trapping function of lake Ketel and to isolate the contaminated sediments from the surrounding areas, the surface- and groundwater. An experimental project is in preparation.

2.5 Polluted beds a costly surprise

In 1867, The New Waterway, a shipping canal between Rotterdam and the Northsea became operational. Although it was in economical terms 'a lucky hit', in terms of hydrological engineering it was rash. As a result salt penetrates far up-country and the safety of the inland polders decreased. One of the arguments for the northern area of the delta project in this century was, to overcome these salination and safety problems. But by doing so tremendous new unforseen problems arose. In 1970 the most important outlet of the Rhine and Meuse, the Haringvliet (Fig.4), was closed off by a sluicecomplex [12]. An estuary was transformed into a freshwater river/ lakesystem. The results were disastrous. The life community died integrally and restoration is nearly impossible. Though an increase in sedimentation was expected as a result of the intervention, only in 1980 did it become clear, that the Netherlands became the rubbish belt of the Rhine, Meuse and Scheldt. More than 150 million m3 of highly polluted sludge have settled there until now. In the next 20 years the amount of polluted sediments will increase with 0.5 to 2.5 billion m3. The ultimate amount depends on the success of the upstream sanitation operations. The costs of a clean up operation (carefully calculated at 15 US $ /m3, stored in isolated and safe depots) are estimated now between 7.5 and 37.5 Billion US $! The alternative, 'to keep it where it is' appears to be even more dangerous and expensive, because many dangerous micro-pollutants, like pesticides and heavy metals, will spread over the area by infiltration, seepage and diffusion processes, with disastrous long term effects and an increase in the amount of polluted soil. As in the case of Lake Ketel and Lake Yssel there is a short term positive side effect. The North Sea is safeguarded against this pollution! The lessons to be learned from this experience are also of interest to other countries. It can be expected that if rivers upstream of a dam are being seriously polluted, then similar accumulation phenomena are likely to occur. The accumulation may develop more rapidly at one dam than at another, but the final result will be the same; lake- and riverbeds are practically lifeless and unable to carry out their essential functions in watersystems. Moreover polluted riverbeds also act as 'storage areas'. It is thought likely, that even if the original sources of pollution are removed, contaminated riverbeds will still act as emission sources over the coming decades. The closure of the Haringvliet has many more negative side effects [12]. It goes too far to discuss them here, but the impact of the project is so destructive, that authorities to day seriously consider to reintroduce tide, by using the Haringvliet sluice as storm 'surge-barrier' and 'tide reducer' and 'outlet', instead of outlet only as it is used now !

2.6 Protection by accident

The 'divide et impera strategy' was also applied in the case of the Deltaproject, but the arguments for doing so and the manner of implementation differed considerably [13]. The compartmentalization operation in the Zuiderzeeproject was basically motivated by opportunities for agriculture. However, in the Deltaproject hydraulic engineering considerations were instrumental (Fig.4). This has eventually resulted in a compartmentalized area characterized by many different types of environment [7]. The seven estuaries were transformed into either fresh-, brackish- or saltwater environments, boarded by dry fallen intertidal areas. One estuary was converted into an environment with reduced, but controllable tidal movements. As a positive result of compartmentation, the central area of the south-western part of the Dutch delta was in time protected against the pollution of the Rhine and Meuse, by the construction of the Volkerakdam and Volkeraksluice (1969), and of the Scheldt by the construction of the Kreekrakdam (1867) and Kreekraksluice (1965). This side effect was not planned. It was just luck, we realized later on. Now it is ready for application.

2.7 Converting an estuary to a salt lake

It is not possible to discuss all the details concerned. A list of references has therefore been appended [3,4]. However, one exception is made. Lake Grevelingen was formed when the Grevelingendam (1968) and the Brouwersdam (1971) were completed [14,15]. As a result the Grevelingen estuary has been transformed into a salt lake (17 g Cl^-/l), surrounded by extensive shallow areas which are now covered with vegetation (Fig.4). The lakebed is unpolluted. The water in the lake is clear; Secchi classification >10 m, even in summer. Primary production rates are relatively high and are still increasing. In spite of high concentrations of N and P, there are no eutrophication problems. The ecosystem in the lake has adapted to the new situation in a reasonably short period of time. The composition of the ecological communities present, is diverse and has now achieved an acceptable degree of stability. The lake is developing as a wetland with an international reputation. How did this happen and how was it brought about? In 1971 the Dutch people were faced with the consequences of the decision to close off the estuary. An active and healthy estuarine community was struggling for its survival, when the influence of the tides disappeared overnight. In the intertidal areas, that no longer remained under water, and in water where the depth exceeded 8 meters, all forms of life died out. Pessimistic predictions began to be made about what the future would hold. However I suggested, to 'create the most favorable new conditions possible, for a saltwater lake and let nature take its course'[3c]. The properties and processes of a saltwaterlake ecosystem were unknown, but by using approaches of 'best professional judgement' and 'adaptive environmental management', the final result is quite acceptable. Although much was left to nature, where necessary, measures were taken to control the situation. The main management actions concerned were control of the waterlevel, residence-time, salinity and stratification, added nutrients and living organisms from the sea. Consequently the link with the sea had to be restored. The sluice in the Brouwersdam must allow water to flow both out and...in. The original sluice was designed only as an outlet. The capacity and location had to be sufficient and adequate for waterlevel-, salinity- and oxygencontrol. It was essential, during the salination process, to ensure a large enough capacity to allow sufficient supplies of oxygen to be introduced into the hypolimnion. This was important since the salinization process had led to a very stable density-stratification. A further requirement for the sluice was to allow a free exchange of organisms with the sea. The developments taking place were studied and monitored carefully, using techniques such as simulation modelling. By doing this, it was possible to have a 'dialogue' with the system. This is called: *The strategy of spontaneous development within certain, man-induced and controlled, environmental conditions* [3c,7].

How has it been possible that, even though the eutrophication level is high, no eutrophication problems have occurred? It has become clear that nitrogen and not phosphate is the major growth limiter [16]. The high phosphate level is thus not important! After all, a large amount of nitrogen leaves the system in a gaseous form, as a result of denitrification processes. Filter feeders such as oysters (*Ostrea edulis*) and mussels (*Mytillus edulis*), together ca 80% of the biomass of the zoobenthos, play an important role in this process. They are filtering out large amounts of algae. From research [16] it appears, that they are filtering the water of lake Grevelingen roughly eight times a year. As a result there is a Nitrogen-turn-over-rate of ca. eight times a year. Bacteria are doing the rest. They convert nitrates to free nitrogen!
It appears that waterplants play another important role. Large stretches of the intertidal zones, that have become permanently submerged, were covered with seagrass (*Zostera marina*). Research has shown, that they secrete substances, which can check the growth of algae. Hypothetically speaking, the seagrass play a part in suppressing the excessive production of algae.
The lake and surrounding former intertidal plains have since 1990 the status of nature reserve on a European level! Moreover it is very attractive for recreational purposes and fisheries. All together good for a roughly estimated gross income of 50 million US $ each year. The main lessons of the new salt lake Grevelingen to be learned are summarized:

- The choice of a salt- rather than a freshwater lake represents another change in (Dutch) tradition. After all, salt in water is seen as a problem in agriculture:
- New saltwater environments offer wide potentials, if their development prospects are approached actively, both in economic and in ecologic denotation;
- By laying down environmental conditions and providing proper administrative guidance this process can be directed. After all, changes in the ecosystems lead to modifications also in the way they can be used. It is thus essential, that choices are made on time and that the decision-making process is speeded up;
- This approach had consequences for the design of hydraulic engineering works.

This approach allows the conditioning of the system as a 'policy and management objective' to be primarily considered in relation to the interests involved. This means that when changes occur, the transformation processes are given priority in policy and management. Experience has shown, that it is important to have a balanced administrative approach involving all the relevant authorities rather than, with a single authority i.e. the government alone [10].

2.8 Changing conditions, a challenge

The most important conclusion that can be derived from experience gained over the last century is, that the design and management of such engineering projects should not simply be directed to certain specific aims, such as safety or waterstorage or water distribution. They need full acknowledgement of the importance of the processes of change that take place in a landscape. Moreover it merits consideration to evaluate carefully former hydraulic engineering projects before starting new ones. Then the role of man in wetland management can be much more profitable. It is not only valid in coastal engineering projects, but also in other project, like weirs in riverbasins. Better than in the past, attempts must be made to harmonize interests and make proper use of the opportunities offered by, water, ecological knowledge, change and creative approaches to watersystems and aquatic infrastructure. *Strategies based on prevention and protection must evolve into more harmonious approaches based on cooperating with nature and dealing with watersystems.* A further differentiation of policy by area is a logical development in this context. The water managers have to develop into active and purposeful entrepreneurs.

3. FROM TREATING OF SYMPTOMS TOWARDS CONTROLLED ECOSYSTEM MANAGEMENT

3.1 Water only for human use?

The revolutionary developments that took place in the Netherlands over the last twenty years, are by no means over yet [4]. Let's have a quick look at the developments of the last three decennia! It might be very helpful to understand the mainframe: After World War II attention was focussed on reconstruction and economic expansion. In this context, in 1968 Dutch government put forward a first national water policy document [17]. Understandably the basic philosophy was, that the demand for water had to be met everywhere and always. The policy was related to the supply of domestic and industrial water, drainage, combating salinization and getting infrastructure necessary to attain this. Groundwater was regarded as the basic supply for drinking water. Water was only seen as a resource for human use! The transport function of water (shipping and pollution) was not mentioned. There was no cost/benefit analysis added. Water quality was defined in terms of 'unacceptably high levels of 'inorganic substances' (read: salt) and organic substances (read: oxygen consuming substances).

Salt water was even referred to as 'useless'(!) and 'poor quality'(!). The basis for the infrastructure was: 'the need for measures to prevent salinization and for combating salt from the river Rhine, water supplies in the Lake Yssel and a link between Lake Yssel and S.W.Netherlands'. 'New reservoirs should be constructed in the dunes and in the new Lake Grevelingen. These measures were estimated at 1.5 billion US $'.

3.2 Protection against pollution

In 1971 the Pollution of Surface Water Act passed the Parliament. The aim was the protection of the environment against pollution, because...the human use was at stake. The policy became operational in three Indicative Multiyear Plans for Water (IMP 1974, 1979, 1982). They have made an extremely important contribution to extending water quality policy. As a result the various water authorities were brought much closer together, which meant that they could learn from each other's experiences. The basic philosophy was the combat of water pollution, both in a preventive and a curative sense. In the first IMP [18] the problem was identified as being an excess of oxygen-consuming substances. The remedy suggested was to treat these substances like the discharge from sewerage systems. One water quality map showing the oxygen content in different areas was prepared as part of this report: The second IMP [19] also included the 'substances on the black and grey lists'. Emphasis was placed on defining the 'basic quality' of the water. The increased knowledge in relation to the purification of non oxygen-consuming substances is also reflected in this policy document. Four water quality maps were given, concerning; oxygen, phosphates, heavy metals and organic micro-pollutants: The relationship between water quality policy and environmental policy was more fully dealt with in the third IMP [20]. Function (use) oriented and ecological objectives were included for the first time. New problems were discussed, such as lake and riverbed pollution and non-point-source pollution: The realization has grown that surface waters are ecosystems, that is to say, where organisms as well as physical, chemical and biological processes have an important role to play. This new insight makes it possible to describe these relations in a more logical and coherent way. It was obvious that in further up-dating such policies, attention should be paid to not only broadening the approach, but also to integrating both quantity and quality of waterpolicies. Developing a stronger ecological basis for water management, policy was also seen as essential.

3.3 Integration of various aspects

In the second Policy Document on Water Management [21], an attempt was made to integrate the various aspects. The document was based on the results of a modelstudy 'Policy Analysis Watermanagement Netherlands' (PAWN) [22,23]. The objective of the 1984 Document was: 'to lay down the main aspects of government policy on water management in, both quantitatively and qualitatively'. To sum up the highlights:

- The watersystem as a whole is of primary importance. This includes everything that is related to the system; water; lake- and riverbeds; banks; salt-marshes and mudflats in tidal systems; infrastructure like rivers, lakes, canals, dams, dikes, barrages and pumping stations; substances that are contained within the water; and not to forget the living creatures and the live communities.
- The wishes expressed by society and the possibilities offered by individual systems were brought into line and choices were made.
- All aspects of water management are required to be included as part of a balanced decision-making process, taking full account of the interrelationships involved. This concerns; safety; agriculture, homes, industry, electricity supply, services sector, shipping, fisheries, recreation, landscape and nature.
- A cost/benefit analysis was added.
- This explains why the operation of the watersystem has become so important. Water is no longer considered as merely a raw material or a way of transport, but the importance of a properly functioning aquatic ecosystem is now also acknowledged: The definition of water quality, as described in the IMP-s, has been integrated into this policy document: Quantity and quality were seen as inter- related subjects, as are ground- and surface-water.
- Attention is also paid to saltwater-systems, such as lakes, estuaries, and the sea.
- A main infrastructure (including the major inland freshwaters, salt coastal waters and the North Sea), managed by the government, is distinguished from a regional infrastructure managed by local authorities.
- The problems identified in the document were; anticipated local shortages of water as a result of drought; the alarming water quality coupled with transfrontier pollution; the poor quality of lake- and riverbeds; the considerable falls in ground-water levels due to extraction, in addition to the ensuing damage to agriculture, nature and landscapes that are associated with it;groundwater pollution; choosing which problems should be addressed first.

As a result the conclusions were different from those arrived at in 1968: Various, in 1968 planned, measures have been dropped; the North-South link; the canalization of the river Yssel; the development of major water supplies in the Lake Yssel; and the closing off of the river Oude Maas. Altogether a saving in investment of about 1.5 billion US $: It was recognized that the majority of problems can be solved by means of small-scale operations. Of the plans involving local waterauthorities, some 50 schemes looked promising; The direct benefit from the smaller schemes would amount annually to 50-150 million US $, for an investment of 250 million.

3.4 The need for progress

Thus, in order to manage water successfully, the relationships between several factors must be taken into account. Integrated water management aims to manage watersystems (or landsystems where water is an essential part) together with the associated lake and riverbeds, banks and groundwater, as one complete unit in relation to the human interests. Arguments in favor of integrated water management are summed up:

- Watersystems function as entirety. The coherence in diversity must be preserved in policy.
- A large number of methods are available to control a system (level, salinity, residence time, collecting, transporting, extracting, infiltrating, separation of salt and fresh water, constructing barrages etc.). However, application must be carefully considered. You never know the ultimate impact; many utilizations have their roots in the ecology of the system, which has its limits.
- Many interested parties are involved with water systems, but all may place different sometimes conflicting demands on the system. Interests and possibilities must be weighed up in a balanced way, taking account of their interrelationship
- Water, with everything in it, is a moving part of the landscape, here today, gone tomorrow and subject to changing authorities. Intervention at one place may have far reaching consequences for quality and utilization elsewhere.

The key question today is, whether sufficient use is being made of the possibilities that water, the infrastructure and creative methods of dealing with watersystems can offer. In other words, there is more need for sustainable management and for small- scale specialized multi-functional engineering, than for new large scale hydraulic engineering projects! In the past emphasis was laid on water as a medium, its use as a raw material and as a transport route, and its protection against the harmful consequences of human activities. Sustainable management still involves distributing water and protecting watersystems from human intervention. However, the development of watersystems also deserves attention. *The wishes of society and the possibilities offered by water systems can and must be harmonized.* There must be more cooperation between nature and the way in which watersystems are dealt with. This should equally well apply when realizing or safeguarding functions of direct human interest. In practice, such an integrated way will concern various areas of policy. It could not only involve, for instance, traditional duties such as protection against flooding, the management of aspects such as quality, quantity and shipping routes, but should also relate to recreation fisheries and nature conservation. The duties and responsibilities for certain policy-areas are vested in various administrative bodies involving both the national and provincial authorities, as well as the local Waterauthorities. An integrated approach to water management must therefore include measures to coordinate these individual policy areas [3d]. Such a harmonization of policy and management by the individual authorities concerned must primarily concentrate on developing administrative agreements for each watersystem, which are then put into practice by the requisite authorities, each having their own duties and area of jurisdiction. The above shows, that the actual watersystems, the opportunities and functions that these systems represent, coupled with the harmonization of administration and management are the central elements in an integrated approach to watersystems! Such an approach also implies a greater regional differentiation in policy matters. Every individual watersystem has different characteristics and processes in addition to different functions and discharge situations. In the meantime care must be taken not to lose sight of national aspects. It must be emphasized that it is essential to have a national approach for water management based on national standards for the protection of watersystems.

There clearly exists a need among local authorities to apply the general policy in a way that accommodates the specific functions and possibilities of the systems in their areas. This strengthens the bond between standards, management objectives and the way in which the system is used.

4. LIVING WITH WATER IN THE NETHERLANDS ANNO 2000

The approach outlined above takes time and has far-reaching consequences in terms of policy. The strategy, for beyond the year 2000 should therefore be considered now. This was in 1985 proposed in the policy document 'Living with Water' [24]. Meanwhile this document has received parliamentary support. It is implemented in the third National Policy Document on Watermanagement [25]. To sum up the aspects of special attention:

- A coherent integrated national waterpolicy, based on a watersystemapproach
- Action-plans, to clean up riverbasins
- Reflection on the policy with regard to groundwater
- A harmonized policy for each watersystem
- Differentiation of emission policy for each watersystem
- Development of policies for polluted beds, non-point source pollution, banks etc.
- Effective utilization of the infrastructure and knowledge of ecology
- Reflection on the administrative and legal machinery and on the financing system.

As a basis for the third document a new Policy Analysis Watermanagement Netherlands was made. Two questions had to be answered: How can water-based flows of materials (not only water) be regulated? In which way can the infrastructure play a part in this process? This study aimed to create decision models and mainly dealt with the characteristics of the system and the control variables.

The views of the Brundtland Committee have now been accepted in The Netherlands. The principle of continuous development is at this moment the pivot of economic and ecological strategy. This also has consequences for the course of the watermanagement strategy. The third document on waterpolicy works out how an integrated watermanagement can be specified into 'worktasks' for the next decade. The aim of the policy is that 'watersystems should be managed and developed in such a way, that they can optimally fulfil their projected functions, both ecological and for human use, insofar as their inherent potentials allow'. The main concept can futhermore be divided into a number of goals:

- Guaranteeing safety against flooding and environmental calamities.
- Surveying and promoting the availability and functionality of water.
- Protecting the quality of watersystems and their further development. In other words having and maintaining a habitable and viable country as a preliminary condition.

The country needs to have sound watersystems, which guarantee a sustainable use. Watermanagement is not only intended to support the conditions necessary for the functioning of watersystems, it should also work as a steering power to define the functions that watersystems can fulfil. Taking into account the immense importance inhabitants and many sections of society attach to watermanagement, it is far from simple to give a frame within which a balanced policy is possible for various differing interests. The most important functions of the document are therefore:

- So far as integrated watermanagement is concerned, to elaborate on such concepts as sustainable development and sustainable use.
- To reach a consensus between watermanagement and the interests of spatial development, ecology and environment as seen against the background of the potentials of these systems and their functioning in an economic sense.
- To point the way in an effective and efficient integrated watermanagement.

The objectives of watermanagement for the planning period of 1990/95 are grouped into four themes, in which fifteen 'worktasks' can be distinguished:

Theme I Protection against pollution.
Worktasks; (1) Oxygen consuming substances; (2) nutrients; (3) heavy metals; (4) organic micro-pollutants; (5) beds of rivers, canals, lakes etc.; (6) calamities.

Theme II. Land-use
Worktasks; (7) banks, intertidal areas etc.; (8) restoration of watersystems.

Theme III. Control
Worktasks; (9) watersupply; (10) drainage; (11) groundwater.

Theme IV. Organization and machinery
Worktasks; (12) administration; (13) legal and infrastuctural instrumentation; (14) financing; (15) international deliberations.

The worktasks are translated in aims and goals to be realized in 1995. For example the aim of worktask (4) is; 'a reduction of, at least, 90 % of the (1989) emissions of organic micropollutants into the surface waters'. The goal for 1995 is, 'a reduction of about 50 % and for a number of pollutants 90 %'.

5. A CHALLENGE FOR HYDRAULIC ENGINEERING IN RIVER BASINS

5.1 Applications

A final word is dedicated to the applications. I would like to focus on the attacking of one of the main environmental problems of the world, the destruction of the catchment areas of rivers like the Nile, Amazone, Rhine, Donau, Ganges, Bramaputrah, Pearl river, Orinoco and the Paranah. All these riversystems and the list could be extended easily, have destructive problems in their catchment areas. The methodology of integrated planning and the development, as presented before for delta areas, can be extended to the complete catchment areas of riversystems. Three examples follow:

5.2 The Amazone river basin threatened by death

An example is the Amazone river basin. In some tributaries, barrages and man made lakes have been created, to produce electricity and many more are planned. Without an integrated watersystem approach, taking into account all barrages (also the planned ones!) and all interests involved in the riverbasin, it is impossible to avoid a disaster; neither in terms of ecological impact, nor in terms of cost/benefit in the long term. Without a careful and balanced decision making, based on policy analysis, it is not justified to decide for new investments in more barrages in tributaries in the Amazona river basin. It is another serious threat to the tropical rainforests! All the functions are at stake! In such a policy analysis there is a coherent range; The riverbasin-*system* as a unity; the *interests* associated with this area; the *potentials* of the ecosystems involved; the *machinery necessary to ensure peoples behavior and the instruments to control the processes of the system*; A *functional organization* responsible for the functional management of the riverbasin and the *financial means*. Alternatives have to be generated and assessed.

5.3 The Nile river system, a new strategy, a must

The Nile riverbasin is another wetland, where it is profitable to prepare comprehensive and up to date plans or policy options, for the development and the use of water, and water dependent land resources, comparable with the PAWN approach [22,23] in the Netherlands. But I will not go into further details.
Egypt has another potentiality I will mention, because it is another example of application, namely to take profitable advantage of the surplus in brackish water and of their coastal lagoons and waters. Egypt can make a 'golden line' of the coastal zone, by using the salt and the brackish water in that area! It requires a daring way of thinking and acting, really a challenge! Instead of reclaiming the coastal lagoons in the Niledelta, for agricultural purposes, or making fresh-water reservoirs, as suggested, one could decide to manage them as controlled estuarine ecosystems and take advantage of their unique position in the delta. Fresh water can better be used to irrigate deserts, there is plenty of room!
Another suggestion is, to make use of the so called 'useless' 10 % of the brackish Nilewater, leaving Egypt now via the Rosetta branch of the Nile, to create new productive brackish and saltwater lagoons and lakes; for example in the deserts West or East of the Niledelta, or in the shallow coastal waters. Summarizing; 'Water-reclamation'(!) is proposed instead of 'landreclamation'; the use of brackish- and saltwater in stead of fresh water... why not?

5.4 The Rhine river basin: largely degenerated

For one of the river systems, the Rhine a diagnosis is briefly worked out. In an article [26] the Rhine, its tributaries and its 185.000 km^2 of catchment area, which stretches across ten countries, are described. A diagnosis of the condition is made. Although smaller than the Volga and Danube catchment areas (1,38 and 0,8 million km^2, respectively), the Rhine catchment area contains the most water. The Rhine catchment area comes second, after the Mississippi, on the list of the world's most economically important catchment areas. Mankind has made far-reaching and large scale modifications and transformations to the Rhine and its tributaries and the catchment area. Alongside economic prosperity, the like of which is unmatched in the history of the world, substantial problems have arisen. For instance the millions of m3 of highly polluted sediments in the river forelands and in the Rhine river delta. Of these, water, soil and air pollution have attracted the most attention during the past few years. There are, however, equally serious hydrological problems as well, which have only recently become apparent. These can best be described by stating that the Rhine catchment area is simply 'drying up' at an increasing rate, due to the combined effects of several factors. It is possible that the greenhouse effect will cause the accelerated disappearance of the large water reserves stored in the glaciers within a century. The water retaining capacity of the catchment area is also becoming increasingly impaired. Further impairment of the catchment area's water reserves will have far-reaching consequences for many human activities. It may be concluded that the river system has, due to human interference, largely degenerated into a shortened, canalized, dammed and 'regulated' shipping route, held in the narrow embrace of two dikes, often used as a sewer and robbed, to a large extent, of its natural beauty. The natural watercourses have been fundamentally damaged (Fig. 5). The diagnosis of the state of art of the system finishes with five conclusion:

- The hydrological problems of the Rhine catchment area deserve at least as much attention as the problems of water quality.

fig.5 Overview of the most important dams with locks and reservoirs in the Rhine catchment area. These constructions have primarily been put into place in order to better regulate the river's water levels and to evenly distribute water drainage throughout the year.

- More attention should be paid to increasing the water storage capacity of the catchment area, with an eye to the sustainability of any solution.
- The river system's hydraulic infrastructure has come into being in an ad hoc manner, mainly in order to fulfil local needs and without realizing the consequences for the whole of the catchment area. An integral approach is necessary.
- To this day, when modifications are made to the river system the consequences for the catchment area as a whole are not realized.
- Sustainable development is not possible with the current hydraulic infrastructure and the way in which it is managed.

Nothing which could be termed sustainable development is evident at present. In the chapter 'Strategy for a solution', it is explained what is meant by sustainable development and that there are limits to sustainable use. Four sustainability functions; 'the carrying capacity-', 'production-', 'regulatory-' and 'information-functions'are used to illustrate these limitations. The limits to sustainable use are also sketched for the various sectors:
- Demands made on natural cycles and energy flows should be reduced to a minimum.
- Genetic and landscape diversity should be maintained as much as possible.
- The attempt to achieve maximum production should be abandoned, in favor of adapting to ecological requirements.
- Permanent and/or renewable resources, (e.g. sun, wind and water power) are preferable to non-permanent and non-renewable resources (e.g. fossil fuels and heavy metals).
- In the search for solutions serious consideration must be given to permanent alternatives. Politically relevant policy analyses or, as long as the economy is a dominating factor, environmental impact statements, are obvious vehicles for this.

The conclusion is drawn that water determines everything and that it is the interdependences that exist in the catchment area, due to the flow of the river and all the substances it carries, which point to the necessity of further international cooperation. The cooperative effort must pay sufficient attention to the basic functional conditions for existence, which are determined by the system and the interests vested in that area. The various factors are inextricably bound up with one another. These are: the (Rhine) catchment area; the interests at stake; the possibilities and limitations of the system; the instruments to manage the situation; the organization; and the finances. Finally seven recommendations are made, which together constitute the proposed strategy:
- *In order to achieve sustainable development it is necessary not only to do justice to the political borders between nations, but also to the natural system borders. In the river basin, the system borders coincide with the watersheds between the catchment areas and sub-catchment areas.*
- *An integral riverbasin approach should become generally accepted.*
- *Sustainable development demands an integral approach involving the whole river basin. Interests in the sub-riverbasins should be attuned to each other and to the catchment area as a whole.*
- *A first prerequisite for a sustainable approach is the public availability of accurate information concerning the actual state of affairs. Citizens and politicians have a right to coherent and sufficient information concerning the system in which they live and the consequences of their actions upon it.*
- *In order to be obtain a greater understanding of the issues involved and their interconnection, and to provide a sound basis for the making of policy decisions, it is recommended that parliamentary permission be obtained for a policy analysis concerning the entire (Rhine) catchment area.*
- *There has been intensive, practically-oriented cooperation between the countries concerned for more than 150 years, with concrete outcomes for shipping, information processing and water quality. Practically-oriented cooperation must be expanded further in the areas of hydrology and ecological recovery of the river and its environs, eventually involving the complete catchment area.*
- *Disasters (like the one at Sandoz) appear to have taken the place of scientific research and rational thought when it comes to the drawing up of adequate environmental regulations. Necessary environmental measures must not simply be thought up as a result of the pressure of public opinion, but must, above all, be based on facts. Management by knowledge must be given priority over management by accidents.*

In the world many more, small and large scale, applications are possible! The main two messages of this article were to emphasize 'the positive role man can play in his environment' and 'let engineers stop to destruct the last unaffected large river systems especially in third world countries'. Let they concentrate their creativity to restore already affected river systems like the Rhine. There is work enough to do! And don't forget 'the one who controls the water, directs and rules developments!'

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Special Session 1

Tensioned Structures

Structures en tension

Zugbeanspruchte Konstruktionen

Organizer:	Ted Happold, UK
Chairman:	R. Silman USA

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External Prestressing in Tension Structures

Précontrainte extérieure dans des structures tendues

Aussenliegende Vorspannung von Zugkonstruktionen

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SUMMARY

The use of external prestressing has proved to be of particular interest for strengthening structures whether for the purpose of adapting them to new loading regulations, or to completely restore their capabilities of resisting environmental loads. This paper deals with tension structures – either new or old – where tension forces are carried by external cables. Three projects are presented: a tension roof structure entirely supported by external prestressing cables; circular tanks prestressed with external individually protected greased strands; cereal silos, which were reinforced by external prestressing.

RÉSUMÉ

L'utilisation de la précontrainte extérieure est particulièrement intéressante pour le renforcement des structures, soit dans le but de les adapter aux nouveaux règlements, soit pour leur redonner leur capacité de résister aux sollicitations de l'environnement. Cet article traite des structures tendues récentes ou anciennes – où les forces de traction sont portées par des câbles extérieurs. Trois projets sont présentés: un toit entièrement porté par des câbles extérieurs; des réservoirs circulaires précontraints par des torons gainés graissés; des silos à céréales renforcés par précontrainte extérieure.

ZUSAMMENFASSUNG

Die Anwendung der Aussenvorspannung erweist sich als besonders nützlich bei der nachträglichen Verstärkung von Tragwerken, sei es zur Anpassung an verschärfte Normenbestimmungen, sei es zur Rehabilitation gegenüber Umwelteinflüssen. Von der Vielzahl jüngerer oder älterer Fälle, bei denen Zugkräfte über aussenliegende Spannkabel aufgenommen wurden, sind drei Beispiele ausgewählt: ein vollständig aufgehängtes Dach, runde Behälter mit Ringvorspannung aus gefetteten Monolitzen, sowie ein Getreidesilo mit äusserer Vorspannung.

1. GENERAL

External prestressing is not a new idea today. Many applications of prestressed structures with prestressing components installed outside the structural material have been realized all over the world during the past thirty years. However its development is more recent.

The use of external prestressing has proved to be of particular interest for strengthening of structures whether for the purpose of adapting them to new loading regulations or to completely restore their capabilities of resisting environmental loads. Today, external prestressing and corresponding techonology are being developed for new structures.

This paper deals with tension structures - either new or old - where tension forces are carried by external cables. Three projects are presented :

- At FELSBERG (Germany) a tension roof structure (after repair works) is entirely supported by external prestressing cables.
- Prestressed decantation circular tanks of a water treatment plant at CHAUNY (France). Use of external individually protected greased strands.
- At SAFI (Morocco), cereals silos, 34 m high, were reinforced by external prestressing.

2. BROADCASTING BUILDING AT FELSBERG (Germany)

2.1 Structure description

The Europe n°1 broadcasting station is housed in a building covered by a prestressed concrete shell, built in 1954.

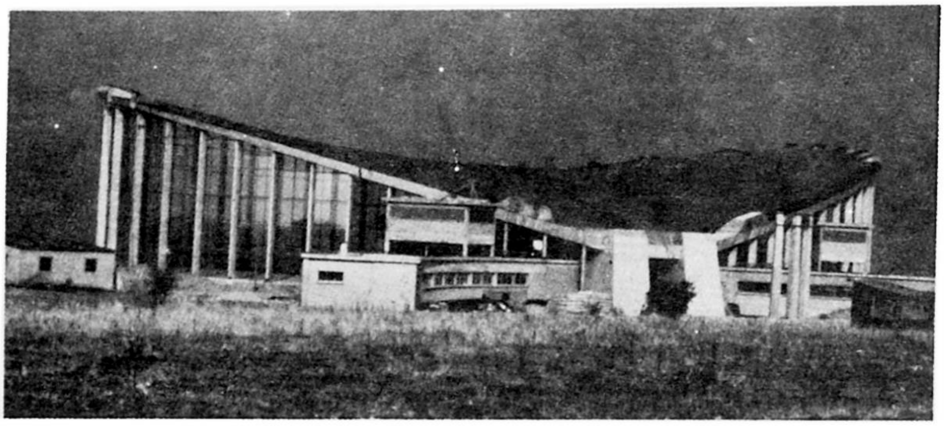

Fig. 1 General view of station building

The building consists of a series of slender columns supporting a reinforced concrete ring beam to which a 5 cm thick concrete shell is fixed. The columns are equidistant and enclose a heart-shaped area, inscribed within a rectangle measuring 86.5 m x 46 m. The walls between the columns consist of full-height glazed panels. The mean line of the ring beam capping the columns is contained within two symmetrical planes in relation to the axis of the heart-shape and inclined at 20 % to the horizontal : the angle of intersection of the dihedron formed by these two planes is inclined at 13 %, the levels of this angle of intersection, with respect to the foundation raft, being at a height of 4.50 m at one extremity and 9.50 m at the other.

The shell is prestressed with cables laid perpendicular to its axis, that is to say across the largest dimension. The surface of this double-cambered shell is generated by parabola corresponding to the cable layout, whereas cross-sections paralell to the symmetry axis of the building present a variable inversed camber due to the shape of the ring beam. The different stresses acting on this ring beam are counterbalanced by means of 6 ties placed in a fan-shaped formation from the point of the heart.

2.2 Analysis of the deterioration

After 25 years of trouble-free service, it was decided to examine the entire structure, following the discovery, in Germany, of defects affecting a similar shell.

The examinations revealed the following defects :

- advanced corrosion of the stirrups supporting the fibreboard panels,
- poor aspect of the ribs housing the prestressing cables and their poor adherence to the concrete shell,
- corrosion of uncovered sheath at the bottom of the ribs,
- superficial corrosion of prestressing wires, the cables being only partially grouted, essentially due to a lack of impermeability of the sheath, a certain amount of grout having probably been lost in the insulating panels, advanced corrosion of certain tie rods in the anchorage zone, at the concrete saddle end.

On the other hand, the shell concrete was found to be most satisfactory.

The client having expressed the request for a complete overhaul of the structure, it was decided to change the prestressing cables and the ties, and to apply a thermal insultation to the outer surface of the shell in order to reduce the risk of internal condensation.

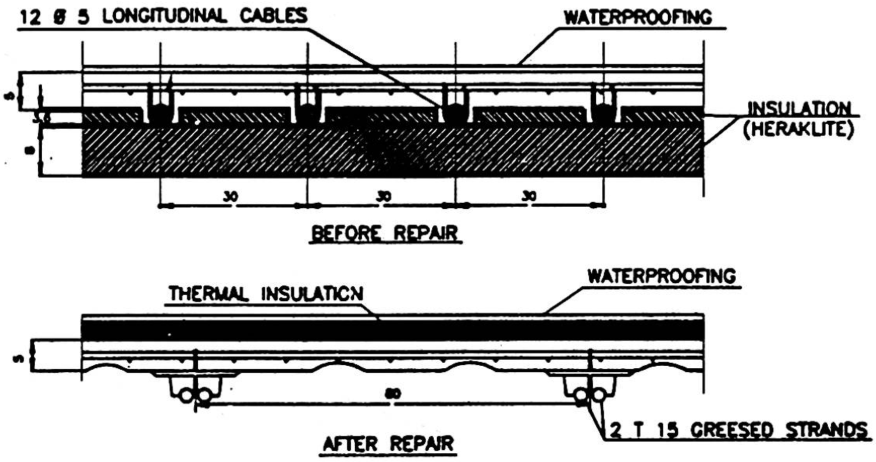

Fig.2 Section through shell

2.3 Rehabilitation of the roof

2.3.1 Replacement of the prestressing cables

Unbonded plastic coated ø 15 mm, strands were adopted to replace the original cables. Placed in pairs at the location of alternate ribs they produced the same prestress as the previous cables.

The operation involved the removal of the fibreboard panels below the ribs, the progressive removal of the ribs and the original cables, made possible by the existence of a low-strength casting joint, the necessary boring in the ring beam in order to pass the new cables, the installattion of these below the shell, the stressing operations being carried out as work progressed. Contact between the strands and the shell was ensured at pin-point locations every 1.50 m, by means of small concrete shims. These shims provided excellent contacts and supported the shell by the curved effect of the stressed cables.

2.3.2 Replacement of ties

This operation resulted in temporary complementary stresses being applied to the roof, through a lack of synchronization in the stressing of the new ties and the removal of the original ones. In order to limit the parasitic stresses connected with this phase of the operation, the ties adopted were of the "prestressed"type. To reduce their size and weight, the compressed section is that of a concrete-filled steel tube.

The installation of the new ties comprised the following phases : placing of steel tube lengths on scaffolding, butt-end welding of these tubes, threading of the central sheath placed on supports to ensure the correct position, grouting between the tube and the sheath, threading of cables and stressing.

With a mind to simplification and safety, the new ties were all identical and each made up of 19 strands ø 15 mm placed in a 273 mm outside diameter tube with a 10 mm wall thickness. They are stressed to 300 t and their overall capacity is largely above that of the original ties.

The new ties were installed next to the old ones, according to the possibility of boring the necessary holes (ø 100 mm) through the ring beam, on one end and the solid abutment at the other end.

3. DECANTATION TANKS AT CHAUNY

The treatment of the industrial effluents is carried out with the use of aeration and homogenisation tanks. Each of these basins consists of a cylindrical tank whose 22 cm thick wall is fixed to the raft base.

- Aeration tank :
  32.00 m inside diameter ;
  4.75 m high
- Homogenisation tank :
  5.00 m inside diameter ;
  5.00 m high

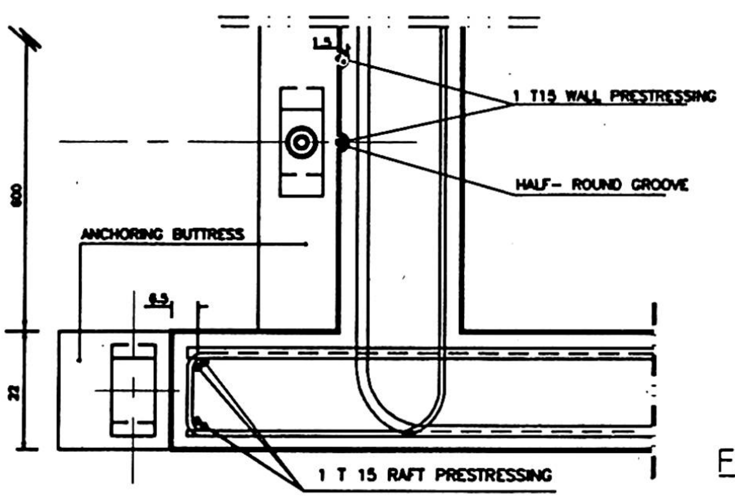

Fig.3 Decantation tanks hoop prestressing

3.1 Prestressing method

The prestressing of these tanks is obtained by means of single greased strands placed on the outer side of the wall and lodged in horizontal grooves formed during concreting. Double protection of the strand is achieved by housing it in a tube which remains visible. Each strand forms one complete loop and is anchored in a vertical buttress. Two buttresses at 180° are used to ensure uniform distribution of the prestressing force.

3.2 Application

The method of applying the prestressing is simple : threading of the strands into a polyethylene tube suspended in front of the groove. When stressing, the tube takes up its permanent position in the groove.

3.3 Advantages

This type of prestressing is particularly advantageous for small storage units. While producing a certain architectural aspect it still remains simple to apply. The structure described above was built with ordinary formwork but the same dispositions can be obtained with the use of climbing formwork. However care must be taken in forming the grooves and their effect on the rebar cover must be reduced to a minimum.

The following method provides a simultaneous solution to the problems of strand protection and proper application of the reactions due to curvature :

- placing the strand inside a larger sized sheath (30 mm minimum int. dia for 15 mm strand),
- grouting the free space between the outer sheath and the greased strand before stressing and then stressing after hardening of the injected grout.

On this site the plastic caps of the anchorage heads remained exposed. Generally they are sealed off and when this is not done they must be protected by painting.

4. STRENGTHENING OF A CEREALS SILO AT THE PORT OF SAFI (Morocco)

The activity of the port of Safi, Morocco's first fishing port, is also for a large part devoted to importation and exportation of cereals. The Safi cereals silo, a large structure built in 1957 which comprises two batteries of three rows of five circular, tangential cells 6 m in diameter and 34 m high, showed serious dilapidation of the reinforced concrete structure : vertical and horizontal cracking due to insufficient rebar and the intensity of the thermal gradient. The design of the strengthening operation led to the adoption of additional prestressing consisting of 40 hoops per cell, evenly distributed over their height. The prestressing force in each hoop is of the order of 20 t.

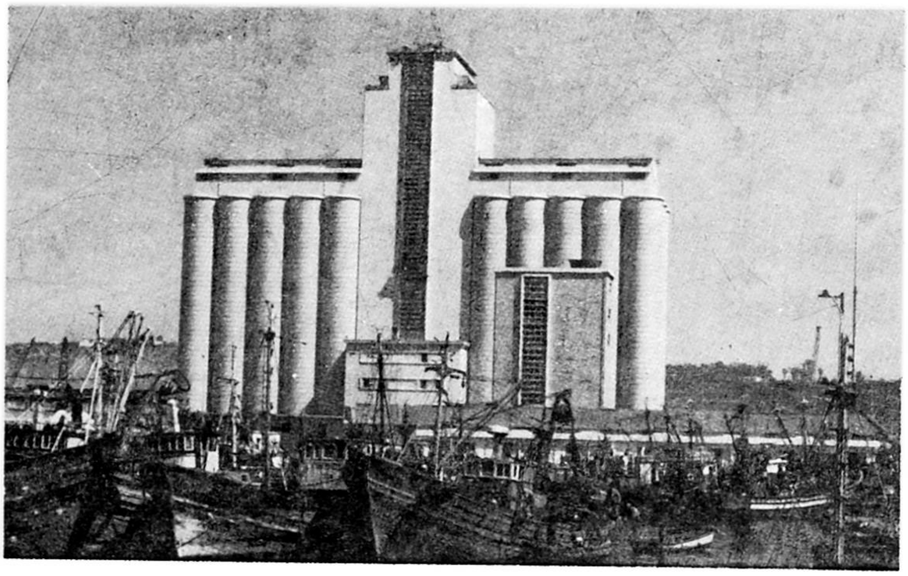

Fig.4 Silo at SAFI after strengthening

4.1 Execution of the works involved several phases :

- successive filling of the cells and sealing of the cracks ; core drilling in the cell walls to allow passage of the cables ;
- placing and tensioning the prestressing tendons ;
- surface treatment and waterproof coating on the entire outer surface.

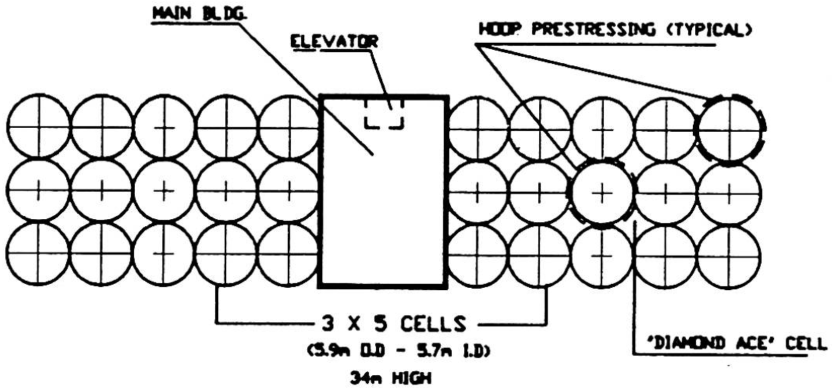

Fig.5 Silo at Safi General layout

The particularity and major difficulty of the operation resided in the fact that the hooped tendons encircling each cell pass through one, two or three other cells, a fact which meant that core-cutting was executed with rigorous tolerances, and the hoops had to be protected, on the inside of the cells, with reinforced micro-concrete, to avoid abrasion by the cereals during filling or emptying operations.

The external prestressing was provided by monostrand T15 greased and sheathed cables, housed in a plastic sheath and then injected with cement grout before being tensioned through "X" type anchorages.

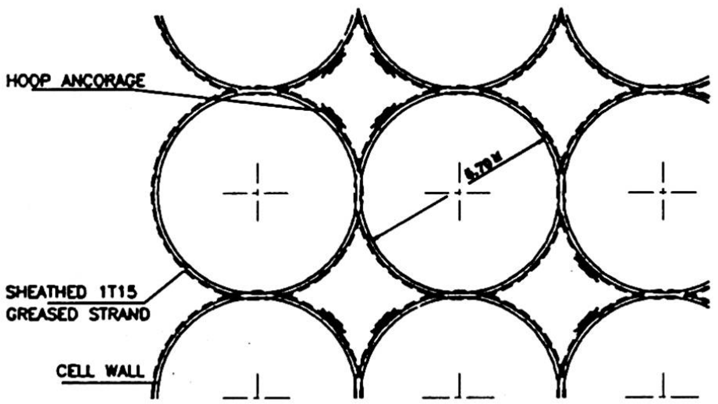

Fig.6 Silo hoop stressing (typical)

4.2 Quantities

- 7040 skew core cuts,
- 1200 hooped prestressing cables,
- 11000 m of sheath protection using micro-concrete,
- 12500 m^2 of surface treatment and waterproof coating.

Special Session 2

Offshore Fixed and Floating Structures

Constructions en mer amarrées et flottantes

Verankerte und frei schwimmende Meeresbauwerke

Organizer:	Chr. J. Vos, The Netherlands
Chairman:	R Halsall Canada

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Offshore Technologies in Japan to Exploit the Ocean

Technologie japonaise pour l'exploitation des océans

Neue Japanische Technologien zur Erschließung des Meeres

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Takayoshi Ota, born 1943, received his civil engineering M.D. from the Kyoto University. His experience covers a broad spectrum from harbour construction projects to development of ocean energy resources and marine ranching. Takayoshi Ota, now in a construction company, is responsible for strategy and planning of civil and marine engineering projects.

SUMMARY

There are expectations for the ocean to be exploited for space, energy resources, biological, and mineral resources going into the 21st century, and the offshore engineering for these will be required to deal with problems concerning the increasingly diversified uses of structures and needs in siting. Recent public opinion for provision of facilities friendly to the environment, needs to be satisfied. In this paper, a number of examples of new technologies and structures being worked on based on such concepts – new types of breakwaters, marine ranches, wide-area clean-up engineering – will be described.

RESUMÉ

Il est fort probable que le milieu, les ressources énergétiques, biologiques et minières des mers puissent être exploités par l'homme dans sa marche vers le 21ème siècle. Il lui faudra donc recourir à des techniques de constructions en mer, afin de maîtriser les problèmes liés à la diversification sans cesse croissante des structures à réaliser et des besoins d'aménagement des sites en résultant. La tendance actuelle de l'opinion publique semble tendre dans le sens d'installations plus favorables qu'hostiles à la protection de la nature et de l'environnement. Ce rapport expose divers exemples du développement de nouvelles techniques et structures fondées sur cette conception plus écologique, comme de nouveaux types de jetées, des fermes marines, des méthodes de nettoyage de grandes surfaces.

ZUSAMMENFASSUNG

Es wird erwartet, daß auf dem Wege zum 21. Jahrhundert die Meere zunehmend für Raum und als Energiequellen wie auch wegen ihrer biologischen und Mineralschätze ausgebeutet werden. Dafür sind moderne Technologien erforderlich, die es erlauben, die mit der zunehmenden Vielfalt in der Anwendung von Strukturen und der Suche nach geeigneten Bauplätzen verbundenen Probleme zu lösen. Außerdem muß danach gestrebt werden, die neuerdings von der Öffentlichkeit gestellten Anforderungen und umweltfreundlichen Anlagen zu erfüllen. In diesem Bericht wird eine Anzahl von Beispielen von erarbeiteten neue Technologien und Bauten wie neuartigen Wellenbrechern, Farmen im und auf dem Meer und Verfahren zum Säubern ausgedehnter Gebiete beschrieben.

1. INTRODUCTION

Ocean space abounds in infinite possibilities, and attention is being focused on it as the last remaining unutilized space. There is a great variety of development projects planned in Japan. Projects presently under construction are, for example, a) Kansai International Airport, the first international airport in the world to be on an offshore artificial island, b) The Honshu-Shikoku Bridges, large-span bridges connecting islands of the Inland Sea of Japan, and c) Tokyo Trans-Bay Highway to cross Tokyo Bay by long bridges and underwater tunnels (Fig.1). Environmental impact assessments have been conventionally made in connection with such offshore development projects using marine space, and such assessments related to ocean space involve various difficulties such as described below.

When effects on the marine environment are to be considered, what must first be done is to predict the effect on the boundless natural system of the sea and to aim for coping with the situation beforehand. In such case, a considerable problem is determining the scope of the environmental impact assessment. Furthermore, there has recently been a rising concern in society about protection of the natural environment such as by regulation of large-scale leisure facilities development and tackling the problem of the global environment on an international level. As can be understood from the oil spills in the Persian Gulf in the Middle East, the effects of the spills will spread with time, and it is said more than one hundred years will be required for a return to the former natural condition.

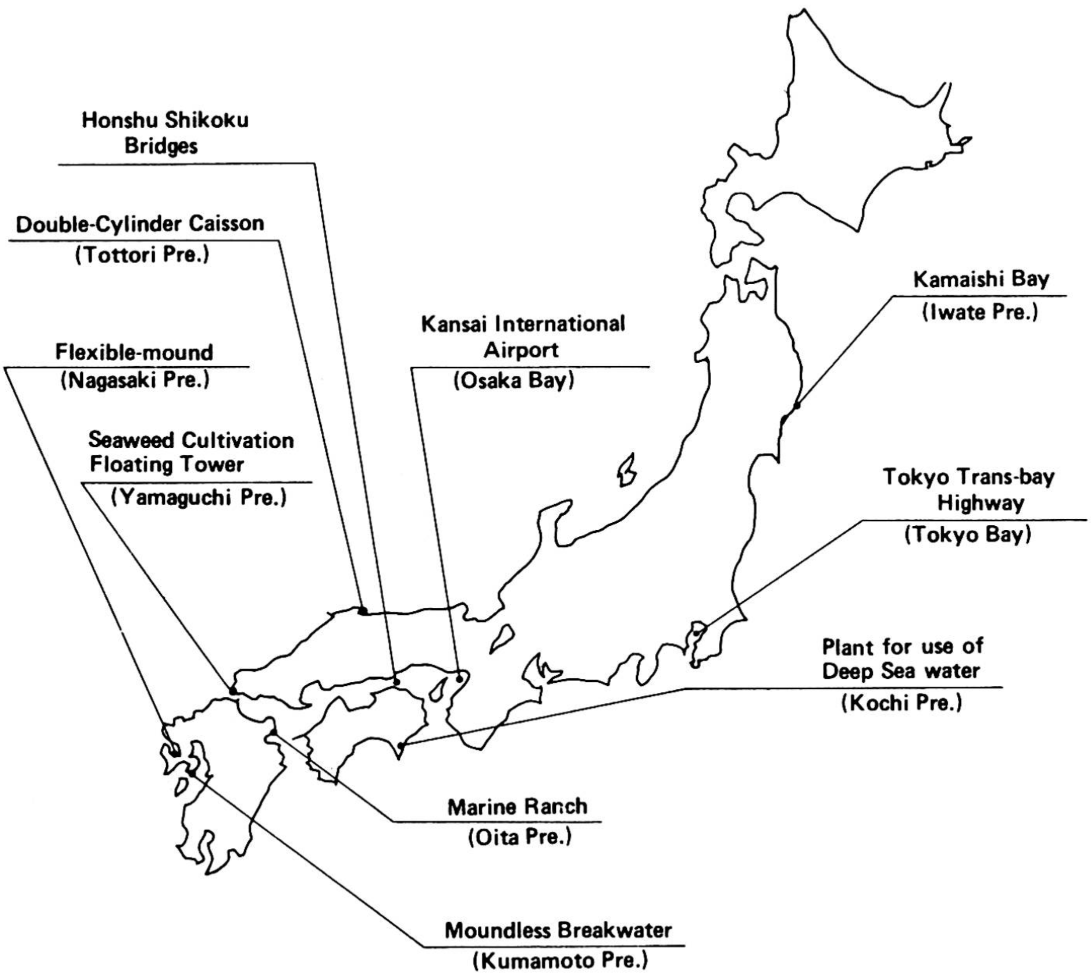


Fig.1 Offshore project map in Japan

Next, it is necessary for the effect on fisheries to be predicted and to provide measures to deal with the situation. Still further, considerations must include the influences on the fishing industry and the people's diet. The regional economy in marine development and the compatibility of pursuing convenience in daily life and the posture to protect the natural environment are becoming increasingly important in recent ocean space development. In the offshore engineering from now on, research and development for dealing with even more severe marine conditions will be necessary. Furthermore, it is needed "not for only unambitious assessment of the impact of construction to be made, but planning of marine development done from the aspect of more positively, in other word, 'creating an environment readily compatible with everyday life of people and natural ecology in addition to the original purpose'."

This paper, therefore, will present a number of cases of R&D and engineering being promoted in Japan, although not yet to an adequate degree, aiming for attainment of new technologies and structures in step with such thinking.

2. NEW TYPES OF SEA AREA CONTROL STRUCTURES

Structures for controlling waves and currents include breakwaters, and training jetties. With the waterfront development of recent years, particularly, with the increased popularization of marine leisure activities, R&D is going on concerning breakwaters for great water depths and for extra soft ground from the consideration of more efficient use of the coastal sea area, and concerning structures capable of managing the sea area while protecting the natural environment and scenic views from the desire to create a more favorable marine environment. A number of examples will be described below.

2.1 Challenging the Deep

A breakwater presently under construction at the port of Kamaishi, Iwate Prefecture, is at a location of water depth as much as 63m, and is drawing attention as the breakwater having the greatest depth in the world. This breakwater, as shown in Fig.2, consists of a foundation mound of rubble-stones from the sea bottom to a water depth of 20 to 30m, with 31 large caissons each 30m in length, width, and height, weighing 16,000t installed on the mound for a composite breakwater.

In manufacture of the caissons, since these are of extra-large size, they cannot be made at one place in a single operation, and therefore, build-up is done in sequence starting from a 6,000-t floating dock and moving from first to fifth offshore concrete placement stations. Construction was begun in 1988, and the third caisson have been installed so far. Completion of the whole project is scheduled for 1998. Upon completion, people living near the shore will be relieved from the fear of tsunamis, the waters inside the bay will be calmed, and navigation of watercraft made safe. Multipurpose ocean utilization will be promoted and a great contribution made to coastal development.

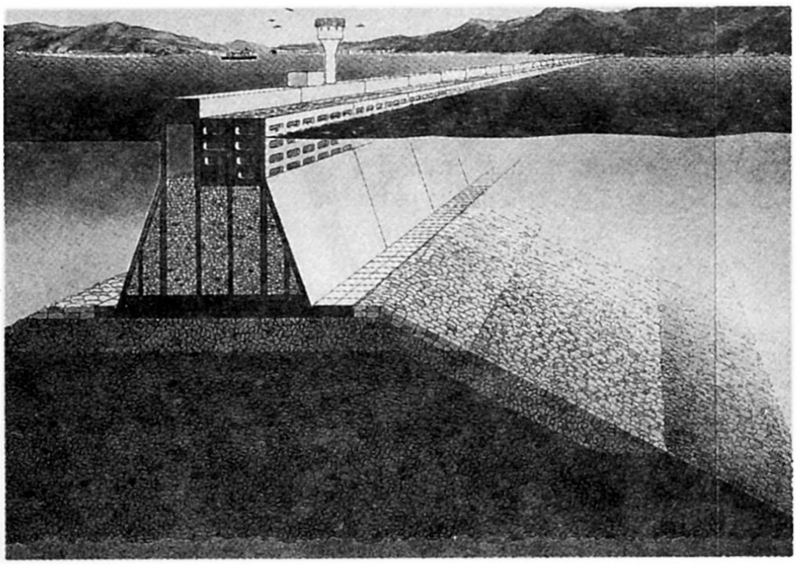


Fig. 2 Breakwater installed at great water depth (Courtesy of Ministry of Transport)

2.2 Overcoming of Soft Seabed

This new type of breakwater with wide footing requires no ground improvement (Fig.3). The adhesive force between the structures bottom and the ground surface underneath, and the horizontal resistance of piles are working against sliding enabling the breakwater's weight to be reduced. On-site proving tests were completed in 1986, and such a break -water has been in practical use at Kumamoto Port since 1988. The construction period required for this type of breakwater is expected to one-forth of that for a conventional gravity type and the cost one-seventh. Studies are being continued with the aim of achieving further improvements.

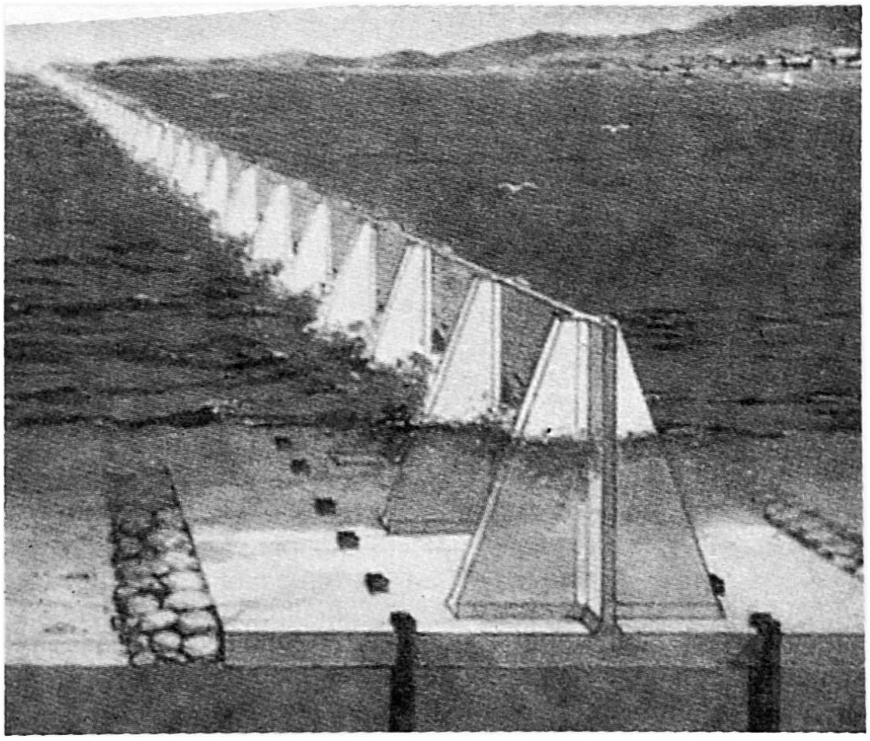


Fig.3 Breakwater installed directly on soft seabed. (Courtesy of Ministry of Transport)

2.3 Flexible-mound

Flexible-mound is a wave control structure of a completely new concept. It consists of a flexible membrane bag of approximately semi-cylindrical shape made of fiber-reinforced hard rubber. Conventional submerged breakwaters break up waves passing across to dissipate their energy, whereas Flexible-mound itself deforms due to incident waves, and through the two effects of the secondly waves (radiation waves) formed by the deformation interfering with waves incident and passing across, and the energy damping by movement of the membrane, the waves at the back side of Flexible-mound will be smaller. It will suffice for the cross-sectional area to be about one-fourth compared with a conventional submerged breakwater so that exchange of sea water occurs more easily, while moreover, there is no obstruction to navigation of watercraft.

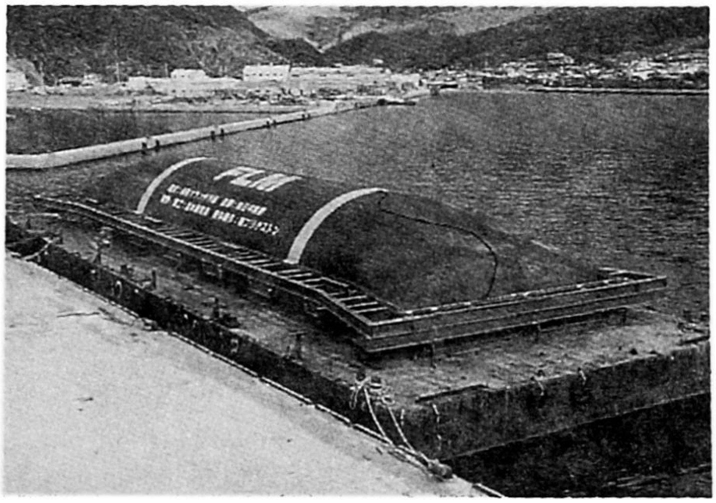


Fig.4 Flexible-mound during airtightness test on a barge (40m(L) x 9m(W) x 3m(H))

Figures 4 and 5 show the airtightness test of it being conducted on a barge and the image of Flexible-mound installed at Omura Bay in Nagasaki Prefecture in 1991. This Flexible-mound is filled with sea water during a storm as shown in Fig.6 for dispating of waves incident from the mouth of the harbor, while during normal times, the sea water is discharged from the bag and the crest is lowered to the level of the sea bottom for a system allowing regular liners and sight-seeing boats to freely navigate the harbor entrance.

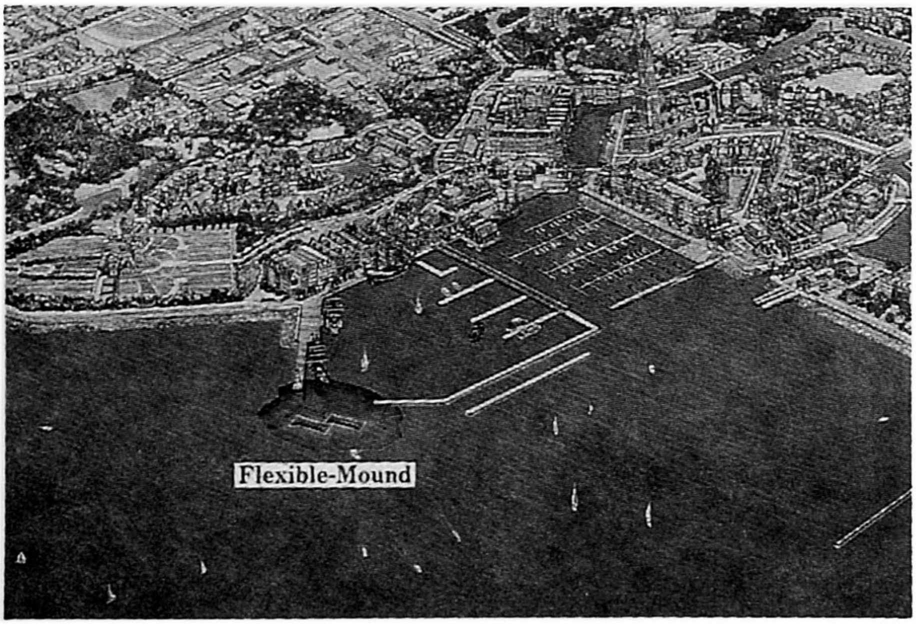


Fig.5 Image of Flexible-mound installation in Huis ten bosch

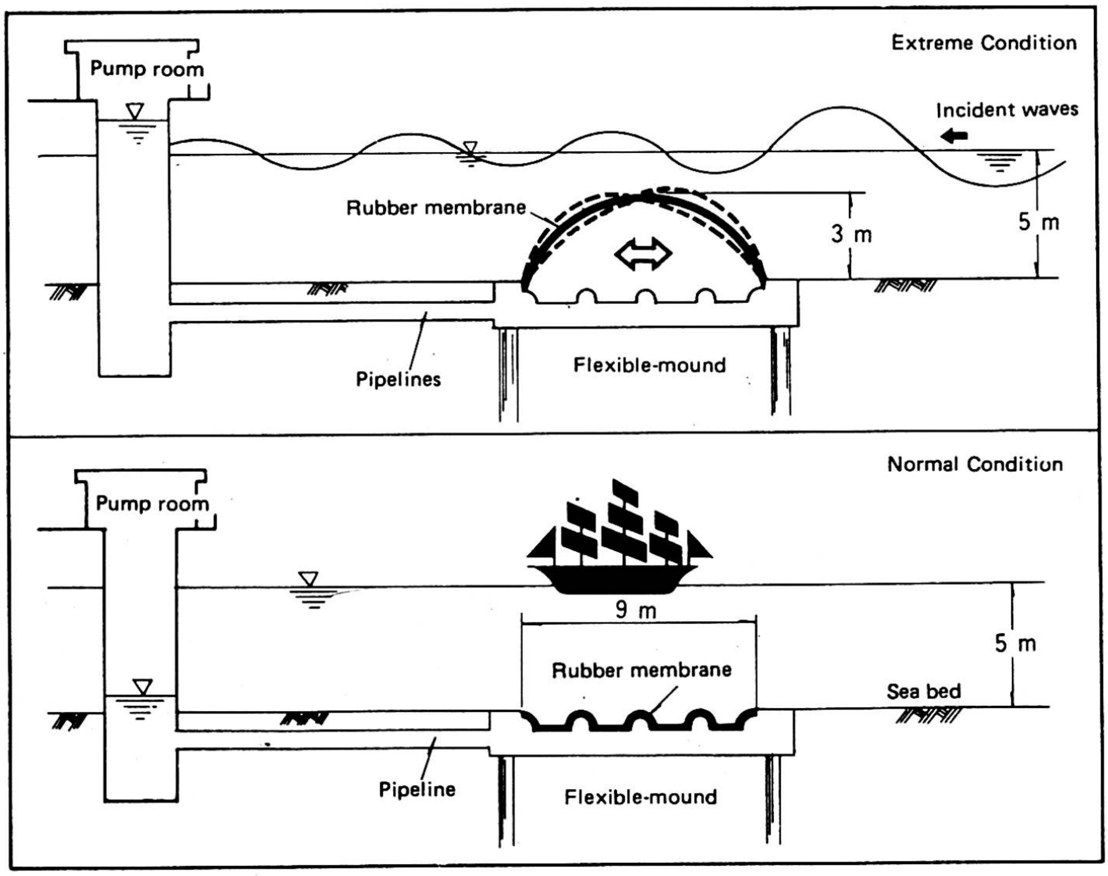


Fig.6 Conceptual drawing of Flexible-mound system

2.4 Double-cylinder Caisson-type Breakwater

The double-cylinder caisson is a new type of caisson which has been under development as a structure for controlling waves at great water depths (Fig.7). The principle feature of this breakwater is perforated double-cylinder structure. The outer cylinder is pervious with a doughnut-shaped retarding pool in the space between the outer and inner cylinders. Waves arriving at the breakwater enter the retarding pool through windows in the outer cylinder, go around either side of the pool, and collide with each other at the back. The section underneath of the retarding pool and the inner cylinder are filled with material such as sand to provide weight. Features of this caisson are the following:

-Being of cylindrical structure, savings can be made in members so that wave forces acting can be alleviated, an economical breakwater for wave control in waters of great depth results.

-The ratios of openings of the outer cylinder wall can be selected as suited for any variation between impervious strucure and pervious structure, while since reflected waves can be made small, this is a breakwater effective for preserving the water quality environment in the harbor and improving navigability of small watercraft in the front sea area of the breakwater.

-Being of cylindrical shape, the normal line of the breakwater can be curved with consideration given from the point of view of appearance.

Demonstration tests were completed at Sakai Port in Tottori Prefecture in 1989, and it is scheduled for caissons 30m in height to be constructed at Shibayama port in Hyogo Prefecture in 1992.

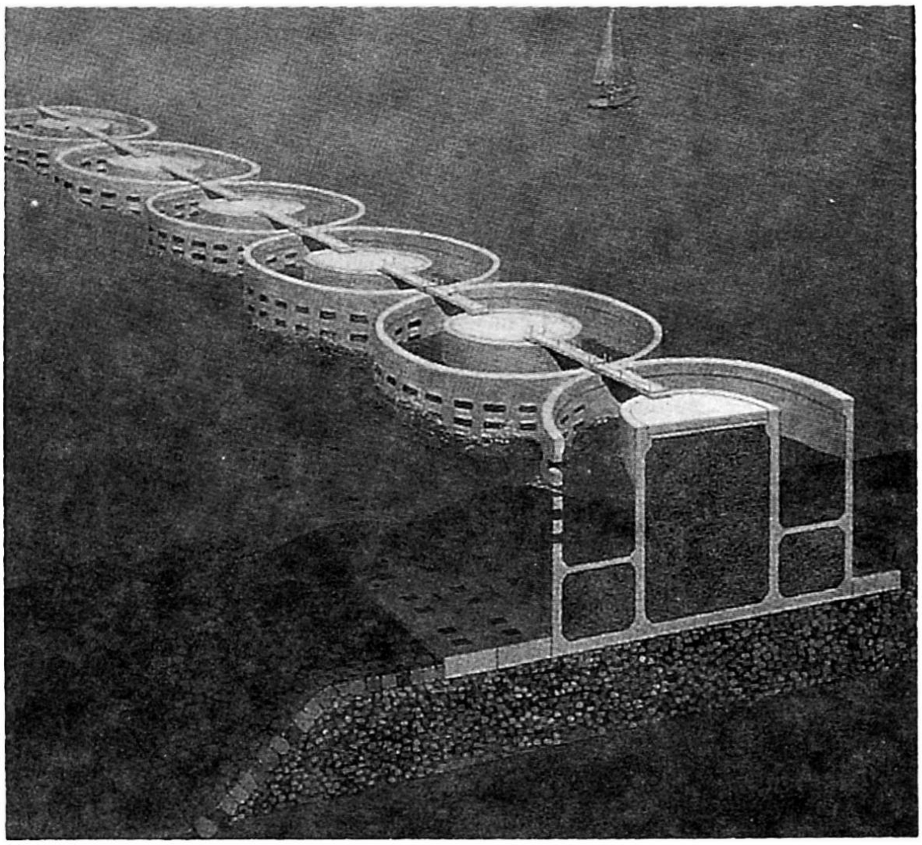


Fig.7 Double-cylinder caisson-type breakwater
(Courtesy of Ministry of Transport)

3. MARINE RANCH SYSTEMS

A marine ranch is a system where the method of putting cattle and horses to pasturage is applied to fishery production, where fish are released into the natural sea and instead of providing fences the range of movement of the released fish is controlled by sound and availability of feed. Since areas available for ocean fishing have shrunk as countries of the world have declared 200-sea-mile exclusive fishery zones, marine ranches which are a form of fisheries made in coastal areas where resources are nurtured, controlled and harvested, have gained attention.

The systematization of marine ranches where synergistic effects are produced through compositing of marine photovoltaic power generating system, plant for effective use of deep sea water, and seaweed cultivation floating tower with marine ranches, is described below.

3.1 Marine Ranch (Acoustic Conditioning Feeding Process Type)

The smallest unit of marine ranch consists of an artificial fish reef and a feeding buoy which supplies feed while emitting sounds several times daily. Figure 8 is a conceptual drawing of the world first marine ranch system introduced in Oita Prefecture. Here, a set of artificial fish reefs and two acoustic feeding buoys are installed, and the movement and quantity of red sea bream are measured by sensors attached to the buoys, with this information, along with sea area environment data, being transmitted by radio waves to an onshore monitoring station.

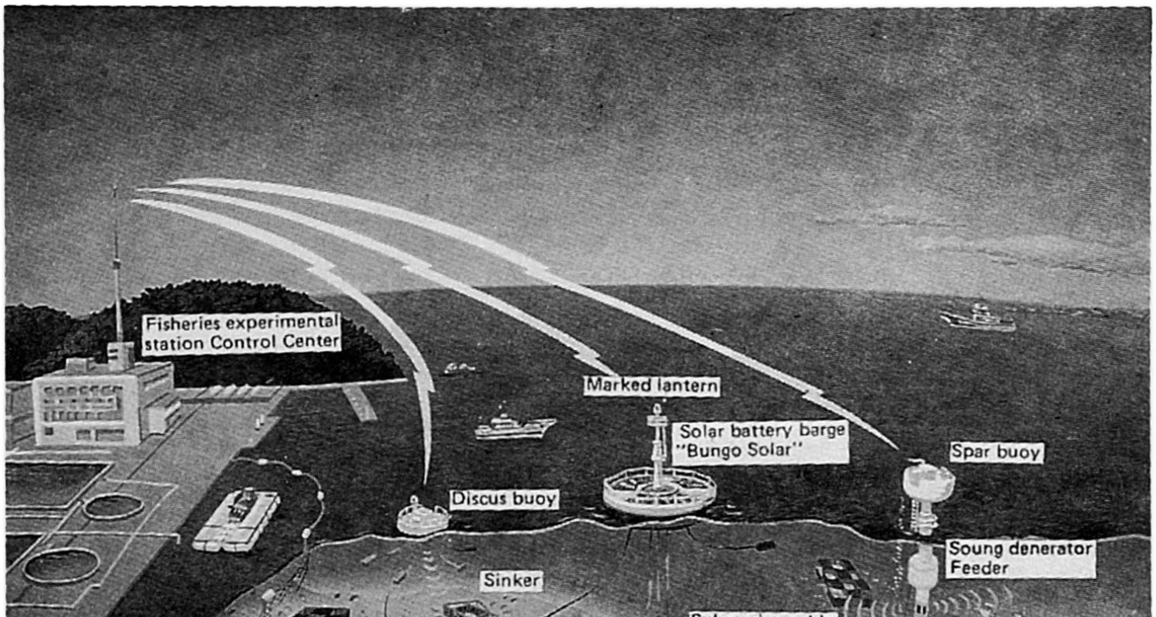


Fig.8 General view of marine ranch

The marine photovoltaic power generating system shown in Fig.9 was developed as the power supply source for this marine ranch. This system consists of 264 photovoltaic cell modules mounted on a barge of diameter 16m and height 3.8m, with this barge moored by three chains at a place of water depth 25m to generate electric power. This barge is a floating structure of concrete with thin walls (25cm) to secure draft while still being sufficiently watertight. For construction of this barge, the knowhow gained with the Arctic Ocean drilling platform, "Super CIDS", was applied adopting a structure with prestress induced in a high-strength, lightweight concrete (σ_{ck} = 3920 N/cm^2, γ_c = 1.85 kgf/cm^3).

Since this marine ranch utilizes the productive capabilities of nature, the amount of feed supply suffices to be one-half of the requirement, and there is the merit that water pollution due to excessive feed considered to be a problem in conventional fish breeding is reduced. There is much expectation of the increased provision of marine ranches as a means of overcoming the trend of decline in catches in coastal fishing seen in recent years

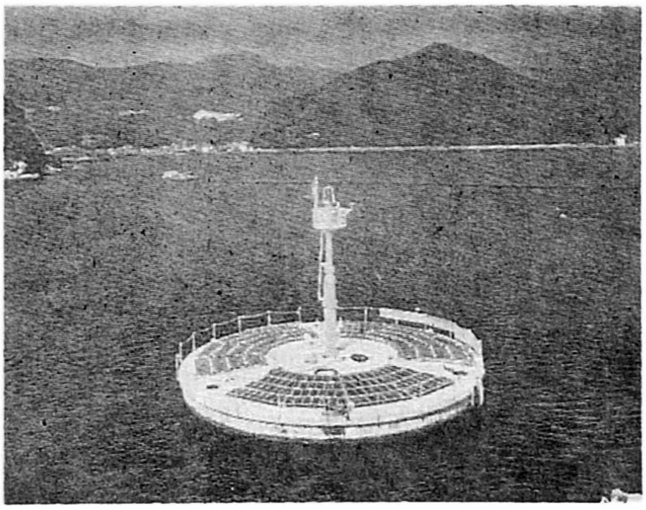
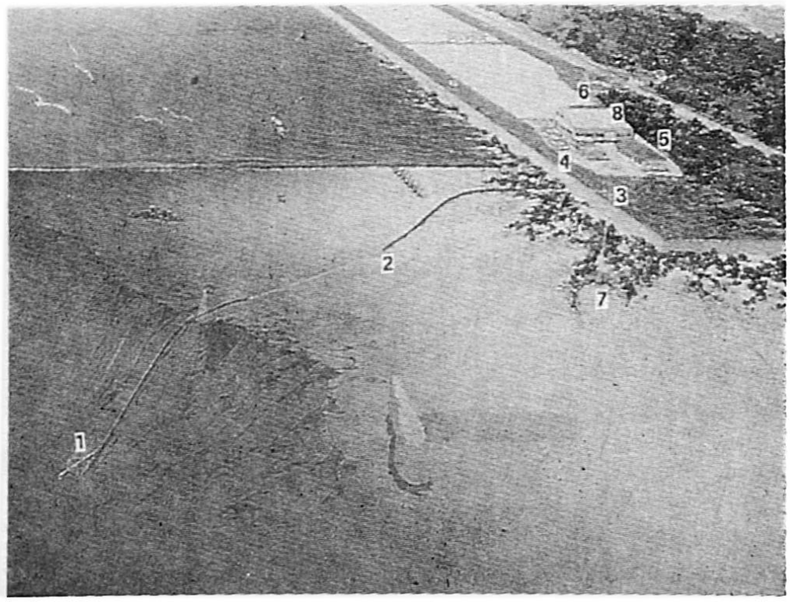


Fig. 9 Marine photovoltaic power generating system

3.2 Plant for Effective Use of Deep Sea Water

Deep sea water is sea water at depth exceeding 200m and has three features of being highly nutrient, very pure, and constant low temperature throughout the year. An experimentation plant for effective use of deep sea water taking advantage of these features was built in Kochi Prefecture in 1989. This plant, as shown in Fig.10 is composed of a deep sea water intake pipe (the high-density polyethlene pipe reinforced by steel wire), surface water intake pipe, pumping facilities, and onshore facilities, and is capable of supplying deep sea water from a depth of 320m and surface layer water from the sea surface in quantities of 460m^3/day and 500m^3/day, respectively, to the onshore experimentation facilities. Especially, the intake facilities of the deep sea water intake pipe (length 2650m, water depth 320m) takes advantage of the knowhow gained with an ocean thermal energy conversion plant constructed in the Republic of Nauru. It is possible for deep sea water and the surface water taken in to be freely mixed together at this research facility to create a breeding environment optimum for the object organisms.

Studies are being made for these characteristics of deep sea water to be taken advantage of for breeding of fishes and shellfishes and as a heat source focusing on the low-temperature properties of the water, cultivation of microscopic algae and refining of anticancer drugs using the algae for a broad scope of applications. Studies are also being made for use in storing of carbon dioxide, cleaning of sea areas, and sea water therapy. In Hawaii, where there are similar facilities, favorable results are already being attained in breeding of fishes and shellfishes, with the stage of commercial application drawing near.



1 Inlet of deep sea water
2 Suction pipe of deep sea water
3 Pump pit
4 Filter tank
5 Research laboratory
6 Experiment building
7 Inlet of surface sea water
8 Machine building

Fig.10 Experimentation plant for effective use of deep sea water

3.3 Seaweed Cultivation Floating Tower

Seaweed cultivation floating tower shown in Fig. 11, is a system for promoting breeding of fishes and shellfishes by stimulating growth of seaweed and phytoplanktons by casting sunlight on the sea bed where light does not easily reach. A demonstration test was conducted in Yamaguchi Prefecture in 1987 with brown algae as the object, while in 1992, proving tests for large water depths are being planned to be carried out in Oita Prefecture. The feature of this system is that the reflecting mirror of the light collector automatically rotates to follow the sun by means of a light sensor, with sunlight passing down through the cylinder of the buoy and being dispersed at the bottom by a concave lens to be cast on seaweed. This is a highly efficient system with little attenuation of sunlight.

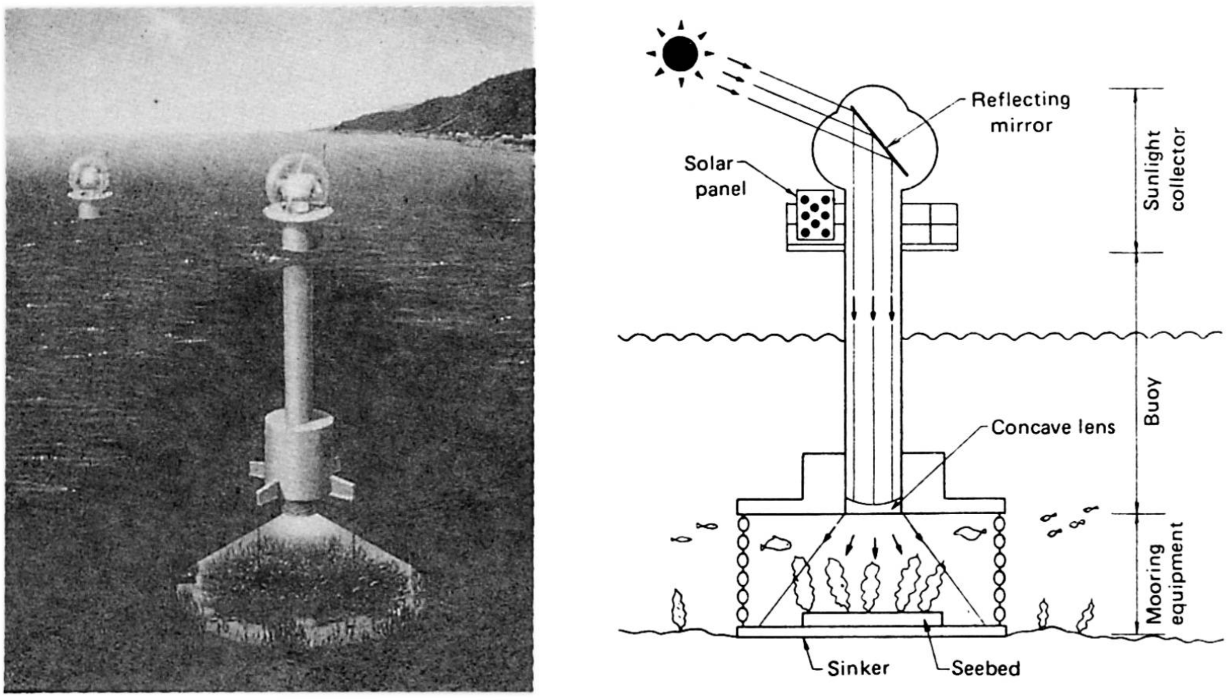


Fig.11 Image perspective of seaweed cultivation floating tower

4. COASTAL WATER CLEAN-UP SYSTEM

With the increase in waterfront development projects it has become necessary for positive measures to be taken for water quality improvement and preservation of sea areas, especially, large sea areas of enclosed nature. For this purpose, technology development is being done for sea water clean-up facilities and simulation of water quality variation prediction. Examples are given below.

4.1 Hybrid Clean-up Breakwater

A hybrid clean-up breakwater is a system consisting of a breakwater which also has the function of cleaning sea water. As shown in Fig.12, a wave arriving from the outer sea runs up the inclined wall of the breakwater and the sea water drops down on a gravel layer filling the interior of the breakwater, passes through the gravel layer, and flows out to the calm inner sea area. Dissolved oxygen in the sea water is increased during this process, while at the same time, organisms adhered to the gravel surfaces clean the water. This clean-up breakwater has low resistance to the passage of water so that water can get through by means of natural energy (tides, waves) or small-scale motive power, for low running cost. This is still at the experiment stage, but it has been clearly shown that substantial improvements in suspended solids (SS) levels, and improvement in chemical oxygen demand (COD) of approximately 30 percent can be achieved.

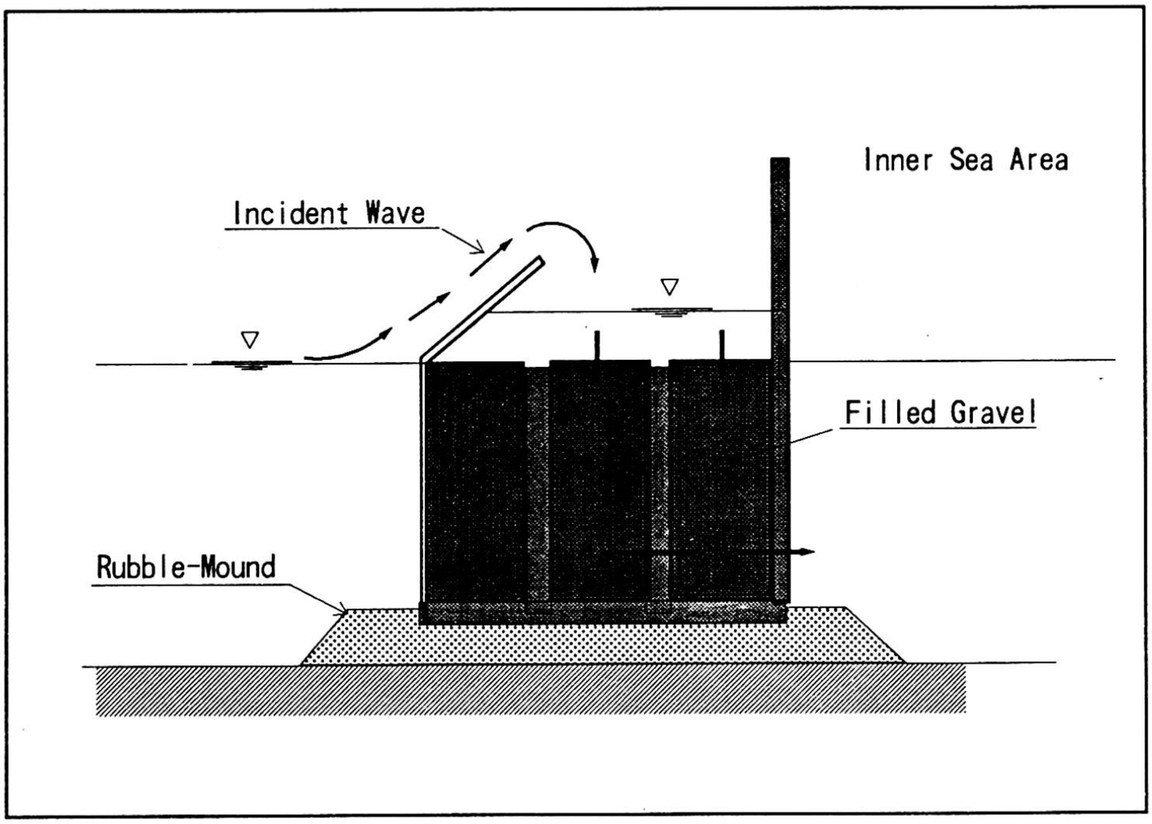


Fig. 12 Conceptual drawing of hybrid clean-up breakwater structure

4.2 Marine Environment Assessment Technology

By marine environment assessment technology is meant a system for grasping current states of water quality, beaches, etc., predicting future changes, or evaluating maintenance and control. This system is still in the process of development, but Fig.13 gives an example of an assessment made of the possibility of water quality preservation in case of a large-scale marine resort development in Nagasaki Prefecture, where a simulation was made of sea water exchange and distribution through tides in artificial channels. Such water quality prediction and techniques for simulation of seashore changes will become increasingly needed at the planning stage of marine development.

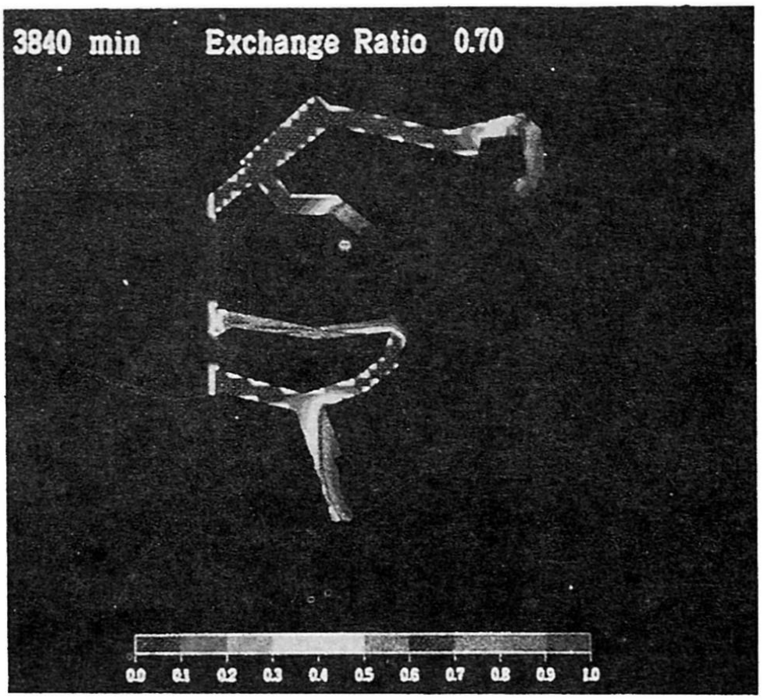


Fig.13 Simulation of sea water exchange distribution in artificial channels

5. CONCLUSIONS

The examples which have been given here are all of technologies or facilities with specific purposes or functions. However, the respective basic conceptions are not for only functional properties, or economic natures to be given first priority; they have the features of "creating an environment compatible even the least bit with the lives of people and ecology." From a technical standpoint, the principal aim is to overcome severe natural conditions such as great water depths, high waves, and very soft ground, but considerations are also given to ecological systems of sea areas. However, these measures are very inadequate as yet, and the technologies now available are still insufficient. For example, these short-comings must be met through introduction of advanced technologies such as biotechnology and new base materials, with these ingeniously combined to fit regional needs.

As a backup for this, it is indispensable for there to be R&D through cooperation between industry, government, and academe of civilian leadership type and cooperation between different fields of business. Lastly, at this time when the topic of the global environment has become a matter of international concern, the author wishes to state that it is his desire to deal with marine development carrying from the point of view of creative engineering friendly to the marine environment." It would be gratifying if this paper were to provide some kind of hint in contemplating marine development of the future.

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Submerged Tunnels, Examples of Marine Structures

Tunnels immergés, exemples de structures maritimes

Absenktunnel, Beispiele von Offshore-Bauwerken

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SUMMARY

Submerged tunnels have been constructed since the beginning of this century. They represent the wide range of engineering practice required for offshore structures, such as: deep water dredging and seabed preparation, marine transport and installation operations, large scale fabrication in drydocks and waterproofing. The paper explains these different items including the most up-to-date solutions.

RÉSUMÉ

Les tunnels immergés sont construits depuis le début de ce siècle. Ils mettent en oeuvre une grande partie des techniques de construction en mer par exemple: dragage en eaux profondes, préparation des fonds marins, transport maritime et opérations d'immersion, fabrication à grande échelle en cale sèche et imperméabilisation. Cet article expose ces différents problèmes et les solutions les plus récentes qui leur sont apportées.

ZUSAMMENFASSUNG

Absenktunnel werden seit Beginn dieses Jahrhunderts gebaut. Ihre Realisierung verkörpert einen breiten Umfang an Bauweisen und Technologien, die zur Herstellung von Offshore – Bauwerken erforderlich sind. Dazu zählen Nassbaggern in tiefen Gewässern und Unterwassergründungen, Überseetransporte und Absenkoperationen, sowie grossformatige Vorfertigung in Trockendocks und Bauwerksabdichtung. Der Beitrag verdeutlicht die einzelnen Bauabschnitte und beinhaltet deren neueste Lösungen.

1. INTRODUCTION AND HISTORICAL BACKGROUND

On request of the chairman of the scientific committee this paper has been introduced in the session on offshore structures of unconventional nature. It serves the purpose of demonstrating that many techniques required for such structures are not only proven art, but are also up to date controllable procedures. It further shows to many engineers present, not being familiar with these techniques, that submersed tunnels can be a solution to many communication problems.

Since the construction of the Michigan Central Railroad Tunnel in Detroit, completed in 1909, almost 100 submersed tunnels have been built. The idea to construct structures like bridgepiers, quaywalls and tunnels in a sheltered dock instead of in an exposed pit, being an obstacle to shiptraffic as well, at location, is even far older. It dates back to the end of the 18th century [1].
It is remarkable to notice that the way the Michigan tunnel was built, still represents the "American" way of constructing tunnels. This is characterized mainly by the way the construction takes place. The "american" or "Steel" immersed tunnels are constructed on a shipyard as a single or usually double steel hull, with some concrete for stability as a keel. This structure is than immersed, towed to location, and locally filled with usually non structural concrete, to obtain the required weight and soundness for immersion and in situ functions (Fig. 2).
The "European" tunnel dates back to 1936, when the Maastunnel under the shipping lane to Rotterdam was constructed. The authorities selected, amongst others, two 2-lane American type tunnels, leaving pedestrians and bicycles, temporarily on one or two of the four lanes available. A contractors alternative, involving just one huge reinforced concrete cross section, containing 2 x 2 lanes plus a double deck pedestrian and bicycle channel, was offered for a lower price and accepted. In this way the "European" or "Concrete" immersed tunnel was born. It was completed 50 years ago, in 1942 (Fig. 1).

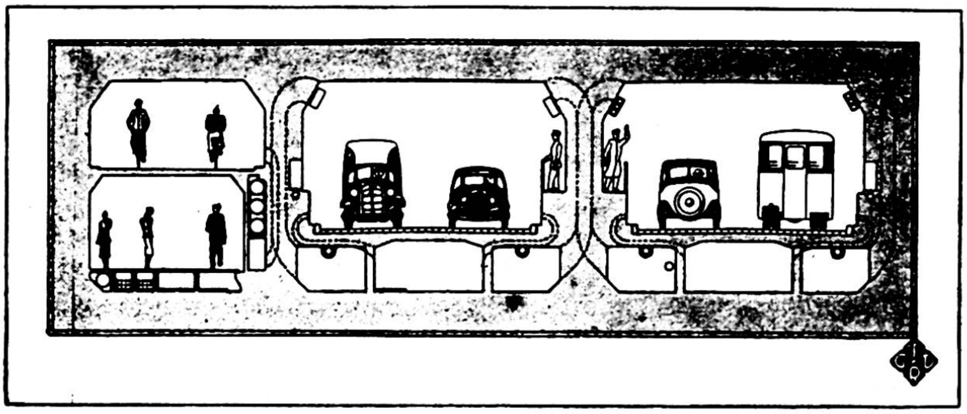


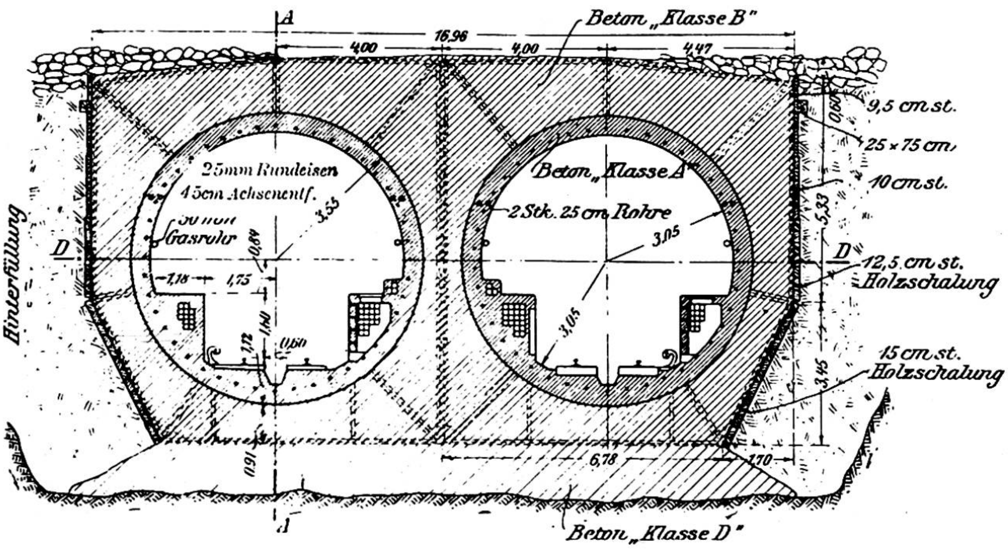
Fig.1 The Rorterdam maastunnel as constructed

At present 42 reinforced "concrete" tunnels and 34 "steel" tunnels have been constructed. 14 of them are constructed in Japan, where both systems are used.[2] Many more submersed tunnels are planned, such as in Greece, Ireland, Hong-Kong, USA, Uk and Holland.

2. BRIDGING, BORING AND IMMERSING

There are of course, like in every engineering discipline, rules of thumb to decide on methods to solve a problem; in this case, how to cross a channel. These rules are however, changing by the development of technology and new public requirements and values. The rules further provide a large area, where all three methods, to cross, have to be considered and evaluated on the basis of costs and quality.
Bridges have been replaced by tunnels because of the impact on shiptraffic. The height of the bridge above the waterline governs the allowable shiptraffic. Today, allowing offshore equipment or large sea going ships to pass, free heights are required of 60 meters and over.
The introduction of an opening span reduces the traffic capacity of the bridge not just during the time of being up, but also before and after the actual opening time. As traffic usually increases, an opening span bridge is no sound solution that will last for long, downstream of cities with a harbour.
The introduction of bridgepiers in shipping channels is a potential danger to shiptraffic that can be quantified quite well with modern simulation techniques.

Last but not least bridge approaches consume scarce space in usually dense industrious areas. All of this makes bridges comparatively less attractive compared to tunnels in a large range of circumstances (Fig. 3).
Bored tunnels need substantial cover underneath the mudline, which usually dictates an overlength of tunnel, especially when the slopes are of limited steepness. They further require suitable soil for drilling to reduce substantial construction risks. As more techniques become available, the feasibility of drilling tunnels increases. Bored tunnels further require substantial length compared to immersed tunnels, in order to depreciate the investment in the shield over sufficient length, to arrive at a competitive price per unit length.



<u>Fig.2</u> Cross section: Michigan Central Railroad tunnel in Detroit

Immersed tunnels are quite flexible in cross section, they only require a dredged trench to be installed and a simple drydock, sometimes located in the future approaches, to be constructed.
All of this explains that immersed tunnels are of increasingly interest for the solution of traffic communication within and around cities. From the number of

tunnels, mentioned in chapter 1, 10 have been completed during the last 5 years. Although no real offshore immersed tunnels have been constructed yet, many plans are under consideration. The Channel tunnel was just not built as an immersed tunnel as the limited width in cross section, being a raillink only and the favourable soilconditions for boring, just ruled out an immersed tunnel. For the Great Belt Link in Denmark, things were different. Although an immersed tube tunnel was offered as more expensive and initiated the potential risk of dredging contaminated soil, it presented less risks compared with a bored tunnel through the geologically complex soilstructure.
The bored tunnel was selected, but presents actually major escalations in time and costs. This may influence the decision process in future offshore tunnelling jobs.

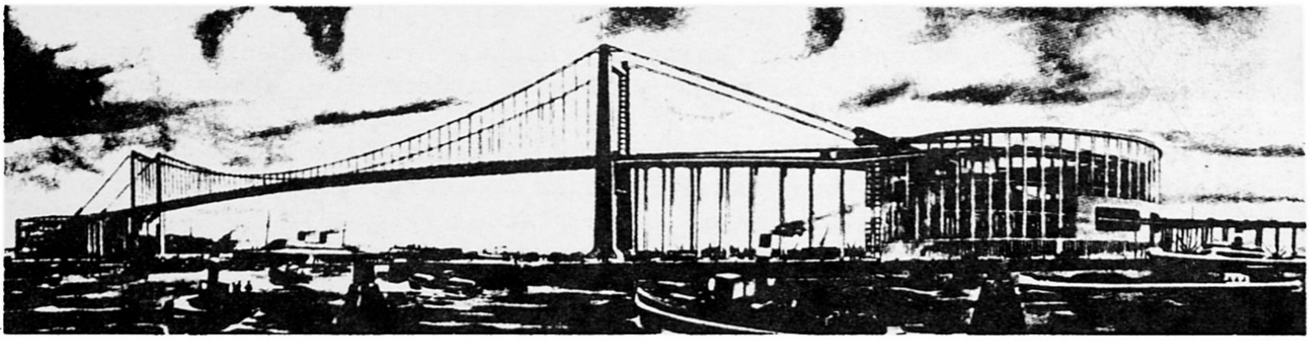


Fig.3 A bridge with spiraltype access structures as proposed for the Maastunnel in Rotterdam.

3. FOUNDATION

Although immersed tunnels, like most offshore structures, float temporarily, they are to be installed on a proper foundation.
It is here where all kind of techniques are used. Tunnels are founded on piles, on a pre-installed gravel or rock beds and on provisional foundations, to be replaced by undergrouting or underbase sand jetting.
This variety of engineering solutions to provide a sound foundation for the immersed tunnel is not only a consequence of geotechnical circumstances at the tunnel location, but also addresses the structural system of the tunnel in longitudinal direction.
The "American" tunnels are usually founded on a gravel or rock bed, being layed on top of a usually quite stiff bottom of a dredged trench. Such a bed, having a minimum depth, provides obviously sufficient elasticity, to safeguard acceptable foundation reactions for tunnelelements of lengths and size as installed in the USA. There is only little information on tolerances being measurable and consequentially tolerable using this method. The record is good and does not show any major problem. The method has been used in Europe as well in a limited scale, especially for service tunnels where uneven subsidence did not raise major problems.
Far more popular in Europe is the method of providing a temporary foundation by means of concrete tiles, on the bed of the dredged trench, on which the tunnel is temporarily founded and geometrically positioned up to quite fine tolerances by means of jacks. The remaining space in between the tunnelbottom and the bed of the trench is than filled with sand. This was originally done by jetting a mix of sand and water from the side of the tunnel through a system of pipes, from which two served the supply of sand and one caused suction in order to

drain the superfluous water (Fig. 4).
At present, the method of just injecting a sandflow through the bottom of the tunnel became more popular, as it avoids any disturbance of shiptraffic and can be applied fast after immersion. This has the advantage, that silt has none or anyhow quite reduced changes to settle in the trench before the final foundation is realized. The sand flow method is based on the principle that velocities in and around a cone of sand being built up underneath a hole in the tunnelslab on the bottom of the trench are such, that the sand settles in a proper way on the outside of the cone. With a centre to centre distance of around 10 m for a 1 m thick void, a sufficient foundation can be realized (Fig. 4) [4].

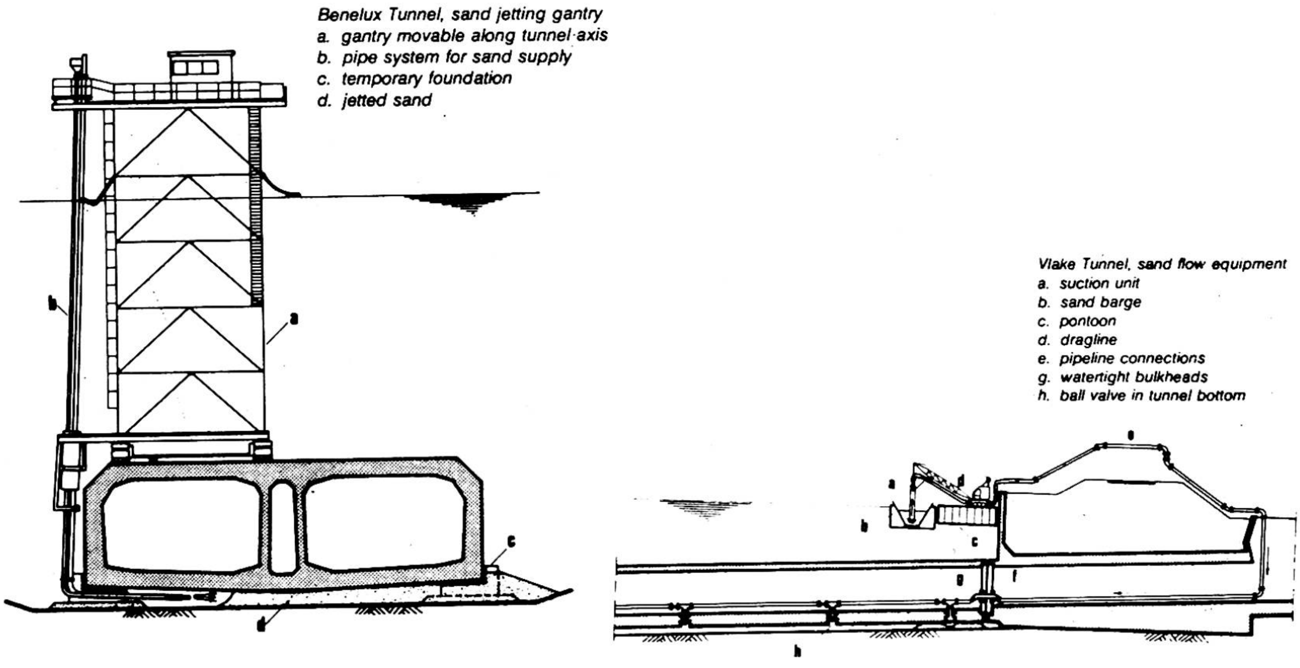
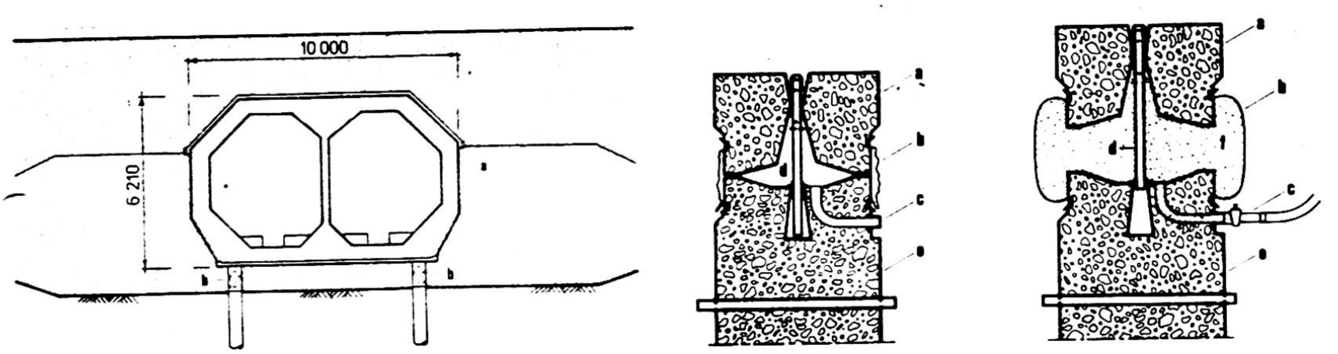


Fig.4 Sand jetting equipment and sand flow equipment in action.

On locations where poor soilconditions would cause unacceptable uneven settlement in the tunnel, or above the tunnel at covered parts outside the actual river, foundations on piles have been provided. This was for instance the case for the Rotterdam subway line (Fig. 5). To meet tolerances, a system was developed with jacks on top of the pre-driven piles.
It should be realized, that for most offshore structures, these methods will not provide a valid solution, as the ratio of horizontal reaction over vertical reaction is basically larger, because of wave forces acting on the structure. Therefore either foundations directly on the seabed or on a prepared seabed are used. In case this is not possible for technical reasons, a skirt is provided around the perimeter and across the bottom of the structure is provided. This skirt penetrates into the seabed. The remaining space is filled by injection of materials that can be mixed with seawater, such as cement and silicate, giving smooth flow characteristics.



Rotterdam Metro Tunnel, cross-section
a. concrete tunnel structure
b. foundation piles with adjustable head

Rotterdam Metro Tunnel, adjustable pile head
a. pile head
b. nylon sleeve
c. grout pipe connection
d. guide rod
e. prefab pile section
f. grout injection

Fig.5 Cross section of Rotterdam subway tunnel and piling system

4. WATERPROOFING AND DURABILITY

A most important aspects of marine structures is the waterproofing and durability. Here again immersed tunnels offer a large record of satisfactory behaviour. There seem to be quite some different approaches towards waterproofing, but most of them just exist, based on historical background.
In the first place the "American" type tunnel had a steel lining. This was not essentially for watertightness or durability, but was there as a consequence of the fabrication method and the structural system. But being there, it was taken for a waterproof hull as well. Many tunnels and other marine structures, including the above mentioned Maastunnel were consequentially provided with a steel or carbohydrants based skin, to provide watertightness.
The construction of tunnels and parts of tunnels by means of pneumatic excavated caissons raised some concern about the resistance of waterproof layers on the outside walls against the soilfriction during placing. It was decided for that reason, to omit the waterproof layer in some cases in Holland and Germany. This decision was further supported by the fact that existing tunnels with watertight coatings were leaking anyhow, because of failing details in joints and details of penetrations. Such leaks were usually quite difficult to trace at their source and to stop.
Since about twenty years now, tunnels in the Netherlands are constructed without an extra watertight layer. The performance is extremely well and can be an example worldwide, provided that a few things are noticed. This concerns concreting including treatment, detailing of joints and penetrations and the provision of back up measures where relevant.
When the concrete has to be the only and consequentially reliable way of defense against leakage, the whole process of concreting with all its aspects has to be controllable in order to provide the required reliability. This has been improved in several ways during the last decade, especially by the ability to study all aspects influencing the hardening process of concrete in one computer model [5]. These aspects concern mix-design, hardening parameters like cooling and heating, environmental aspects like temperature and wind and construction parameters like formwork and time of stripping.
Working with such a model, stresses during the hardening process of concrete can be predicted and controlled, enabling us to select an effective way of construction in view of costs and durability (fig. 6).

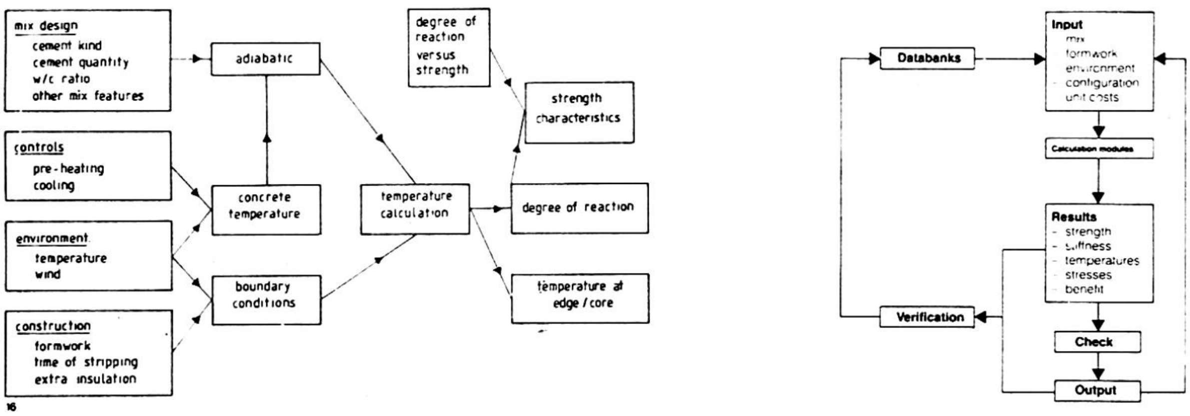


Fig.6 Relation in between construction parameters and concrete characteristics. Flowsheet of a computerprogram analyzing this.

With concrete being sufficiently impermeable by good design, practice and control, only the details, such as construction joints, joints to be provided for expansion and rotation and joints to link independently immersed units together are left for attention.

For construction joints good practice, such as jetting fresh stripped surfaces, is quite common and satisfactory. Joints in between independently immersed elements are usually carried out with double waterstops. Most remaining trouble in the past has been caused by joints to provide expansion and rotation freedom within one tunnel element. It is common practice today, to take special measures during pouring of concrete around such joints, to avoid honeycombing and air entrainment, in the vicinity of the waterstop in the joint. On top of that, means are provided to inject possible leaks in between the concrete and the waterstop anyhow, with some back up for injection after final installation (see fig. 7).

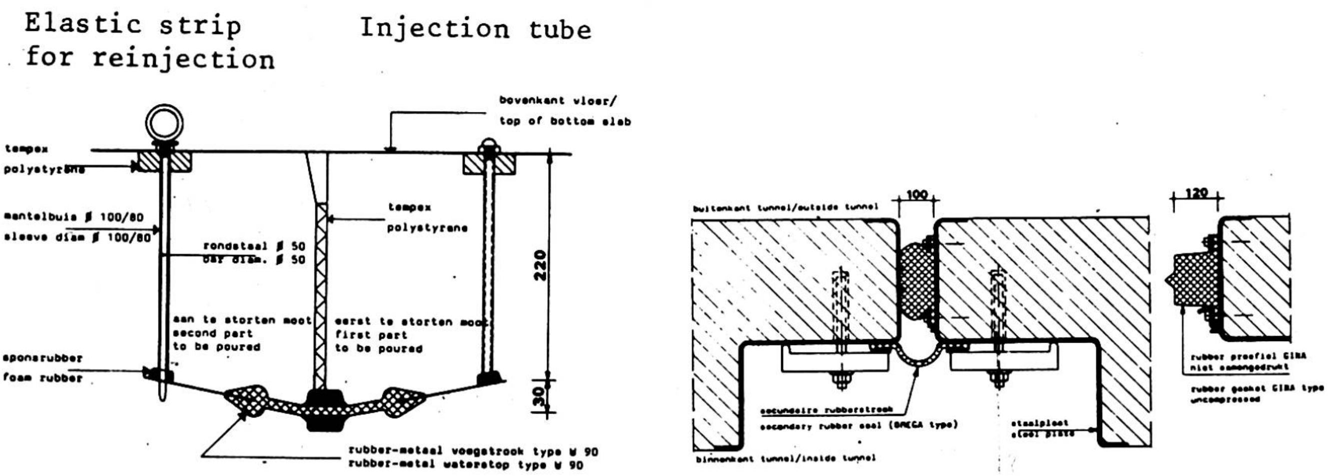


Fig.7 Joint details for joints within and at ends of submersed units.

It can be concluded that watertightness for concrete marine structures is no problem anymore, provided that sufficient know-how is being made available and sufficient quality control is being applied to the job. As durability of the structure requires more or less the same effort, it can be concluded that this can be assured in the same way.

5. STRUCTURAL SYSTEM

The American type tunnels have always been solid structures in longitudinal way for the length of one immersed unit. Connections in between units have also been designed quite stiff, not allowing rotations.
In Europe, where tunnels have been constructed on soils of less stiff nature, the concept of hinges within the units at distances interfering with the casting joints came up and is commonly used. The elements are made stiff by prestressing from bulkhead to bulk-head during float up, tow and immersion. After installation the prestressing cables are removed and the element can follow the differential settlement of the riverbed without forces being introduced in longitudinal direction of the tunnel element. A secondary benefit of this system is the fact, that less than minimum reinforcement in longitudinal direction can be applied in the tunnelelement as no mechanism to cause brittle failure in longitudinal direction is present. In some cases, the temporary prestress is only provided in the area of the joint. In such a case the longitudinal reinforcement should of course have a minimum value as required for membrame tensile stresses in the cross section.
An other aspect of the structural system for reinforced concrete tunnels is the internal force distribution in transverse direction. As shear usually governs the design of the cross section, several systems are available to decide on dimensions of the cross section. In case of low waterdepth, say less than 15 m, or small spans as in case of railtunnels or two lane tunnels, just normal reinforced concrete plate type structures can form roof, bottom and sides of the tunnel. In case of larger depths and wider tunnels, with 3 lanes, sizing roof and bottom will not result anymore in tunnels of minimum cross section still being able to float. In such cases a selection has to be made in between a larger cross section, requiring more concrete, dredging and tunnellength, or solutions with transverse prestressing, providing stirrup reinforcement in roof and bottom or bent up bars in roof and bottom. It may be clear, that an approach for an effective solution now requires more partners in the construction process than just the designers.
Such choices, to be obtain the most effective structure, in a discussion in between designers and constructors, are quite common and even required during the design of offshore structures.

6. CONSTRUCTION FACILITY

Large offshore structures as well as immersed tunnels have been constructed in both existing shipyards and dedicated "polder" type drydocks. Availability, soilconditions, local law, and an increasing impact of environmental aspects govern the choice of a construction facility for a specific job. It is quite possible in certain cases where more tunnels have to be built in a small area, that the same facility will be used several times. In Holland, the Hijnenoord dock, in the vicinity of Rotterdam, was used for seven immersed tunnels, since its construction in 1966.
Sometimes tunneldocks are provided temporarily in the future approaches to the tunnel. This reduces extra dredging work in case of small projects and low draft access to the tunnel trench.
Just as for offshore structures, parts of ship repairdocks, or abandoned drydocks, are sometimes made available for the construction of immersed tunnels. Fast construction becomes quite important in that case.

7. IMMERSION SYSTEMS

Whereas the construction of the elements for an immersed tube tunnel is still of a comparatively conventional character, the marine operations, containing float up (will it float ?, etc.), tow (can it be towed regarding draft, tide, waves and current, etc.) and immersion (will stability be sufficient in all stages; is the time frame sufficient, etc.) are not.
Recent practice has shown, that it is quite useful to consider the skills required for the immersion procedures as an integral required experience in the design and construction of an immersed tunnel job. This means that immersion and the preparation of immersion has so many effects on the total construction of an immersed tunnel, that it can not be considered as a subcontract in the whole procedure.
Apart from design and integration of embedded items for float, tow and immersion, of the elements, unconventional disciplines like weight control, required strength for operations and possible impacts during operations are to be considered.
Beyond this, two basic design philosofies are valuable for the selection of the main parameter of the immersion system. The tunnel elements may have sufficient buoyancy for float and tow and will have to be ballasted for immersion and provisional installation. This method requires quite light immersion equipment, but involves substantial work in the elements before, during and after installation.
The other method, as quite frequently used in the USA involves floating up, towing and immersing tunnel elements without any floating capability. The equipment is consequentially more expensive, but savings are made by having no ballast equipment for storage and pumping within the elements and having no need for the installation of ballastconcrete after installation.

8. CONCLUDING REMARKS

It is clear from the few aspects being touched in this paper, that there is not a thing like an ideal design for a submerged tunnel. Project parameters, like draft, type of traffic, length and depth will provide different challenges to the designers. The design parameters, like structural system, waterproofing and foundation still offer a wide variety of solutions. Both project and design are having an impact on the construction method.
Quality control, especially where information technology plays a role, provides means of simulating construction processes, like marine operations for towing and immersion, like concrete hardening for strength and stress development and like surveying for weight control. This will reduce risks and provide new technologies for faster construction of cheaper and more durable structures.
This is the case in the offshore industry as well. The present record of immersed tunnels in the world proofs it.

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Special Session 3

Renewable Energy Structures

Constructions en vue de l'utilisation des énergies renouvelables

Konstruktionen zur Nutzung der wiederverwendbaren Energien

Organizer:	Jörg Schlaich, Germany
Chairman:	O.P. Goel India

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Large Scale Solar Power Stations in India

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Prof. Rao, born 1936, received his Dr. Ing. degree from the Technical University Munich. He is a Professor of Civil Engineering since 1972 and was Head of the Structural Engineering Laboratory IIT Madras from 1973 to 1984. Prof. Rao is a leading expert in India in the design of tall structures such as TV towers and Cooling Towers.

SUMMARY

Need for immediate action for the setting up of large scale solar power stations in tropical countries such as India is highlighted. Characteristics of three different systems, already used elsewhere, have been compared with the possibilities existing for utilisation in developing countries. The Solar Chimney (atmospheric power tower) has been identified as a good choice for the given conditions. A proposal is suggested for working out detailed designs for a 30 MW Power Station in India.

1. INTRODUCTION

Out of the different options we have as Renewable Energy Sources, Solar Power is the most abundantly and most widely available Renewable Source of Energy. During the last 2 or 3 decades when extensive work has been going on for tapping the Renewable Sources of Energy it has been realised quite early that such attempts can be broadly classified into two categories namely:

(i) Schemes for SMALL SCALE decentralised power generation

(ii) Schemes for LARGE SCALE centralised power generation

Because of the generally low efficiency of the systems making use of renewable sources of energy initial work in the area has been mainly on small scale systems. Only recently efforts are being directed more and more towards setting up of large scale plants, for example, as in the case of wind mill forms for Wind Energy; Distributed Collector Systems, Centralised Receiver Systems and Solar Chimneys for harnessing solar power.

2. LARGE SCALE SOLAR POWER GENERATION

The three currently available large scale power generation systems using solar energy are:

(i) Distributed Collector Systems (DCS) using parabolic trough collector systems

(ii) Centralised Receiver Systems (CRS) using large number of heliostats with a large scale solar tower at the middle

(iii) The Solar Chimney (Atmospheric Power Tower), using large area at the base of chimneys for collection of heat from solar radiation

When options available are more than one there is a natural tendency amongst the scientists and technologists to start discussing which of the alternatives is the best one. It is no doubt a healthy form which leads to rational decisions leading to most economical solutions. We the inhabitants of this world are, however, today unfortunately not in a position to allow ourselves enough time for such an extended discussion. As per reasonably accurate forecasts made by experts in the field the conventional energy sources available on our planet - Fossil Resources except coal which is a highly pollutant fuel - are to get completely exhausted within the next to 30 to 40 years (Table 1). Hence the urgency of the situation demands that we make use of all methods of generation rather than losing time on discussing which system is to be used. A parallel for such a situation exists already in

India where the quality of coal available everywhere is so poor that while operating the thermal power stations in India it is no longer discussed for about which coal is to be used. Coal from all sources is used as per the availability. Thus there is a strong case for trying out all available methods for centralised solar power generation in developing countries like India which happen to be in the tropical zones and are thus endowed with large amounts of solar radiation.

3. CASE FOR SOLAR CHIMNEY (ATMOSPHERIC POWER TOWER)

While there is a strong case for introducing all available proven systems in India, even a cursory evaluation of the available systems seems to indicate that the system based on the Solar Chimney has got certain advantages for a country like India. The Distributed Collector System using Parabolic Trough Collectors heating up a suitable fluid carried through pipes along the axes of the collectors makes use of a very sophisticated technology (because the troughs have to track the sun) and is heavily dependent on foreign exchange requirements. Also the maintenance of such a system seems to require very sophisticated establishments. The technology used in Solar Tower (Centralised Receiver System) is even more delicate and sophisticated because it requires very accurate controls which keep moving the heliostats around two axes to track the sun's movement for most efficient energy conversion. On the other hand the principle used in Solar Chimney is very simple and construction is so robust that the plant can be set up very easily with technical knowhow and facilities already available in developing countries.

Yet another, very important point in favour of the Solar Chimney is that unlike the other systems which depend only on direct radiation, the Solar Chimney can operate even under diffused radiation. The natural storage medium - the ground - ensures that the plant can operate at a constant rate until well into the hours of darkness. The main advantages of a Solar Chimney can be summarised as given below [1] :

- It makes use of global solar radiation, including diffuse radiation when the sky is overcast
- The natural storage medium - the ground - a 24 hour operation possible with large-scale installation
- Aside from the turbine and generator there are no moving parts or parts that require intensive maintenance
- No water is required to cool mechanical parts
- It features a simple, low-cost design utilizing know-how and materials that are also available in Third World countries (glass, concrete, steel)

A high proportion of the costs is accounted for by work that is simple and can therefore also be done by local labour in developing countries. This would benefit the local labour market while at the same time helping to keep the overall costs down.

4. THE INDIAN SCENARIO

The total installed power generation capacity in the country as on date amounts to about 65,000 MW in which as much as about 70% comes from Thermal Power Stations. In the next five year plan (1992 - 97) this power generation is to be augmented by another 35,000 MW out of which again as much as about 32,000 MW is to come from thermal power stations. Unfortunately the coal quality available in India is so poor that the ash content is sometimes as high as about 40 %. This has resulted in a severe environmental problem. The fly ash production from thermal power plants as on date in India is estimated to be about 40 million tonnes per year and is expected to reach a staggering figure of about 80 Million tonnes by the end of the century. Disposal of this industrial waste is going to be a serious problem.

Furthermore, as coal is available only in Central India region, it has to be transported over large distances to places where thermal power plants are located. The already meagre transport facilities available in India - particularly by rail - are heavily strained with this additional task of movement of coal. In fact the country has embarked upon development of suitable port facilities at a number of locations along its long coast line around Southern India to serve predominantly, if not exclusively, the purpose of feeding the thermal power stations at different locations with coal supplies.

Large scale solar power generation will contribute to mitigate the problems discussed above. For Solar Power generation using the concept of Solar Chimney (Atmospheric Power) the Rayalaseema region in Andhra Pradesh or the Rajasthan Area (Thar Desert) seem to be two of the suitable sites (Fig.1). Out of the two, Rayalaseema seems to be better because most of the region is rocky and barren and thus ideally suited for the Solar Chimney System of operation. For making use of the economies that accrue depending on the size of the plant, a plant with a minimum capacity of 30 MW seems to be desirable. Such a plant is estimated to require

(i) a chimney of a height of about 650 m and diameter of about 45 m and

(ii) a collector area of about 4 square kilometers at the base of the chimney

In India we are already building T.V towers and chimneys upto heights of about 350 m. So building a tower of a height upto 650m should not present insurmountable problems in India. In fact this can be carried out without any great difficulty with the expertise already available with a number of Indian Construction Companies.

To be able to find 4 to 5 square kilometers of area for the collector area in the regions mentioned should also not be a problem because large tracts in this region are

(i) mostly barren with very little habitation and

(ii) subjected to intensive solar radiation through all seasons of the year.

5. SUGGESTED PLAN OF ACTION

Well established and well documented information is already available about the working of a pilot plant established at Manzanares in Spain [2], [3]. Using these already established design criteria, a site specific design should be worked out IN FULL for one of the selected locations in India. The design has to be in great detail taking into account actual realistic data about

(i) metrological and geotechnical parameters of the site chosen

(ii) Material and construction practices and technologies suitable for Indian conditions

The designs should be so detailed in nature that they permit an immediate cost evaluation of the project. Then these costs could be compared with costs of conventional thermal plants but giving proper Weightage also to such additional factors like Costs of environmental protection, waste disposal, transport bottlenecks etc associated with conventional thermal plants. If necessary organisation like United Nation and World Bank could be approached not for financing the initial design costs but also for assistance for the erection of the plant itself according to the finalised design.

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TABLE 1 : AVAILABILITY OF FUELS

FUEL TYPE	MAY LAST FOR A FURTHER PERIOD OF (YEARS)
1. OIL RESERVES	45
2. GAS RESERVES	55
3. URANIUM	80
4. COAL *	250

* (Mostly of very poor quality; particularly pollution intensive)

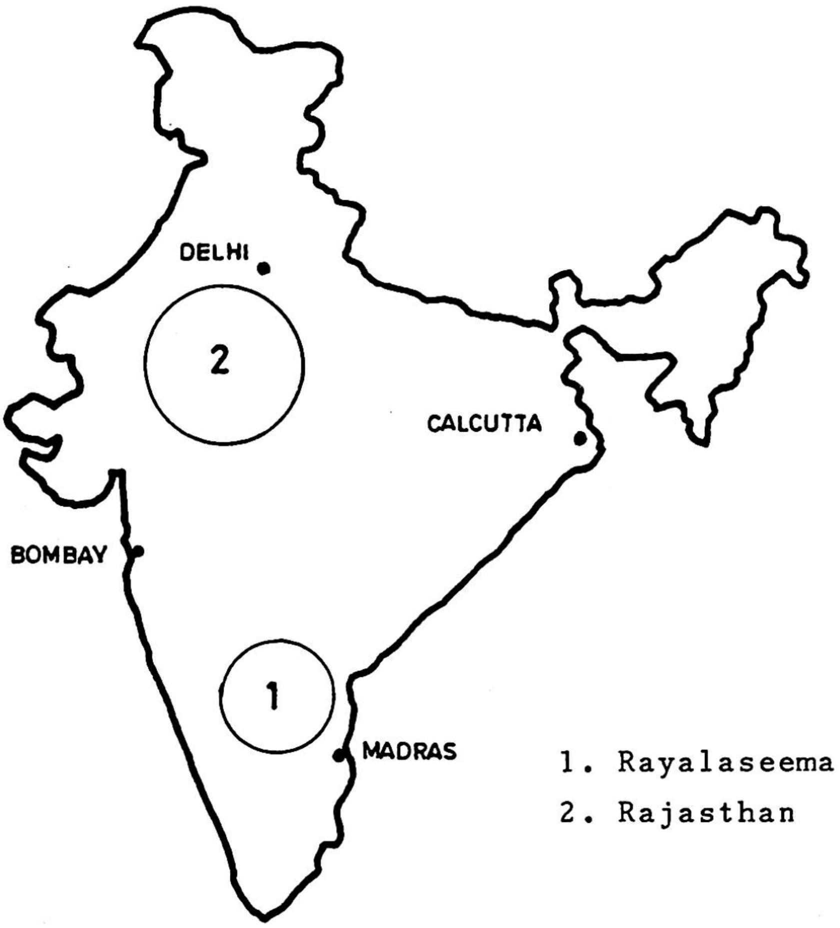

Fig.1 : Large Scale Solar Power Generation in India - Possible Locations

Seminar 1

Creative Design as Reflected in Practical Applications

Idées créatrices dans le projet et applications pratiques

Kreative Entwürfe und Anwendungsbeispiele

Organiser : Ch. Vos
The Netherlands

Chairman : G. Breitschaft,
Germany

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Future Horizons for Concrete Construction

Perspectives dans la construction en béton

Neue Horizonte im Betonbau

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SUMMARY

The paper reviews significant trends in concrete and discusses these in relation to materials and construction techniques. The importance of education and training at all levels, to spread a better understanding of concrete, is stressed. Future directions are signposted in terms of high performance concrete, better liaison between design and construction and new materials.

RÉSUMÉ

Cette étude analyse les tendances significatives du béton et les examine en fonction des matériaux et des techniques de construction. Elle souligne l'importance de l'éducation et de la formation à tous les niveaux, en vue de propager une meilleure compréhension du béton. Elle indique les voies futures à suivre sous forme de bétons à hautes performances, d'une meilleure liaison entre les projets et les réalisations, ainsi que de nouveaux matériaux.

ZUSAMMENFASSUNG

Der Beitrag diskutiert herausragende Trends im Betonbau, wie sie besonders im Bereich der Werkstoffe und der Verfahrenstechnik zu sehen sind. Ausbildung und Schulung zur Verbreitung besserer Betonkenntnisse sind auf allen Ebenen dringend geboten. Zukunftige Entwicklungen wie Hochleistungsbeton, neuartige Werkstoffe und eine bessere Verbindung der Projektierung mit der Ausführung werden skizziert.

1. INTRODUCTION

Primitive forms of concrete have been used in construction for at least two thousand years. However, the material, which engineers today identify as concrete, dates back only to the middle of the 19th century and began to achieve wide structural application about a hundred years ago. Around the turn of the century a few engineers began to appreciate the exciting potentialities of reinforced concrete and the freedom of design thereby created. Since that time, advances in the design and service performance of concrete structures have depended upon developments not only in the basic material properties of concrete but also in steel (e.g. leading to the practical realisation of prestressed concrete) and in plant and techniques of construction.

My own formative years as an engineer coincided with the emergence in post-war Europe and elsewhere of concrete as the dominant structural and architectural material for the latter half of the 20th century. During the 50's and 60's there was a dazzling succession of notable achievements and applications of concrete in structures. At this time prestressed concrete was making its first great strides en route to becoming the preferred material for medium span bridges; the architectural trend was to employ concrete as the dominant facing material, both inside and outside buildings. Most engineers thought that provided a reasonable job was made of mixing and placing, concrete could do no wrong - it was an adaptable material with a long maintenance-free design life.

Moving into the 70's and 80's, there has been a succession of problems with concrete construction. Most of these problems were avoidable but there is no doubt that they have undermined confidence. This has caused engineers to be much more careful to avoid mistakes and misuse of the material likely to lead to future difficulties in service and has persuaded architects to prefer brick to concrete as a facing material. This paper looks ahead to gauge the likely impact of recent developments in concrete in terms of both the material and the ways in which it is being employed in the construction of buildings and bridges.

Amongst the traditional constituents of concrete - Portland cement, water and aggregates, cement has changed with time to some extent because of trends in the manufacturing process - together perhaps with a perception by cement producers of user demands for higher strength concrete. Such changes have been well documented in the U.K. [1] and are probably representative of the situation in most other countries. However, other more significant trends have also been taking place over the last three decades

- development of cement-replacement materials and superplasticisers
- enhanced interest in the long-term performance of concretes
- greater collaboration between designer and constructor
- application of high strength concrete in practice.

These trends are closely inter-connected and will be discussed under two headings:

A - Materials for Concrete
B - Construction Techniques

2. MATERIALS FOR CONCRETE

2.1 Cement-replacement Materials

Initial moves to replace a proportion of Portland cement in concrete arose principally from a search by industry to find uses for waste materials. Can we use it in concrete? - seems to be an early question which arises for waste products. However, research has shown that three such materials have beneficial effects in concrete.

- Pulverised fuel ash (pfa, often known as fly ash) a waste product from coal-fired power stations has been widely used typically replacing 20-30% of Portland cement, the presence of pfa slows down the early growth of strength of concrete; if properly cured, it will enhance the final strength and decrease the permeability of the concrete.

- Ground granulated blast-furnace slag (ggbs) from iron production has also found extensive application. It can enhance strength but has particular merits in lowering the heat of hydration in large pours and in improving the resistance of concrete to sulphate attack.
- Condensed silica fume (csf) which stems from silicon production is a very fine material (also known as micro-silica) which can, with care, produce very high strength concrete.

These products can be of significant value in concrete structures but all require particular attention in placing and curing. The workability of concrete mixes containing csf poses special difficulties if placing is not carried out expeditiously. Without adequate curing for at least three days [2] the potential long-term strength and durability of concrete which includes pfa, ggbs or csf will not be achievable.

2.2 Superplasticisers

The development of chemical admixtures in order to modify the early behaviour of fresh concrete has long been a feature of the manufacture of concrete elements. Retarders and accelerators have been used when appropriate to modify the setting process. Plasticisers are employed to improve the flow properties and help the placing of concrete in complex shapes, around formwork or in difficult environmental conditions. The advent of superplasticisers [3] which have dramatically enhanced flow properties and workability without sacrifice of strength, has been a great boon in concrete construction. It has led to inherent improvements for in situ concrete and has made more possible the practical use of all the cement-replacement materials described above. Concrete containing a superplasticiser can be pumped for long distances (vertically or horizontally), revolutionising work on confined construction sites.

2.3 Permeable Formwork

Concrete engineers constantly emphasise the importance of the exposed surface region of a structural element. The durability of the element relies upon the ability of this region, 15-20mm thick, to resist the ingress of air, water, chlorides, sulphates and other deleterious substances. Attention has been drawn to methods of improving the surface region and various coatings and surface treatment have been tried, with varying success. The introduction of a proprietary system of permeable formwork, which effectively drains off surplus cement paste and air from the surface, has provided a means of permanently improving the surface region by eliminating blow holes and lowering the porosity and permeability of the formed surface of the concrete. Recent research [4] has shown the effectiveness of this technique and it is to be hoped that widespread use will not be hindered by high cost.

3. CONSTRUCTION TECHNIQUES

Closer collaboration between designer and contractor has led to major improvements in concrete structures and significant advances in the economics and speed of construction.

3.1 Fast Track Construction

There have been major projects in large cities such as Chicago, Hong Kong and London which have concentrated upon 'fast track' concrete construction. For example in London, the Broadgate and Docklands projects have provided opportunities [5]for the application of well-designed combinations of precast and in-situ construction and the first major use in Britain of post-tensioned (bonded and unbonded) concrete floors. Information technology has also played its part; the availability at comparatively low cost of sophisticated software and hardware now permits rapid and accurate analysis and design of complex structural frames. Thereby, over-conservative designs can be eliminated.

3.2 High Performance Concrete

The United States has led the world in the employment of high strength concrete for tall buildings, adopted primarily to reduce the excessively large column dimensions needed for conventional concrete. Thus in the concrete building which is currently the tallest in the world (Fig. 1) - 311 South Wacker Drive in Chicago - it is reported [6] that concrete of 110MPa cylinder strength was used for the base columns and 72MPa higher up the building. Other U.S. buildings have used an even higher specification for a cylinder strength of 130MPa.

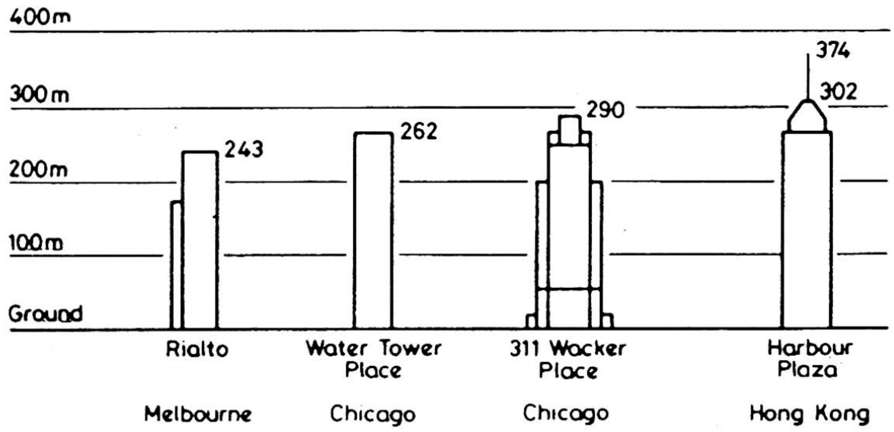

Fig. 1 - Tall buildings of concrete construction [7]

In Hong Kong, 60MPa cube strength concrete (equivalent to about 48MPa cylinder strength) is being used in the 78 storey Harbour Plaza building currently under construction. On completion it will be the tallest reinforced concrete building in the world (Fig. 1). The use of high strength concrete leads to the idea, identified by several authors, [8, 9], of high performance concrete which incorporates three parameters:

- high compressive strength
- high durability
- high deformational (or dimensional) stability.

All three parameters can be of importance for key structures. In tall buildings, high strength should go hand in hand with high deformational stability or stiffness. A high value of modulus of elasticity of concrete will reduce sway and should be included in the specification; however, brittleness can be an undesirable characteristic of some high strength concretes. High durability will also be required in harsh environmental conditions. In North Sea offshore concrete structures for the oil and gas industries, the demand for a concrete possessing a high compressive strength and adequate durability to combat the hostile environment led to the specification not only of a high strength grade but also of maximum values of permeability. This form of specification was repeated even more stringently for the Channel Tunnel. Nevertheless, no simple, rapid test of concrete permeability has been adopted as a standard in Britain or elsewhere; thus permeability monitoring tends to be very limited during the production stages of such projects. This issue needs to be resolved quickly if the specification of permeability is to have any real meaning beyond the stage of mix design.

For concrete bridges all three parameters become essential. For example, match-cast segmental construction, which has proved to be an outstandingly successful technique for multi-span prestressed concrete bridges lends itself to (and benefits from) the use of high performance concrete. Deformational characteristics assume importance - a high modulus of electricity, low creep and low shrinkage are all desirable properties. Strength and durability are also paramount in this form of structure, bearing in mind the very large costs which have been incurred in recent years in maintenance and repair of concrete bridge decks and sub-structures, in the United States and elsewhere.

Within the limited scope of this paper it has only been possible to indicate some general developments in construction techniques illustrated by one or two examples from recent practice. However, the inter-dependence of construction techniques and choice of concrete is clear; advances in construction techniques for concrete are normally only possible when accompanied by improvements in concrete and its properties.

4. WHAT NEXT?

Concrete construction is now at an extremely interesting stage in its evolution. It has suffered in the past from its own apparent advantages, in that it is very simple to make concrete: its constituents are readily available and even unskilled, untrained labourers can make a credible concrete slab or lintel. This low technology approach is still with us, but in many countries the high costs of maintenance, repair or replacement of defective concrete structures are even more persuasive to clients than the voices of the many engineers who have long understood that concrete needs a high-tech approach, with well trained personnel on site. Attitudes are certainly changing, but everywhere, more effective education and training in concrete construction for engineers and concretors are needed to maintain evolutionary progress.

The adoption of high performance concrete for prestige projects is an excellent indicator for the future. It has been adequately demonstrated in the United States [6] that high performance mixes for buildings can be produced consistently by ready mix suppliers and placed successfully on site. The critical importance of extended curing procedures is again stressed here. Sampling and testing including routine taking of cores from the structure are essential; for structures in harsh environments, tests should include the measurement of permeability or diffusion of the concrete. Other major projects such as off-shore structures and bridges are increasingly employing high performance concrete to ensure satisfactory long-term performance.

The closer integration of design and construction with careful review of alternative schemes at the concept design stage, taking due account of speed, cost and ease of construction, is leading to benefits for client, designer, contractor and user. A recent case study [10] on a building in London's Docklands Enterprise Zone has set out the options considered, as well as the chosen solution, which was an interesting in situ concrete building with post-tensioned floors. Publication of case studies of this type is a valuable initiative which could usefully be repeated in other countries. In reports of completed structures, often too little is heard of the rejected solutions and the reasons for the final decisions made. However, the important conclusion to be drawn here is the desirability of close liaison between engineers experienced in both design and construction, architect, building services engineer and client for best use of available technology in concrete.

It is difficult to forecast with any precision the development of new materials. Steel continues to reign supreme as the reinforcing medium for concrete. In terms of corrosion it poses problems and there are various developments of non-corroding polymer materials as possible alternatives to steel. Kevlar has been employed for cables for certain structures; it needs protection from ultra-violet light but is non-corrosive and has a reasonable performance in creep [11]. Other high modulus polymers, produced by extrusion or die-drawing, thereby re-orienting the molecules in one direction, are strong in tension, but have a poor creep performance [12]. However, new possibilities are being examined in research in several countries and in the near future we should see polymer materials used as reinforcement for concrete elements in marine or other environments where concrete structures deteriorate rapidly

Future horizons for concrete encompass better use of established technology, arising from a wider understanding at all levels of concrete as a material. They also include further developments in technology and the use of new materials within concrete and as reinforcement.

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Saint Sava Temple – Heavy Building Assembly Application

Temple Saint Sava-Application de la préfabrication lourde

Saint Sava Tempel-Anwendung Schwerer Montagebau-Elemente

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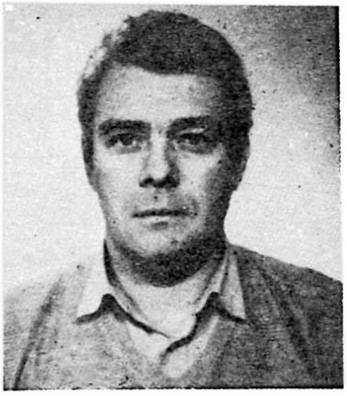


Dušan Arbajter, born 1945, received his civil engineering degree at the University of Belgrade, YU. He worked as a civil engineer on site later on as a designer. He was involved in large projects with design and erection of heavy assembly structures. Presently he is assistant general manager for design, marketing and computer departments, in KMG Trudbanik, Belgrade, YU.

SUMMARY

Saint Sava Temple is a building which was designed and erected applying very advanced design tools and programmes as well as electronic device and equipment. The article presents the methodology of design and calculation of the main dome in all its phases of construction and life This is the first time that such a huge structure was lifted to such a height, without having performed research and checking on the model before. All measured data is presented as reference to those obtained during the design, showing that the design and technology involved were well thought out in advance.

RESUME

Le Temle de Saint Sava représente un ouvrage dont les études et la construction sont basées sur l'application des moyens et des logiciels les plus modernes, ainsi que des appareils électroniques et équipements récents. Le présent exposé présente la méthodologie d'étude et de calcul de la coupole principale, ainsi que de toutes les phases de sa mise en place. C'est une première mondiale, qu'une construction de tel poids soit élevée à une telle hauteur sans essais et vérification préalable sur modèle. Toutes les valeurs mesurées sont — comparées aux calculs, prouvant que les études et la technologie appliquée ont permis d'évaluer à l'avance les valeurs et données réelles.

ZUSAMMENFASSUNG

Sant Sava Temple ist eine Bauanlage, projektiert und montiert unter Anwendung von modernsten heute bekannten Mitteln und Programmen sowie elektronischen Anlagen und Ausrüstungen. In diesem Referat werden das Projektierungs, und Berechnungsverfahren der Hauptkuppel, sowie alle Phasen ihre Hebung und Entstehung dargestellt. Eine so schwere Konstruktion wird dabei zum ersten Mal in der Welt ohne vorherige Untersuchungen und Kontrollen am Modell auf eine solche Höhe gehoben. Alle Messwerte werden parallel mit während des Projektierens erhaltenen Rechenangaben dargestellt. Dadurch wird gezeigt, dass durch das Projekt und die angewandte Technologie schon im voraus die eigentlichen Werte richtig bestimmt wurden.

BUILDING AND DESIGN HISTORY

The building is being constructed on the place where the naturalized Turk Sinan Pasha burnt the remains of St. Sava in 1595. On the eve of World War II, in 1935, the construction of the present day cathedral church began, assuming the size of the largest Orthodox church in the world. Construction was resumed 45 years later, in 1986, according to the original preliminary design of the authors, Arh. Bogdan Nestorović, and Arh. Aleksandar Deroko, both Professors on Belgrade University.

The St. Sava Temple was designed in the Serbian - Byzantine style. The layout is shaped as a cross, sized 91 by 83 meters in plan. The height of the building is 80 meters, including the cross. The building is dominated by a central dome spanning 33 meters, and four semi-domes at the wings. The facade will be clad in marble. The original design project proposed a structure composed of masonry and partly of reinforced concrete.

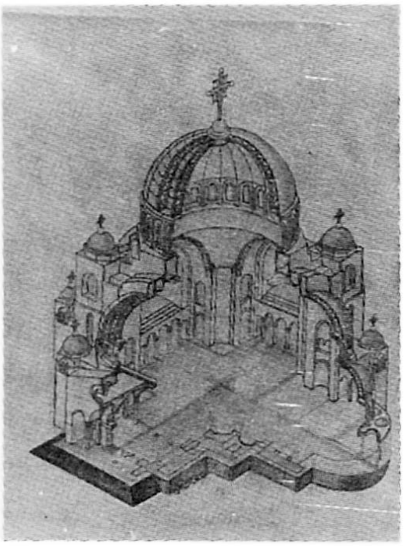


Figure 1.

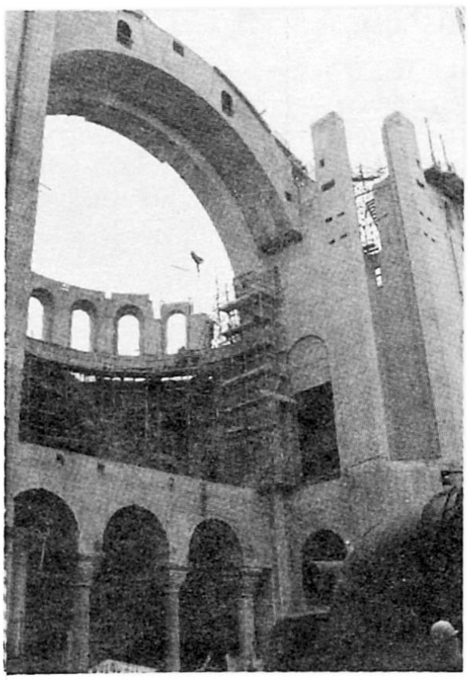
Figure 2.

The as-built state of the foundations was only learned after detailed investigative work. The four central bell towers were founded on 532 "Simplex" piles, 6m in depth, according to some reports. The massive perimeter walls are laid on strip foundations 4m in depth. The quality of the various materials used, i. e. brick, concrete, reinforcement, marble, etc., has been established through investigative work. By carrying out detailed surveys of the existing structure, the as-built outlines of the building were determined, which were to serve as a starting point for further design and construction work.

GENERALLY ABOUT "Saint SAVA" TEMPLE - TECHNOLOGICAL POINT OF VIEW

"St. SAVA" Temple is the greatest sacral building under construction nowadays, one of the greatest Orthodox Temple, the first which is being executed under very high level of assembling of building static system, although it is unusual and unique in building construction assembly practice concerning its geometrical shape (figure 1).

This building, in its essence has the permanent constructing and historical value and it is quite different from any other. Relying on many successful, but indeed, different experience in assembly, KMG "Trudbenik" has devised a constructing technology model of Temple system, providing the maximum parallel works, quality, economy as well as high speed of construction, running before scheduled time, therefore, we can say undoubtedly that it has contributed to significant innovation in building construction of our times.



SEPARATION OF BUILDING - TECHNOLOGICAL PARTS

The original design project proposed a construction combining brick and concrete. For obvious reasons such a structure was kept to the extent in which construction had progressed so far. First of all repairs in the foundation structure had to be carried out, as well as the separation of the wing sections from the central part by way of expansion joints. Tying up of the

foundations, the existing part and the new structure of the forthcoming stages of construction was achieved with reinforced concrete columns and tie-beams.
Expansion joints of the wing sections were carried out along the line of intersection between the semi-domes and the main arches, and vertically down the bell towers up to the foundations. The continued construction was designed as a fully prefabricated rein- forced concrete element structure. The fact that the building is geometrically extremely complicated from a structural point of view resulted in the breaking down of the elements into precast components outlined with straight lines to the greatest possible extent. All walls have been designed as hollow boxes which, when assembled into a whole, give the building its massive appearance (picture - right).

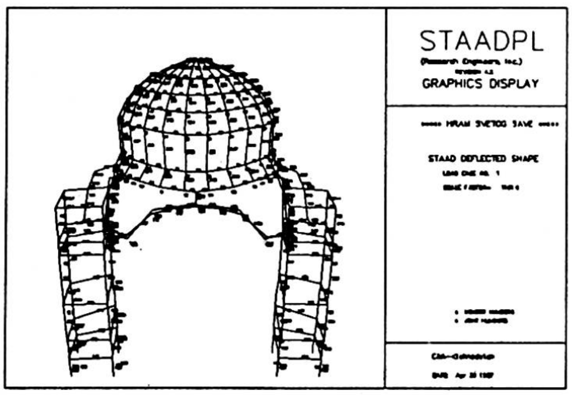
All arched shapes of the galleries and vaults have been transformed into assemblies of elements curved in two dimensions which, having been erected, form a three-dimensional shape. The semi-domes and the dome have been linearized by designing a system of arched trusses and two layers of curved decking. The precast parts are bound into a whole by in-situ cast parts of the structure which provide the required safety and long life of the building.
The bell towers were initially started as a combination of brick and concrete columns, and have been continued as a concrete box-structure which provides the greatest possible resistance of the towers with the least possible weight. This part of the building has been completed by applying the sliding shuttering method (slipp-form), whereby the advantages of prefabrication were exploited. The central part of the building Includes four main arches between the bell towers and the central dome with the pendentive underneath (figure 2).

FOUNDATION

It was found that kind and type of foundation chosen by previous design, was not adequate, even for carrying loads imposed from whole building which is according to new design lighter by 30-40%. During the time it was discovered that length of "Simplex" piles bellow the main tower-column is actually about 6m with head laying at level of -10m It was decided that, before the lifting of main dome will start, improvement of main columns to carrying gravity and other loads, have to be done. It was decided to improve the main column foundation by adding (replacing) 13 old piles bellow slab with new one which is 1.4m in diameter, and deep to the -17m level (reaching the rock).

STRUCTURAL ANALYSIS

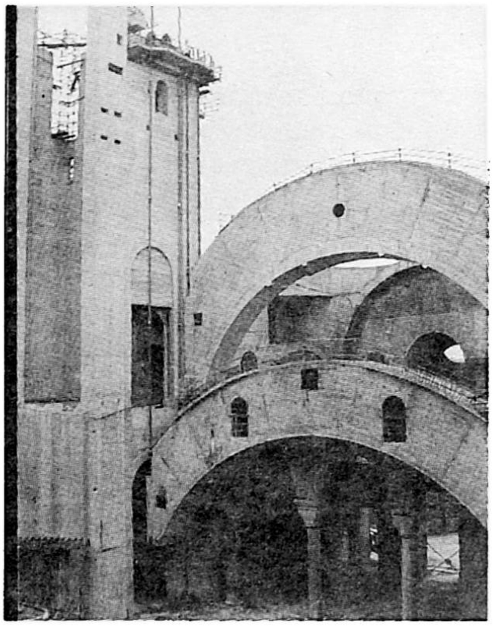
Structural analysis of building structure is made according to new JUS codes, standards of Yugoslavia and appropriate codes. After the building is splitted in to the five parts, calculation is made concerning the wings as one model and central part as another. Separate parts of structure which belongs to prefab group of elements are treated through the calculation as elements which have to be checked against the loads through the transportation and erection time.



Again this elements are checked through his "second life", passing the lifting or pulling phase of erection (elements for arches, main dome and pendentive). Finally all this elements are checked for their "third life" and final life in structure which has to last for next five hundred years as minimum. For a first time dynamic calculation and finding the dynamic characteristics of structure, we used program "TABS" from Berkeley University. Parallel the calculation is made using USA program "STAAD". Dimensioning of all elements are made according to new Yugoslav recommendations which are mainly in accordance with European codes. To prove the static calculation and all of our presumptions, it was made decision to provide all main structures and elements needed for lifting purpose, with measurement instruments during the lifting procedure. All measurement instruments are connected to the computers for purpose to get all data collected for analysis which could be carried out later on. By this way, we are in position to see (in live) directly on computer monitors all relevant data concerning deflection, jack's stroke, leveling of supports, deformations and stresses of main elements .

"CHAINS" AND LIFTING METHOD TECHNOLOGY

The main arch is one of the elements linking the bell towers both physically and in terms of communication. All four pairs of arches were very successfully lifted and fixed into position between January and June 1988, and they are now an integral part of the building. On the outer arches, which belong to the wing sections, the semi-domes have been formed, each consisting of eight curved reinforced concrete trusses covered with curved slab decking.



The assembly of arch assembly-bearers of SEMI-CUPOLA, with weight of 4000 kN/pcs, prefabricated on the ground, presents an innovation from aspect of devised and applied technological lifting equipment (presently known as "chains"). Its very low price, efficiency, duration, lifting force, resisting, remarkable easy operating and, above all, possibility of application for lifting of heavy load on any elevation in building construction and energetics. "Chains", as completely new system were tested against safety factor of overloading between 1.6 and 2.2.

The expansion joint arch rests "hanging" from chains in the lifted position until it's own columns are subsequently cast underneath. It is then released from the chains and, together with the columns, forms a framed system in a "portal" configuration (see picture - left).

Throughout the above mentioned stages of static lives of the main arches we carried out detailed analyses of the arches, both in terms of stresses and deflections. The dimensions of the arches were reduced, optimized, so that the resulting structure is as light as possible for technological purposes, and at the same time strong enough for the life span of the building.

HEAVY ASSEMBLY PUSHING TECHNOLOGY-RAISING OF MAIN DOME

Working out and very heavy building construction assembly of the CENTRAL CUPOLA, weighting 40000 kN, by pushing method, presents characteristic building engineering project, unity in church constructing and Christianity in general. The main gallery, which bears cupola and connects central bell-towers, is prefabricated on the site as a monolith, on gravel embankment, height 120 cm.

Leaving of technological passage for heavy machine resources and transports to the central part of the Temple from South side, makes possible, with special access to the assembly, the execution of the complete structure of the central cupola in one phase, i.e. in continuity, which also has essentially effect on positive course of all work realization. Began on the ground in the beginning of November 1988 and quite completed-assemb-led at the end of February 1989. During execution of concrete works, the method of electrical resistance thermal treatment of fresh concrete in winter period, was applied. The main dome is assembled from 24 curved reinforced concrete trusses with two

Figure 3.

layers of curved decking forming outer skins around either flanges of the trusses (figure 3). The bottom decking is intended for mosaic of church ornaments on the inner surface of the dome. Electro-hydraulic lifting equipment, according to the requests and conditions prescribed by KMG "Trudbenik" were designed and delivered by Hydraulic and Pneumatic equipment and devices factory "Prva Petoletka" Trstenik, YU.

Figure 4.

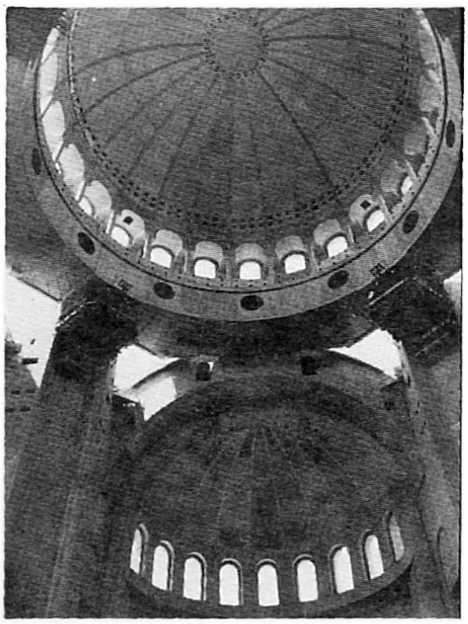


Figure 5.

Assembly-Lifting of the Central Cupola structure, with completely executed copper covering works, and cross, weighting 4000 Mp from the ground up to the designed position on level +40,09m, presents the achieved level of technology for XXI century. The safety speed of lifting of whole 2,50m/day should be possible by devised technology of assembly-pushing by hydraulic integral lifting power of cca 5000 Mp applying proportional serv-valves as well as strike and pressure pickup and electrical devices and by computer leading of unify lifting of cupola on all four reactive supports simultaneously. Vertical stepping of 110mm in one step, was realized by application of reinforced concrete slabs-cribbing (MB-50 MP) in all reactive supports, successively placed under the jacks or cupola by humanized mechanical means which are part of robot engineering resulted as technological achievement of KMG "Trudbenik" and "Prva Petoletka".

Lifting for a first 13m (figure 4) was done with supports passing by the bell-towers, in order to not destroy the r.c. column executed before the second world war. Reaching the proper height, all equipment and support steel (pi shaping) girder are moved in to the slit which is left intentionally during the slip-forming columns. Every day was necessary to cast in situ around the cribbing slabs in order to finalize the column for 2.50 m/day. Column which is assembled of cribbing slabs, placed by means of hydraulic manipulator "robot", are stiff enough for 2.5m therefore the process of pushing cupola is lasted no more then 5 hours each day (figure 5).

Over 280 electronic elastomers were placed allover the cupola and it's elements. All hydraulic components are supplied by measurement instruments to have information about jacks stroke and jack pressure to make possible specially designed computer to take control over the automatic lifting operation. Full independent outside electronic leveling system is attached to computer control to in-

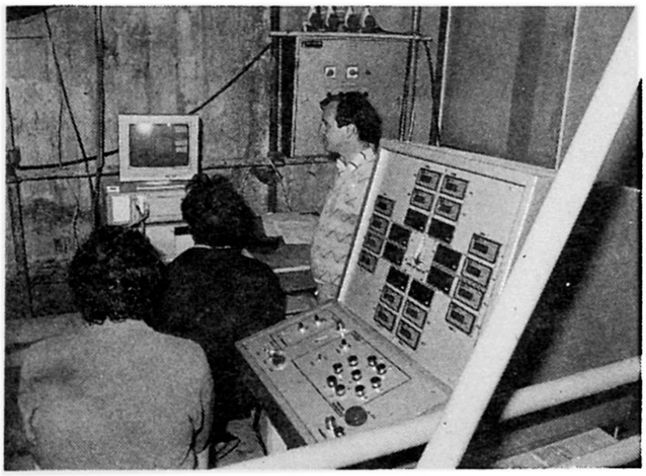


Figure 6.

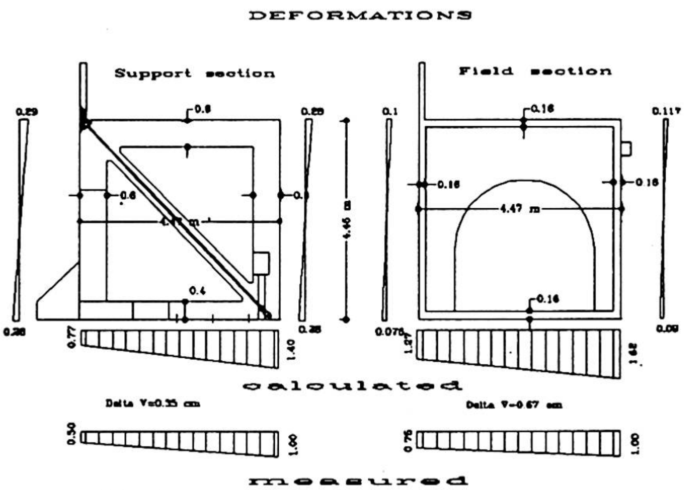
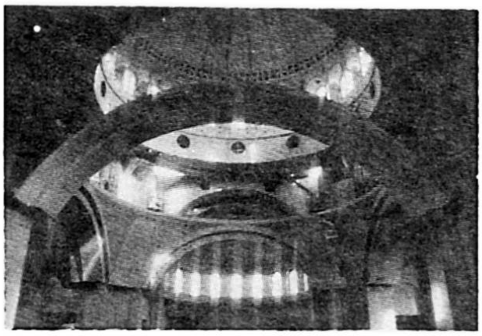


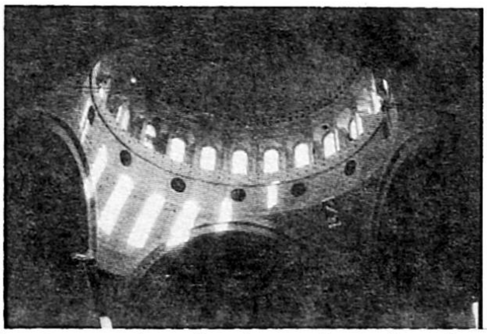
Figure 7.

sure the exact leveling information, which could serve to stop lifting operation in case of misleveling greater then 5mm (figure 6). One of two working PC-AT clones is collecting and monitoring over 24 essential data for performing operation without any mistakes. Graphical presentation is most suitable way for very fast and easy visible recognition for leading engineer to react properly in time.
The last lifting operations were performed on level +39,69m and in the same time, the certain parts of cupola were on +80m, avoiding very risky and complicated assemblies on such big height. Complete covering works by copper sheet on wooden basis and with cross, performed in March and April, while cupola was on the ground.
The results obtained during the lifting operation is shown on diagram (figure 7). It is obvious that stresses and deformations measured and calculated are very fine in conjunction even no any single model in design phase is not used to investigate how dynamic process could interfere structure.

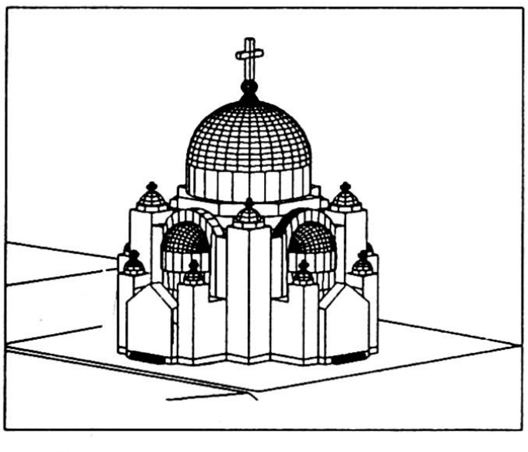
PENDENTIVE

Underneath the main dome, again at ground level +/- 0.0m, the pendentive is assembled. It represents a transitional tie element through which the rectilinear plan of the church hall changes to the circular plan of the main dome. Once the pendentive has been lifted into its position at level +40m, and secured against the main dome, the central part of the church will be rounded off.





Structural connection between pendentive and main dome is to be done by supporting the dome in four position by means of hydraulic jacks capable to produce force of 3000 kN each (total force 12000 kN). These means that pendentive will take care of additional loads coming latter from applied mortar, mosaic and outside marble.
Again, the most efficient lifting technology and equipment called "chains", is used. Pendentive weighted about 1100 Mp, spanning in perpendicular direction 24*24 m, with height of 14m on the ground, lifted on 28m on their position beneath the main cupola.
During the two days at the end of January 1990, pulling of assembly structure of "pendentive" on its position is very successfully done. Total time of pulling was 36 hours, in which we reached speed of erection of 2.0 m/h. "Pendentive" is positioned under the lower ring of "dome" so precisely, reaching the accuracy which is far of prescribed by technology design (tolerance of 5cm.).
After upper part of Saint Sava Temple is completed, waiting for finishing inside and marble with copper covering from outside, the underground part of Temple is in preparation for execution.



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Concrete Cube – Shaped Display Hall

Bâtiment d'exposition cubique en béton armé

Stahlbeton – Ausstellungshalle in Würfelfrom

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SUMMARY

This paper deals with various design and construction aspects of a Display Hall building in Bhopal, having intersecting hollow concrete cubes as its roofing system. The topmost point of the cube is 6 meter above floor level. Structural feasibility analysis, detailed design and specialist construction supervision have been undertaken by the authors.

RESUME

L'article traite de différents aspects du project et de la construction d'un bâtiment d'exposition à Bhopal, caractérisé par des cubes vides en béton formant son système de toiture. Le point le plus élevé du cube est à 6 mètres au-dessus du sol. L'analyse structurale et de faisabilité, le projet détaillé, et la supervision de la construction ont été entrepris par les auteurs.

ZUSAMMENFASSUNG

Der Beitrag behandelt verschiedene Entwurfs-und Baugesichtspunkte einer Ausstellungshalle in Bhopal. Ihr Dachtragsystem besteht aus sich überschneidenden, hohlen Betonwürfeln, deren höchster Punkt 6 Meter über dém Hallenboden liegt. Die Autoren waren mit der Machbarkeitsstudie, Konstruktion und Bauleitung der Spezialarbeiten beschäftigt.

1. INTRODUCTION

The Display Hall located at The Nehru Rose Garden, BHEL Township, Bhopal, India, was built in 1989. The plan of this building as envisaged by its architect is shown in Fig.1. This is generated by combining plans of three intersecting hollow cubes of

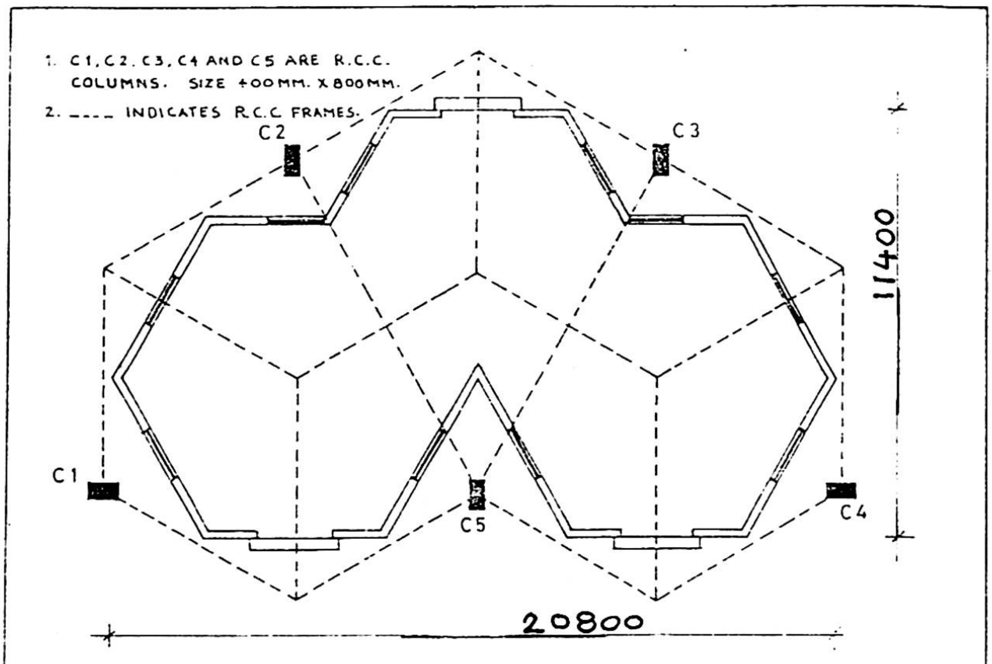

Fig.1 GROUND PLAN AND LOCATION OF COLUMNS DISPLAY HALL, NEHRU ROSE GARDEN BHEL, BHOPAL

reinforced concrete with overall plan dimensions of 11400x20800mm. The entire roof structure rests on five RCC columns, each size 400x800 mm shows as C_1 to C_5 resting on rectangular RCC footings on soft rock with SBC of 25 T/m^2. It is 1500 mm below the ground level. A hinge of size 250x650 mm, length being 500mm is provided at 1000mm above the base of the footing to facilitate hinge action. The topmost point of these intersecting hollow cubes shaped roof is at six meters above hall floor level as seen in Fig.2 & 3. The slopes of roof panels and supporting edge beams are of the order of 55°. A cutout on top of each cube provide ingress of natural daylight.

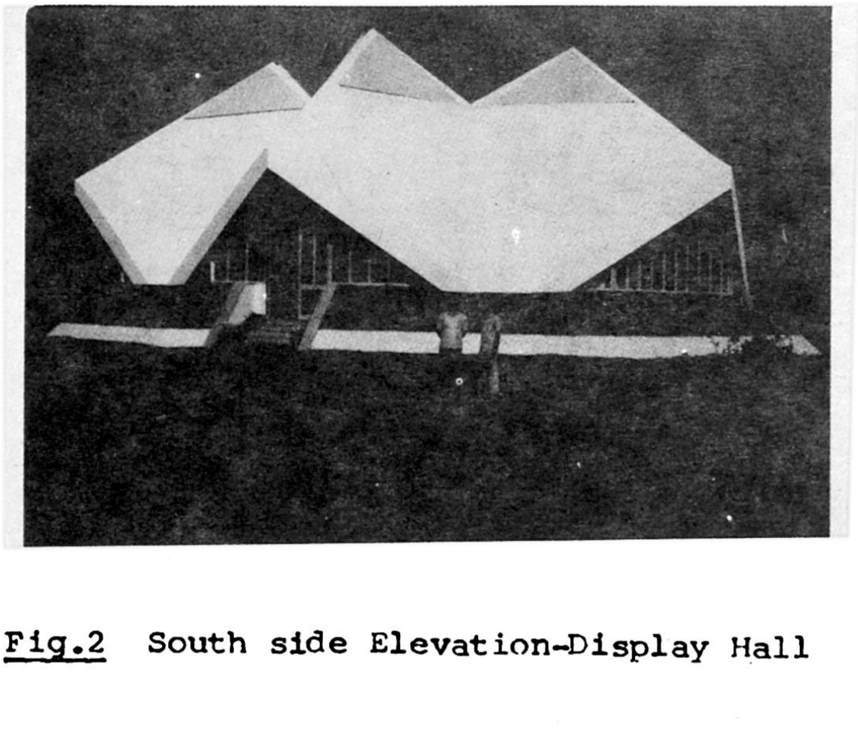

Fig.2 South side Elevation-Display Hall

2. INITIAL DESIGN CONSIDERATION OF STRUCTURAL SYSTEM

The project architects have visualised hollow concrete cohabit cubes consisting of solid slab panels supported on each of its edges by edge beams. These beams in turn rest on space frames as shown by broken line in Fig.1. These inclined slabs have 150mm thickness. These are designed as two-way slabs [1] and suitable reinforcement for restraining torsional effects at each corners is provided. The inclination of roof beams is also of similar order. They also serve forming for the openings for entry and exit of this pavillion as shown in Fig. 4.

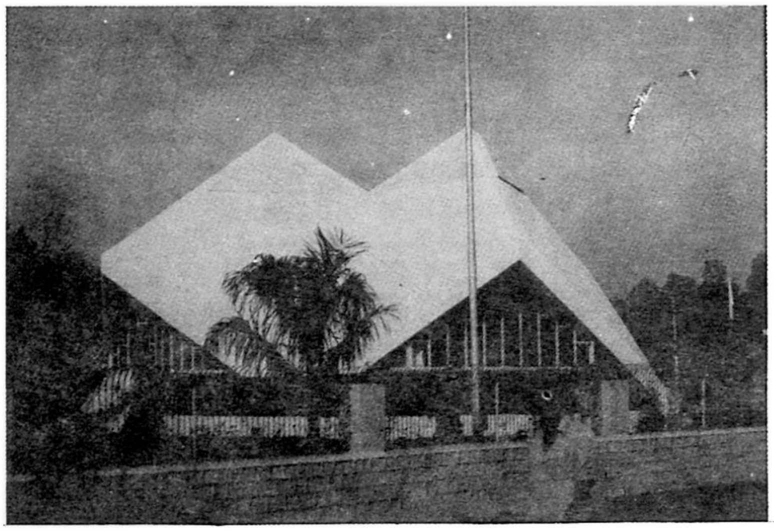

Fig.3 East Side Elevation of Building.

3. FINAL DESIGN CONSIDERATIONS

Some final design considerations in relation to the following elements are given below :

3.1 Composite Tie Beam

Seven steel-concrete composite tie beams were provided at plinth level to take up the horizontal reactions of the space frames at the foundation level in the form of three equilateral triangles. These consist of size 200x300 mm with 4 No ISA 50x50x6 mm suitably laced by 10 mm diameter links. These tie beams are connected to columns through bolted collars made out of 8 mm thich steel plate. The composite beam has to be envisaged to expedite the construction.

Fig.4 Details of Opening South Side, Display Hall Building.

3.2 Inclined Slab Panels and Supporting Space Frame

The type of structure as described above necessiates an integrated Finite Element analysis using the plate and beam elements in space. However due to the paucity of time, intitutive simplified elementwise analysis was undertaken like, roof as an inclined RCC slabs with appropriate edge conditions [2] and RCC space frames [3] supporting the inclined slabs and transferring the load to the foundations [4].

The inclined slabs were 150mm thick reinforced with 8mm diameter bars with 100mm centres bothways, suitably bentup and anchored. The Fig.5 shows details of this arrangement. The inclined roof beam members of the space frames were analysed and designed for combined effects of bending, shear, torsion and direct forces and thus adequately reinforced accordingly [5] M-20 (20 N/mm^2) Grade Concrete was used for roof slabs and supporting beams and columns. High strength deformed Bars Grade 415 were used as steel reinforcement of this structure as shown in Fig.6. below. This imparts adequate waterproofing property and gives enough durability to this structure.

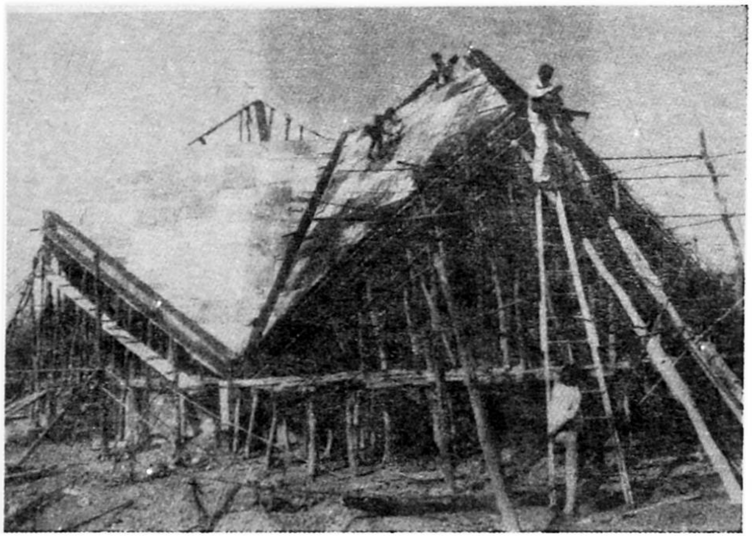

Fig.5 Details of slab reinforcement.

Fig.6 Details of Edge Frame Reinforcement.

4. SOME SIGNIFICANT DETAILS OF CONSTRUCTION PROCEDURE

Some typical and unique features of this type of construction adopted during construction of this Display Hall are discussed and highlighted below.

4.1 Detailing of Beams and Column Junction

The inclined space frames which constitute the most significant part of the structural system are very carefully detailed to ensure proper provision of torsional transverse stirrups, without causing excessive congestion for smooth ingress and compaction of concretemix in the forms to enable adequate compaction of concrete. The Fig.6 shows these details. Similarly the function involving sloping beam, edge beams and vertical columns are given due consideration in reinforcement detailing to achieve proper compaction of concrete. In view of the complex three dimensional geometry of this structrue the laps and anchorages for the reinforcement are carefully detailed [6]. Due care is taken to ensure proper cover to reinforcement in the various structural components of this building.

4.2 Care in Formwork and Usage of Double Shuttering

As the slopes of slabs and beams are steep, of the order of 55^{o}, therefore, extra precaution was needed to ensure correct level of formwork. It was suitabley braced to reduce risk of settlement during concreting operations. Smooth plywood double shuttering was employed to prevent flowing of mix and achieve proper compaction of concrete to resulting in dense and durable concrete mass with smooth surfaces.

5. CONCLUSION

Some of the important conclusions of this discussion are as follows :

- The envisaged form of this display hall incorporates the usual structural efficiency of **Shell Form** to a large extent with the added advantage of simplified formwork was required. The provision of sufficient openings and cutouts at top of cube shaped roof caters for allowing natural daylight, thus reducing energy requirement for lighting and cooling purposes of this building.

- The intitutive simple analysis taking advantage of continuity is in close proximity with the Finite element method of analysis and is less time consuming. It was also incorporating better feeling of behaviour of entire structural system.

- The form adopted for display hall at the Nehru Rose Garden, blended very well with its total environment and described very well the concept of form of a **Rose Bud.**

ACKNOWLEDGEMENTS

The authors wish to acknowledge their sincere thanks to The Principal & Chairman, Industrial Consultancy Services Centre, M.A. College of Technology, Bhopal and to The Bharat Heavy Electricals Ltd., Bhopal for all necessary help in publication of this paper. Also wish to accord their deep sense of gratitude to Prof.S.V. Sahasrabudhe of Architecture Dept., M.A.College of Technology, Bhopal, for nice photographs, Mr.S.Bhatt for preparing sketches and Mr.B. Vijaykumar for excellent typing work.

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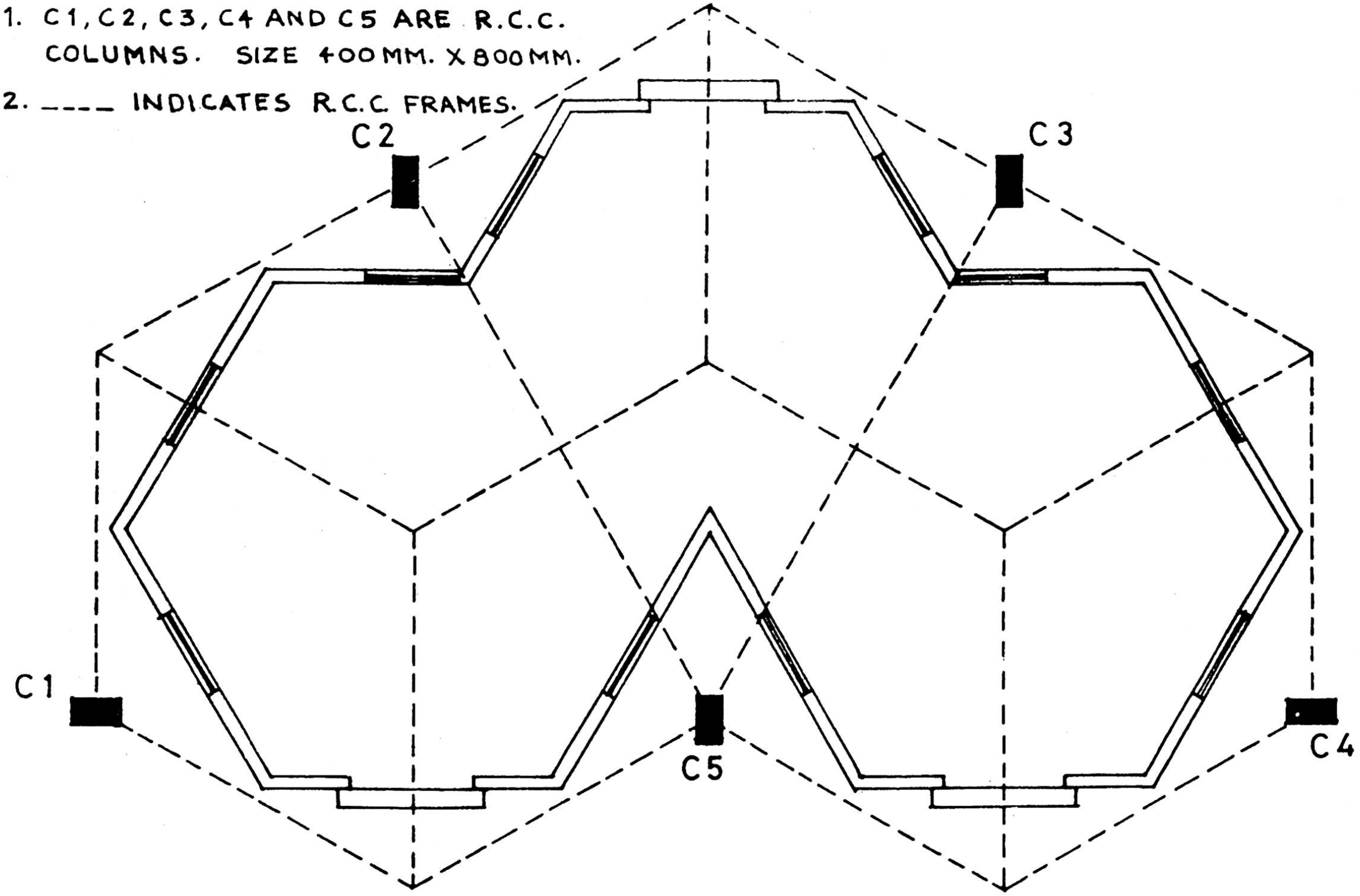

FIG. 1 GROUND PLAN AND LOCATION OF COLUMNS

DISPLAY HALL, NEHRU ROSE GARDEN BHEL, BHOPAL

Seminar 2

Bridge Design and Construction

Projet et construction de ponts

Brückenentwurf und -konstruktion

Organizer: Y. Fujino, Japan

Chairman: R. Rao USA

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Innovative Cable Erection System for Cable-Stayed Bridges

Système novateur pour montage des fils des ponts haubanés

Neuartiges Seilmontagesystem für Schrägseilbrücken

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Anthony Freeman, born 1946, received his Engineering Science degree at Oxford University, England. With wide experience in steel bridge construction, he now runs his own consulting practice specializing in construction methods and systems, in Bangkok and in London.

SUMMARY

The Second Hooghly River Bridge in Calcutta, now nearing completion, will have a cable-stayed main span of 457 metres, one of the longest in the world. The parallel wire Hi-Am cables are currently being rapidly erected using an innovative scheme and equipment, which are describeu in the article. The core of the system is a set of 600 tonne capacity hydraulic strand jacks and pumps which was made in Bangkok: it is being used both for pulling in and final stressing in one continuous operation. The Contractor's team of Indian engineers is carrying out the work without foreign supervisors.

RÉSUMÉ

Le pont "Second Hooghly River Bridge" à Calcutta, actuellement en voie d'achèvement, est un pont haubané de 457 mètres de portée centrale, une des plus longues du monde. Les câbles à fils parallèles Hi-Am sont actuellement rapidement mis en place grâce à une méthode et un matériel novateurs qui sont décrits dans l'article. La base de cette méthoae est un jeu de vérins de précontrainte et pompes hydrauliques do 600 tonnes de capacité, fabriqués à Bangkok.Ces vérins sont utilisés pour le tirage et la mise en tension des câbles en une seule opération continue. Les travaux sont dirigés par une équipe d'ingénieurs indiens.

ZUSAMMENFASSUNG

Die Second-Hooghly-River-Brücke in Kalkutta, Indien, wird bald fertiggestellt. Mit 457 Metern wird ihre Stützweite eine der längsten der Welt sein. Die Montage der Paralleldrahtseile Typ Hi-Am erfolgt unter Benutzung eines neuartigen Systems und mit Geräten die im Artikel dargestellt werden. Mittelpunkt des Systems sind litzenziehende Hydraulikpressen und Pumpen, die in Bangkok hergestellt wurden und 600 Tonnen Ziehkraft aufweisen: Sie werden für alle Phasen des Einziehens und Spannens ohne Unterbrechung eingesetzt. Die Arbeit erfolgt ohne ausländische Überwachung.

1. INTRODUCTION

The Second Hooghly River Bridge in Calcutta, India, has a cable stayed main span of 457 metres, currently one of the longest in the world. Articles describing the Bridge design and other aspects of its construction can be found elsewhere in this Publication and in [1].

At the time of publication of this article erection of the main cable stayed river span is being completed with admirable speed despite severe delays during construction of the earlier elements.

The steelwork and concrete slab elements of the deck are constructed using methods and equipment which were employed for the sidespans over the Calcutta and Howrah shores; only cable erection is a new operation for the crews building the Main River Span.

The cable erection scheme and the equipment for it were conceived, developed, and designed in detail by 3F Engineering Consultants, Bangkok, who were appointed after an international competition. The system was designed to be as "contractor-friendly" and rapid in use as possible.

The remarkable rate of erection being achieved at the time of publication by the all Indian crews indicates that the aim was achieved. No 3F supervision has been necessary other than three advisory visits. The rate of main span erection is especially remarkable in view of the comparison with the rate achieved on the side spans.

2. HISTORY

2.1 Bidding

The Contractor, Braithwaite Burn & Jessop Co Ltd (BBJ), invited international tenders for the design of an erection and stressing scheme for the bridge's main support cables in 1988. 3F Engineering Consultants, who won the contract, had been newly formed in Bangkok by key members of the team which had been responsible for the successful rapid completion of Bangkok's 450 metre span Rama IX cable stayed bridge. [2],[3].

3F's brief was subsequently extended to include the development and design of schemes for erection and stressing of Temporary Cables (used to secure the pylons during construction) and of the permanent Holding Down Cables which counteract uplift in the bridge's end supports.

3F's Contract was awarded in May 1988. After an intensive development effort in consultation with all parties, 3F's concept proposals were approved in August 1988 by BBJ, the Hooghly River Bridge Commissioners and their Engineer, Schlaich Bergermann and Partners of Stuttgart (the Bridge's Designers). The design phase was completed in April 1989.

The original intention to send Thai supervisors from the Rama IX Bridge team was subsequently cancelled by mutual agreement because of changed circumstances. 3F's detailed Method Statements and Drawings coupled with a limited number of visits proved anyway sufficient for BBJ's experienced team to carry out the operations quickly and effectively. Cable Erection work on site commenced in July 1991.

2.2 Hydraulic Strand pulling Stressing Equipment

Procurement of the novel stressing jacks from international suppliers was the subject of a later international tender based on 3F's outline design and performance specification, but no suitable offer was received. 3F's proposal to carry out the detailed design and to arrange for the manufacture of the equipment in Thailand was then accepted, and the work was entrusted to Vemac Co Ltd of Bangkok after a further round of bidding. The equipment was ordered in January 1990 and arrived on site in Calcutta one year later.

3. THE PROBLEM

The cables of many cable stayed bridges are arranged for stressing at the deck end as was the case at Rama IX Bridge. Hooghly bridge's final design has the cable stressing anchorage zone in a tulip shaped chamber at the pylon head.

This arrangement permits an economic open deck cross section with simple deck cable anchorage details, but it poses an interesting challenge for the cable erection system designer: the stressing chamber is restricted in size and access to the individual anchorages within it is difficult; both the stressing and the pulling-in equipment have to be fitted into and mounted on the relatively small space available at the pylon head, and the means of bringing them there have to be provided.

If all these problems can be solved, however, the advantages for the permanent structure of keeping the deck simple with all the complications concentrated in the relatively small pylon head zone can actually benefit the construction contractor also.

4. CONCEPT

Earlier feasibility studies by others had considered pulling-in and stressing as two separate operations requiring different sets of equipment. 3F considered that an essential requirement of the scheme must be the elimination of the need for such time consuming and potentially dangerous equipment changes in mid-operation.

At the heart of the scheme were the 600 tonne capacity strand pulling Jack and Pump sets, designed to operate at three widely different speeds. Conventional winch powered Hoists were to be used for the first stage of lifting after which the Hoist and the Jack pulling pilot strands would work together.

4.1 Use of Strand

Stay cables are normally pulled in by winches and finally tensioned by jacks working on a series of coupled screwed rods. This system, used for instance at the Rama IX Bridge, had also been proposed for Hooghly. The cable sockets were provided with threads suitable for screwing in such screwed rods.

Bundles of prestressing strands have become commonplace in recent years for heavy lifting operations. Use of strand as the main pulling/stressing element at Hooghly made it possible to achieve the aim of carrying out pulling-in and stressing in one continuous operation. It also eliminated the need to handle and change heavy screwed rods and equipment high above the bridge deck and in and around the difficult environment of the pylon head.

Detailed investigations at the concept stage confirmed that with the use of high strength alloy steels it was feasible to connect sufficient strands to the female thread provided in the cable sockets.

4.2 Hydraulic Jacks and Pumps

No suitable standard jacking equipment was available which could meet the requirements as well as fit in the confined space of the anchorage/stressing chamber of the pylon heads. BBJ was also anxious not to be dependent on any one equipment supplier.

3F therefore made the basic design of the Jacks, Strand Anchors and Stools, (Fig. 3) for the purpose, together with a performance specification for the Hydraulic Pumps and System.

The arrangement using four standard 150 tonne rams between heavy steel slabs was adopted instead of the alternative and more common hollow ram jacks for the following reasons:

- shorter overall length suitable for the restricted space available;
- two rams can be disconnected to double the high speed for pulling in operations where the load is low;
- the strands are visible and accessible between the anchorages within the Jack;
- use of standard 150 tonne rams increases the range of possible manufacturers and is more appropriate for such a special requirement.

4.3 Main Hoist

The first phase of cable erection required a fast method of lifting, for which the Main Hoist was developed. The Hoist is used to lift the upper cable socket beside the cable plane until it is just above the previously erected cable at which point the Jack is connected and Hoist and Jack work together. The upper sheave block runs on a trolley which allows the cable socket to be moved back into the cable plane as it approaches the pylon.

5. EQUIPMENT MANUFACTURED IN THAILAND

3F carried out the detailed design of the Jacks and Strand Pulling Equipment for Vemac and checked and supervised their hydraulic system design. A large screwed rod and nut were also produced for stressing the Holding Down Cables. All the equipment was tested at Vemac's works under 3F supervision to check both for correct operation of the grips and release mechanisms and also to test for strength. Some of the tests were witnessed by BBJ's Technical Adviser.

5.1 Hydraulic Jacks and Stools and Strand pulling equipment

5.1.1 The Jacks are equipped with electrically operated hydraulic valves and equipment (not shown in Fig. 3) mounted between two of the cylinders which allow smooth remote control. A single manual valve allows two of the cylinders to be disconnected for double high speed operation.

5.1.2 The Stools are designed to transfer the Jack load to the permanent Cable Bearers with sufficient space between the legs to allow the permanent Bearer Bars and shims to be handled into position after the cable is fully stressed. The stools are not required for the lower cables where removable Jack Bearers are provided in the permanent Pylon Head design.

5.1.3 The Strand Pulling Equipment consists of Adaptors and Rings and Jack Anchor Blocks designed for standard CCL type XL three segment wedge grips. Six types of Adaptor and two types of Ring allow 30 or 52 standard 15mm strands to be connected to the six different sizes of cable socket. The large Rings in which 38 strands are anchored are provided with strengthening clamps to control grip bursting: both Rings and Clamps were extensively tested before despatch of the equipment from Thailand.

5.1.4 The Jack Anchors are provided with a release system consisting of tubes which are pushed up against the underside of the grips by a screw operated release plate. This system has to be used at the end of stressing and also if for any reason a pulling-in and stressing operation has to be reversed.

5.2 Pumps and Remote Control Boxes

5.2.1 The high and low pressure pumps are mounted at each end of the electric drive motor shaft and valves and pressure sensors are provided to allow both automatic and manual selection of speed. The Pumps are self contained in weatherproof steel boxes, and are normally positioned on the stagings outside the Pylon Head Stressing Chamber where they can easily be checked and maintained. Hoses and cables are passed into the Jack in the stressing chamber through an unused cable port.

5.2.2 The control box is connected by cables to a socket mounted on the Jack's valve and equipment panel. The control box is equipped with push button controls and warning lamps and with a digital pressure gauge the sensor of which is fitted in the Jack pressure line.

6 EQUIPMENT MANUFACTURED IN INDIA

Whilst most of the locally manufactured equipment was made by BBJ's own workshops, the winches and sheaves of the main hoist were the subject of a tender which was won by Sureka Engineering Ltd of Calcutta.

6.1 Main Hoist

6.1.1 The Main Hoists use Sureka 5 tonne winches arranged to give hoisting capacity of up to 30 tonnes through up to 6 falls on two triple sheave blocks. The upper hoist blocks are arranged on runway beams allowing them to be positioned 650 mm out of the cable plane during the first phase of cable erection.

6.1.2 Two sets of Main Hoist equipment are provided on each pylon, arranged so that the winch operator can easily see the cable he is lifting throughout its journey. The reeved-up blocks are moved by the Tower Crane from the Backspan to the Mainspan side of each Pylon Head ready for each new cable.

6.2 Tower Crane

6.2.1 The 2 tonne lifting capacity Tower Cranes were designed to lift all items of cable erection equipment from deck level to the pylon heads. They are equipped with 1 tonne capacity electric Tirak winches with Cable Reelers manufactured by Secalt in Luxembourg: no conventional winch was available which could be fitted in the confined space available.

6.2.2 Slewing and trolley movements are carried out by hand. The slewing bearings are PTFE rings bearing on machined stainless steel runners welded to the tubular crane columns.

6.2.3 The cranes are designed to be dismantled manually and stowed in and on the pylon head. Special clamps are provided to secure the main boom section on top and the tubular columns retract into one of the cells of the Pylon Head structure. All the other parts can be stowed in another of the cells. This will allow the crane to be brought back into service for any maintenance work in future so that restressing or cable replacement operations will be possible.

6.3 Stagings and Auxiliary Hoist

6.3.1 Stagings are provided for safety and security at the pylon head: Staging Units A give access to the Main Hoist upper block and to the screw which operates the lateral travel trolley. Staging Units B give safe access over the stressing chambers and to the ladders down the inside walls; one of their longitudinal beams also serves as a runway for a 6 tonne capacity trolley hoist which is used for moving the Jack/Stool set from cable to cable.

6.3.2 Also mounted on Staging Unit B is the Auxiliary Hoist consisting of another Tirak winch and Cable Reeler. The 9.5mm wire rope from this hoist is passed down over a pulley, through the centre of the Jack, over a further pulley, and its end clamped off to the strand bundle near the cable socket. This Hoist is used during the lifting phase to pull the strand bundle ahead of the Cable Socket until the pilot strands can be secured by riggers on the stagings and fed through the Jack. Use of identical winches for the Tower Crane and Auxiliary Hoist allowed flexibility of maintenance and application of these two partially interchangeable equipment items.

6.3.3 In addition to the stagings designed by 3F, the bolting stagings around the whole Pylon Head were retained to give access during Cable Erection. These are omitted from Fig. 1 for clarity.

6.4 Saddles

Saddles are provided to ensure that curvature of the ends of the cables during erection operations are limited to 2.5 metre radius.

6.4.1 Bottom saddles. These were devised to fit easily to the permanent deck cable anchors in such a way that their attitude was automatically correct with no need for adjustment. Additional special bottom saddles were required and provided for the sets of five closely spaced backstay cables connected to the deck above the holding-down piers.

6.4.3 Cable Saddles. These saddles were provided with yokes for lifting with the Main Hoist block and with special prongs which engaged the Pylon Head steelwork in such a way as to ensure correct alignment after the lifting and first pulling-in phase. They were able to accommodate any of the six sizes of cable and socket by the use of plywood packings for the smaller sizes.

7 TYPICAL OPERATION

7.1 Preparation

7.1.1 At deck level. The cable is unreeled and grouted with polyurethane filler and pulled up the bridge on special support rollers. When the live (stressing) end reaches the pylon it is loaded into the Cable Saddle. The strand Adapter/Ring set complete with strand bundle is screwed into the cable socket, and the Main Hoist lower block and Auxiliary Hoist wire rope are attached. The Bottom Saddle is fitted to the correct cable anchor.

7.1.2 At the Pylon Head. The Jack/Stool assembly is moved and set in position and the bearer bars are prepared in readiness. The strand bundle is lowered to the deck with the Auxiliary Hoist, and the Cable Saddle is lowered to the deck on the Main Hoist.

7.2 Erection.

7.2.1 First Lifting Phase. The loaded Cable Saddle with handlines attached is lifted with the strand bundle kept ahead by the Auxiliary Hoist. When the bottom socket reaches its deck anchor, lifting is suspended while the cable is placed over the Bottom Saddle and the bottom socket is set. In the case of main span cables the Cable Saddle is first lifted as high as possible to allow the cable dead end to be manoeuvred through the pylon at deck level. The cable is then lowered again and the dead end pulled up the main span deck to its anchorage and set. Lifting is then resumed until the Cable Saddle reaches just above the line of the previously erected cable.

7.2.2 Second Lifting Phase (Pulling in Phase). The pilot strands have by this stage in the lifting been fed into the pylon and through the Jack, and the Jack set on double-high speed. (Two rams disconnected). The Jack and Main Hoist, working together, are now used to move the Saddle along the Final Cable Axis until the Saddle reaches the pylon. During this stage the load on the Jack steadily increases while the Main Hoist load reduces. When it reaches the pylon, the position of the saddle is fixed using a combination of the special centralising prongs engaging the pylon steelwork, adjustment of the Main Hoist, and a pair of chain blocks.

7.2.3 Final phase (pulling the socket into the pylon and stressing). Setting the saddle can be accomplished with little interruption of the continued cycling of the Jack, which now pulls the socket out of the saddle into the pylon, the cable itself sliding over the curved part of the saddle.

As the socket passes into the pylon, minor adjustments of the saddle attitude are easily made by the team on the staging responding to their good view of the clearances round the socket: they simply use the Main Hoist and the Chain Blocks.

As the load builds up, the Jack speed is reduced in two stages, first by reconnecting the two disabled rams, and later by changing from the low to high pressure pump. As soon as the socket anchor Ring emerges from between the cable bearers, the strengthening Clamps are fitted. As soon as the socket itself emerges, permanent shims are used to "follow up" for security, until finally the bearer bars and permanent precalculated shims are fitted.

Before the final stroke of the Jack is taken, the lower Jack Anchor's grip release system is activated. The Digital Pressure Gauge readout is used to check the load at the calculated final shim height, and after the figures are accepted, the final shim is fitted and the Jack released.

7.3 Moving to the next cable.

The complete strand bundle is now turned anticlockwise together with the Jack Anchors to unscrew the strand Anchor from the socket. The Jack/Stool assembly, complete with strand bundle is now moved using the Trolley Chain Hoist and set in the next position on the opposite side of the pylon head. With the upper Anchor Block grips also released, the strand bundle is now pulled down out of the Jack and lowered to the deck using the auxiliary hoist.

8. SPECIAL OPERATIONS

8.1 Temporary Cables

Separate procedures and equipment which are not covered in this article were used for erection and stressing of the relatively small Temporary Cables.

8.2 Holding Down Cables

The Holding Down Cables were stressed in a special procedure using the Jacks and Stools and a large Threaded Rod in place of the strands. (In the event a substitute jack consisting of eight 100 tonne rams was used for programme reasons.)

8.3 Early Stay Cables

8.3.1 The first four stay cables at each pylon head were erected by a simpler procedure without the use of the Cable Saddle.

8.3.2 The next 10 cables in each pylon head use the procedure in section 7 but with the Jack resting on its own removable "jack bearer" built into the pylon. The jack bearers were provided in the permanent steelwork because of the close proximity of the bottom cable bearers to each other.

9. CONCLUSION

An innovative integrated cable erection and stressing system has been developed and successfully used to such advantage that a dramatic acceleration of the rate of erection of the Second Hooghly River Bridge during construction of the Main Span is being facilitated.

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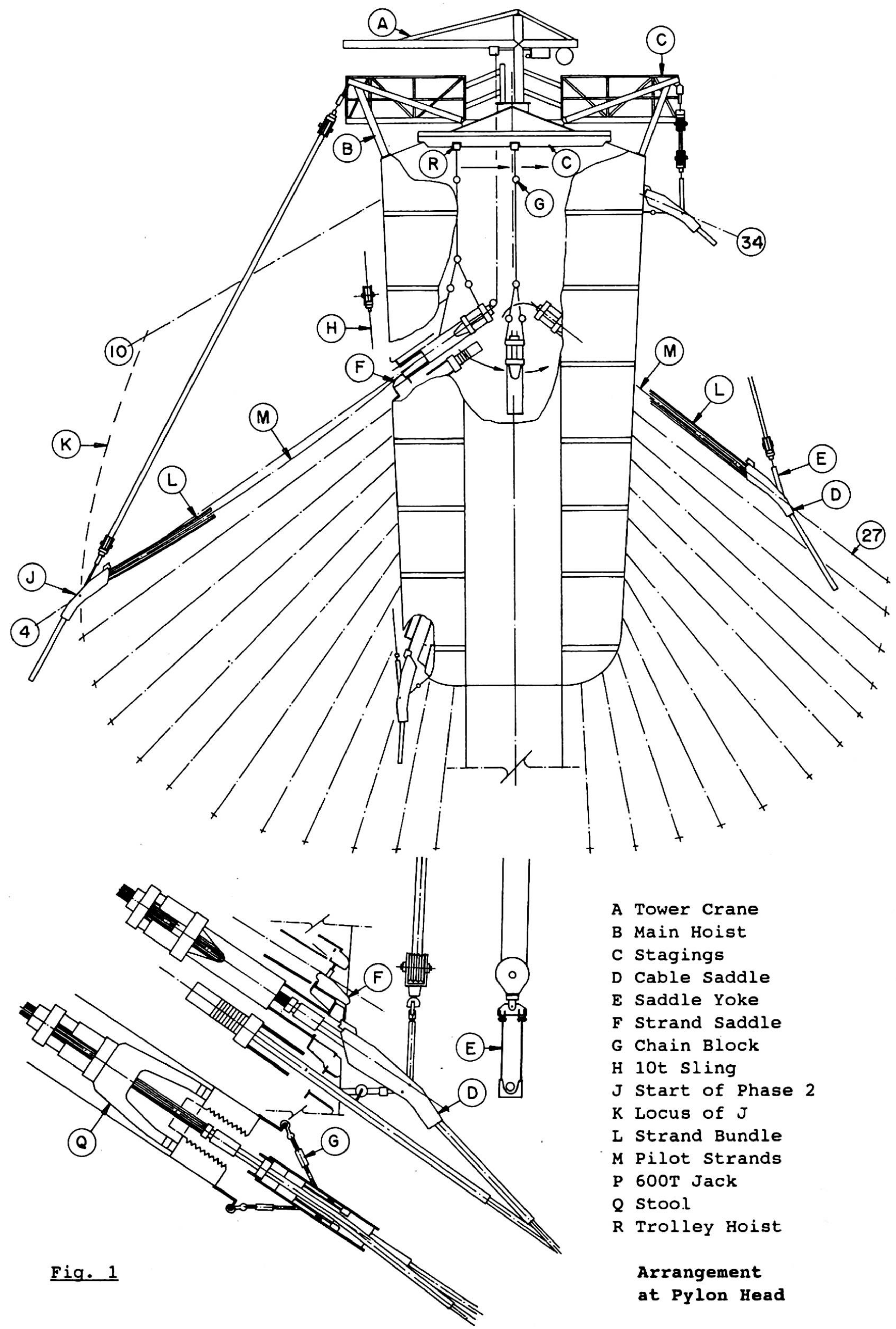
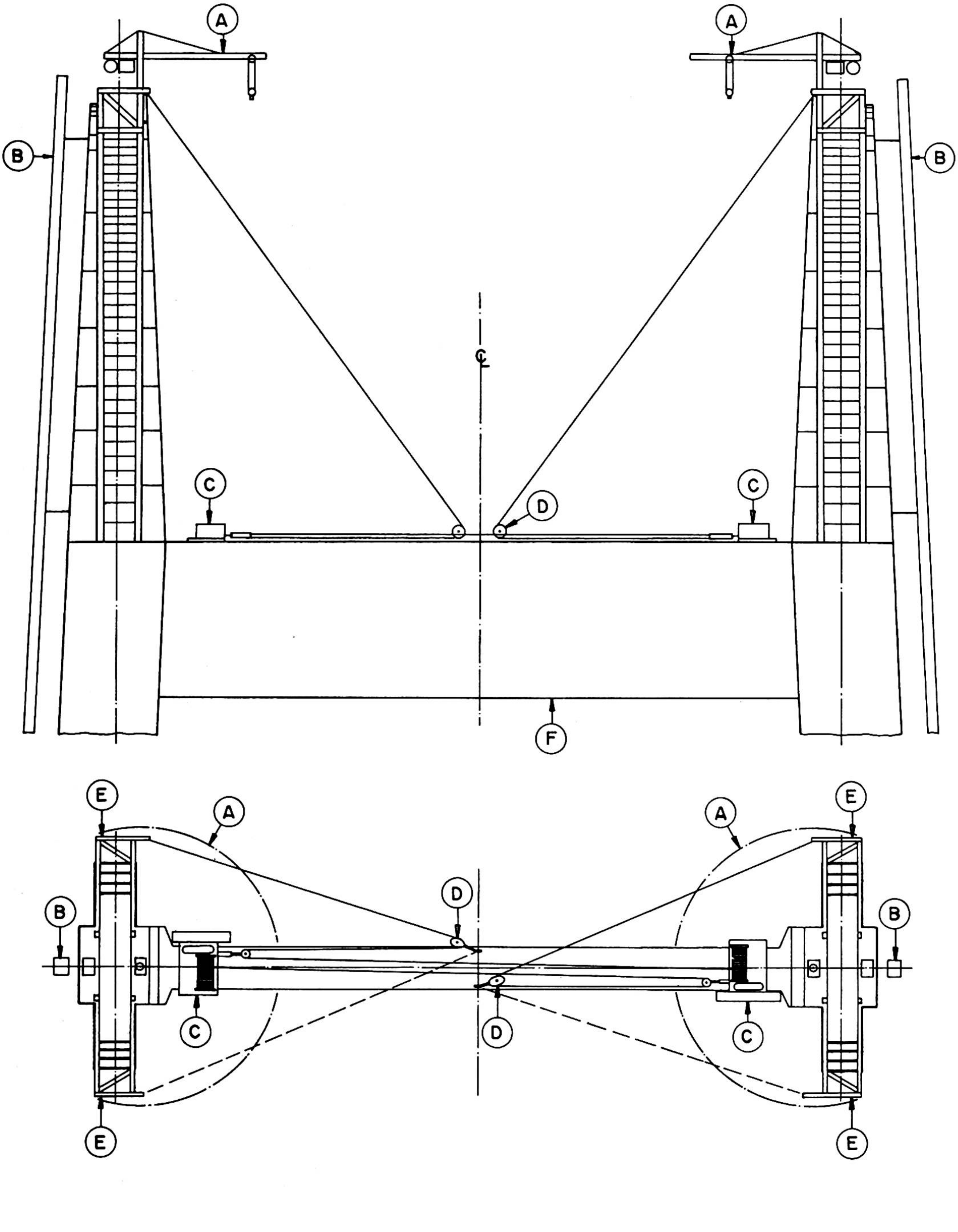


Fig. 1

Arrangement at Pylon Head



A Tower Crane
B Personnel Hoist
C 5 Tonne Winch
D 10 Tonne Pulley
E Trolley Runway
F Portal Beam

Fig. 2. Arrangement of Main Hoist at Pylon Head

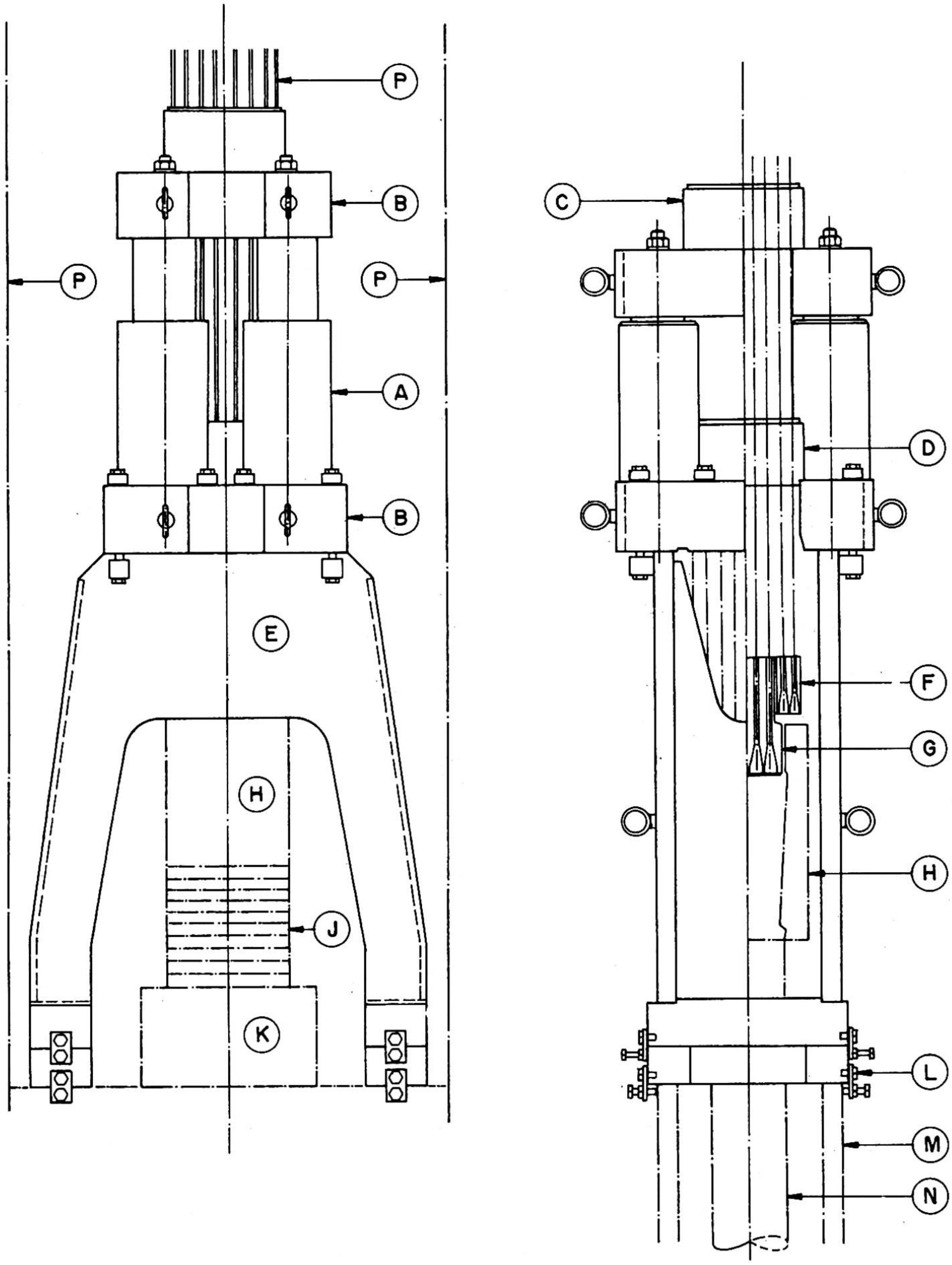


Fig. 3 3F/Vemac 600 Tonne Cable Stressing System - Jack and Stool

A	150 tonne Ram	F	Ring	L	Spacers
B	Steel Slab	G	Adapter	M	Cable Bearer
C	Upper Jack Anchor	H	Cable Socket	N	Cable
D	Lower jack Anchor	J	Shims	P	Walls of Stressing Chamber
E	Stool	K	Bearer Bars		

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Seminar 3

Structures to Withstand Natural Disasters: Experiences and Applications

Structures résistant aux catastrophes naturelles: expériences et applications

Bauwerke zum Schutz gegen Naturkatastrophen: Erfahrungen und Ausführungen

Organizer: Johan Blaauwendraad, The Netherlands

Chairman: V.V. Alekseev, Russia

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Seismic Damage and Retrofit to California's Urban Concrete Bridge Structures

Dommages dûs aux séismes et réparation des structures de ponts en Californie

Bebenschäden und Reparatur kalifornischer Betonviadukte

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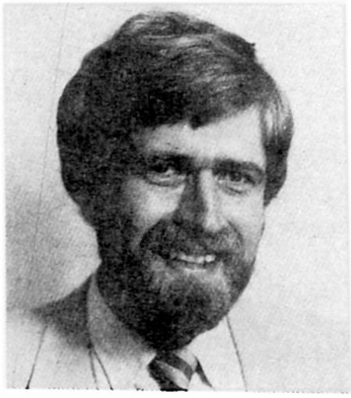
Univ. of California
San Diego La Jolla, CA, USA



Frieder Seible has been a member of the UCSD faculty since 1983. He has Civil Engineering Degrees from Germany, Canada and the USA and he is a member of the Seismic Advisory Board for Caltrans. His research interests combine large scale experimental testing and nonlinear analytical modeling of structural concrete systems.

SUMMARY

The Loma Prieta earthquake of October 1989 has re-emphasized the vulnerability and failure consequences of urban freeway bridges in a major seismic event. An overview of encountered urban bridge damage in recent earthquakes in California, is presented together with retrofit strategies to mitigate seismic bridge hazards in future earthquakes. Photo documentation of encountered damage and implemented temporary and permanent retrofit measures is provided.

RESUME

Le tremblement de terre de Loma Prieta d'octobre 1989 a rappelé la vulnérabilité et les conséquences de la rupture de ponts-routes urbains lors d'un tremblement de terre important. Les dommages encourus par des ponts urbains lors de récents tremblements de terre en Californie sont présentés ainsi que les méthodes de réparation en vue de diminuer les conséquences de futurs tremblements de terre sur les ponts. Une documentation photographique des dommages encourus et des réparations temporaires et définitives est présentée.

ZUSAMMENFASSUNG

Das Loma-Prieta-Erdbeben vom Oktober 1989 führte erneut die Verwundbarkeit und die Folgen eines Einsturzes von Stadtautobahnviadukten vor Augen. Der Beitrag gibt eine Schadenübersicht nach jungeren, kalifornischen Erdbeben an städtischen Brücken und Strategien zu ihrer Ertüchtigung, um die Gefährdung durch zukünftige Beben zuverringern. Schadenmuster und temporäre wie permanente Massnahmen sind durch Bildmaterial dokumentiert.

1. INTRODUCTION

Recent earthquakes in California – San Fernando 1971 (M6.4), Whittier 1987 (M5.9) and Loma Prieta 1989 (M7.1), have repeatedly demonstrated the vulnerability of urban concrete freeway bridges to seismic attack. Ever since the 1971 San Fernando earthquake [1], the need for a major seismic bridge assessment and retrofit program, particularly in California but also in the rest of the United States, was recognized and subsequent seismic events reemphasized the need for accelerated retrofit research and implementation. Caltrans, the California Department of Transportation, developed a three phase bridge retrofit program in 1971 focusing on movement joints, single-column bents and multi-column bent bridge structures.

By the mid-1980's, the Phase I retrofit program of providing seismic restrainers across movement joints was virtually completed and attention turned toward the more difficult problem of improving strength and ductility of bridge columns both in single and multi-column bents. A comprehensive research program was initiated at the University of California, San Diego (UCSD) to develop effective economical and technically feasible means for improving the flexural ductility of plastic hinges in single-column bents. The October 1987 Whittier earthquake shifted the focus to a potentially bigger problem, namely the brittle shear failure in short multi or single-pier bents [2], which comprise a large number of bridge bents in freeway overpasses.

Finally, the Loma Prieta earthquake of October 1989 uncovered problems with double-deck viaduct structures and knee joints in outrigger bents. Caltrans responded with accelerated and significantly expanded and specific retrofit research on single and multi-column bents, double-deck viaducts and outrigger bents, paralleled by implementation of temporary retrofit measures to minimize immediate seismic bridge hazards and followed by a detailed assessment of all 25,000 bridges in California and permanent retrofit designs for over 4,000 bridge structures currently in progress [3].

In the following, an overview of encountered seismic damage to concrete bridge structures in recent California earthquakes is provided together with examples of retrofit implementation. The intent of this photo documentation on urban seismic bridge damage and retrofit is to demonstrate that we are "competing against time" (George Housner, 1990 [4]) with our efforts to mitigate hazards posed by manmade structures in earthquakes.

2. ENCOUNTERED BRIDGE DAMAGE

The 1971 San Fernando earthquake caused significant bridge damage, particularly to newly constructed interstate bridges. Key problems identified ranged from excessive seismic displacements and subsequent unseating of complete bridge spans at movement joints, see Figs. 1a and b, inadequate confinement of flexural plastic hinge regions in columns, see Figs. 1c and d, and Figs. 2a and b, anchorage problems with large diameter ∅ 57 mm (#18) column reinforcement into the footing, see Fig. 2d, brittle shear failure of short columns with insufficient shear reinforcement, see Fig. 1e, and joint failures of knee joints due to the lack of joint shear reinforcement, see Fig. 2c. It is of interest to note that subsequent earthquakes such as Whittier (1987) and Loma Prieta (1989) did not uncover completely new problem areas which were not already identified in San Fernando (1971) but rather reemphasized some of the above mentioned problems.

While design guidelines for new bridge structures were immediately changed to reflect higher seismic force levels, confinement of column concrete particularly in potential plastic hinge regions and increased force and displacement requirements for movement joints, seismic retrofitting of existing bridge structures focussed initially on movement joint restrainers to prevent unseating and span collapse.

The Whittier earthquake (1987) caused significant damage only to one urban concrete bridge structure, the I-5/605 crossing where short piers of a skew multi column-bent bridge structure failed in shear. The large number of existing freeway overheads which feature these short piers, designed and constructed prior to 1971, pose probably the most severe seismic bridge hazard in

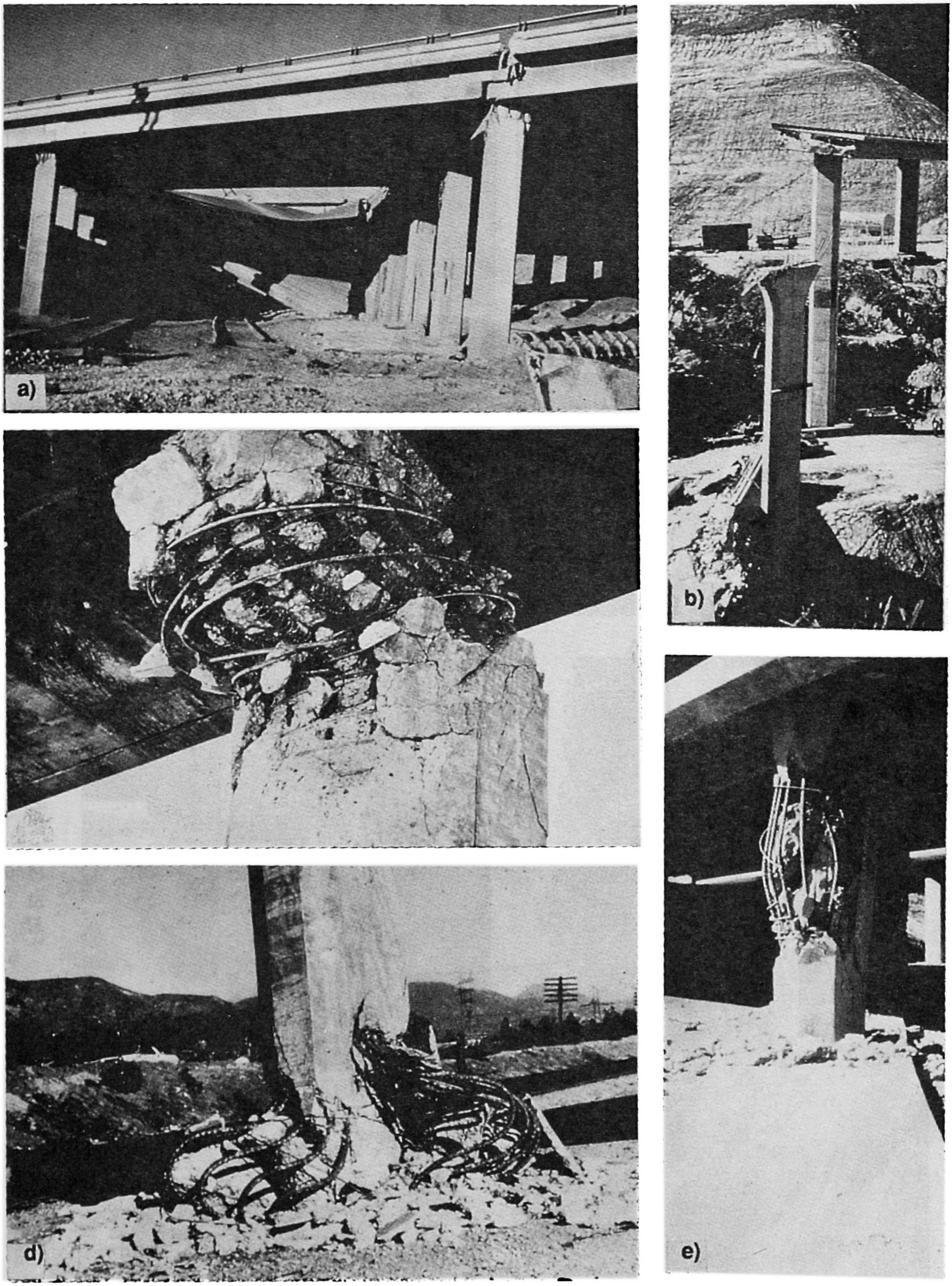


Fig 1. Bridge Damage During the 1971 San Fernando Earthquake

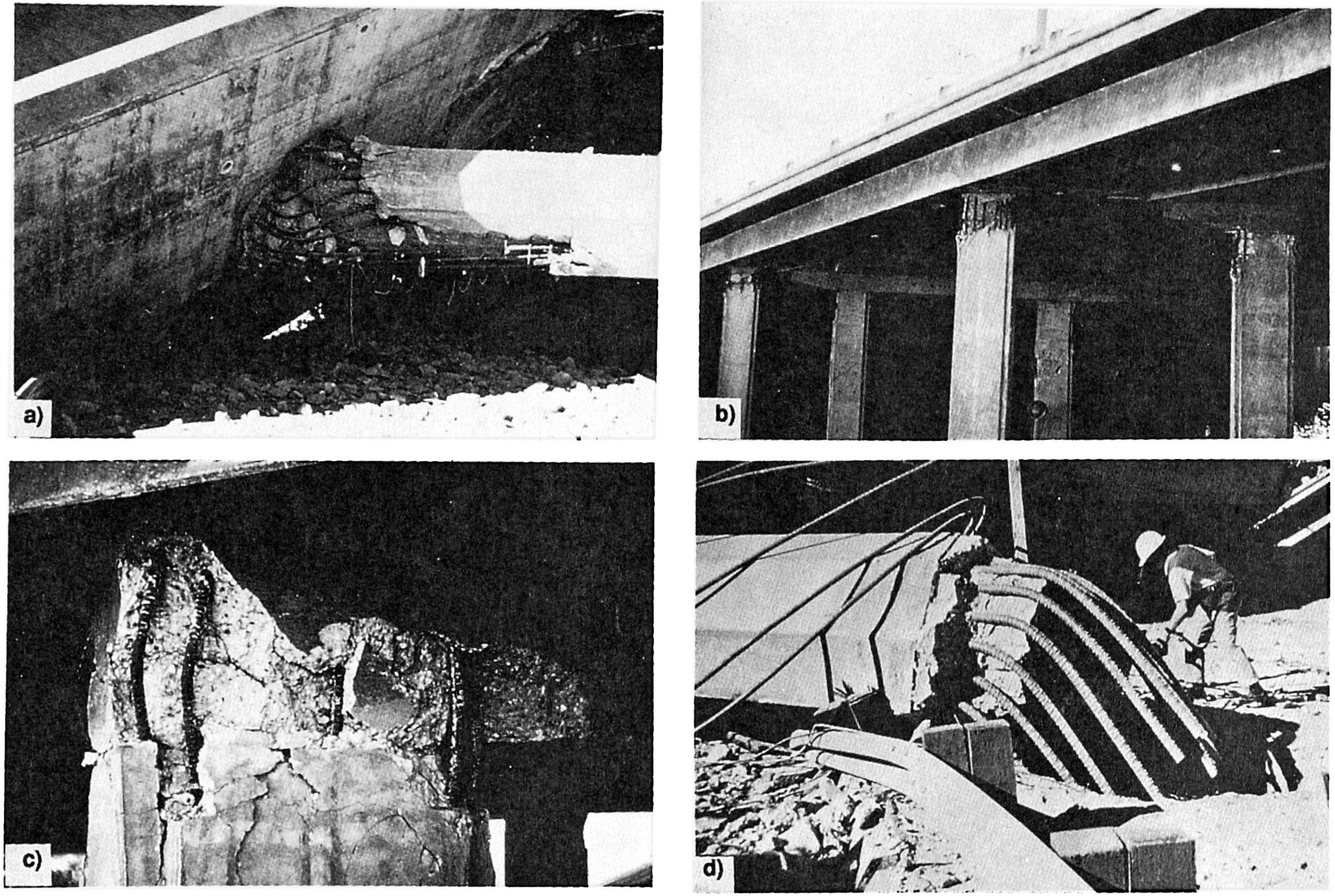


Fig 2. San Fernando Earthquake Bridge Damage (continued)

urban concrete freeway systems since transverse pier reinforcement typically consisted of nominal 12 mm Ø bars @ 300 mm (#4 @ 12 in.) and was not designed for the plastic shear which can be developed by the flexural column capacity, based on current seismic capacity design principles [5].

Finally, Loma Prieta (1989) revisited all previously encountered problems with emphasis on double-deck viaduct structures through the collapse of a 1 km (0.7 mile) long section of the upper deck of the Cypress Viaduct in Oakland, and significant damage to other double-deck viaduct sections in San Francisco.

The collapsed upper deck of the Cypress Viaduct in Oakland is shown in Fig. 3a, featuring columns and pedestals reinforced with 12 mm Ø ties @ 300 mm (#4 @ 12 in.) and joint regions without joint shear reinforcement. Figure 3b depicts a lower cap/column connection with pullout failure of top and bottom cap reinforcement due to inadequate anchorage length and Fig. 3c shows a typical joint failure of the lower cap/column joint region. Typical column shear failure was encountered on Highway 101 – Central Viaduct – see Fig. 3d, and lap-splice failure of column bars in the plastic hinge at the top of the footing was encountered in single-column bents on the West Grand Avenue Connector in Oakland, see Fig. 3e.

Outrigger bents showed problems in flexure and shear in the cap and shear failure of knee joints, see Fig. 4a, due to lack of shear reinforcement, and a fractured 57 mm Ø (#18) bar was encountered in a damaged knee joint on I-980, see Fig. 4b, which can be attributed to large strains introduced during bar bending (6.25%) and possible strain aging effects.

Finally, on struve slough, Figs. 4c and d, the plastic hinge at the column top sheared off and the column offset in the longitudinal bridge direction and punched through the reinforced concrete deck slab.

Additional seismic bridge problems not shown in the figures are liquefaction and associated support displacements at piers and abutments, abutment wing and back wall failures due to superstructure impact, and footing failures due to inadequate flexure, shear and/or joint shear reinforcement.

As a consequence of the damage observed in these earthquakes and analyses of typical structures, the following major problem areas in concrete bridge structures have been identified:

- Inadequate flexural strength of columns and cap beams resulting from design to elastic theory, and from inadequate development of reinforcement.
- Inadequate flexural ductility resulting from insufficient confinement reinforcement in plastic hinge regions, coupled with inadequate detailing.
- Inadequate shear strength of columns resulting from underestimating flexural strength, lack of a capacity design approach and insufficient, poorly detailed transverse reinforcement.
- Inadequate joint shear strength, particularly in column/cap beam connections, and at column/footing connections.
- Inadequate superstructure moment capacity to force plastic hinges into columns under longitudinal response to earthquakes.
- Inadequate footing moment and shear capacity to sustain column plastic moment capacity.
- Inadequate pile capacity (particularly uplift) to sustain column plastic moment capacity.
- Liquefaction potential of foundation material for pile-supported footings.

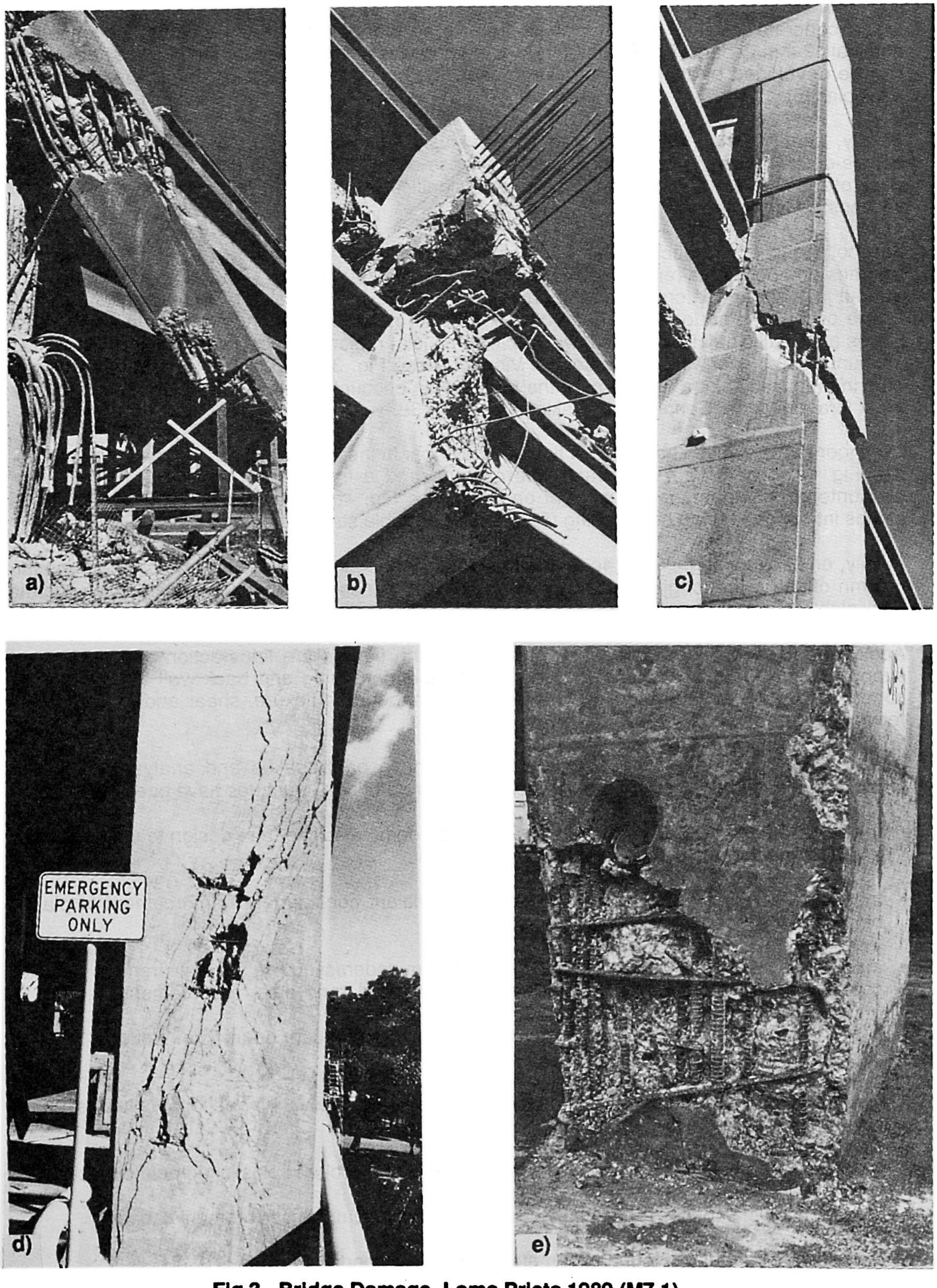


Fig 3. Bridge Damage, Loma Prieta 1989 (M7.1)

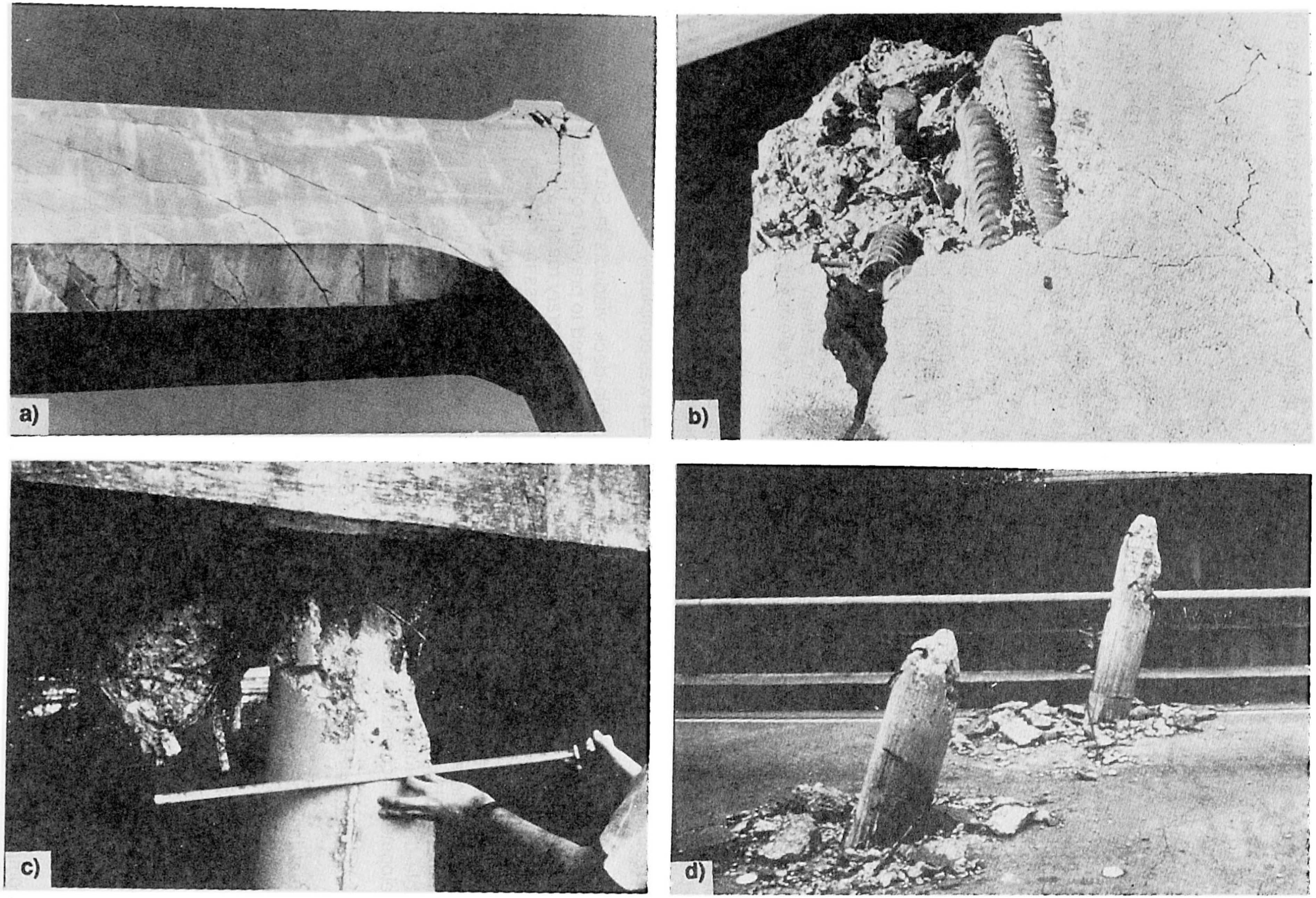


Fig 4. Knee Joint and Plastic Hinge Failure, Loma Prieta 1989

Inadequate structure ductility to sustain potential relative displacements between piers of bridges crossing active faults.

3. RETROFIT IMPLEMENTATION

The Caltrans seismic retrofit program, which began following the 1971 San Fernando earthquake, consists, as outlined above, of three phases, namely (1) movement joint restrainers, (2) single-column bents, and (3) multi-column bents. Phase 1 was completed in 1989 for all bridge structures in California and examples of cable restrainers, whose function is to prevent drop-type failures at expansion joints, hinges and abutment seats, are depicted in Figs. 5a and b. A total of approximately 1,300 bridge structures were retrofitted by Caltrans under the Phase 1 retrofit program.

The Phase 2 and Phase 3 programs are currently proceeding simultaneously and, since Loma Prieta, at an accelerated pace. Both phases address above outlined problems of column flexural strength, column flexural ductility, column shear strength, cap capacities and ductility, superstructure capacities, joint shear, reinforcement development, footing capacities, and abutment capacities. Based on research primarily performed at the University of California, San Diego for Caltrans [3], flexural ductility and shear strength in existing columns and piers can be ensured through partial or full height steel jacketing, see Fig. 5d. Other retrofit measures which are currently being implemented in California for bridge columns consist of composite fiber jackets with glass or carbon fibers in an epoxy matrix and actively prestressed with a Portland cement grout pressurized bladder which is placed between the existing column and the fiberwrap.

A flared pier wall which experienced shear distress during the Loma Prieta earthquake was repaired and retrofitted with a full height steel jacket, see Fig. 5c, for increased shear capacity. The previously discussed joint shear failure in an outrigger knee joint of I-980, see Fig. 4b was repaired by full replacement of the joint concrete, see Fig. 6d, and added joint shear reinforcement, while the outrigger bent shown in Fig. 4a was completely replaced, see Fig. 5e.

Following the Loma Prieta earthquake, several double-deck viaducts in San Francisco were closed to traffic and temporary retrofit strategies were designed to prevent collapse in the case of additional seismic activity in the near future. Some of the temporary retrofits were fully or partially implemented, see Figs. 6a, b and c. However, their ineffectiveness in providing required lateral confinement levels and their lack of global structural seismic retrofit strategy, see [3], prompted a reevaluation of these temporary retrofit schemes and resulted in the immediate design of permanent and final retrofit measures, which are currently being scrutinized, proof tested and implemented [3]. The difficulties encountered during the design process of the San Francisco double-deck viaduct retrofits and other ongoing retrofit projects showed the need for the development of consistent seismic assessment and retrofit strategies for bridge structures.

Retrofit strategies tested and implemented to date in California consist of

- steel jacketing, composite fiber wraps or prestressed wire wraps to enhance the flexural ductility in plastic hinge regions through active or passive confinement
- steel jacketing or composite fiber wraps to increase the shear capacity of existing columns and pier walls
- concrete jackets on knee joints to increase the joint shear area and to allow additional placement of joint shear reinforcement
- reinforced concrete footing overlays to increase the footing capacities in flexure, shear and joint shear
- complete replacement of damaged or inadequate components such as joints or complete bent systems.

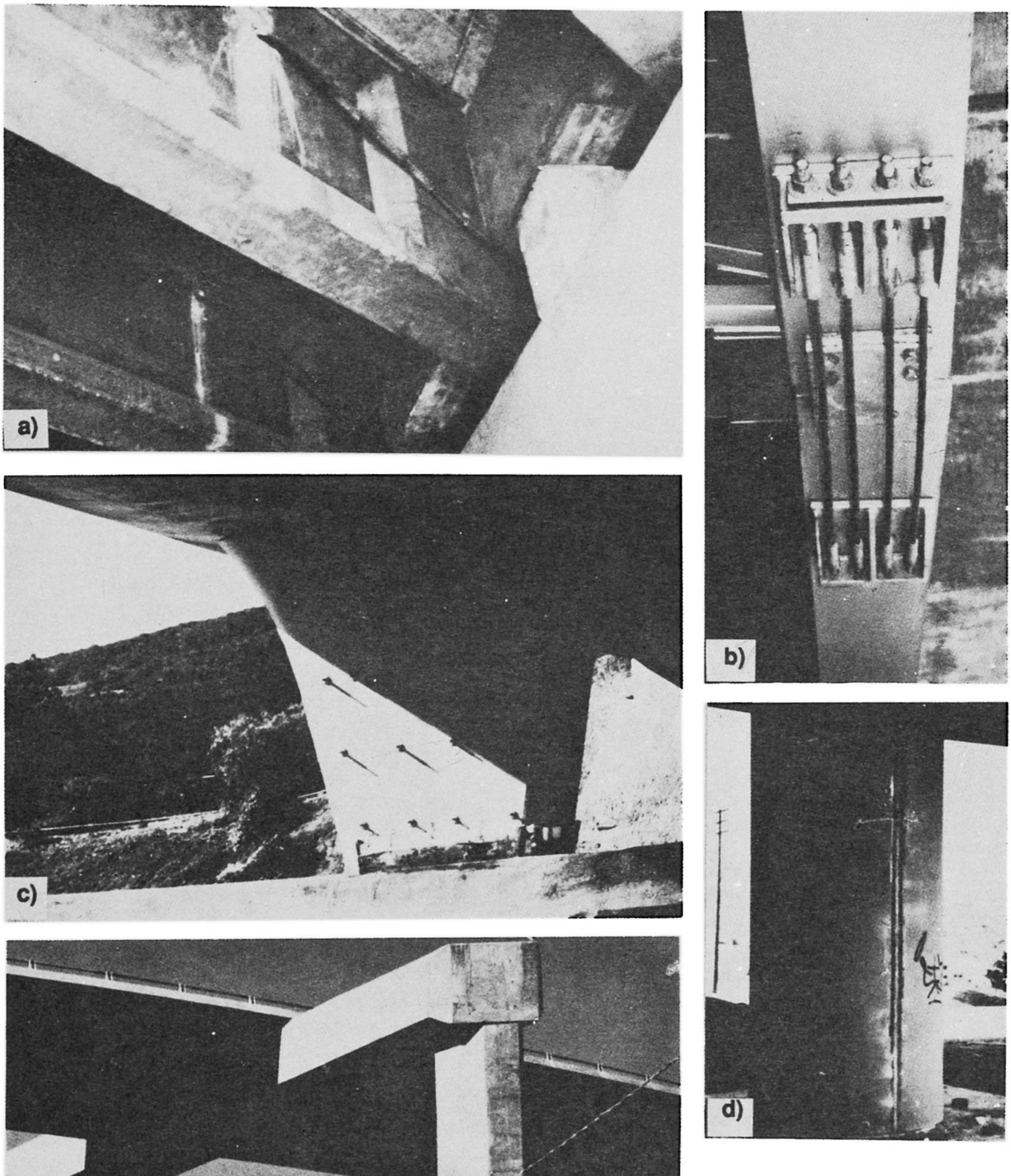
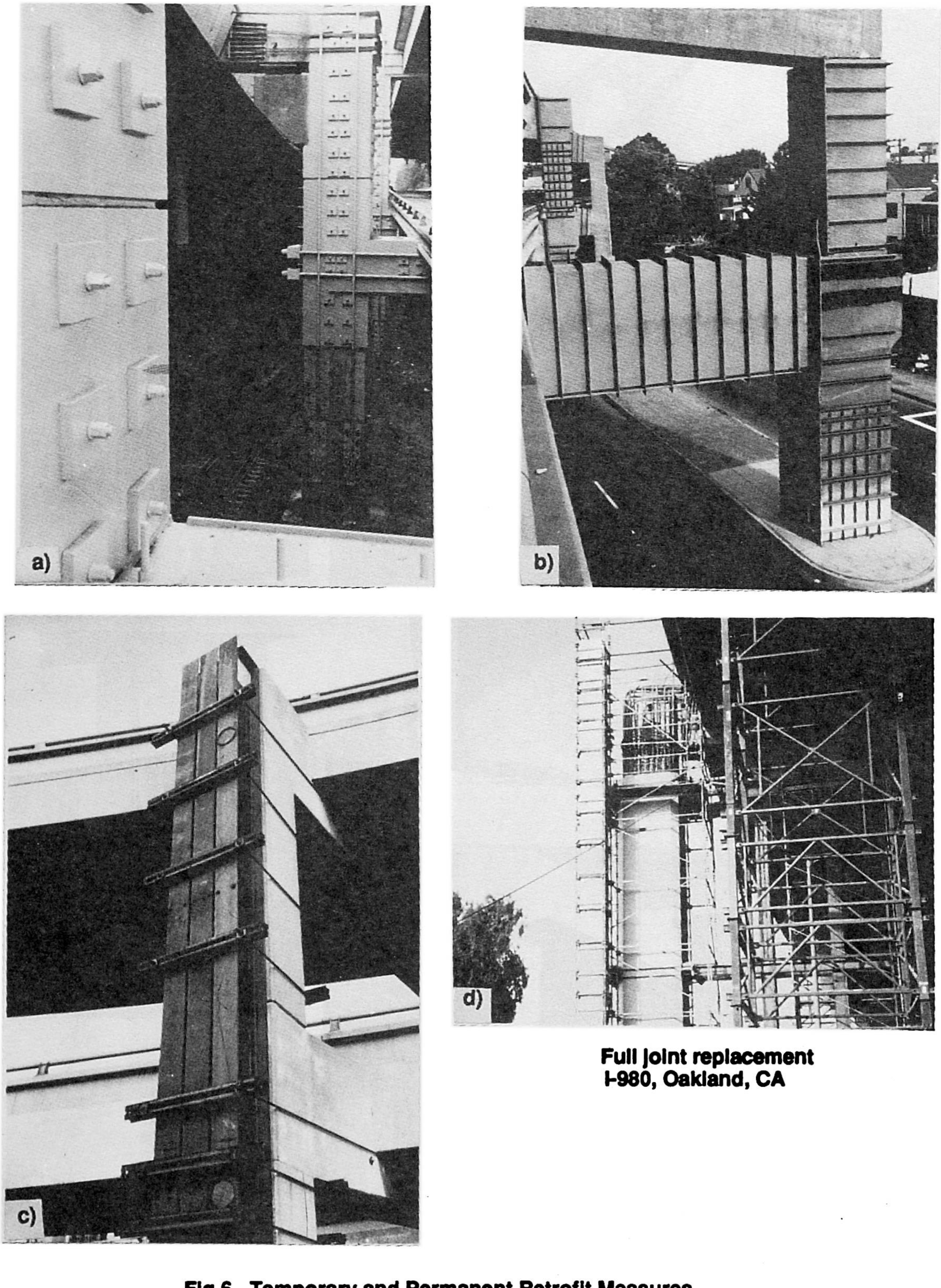


Fig 5. Implemented Permanent Retrofit Measures



Full joint replacement
I-980, Oakland, CA

Fig 6. Temporary and Permanent Retrofit Measures

The underlying retrofit philosophy is to create a structural system which is redundant and which has a ductile global collapse mode through the formation of well defined local ductile mechanisms.

4. CONCLUSIONS

Earthquakes are viewed as natural disasters due to their unpredictable nature and devastating consequences in the form of failures of manmade structures such as buildings, bridges and lifelines. On the example of urban concrete bridges, the vulnerability of manmade structures under seismic attack is demonstrated and measures are outlined toward seismic hazard mitigation of existing structures. The unknown state of existing bridge structures and the enhancement of their seismic performance through retrofitting pose challenging engineering problems which greatly exceed the complexity of seismic design for new structural systems. Significant developments are needed both in research and engineering applications to extend the state-of-the-art of seismic behavior assessment and retrofitting of existing structural systems.

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Seminar 5

Urban Transport Structures

Structures dans les transports urbains

Bauwerke für städtische Transportsysteme

Organizer: John Breen,
USA

Chairman: S.P. Chakrabarti
India

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Second Stage Expressway System in Bangko:

Deuxième phase du système de voies express à Bangkok

Zweite Ausbaustufe von Bangkoks Expressstrassennetz

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Ekasit Limsuwan, born 1947 in Bangkok, received his Civil Engineering degree from Chulalongkorn University. He obtained his Ph.D. from the University of Texas at Austin, worked for Centre for Highway Research in the USA. In Bangkok he worked with several Consulting firms in structural concrete, bridge and building structures.

Theerapong ATTAJARUSIT
Deputy Governer
Expressway & Rapid Transit Authority
Bangkok, Thailand

Theerapong Attajarusit, born 1942 graduated from H Chulalongkorn University and completed his post-graduate study from Univ. of Illinois at Urbana the USA. He has been teaching at Khonken University for several years, worked with Consulting firm in Bangkok and joined ETA as a director of the Technical department. He has been Deputy Governer for planning and development since 1991.

SUMMARY

Second Stage Expressway System in Bangkok (SES) is one of the most outstanding projects in the urban transportation system. The project has studied and planned, for more than two decades, the master plan has been implemented for the first stage and now for the second stage, while the third and fourth stages are in the process of design and study, respectively. Project development of the SES in cooperation with the management to privatization at a great success will be introduced. Project execution has carefully been pursued to obtain the most reliable project of effective productivity, high quality and accurate performance. The structural systems of segmental box girder and U-beam section will be presented with their appropriate construction techniques. The operation system for the SES will also be discussed concerning toll collection, revenue, traffic regulation, inspection, repair and maintenance.

RÉSUMÉ

La deuxième phase du système de voies express à Bangkok (SES) est l'un des plus remarquables projets dans le domaine des transports urbains. Cette réalisation a été étudiée et planifiée durant plus de deux décennies; elle comporte le projet principal ayant déjà été exécuté au cours de la première étape, puis la seconde étape actuelle, enfin les troisième et quatrième phases qui sont en cours d'étude. L'article présente le développment du projet de la deuxième phase du SES avec le concours d'une gestion privatisée de grande ampleur. L'exécution de ce projet a été poursuivie avec soin, en vue d'obtenir un ouvrage à fiabilité maximale, de haute qualité et offrant les performances ciblées. En outre, cet article expose les systèmes structuraux comportant les poutres-caissons en segments et les poutres à section en U, ainsi que les techniques de construction adéquates. Il analyse l'ensemble opérationnel du système de voie express SES, quant à la perception des droits de péage, la régulation du trafic, les inspections de contrôle, les réparations et l'entretien.

ZUSAMMENFASSUNG

Der Ausbau von Bangkoks Expressstrassennetz ist ein sehr ambitiöses Vorhaben, dessen Projektierung bereits über zwei Jahrzehnte währt. Zur Zeit wird die zweite Stufe des Masterplans umgesetzt, die dritte und vierte sind in Projektierung bzw. Studienphase. Mit grossem Erfolg wird die Privatisierung des Projekts vorangetrieben, wobei Landerwerb, Vergabe, Managementauswahl und Finanzierung besonderen Anforderungen hinsichtlich Effizienz, Qualität und Zielerfüllung unterlagen. Als Tragsystem wurden segmentierte Hohlkästen und U-Querschnitte gewählt. Der Beitrag bespricht auch das Betriebssystem hinsichtlich Strassenbenützungsgebühr und Amortisation, Verkehrsregelung, Inspektion und Unterhaltung.

1. INTRODUCTION

Bangkok is a wellknown beautiful city in the East, it is named as Vanice of Asia since water transportation had been used for long period in the past. But now Bangkok becomes a big city of the most serious traffic congestion. Bangkok has developed to so much in the last two decade, canels had been converted to road ways or drainage system instead of serving transportation system as usual. The population in Bangkok now is about 5 million in the metropolis or 8 million in the Greater Bangkok Area (GBA) including surrounding suburban. The population as expected to grow and may become 10 million within a decade.

Traffic congestion in the metropolis are very serious and become one of the nation critical problem. Vehicle speed on various main road are lower than 10 kilometer per hour in the rush hour and the people are suffered from travelling times in the city. The major cause may consider from poor-town planning, too many vehicle on the road, and lack of efficient public transportation.

In solving the traffic problem, various means have been introduced such as expressway system, mass transit system, eleveted highway, improvement of train services, and implement of water transportation. The Second Stage Expressway System (SES) is a continuation project of the First Stage Expressway System (FES) with an approximate 40 kilometer has been estabished and implemented to link with the FES at Makhasan, central interchange. Total cost of the project will be Baht 27.5 billion (US $ 1.10 million) within 5 years of construction. The first phase of 27 kilometers is supposed to open for traffic in March 1992.

This paper will present development of the project, project execution, operation and maintenance of the whole system. The Structural system for the expressway, and construction techniques will also be introduced as the most effective planning and scheduling to accommodate the execution period of 6 years including land acquisition, design, and construction.

2. PROJECT DEVELOPMENT

The study on long term improvement of Bangkok transportation system had been conducted between 1971-1975 by expert team arranged under bilateral assistance from Repubic of Germany. In accordance with such report, the Expressway and Mass Transit Authority (ETA) has been established since 1972 to responsible for implementation the long term project. The First Stage Expressway System (FES) had started by then and opened for operation since 1982. of first phase and followed by the success of a longest single plane cable stayed bridge in 1987 of the second phase. The Master plan of multi-projects for solving traffic congestion in Grater Bangkok have been summeried in Fig 1 including rapid transit project, and expressway systems; stage 1, 2 and 3, respectively.

The Second Stage Expressway System (SES) had been joinly studied by Japanese International Cooperation Agency (JICA) and ETA to recommend the route as shown in Fig 2, consists of two routes North-South from Chang Wattana to Bangklo (25 km) and East West route from Makkasan to Srinakarin Road (13.5 km). In detail design, East route of 2 km along San Saeb Canal had been included for purpose of combining and dispursing the traffic.

The development of SES will improve the traffic congestion in the Greater Bangkok Area (GBA), especially in the central Bangkok Metropolis as a result of a network formed between the SES and the FES. The new expressway to the North and East will help ease the traffic density in the city center. Travel time can be saved by 20% of normal travelling period and travelling speed can be increased by 24% so it will result in the reduction of traffic expense by Baht 14.0 million (US$ 0.70 million) per day. The SES will encourage commercial and residential development along its route. This will have the additinal benefit of spreading economic development through-out the Greater Bangkok Area. Better roads and reduce traffic congestion has improved psychologically effect on motorist which can not be measured in term of money.

The feasibility study of the SES was also considered by the office of the National Environment Board and the subcommittee controlling and co-ordinating the project relating to the serveys, designs and studies of the environmental impact. The subcommittee are considered representatives of various concerned offices.

3. PROJECT PRIVATIZATION

The cabinet passed a resolution for the ETA to consider a private investment in the SES project by mean of the grant a concession to the private sector to build and manage the project in accordance with conditions and procedures prescribed by the ETA.

The project privatization is a joint success between the government and the private sector for the development of the country. The investment value of the SES makes it the world's second largest public utilities concession project. This project is aimed at the spread and coordination of profit, rather than at a party's benefit or loss. The Bangkok Expressway Company Limited (BECL) has been awarded in this SES project with the term and conditions of the concessions as follows:

The investor must have a registered capital of approximately 20 percent of the project value which must not be less than Baht 1,800 Million Baht (US.$ 702 million).

BECL will bear the total costs of the construction and accessories and the investment risks without the goverment's guarantee to any loans.

The expressway must be constructed according to the required standards of the ETA and the construction must commence by 1990 and be completed by 1995 in respect of the first stage covering 39 kilometers.

BECL will refund the cost of land acquisition arrangement with interest at total of Baht 16,815 million (US.$ 673 million) in the last 15 years.

The toll rate for the urban and the suburban area must be Bath 30 (US.$1.20) and Bath 15 (US.$0.60), respectively with the discount of Bath 5 (US.$0.20) for the use of a combined area. The rates must be adjusted in accordance with the inflation rate at every 5 year

The toll revenue collected in the urban area will be shared between the ETA and BECL at the rate of 40/60, 50/50 and 60/40 in respect of the first, second, and third nine year periods, respectively.

The Expressway system and its accessories will belong to the ETA after the expiration of the 30 year period.

4. PROJECT EXECUTION

ETA put all of its effort to achieve the success of projects under its responsibility. The increasing number of the FES users has shown the demand and favor of using the expressway. Besides ETA successfully invited private sectors to invest in the SES and the Mass Transit System, of which a huge sum of investment is needed, so the implementation of project on privatization basis has lessened the financial burden of the government. In addition, ETA has also implement the Third Stage and the Fourth Stage Expressway System Project and the Ekamai-Ramindra Project to cope with the ever increasing traffic volume.

The Bangkok Expressway Co.,Ltd. (BECL) as awarded by the government, through the ETA for a 30 year contract to build and operate the SES has proposed the management team as shown in Fig. 3; comprising project manager, contractors under the supervision of ETA'S engineers; independent design checker and independent certification engineer. The construction of the 39 kilometers expressway is scheduled to commence on the March 1, 1990 (Fig. 4), with an estimated amount of investment of Bath 25,000 million (US.$ 1,000 million)

The financial package of the SES project is recognized as an outstanding example of innovation and co-operation between local and forign financial institutions. Shareholder of BECL authorized an increase in capital up to Bath 5,500 million (US $ 220 million) with an initial capital as already been registered. Onshore credit facilities with a syndicate of 11 major local banks are structured to provide loan, garantee, note, aval and acceptance financing of up to Baht 22,000 million (US $ 880 million). The on-shore credit facilities are further supported by an off-shore credit facility which was executed between 30 major international banks to provide gaurantees to barrowings of an amount up to the lower of US.$ 275 million.

Land acquisition to construct the SES has been carried out by ETA. The land and the building to be expropriated for the construction at total of 5,567 plots of land and 8,476 buildings. The Royal Decree issued in 1987 has been enforced so that ETA can gradually commence to appropriate the immovable property located in the right of way. A committee responsible for the initial price of immovable property, will consider the compasation under the criteria as

Land based on the higher appraised value will be in accordance with the cost of land as listed on the dated of enforcement of the Royal Decree

Building indemnity payment for buildings consists of removing cost, labor cost for reconstruction, design fee, and other compensation costs.

5. STRUCTURAL SYSTEM

The structural design of the SES uses the latest internationally proven technology and is intended to facilitate construction work with the minimum of discruption to traffic flow and the surrounding areas. A combination of segmental box and U-beam construction will be used. Both methods employ precast concrete components to create road deck, allowing precise quality control and as the components are cast off site, this again helps to minimize disruption to the traffic.

5.1 Substructures

Since soil condition in various parts of Bangkok are somehow difference from one places to the others, and due to soft soil condition then long piles of various length are used in this project. The average length of 40.00 meters are constructed by bored piles technique, except the location of pilecaps on swamp are where precast driven piles are used instead. Pile-caps are cast on pile groups with a typical of 5 piles per peir. The peirs are box section with an average height of 10.00 meters and the caps are designed to accommodate the differential settlement of 50 mm. Structural portions of ramps or transition zones between ground and elevated section, the structures are designed and constructed by precast piles of diffrent lengths, flat plate mate, retaining structures and back-fill to support the pavement. The structures will accommodate long term differential settlement and will obtain smooth ride.

5.2 Segmental Box

A single box girder is designed to accommodate 3 lanes traffic. The system consist of 14 segments per span, are assembled span by span and then stressing by dry joint external post-tensioned system as shown in Fig 5. Reinforced concrete continuous deck will joint each span together with special details to obtain smooth connection as which the expansion joint will be provided at every four spans. Fix and slide bearing units are used for each span to accommodate diffrential settlement, thermal elongation, creep, strinkage and prestressing losses.

5.3 U-Beam

Only some section of the project that required multi-box girder due to some limitation of site congestion and peir location. The cross section as shown in Fig. 6 will be precast member of a U-shape. Top deck is cast in-situ to complete the whole section with provision of shear connectors at the interface between web of U-beam and the top deck. Ends of each span will link together as a diaphram action for lateral stability and as for a continuous deck between span to obtain smooth connection. The span length of U-beam varies from 22.00 meter to 35.00 meter depends on the geometric configuration and peir location. The expansion joint will also be provided at every 4-6 consecutive spans in the same manner as the segmental box.

6. CONSTRUCTION

The SES currently under construction carried out by the Bangkok Expressway Company limited (BECL). The BECL in turn appointed Kumagai Gumi Company Limited as a Project Manager and five construction companies group have been awarded the six civil works contracts for the first phase. These include contracts for the substructure work at ground level, including construction of the main supporting columns for the elevated roadway and for the superstructure work, to erect and finish the road deck. The construction of the first phase currently underway includes the North-South route from Changwatana to Phayathai and the East-West route form Phayathai to Rama IX. It is due to be completed and fully operational during 1993. The second phase which is in the process of land acquisition will see the start of construction in 1992. It comprises 12 kilometer North-South connection between Phayathai to Bangklo at the Cable Stayed Bridge and East-West from Urupong to Rachadamri. This will be completed in 1995.

The construction techniques for segmental decks with total length of 20 kilometers, the box girder segments have been prefabricated at the world largest precast yard in Bang Pa-in, 60 kilometer away from Bangkok, are loaded onto the several vehicles of the groups fleet to deliver at the construction site where peirs are ready for erection. Luanching gantries with total length of 96 meter are used to support and erect the segments prior to post-tensioning of external prestressing. Bearing units as elastomeric pad are installed after stressing and then top decks are simultaneously cast to meet the requirement as well as the parapet.

The construction of the expressway on North-South route along water supply canel, with some difficulties including narrow work spaces, time restriction, heavy traffic and noise problem with neighbourhood, then U-beam construction are used for this portion. The U-beams of average span length 30.00 meter and weight of 80 ton are cast in the precast yard at distance about 4 kilometers from the site, they are carried on a special transporter, to the site and then are hoisted from the transporter using 58 meters launching gantry which following the completion of each span as self-driven to the next section. Once U-beam installation is completed, reinforced concrete slab which make up the actual road deck are cast over precast formwork. The parapet wall then are constructed ulilising travelling formwork systems to complete the whole roadway section.

7. OPERATION AND MAINTENANCE

The FES and SES will be operated adopting the flat tariff and on-ramp toll collection system. The location of the on and off ramp have been determined as shown in Fig 7. Toll gate structures, refuge island, toll booths, toll buildings and equipment installation are included in the cost.

Expressway lighting and other electrical system will be provided on throughway, interchange, rampways, at grade intersection, toll plaza, and toll buildings. Subsystem such as closed circuit TV system, sign, control system and emergency power unit will be istalled and operated in the regular basis.

The operation system will be controlled by the ETA under the management of the BECL. For the structures and operating equipments will be subjected to general inspection on routine basis, daily, monthly or anually. According to this inspection, conditions of structures are evaluated and classified for the maintenance. Some items may be subjected to a detailed or special inspection and then repair or retrofitting may required as necessity. The ETA is forming a specific program to solve some problems of the traffic at the interface between the expressway system and the local roads of GBA, so that the stable transit system in the SES and traffic congestion will be relieved.

8. CONCLUSION

The Second Staye Expressway System in Bangkok has been well studied, planned and developed considering various aspects such as traffic valume, travel time, financial effects, social factor and environment impact. The concept of project privatization in co-operative between the government and private sector to reduce burden of investment, minimize construction duration and obtain excellent management. The structural system related to the construction techniques as employed in this project has proved to most the efficient and advanced technology to achieve high quality structures of better performance and to sastisfy the project objectives in reduce traffic congestion in Bangkok at remarkable saves on travelling times and reduction of traffic expense.

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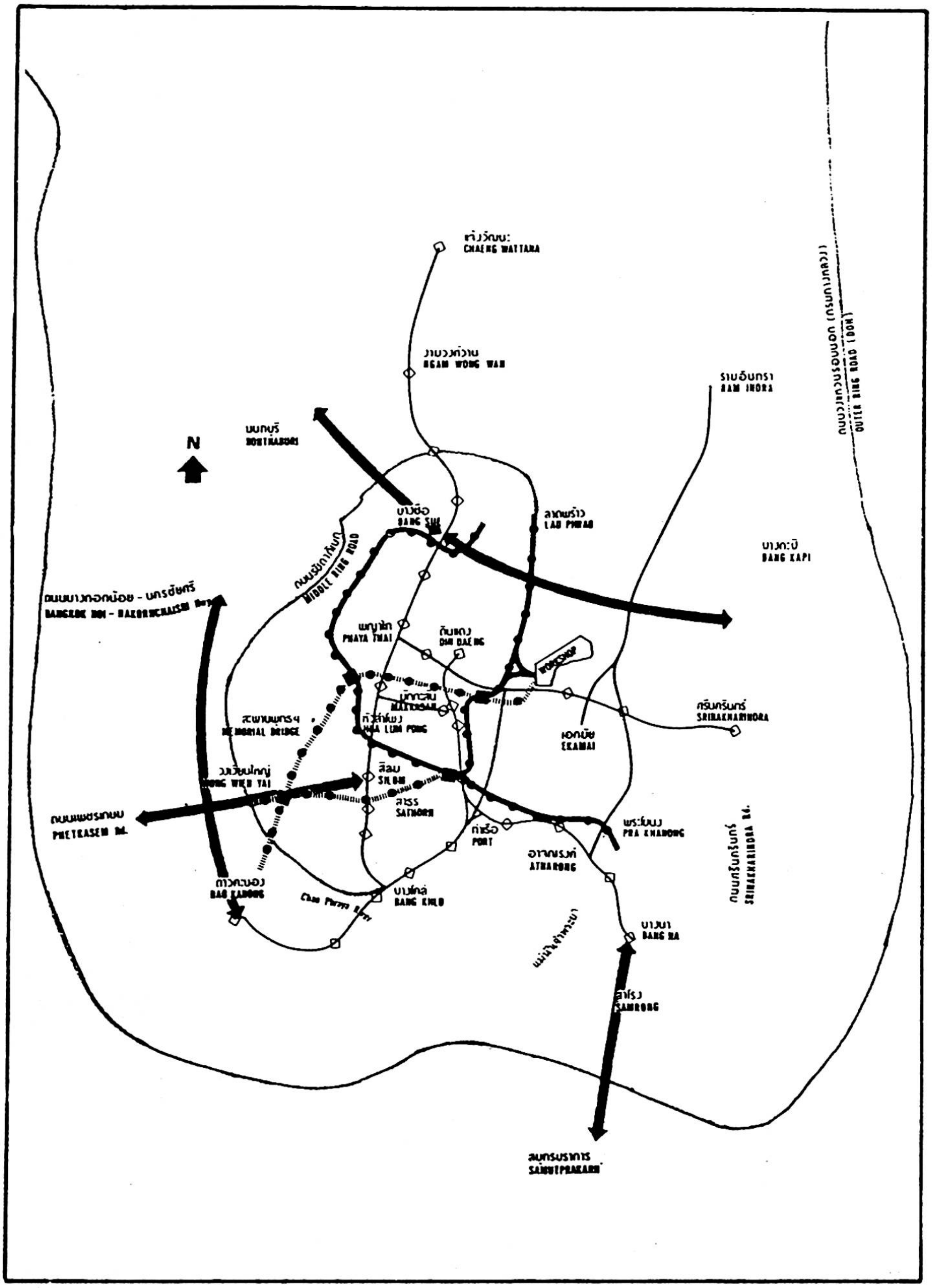

Fig.1 Expressway and Mass Transit System in Bangkok

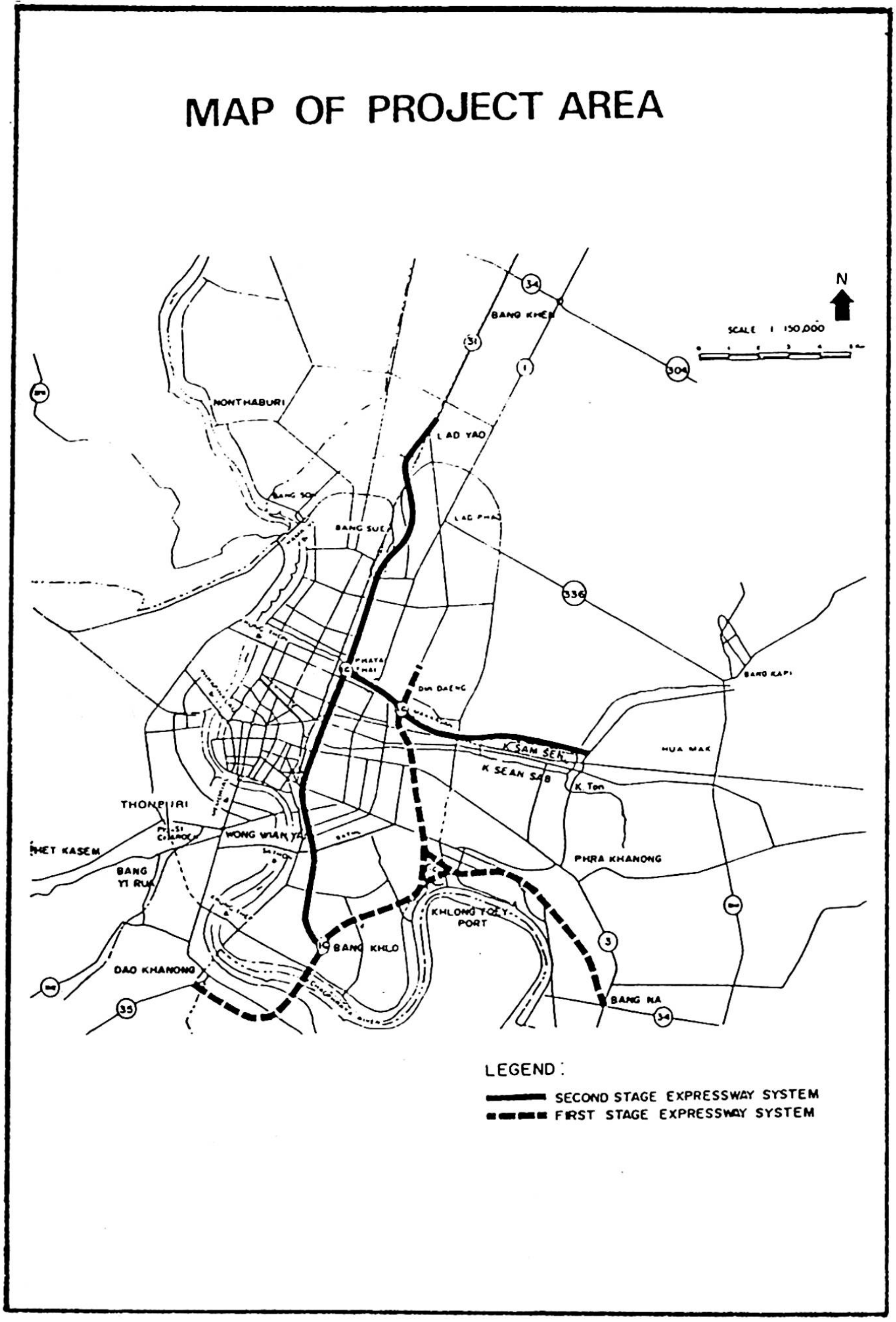

Fig.2 The Second Stage Expressway (SES)

MANAGEMENT TEAM

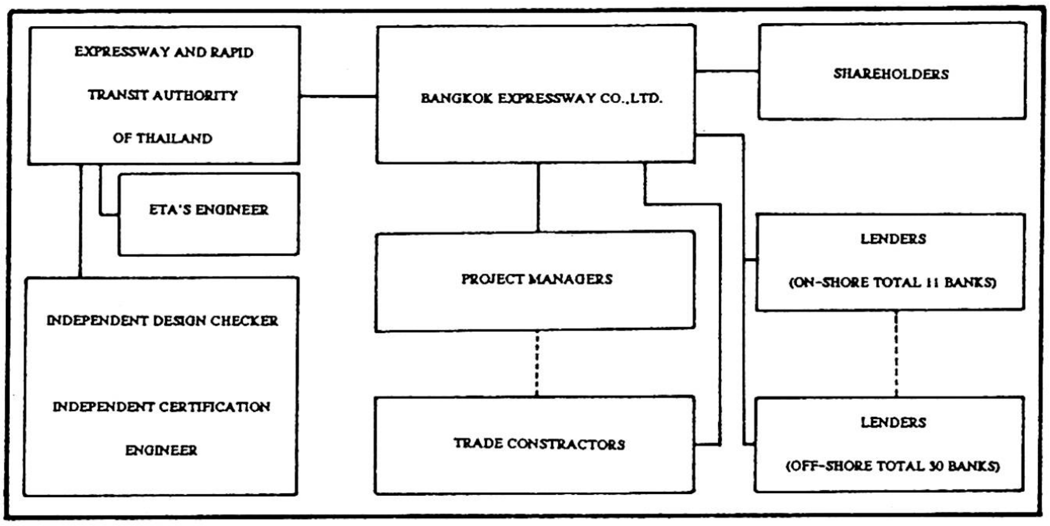

Fig.3 SES Management Team

MASTER PROGRAMME

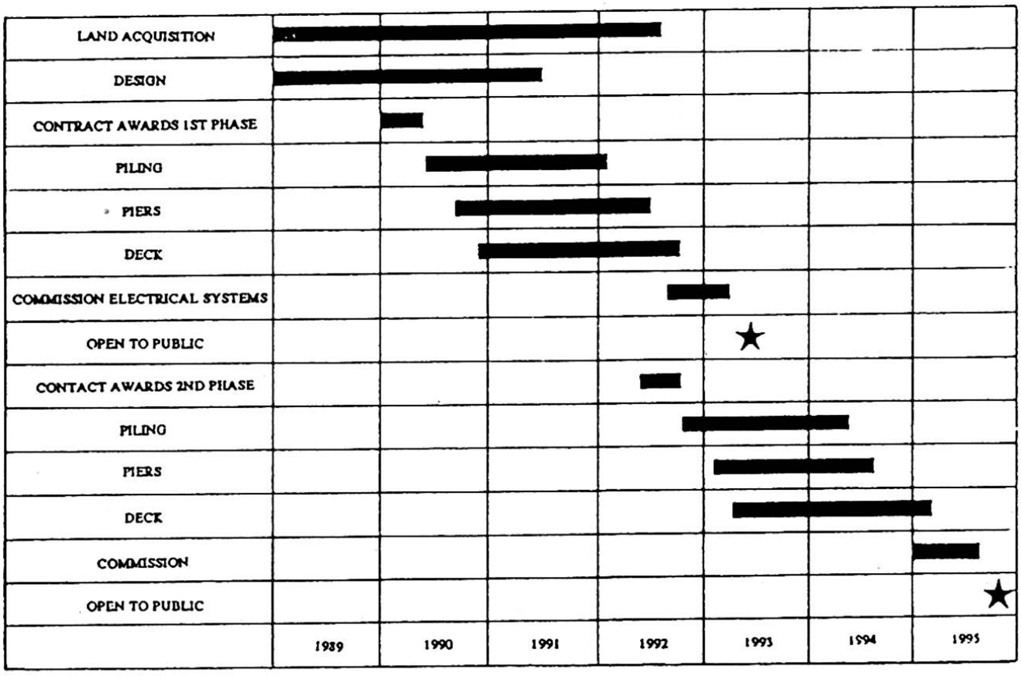

Fig.4 Master Schedule for the SES

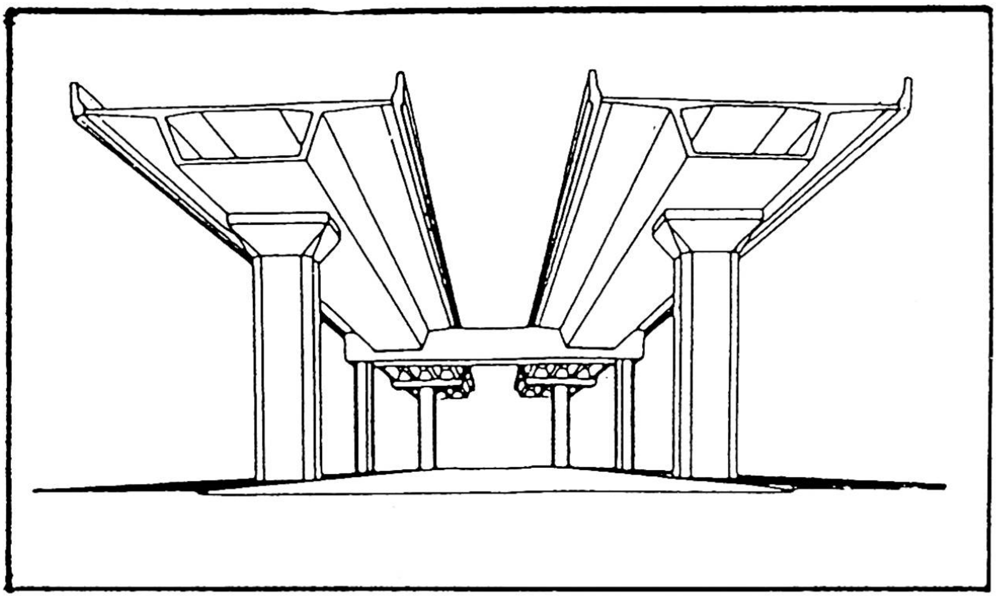

Fig.5 Segmental Box Girder

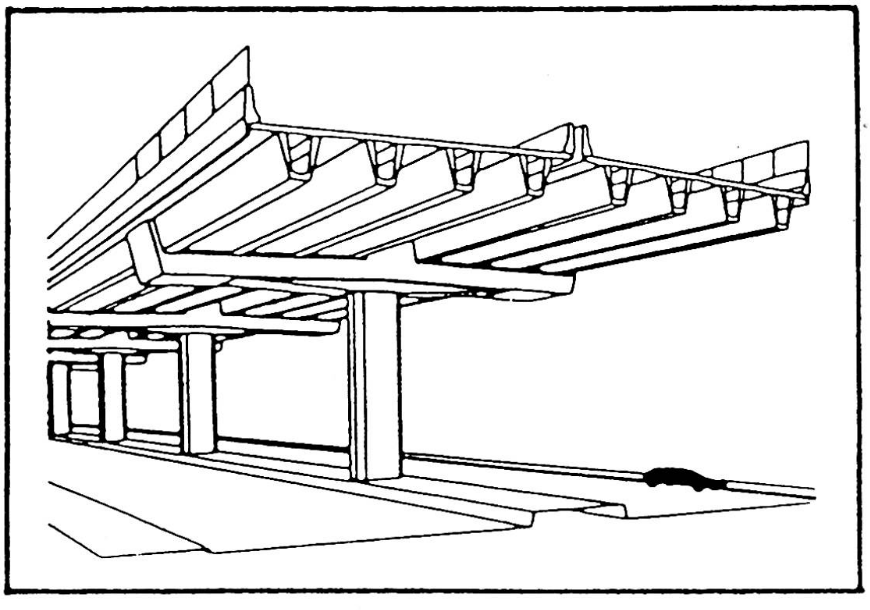

Fig.6 U-Beam Section

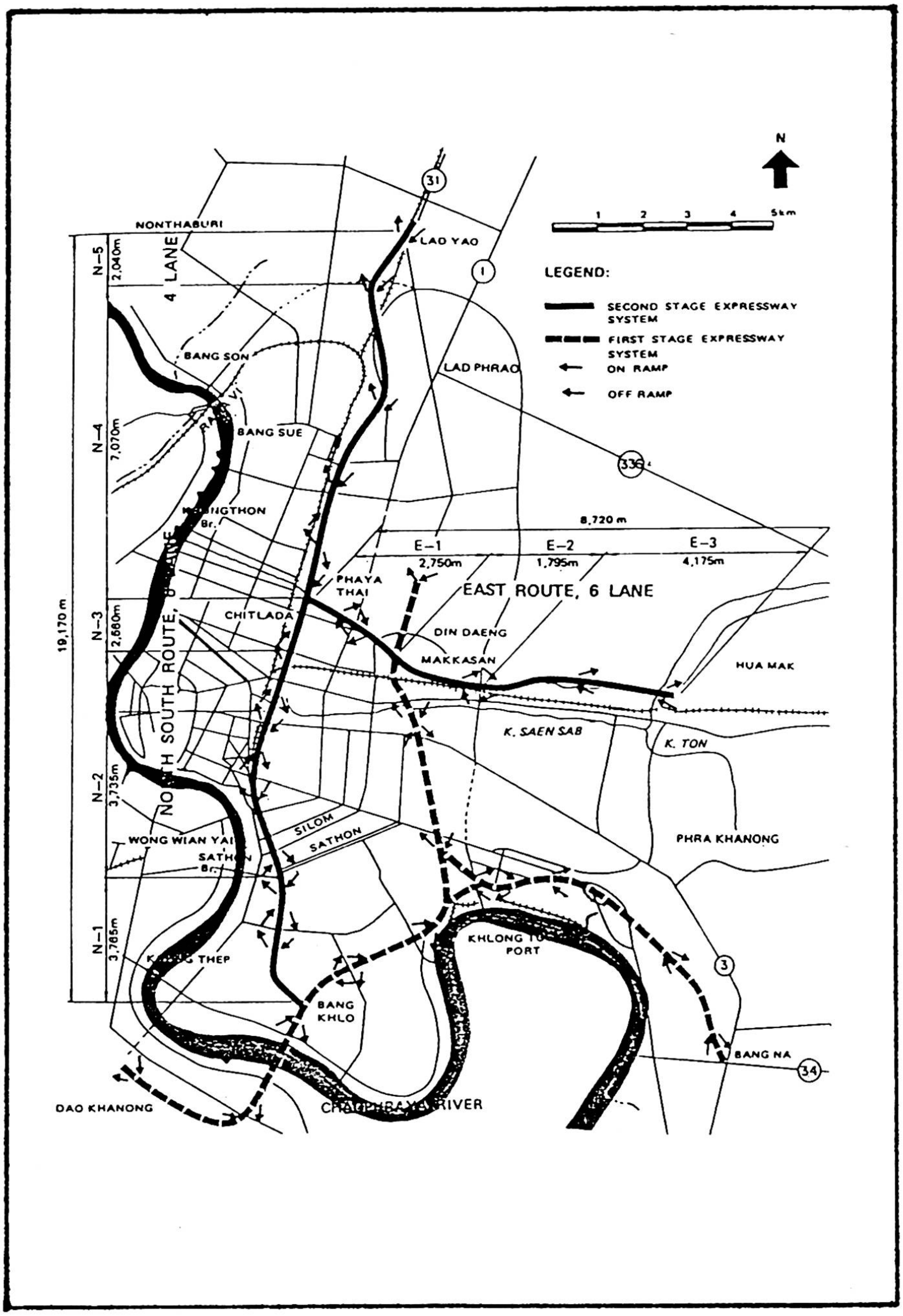

Fig.7 Ramps and Toll·Booth Locations

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Rehabilitation of Transit Authority Structures in New York

Rénovation des structures du réseau urbain à New York
Sanierung von New Yorks Transportsystem

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Mysore L. Nagaraja is a licensed Professional Engineer in New York and New Jersey. He has a Masters Degree in Civil Engineering. Presently he is responsible for New York City Transit Authority's multibillion dollar Capital Program. Mysore Nagaraja has 26 years of professional experience which includes 16 years in the field of transportation, bridge design and petro-chemicals.

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Raza, A. Khan has over thirty years of engineering, research and management experience. A licensed Professional Engineer in New York and New Jersey, Raza Khan is presently responsible for the structural design of the NYC Transit Authority's multi-billion dollar Capital Programme.

SUMMARY

The New York City Rapid Transit, the largest and oldest system of its kind in the United States of America, is being restored to a state of good repair. The capital investments in the rehabilitation of its infrastructure, is the only viable alternative to ensure that the system will continue to serve its 3.5 million daily customers. This article describes some of the more important rehabilitation work performed in the past several years.

RESUME

L'administration du réseau urbain de New York – le plus ancien et le plus grand système de son genre aux Etats Unis – est en train de remettre en état son réseau routier. Les investissements pour la rénovation de l'infrastructure sont la seule alternative possible qui permette au système de continuer à desservir 3, 5 millions d'utilisateurs quotidiens. Cet article décrit quelques-uns des travaux de rénovation les plus importants réalisés au cours des dernières années.

ZUSAMMENFASSUNG

New York Citys' Rapid-Transit-System, das grösste und älteste öffentliche Transportsystem der Vereinigten Staaten, wird gegenwärtig in einen guten Unterhaltszustand zurückversetzt. Die Kapitalinvestitionen zur Sanierung seiner Infrastruktur sind die einzige mögliche Alternative, um die Gebrauchstüchtigkeit für seine täglichen 3, 5 Millionen Benützer sicherzustellen. Der Beitrag beschreibt einige der wichtigeren Sanierungsarbeiten aus den vergangenen Jahren.

1. INTRODUCTION

The New York City Rapid Transit System, the largest and oldest in the United States and one of the oldest in the world, consists of elevated, and subway track spread over the four boroughs of Brooklyn, the Bronx, Queens, and Manhattan. It carries an average of 3.5 million passengers per day. Over 5,000 subway cars carry one million passengers during every rush hour period, guided, controlled, and powered by 10,000 signals, 1,400 switches, 70 power substations, and 700 miles of track. Simply put - the New York City Transit Authority moves the people of New York.

The system was built in stages since 1885, bringing it to the present day level of completion. Considering the age, the system has maintained its status as one of the foremost systems in the world and has served the New York metropolitan area whose demands and expectations are diverse. This is probably the only system in the world that operates 24 hours a day, 365 days a year. The successful operation of a system of this magnitude and age requires viable solutions to the numerous problems encountered during its service life. The replacement cost of the system, in 1990 dollars, is estimated to be around 200 billion, not including the value of the real estate. Total replacement would be, therefore, out of the question. The only alternative is rehabilitation and properly scheduled maintenance.

We are moving towards a 21st century technology in terms of communications, signal systems, and cars. In order to readily accept this technology for operational use, all the tunnels and structures need to be rehabilitated and brought into a state of good repair.

The system comprises of a total of 230 route miles. Out of these 230 route miles, 123 miles or 54% of the system is underground. Another 37 miles or 16%, is in open cut, on embankment or on grade, while 70 miles or 30% is on elevated structures, which can properly be classified as continuous bridges. These 70 route miles include 181 track miles and 155 stations.

2. ELEVATED STRUCTURES

Some of the problems we face today on the elevated structures stem from the fact that most of the elevated lines were originally privately owned and operated. As a result we have structures of different size, of varying construction details, designed for lighter loads and less frequent operation, and meant to meet different social and environmental conditions. These factors compound the common maintenance concerns such as normal wear, corrosive attack by the elements, foundation settlement, fatigue failure, and obsolesence.

In order to understand the rehabilitation work, acquaintance with the nomenclature and the basic design elements of the elevated structures is necessary.

Foundations supporting the columns of the elevated structure are normally unreinforced concrete pedestal type footings, approximately ten feet deep, which support the elevated columns. Older columns are generally built-up sections. Today we use single wide flange members.

Rigidly connected by brackets to the tops of the columns are built-up members called cross girders. Attached to these, running parallel to the tracks, are built-up members called track stringers.

Clamped on top of the stringers are the cross ties which support the tracks. In addition to these basic elements, bracing, stiffeners, and expansion joints are provided as required. Design loads include a combination of dead load, live load, impact, wind, and traction loads.

2.1 Structural Rehabilitation

The Transit Authority utilized the services of a consulting firm to perform a study of the condition of our elevated structures. This study was completed in 1978 with the conclusion that the structures were generally in a good condition, but identified need for specific rehabilitations. This study complimented the Authority's periodic in-house inspection. Based on the in-house inspection and the consultant study, the following specific needs for rehabilitation were identified:

- o Column Replacement (Jamaica Line).
- o Rehabilitation of Steel (over mezzanines).
- o Rehabilitation of Track Supporting Members.
- o Rehabilitation of Expansion Joints.

2.1.1 Column Replacement

On the Jamaica Line the Consultant found that, in an area near Crescent Street, the columns are overstressed by as much as 50% due to the loading from heavier cars used in the 1920s and 1930s. The original cars used on the Jamaica Line were constructed of wood, and were lighter in weight.

This line was constructed between 1888 and 1918, with several modifications made over the years. As a result, the line is not of uniform construction. In the section between the Van Siclen Avenue and Cypress Hills stations, a two track structure is supported on latticed columns comprised of four angles held together by lacing plates. In 1980 and 1982 the Authority awarded contracts totalling $8.5 Million for the repair and modernization of this section. including the replacement of 192 columns.

The replacement procedure of columns was fairly simple. After suitable traffic barricades were placed, a timber grillage was laid on the street adjacent to the old column, to serve as a temporary footing.

Two 14" wide flanged columns were secured between this grillage and the cross girder above, to temporarily take the column load. Working from mechanized scaffolds, ironworkers removed the old column connections. Utilizing a telescoping crane the old column was removed, and a new wide flange column put in place and connected.

Following the removal of temporary supports, the column base was cast in concrete.

2.1.2 Rehabilitation of Steel (Over Mezzanines)

At stations on the elevated lines, the control areas and mezzanines are often hung from the structure, below the trackways. In lieu of track stringers in these areas we use thru-span girders, so called because the trains run between them. These thru-span girders rest on the top flanges of the cross girder.

In a thru-span area a system of floor beams support the concrete and steel track decks, which also serve as the roof of the mezzanine. While elevated lines generally avoid drainage problems by the use of open decks, these solid decks require a drainage system, which in turn requires maintenance in order to avoid the problems of clogged drains, ponding water, leakage, and corrosion. Areas where steel members protrude above the concrete deck are particularly susceptible to water intrusion and its attendant problems.

The drainage system which presently exists in many thru-span areas is largely dependent upon a series of short pipes which pass through the webs of existing beams. Being beneath the track and ties, these pipes are difficult to access and have tended to clog. Water backing up from these blocked drains has caused corrosion of the structural members and leakage along these members to the mezzanines below.

The new design being used at thru-span section consists of a structural slab, supporting the track concrete. The separation plane is waterproofed. Drainage is into the track troughs, to an inlet at the end of the thru-span section, and then by drains and leaders into the City sewers. Note that this is a much simpler system, much easier to maintain.

The corrosion of the thru-span girders caused by the malfunctioning drainage system is repaired by adding web plates to restore the strength of these members.

2.1.3 Rehabilitation of Track Supporting Members

Another problem we have on elevated structures involves the top flange angles of the track stringers. Between stations the track is supported on wood ties which rest directly on these top flange angles. Moisture, which is absorbed by or trapped under the wood ties, causes corrosion of the top flange angles. This corrosion is generally not visible until the ties are lifted. Depending on the extent and frequency of the corrosion, top flange angles are either spliced in the corroded area or completely replaced. New material is connected to existing using high strength bolts.

2.1.4 Rehabilitation of Expansion Joints

At approximately every 100 feet along the elevated structure, the connection of the track stringers to the cross girders provides for expansion. The seat bracket is composed of two angles with plates in between them and is attached to a cross girder. The rocker pin, a 4 inch diameter half round steel pin, slides on this seat bracket to allow for expansion. The track stringer is supported on the round part of the pin, allowing for rotation of the stringer. The constant sliding and rotating at this connection, coupled with corrosion, results in wear of the rocker pin and seat bracket. As this wear occurs, the top of this stringer will drop, causing a difference in elevation of adjacent stringers. This in turn results in excessive wear of the tracks. Under the Authority's continuing inspection program, these stringer elevations are recorded. When the difference in elevation exceeds1/4 inch, replacement of the rocker pin is indicated.

The rocker pins presently are of carbon steel. We have switched to stainless to minimize corrosion, and to provide a smooth sliding surface.

Where the seat brackets have significant wear, we are replacing them with a newly designed seat bracket with stainless steel wearing surface.

3. SUBWAYS

The New York City Transit Authority's underground system includes the subway tunnels and other auxiliary structures. The subway tunnel sections are primarily of the following types:

a) Circular cast iron tunnel.

b) Concrete bent construction (Rectangular open cut section.)

c) Steel bent construction (Rectangular open cut section.)

Auxiliary subway structures associated with the operation of the railroad and contiguous to the tunnels include vent shafts, emergency exits, equipment rooms, crew quarters, etc. The underground structures are generally waterproofed to an extent that depends on the elevation of the ground water at the time of construction. The structures partially below the water table are provided with waterproofing under the invert and along the sides to a height above the ground water level. When the structures are totally below ground water and constructed in earth, they are completely waterproofed. If the invert is constructed in rock, the waterproofing is omitted and a non-structural slab is used with weep holes to relieve the water pressure.

In general, two types of waterproofing were used in the construction of the Transit Authority tunnels. The brick and mastic waterproofing was used for the most severe situations and consisted of bricks laid with a mastic mortar. The second type was the ply waterproofing which was originally made out of a coal tar product and a cotton fabric. The coal tar product later evolved into a petroleum based product. The tunnels presently in use by the Authority date back to the turn of the century. Due to age, deferred maintenance and changed conditions surrounding these tunnels, cracks have developed in the tunnel envelope. The presence of water outside, coupled with waterproofing that, in many instances, has become ineffective due to the passage of time, has resulted in water leaking into the tunnels.

The water infiltration corrodes reinforcing bars, structural steel, deteriorates line equipment, undermines the invert, overloads the drainage systems, deteriorates tracks, creates hazardous conditions for maintenance personnel and finally impacts on the operation of the railroad.

3.1 Water Remedy Work In Subways - History and Methodology

The extent of water infiltration depends on the causes and therefore, the approach to remedy the water condition must be tailored to suit the conditions. Substantial amounts of water infiltrating into the tunnels has required lowering the ground water level outside the subway tunnel. A number of contracts were awarded to install dewatering wells and well point systems to remedy the severe water infiltration problems on the Nostrand Avenue and Lenox Avenue Lines and at the Essex Street Station.

In locations where the invert has been undermined, cement grouting of voids as well as replacement of structural inverts have been utilized as remedies. Cement grout was utilized to fill voids below the invert at Essex Street Station in 1982. A 275 foot length of structural invert replacement north of 42nd Street on the 8th Avenue Line was completed in 1987. A combination of cement grouting and invert replacement was completed in 1990 between 110th Street and 116th Street on Lenox Avenue.

Actively leaking cracks and damp patches of tunnel surfaces must be treated using methods that stop the water by filling in the cracks. Several products and methods were utilized over the last ten years. A summary of products used on various contracts is provided in Table 1. The early attempts to stop water leaks were within the limits of the stations. These stations were part of the station modernization program. These projects utilized various types of cementitious repair products, such as Sika-set Plug, Master Builder Set-45, Five-Star waterproofing and Vulchem Sealant. To a large extent, these products were not very successful in sealing leaks. For example, the Contract for the rehabilitation of Bergen Street Station in 1982 utilized a combination of Sika cementitious plugs and a Five-Star cementitious coating to treat a severe water condition. This approach was not effective and Bergen Street Station was subsequently redone, years later, using chemical grout as part of the Culver Line Rehabilitation Contract. The original design of the first large water remedy contract on the 4th Avenue Line, while never awarded, specified cementitious grout and was subsequently changed to chemical grout by addenda.

3.1.1 **Use of Chemical Grout**

The Transit Authority's first exposure to chemical grouting was in 1968 when following the advice of Professor Chebetorial, approximately 200 ft of track invert north of Newkirk Avenue Station was granted using AM9 grout. The objective was to grout the soil beneath the invert. The contract was terminated halfway through due to failure of the grout to stop the water inflow.

The Transit Authority initiated a program to perform structural rehabilitation of the subway tunnels in the early 1980's. These early contracts included water remedy work. In these contracts, an attempt was made to seal all cracks in the structure, leaking and non-leaking. The Transit Authority has utilized a number of consultants in developing and evaluating the use of various types of products to seal leaks.

In December 1982, a successful demonstration was performed at Metropolitan Avenue Station in Brooklyn utilizing a chemical grout to seal leaks. The product used was TACSS 020 polyurethane grout manufactured by DeNeef Construction Chemicals.

Transit Authority design projects subsequently specified the use of chemical grout. The contract for the rehabilitation of the 8th Avenue Line, advertised in 1985, was the first major line contract which utilized the TACSS 020 chemical grout. The contract for the rehabilitation of the Culver Line was awarded with TACSS 020 specified as the chemical grout. The contractor requested approval of Scotch Seal 5600, a polyurethane grout manufactured by 3M Construction Products in lieu of the specified product. The use of Scotch

CONTRACT NUMBER	DESCRIPTION	YEAR	PRODUCTS USED
C 30399	Rehab. of Bergen Street Station Borough of Brooklyn	1982	'Hey' Di Powder X 'Hey' Di Special Five Star Waterproof Plug Five Star W.P. Coating ('8")
T 31563	Repl. Tracks W8 St. To W32 St. 6th Ave. Borough of Manhattan	1983	Five Star Waterproofing Sika Set Plug Sika Top 123 Gel Mortar Hey Di K-11 Cement W.P.
Z 32271	Structural Improvement 4th Ave. BMT Line, Borough of Brooklyn	1984	Master Builder Set-45 Sika Set Plug Vulkem 116 Sealant
A 35553	Station Mod. of Kings Highway Station Borough of Brooklyn	1982	Sika Flex 1A
A 35522	Station Mod. of Church Ave. Station Borough of Brooklyn	1982	Sikadur 52 Epoxy Sealer Sikadur 33
C 20786	Archer Ave. Wrap Up Borough of Queens	1987	Acrylate AC 400
C 20167	Route 131A, Sect. 1 thru 7 63rd St. Tunnel Wrap Up Boroughs of Manhattan and Queens.	1988	Acrylate AC 400

Table 1 Record of Water Remedy Products

Seal 5600 was approved after a successful demonstration test at the Bergen Street Station. When the Authority was introduced to Scotch Seal 5600, the preparation of the new routes wrap-up contracts for the Archer Avenue and 63rd Street was under way. In these contracts, polyurethane grouts (3M Scotch Seal 5600 and DeNeef Flex 44LV) for large joints and cracks and acrylate grouts (Geochemical AC-400 and Celtite Terragel 55-31/32) for finer cracks were specified. Construction on these two contracts was completed utilizing both the polyurethane and acrylate grouts. Post construction feedback on both the 63rd Street and Archer Avenue contracts indicated that the acrylate grouts did not withstand the effects of wet-dry cycles and movements caused by seasonal changes. It was a result of this information that a decision was made in 1990 to utilize polyurethane grouts on all contracts.

3.1.2 Current Approach

At the present time, Transit Authority water remedy contracts are aimed primarily at sealing only active water leaks within the subway structures. The current specifications for chemical grouting to seal active water leaks designates the use of a polyurethane grout. These polyurethane grouts contain mainly urethane prepolymer and acetone. The polyurethane grout is pumped under pressure into the crack through drilled holes, reacts with water by foaming to form a flexible closed void solid which seals the leaking cracks within the structure.

This flexible closed void solid is capable of withstanding the movements of the subway structures caused by seasonal changes and train operations. In evaluating polyurethane grout, physical properties such as viscosity, solid content, density, tensile strength, elongation, shrinkage, etc. are considered. Two examples of the products currently being used are Scotch Seal 5600 manufactured by 3M Construction Products, St. Paul, Minnesota and Hydro-Active Flex LV manufactured by DeNeef Construction Chemical, Waller, Texas.

The contract specifications provide for grouting to be done in a series of up to three passes. The first pass seals all active leaks, the second pass seals new and migrated leaks and the third pass completes the sealing of any remaining leaks.

The quantity of lineal feet of leaking cracks is established during the design phase on the basis of a comprehensive field survey. The designers walk through the tunnel and record the location and the length of all the cracks. The total is increased to allow for new and migrated leaks. The field survey data which shows the location and length of cracks is made available to the prospective bidders during the bid period. A final inspection is made after the contract is bid by a team made up of Authority and contractor personnel. In establishing grout quantities, it is estimated, based on past experience and input from the manufacturers, that one gallon of grout will seal three lineal feet of leaking crack.

The contract specifications include directions on handling, storage and disposal of the chemical grout as well as safety precautions to be followed during the grouting operation. The cured materials are essentially non toxic.

3.2 Other Rehabilitation Work

In addition to the water remedy work utilizing cement and chemical grouting, other significant rehabilitation work was performed in the subway structures to restore them to a state of good repair. This work can be divided into two categories - Work that is the result of water intrusion over the years and includes such items as repair of corroded structural steel and replacement of track. Work in the other category includes upgrading of the pump rooms, ventilation plants, and tunnel lighting. The work in the later category is also necessary to improve the efficiency, reliability and most of all the safety of the system.

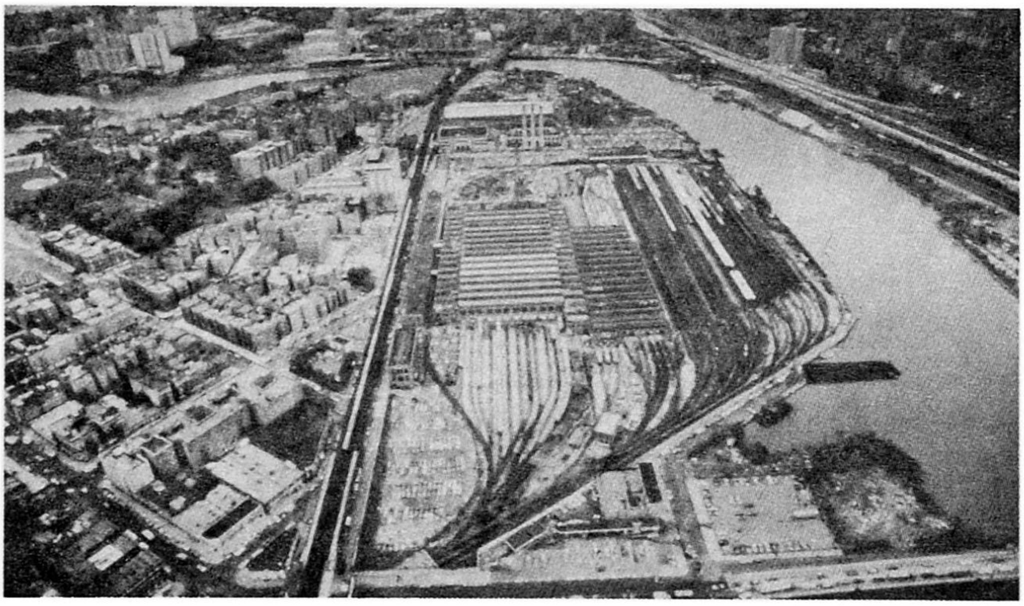
4. CONCLUSION

The mission of the Transit Authority is:

> "To achieve excellence in providing a safe, convenient, comfortable, reliable, cost effective, responsive, and customer oriented transportation system."

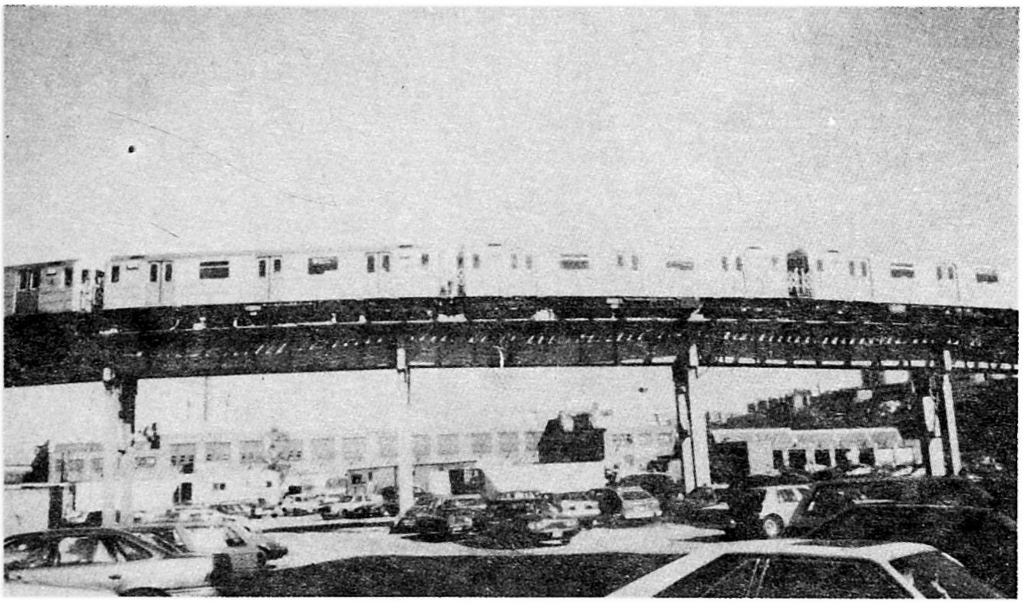
An infrastructure that is sound and in a state of good repair is essential to the safety and the reliability of the system, and would go a long way in accomplishing the mission of the Transit Authority.

Over the last decade, the Authority invested substantial amount of money in the rehabilitation of the infrastructure. The return on investment is visible in a restored, reliable and vibrant system that is being noticed and appreciated by the riding public. More remains to be done to protect the earlier investments, and to retain the gains made to date. The 1992 - 1996 Capital Program, which envisions an investment of over seven and one half billion dollars in the rehabilitation of the line structure, stations, track, shops and bus depots, etc., is vital to the future of public transit operations in New York City.

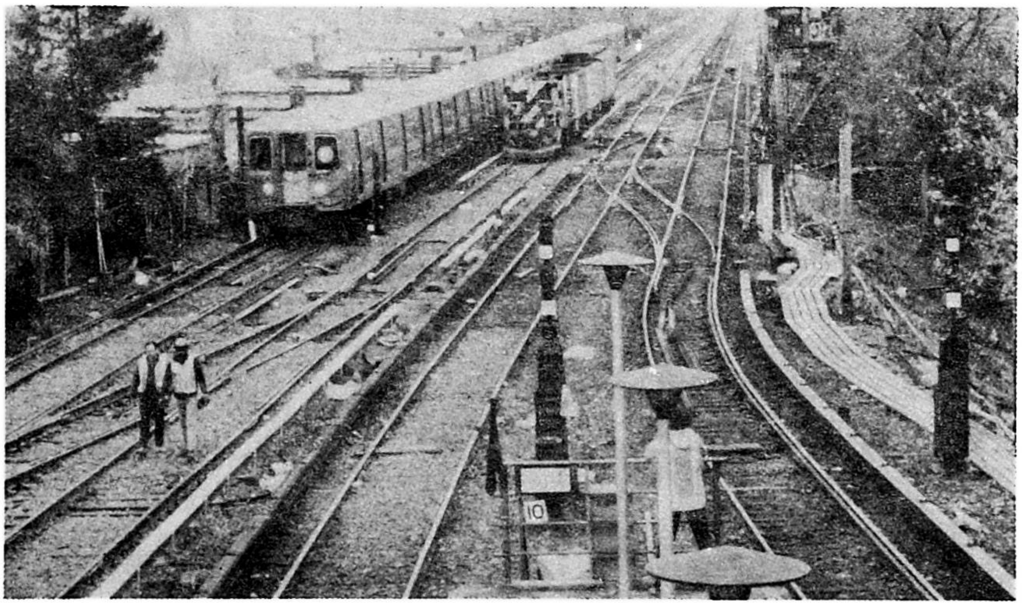


TRAIN STORAGE YARD

SUBWAY STATION



ELEVATED STRUCTURE



TRACK ON EMBANKMENT

Seminar 6

Bridge Management Systems

Systèmes de gestion des ponts

Brückenunterhaltungssysteme

Organizer: Aleksandar Pakvor, Yugoslavia

Chairman: Y. Fukumoto Japan

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Introduction to Bridge Management Systems

Introduction aux systèmes de gestion des ponts

Einführung in Brückenmanagement – Systeme

Per CLAUSEN
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Per Clausen, born 1945, M.Sc. 1971 from the Technical University of Denmark, B. Com. 1978. Employed in the construction sector until 1978. Since 1978 employed in the Road Directorate, in the last five years as Director of Bridge Department.

SUMMARY

The paper is an introduction to Bridge Management Systems and the newest developments and trends. The following subjects will be briefly discussed: data bases; inventory; inspections, condition rating systems, deterioration models; maintenance; rating; ranking, priorities, optimization with limited funds; repair, rehabilitation, replacement; predictions of future needs (short term – long term); routes for heavy trucks, service information for road users; future developments.

RÉSUME

Cet article expose les données de base des systèmes de gestion des ponts, ainsi que les mises au point et les tendances les plus récentes dans ce domaine. Il traite les points suivants: banques de données; inventaire; inspections de contrôle, systèmes d'appréciation des conditions, modèles d'altération; entretien; évaluation; classement par rang, priorités, optimisation avec des fonds limités; réparations, rénovations, remplacements; prédiction des besoins futurs (à court terme et à long terme); itinéraires des poids lourds, service d'information pour les usagers; developpments futurs.

ZUSAMMENFASSUNG

Als Einführung in neuzeitliche Systeme für das Brückenmanagement werden eine ganze Reihe von Punkten ausgesprochen, wie Datenerhebung und -verwaltung, Inspektion, Beurteilungssysteme und Schadenentwicklungsmodelle, Prioritätenauswahl bei begrenztem Budget, Reparatur und Ersatzbau, Prognose zukünftiger Anforderungen und Verkehrslenkungsmassnahmen.

INTRODUCTION

In many counties, 70 % or more of the bridges have been built over the last three decades. To maintain these bridges in acceptable condition now requires more effective inspection processes, maintenance and repair. The right investment made now means lower total costs and thus savings in the long term. Through a bridge management system you can identify bridge needs and establish priorities. BMS systems must have activities described in manuals and with a standard terminology. BMS must coincide with the agency's policies, long term objectives and budgetary constraints. But a good BMS-system will vary from agency to agency depending on the specific requirements and preferences, environmental considerations, the traffic pattern and the national way of doing things. Even though the BMS structure may vary there are some basic elements that do not change. I will try to present some of these elements and speak about developments as I see them, based on 15 years work with the ideas behind BMS-systems and discussions with colleagues from many countries.

Data banks

The data banks are the foundations of an effective BMS-system and a computerized data bank is necessary for effective handling of the large quantities of data, if you have more than 200 bridges. The data banks must be very carefully planned. Too much data can spoil a good system. All data banks need updating and this costs money. You must decide what kind of models and analysis you want in your system, and the data requirement must be established before the data base is designed and programmed. Only information that will be used in the managing process must be stored. Standardization of data, simplicity and easy access are the keywords. It must be possible to add and remove data and to adjust or extend the system easily. Based on experience, you must be able to develop your bank - and in fact the whole edp-structure. Ways of data collection, sorting orders and information search paths must be thought out. Data groups can include administrative data, condition data, maintenance data, cost data, load capacity data and so on. The trends in the contents of the data banks, as I see it, are:

- more data from inspections
- more data for planning of maintenance
- more data for prediction of deterioration, data that describe the effect of different activities
- more economic data for budgetting.

The necessary work for analysis and programming of a prototype data bank and system varies from 5 to 10 man-years. This includes the handling of data from the inventory, the inspections and maintenance work.

The inventory

The inventory data normally are:

- data for identification
- data for location information
- data for administrative information
- data for technical information
- data for management of heavy trucks.

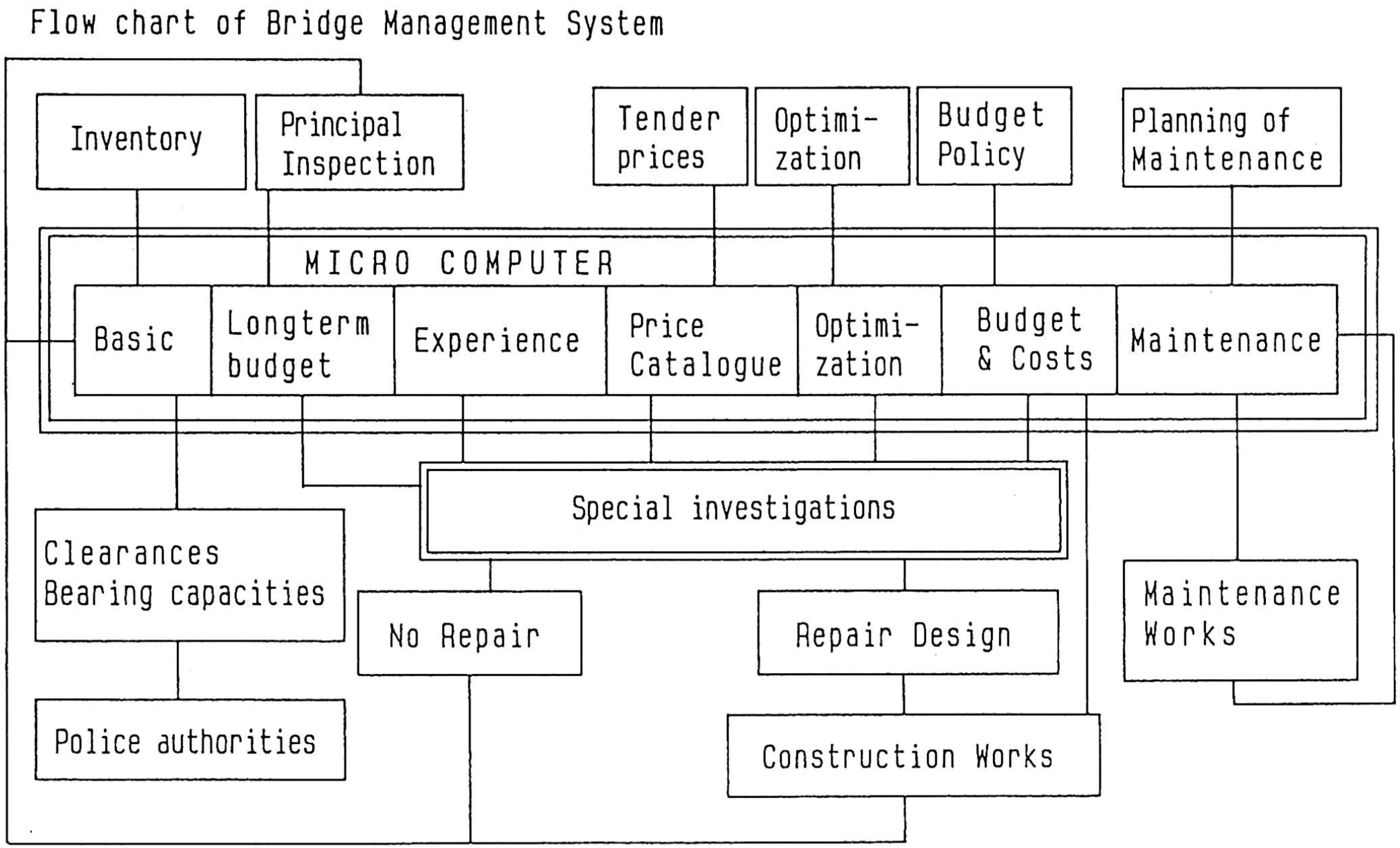

Fig. 1: Interrelated activities.

The inventory must always be kept up to date. Again, bear in mind that you should collect only necessary data, data you will use. The aim is to keep the amount of data to a minimum.

The inspections

In a BMS-system all activities must be based on the results of inspections. Normally, there are three kinds of inspections: superficial inspections, principal (general) inspections and special inspections. All kinds of inspections must be described in manuals.

Superficial inspections are done continuously together with the inspection of roads. It is a visual inspection, carried out by technicians. It controls the routine maintenance and ensures that nothing unforeseen has happened.

A bridge is given a **principal inspection** every 3-6 years depending on its condition and the type of construction. It should be carried out by trained engineers with a knowledge of structural mechanics and material properties. A bridge inspector can be responsible for 600-1000 ordinary bridges. All the data for the condition rating must be standardized and described in the manual. Condition rating systems for bridges and components have been developed in many countries using a numerical code, for example from 0 - 9 or from 0 - 5. You must obtain a uniform evaluation for all the bridges. In some cases you need engineering judgement. Often inspections also contain data on standardized maintenance or repair works and the amounts of different kinds of work. A sub-system can include standard costestimates for each maintenance type and can automatically calculate the total maintenance costs, when the inspector has described the types and the amount for each type. The sub-system may also produce tendering documentation for maintenance works.

Principal inspections are often visual. Development of inspection methods, easy and cheap, especially non-destructive methods, is needed. Fortunately many are making great efforts to develop these tools for practical use, for instance measurement of electrical potential, vibration analysis, ultrasonic tests, infra-red photography, radiography and radar. Perhaps we should also equip our bridges with monitoring instruments for inspection. There are already some examples of this; corrosion-cells could be mentioned. New technology on computer-automated bridge inspection is under development. You must describe the minimum conditions that will be acceptable from an operational and safety standpoint. These minimum conditions must be accepted by the politicians. Conditions below the minimum thresholds must trigger an immediate action.

If a principal inspection reveals a need for repair or rehabilitation it must be followed by a **special inspection.** Special inspections must be done by experts, consultants, and with the use of laboratories if needed. It is important to determine not only the nature of the damage but also its cause. The collected data must be standardized and some of it put in a "feed-back" module of the BMS-system. We hope to develop some deterioration models based on collected data and our experience over the years. But remember that these data give a prognosis based on the practice of the past and not the practice of the future. Judgements based on expected developments of the practice have to be added. The result of a special inspection must be a description of the damages and its causes, predictions of the future behaviour of the bridge, its remaining life and various repair strategies.

Maintenance

Based on the inspection results you can plan the maintenance works. If you have standardized the different types of maintenance or minor repairs, the BMS-system may calculate the amount of each type, the total costs, print working-orders for the personnel, or produce documents for tendering.

We know that some maintenance has to be carried out as a running routine to achieve the desired economic life of bridges. Add to that many works with level-of-service concepts with defined maintenance thresholds as a basis for budget allocations. Modern principles for quality assurance and certification must be considered Estimated maintenance costs must be considered as the necessary "basisfunds". Funds for repair, rehabilitation and reconstruction are needed in addition.

Predictions of future needs for repair, rehabilitation and reconstruction

In connection with the inspections you need to make an estimate of future needs at the project level, and also at the network level. You also need to predict the **service life** and the economic life of the bridges. Service life depends on structural adequacy (often 50-100 years) or functional adequacy (perhaps 25-50 years). The economic life we define as the period after which investment in maintenance, repair or rehabilitation does not "pay-off" compared with the investment in a new bridge.

Life-cycle cost models at the project level resemble well-known models for making investments, where you compare alternatives over time and calculate the rates of return. You convert future to present values using a discount rate and select the best alternative with the lowest costs. The question whether to rehabilitate or replace can be decided from the curve in fig. 2. It is simply the sum of first costs plus a discounted future replacement cost.

Rehabilitation will often be attractive compared with replacement. It is important that we are able to improve our rehabilitation methods. The savings for society can be tremendous. We also know that an investment of 1 unit in preventive maintenance or repair can result in savings of 2 - 4 units, because of an extension in service life or postponed rehabilitation. But the development of expert systems for the assessment and choices between technical solutions, products, intervention frequencies etc. is much needed. It is hoped that the use of BMS-systems can create the background for this.

Some **deterioration models** have been produced, but deterioration modelling is complex and a large number of factors are involved. The curves so far produced have not yet reached the stage and the detail needed. Fortunately, research and development concerning these matters have been started up in many countries. Various techniques, either statistical or stochastic, have been applied to predict bridge conditions. Markov chain and Monte Carlo simulation

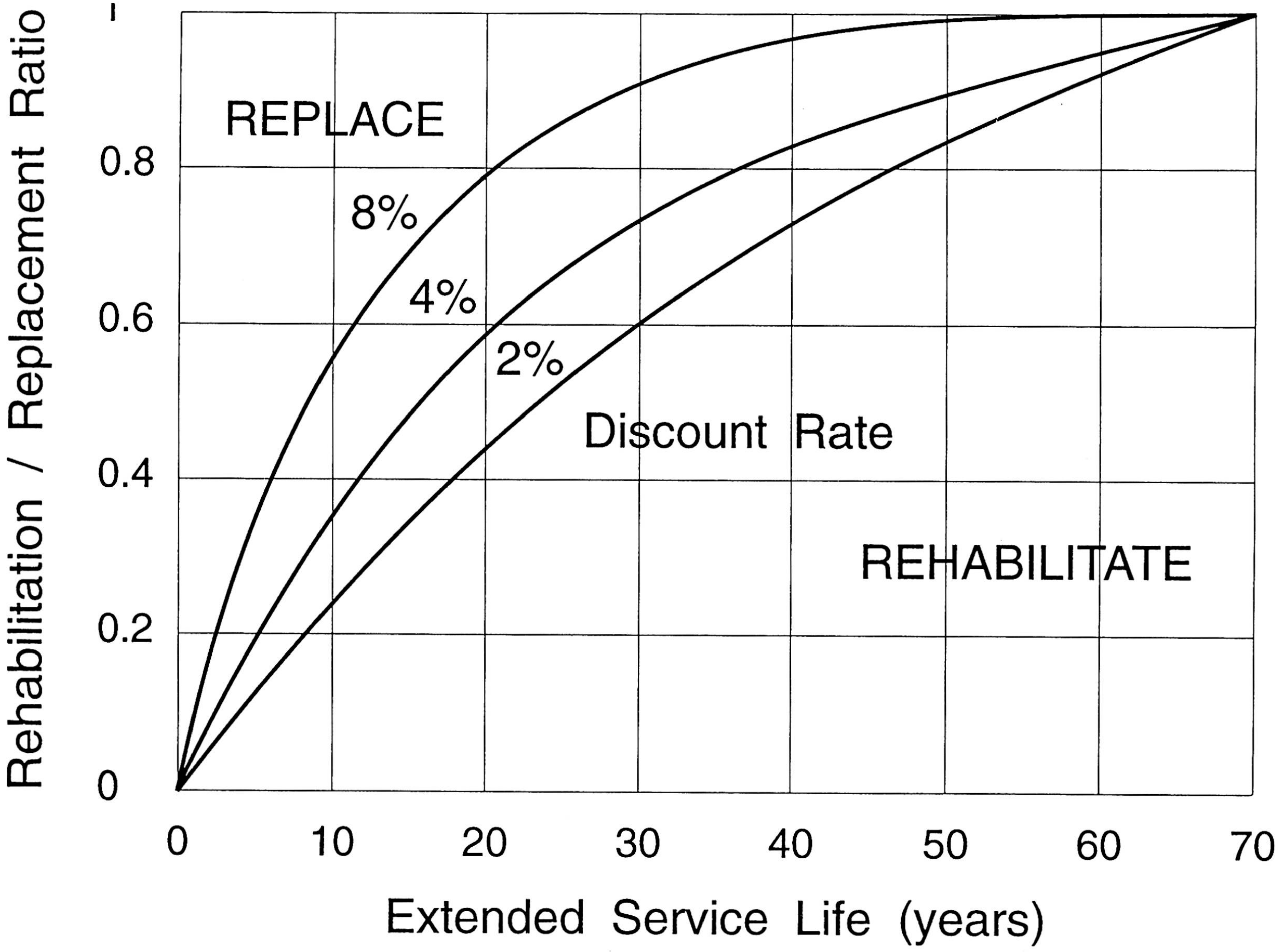

Fig. 2. Life-cycle cost comparisons

techniques could be mentioned. I find the present techniques a little bit too "theoretical" for practical use. I have more confidence in the hard way - to collect data on each bridge and to make an analysis based on data for the whole bridge stock. It must be emphasized that the prediction of bridge deterioration and the estimation of remaining service or economic life are important for the optimization process in bridge management. Budget planning for the short and long terms must describe the needs for funds.

Rating - ranking

Through the inventory and the inspections and investigations you have rated the bridges and have established a background for decisionmaking - whether to repair, rehabilitate or to do nothing and then reconstruct. In the calculation for each alternative you must include road user costs. The uninterrupted traffic flow is in focus. Possibilities for minimizing the disturbance to traffic may be the decisive factor.

Budget needs usually exceed the available funds. Therefore you need to rank your needs - you must describe your priorities. It must be done with a network model that considers alternative treatments for every bridge in the network compared with alternative treatments for other bridges to determine what can be accomplished with limited funding. The model can be based on purely economic criteria. The highest priority is given to work for which a postponement would result in the greatest cost increase. Other criteria can be used if desired, e.g. load carrying capacity problems, classification of roads in order of importance, military considerations etc. There have been attempts to make "multi-year analyses", where bridge conditions, traffic factors and budgets are analysed over a planning period. The analyses consider the short and long term costs for the various courses of action and their effect on future conditions.

Routes for heavy transports

As a part of a BMS-system there can be module for handling heavy transports. Load bearing capacity must be reviewed after each principal inspection. The bearing capacity of bridges must be classified in a uniform way for comparison with a similar classification of heavy trucks. By making a classification system both for bridges and trucks, you can manage the heavy trucks and the necessary permits and avoid overloading as much as possible.

BMS-systems are also a tool for better service to road-users. Quick route-planning for very high or wide transports is possible. In fact you can improve the answers to all questions concerning bridge data through easy access to data and the possibility of making an analysis.

Future development and trends

Future development and trends for BMS-systems, as I see it, will include:

- development of "level of service" concepts
- graphic data, documents, drawings and photos in the data bank in digital form
- use of probabilistic models
- more research and development on maintenance, repair and rehabilitation

- development of non-destructive testing methods
- instrumentation of bridges
- development of expert systems based on data and results from the use of BMS-systems.

The forum of European National Highway Research Laboratories, in its Strategic European Road Research Programme (SERRP) has proposed the following subjects as being of special importance for further research:
- standard methods of load capacity testing
- life-cycle cost models related to different structural components
- deterioration models for structures
- methods of maintenance or replacing trafficked bridges
- strategies for bridge repair and optimization of budgets.

In the past, bridge management often consisted of decisions made on a case-by-case basis at the project level.

In the future we must work at the network level, and consider the data and condition of the entire bridge stock. BMS-systems can bring us into a position to do this.

Final remarks

If you want to start up a BMS-system my advice is: "Think big - but start small". Be sure that you can operate the system, so that it is continuously updated. Then you can add more and more modules to the system and at the same time develop your organization and staff. If you want it all at the beginning, you will probably fail.

The real engineering challenge and the major benefits for seciety lie in the many questions concerning the correct handling of maintenance, repair and rehabilitation and not so much in the further optimization of construction disciplines. I hope that more and more engineers and researchers will realize this.

We are still searching for a lot of answers and I hope that this seminar will be a help for us all in finding some of them.

Seminar 7

Society – Engineer – Environment
Société – Ingénieur – Environnement
Gesellschaft – Ingenieur – Umwelt

Organiser: TN Subba Rao,
India.

Chairman: H Von Gunten,
Switzerland

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Environment – The Engineer's Human Response

Environnement – réponse humaniste de l'ingénieur

Umwelt – des Ingenieurs humane Antwort

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President
Gammon India Ltd.
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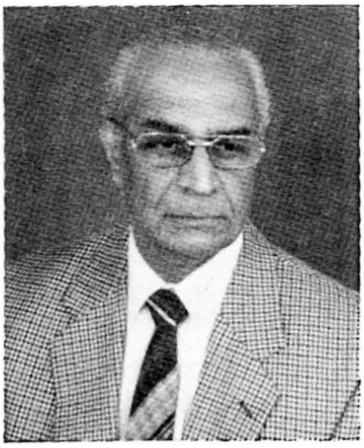

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SUMMARY

The role of the engineer has become more complex today. He is not a mere builder or one who has to accomplish his tasks within the confines of his immediate environment. Now, as never before, his role has expanded and has become global in its responsibility, coverage and application. He is now a part of the Sustainable Development on this planet, he is obliged to keep the needs of the future generations in perspective when applying his professional skills and he must help preserve the global eco-system, without delaying today's pressing needs of Man. We need to examine his new profile.

RESUME

Le rôle de l'ingénieur est devenu plus complexe aujourd'ui. Il n'est plus celui d'un simple constructeur accomplissant son devoir dans les limites strictes de son environnement immédiat. Son rôle s'est accru et est devenu global, dans sa responsabilité et son domaine d'application. Il fait partie d'un plan de développement continu et harmonieux sur cette planète. L'ingénieur doit tenir compte des besoins des générations futures, dans l'application de ses connaissances professionnelles. Il doit contribuer à maintenir l'équilibre de l'écosystème global, sans négliger les besoins de la société actuelle. Il faudrait rechercher un nouveau profil de l'ingénieur.

ZUSAMMENFASSUNG

Die Rolle des Ingenieurs ist heutzutage umfassender geworden. Er ist nicht länger ein blosser Baumeister, der seine Aufgaben im gegebenen Rahmen seiner unmittelbaren Umgebung erfüllt. Wie nie zuvor hat sich seine Rolle erweitert und ist bezüglich Verantwortung und Tragweite der Eingriffe global geworden. Er ist nun einge spannt in die Maxime des dauerhaften Wachstums dieses Planeten. Er hat sich bei der Anwendung seiner beruflichen Fähigkeiten von den Bedürfnissen zukünftiger Generationen leiten zu lassen und das weltweite Ökosystem bewahren zu helfen, ohne dabei die akuten Nöte der Menschheit zu vernachlässigen. Wir müssen dieses neue Berufsbild analysieren.

I. PREAMBLE

We live in a World which for millions of years has supported an awesome variety of plants and animals and has a human population crossing five billion today and reaching eight billion in the next 25 years. We all share and depend upon the same world, with its finite and often non-renewable resources. This implies the need for an **Ethic** common to all humankind to ensure a durable future.

We depend for survival, health and psychological well being on the physical integrity of the biosphere and the cultural continuity of our own local environment. Hence, we have a common interest in shaping an attitude that encourages more responsible use of natural resources. This is a religious imperative, links all men to a global inter-dependence, and demands unified response from individuals, communities, corporations and nations alike.

We are tenants of the World only in our own generation and hence we have no right to exhaust or deplete the finite resources of our planet. Its **'Stewardship'** by Man implies caring management, not selfish exploitation; it involves a concern for the pressent and the future and a conscious recognition that the world we manage revolves around a abiding interest stitched to man's own survival and longterm wellbeing.

Sustainable development and the aim of an acceptable quality of life for all, cannot be separated from responsible environment management-both must be integrated with all facilities of national and international bodies. "Development cannot take place upon a deteriorating environmental resource base as the environment cannot be protected when growth leaves out of account the costs of environmental destruction"(8). Therefore, environmental health has to be an important parameter in planning for economic growth.

In former years, the environment has not been a dominant subject in people's mind. Serious environmental problems are the result of both short term expediency and long term ignorance. The relationship between population, resources and environment is complex and complicated. There is inequity and inefficiency in industrialised and developing countries alike. Poverty, economic stagnation and environmental degradation interact to create tension through mindless competition for non-renewable resources, land or energy.

Some kind of **value system** is therefore inevitable; Environmental quality must ensure a balance between technical, social and economic parameters.

II. DEVELOPMENT AND GROWTH

The economists believe that to meet the basic needs of global population, without sacrificing security and stability, a five to ten fold economic expansion must take place soonest. They point out that security in an environmentally hostile world is almost an impossible task.

"Political realities in every country influence national, and hence global priorities. The affluent nations of the North, with sufficient capital to address environmental problems, now ask or cajole the struggling nations of the South to follow their lead. Yet, these nations burdened with debt and barely able to sustain the most basic needs, have a far different set of priorities. Their focus is grounded in the present rather than responding to the needs of the future. Both the ability and willingness to act on long range problems become a function of affluence"(1). Accordingly, national priorities are set within the framework of the political environment.

"Another challenge encountered on the path to a sustainable future is market economics. This type of economics historically rewards production and consumption, gauging growth-success by output of goods and services and harvesting or extraction of scarce dwindling resources. Engineers and economists would doubtless agree, that the true costs of depleting our capital of natural resources and polluting the environment are not reflected in the economic decisions that are made. The fact remains that economics and environment have been disconnected, both in our decision making process and in our institutions, and they must be merged into a new science of **'Ecological Economics'**,if sustainability is to become a reality"(1).

"Development, which is essentially change, does not necessarily involve degradation of the environment. Hence, **"Sustainable Development" may be described as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change, are all in harmony and enhance both current and future potential to meet human needs and aspirations"**(2). There can be no question of sacrificing the environment for the sake of development. What is needed is a new era of growth, forceful and yet socially and environmentally sustainable. The ideal for developing nations would be to improve their economic growth and for the developed nations to maintain theirs. "In trying to meet the needs of the present, let us not compromise the ability of future generations to meet their own needs"(8).

Strategies for sustainable economic growth mainly concerns energy, efficiency, conservation of non-renewable resources, development of alternative energy supplies and environmental conservation. It will involve new policies of urban development, eco-layouts, housing design, transportation systems and choice of appropriate technology among others. It must not endanger the natural eco-systems that support life on earth, the atmosphere, water, soil and living beings.

It is truly stated that development is responsible for environmental stress, a result of the growing demand on scarce resources and the pollution generated by the rising living standards of the affluent. Poverty too pollutes the environment, again creating stress. The poor will often destroy their immediate environment in order to survive. They will cut down

forests and allow their livestock to overgraze grasslands. The potential effect of these changes makes poverty a major global scourge. "Thus more than development, it is the lack of it, which is seriously detrimental to the environment"(8).
Earth was created by God for man and not vice-versa. People are the ultimate resource. We must think of preserving them, today and tomorrow.

III THE ENGINEER'S NEW ROLE

"It is a known fact that an engineer solves problems and delivers solutions within the constraints of time, money and available knowledge. Yet to be agents of change, engineers must be **'proactive and creative'** and must seek to bring in environmental concerns in order to evolve and mould new options" (1). To achieve this there is a need for a professional ethic. The Engineer's orientation should change, from a **'confined thinking'** to one with a **'global mission'**, to enhance the quality of life for all humans and to preserve the quality of their environment. "Engineers thus become **'facilitators'** of sustainable development through the information that they provide, the decisions that they make and those that they influence"(1).

Once engineers were at the forefront of societal change and were looked upon as **'Leaders'**. Where the engineers have gone wrong is in the manner they have set out to improve the human lot and have assumed that this just means the greater exploitation of natural resources for the benefit of humanity. It is very necessary for the engineer to maintain a balance with ecology in the decision making process. For this reason, a human approach and the use of social science should be incorporated into the engineers skills.

The engineer as a project team leader or as a member of a team bears much of the responsibility for recommending technological alternatives. The choices that are made have a crucial impact on whether the project ends up creating problems instead of offering solutions. "Environmental aspects of all actions must have equal standing with economics and engineering as part of the project's **'go-no-go'** test"(1).

"Engineers must begin to refine existing technology options and focus on improving the resource use and minimising waste generation. Wherever possible, renewable resources should be substituted for non-renewable ones. Processes, products and technology that yield detrimental impacts must be replaced by those that do not"(1). Engineers must research new and better options for the future, through improved waste recovery processes, and must substitute environmentally safe products and processes for harmful ones, including cost-effective and timely environmental restoration technologies.

Thus as facilitators of sustainable developments, engineers must amass the skills, knowledge and information which create the path to a sustainable future. Before engineers can seriously assume such a role, it is evident, deficiencies in their environmental education must be remedied. "Whatever their discipline, the promotion of sustainable development demands that engineers cultivate an understanding of the issues, problems and especially risks and potential impacts associated with their decisions"(1). The importance of this primary need is as clear as daylight.

Paul Hofseth named us **"Pathfinders in the world of environmental technology"**. There must be fundamental changes in our approach to future global development and these changes must be initiated soon. From the Engineer's standpoint such a change requires movement towards a set of realistic, concrete steps that can be implemented at the microlevel. "The ultimate technological challenge to sustainable development represents the revolutionary leap that will be required, if the technologists are to help open the doors to a future, where all individuals can truly share in the bounties of the earth; where each society and nation can achieve more and more with less and less; where humanity can flourish in perpetuity on our planet"(1).

IV SOCIETY AND ENGINEERING

Every society practices engineering to some degree. But it is only in the last 100 - 150 years that society has really become mechanised on a large scale. A considerable degree of civilization can be secured with a minimum of engineering and though we could admiit that without engineering, civilization is impossible, it is not always of first importance.

"The Chinese who led the World in the invention of printing, the mariner's compass and gunpowder did not advance from their auspicious beginnings but evolved a civilization in which engineering had almost no place. Even their buildings, though graceful and charming, were modelled on tents and called for no great skill in their erection"(5). The Emperors used Jesuit missionaries to make fountains and clocks, but there they stopped. In due course, they paid heavily for this when a mechanised Europe attacked them and imposed its will on them.

An even more notable example of this neglect can be seen in the Greco-Roman World. The Greeks were in some respects pioneers of engineering, and the many buildings which still bear witness to Roman competence belong to the same tradition. Archimedes not only was a mathematician of incomparable genius but at times turned it to practical use, as when he invented hydro-static servomechanisms or devised engines of war to confound the Roman besiegers. Yet, despite these promising beginnings, the Greeks stopped and did no more for engineering. "The trouble with a society that does not believe in engineering or see its possibilities, is not that it is not civilized but that it is not likely to survive"(5).

In the past, the Engineer was somehow thought to be sordid and engaged in tasks below the dignity of a civilized man. "The contempt for applied mechanics displayed by Archimedes was a product of a society in which there was no shortage of cheap human labour"(5). It did not motivate the men to seek labour saving devices. This is a social fact of first importance and it is not irrelevant to modern times. The prodigious growth of engineering since the end of the 18th Century, has indeed been rendered possible by the epoch making developments like the internal combustion engine, electricity, nuclear energy, computers, etc., but this itself would never have happened, if there was no attitudinal change towards the part played by engineers in society.

"The final challenge on the path towards a sustainable future is the engineering field itself. The Engineer has always been viewed as the leading instrument in the process of social adaptation and growth. The future, therefore, will demand more of the engineering profession than has been asked in the past - demands that will require perspectives to be changed and horizons broadened"(1).

V. WHY ENGINEERING?

If China and Russia were more mechanised, they might not have experienced the revolution or it could have occured in a less virulent form. "Now, engineering tends to suggest that there is a cure for most evils and that the age old troubles of man such as starvation, disease, floods and the like can be surmounted by a proper use of machines"(5).

It is indeed significant that the classic case of growth without revolution should be in the USA, which has used **'Engineering'** on the greatest possible scale.

Man's struggle for existence cannot merely be maintained by exploiting natural resources but when such wealth is put to responsible use, it can certainly be made more agreeable. I would confidently assert, that life is more comfortable now for the mass of mankind than it has ever been and that this is almost due to man's increasing conquest of nature through purposely engineered machines. "A society which has become accustomed to seeing its own life improved by many engineering actions will develop a rational approach to its problems, realise that stability is something almost beyond price and be very cautious of losing it"(5). The advance of science and its practical application through engineering and chemical technology, has shown that mankind has the potential ability to achieve any standard of material wellbeing that may be desired.

"In the last few years, we have begun to ratchet our environmental concern up a few more notches to seek out opportunities to directly attack environmental problems as a purpose of the engineering effort itself and to exploit our talents in the solution of the nations present environmental problems and the prevention of future ones"(1).

In this context, can our society afford an environmentally conscious engineering technology? I believe it can and must. Contemporary shortterm thinking stands in direct contradiction to continuous sustainable development; The prodigious effort required today to correct the damage already done to our eco-system, should remind us of the consequences of our future actions.

Ofcourse, to build now in accordance with environmental considerations is more expensive than was previous construction. Nevertheless, as environmental leaders, we must invest our efforts at all levels, so that the price paid for our resources corresponds to their limited availability. This is a long term task. We must first fully learn how to build environmentally before the market forces us to do so.

Until recently, buildings were demolished and the waste thrown into landfills. Today, another approach is beginning. Instead of demolition, buildings are disassembled, materials are carefully separated and most of those recycled.

VI. ENVIRONMENT AND CIVIL ENGINEERING INDUSTRY

Each Sector within the civil engineering industry has differing environmental goals. The challenge is to establish a unified approach to provide a consistent programme for implementation. In addition to developing a state of the art approach with a view to the long term, the civil engineering industry must first acknowledge the increasing public awareness of environmental issues and must be seen to respond to environmental concerns.

The industry needs to be aware of emerging scientific findings and policy issues and to anticipate long term implications. The present approach is fragmented and not at all co-ordinated. It does not anticipate the needs for applied research or testing at a sufficiently early stage when environmental scientists have identified emerging problems.

The environmental impact of building congestion is only beginning to be understood. The need for research and testing is obvious to architects and engineers, but I also believe that manufacturers, contractors and developers have an essential role, namely how their methods and approaches may need to be adapted with an environmental emphasis.

It is, therefore, in the civil engineering industry's interest as well as its imperative care for the environment, that the industry's response should not be entirely reactive, nor solely and passively confined to satisfy statutory regulations. There is clearly a role for the industry to undertake its own initiative to provide sound information and incentive for change.

Major industrial cities often have special difficulties with slum clearances, which can result in the breakdown of communities. In new housing developments, the initial lack of both social facilities and landscaping can leave unseen many visible scars on the human habitat. New road networks, however necessary, can cause further disruption.

In smaller towns, expansion can destroy the established character and charm when supermarkets, petrol stations or office blocks of inappropriate scale replace existing historic buildings and road widening schemes out off corners and encourage traffic.

Yet our towns and cities must be prosperous to survive. All these problems and contradictions can only be resolved by engineering planners who have sensitivity, courage, vision and common sense.

The engineering profession has recognised that in the management of the environment, preventive strategies and policies are more effective and less costly than corrective measures. The application of recycling technologies and systems for utilising industrial residues are examples of the encouraging trends that are emerging.

VII EVALUATION OF ENVIRONMENTAL PARAMETERS

It is appropriate that we should start off by focussing on **'Environmental Impact Assessments'** of major engineering projects for human settlements, deforestation, land degradation, water resource depletion, flooding, mining and industrial activities; The list is not exhaustive. The use of such assessments as a process to incorporate environmental considerations is gaining increasing acceptance. Many, if not most countries, now have legislation requiring the use of EIA process before approval is given for construction and operation of large scale engineering projects.

This is very necessary, as environmental pollution caused by high population density and over development, destroys the basic safety and sanitation of the urban environment and threatens residents' lives and property.

Development generates wastes, air and noise pollution which all continuously change and damage the environment. Rapid urbanization and economic growth overshadows many historical and cultural values. Traditional structures, historical streets and cultural relics are encroached upon by tall modern buildings and noisy highways. On the other hand, rapid economic growth can also change and damage the social fabric and culture of society. In a lifestyle that stresses consumption of goods, pursuit of material gain and rapid social change, it is not easy to create an artistic, cultural environment. Preservation of cultural values in urban areas is vital to the larger urban qualilty of gracious and good living.

Space in a city is limited and property values are high. This makes urban open areas expensive. However, despite their high price tag, many residential areas have poor sunlight, inadequate air circulation and are too small to provide basic facilities like parks, green areas and walkways. Running water and sewage systems are lacking and there is often no way to build them now. In search for comparatively cheaper land, unplanned development around urban areas begin. This shifting from the city center not only hastens destruction of forests and farmlands but also makes long distance commuting a necessity and leads to traffic congestion. Often mountain slopes and swamplands are developed in such a way that rainstorms and earthquakes create landslides and floods in urban areas.

Structures must be integrated into the environment, landscape or cityscape. Heavy and brutal forms are simply offensive as they lack scale and proportion. The structure must have an effect on people and this will depend on the purpose, the situation, the type of society and on sociological relationships and initiations. People want to meet with joy in their man made environment and hence structures must bring out the qualities of buoyancy and relaxation. Now, as never before, there is need for a realisation of the holy linkage between **Man and Nature**, for his material, social and religious well-being. My ancestors adopted this as a religious doctrine and worshipped the Elements. How enlightened they were!

It is not always easy to evaluate the EIA of all the above parameters for a project's **'PASS-FAIL'** test. We have still to compile data but qualitative judgement must be exercised and engineering options proposed to the decision makers.

VIII. IMPACT OF SOME PROJECTS ON THE ENVIRONMENT

The following few cases, among many others in the world, illustrate the pragmatic and progressive interest shown by engineers, economists, politicians and a caring public, in directing the course of engineering projects.

- **Nam Chon Dam - Thailand**

The dam, a $400 m project proposed in 1982 and located in Thung-yal wild life sanctuary, would have led to large scale forest destruction through submergence and poaching, extinction of rare and endangered species, illegal settlement and other harmful effects, and all for a 2% contribution to Thailand's energy needs. The intense debate on the need or otherwise for the dam has resulted in the project being delayed indefinitely, in effect cancelled.

- **Narmada Sagar Dam - India**

The Narmada river basin programme comprises of four large and several smaller dams plus a huge canal network. They are designed to bring irrigation, electricity and drinking water to large parched areas of Gujarat.

The development has been widely criticised by both local and NGO's alike, primarily because of environmental and resettlement concerns. The Japanese decision in May 1990 to suspend financial support underscored the issues. These events helped focus attention on the problems, and several programmes for resettlement backed by legislation, specific studies and work programmes on fisheries, catchment treatment and wildlife are underway. A wary and informed public, together with the support of crusading environmentalists and engineers, has ensured protection.

- **Balem - Brazilia Highway**

This is a classic case of the impact of locating a 1900 km highway to open up the hinterland in the Amazon basin, without adequate prior legislation on the deforestation of the dense Amazon jungle on either side of the highway and now even farther inland. Large numbers of migrants hence encroached the area in search of land and employment. Cleared area in one sector of the highway increased 300 times in 25 years, secondary and feeder roads surfaced and the population increased from 100,000 to 2m in the zone of influence. "One traveller described this land degeneration as a 'Ghost landscape"(4). The use, or rather misuse or overuse, of the forest resource generates a backlash on other natural resources too, such as soil, water, hydropower potential, fish stocks and other natural resources. Shortcomings spill over to the Agri-sector, Public health etc. This shortsighted policy affects not only the present but future generations as well. In this context, the Engineer's immense responsibility in providing advice to the administrators is self evident. The project has now become a global concern and corrective measures are on.

- <u>The Upper Pampanga Project</u>

This is the first large scale multipurpose water resources development project in the Phillipines, and centres around the Pantabangan dam completed in 1977, to impound 3 billion cu.metres of water, and costing $ 120 million.

The project was conceived to provide irrigation facilities, power and control flood damage. Unfortunately, due to sudden population migration to the area plus improper land development leading to erosion and reservoir siltation, the objective of the project has been defeated. Soil erosion has led to loss of organic matter and nutrients, reservoir sedimentation and loss of hydropower, irrigation water etc. Inadequate government control, rural poverty, ineffective planning of land use are some of the reasons attributed to this malady. The case reflects basically lack of political will and a multilevel approach to resource management.

One should, however, not be misled to the conclusion that no environmental planning is being done despite the concerned persons being aware of its short and longterm consequences.

Take for example the case of:

<u>The Carajas Iron-ore Project</u>

Started in 1983 and costing USD 5 billion, it involves mine site development, 900 km railroad, port facilities at Sao Luis for 35 m. tons of ore export and urban infrastructure. The project was developed with close attention to the environmental impacts; these covered climatology, ecology, botany and related disciplines. The company in charge established policies in relation to forest clearing, topsoil stock piling, erosion control, vegetation regeneration, fauna protection, creation of protected reserves, related manpower training, land reclamation etc. A permanent cadre of engineers, scientists and ecologists monitor the performance and advise the management. What a responsible beginning.

Apart from this project, a great deal of thought and follow up action has been given to the construction of the Oesterschelde Storm-Surge Barrier (Netherlands), the Carlisle Bypass (U.K.), The Eurotunnel Project, the Storebelt Crossing (Denmark), The Savern Barrage (U.K.), the proposed Danube and Ganga river basin cleanup, to mention a few. Today **Environmental Studies** have become part of a major project's evaluation criteria. Still many gaps remain. Many decisions in the absence of data, are purely based on judgement and qualitative appreciation. But we have to move on, pressed by national and political compulsions.

IX. SOME GLOBAL PHENOMENA AFFECTING ENGINEERING THINKING

- The Greenhouse Effect

Carbon dioxide in the atmosphere acts like a shield trapping just sufficient quantum of solar radiation for keeping the temperature balance on earth. Fossil fuels and other man induced processes and actions are increasing the carbon dioxide content and causing the temperature on earth to increase rapidly. It is modelwise predicted that the likely doubling of carbon dioxide content **within** the next century will increase the earth's temperature in the range of 1.5° C - 4.5° C"(7). This will no doubt cause melting of ice and expansion of the sea both of which will affect sea level, tidal effects and ocean currents; What are the consequential effects? Submergence of estuaries, atolls and flat land areas like Bangladesh, coastal erosion, obsolesence of coastal defences and harbour structures, increased salt water penetration, change of beach life etc. Current estimates predict upto 0.65m rise in sea level at some places within the next fifty years. Engineers designing thermal, industrial, hydraulic and similar projects cannot overlook this aspect, nor the impact of pollutants caused by their design processes.

- The Ozone Phenomena

Man has been protected from high ultra violet radiation from the sun by the presence of Ozone layer. Chlorofluorocarbons (CFC) released by industry through Aerosol sprays, air conditioners, cleaning agents, refrigeration and foam, exceeding 750,000 tons by present estimate, are breaking the ozone layer and a **hole in the sky as large as Alaska** is observed recently, through satellite imagery. Ninety percent of the release arises from affluent nations and the Russian States plus China. The impact is more above 50° latitude and will certainly affect whether patterns, wind velocity and direction, bird movements, besides causing acute diseases in living beings. Already citizens in some countries like Chile are warned not to go out beteen 10 AM & 3 PM, and in general people are advised to wear large hats, protect eyes with special UV absorbent glasses and cover themselves adequately from the sun during the day. Unless CFC's are checked by using alternative solutions, the outcome will be eventually catastrophic. The engineer cannot overlook this factor in his concept of structures, particularly external cladding, covered passages, etc. if solution is delayed.

- Acid Rain

The pollutants in the atmosphere mainly caused by thermal stations and industries, eg. So_x, No_x, Hydrocarbons etc., are absorbed and deposited on earth by high humidity and rain in the form of acids and cause widespread destruction to foliage, structures and human health. Winds carry the chemicals long distances and this is not a confined local phenomenon. Engineers must provide the basis for evaluating this pollution when citing new power stations and the like. In the U.K., the Government has decided to locate thermal power stations far away from cities and disperse So_x above 300 m.

- The Japanese Scenario

Japan, a nation with hardly any natural resources and rich in industry has shown the path for energy conservation and pollution control.

- Since the oil crisis in 1973, the energy consumption has been down by 30%.
- Pollution levels of So_x and No_x is the lowest among OECD countries and less than 10% of that in USA.
- Despite tripling of automobiles in the last 30 years, the concentration of No_x has remained steady during the last decade.
- 30% of the total cost of thermal power industry is invested in pollution control investment and this industry has grown phenomenally.
- Generally, the industry has become conscious of the need to control pollution and save energy in every way as a result of legislation and educational awareness.

Inspite of the additional costs to install pollution control measures, Japan's **GDP has grown eight times during the last thirty years, thus dismissing the oft-felt fear that such expenditure is counter productive.** Perhaps survival is the key motivator.

The **Montreal protocol** and the **General Environmental facility (GEF)** are movements in the right direction to control global pollution.

CONCLUSION

The Greenhouse effect, depletion of the ozone layer and perennial acid rain are all man made. Add to this the problems and consequences associated with deforestation, decreasing aquifer recharge, soil erosion and the like and we are presented with a 'Doomsday' scenario. The degradation of the planet's eco-system has enhanced the engineer's role as a 'facilitator' of change. He is no more a mere local builder. **His professional mission has indeed shifted from 'environmental concerns' to 'sustainable development'.**

Yes, our perception of what is an **'ENGINEER'** itself needs redefinition. He is now a unique and important **'citizen of the world'.** He supplements my ancestors profound vedic dictum

'Vasudaiva Kutumbakam' - 'The world is one family'. This gathering of ours from all over the world beautifully symbolises this philosophy.

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Global Climate Change: What Can Structural Engineers Do to Help?

Changement climatiques globaux: que peuvent faire les ingénieurs civils?

Globale Kilmaänderungen: Was können Bauingenieure tun?

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SUMMARY

By emitting carbon dioxide and other so-called greenhouse gases, mankind's industrial and agricultural activities threaten to change the global climate in unprecedented ways. Scientists believe that average temperatures may increase by 3°C by the middle of the century, causing sea-levels to rise, farmlands to dry up, and much more. Structural engineers need to be aware of these potential impacts so that they design and build projects that are able to withstand the increased stresses of tomorrow's climate. They must also emphasize designs that are extremely energy-and-water efficient.

RESUME

En émettant du bioxyde de carbone et d'autres gas provoquant l'effet de serre, les activités agricoles et industrielles de nos sociétés risquent de modifier de façon jamais vue auparavant la situation climatique globale. Des scientifiques pensent que les températures moyennes pourraient augmenter de 3°C avant le milieu du siècle prochain, entraînant entre autres l'élévation du niveau des mers et la sécheresse de régions agricoles. Les ingénieurs civils doivent être conscients de ces dangers potentiels afin de concevoir et réaliser des projets capables de résister aux effets climatiques futurs. Ils doivent aussi proposer des projets extrêmement économiques du point de vue energétique et de l'utilisation de l'eau.

ZUSAMMENFASSUNG

Durch die Emission von Kohlendioxid und anderer sogenannter Treibhausgase drohen die industriellen und landwirtschaftlichen Tätigkeiten der Menschheit das Klima in noch nie dagewesener Weise zu verändern. Nach Meinung der Wissenschaftler könnten sich bis Mitte des nächsten Jahrhunderts die Durchschnittstemperaturen um 3° C erhöhen, so dass der Meeresspiegel ansteigt, Ackerland ausdörrt und anderes mehr. Dieser möglichen Auswirkungen müssen sich Bauingenieure bewusst sein, damit die Projekte, die sie planen und bauen, den zukünftigen Klimabelastungen gewachsen sind. Insbesondere ist bei der Planung auf höchste Wirschaftlichkeit im Energie-und Wasserverbrauch zu achten.

Could you imagine building a major roadway that soon buckled and crumbled into a useless pile of rubble because the frozen ground beneath it warmed up and shifted? Or a coastal highway that had to be abandoned after 10 or 20 years because the sea kept flooding it and eroding its edges? Or how about building a city in a place that became so dry that there was no longer enough water for the people living there to bathe or cook? Or where the temperatures became so hot that the building materials you used could not handle the stress?

Surely, such fiascos could only happen to companies that are careless or guilty of poor planning. But disasters of this type will be become increasingly commonplace in the decades ahead if engineers and other professionals involved in major construction projects ignore the phenomenon of global climate change.

In the past, projects intended to last for 30 to 100 years or longer could be designed to meet the constraints of the current climate. But today this is no longer the case. Scientists now have strong evidence that the climate will change in unprecedented ways over the next 50 to 100 years. They have learned that mankind's industrial and agricultural activities are emitting carbon dioxide and other so-called greenhouse gases that are changing the way the atmosphere absorbs the sun's energy. This threatens to upset our climate's delicate balance faster and more dramatically than ever before in human history. If no action is taken to reduce greenhouse gas emissions, many of the world's societies and eco-systems may suffer devastating damage.

Is this just another exaggerated disaster scenario designed by the press and environmentalists to frighten people? No, it is not. As director of the Information Unit on Climate Change, it has been my privilege to meet and to work with some of the leading researchers in this field. Scientists are not hysterical types. In fact, they are extremely conservative, and they are used to having their work judged by the rigorous and demanding standards of their scientific colleagues. They do not pander to environmental activists or to other politically motivated groups.

Higher temperatures and sea-levels

Scientists believe that one of the main effects of mankind's emissions of carbon dioxide and other greenhouse gases will be global warming. Assuming that no action is taken to reduce emissions, computer models of the earth's climate predict that global average surface temperatures will rise by 1-3 degrees centigrade by the year 2030. This is larger and faster than any such change over the past 10,000 years. There is some evidence that this warming has already begun. Further global warming would shift climate belts towards the poles. For example, according to the global warming scenarios predicted by many models, the climate of Finland will come to resemble that of present-day northern Germany, and Iceland will experience conditions similar to Scotland's. It is less clear how warmer, semi-arid regions will be affected, but the expectation is that higher temperatures will cause more droughts and expanding desertification in many developing countries.

Clearly, rising temperatures will have a direct impact on infrastructure such as roads, buildings, and dams. For example, global warming would lead to a general melting of permafrost in Alpine and northern tundra regions, making the ground less stable for existing transport and building infrastructure. Elsewhere, higher summer temperatures would lead to increased heat stress for people as well as for physical infrastructure. In addition to higher average temperatures, global warming would cause an increased frequency of extreme events, such as heat waves. For example, the city of Washington DC currently experiences 36 days per year when the temperature exceeds 90° Fahrenheit and one day when it exceeds 100° Fahrenheit, or 33 and 38 degrees Celsius respectively. But a study by a NASA scientist concluded that if atmospheric concentrations of carbon dioxide double, then the number of days above 90°F would increase to 87, and the number of days above 100°F would increase to 12. In other words, the temperature for most of the summer would exceed 90°F, with two weeks above 100°F. How much of the existing infrastructure has been built to withstand years of such stress?

Perhaps the most dramatic result of higher temperatures will be a rise in sea-levels. Global warming would cause the sea to rise in two ways: through thermal expansion of ocean water, and by discharges of fresh water from continental ice caps and mountain glaciers. Many scientists believe that the global mean sea-level has already risen by 1-2 centimetres during the past century. Climate change is expected to cause a further rise of some 20 centimetres by the year 2030 and 65 centimetres by the year 2100. Some forecasts call for even higher sea-level rises.

Higher sea-levels would cause immense damage. Perhaps 20 centimetres doesn't seem like much, just as a 1 or 2 degree temperature rise may not sound so dramatic. But a rise in sea-level would create irreversible problems for millions of people. Some of the nations that are most at risk are small islands in the Pacific, the Indian Ocean, and the Caribbean -- some of which may have to be completely abandoned -- as well as Bangladesh, Egypt, Gambia, India, Indonesia, Mozambique, the Netherlands, Pakistan, Senegal, Surinam, Thailand, and Vietnam. Other high-risk areas are estuaries and low-lying cities and provinces such as Sydney, Shanghai, and southern Florida.

The direct costs of rising seas would amount to hundreds of billions of US Dollars. One leading economist (William Nordhaus) has calculated that protecting coastlines from a 70-centimetre sea-rise by building dikes and other barriers would cost 618 billion dollars in terms of 1981 dollars during the next 100 years. The indirect and non-market costs of a sea-level rise would dramatically increase this figure. Indirect costs would include the loss of coastal industries such as fishing and tourism, and of buildings and other infrastructure. The costs of resettling populations and of rebuilding would also have to be considered, as would non-market costs such as social dislocation, the intrusion of salt-water into estuaries and aquifers, and the loss of biologically rich eco-systems. Economists are now trying to refine new methodologies for measuring these indirect and non-market implications.

Worsening storms and droughts

Most accounts of climate change have emphasized the outlook for hotter temperatures and higher sea-levels. But in fact these two impacts may not be the most important. Other changes, such as growing storm activity and increasing droughts and water shortages, may wreak even more damage. Scientists believe that climate change may cause hurricanes and tropical storms to increase in intensity and perhaps in frequency. Meanwhile, expanding droughts and dryness would put greater pressure on global freshwater resources. The large water requirements of households, industry, and agriculture are already creating problems in areas where water is scarce. Conflicts over water resources are likely to worsen, particularly in regions with rapid population growth.

Climate change will make water resources even more vulnerable than they are now, particularly in arid and semi-arid countries. If climate change reduces precipitation in a region, the freshwater storage reserves, primarily in the form of groundwater, will steadily shrink. An increase in extreme events such as droughts and floods, or even more modest variations in precipitation from year to year, can also seriously disrupt water supplies. Lowered fresh-water levels would require major adjustments by urban settlements located on the shores of rivers and lakes and would have an enormous impact on engineering projects -- not only on dams and other water-related projects, but on any building or project that consumes water.

These dramatic impacts -- warmer temperatures, higher sea-levels, droughts, and storms -- would clearly have social and economic repercussions. Disputes over limited or diminishing resources such as water and arable land would proliferate, both between individual countries and within them. This would put societies under greater stress. Where adjustments could not be made quickly enough, social unrest, protest movements, and political instability would probably increase. In already-fragile societies, the stress of climate change could lead to either complete social breakdown or to more authoritarian rule. If climate change has its predicted impacts, many developing countries may lack the necessary resources for protecting themselves. Social upheaval and economic crisis would strongly affect the project needs of developing countries as well as their ability to maintain and to pay for these projects.

What can be done?

So much for the likely consequences of climate change. Now, what can you, as concerned citizens and as engineering professionals, do to help minimize climate change and its impacts? Allow me to make the following proposals:

First and most importantly, reduce the use of fossil fuels by the projects that you construct. Energy from fossil fuels is believed to be responsible for about one-half of man-made climate change. In the year 1985 alone, the combustion of oil, gas, and coal released some 5.3 billion tons of carbon dioxide into the atmosphere. At current rates of per-capita emissions and world population growth, CO_2 emissions will more than double in many regions by the year 2025. To prevent this, we must make technical improvements to the composition of fossil fuels, increase our energy efficiency, and replace fossil fuels with solar energy and other energy sources that do not emit greenhouse gases. Governments may soon coax industry to reduce its fossil-fuel emissions by imposing national emissions targets, carbon taxes, and tradable emissions permits schemes. Most OECD member states have set national targets for stabilizing or reducing their emissions of greenhouse gases. In 1990, the Council of the European Communities adopted a policy that provides for stabilizing the emissions of carbon dioxide at 1990 levels by the year 2000. However, unless much more drastic efforts are made, Europe's emissions seem set to *rise* by 11%.

As shown by the dramatic recent evidence that an enormous ozone hole may be opening up over the Northern hemisphere this spring, sudden and frightening evidence that confirms climate change could come at any time. This would result in growing pressure on you to make rapid improvements in the energy-efficiency of your designs. In addition to tackling this technological challenge, you may want to support efforts to reduce emissions via reliance on carbon taxes, which would probably be the most economically efficient way to achieve this goal.

Your second contribution can be to radically raise the water efficiency of all your project designs. For example, many areas of India, the site of your last Congress, already experience dry periods that force people to make careful use of water resources. Improved water management will prove even more essential if climate change reduces the monsoons or regular rainfall. Other important steps you could take would be to support government efforts to sensitize people to the problems of water wastage and to introduce policies or taxes to constrain demand. Finally, you could support the creation of a worldwide inventory of national water resources to support water-use planning in the event that climate change has its predicted effects on water supplies.

The third way you can contribute is by planning for rising sea-levels. Don't build inappropriate projects in vulnerable areas. Meanwhile, support the efforts of coastal nations to discourage unsustainable development in coastal areas and to implement emergency preparedness and response mechanisms. Most of these measures would have numerous benefits for these countries and would be justified even if sea-levels do not rise as much as predicted. Don't forget that in addition to the havoc caused by rising sea-levels, your designs may also have to cope with other stresses, including increasing storms, droughts, and floods.

Fourth, do not allow your projects to lead to a net loss of forest cover. Although industry and energy are the leading causes of climate change, the over-exploitation of ecological resources also produces greenhouse gases. Deforestation, which over the past 25 years has lead to the loss of more than 15% of the tree cover in some countries, has a number of adverse effects on the climate. Most importantly, it releases into the atmosphere carbon that was previously sequestered in trunks and leaves, either directly through burning, or indirectly through decomposition. Deforestation also reduces evapotranspiration, particularly in rain-forests, which upsets the atmospheric water cycle on both a small and a large scale. justifications for massive deforestation in the first place.

Reforesting the earth will be critical to reducing the amount of carbon dioxide in the atmosphere. Growing 370 million hectares of new forest, an area equal to about one-half of the Amazon Basin, would absorb 17% of current annual fossil-fuel emissions of carbon dioxide. The problem is that, with a growing world population putting ever greater pressure on land resources, it is becoming increasingly difficult to set aside large tracts of forest. We must all make special efforts, then, to reverse the current trend of cutting down more trees than we plant.

So far I have outlined several ways that engineering professionals can help people to cope better with the impacts of climate change. But there is much more you can do as well. You can transfer technology to developing countries to enable them to participate in solving what is truly a global, and not merely a national problem. You can also, as other industries and professions have done, become involved in the negotiation process for a legally binding global treaty on climate change. Whether climate change proceeds quickly as some scientists believe it will or at a more moderate pace, a delay in adopting global policies to reduce greenhouse gas emissions could lead to significantly more global warming. The negotiation process began in 1990, when the United Nations established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (INC) to draft a legally binding climate treaty. The draft convention is to be ready for signature at the UN Conference on Environment and Development (UNCED) in June 1992. Even if we act now, it is probably too late to avoid some degree of climate change, but if governments can agree on policies to reduce greenhouse gas emissions, negative effects such as higher temperatures could be greatly reduced.

By recognizing the scientific evidence on climate change, then, the engineering profession can build infrastructure that will be suitable to tomorrow's climate and that will not prove obsolete before its time. It can also help to reduce the negative impact of human activities on the global climate, and help people to adapt to those changes that we are unable to prevent. I hope you will accept this challenge.

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Climate Change: What Can We Do About it

Changements climatiques: que faire?

Klimaveränderung – was können wir unternehmen?

N. SUNDARARAMAN
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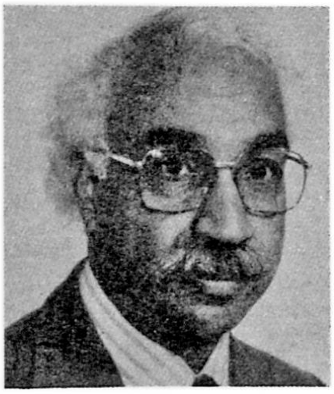

N. Sundararaman, born 1937, got his Ph.D. in meteorology from the University of California at Los Angeles, USA. After working as a professor for some time, he became the Manager of the Air Quality Division of the US Federal Aviation Administration. His work encompasses ozone depletion and climate change.

SUMMARY

Given that the atmospheric concentrations of the greenhouse gases (GHGs) ar likely to continue for some time to come, some global warming appears inevitable. While international efforts are underway to eventually stabilize GHG concentrations, adaptation should become an important part of the response options. Bridge and structural engineers have a vital role to play here.

RESUME

Une mise en garde globale devient inévitable, puisque les concentrations atmosphériques de gaz, combinées avec l'effet de serre, risquent de se poursuivre dans les années à venir. Bien que des efforts soient en cours à l'échelon international pour stabiliser ces concentrations de gaz, il est nécessaire de s'adapter à la situation actuelle. Les ingénieurs civils ont un rôle vital à jouer dans ce domaine.

ZUSAMMENFASSUNG

Bei den gegebenen Konzentrationen von Treibhausgasen in der Atmosphäre, mit der wir wohl noch eine ganze Weile werden leben müssen, scheint eine globale Erwärmung unvermeidlich. Trotz gegenwärtiger, internationaler Anstrengungen, ihre Konzentration langfristig unter Kontrolle zu bringen, sollte eine Anpassung an die Klimaveränderung zur wichtigen Handlungsoption werden. Brücken und Hochbauingenieuren kommt dabei eine wichtige Rolle zu.

1. INTRODUCTION

1.1 The views expressed in this paper are my own and do not in any way reflect the official positions of the Intergovernmental Panel on Climate Change (IPCC) or of its sponsoring organizations, viz., the World Meteorological Organization and the United Nations Environment Programme. This paper is based on the findings of the IPCC First Assessment Report [1] and the 1992 IPCC Supplement [2].

1.2 It may be noted that SI units are not used this paper.

2. THE GREENHOUSE EFFECT - SCIENTIFIC EVIDENCE

2.1 There is ample scientific evidence that the greenhouse effect is valid:

- From observations of the atmospheric compositions of the planets Mars and Venus, their surface temperatures can be deduced using the greenhouse theory. The calculated temperatures compare very well with observed values as may seen from the table below.

	Main GHGs	Calculated temperatures, °C		Observed temperatures, °C
		Without GHE	With GHE	
VENUS	>90% CO_2	-46	523	477
MARS	>80% CO_2	-57	10	-47

Note: GHG - greenhouse gases; GHE - greenhouse effect.

Table 1 Planetary temperatures - comparison of observations and calculations using greenhouse theory

- Atmospheric concentrations of carbon dioxide and methane over the past 160,000 years can be deduced from ice cores; corresponding temperature values can be obtained from deuterium data. The concentrations for both gases correlate exceptionally well with the temperatures as can be seen from figures 1 and 2 below.

3. CALCULATIONS OF CLIMATE CHANGE

3.1 The so-called coupled general circulation models (CGCMs) are used to calculate changes in temperature and other climate variables (precipitation, soil moisture etc.). The models include atmospheric and oceanic processes, some of them parameterized. The parameterizations constantly undergo evaluation and improvement. Nevertheless, the models are the only tools available to project future climatic states (in this paper, only changes in temperature will be discussed). About half a dozen of these models are in existence today.

3.2 The time evolution of the future atmospheric concentrations of the greenhouse gases is a very critical input to the models.

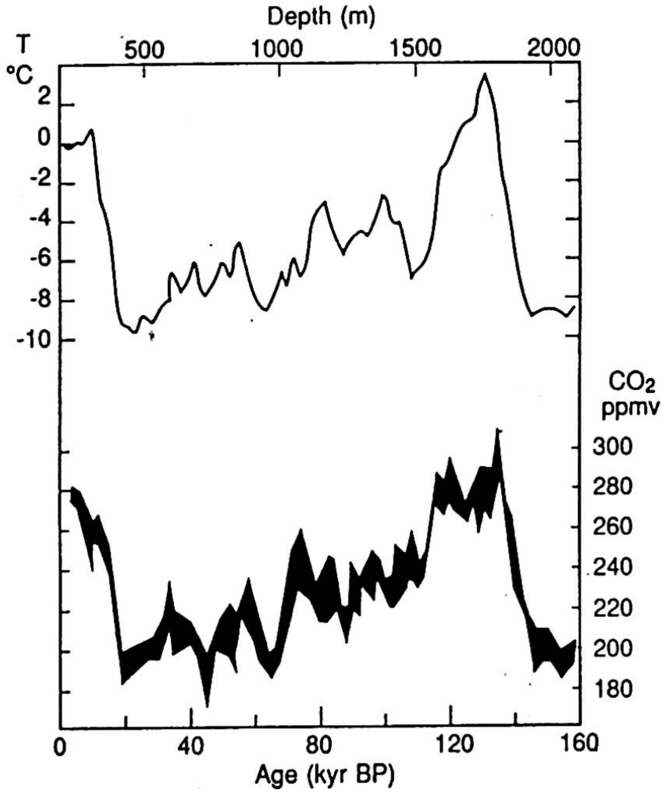

Figure 1 CO_2 concentrations (bottom) and estimated temperatures (top) in the last 160,000 years

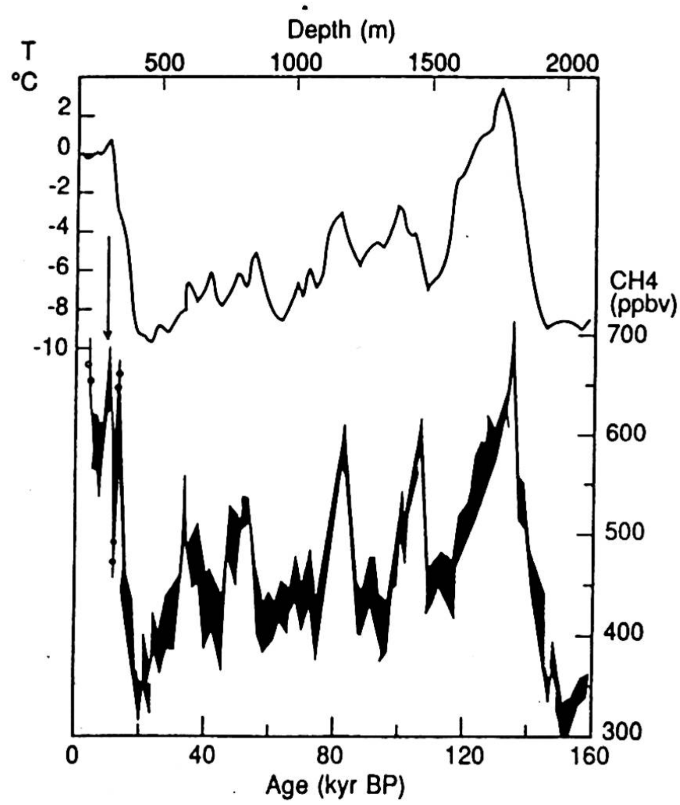

Figure 2 Methane concentrations (bottom) and estimated temperatures (top) in the last 160,000 years

Such evolution is very hard to forecast since many socio-economic factors such as rates of economic growth and the means to satisfy the latter's energy and other needs would influence future emissions of the greenhouse gases. In addition, a detailed knowledge of the chemical and other sinks of the gases is needed in order to calculate the amounts that would remain in the atmosphere. The task becomes mammoth and fraught with large uncertainties when time horizons of a century or more - typical of global warming due to greenhouse gases - are considered.

3.3 Thus, assumptions have to be made about future emissions of the greenhouse gases. Such assumptions are known as emissions scenarios; they are more in the nature of working hypotheses and are not predictions of future emissions. In this sense, then, there are no predictions of future climate. (This, however, is not to say that climate is not predictable - quite the contrary.)

3.4 The IPCC considered 4 emissions scenarios in its first assessment [1] to illustrate the effects of different response options. One of them (the Business-as-Usual scenario or Scenario A) assumes that no action is taken to stabilize the concentrations of the greenhouse gases. The others correspond to an equivalent doubling of atmospheric CO_2 over the pre-industrial value (of 280 parts per million by volume) assumed to occur in the years 2030, 2060 and 2090 respectively. (The radiative effect of all greenhouse gases is often expressed in terms of the concentrations of CO_2 that would be required to produce the same effect - this is the concept of "equivalent CO_2".) They are all shown in figure 3.

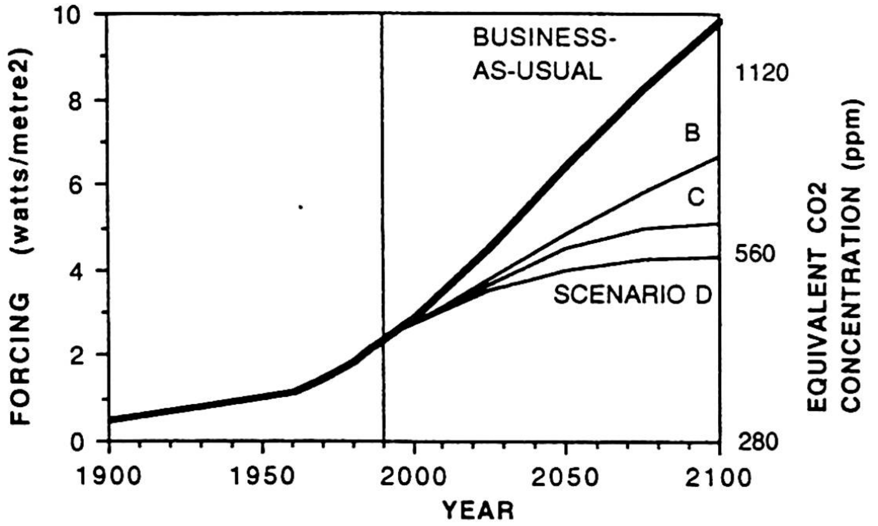

Figure 3 IPCC Emissions scenarios

3.5 The IPCC calculations of increases in the global average temperatures corresponding to the Business-as-Usual scenario is given in figure 4. The range of estimates given, from high to low, indicates the uncertainty in the calculations. The uncertainties arise from feedback mechanisms (such as, for example, of the shrinking ice and snow leading to reduced reflection back to space of incoming solar radiation). The calculations of temperature increases as well as increases in mean sea level rise for 3 of the 4 scenarios are given in table 2.

4. THE CONCEPT OF THE "REALISED" CLIMATE CHANGE

4.1 In figure 4, it may be noticed, the ordinate is labelled "realised temperature rise". This is an important concept and has some implications for responding to global warming. It is best illustrated by the following example.

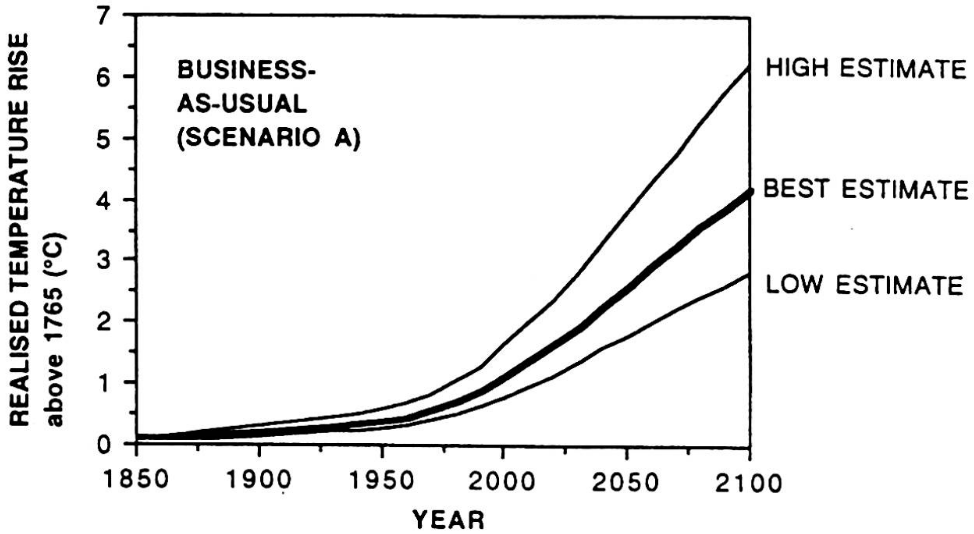

Figure 4 Calculated increase in the global mean temperature for the Business-as-Usual emissions scenario

Emissions scenario	Rate of increase of temperature °C/decade	Rate of increase of sea level cm/decade
Business-as-Usual	0.3 (0.2-0.5)	6 (3-10)
Scenario B	0.2	4
Scenario C	0.1	3.5

Table 2 Calculated rates of increase in the global average temperature and mean sea level for a few IPCC emissions scenarios (The numbers in parentheses indicate the uncertainty range)

4.2 Barring unusual weather phenomena, the daily maximum in the temperature usually occurs around 2 or 3 o'clock in the afternoon. The cause of the temperature is the forcing by the sun. The forcing maximum is at local noon but the maximum in temperature is only observed a few hours later. That is, the "commitment" to maximum temperature is made at noon but at noon the "realised" temperature is less than the maximum, i.e., that which is already "committed" for happening. The reason of course is the time lag in the response of earth-atmosphere to the solar forcing.

4.3 The same concept applies to global warming. In the case of the daily temperatures, the lag is of the order of an hour or so. In the climate case, the lag can be several decades to centuries (because of the huge heat capacity of the oceans).

4.4 Thus, as long as greenhouse gases continue to increase in the atmosphere - and at present all observations indicate monotonic increases in CO_2, methane, nitrous oxide, the chlorofluorocarbons, all of them with greenhouse properties - the temperatures would be less than what would be "committed" to. This is more readily understood in the case of sea level rise.

5. IMPORTANCE OF ADAPTATION AS RESPONSE TO CLIMATE CHANGE

5.1 Given the nature of the "realised" effects, a certain amount of warming (and associated impacts) would appear inevitable. It would be quite a while before the concentrations of the greenhouse gases can be stabilized, assuming that such a goal is aimed for and steadily pursued. In the meanwhile, the greenhouse gases emissions would continue, increasing with time the greenhouse forcing.

5.2 Thus, it would be prudent to include adaptation in the measures to respond to climate change. Adaptation should be deemed an important part - perhaps the major part in the next two or three decades - of the available options. This has to be done at primarily the national level. But in order to adapt, and adapt at least cost (assistance in this regard to the developing countries is another matter altogether and is not discussed here), better knowledge of the impacts of climate warming on the physical and socio-economic systems would be necessary. The bridge and structural engineers have a vital role to play in this effort.

6. CONCLUSION

6.1 It is an observational fact that greenhouse gases are increasing in their atmospheric concentrations today. The trend is likely to continue for some time to come (given, for example, that the time scale of restructuring energy systems is a few decades). And, at any given time, the temperature increase would be always less than what is committed for. Thus, adaptation becomes an important option to manage climate change. This requires a good knowledge of the impacts of climate change on the physical and socio-economic systems. The IABSE could contribute constructively in this effort.

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Society-Engineer-Environment: Perspective of Practising Consultants

Société – ingénieur – environnement: point de vue de l'ingénieur-conseil

Gesellschaft, Ingenieur und Umwelt: aus der Sicht eines Beratungsbüros

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SUMMARY

In this article, an attempt has been made to draw up the present perspective of the interrelationship of society-engineer-environment from the point of view of practising consultancy agencies in the field of environmental management. The counteractive strategies, social role of engineers, environmental screening approaches for vulnerable projects, the concepts of sustainability and its quantifiable assessment possibilities, have been discussed.

RESUME

L'article exprime le point de vue d'un ingénieur-conseil spécialisé dans la gestion de l'environnement, sur l'évolution possible de la relation entre la société, l'ingénieur et l'environnement. Il traite de stratégies communes, du rôle social de l'ingénieur, des approches écologiques de projets sensibles, des concepts de développement continu et harmonieux, et de l'évaluation de diverses alternatives.

ZUSAMMENFASSUNG

Der Beitrag zeichnet die gegenwärtige Perspektive der Dreiecksbeziehung zwischen Gesellschaft, Ingenieur und Umwelt aus der Sicht eines Beratungsbüros mit Tätigkeit im Umweltmanagement. Er behandelt Eindämmungsstrategien, die soziale Rolle des Ingenieurs, Umweltveträglichkeitsprüfungen für sensible Projekte, die Konzepte dauerhaften Wachstums und Möglichkeiten seiner quantitativen Beurteilung.

INTRODUCTION

In today's world, the interrelationship of society, engineer and environment can be viewed from many angles. One such perspective is that of practising consultants engaged in project implementation. This perspective, perhaps, develops from the following definitions of these building blocks:

Society : A structured and collective system of human organisation for large scale community living that furnishes protection, continuity, security and an identity.

Engineer : A person versed in the art of science of making practical application of knowledge in the design and construction of bridges, buildings, mines, plants, machinery and the like.

Environment: The aggregate of surrounding things, conditions and influences.

The above characteristics of 'Society', 'engineer' or 'environment' introduce certain functional demands in them. An engineer turns out to be the initiator of industrialisation which in turn leads to urbanisation of the society with increased population. This in turn, puts pressure on the local environment and ecosystem of the planet earth.

The above interrelationship is best represented with a system that can be called as a "model of concentric subservience" (Fig.1), in which the engineer is at the core with concentric envelops of the society, environment and the planet Earth. The engineer's efforts of disturbing the nature lead to societal problems which in turn, result in the disturbance of ecosystems in the local environment. All these degradational effects are supposed to be solely contained by the planet Earth with its self-sustaining natural systems.

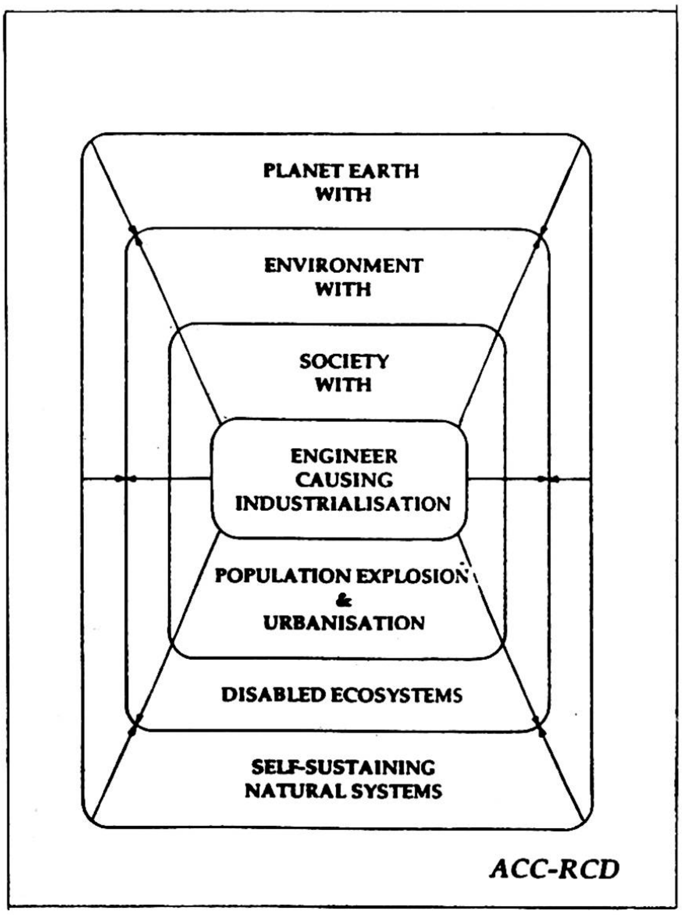

Fig 1. Model of concentric subservience

PRINCIPLES OF SELF SUSTAINENCE

Needless to mention that when there is no natural or man-made perturbation, the biosphere turns out to be an excellent autosustainable and self-generating system with only the solar energy as the external input (Fig.2) [1]. But the total elimination of natural or man-made perturbations is not possible in most circumstances. Even then, as long as the perturbations are within limits, the self-sustainance of cyclic phenomena can be restored as displayed in Fig.3.[2] which depicts man-made and

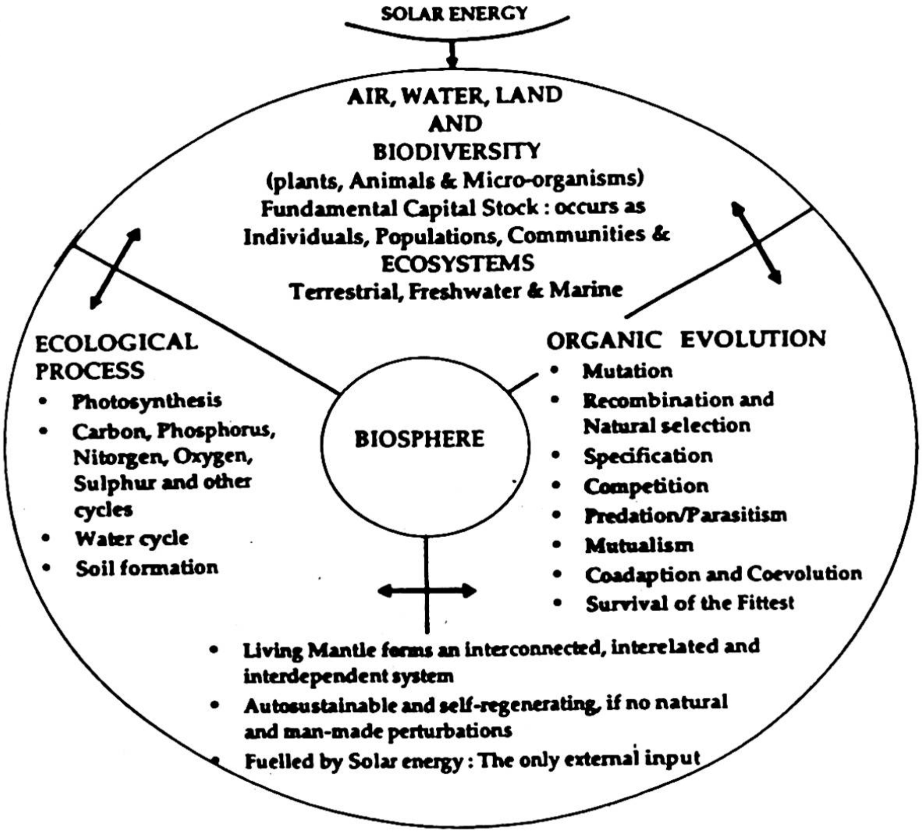

Fig. 2 Interactive components of Biosphere

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natural contributions to the natural carbon cycle through fossil-fuel burning and volcanic eruptions respectively.

If one attempts to critically study such phenomena in nature, one finds that the self-sustainance of natural systems is governed by the three basic principles of sustainability, which are as follows:

(i) Outputs: Waste emissions from a project should be within the assimilative capacity of a local environment to absorb without any unacceptable degradation.

(ii) Renewable inputs: These should be within the regenerative capacity of the natural system that generates them.

(iii) Non-renewable inputs: The depletion rates should be equal to the rate at which renewable substitutes are developed by human invention and investment.

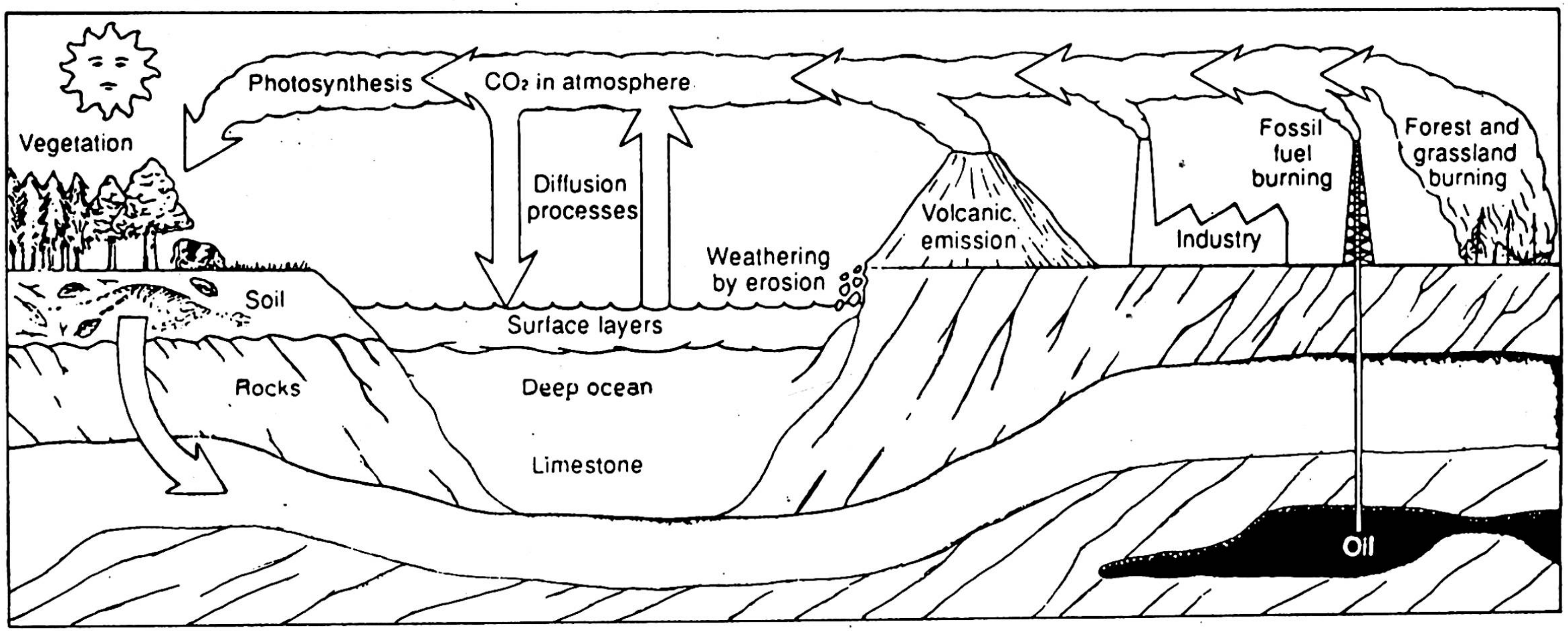

Fig.3 Carbon Cycle at global level

Unfortunately, the above principles of sustainability in real-life situations are difficult to be realised or implemented due to several constraints, two of which need special mention - fallibility of engineers and intrinsic conflicts in managing our environment. These aspects are expounded below:

CONSTRAINTS OF SUSTAINABILITY

Fallibility of Engineers

If one tries to track down the engineering catastrophies in historical times, one may find countless examples of failures, some of which are due to human frailties and some due to human faults. Let us consider the following examples:

* Failure of Tacoma Narrows Bridge in U.K. in 1836, in which case the disastrous effects of a natural phenomenon like wind excitation was, perhaps, beyond the comprehension of designers then.

* Collapse of Coledale Embankment in New South Wales in 1988, in which the proneness of the land to subsidence could not be gauged.

* Failure of challenger shuttle in 1986 which is ultimately traced to neglectof inspection of components.

All these examples reveal the concealed uncertainly in engineering profession which has been aptly defined in the context of structural engineering as follows [3]: "Structural engineering is the art of modelling materials we do not wholly understand into shapes, we cannot precisely analyse so as to withstand forces, we cannot properly assess in such a way that the public at large has no reason to suspect the extent of our ignorance".

Conflicts in Environmental Management

The above weakness of engineering profession gets aggravated manifolds with several conflicting issues that emerge in managing our environment. The more critical issues can be summarised as follows:

(a) While the growth of human population and human activity is explosive in nature, the counteractive approaches are adaptive and slow.

(b) While the environmental changes are science-induced, our understanding of such science is still incomplete.

(c) While in the management of environment there is a strong superimposed effect of economic and social processes, our understanding of such additional impact is grossly inadequate.

(d) While the economic development is a resource-use concept, the environmental protection is a resource conservation and management concept.

ENVIRONMENTAL IMPACTS OF HUMAN ACTIVITIES

In such conflicting situations aided and abetted by human frailties, the environmental impacts have been enoumous due to human activities. The decline of ancient civilisations in the plains of the Euphrates-Tigris, the Nile, the Indus, the Ganges, etc. was believed to be due to indiscriminate deforestation, decimation of animal life, etc.

With increasing tempo of industrialization in the 18th century the impacts of human activities on our environment have been significantly higher than what was, perhaps, experienced in the prehistoric times. An idea of the magnitude of such impacts can be had from Table 1 [4].

Table 1 - ENVIRONMENTAL IMPACTS OF HUMAN ACTIVITIES SINCE BEGINNING OF THE 18TH CENTURY

- **POPULATION INCREASED BY A FACTOR OF EIGHT**
- **LIFE EXPECTANCY DOUBLED**
- **INTERNATIONAL TRADE OF MANUFACTURED GOODS INCREASED BY A FACTOR OF EIGHT HUNDRED**
- **LOSS OF SIX MILLION SQ.KM. OF FORESTS**
- **SEDIMENT LOADS IN RIVER SYSTEMS INCREASED THREEFOLD**
- **CARBON FLOW TO SEA ESTIMATED BETWEEN ONE TO TWO BILLION TONNES A YEAR**
- **WITHDRAWAL OF WATER FROM THE HYDROLOGICAL CYCLE INCREASED TO 3600 CUBIC KILOMETRES PER YEAR**
- **METHANE CONCENTRATION IN ATMOSPHERE DOUBLED**
- **CARBON DIOXIDE CONCENTRATION INCREASED BY 25%**
- **MORE THAN 70,000 CHEMICALS SYSTHESISED**
- **EMISSION OF IMPORTANT TOXIC ELEMENTS (TIMES MORE THAN THE NATURAL FLOWS)**
  - **Pb (18), Cd (5)_, Zn (3)**
  - **A, Hg, Ni & V (Each 2)**
  - **S & N (≈)**
- **CFC & DDT ESTABLISHED AS MAJOR ENEMIES OF ENVIRONMENT**

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The resultant environmental concerns are summarised in Table 2.

Table 2 - RESULTANT ENVIRONMENTAL CONCERNS

- *RURAL-URBAN DRIFT LEADING TO ENORMOUS PRESSURE ON WATER SUPPLIES AND WASTE DISPOSAL*
- *EROSION AND SEDIMENTATION CAUSING PERENNIAL AND RECURRING FLOODS*
- *POLLUTING EMISSIONS (PARTICULATE, LIQUID AND GASEOUS) LEADING TO CLIMATIC CHANGES/GREENHOUSE EFFECTS*
- *ACID RAINS AND PHOTOCHEMICAL SMOG*
- *DEPLETION OF OZONE LAYER AND THREAT OF UV RADIATION*
- *POLLUTION OF RIVERS AND INLAND WATERWAYS*
- *POLLUTION HAZARDS OF FOOD CHAIN*
- *DESTRUCTION OF BIODIVERSITY*
- *DESERTIFICATION*

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PRAGMATIC STRATEGIES FOR ENVIRONMENTAL MANAGEMENT

In the backdrop of what has been discussed above, it appears essential to adopt new and pragmatic strategies of environmental management which should consist of at least the following elements:

* Replace the "Pollute-First-and-Clean-later" approach by "Economic-cum-Environmental Planning".
* Environmental quality to match the needs and aspirations of the growing population.
* Minimise the deleterious effects of human and industrial activities through restorative and preventive measures.
* Balance the socio-economic development including the environmental preservation so as to spread the benefits as widely as possible.

Social Role of Engineers in New Strategy

With the adoption of such strategies it is possible to define the social role of engineers in environmental management as follows:

* To appreciate the new demands of the society and not to isolate from the social forces.
* To classify a project for environmental screening based on location (environmental fragility), scale (magnitude of environ-

mental effect) and sensitivity (sustainability or vulnerability of effects).

* To undertake Environmental Impact Assessment (EIA) studies for projects for which environmental screening is essential.
* To select Environmental Mitigation Plans (EMP).
* To fix up institutional arrangements for execution and monitoroing.
* To organise environmental management training.
* To adhere to the principles of sustainability within the limits of practicability and techno-economic feasibility.

The fulfilment of the above roles of an engineer becomes more pertinent in the context of projects already classified as of high priority for environmental screening, some illustrations of which as per the World Bank norms are given in Table 3 [5].

Table 3 - PROJECTS CLASSIFIED FOR RIGOROUS ENVIRONMENTAL SCREENING

- DAMS AND RESERVOIRS
- FORESTRY PRODUCTION PROJECTS
- LARGE SCALE INDUSTRIAL PLANTS AND ESTATES
- IRRIGATION, DRAINAGE, CHANNEL TRAINING AND FLOOD CONTROL
- LAND CLEARANCE AND LEVELLING
- MINERAL, OIL AND GAS DEVELOPMENT
- PORT AND HARBOUR DEVELOPMENT
- RECLAMATION OF NEW LAND
- RESETTLEMENT
- RIVER BASIN DEVELOPMENT
- THERMAL AND HYDROPOWER DEVELOPMENT
- MANUFACTURE, TRANSPORT AND USE OF PESTICIDES/TOXIC/HAZARDOUS MATERIALS

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The most critical role of engineers in handling these projects is to conduct EIA studies for which certain guidelines can be adopted as highlighted in Table 4.

Table 4 - CHECKLIST OF MORE IMPORTANT ISSUES FOR EIA STUDY

- USE OF AGROCHEMICALS IN A PROJECT
- PROTECTION AND MANAGEMENT OF BIOLOGICAL DIVERSITY
- COASTAL AND MARINE RESOURCE MANAGEMENT
- MANAGEMENT OF CULTURAL PROPERTY
- HAZARDOUS AND TOXIC MATERIALS HANDLING
- INDUCED DEVELOPMENT AND ASSOCIATE DSOCIO-ECONOMIC ASPECTS
- INVOLUNTARY RESETTLEMENT ISSUES
- LAND SETTLEMENT
- NATURAL HAZARDS
- OCCUPATIONAL HEALTH AND SAFETY
- INDIGENOUS PEOPLES
- TROPICAL FORESTS
- PROTECTION OF WATERSHEDS, DAMS, RESERVOIRS, IRRIGATION SYSTEMS, ETC.
- CONSERVATION OF WETLANDS
- CONSERVATION OF WILD LANDS
- PRESERVATION OF INTERNATIONAL AGREEMENTS ON RESOURCES

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Faculty Enrichment for Engineers

For more effective functioning in the realm of integrated E-C-E planning, certain preparation is necessary for engineers for enhancement of professional background. A few critical areas of faculty enrichment can be summarised as follows:

a) Innovative approaches for preserving biosphere, selecting cleaner technology and waste management.

b) Development of environmental information systems.

c) Adoption of systems analysis and modelling in environmental management, particularly in view of the multi-disciplinary nature and complexity of sub-system.

In this regard, mention may be made of the endeavour being made by ACC in rehabilitation of quarries, greening of land with appropriate plantations and waste management with new product technologies through in-house multi-disciplinary developmental efforts. In all such exercises, process engineers, agricultural scientists, organic chemists, material scientists, etc. work hand-in-hand.

ASSESSMENT OF SUSTAINABILITY

It need not, perhaps, be repeated that sustainability is the key word in the management of environment but it should certainly be considered that any quantitative assessment of environmental sustainability is always a complex issue. Often attempts are made to measure sustainability through such macroeconomic indicators as:

- Population stability
- Greenhouse gases
- Acidification
- Toxic substances
- Soil degradation
- Aquifers depletion
- Species extinction, etc.

For specific projects, other indicators like energy intensity, material intensity, renewable energy proportion, recycled proportion, etc. are also applied.

But none of these indicators or for that matter, even those developmental indicators like GNP, Price Indices, etc. do not reflect truly the development in a society. Hence, the environmental scientists and engineers, in association with the sociologists, are trying to look at the feasibility of adopting an all together new concept " QOL " - "Quality of Life" - as the proper indicator in economic cum environmental planning. Index QOL is conceived as a function of the objective conditions appropriate to a selected population and subjective attitude towards those conditions held by persons in that population. The mathematical representation of such a concept is obviously not easy, although numerous attempts are being made [6].

CONCLUSION

From the foregoing it is, therefore, obvious that the interrelationship of 'Engineer - Society - Environment' in our planet is an involved one in which there are opposing forces of degradation and restoration, demanding pragmatic management efforts. The practice of technology cannot be kept aside and at the same time, the degradation of environment cannot be permitted. This kind of dichotomous demands needs to be appreciated from what has been stated by Arnold Bacer: "If the practice of technology leads to frequent or dangerous dislocations in the natural environment or in the society, then it is perfectly right to suspect that there is something wrong with the technology itself". This concept is pervading fast enough through the entire society and the engineers are certainly re-orienting themselves to meet the social demands of industrial progress through cleaner technologies and effective waste management. In this approach, there is a strong role of specialised consulting agencies who are already geared up to manage the environment in association with their clients in a pragmatic manner.

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Teach-In 1

Structural Concrete: Concepts and Practices

Structures en béton: concepts et applications

Betonbau: Kozepte und Anwendungen

Organiser: Jorg Schlaich
Germany

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TEACH IN
STRUCTURAL CONCRETE

J.E. Breen
The University of Texas at Austin

Presented by

L. Wyllie
Degenkolb and Associates

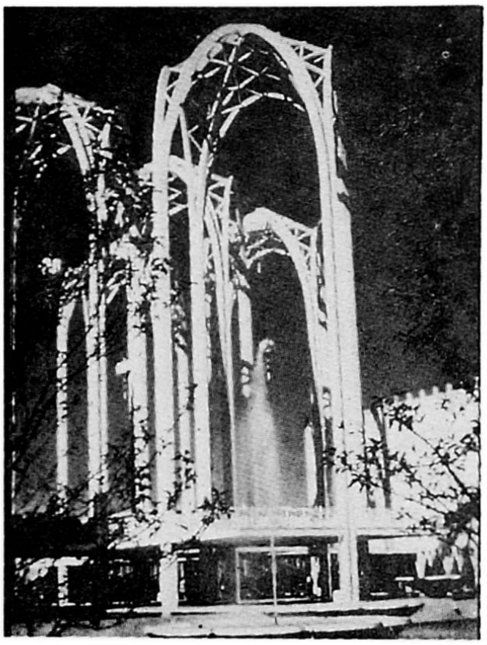
March 2, 1992
New Delhi

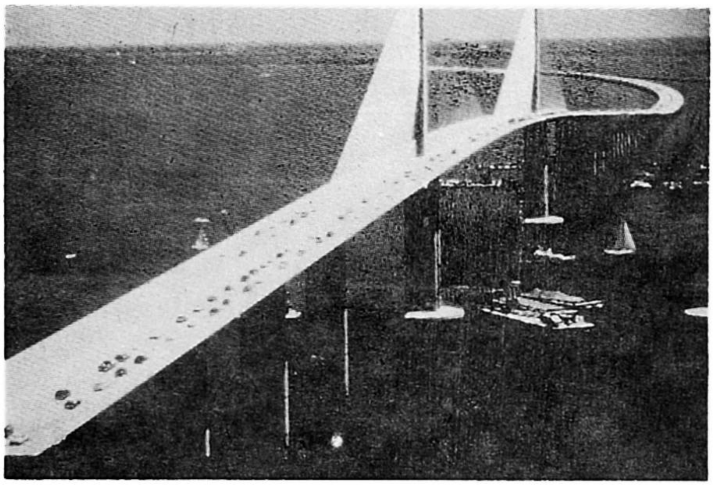
In this Introductory section of today's Teach-In on Structural Concrete, we wanted to explain why IABSE, and particularly Working Commission III, Concrete Structures, is leading an international effort to refocus our approach to design of concrete structures.

Indeed -- Why Structural Concrete?

After all, Reinforced Concrete is well over 100 years old and Prestressed Concrete is now over 50 years old.

We have shown that we can build truly beautiful structures





and breathtaking bridges -- monuments that any age would envy.

In view of this well-developed industry and the impressive knowledge base which surrounds it --

- Why do we want to re-examine fundamental approaches?
- Why is there any urgency to do it now?

Structural concrete is definitely a world-wide industry. Projects frequently cross continental lines producing an increased need for harmonization. Today's communication explosion creates global interaction. Engineers in one country frequently work on projects a continent away with totally different codes and standards.

The lack of harmonization is particularly apparent when the project includes prestressed concrete. While CEB and FIP have collaborated in an impressive way, the world-wide status is still disturbing.

There is an absence of an overall unifying approach which smoothly meshes reinforced and prestressed concrete. The fragmentation is obvious in technical societies in countries such as the USA where we even have one professional group for pretensioners and a completely different one for post-tensioners. It is mirrored by serious divisions in education and textbooks for reinforced concrete and for prestressed concrete.

The complaints of many designers working in many lands led Working Commission III to become conscious of the growing frustration of code users with our man-made fragmentation. We decided that the time to unify Structural Concrete is now. We had a most successful colloquium in Stuttgart in April 1991 where it became apparent that the feeling was world-wide. We hope that the results and the summary statement from the Stuttgart Colloquium will spark other organizations to act.

During this Teach-In we want all of you to focus on the advantages of a consistent approach to reinforced and prestressed concrete in both education and practice. In the talks that follow we will be focusing on a design approach that gives major focus to overall structural behavior and flow of forces throughout the structure. It will reacquaint you with useful and highly transparent models.

We want to, wherever possible, eliminate conflicts in codes and standards.

Concrete does not stand alone -- in each country structural engineers must develop an overall framework to facilitate mixed or composite construction.

In order to communicate our ideas, we suggest a few definitions.

The most basic is the term "Structural Concrete." We ask that this term be used for the entire spectrum of concrete used for structural proposes from non-reinforced applications through applications which have a mix of non-prestressed and prestressed reinforcement.

Another useful term is "active reinforcement" or some may prefer the term "prestressed reinforcement". Note we consider only that portion of the reinforcement capacity developed by the construction operations as "active."

The complementary term is "passive reinforcement" or some may prefer the term "non-prestressed reinforcement." Note that this includes that portion of the active reinforcement capacity which is not developed during prestressing operations. This is the stress increase above the effective prestress level developed in bonded tendons as they resist higher levels of applied load.

It is very convenient to think of prestressing as a load type action applied by the constructor which are additive to other loads. These loads, including their axial and normal components and eccentricities, can be entered into the analysis and combined with other loads. The final effect must be countered by the resistance.

ACTIVE REINFORCEMENT

- Any reinforcement which is mechanically electrically, or chemically stressed by constructor controlled methods during the construction process
- Only that portion of the active reinforcement capacity which is developed by the construction operations

PASSIVE REINFORCEMENT

- Any reinforcement which is not actively stressed by constructor controlled methods in the construction process
- Includes the developable capacity of active reinforcement in excess of that developed during the construction process

SUPERFLUOUS TERMINOLOGY

- Fully prestressed concrete
- Partially prestressed concrete
- Reinforced concrete
- Secondary moments or Parisitic moments

USEFUL TECHNICAL TERMINOLOGY

- Pre-tensioning
- Post-tensioning
- Internal tendons
- External tendons
- Bonded reinforcement
- Unbonded reinforcement
- Precast concrete
- Cast-in-situ concrete

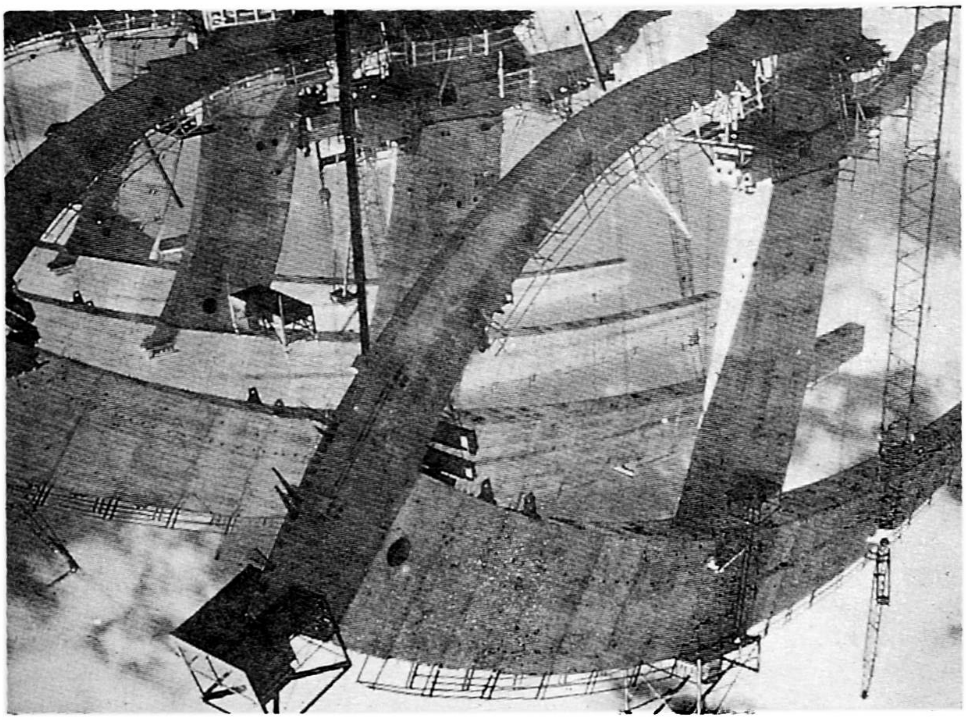
By the use of these definitions it becomes unnecessary to use some terms which cause considerable confusion such as fully prestressed concrete and partially prestressed concrete. Prestressed concrete members all have both active and passive reinforcement. Thus, prestressed concrete members are also reinforced concrete although we usually use that term to imply non-prestressed concrete. Using "Structural Concrete" eliminates these artificial distinctions.

One of the main advantages in considering prestressing as a load is that calculations of secondary moments becomes de-mystified and their redistribution more obvious. All that is required is a conventional analysis which correctly considers boundary conditions, restraints, and realistic stiffnesses.

Many traditional technical terms continue to be useful but do not require separate codes, standards or design procedures.

It is amazing that constructors have little difficulty in treating all of the various forms of structural concrete in a unified way while we designers often run into artificial discontinuities in theories, approaches, codes and standards.

Both designers and constructors conquer these man-imposed obstacles in their battles with the forces of gravity and nature. Why do we make life so hard for ourselves in the design process?



So that you may better understand WCIII concerns, we have outlined a few inconsistencies drawn heavily from a North American perspective, but found to be fairly representative.

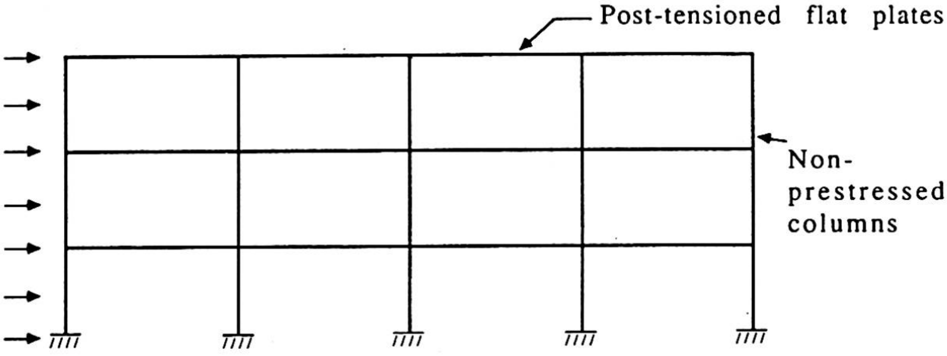
In spite of the rapidly growing use of prestressed concrete construction in the USA, most American universities either do no teach a course on reinforced concrete or restrict such courses to graduate students.

Our separate treatment of "reinforced concrete" and "prestressed concrete" in university courses and in textbooks gives the newcomer the false impression
that these are fundamental differences between the subjects.

It is not only the universities that are divided -- Many countries have separate standards for "reinforced concrete" and "prestressed concrete." Often these separate standards have conflicting notation. Totally different approaches are used to express the same fundamental principles -- Approaches lack transparency and abound in confusing empirical equations. The variety of overlapping codes and standards is breeding errors rather than minimizing them.

When a country has completely separate standards for reinforced concrete and for prestressed concrete, it becomes very difficult to decide questions such as the proper degree of restraint which these prestressed slabs provide for the non-prestressed columns. Modern designers live in a mixed world!

CODES AND STANDARDS

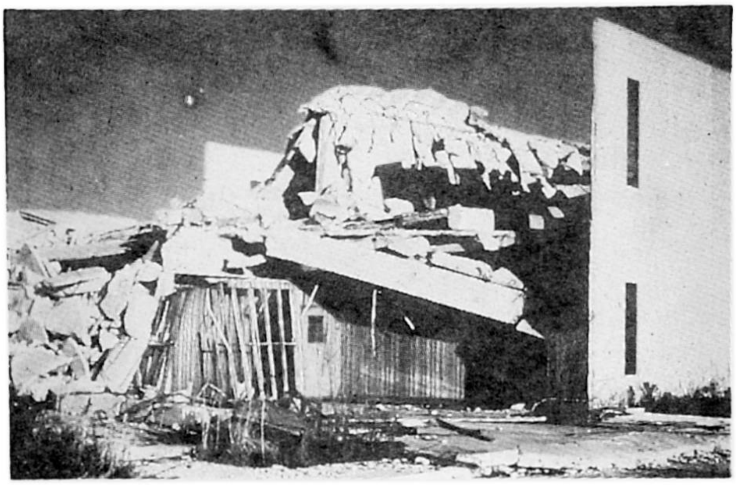


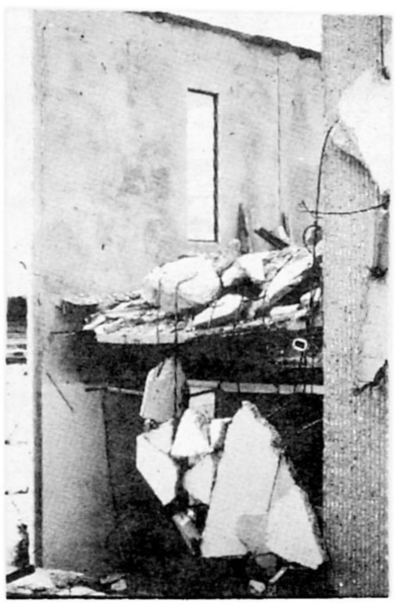
A universal complain is that codes and standards are becoming increasingly complex as they blindly adopt excellent "research models" instead of transparent, designer-friendly models which we will emphasize today. Innovation is limited by the narrowness of the empirical models.

Numerous structures have experienced substantial distress and structural failure due to poor detailing induced by the lack of overall consideration of the flow of forces and the restraints active in the structure.

An ugly example is this office building for a major engineering company. Structural engineers employed by the company frequently visited the construction site to see their new offices growing.

The building was virtually complete - the electricians incorrectly wired a 3-phase electric motor. They turned on the power - a small motor on the roof surged - the entire building collapsed with a number of workmen killed.

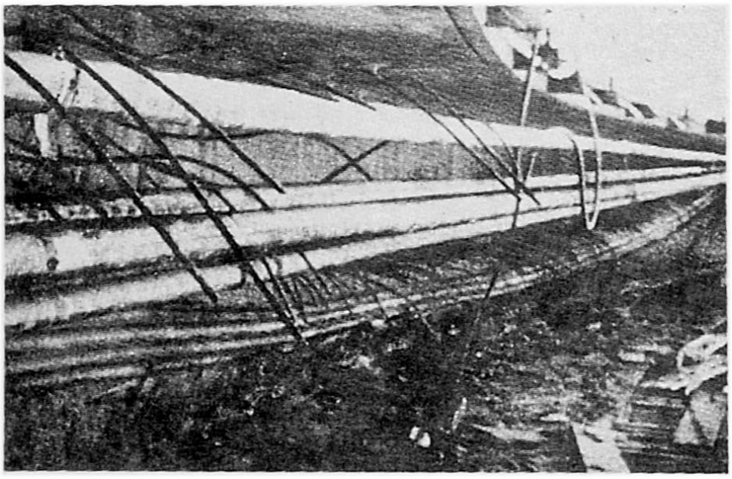




The tilt-up prestressed walls and the cast-in-situ post-tensioned beams were correctly proportioned in terms of section-by-section analyses. No thought or attention was given to tieing the various members together. The beams had no supports under their ends and were rubbing by friction on the walls -- when friction was broken, the building collapsed.

Minimal attention to force paths would have saved lives and property.

Another example of poor detailing due to lack of consideration of applied loads and force paths was shown in a major curved bridge.



No tie-back reinforcement and inadequate cover was present to equilibrate out-of-plane forces when the tendons were stressed -- the arc became a chord. Again, minimal attention to good detailing and force paths would have prevented their collapse

The primary tools required to implement a consistent structural concrete methodology need to be highly transparent and design-oriented such as the Strut-and-Tie Models. Tools like interactive graphic programs and finite element analysis can be useful if they are used to help with force paths and not as strictly numerical output.

In this session today we hope that we can bring to this great Indian sub-continent our version of what a consistent and transparent design philosophy can do.

Our challenge today is to help you move towards unity, simplicity and clarity in your approach to Structural Concrete.

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Strut-and-Tie Model Design of Structural Concrete

Analogie du treillis dans les structures en béton

Stabwerkmodelle für Konstruktionsbeton

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SUMMARY

Only through an intelligent model can a complex reality become translucent and understandable to a designer and there lies the key to quality in structural engineering. Strut-and-tie models can illustrate very well the internal flow of forces in structural concrete and thereby, provide valuable assistance to the designer who is striving for an appropriate and functional conceptual design. Moreover, such models are good enough to serve as a basis for the design and dimensioning of the modelled structure or structural detail for the cracked state.

RÉSUMÉ

Une réalité complexe ne peut être comprise qu'à travers un modèle cohérent et intelligible; pour l'ingénieur ceci est la clef d'un dimensionnement efficace particulièrement dans le domaine des structures. L'analogie du treillis permet de visualiser de façon très claire le cheminement des forces dans les structures en béton; ceci constitue une aide précieuse pour l'ingénieur lors du dimensionnement approprié d'éléments porteurs ainsi que des détails de construction. De plus, de tels modèles représentent le fondement du calcul des constructions en béton armé et précontraint à l'état fissuré.

ZUSAMMENFASSUNG

Weil man nur bearbeiten kann, was man versteht, ist die Wahl eines intelligenten Modells, das ein komplexes Tragwerk durchsichtig und verständlich macht, der Schlüssel zur Qualität im Konstruktiven Ingenieurbau. Mit Stabwerksmodellen kann der innere Kraftfluß sehr anschaulich dargestellt werden. Dadurch sind sie auch eine wertvolle Hilfe für den Entwurf zweckmäßiger Tragwerke und Details. Sie sind außerdem eine geeignete Grundlage für die Bemessung von Stahl-und Spannbetonkonstruktionen im gerissenen Zustand II.

1. INTRODUCTION

Breen [1] proclaimed at the IABSE Colloquium:'Structural Concrete' in Stuttgart "useful and transparent models, which can enhance the designer's realization of structural action" and he emphasized several times strut-and-tie models (STM) as such a tool. Beginning with Ritter's truss model for beams such models were used for the visualization of forces in some specific cracked reinforced concrete elements and for proportioning their reinforcement. Thürlimann and his Zürich School developed a more general design concept using stress fields on the basis of theory of plasticity. More recently Schlaich and his co-workers proposed to generalize the strut-and-tie method for the application to all kinds of structural concrete elements or structural details and to compliment the method by a unified concept for the dimensioning of cracked structural concrete, including the node regions of struts and ties [2, 3, 4].

Such a concept is urgently needed considering the Codes of Practise, which give design rules only for elements with linear strain distribution (B-regions) but neglect all others, more complicated ones, where damage most frequently occurs. The lack of a consistent methodical approach for the design and dimensioning of such discontinuity regions (D-regions) is felt particularly when they are taught to the students. Considering the importance of the D-regions for the safety and endurance of structures their design cannot be left to the draftsman's skill or the engineer's good guess. Any rational approximate method is better than this state of dimensioning.

2. MODELS FOR STRUCTURES CONSISTING SUBSTANTIALLY OF B-REGIONS BEAMS, FRAMES AND ARCHES

This concerns the majority of the daily building activity (even more if we include the slabs, see sect. 4). Though these structures consist widely of B-regions (fig. 1 shows a typical example) they only in very rare cases can do without any D-regions.

In B-regions the Bernoulli-hypothesis of plain strain distribution is valid (B stand for beam or Bernoulli). Their internal state of stress is easily derived from the sectional forces (bending and torsional moments, shear and axial forces) through clearly defined models as discussed below.

Regions in which the strain distribution already for a linear-elastic stress-strain law is significantly non-linear due to static (e.g. concentrated loads) or geometric (e.g. corners, bends, openings) discontinuities are called D-regions (where D stands for discontinuity, disturbance or detail).

Of course, it would be unreasonable to begin immediately to model these structures with strut-and-tie-models (STM) or even with finite elements. Rather the common practice should be maintained to model the real structure by its statical system, i.e. one-dimensional elements following the center lines of the real sections, and to analyse its support reactions and sectional effects, the bending moments (M), normal forces (N) shear forces (V) and torsional moments (T). It should be emphasized, that this analysis in cases of structures with predominantting B-regions such as in fig.1 yields satisfactory results for the deformations and forces if it is carried through the D-regions even, i.e. if even the D-regions are for that purpose treated as B-regions - but only for this overall analyis, not for the dimensioning of the D-regions themselves! In cases of doubts, i.e. if the D-regions appear to dominate against the B-regions, the method described in sect. 3 should be followed.

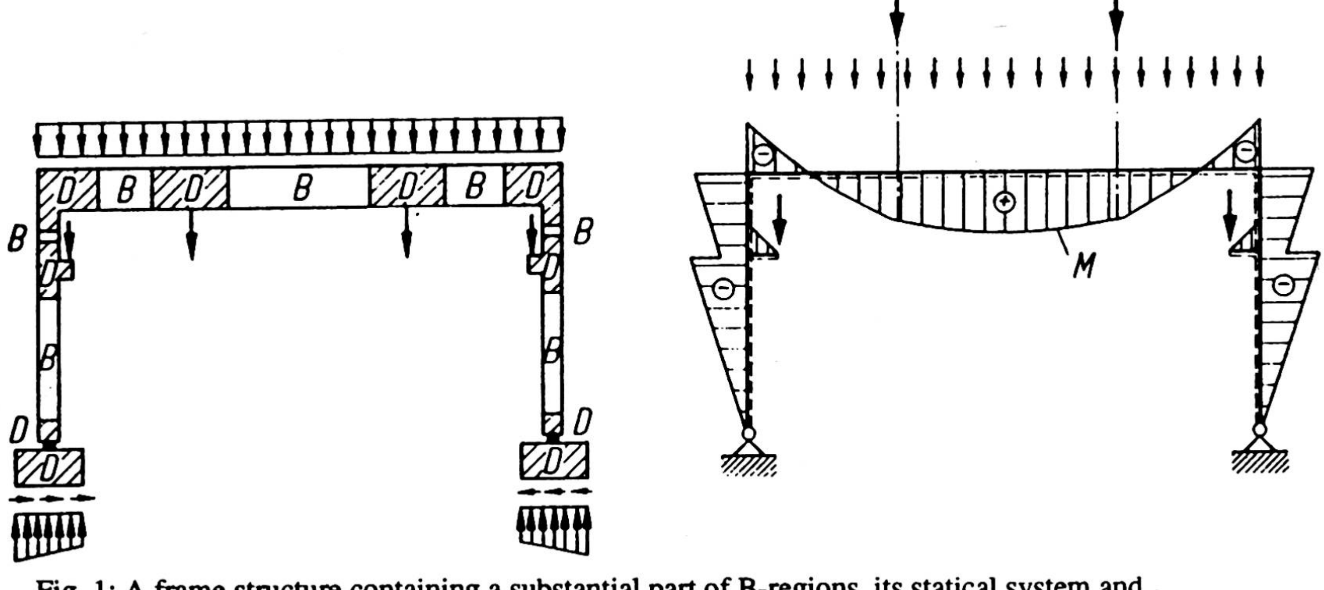


Fig. 1: A frame structure containing a substantial part of B-regions, its statical system and its bending moments.

As already mentioned, for calculating the deformations and, in case of a statical indeterminate structure, the sectional effects, one will certainly start applying sectional values (bending stiffness EI, torsional stiffness GI_t, axial stiffness EA etc.) on linear-elastic basis.

If the sectional forces are known the dimensioning of the B-regions, especially of their reinforcement may follow standard procedures. As long as a section is uncracked (e.g. in columns or due to prestress), the inner forces are calculated with the help of section properties like cross sectional areas and moments of inertia. If the tensile stresses exceed the tensile strength of the concrete the truss model [1] applies (fig. 2). Since for B-regions with light transverse reinforcement, the truss model yields unrealistic low inclinations for the struts, efforts have been made to explain the mechanical meaning of the V_c-term, applied for correction by several codes, because the inclined compression chord explanation can apply only to D-regions. It has been shown, that by considering the concrete tensile strength it is possible to model the load bearing behaviour of the webs of a B-region consistently /5/.

The overall analysis and the B-regions dimensioning provide also the boundary forces for the D-regions of the same structure. As long as the D-regions are uncracked, they can be readily dimensioned and analyzed by standard procedures including finite elements analysis (FEA) applying Hooke's law. If they are cracked the STM design has to be applied for dimensioning /2,3,4,6/. For finding the geometry of the strut-and-tie-models especially for unusual cases, an elastic analysis on FE basis is helpful (Table 1). The loadpath method supports the finding of the model geometry and trains the designer's understanding of the flow of inner forces. However, the number of D-region types for beams and frames is rather limited and the experienced designer will soon be able to rely on his STM-collection. Efforts are being made to provide practice with a reliable collection of such cases (further comments on D-regions see sect. 3).

For later improvement and review and with the real dimensions and reinforcement in hand, it may be necessary to repeat the analysis using non-linear moment-curvature relations. This will become a must for structures with strongly geometrically non-linear behaviour, with theory of second order effects or in case of buckling problems. Fortunately there are handy computer programs available today for that purpose.

It must indeed be warmly welcomed, that most instability problems can today be solved by a theory of second order analysis on basis of imperfections, whose assumption poses no problem to the experienced designer.

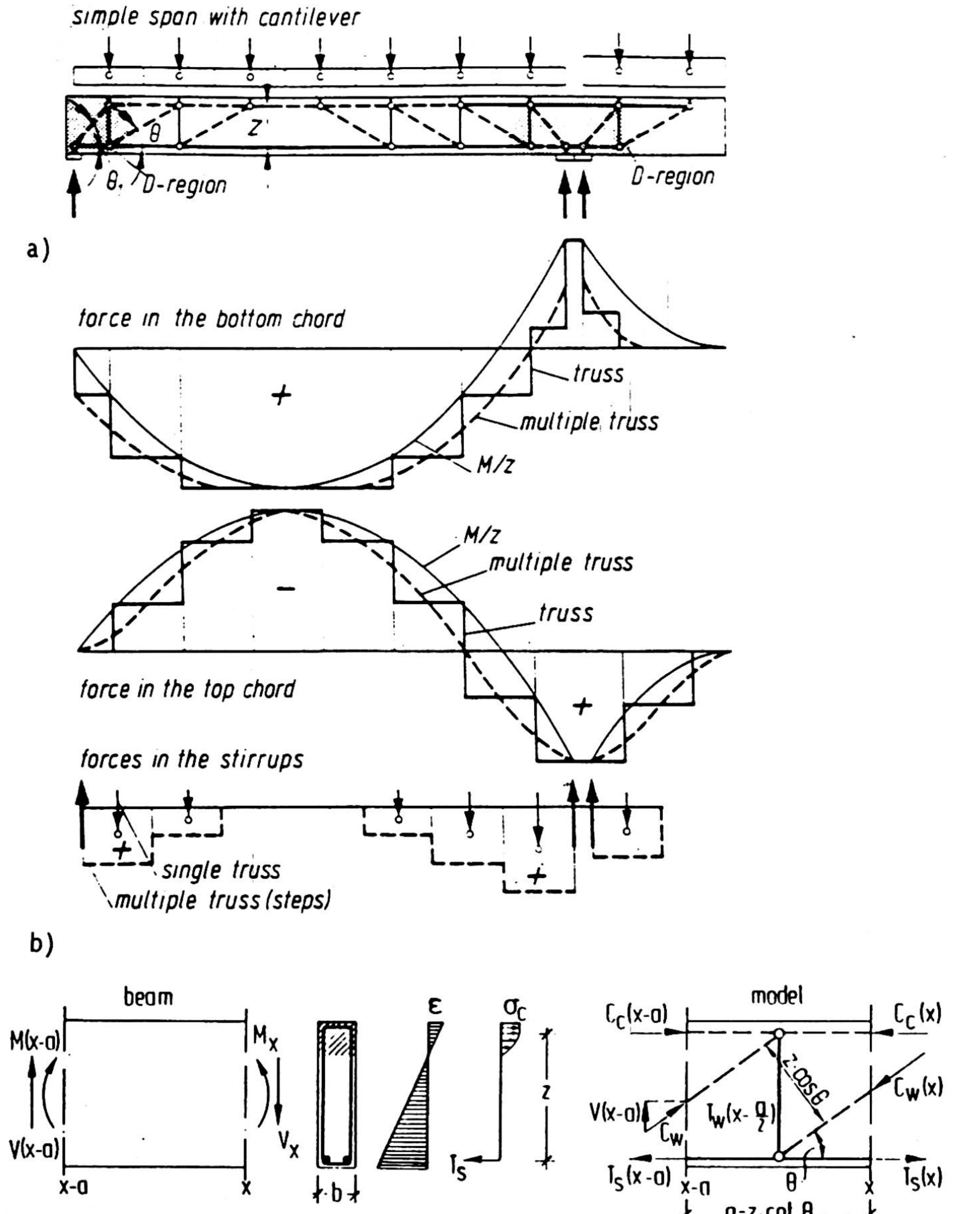
Table 1: Analysis leading to stresses or strut-and-tie-forces.

<table>
<tr><td colspan="2" rowspan="3">Structure
Analysis</td><td colspan="3">Structure consisting of:</td></tr>
<tr><td colspan="2">B- and D-regions
e.g., linear structures, slabs and shells</td><td>D-regions only
e.g., deep beams</td></tr>
<tr><td>B-regions</td><td>D-regions</td><td>D-regions</td></tr>
<tr><td colspan="2" rowspan="2">Overall structural analysis (Table 3) gives:</td><td rowspan="2">Sectional effects
M, N, V, M_T</td><td colspan="2">Boundary forces:</td></tr>
<tr><td>Sectional effects</td><td>Support reactions</td></tr>
<tr><td rowspan="3">Analysis of inner forces or stresses in indivdual regions</td><td>State I (uncracked)</td><td>Via sectional values
A, J_B, J_T</td><td colspan="2">Linear elastic analysis*
(with redistributed stress peaks)</td></tr>
<tr><td rowspan="2">State II (cracked)</td><td colspan="3">Strut-and-tie-models
and/or nonlinear stress analysis *</td></tr>
<tr><td>Usually truss</td><td colspan="2"></td></tr>
</table>

* May be combined with overall analysis

---

1 . Here the expression truss model is used to define the special application of the general STM to B-regions. A truss has compression and tension chords parallel to the surface lines, inclined struts or compressive stress fields and transversal ties representing the stirrup reinforcement and/or tensile stress fields.



$$C_c(x) = \frac{M(x)}{z} - \frac{V(x)}{2}\cot\theta$$

$$C_w(x) = \frac{V(x)}{\sin\theta} \longrightarrow \sigma_w(x) = \frac{V(x)}{b\,z\,\sin\theta\cos\theta} \text{ (smeared diagonal stress)}$$

$$T_w(x-\tfrac{a}{2}) = V(x) \longrightarrow t_w(x-\tfrac{a}{2}) = \frac{V(x)}{z\cdot\cot\theta} \text{ (per unit length of beam)}$$

$$T_s(x) = \frac{M(x)}{z} + \frac{V(x)}{2}\cot\theta$$

$V(x)$ may include shear forces from torque M_T

c)

Fig. 2: Truss models of a beam with cantilever: (a) model; (b) distribution of inner forces; (c) magnitude of inner forces derived from equilibrium of a beam element.

3. MODELS FOR STRUCTURES CONSISTING OF D-REGIONS ONLY E.G. DEEP BEAMS

In this case the analysis of sectional effects by a statical system makes no sense anymore and the inner forces or stresses can be determined directly from the applied loads following the principles outlined for D-regions above, already.

In /3,4/, where the modelling and dimensioning of D-regions with STM is described in all details, it is proposed to orientate the geometry of the STM at the elastic stress fields, which means to utilize the same model for the serviceability and the ultimate stress check (fig. 3). Of course this does not exclude adjusting the model geometry whilst approaching failure towards an increase of the internal lever arms (fig. 4).

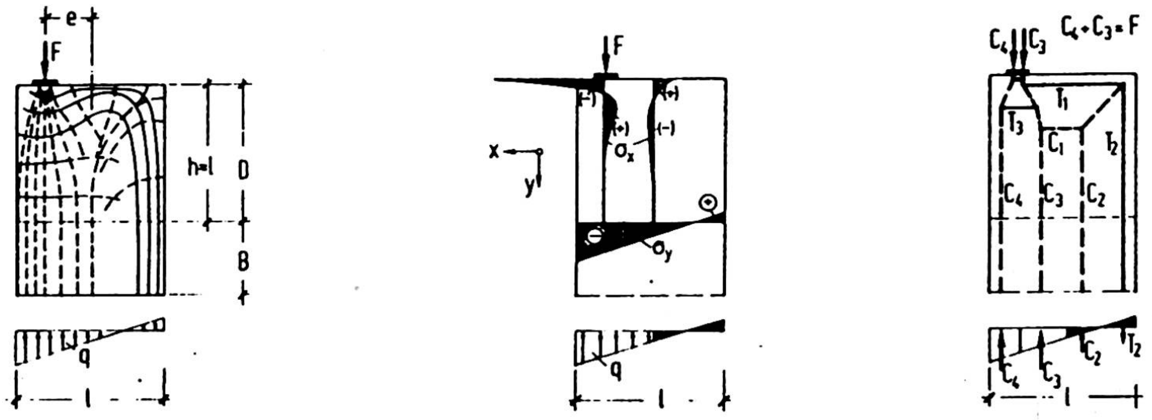


Fig. 3: A typical D-region: (a) elastic stress trajectories; (b) elastic stresses; (c) strut-and-tie-models.

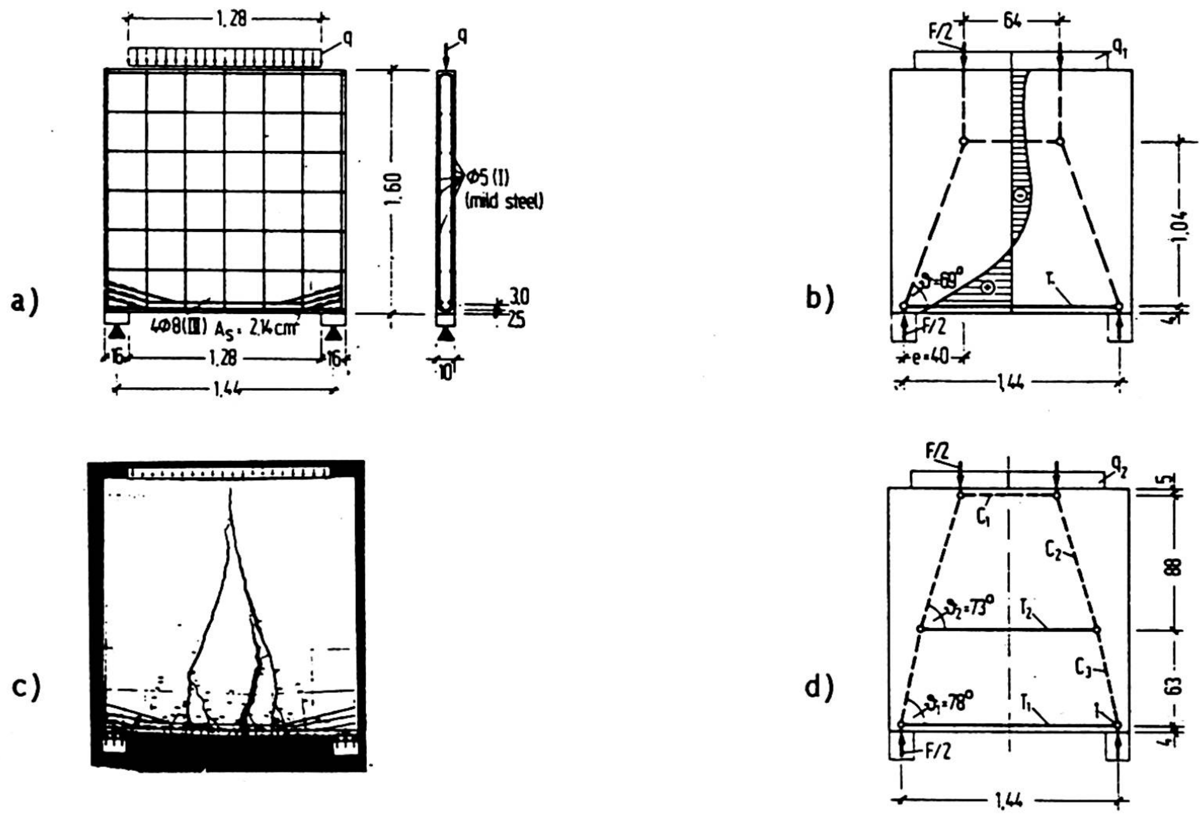


Fig. 4: Deep beam: (a) Tested specimen WT2 /7/; (b) model oriented at the theory of elasticity; (c) crack pattern from test; (d) model adjusted to the failure mechanism.

The designer will decide in the individual case, whether he finds his STM on his own, where the "load-path method" will be a valuable tool (fig. 5), or if he wants in a more complicated case to start with a linear elastic FEM analysis (fig. 6).

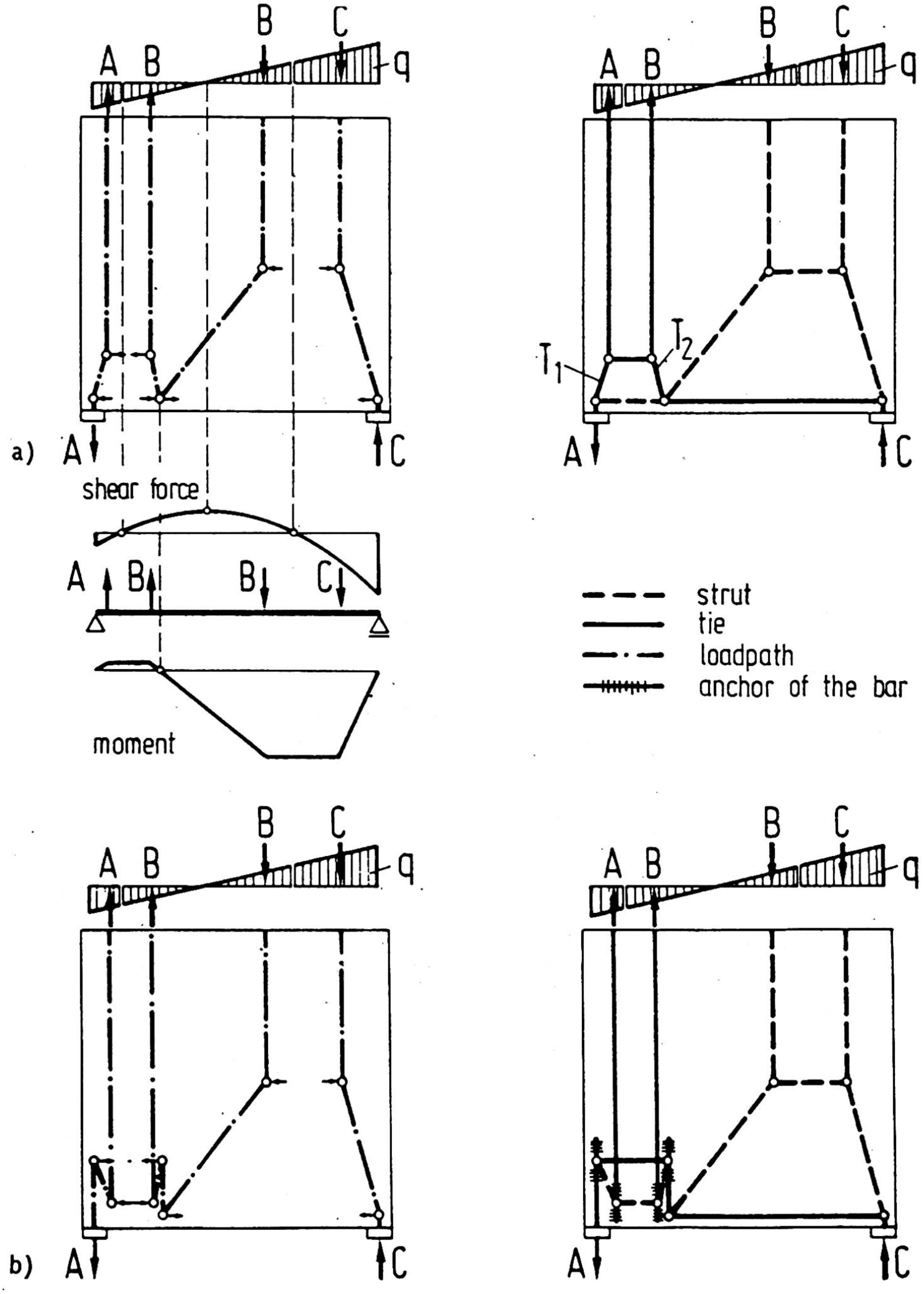


Fig. 5: Application of the load path method for finding the appropriate strut-and-tie-model. Two models for the same case: (a) requiring oblique reinforcement; (b) for orthogonal reinforcement.

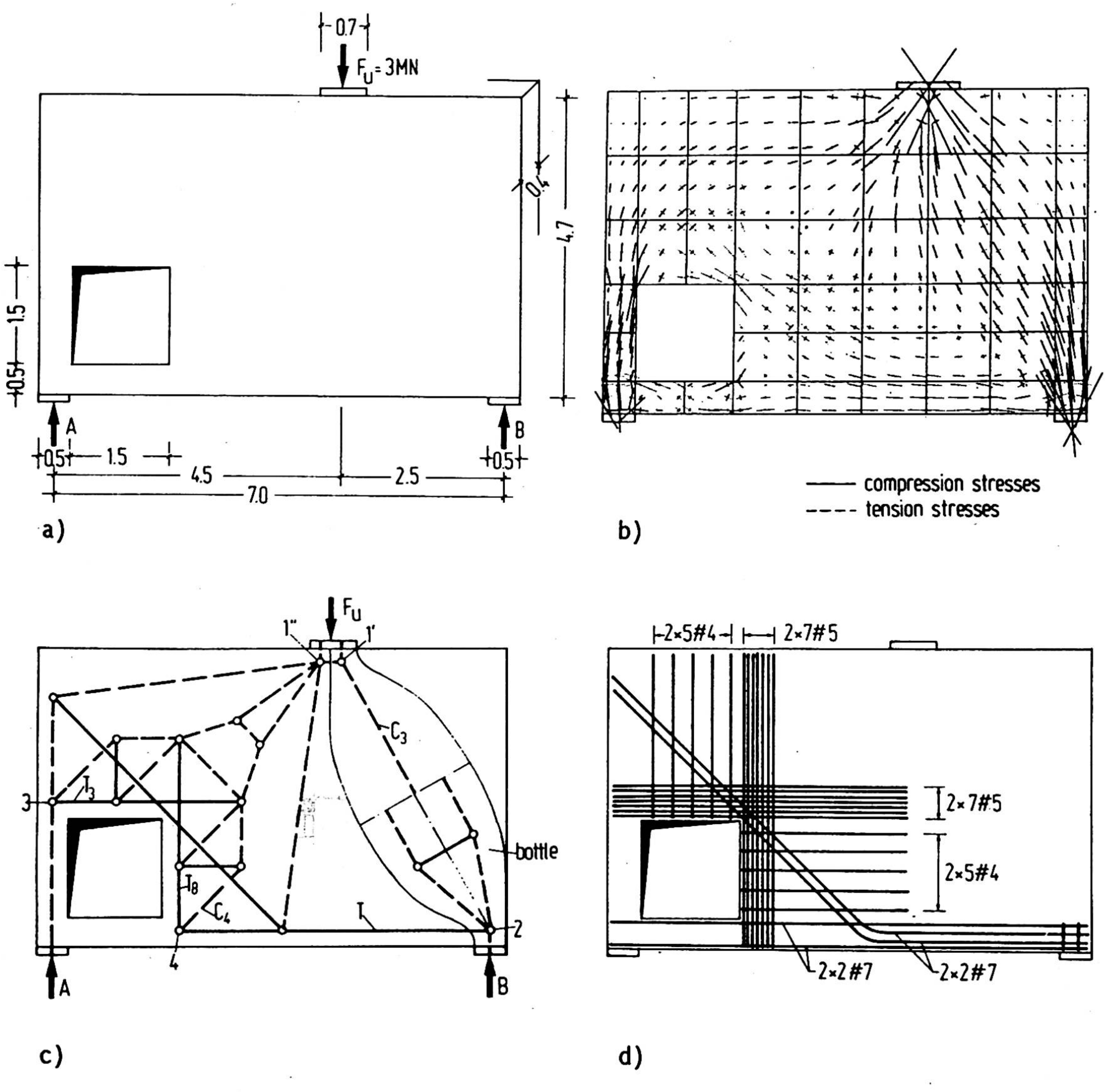


Fig. 6: Deep beam with a large hole: (a) dimensions /m/ and load; (b) elastic stresses; (c) complete strut-and-tie-model; (d) reinforcement.

Recently the fact that the STM-dimensioning is a combined graphical and analytical method has led to very useful CAD programs, which permit to develop, optimize and dimension STM on the screen /8,9/. This also opens the door to not only dimensioning D-regions but also to analyse them by attributing non-linear constitutive laws to the struts and ties thus being able to evaluate the deformations and the redundant inner forces for statically indeterminate supported deep beams. Comparisons of such analyses with test results on the one, and non-linear FEA on the other did yield promising results.

There has been some dispute on the so-called ambiguity of the STM, mainly from code-makers running after cookbook recipes. It's not the STM, it's reinforced concrete itself, which has fortunately the capability to adjust its inner flow of forces to the designer's reinforcement layout. A complex and intelligent material belongs into the hands of an experienced designer. He will find the right STM for his specific case and will keep serviceability and ductility requirements in mind, when optimizing it towards ultimate load capacity.

Fortunately there is a lot of progress with the non-linear FEA of cracked reinforced concrete. Thus the designer has the tool to review his STM results, from which he of course has to collect the reinforcement layout before doing a FEM check. Comparing both results will have a high pedagogical value and avoids misinterpretations of black-box computer outprints.

Such a procedure should be followed as a golden rule: Dimensioning on basis of relatively simple models, thereafter rewiew on a suitable level of sophistication.

Non-linear FEA appears to be of special value, if the overall deformational behaviour of a deep beam or the reactions of a statically indeterminate supported deep beam structure is asked for. It will also be able to describe and clearly trace failures of concrete in compression or tension as well as of the reinforcement. For that of course it must be possible to model the real crack pattern, especially discrete cracks often responsible for failure. But doubts arise with respect to its capability of describing the behaviour of nodes. For that purpose it would be necessary to computerize the concrete at a microlevel i.e. to follow with the finite elements down to the gravel and reinforcement ribs.

From that it follows, that even a FEM analysis should be followed by a STM check especially with respect to the safety of the nodes (fig. 7).

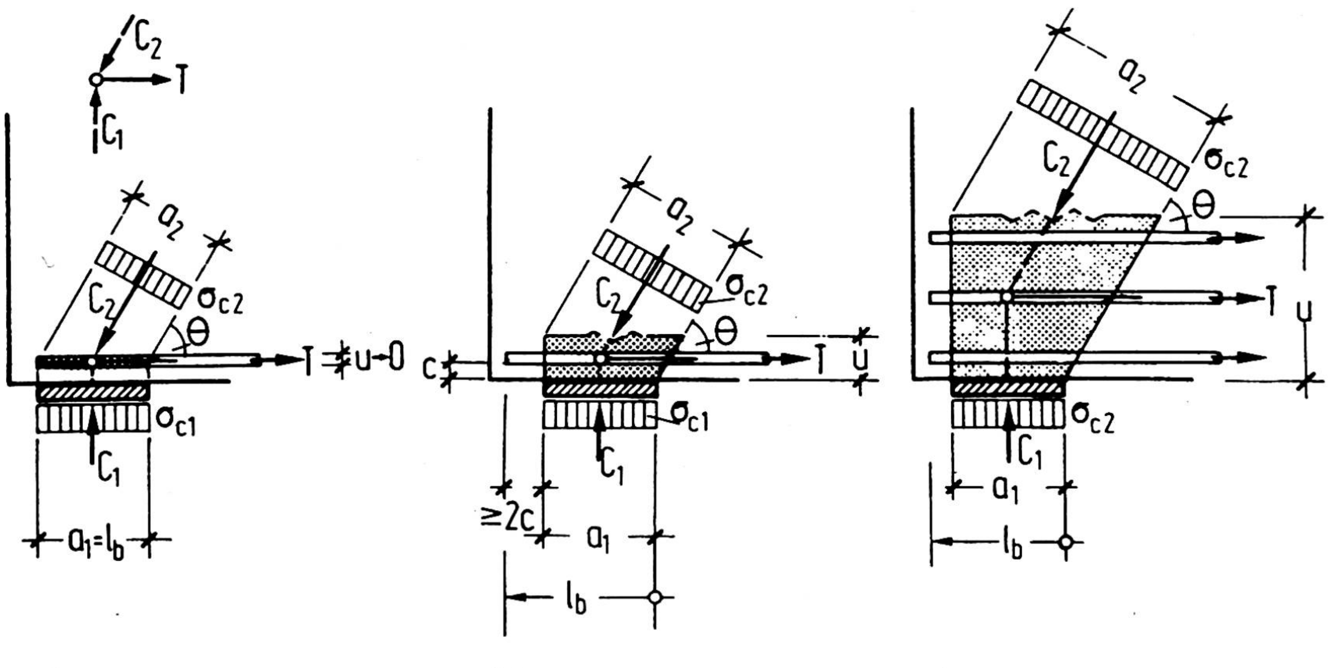


Fig. 7: Typical node for the anchorage of reinforcement: (a) one layer; (b) one layer with additional length behind the node; (c) three layers with additional length behind the node.

4. MODELS FOR SLABS AND FOLDED PLATES

Since these structures may as well be sub-divided into B- and D-regions, the same models and methods as discussed above may be applied as well. In fact they predominantly consist of B-regions (plane strain distribution). Starting from the sectional effects of the structural analysis, imaginary strips of the structure can be modelled like linear members.

However, it would be desireable to develop a real STM approach which considers that the principal moments and forces of slabs do not follow straight lines parallel to the edges.

Further there is no satisfactory model as yet describing punching of slabs. For the large variety of slab shapes with all kinds of openings it is very helpful, that today FEM programs on linear-elastic basis are available to any designer. Since slabs rarely do reveal substantial cracking, it may not be very desirable to repeat such an analysis with non-linear FEM. Rather will an overall ultimate capacity check by means of the yield line theory provide useful additional information.

5. TREATMENT OF PRESTRESS

In a paper on modelling of structural concrete, a word on the treatment of prestress may be expected. However, it appears sufficient to mention that consistency between reinforced and all "types" of prestressed concrete can easily be reached if for the analysis of the sectional forces prestress is simply treated, what it really is: a self-equilibrated outer load, though artificially applied. Whilst dimensioning, its forces are treated as are other forces. After grouting the prestressing steel will then assume the role of reinforcement (with an initial prestressing force and with special properties).

In case of prestress without bond or of external prestress after prestressing the tendons take the role of free ties whose changes of forces due to loads may be estimated or analysed on basis of a statical indeterminate system /3/.

With this the same models and methods as already discussed apply also to the case of prestress (fig. 8). This treatment helps to avoid useless discussions as those, whether the statical indeterminate moments due to prestress are restraint forces which disappear due to cracking or not. Of course they are not, they are moments as those due to any other outer loads which cannot dissappear but of course be redistributed. This view of prestress is a valid basis for the consistent treatment of structural concrete and for a simplification of codes.

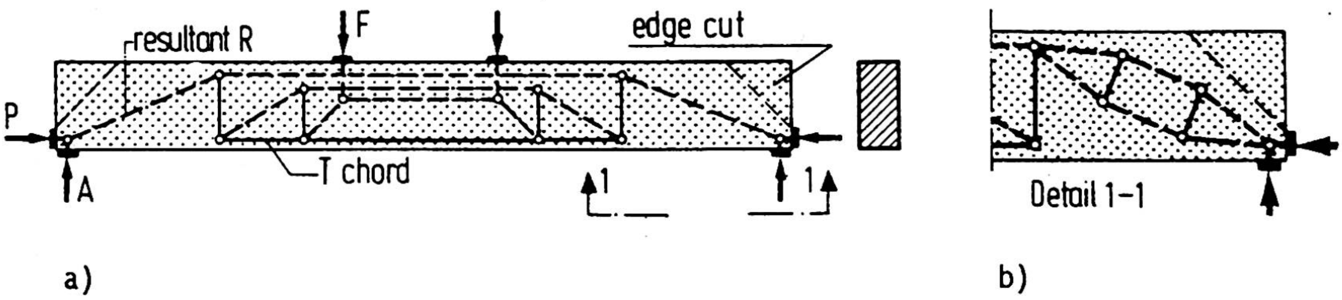


Fig. 8: (a) Strut-and-tie-model of partially prestressed beam with rectangular cross section;
(b) detailed strut-and-tie-model of the beam area, where the resultant is within the beam section.

6. SUPPORT OF A CANTILEVERING BOX GIRDER ON TWO WALLS

AN EXAMPLE: The reader will understand the STM-method best by following an example described in all details here:

6.1 General Layout

How to carry the forces in the connection of the members shown in Fig. 9a? Normally diaphragm walls are introduced in the box girder, either two directly above the two supporting walls (Fig. 9b), or - because the inner one is difficult to construct - just one at the end of the box girder (Fig. 9c). The best solution, a diagonal wall, is not obvious in the beginning.

6.2 Frame Corner with Diaphragm Wall at the Box Girder's End only

The diagonal struts C_3 (Fig. 10a) which balance the chord forces T_1 (from the box girder's tensile flange) and T_2 (from the tensile wall) with the compressive forces C_1 and C_2 from the respective compression chords of the frame type structure can only be transferred within the two webs. Therefore, all the chord forces which in the adjacent B-regions are well distributed over the whole widths of the flanges have to be deviated and bundled into the small width of the webs.

First of all, this requires considerable transverse reinforcements in the four chord members according to the strut models given in Figs. 10b-e. The models are all of one type, which appears very frequently in D-regions of very different structures. The internal lever arm z of the transverse forces in Figs. 10c and 10e, oriented at theory of elasticity is approximately 0,6 b. In Figs. 10b and d the corresponding lever arm depends also on the length of overlap of longitudinal reinforcement. Standard lap lengths in Codes do not apply for this situation where the lapped bars are arranged at some distance from each other. A more detailed model (Fig. 10f) of this typical problem shows different transverse tie forces in different places.

Looking again at the struts C_1 and C_2 in plan and sections of Fig. 10 we realize that the corresponding stress fields must be squeezed through the bottleneck of the singular node 2 whose dimensions are restraint

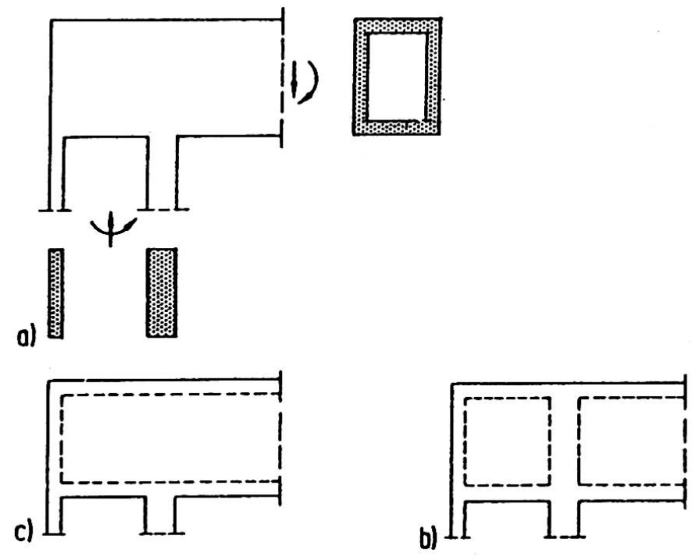


Fig. 9: a) View and cross-section of the box girder and support walls. b) Longitudinal section with interior diaphragm wall. c) Longitudinal section without interior diaphragm wall

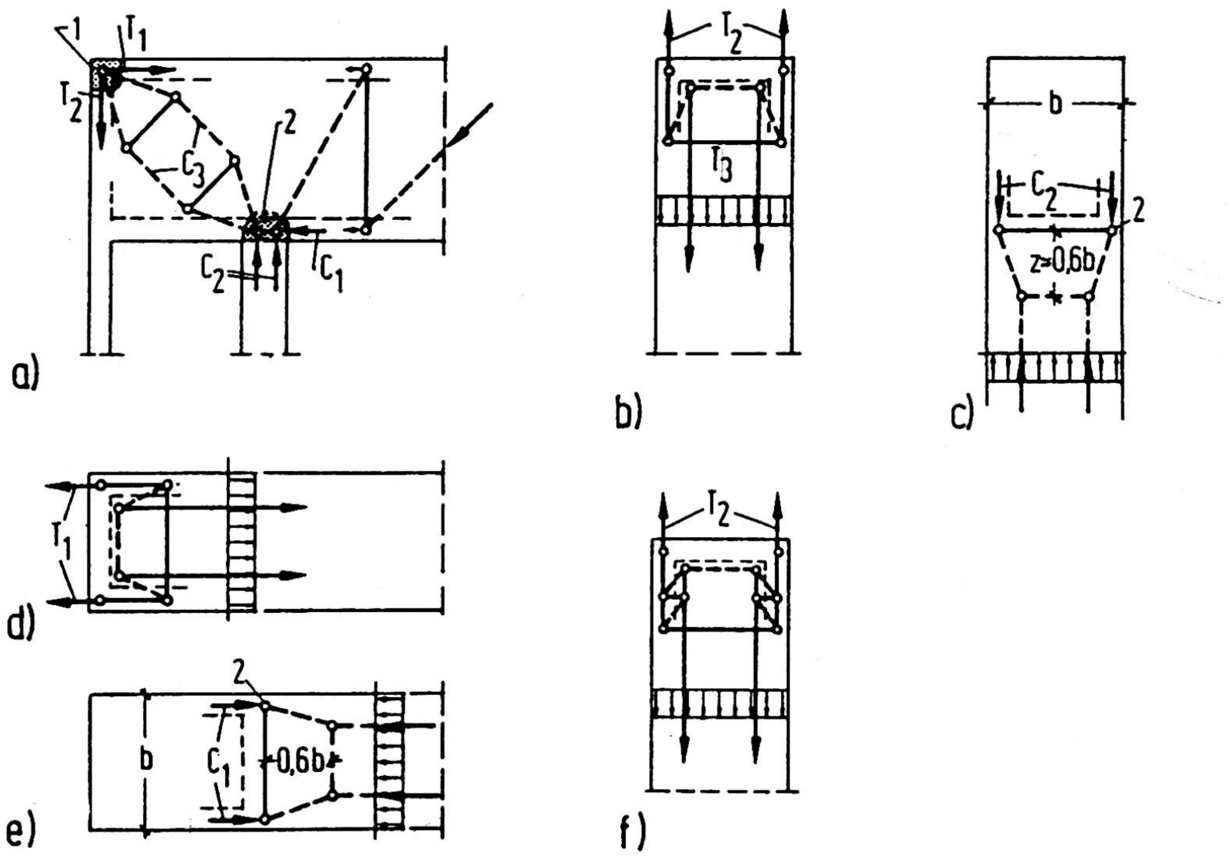


Fig. 10:Strut-and-tie models for the structure without internal diaphragm wall. a) Web; b) tensile wall; c) compression wall; d) top flange; e) bottom flange. f) Refined model for the lap problem characterized in Figs. b and d

by the thicknesses of the compression wall, web and bottom slab of the box girder. This node will dictate the concrete dimensions, the large width b of the boxgirder slab cannot be used as compression zone. What an unreasonable structure! Who would have recognized this, applying the usual design rules?

A similar problem may arise in node 1, where tensile bars for the total chord forces T_1 resp. T_2 must be arranged within the thickness of the web or at least very close to it in order to avoid large "slab moments" in the deck and wall. Also this node will become a singular node if reinforcing bars were bent sharply around the corner as shown in Fig. 10a. Consequently, the diagonal strut force C_3 in the web will spread out between nodes 1 and 2, thereby creating transverse tensile forces as indicated in Fig. 10a. Therefore it is much better to bend the chord reinforcement using a mandrel which is adapted to the dimensions of the frame corner (Fig. 3).

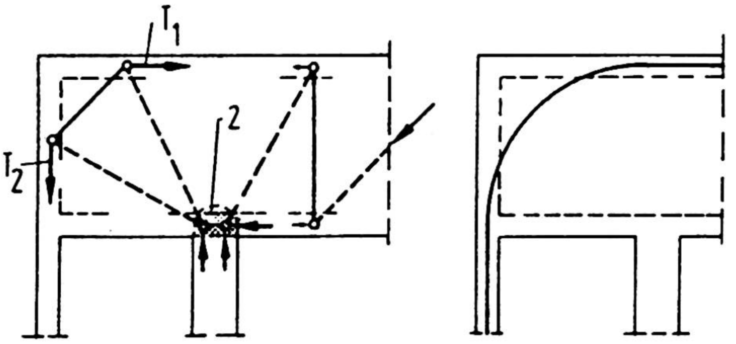


Fig. 11: Model and corresponding chord reinforcement with a well adapted mandrel diameter

By the way, omitting the lower diaphragm plate between the two walls would do no additional harm to the (poor) structural solution. Either none or two orthogonal disphragms are needed, as will be shown hereafter.

6.3 Frame Corner with Two Diaphragm Walls

The necessary transverse reinforcement in the boxgirder plates and the supporting walls is the same as before; but the singular nodes are avoided since the chord forces T_1, T_2, C_1, C_2 now enter the web reasonably well distributed over the whole length of the diaphragms (Fig. 12a). In other words: Each chord plate is no longer supported on two points only but rather along two lines (Fig. 12b). As a consequence the load bearing capacity of the frame corner is essentially increased by the additional diaphragm wall.

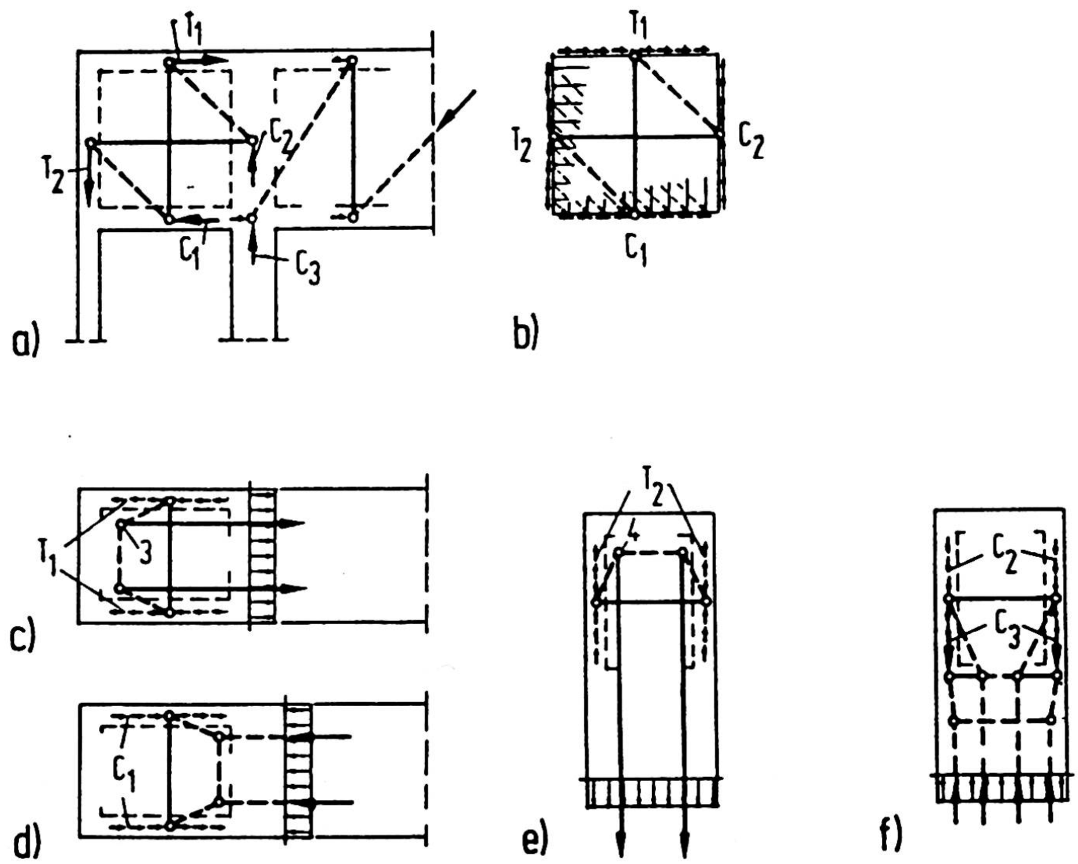


Fig. 12:Strut-and-tie models for the structure with internal diaphragm wall. a) Basic model for the web. b) refined model for the web with smeared forces. c) Top flange. d) Bottom flange. e) Tensile wall. f) Compression wall

6.4 Frame Corner with Diagonal Diaphragms

The best structural solution for the discussed problem is the diagonal diaphragm which follows the load path T_2 in Fig. 13a. This model avoids not only the singular nodes but also the transverse reinforcements in the flanges and walls. Only the spreading out of the support forces C_3, resulting from the shear forces of the webs, require some transverse reinforcement T_3 near the top of the compression wall (Fig. 13b).

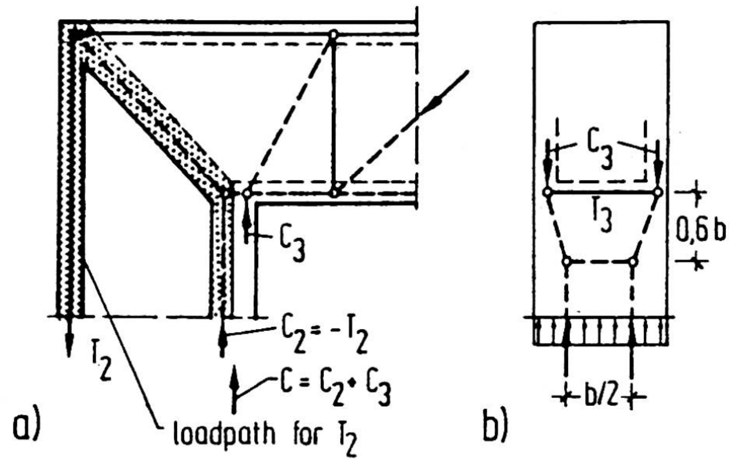


Fig. 13:a) Diagonal diaphragm following the load path for T_2 of the strut-and-tie model. b) Model for the compression wall.

We can conclude from this example that strut-and-tie models are not only suitable for dimensioning but are also very helpful for the conceptional design of good structural solutions.

6.5 The same Structure with Prestress

Let's prestress now the top plate and tension wall of the structure without inner diaphragm wall (see Fig. 9c) with prestressing forces $P_1 = T_1$, $P_2 = T_2$ just large enough to balance the concrete tensile forces T_1, T_2 due to dead load (Fig. 14a). At first sight one could think that thereby also the problem of transverse forces in the frame corner is cancelled, at least in the prestressed members. But it isn't at all! The model with prestress applied as external forces (see section 5 and [2,3]) discloses that the load paths of the compression forces C_1, C_2 have to squeeze as before (see section 6.2) through node 2 into webs in order to arrive at their "supports" provided by the anchor forces P_1, P_2 of the tendons. In order to avoid further detours of the load paths (see Fig. 10b and d), the tendons in the corner should be arranged within the web, either similar to Fig.11 or Fig.14b, thus balancing the compression strut in the web directly.

If the load is increased after prestressing, e.g. due to live loads or a safety factor for ultimate conditions, the tendons react like non-prestressed reinforcement with additional tendon forces ΔT_1, ΔT_2. These are anchored by bond according to the model shown in Fig. 14c.

In the structure with inner diaphragm wall (acc. to Fig.12) the tendons may be distributed over the whole width b of the structure and anchored near the edge, if transverse forces are carried according to the models given in Fig.12c and e. However, the position of the model nodes 3, 4, which in Fig.12c and e represent the centroid of bond forces, have to be reconsidered for the prestressing tendons (see Fig. 14c). The prestress force P is always applied at the tendon anchor. Only that part of the tendon force ΔT which exceeds the initial prestress force P is anchored by bond, and these bond stresses may develop at a considerable distance from the anchor.

Separating the prestressing loads from the additional tendon forces after prestressing as suggested by Breen, Bruggeling and Jennewein [1,10,11] is reasonable also for the application of strut-and-tie models to prestressed D-regions and leads to a clear understanding of structural behaviour.

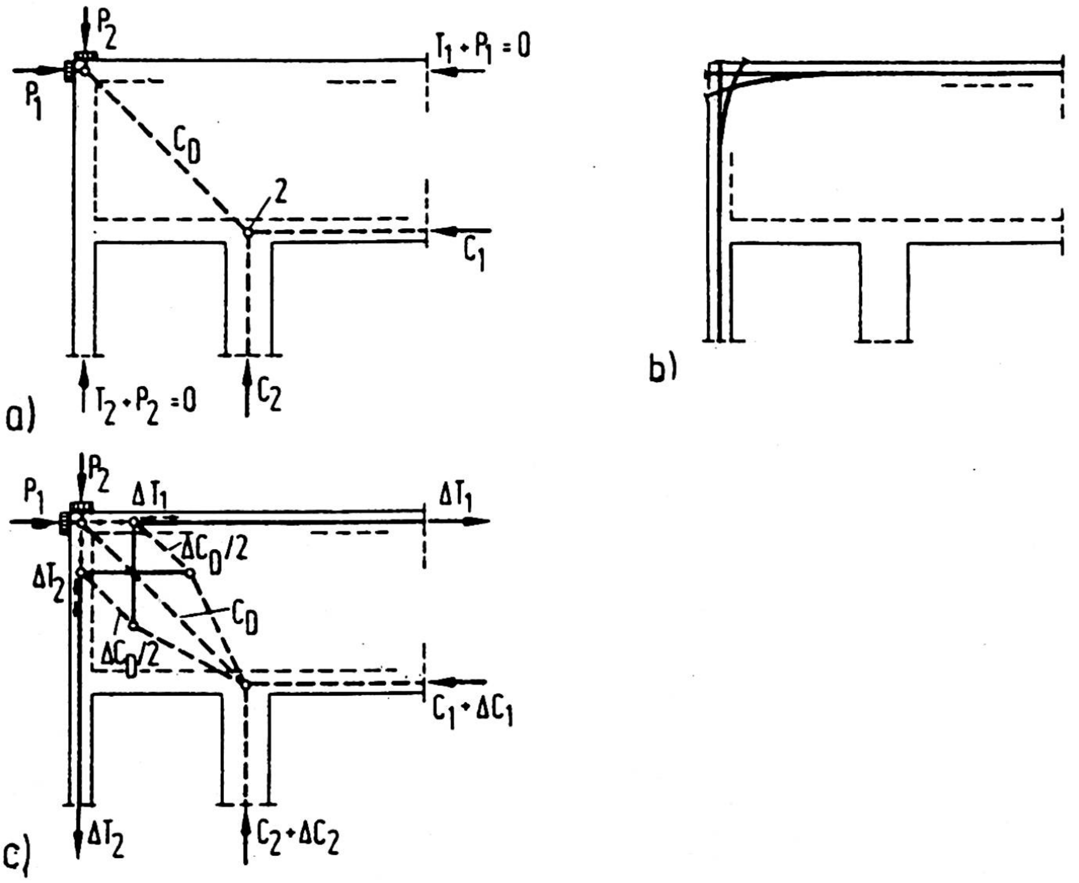


Fig. 14:Prestressed structure without internal diaphragm wall a) Top slab and tension wall prestressed under dead load to give zero concrete stresses. Model showing the load paths.. b) Practical reinforcement layout c) Strut-and-tie model for increased loads, prestress as before.

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Teach-In 2

Durability in Design, Detailing and Construction

Durabilité des constructions: dimensionnement, projet et détails constructifs

Dauerhaftigkeit von Bauwerken: Projektierung, Konstruktion und Herstellung

Organiser: Bernd Hillemeier,
Germany.

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Durability in Design, Detailing and Construction

Chemical and physical effects on the durability of concrete structures

Bernd Hillemeier, Univ.-Professor, Dr.-Ing., Department of Civil Engineering, Technical University of Berlin

1 General

Today, the main criteria for durability are well understood, agreed upon, and reflected in most specifications and codes [1],[2]. Improved durability of stauctures requires both, knowledge of materials and experience in execution. The fields which have to be mastered are improved materials characteristics, architectural and structural design, process of execution, inspection techniques and maintenance procedures.

Planning and execution must meet quality assurance requirements. Quality assurance covers technology as well asorganization: The construction company, the local branch,the building site, the client and the architect need to be involved in every total project. Schematised approaches to service life design are not considered reliable in practice.

Concerning these specific items, the Teach-In is subdivided into the following main sections: 1.Theoretical Background (Hillemeier), 2. Design (Pakvor), 3. Execution (Limsuwan), 4. Curing (Müller), 5. Examples (Dillman).

2 Influences on durability

Durability of concrete structures is mainly controlled by transportation processes of heat, moisture and chemical substances and by physical, chemical and biological corrosion as type and rate of degradation processes of concrete and steel.

Dominant factors for durability of structures are water and the transport mechanisms of water and gases within pores and cracks. Planning and design must aim to minimize negative effects of water attack.

3 Necessity of dense and durable concrete

Concrete consists of two major phases: cement paste and aggregate. The mechanical as well as the durability properties of concrete are determined above all by the cement paste.

Cement and water react with each other to form the fibrous and very finely interlocking cement gel. The cement needs only a portion of the mixing water for its hydratation. Water that is not used by the cement evaporates, leaving capillary pores behind that runs through the cement paste like veins. It is obvious that a high water content and insufficient curing increases the evaporation and thus the number of capillary pores breaking through to the surface of the concrete. Acidic gases invade the concrete through these pores and react with the alkaline elements of the hydrated cement.

3.1 Concrete attack mechanisms

Carbonization. Carbon dioxide (CO_2) in the air changes alkaline calcium hydroxide into neutral limestone and thus prevents the rust protection of the steel reinforcement:

$Ca(OH)_2$	+ CO_2	→ $CaCO_3$ + H_2O
high alcalinity, pH ~ 12,6, corrosion protection of steel	gas, 0,03 V-% in the air	lime-stone, pH ~ 8 , no corrosion protection of steel

Chloride attack. The permeability of concrete facilitates the entry of chlorides. This, in turn, makes the destructive chloride corrosion possible. It is well known that the presence of significant levels of free chloride ions (0,4 M-% of cement Cl combined with Friedel-salt $C_3A \cdot CaCl_2 \cdot 10H_2O$) causes disruption of the protective passivating, thin film of gamma ferric oxide which forms on steel embedded in concrete by virtue of the high alkalinity of the concrete pore water.

The objective is therefore to limit chloride levels in the concrete mix constituents to as low a level as possible and to provide a dense concrete of low permeability to reduce the intrusion of chloride ions from external sources.

Sulphate attack. High concentrations of sulphate ions, particularly of magnesium sulphate, attack concrete. This attack involves the formation of calcium sulphate ($CaSO_4$ - gypsum) and calcium trisulphoaluminate within the cement matrix by reaction of the sulphate ions with the cement constituents, calcium hydroxide and tricalcium aluminate (C_3A) respectively. These reactions are expansive, which can weaken the concrete and cause cracking and breakdown of the concrete core.

Acid attack involves, initially, the softening of the cement matrix by the removal of calcium oxide leaving only hydrated silica and alumina. Strong acids may even dissolve silica and alumina hydrates.
The mechanism and kinetics of dissolution of the cement matrix and sbluble aggregates in concrete subject to carbonic acid attack are complex. In the first instance, it is necessary to establish whether a water is undersaturated with carbonate, contains free carbon dioxide and is aggressive to concrete, or is oversaturated with carbonate acid and can deposit calcium carbonate.

From the point of view of a permanent contact of water with a concrete surface the state of undersaturation of water with respect to calcium carbonate is important. A simple technique exists to establish the undersaturation state of a water, commonly called the marble test, which is used by hydrochemists. The test is specified in DIN 4030. [3]

To summarize, the key elements determining the durability of concrete are:

1. low water/cement ratio and sufficient cement content so that the cement particles are densely packed.
2. intensive curing in order to keep the water required for the chemical reaction from evaporating. Both are prerequisites for a
3. good quality concrete cover for the steel reinforcement.

The well-known relationship concerning Power's theory according to which the percentage volume of capillary pores decreases by reducing the water/cement ratio leads to the major requirement for durable concrete:

Limitation of the volume of pores in hydrated cement

$$V_K = c / \gamma_W \cdot (w / c - 0{,}36 \cdot m)$$

where

V_K Capillary pores in the cement paste [dm^3]

c cement content [kg]

w/c water cement ratio

γ_W density of water [kg/dm^3]

m maturity of cement paste, degree of hydration $m \sim 0{,}17 \ln(d)+0{,}18$ (for Portland cement, at 20 °C)

d age of cement paste in days

An intensive curing must make sure that the cement has enough water available for the hydratation process which will serve to minimize the capillary pores. During the planning and design phase quality assurance (QA) measures have to be involved to actually realize the specific requirements for a dense concrete. ISO standards 29000 to 29004 represent the relevant quality assurance measures.

3.2 Concrete resistance properties

Permeability is influenced by the pore structure of the cement paste. For a characterization of the relevant pore structure with regard to the transport of substances into and within porous building materials, two parameters are of importance:

- relevant porosity, and
- pore size distribution.

Relevant porosity means pores which are interconnected so far that a transport of liquids or gases and/or the exchange of dissolved substances is possible. At the same time, the relevant porosity corresponds to the maximum reversible water content and, in the case of cement paste, lies in the region of between 20 and 30 per cent.

The pore size distribution influences particularly the type and the rate of transport mechanisms and binding mechanisms in respect of water. The size of pores in the cement paste covers a range of several orders of magnitude. According to origin and characteristics, the pores are described as:

- compaction pores
- air pores
- capillary pores
- gelpores.

Expressed in more general terms, the following classification appears to be convenient:

- micropores (10^{-10} to 10^{-7} m in diameter), gel pores
- capillary pores (10^{-7} to 10^{-4} m)
- macropores (10^{-4} to 10^{-2} m), compaction pores + air pores

Free surfaces of solids exhibit a surplus of energy due to a lack of binding components to the adjacent molecules. This energy is called surface energy. In the pores of the cement paste surface energy causes the water vapour molecules within the pores to adsorb to the pore surface (adsorption), the thickness of the water film thereby depending on the degree of humidity within the pores.
Due to the fact that the ratio between the surface area and the volume of the pores increases with decreasing pore radius, the rate of the water quantity adsorbed relatively to the pore volume will also increase until, at a certain limit value of the pore radius, the pore is completely filled with water. This process is called capillary condensation. The limit value of the pore diameter primarily depends on the water content of the air within the pore which, in the case of constant conditions, is proportional to the humidity of the air surrounding the concrete. (Fig. 1)

Any transport processes of gases, water, or substances dissolved in water are diffusion processes in respect to the ambient conditions.

Diffusion processes are induced by the tendency of equilibrating differences in concentrations. The driving forces for diffusion are therefore differences in concentrations.

Carbon dioxide diffuses into concrete due to a chemical reaction with CO_2 developing at the pore walls in the concrete, which causes the concentration within the pores to be reduced. This applies equally to oxygen when it is consumed during corrosion of the reinforcement.[1]

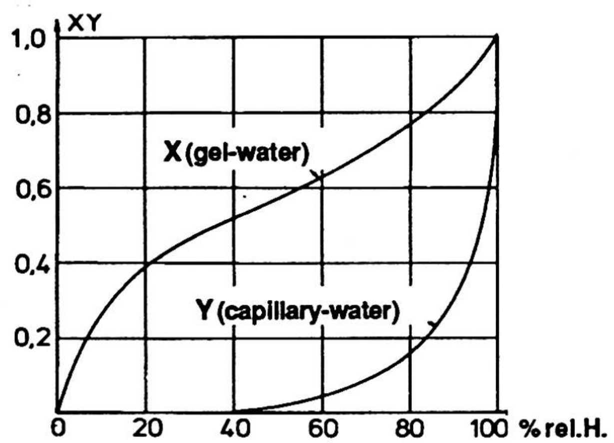

Fig. 1 Sorption-isothermes (Powers)

In the case of continuously immersed structures, large quantities of water may, under unfavourable conditions, be transported. A continuous transport of water will develop when water is allowed to evaporate at the concrete surfaces exposed to the air. The intensity of this water transport depends on the following three variables:

- evaporation
- capillary suction
- hydraulic pressure.

With the water, dissolved agents (carbonate, chloride, sulphate, etc.) will be transported. However, these agents are left behind in the concrete in the region of evaporation where they are likely to arrive at considerable concentrations. Efflorescence phenomena may also be due to this effect: the agents first dissolved are caused to crystallize at the concrete surfaces.

In concrete the expansive forces due to salt crystallization near the surface only cause minor problems, of importance is the chemical effect of the increased concentration of aggressive substance. However, in other porous materials such as sandstone, marble, masonry, etc., bursting and scaling due to salt crystallization is a serious cause of deterioration. This mechanism results in rapid deterioration of sculptures, monuments, etc. exposed to aggressive environments.

3.3 Cracking of Concrete

Cracking of concrete will occur whenever the tensile strain to which concrete is subjected exceeds the tensile strain capacity.

The tensile strain capacity of concrete reaches a nearly constant limit value of about 0,15 ‰ approximately after the 7 th day of age. This ultimate value is nearly the same for all types of concrete. The minimum ultimate tensile strain of about 0,05 ‰ is found in the concrete age between 6 hours and one day.

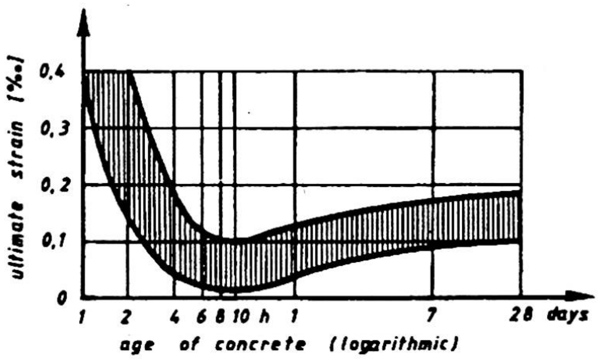

Fig. 2 Ultimate tensile strain of concrete depending upon age. [1]

As Fig. 2 shows young concrete is especially prone to cracking. Within the transition phase leading from fresh ("green") to hardened ("young") concrete, a critical period with very low tensile strength and a very low deformability is observed.

To consider whether a concrete may get cracked the different types of local deformations have to be added and compared to the ultimate tensile strain rate. Influences causing lokal strains which lead to tensile stresses if the movements are restrained are:

- drying shrinkage
- contraction due to temperature change
- externally imposed loading and/or deformation conditions
- expansion of material embedded within the concrete, (corrosion of reinforcement, alkali aggregate reaction,...)

Shrinkage can be assessed analogous to temperature change ΔT. The applicable range tends from 10 to 45 degrees Celsius, depending on the environmental conditions. Cracking occurs if

$\varepsilon \sim 0,5 \cdot 10^{-5} \cdot (\Delta T_{Temp.} + \Delta T_{Shrink.})$

exceeds the ultimate tensile strain.

The temperature distribution in the cross section of a structural element has generally to be analysed with the equation for non-stationary heat conductivity:

$$dT/dt = \lambda/\rho c * d^2T/dx^2$$

In most cases it will be possible to transform the model of consideration to a one dimensional problem.

4 Corrosion of reinforcement

The corrosion process can be separated into two single processes, the cathodic and the anodic process.

The anodic process is the real dissolution of iron. Positively charged iron ions pass into solution:

Anodic process: $Fe \rightarrow Fe^{++} + 2e^-$

The surplus electrons in the steel will combine at the cathode with water and oxygen to form hydroxyl ions.

Cathodic process: $2e^- + 1/2\ O_2 + H_2O \rightarrow 2(OH)^-$

After some intermediate stages, the iron and hydroxide ions will combine to form rust which, at least theoretically, can be written as Fe_2O_3. Water is only necessary to enable the electrolytic process to take place.

The highest corrosion rate will occur in concrete surface layers, subjected to highly changing wetting and drying conditions.

At the steel surface, anodically and cathodically acting areas may be situated either close together (micro-cell corrosion) or at locally separated places (macro-cell corrosion) even over relatively great distances. Consequently, corrosion may occur in areas of the structure where the direct access of oxygen to the surface of the reinforcement is impeded.

5 10 rules for durable concrete [4]

1. Select high quality materials

- Cement: Select high strength, moderate C_3A (5-8 %), moderate alkali content, uniform quality.
- Aggregates: Check soundness and impurities, control content of fines < 0,30 mm to ensure stability at high slump, uniform grading.
- Admixtures: Select efficient water reducers (superplasticizers), air entrainers at high slump benefit by modified batching process, check air spacing factor (<0,2 mm) and specific surface for frost resistance.

2. Get mix proportions right

- w/c ratio < 0,50 is imperative.
- Cement content > 380 kg/m^3 gives high "self healing" ability in cracks and joints.
- Stable mix at high slump requires selected grading of sand and efficient superplasticizers.
- Small dosage (< 5%) of CSF (condensed silica fume) benefits strength and stability, large dosage impairs constructability.
- Full scale site trials are essential before mix is chosen.

3. Employ modern automatic batching plants

- Batcher type and batching procedure affects obtained properties.
- Select optimum batching procedure.
- Print-out of each batch (100% control).

4. Develop sound work procedures beforehand

- Think concreting before steelfixing. Ensure back up of plant and materials.
- Do trials or mock-ups if in doubt.

5. Compact the concrete generously

- Revibrate top layer for increased strength and elimination of voids under embedded items. (Revibration is an added bonus in slipforming).
- Make sure the concrete cover to the rebars is fully compacted

6. Ensure adequate cover to rebars

- Min. 50 mm cover to main reinforcement.
- Quality of cover is as important as thickness.
- Deficient cover is made up by cement-based coating (for 30-50 mm cover) or epoxy coating (< 30 mm cover).

7. Pay attention to construction joints

- Remove laitance (surface retarder and water jet are efficient on large areas).
- Apply rich mix against joint. Vibrate thoroughly.

8. Make allowances for temperature

- Avoid excessive temperature differences across sections. Temperature rise in thick sections can generally be expected as 12°C/100 kg cement.
- Initial temperature can be efficiently reduced by ice flakes as part replacement of mixing water (8 kg/m^3 ice gives 1°C Temp. reduction).

9. Keep design simple

- Genereous sections are easier to pour.
- Roundeo and smooth surfaces discourage surface decay.
- Avoid sudden changes in geometry.
- Larger rebars take less space.

10. Use trained and skilled operators

- Only the operators performing the work can efficiently and continuously affect the quality of what is being produced.

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REPAIR AND MAINTENANCE

by

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1. INTRODUCTION

Durability becomes one of the most important factors in planning, design, construction and maintenance of structures. It is established that construction materials, load levels, and environmental conditions govern the service life of structures. The most common construction materials such as concrete and steel may be considered inherently durable ones, if properly designed for the enviroment and carefully produced or fabricated with good quality. However, concrete is potentially vulnerable to be attacked under different exposures unless certain precautions are taken. Deterioration of concrete structures at manifest condition is more inducive to further damage, which may render its unsuitable for futher use. Even economic and political consideration may be important in decision on maintenance and repair, preventive maintenance will play the major role in controlling durability of structures.

In general, early attention to seal the cracks and restoration of water-proof joints may eliminate the need for costly repairs. The durability performance and service life relationship as shown in Fig.1, can be extended by periodic inspection, proper maintenance and repairs. In the case where more extensive deterioration has already occured, or earlier measures have not controlled a potential problem, an investigation should be made to determine the cause and steps taken to counteract the situation during the repair operations.

This paper has introduced inspection procedure, testing and monitoring methods, repair materials and techniques. Examples of repair cases for a chimney, bridge and building have been presented in accordance with their deterioration, structural evaluation and repair techniques.

2. INSPECTION WORK

Durability problems with part of the existing structures have emphasized the need to follow a rational operation and maintenance strategy in the upkeep of structures. If the problems have grown to levels where the traditional approach of repairing damaged structures, attempting them back to initial quaility will be exorbitantly expensive. New ways of handling such problems on both structural level and safety and reliability level have been sought. In the intermediate with unclear maintenance and repair strategies, size of the problems has been getting worse, especially problems concerning concrete structures, because major parts of concrete problems are rather new and the number of concrete structures is rather large.

Regular and systematic inspection shall be performed in order to identify and quantify possible ongoing deteriorations. Inspection constitutes an integral part of structural safety and serviceability by providing a link between the environmental condition to which the structure is subjected and the manner in which it performs with time. In an advanced form the general strategy toward durability should incorporate systematic inspection routines for structures in services, including automatic data recording and handling dicision models based on forcasting rate of degradations, and economic consequences of either short-term or long-term remedial measures. To arrive at comparable figures of alternative solutions, present-day value of the future costs for maintenance, repair and eventually demolition and rebuilding, must be sought.

Rational decision models applying modern probabilistic methods including safety policy and economics, are indispensable elements of an in-depth going appraisal. The element of investigation may in general contain the following items:

- Perform visual inspection.
- Check of original design : drawings, calculations.
- Check execution data : technical, non-technical, quality statement, inspection record.
- Perform in-situ testing : non-destructive, destructive, sampling.
- Perform laboratory testing : mechanical, physical, chemical.
- Perform recalculation.

Based hereon dicisions regarding safety precaution, repair, strengthening/upgrading, demolition and prevention of occurrance, must be made. Check list as provided in Table 1 has been established by RILEM and recommended by CEB (1) for investigation of deteriorated concrete.

3. TESTS AND MONITORING

The traditional testing of concrete at 28 days is a simple and operation means of verifying the strength requirements. With the growing concern for durability characteristics of concrete, much more involved testing is required in order to clarify if a concrete will be durable in a structure exposed to certain aggressive environments.

The tests and monitoring must concentrate on enviromental aggressivity, concrete quality, structural detailing, loading condition, crack sizes and surface condition. Test methods as shown in Tables 2 to 5 are for strength evalution, void location, water penetration, and chemical analyses as part of concrete and Table 6 is for evaluation of reinforcement condition and location as part of reinforcing steel.

In-situ load testing may be required to determine the performance of a structural element under loading greater than the working loads. A load test may be undertaken either to overcome the doubt concerning the quality of construction or design or to establish the behavior of a complete structures after services. Sophisticated analysis techniques can be calibrated using load tests. Where the test is undertaken to demonstrate that the structure behaves satisfactorily under load, it will be generally sufficient to measure the deflection. These must be shown to remain within acceptable limits, correlate with predicted values and recover substantially on unloading.

Long-term monitoring of a structures over a period of time can be used both to check on the safe working of the structures and also to provide information on its response to load or under service condition. When a structure is progressively deteriorating, long-term monitoring can be used to indicate when replacement or repair become necessary. Unlike load testing, this form of evaluation relies on loads occurring during the normal use of the structure. The loads that are imposed must be quantified to enable the structural adequacy to be determined. Due to the duration over which measurements are taken, the instrumentation must have good long-term stability. Movements in particular may need to be related to a reliable fixed datum and possibly also to second independent measuring system. Allowance must be made for the effects of daily or seasonal changes in temperature or humidity, and these must be separated from the permanent movements such as increases in crack widths.

4. REPAIR TECHNIQUES AND MATERIALS

Materials

Modern technology has made available many kinds of materials for repair and maintenance of concrete. These range from low-viscosity polymers for the sealing of very fine cracks, very rapid setting cements for repairs in the presence of flowing or seeping water, special concrete for overlays, to portland cement motar and concrete itself. As summerized in Table 7, it can be a guide for selecting repair materials to suit crack sizes and application techniques. The engineer will be faced with an array of potential materials to choose from, requiring a special knowledge for proper evaluation. A final selection will depend on many factors, such as properties during repair, mechanical reponse, long-term durability, cost index and prior field experience.

In repair, all damaged materials must be removed until a sound surface is reached, then cavity should be prepared to ensure good bonding between the concrete and the repair materials and to ensure proper consolidation. Measures should be taken to remove aggressive materials or to prevent their re-entry. It should be emphazied that all major causes of damages or deterioration must be properly taken care of for satisfactory condition prior to the execution of repair work.

Repair materials must be adjusted to conformed the properties as required for specific strength or durability as structural performance. Material testing must be conducted to satisfy the condition before usage.

Techniques

Injection - This technique has been successfully applied to very fine cracks as small as 0.05 mm with low viscosity polymeric grout. Such materials should be capable of forming a solid polymer in situ after injection. Epoxies are a popular choice, and many proprietary formulations are commercially available. The epoxy is injected under pressure in order to penetrate the very fine and to tortuous crack pattern that may exist. The success of pressure grouting depends on proper application to ensure that all cracks are sealed. The grouting can restore structural integrity as well as seal cracks against seepage.

Grouting - The grouting method is normally applied for larger cracks or joints. Cementetious mortars and caulking materials are general used. For durable and successful seal, the crack should be cleaned out and cut back to form a V-shaped groove into which the sealant can be well compacted. For deeper cracks and narrow cavities, pressure grout many be required. A good-quality portland cement mortar is satisfactory for larger cracks. In the presence of moisture, quick-setting admixtures should be used. For finer openings under dry conditions, caulks and putties based on organic polymers can be used. Sealants are of many types and properties; the selection should depend on considerations of anticipated service conditions, such as applied loads, condition of exposure, and the like. Once cracks and joints are repaired, a general protective coating is both beneficial and aesthetic.

Patching - This may involve filling of tie holes, bolt holes, prestressing ducts spaled holes, and so on. The simplest approach is to use dry-pack mortar for shallow hole and conventional replacement mortar for deeper cavities or for filling around rebars. If the area is so large, then shotcrete techniques may be used for some applications. Mortar should be as dry as possible, consistent with good compaction and pumpability. The use of admixtures to improve flow characteristic and to avoid shrinkage on subsequent drying may be advisable where the creation and maintenance of a good bond is important. All unsound, unbonded concrete should be removed, since a good bond is required between the old concrete and patching material. A mechanical bond by roughening the surface and shaping the hole to provide a mechanical key. Priming with cement mortar or a polymer bonding agent will develop additional chemical bond between the old and the new concrete.

Placing - For large cavities, replacement concrete may be used for economy. The use of admixture to improve fresh concrete properties and to avoid shrinkage are essential to develop good bond to the existing one. In difficult situations, the use of prepacked aggregate may be advisable with the mortar grouted in subsequently as for good quality, controlled gradation and satisfy flowability. The use of replacement mortar and concrete or equivalent materials such as polymer concrete, or high performance concrete, is common practice in localized repair of concrete structure. If reinforcement is corroded, the surface rust should be removed and where possible it is advisable to completely expose the outer layer of reinforcement to provide additional interlocking. Mechanical bond or chemical bond may also be provided to develop additional bond between the old and the new concretes. Alternatively, use of materials such as polymer concrete or latex modified concrete can be used to provide good bond by itself.

Overlaying - Overlaid techniques generally be applied to the surfaces where extensive deterioration does not warrant localized patching or placing. Normally the applied resurface is rather thin as for pavements, bridge decks, or slabs. The overlays are to be bonded directly to the underlying sound concrete and strong bond should be developed. The overlay should match the underlying concrete in thermal properties, or have good crack resistant properties. On vertical surface, pneumatic application may be used. In some cases, additional reinforcement is required, especially where considerable structural damage has occured, or when a thicker layer of new concrete is used. Conventional portland cement concrete using special quick setting admixtures is most commonly used, but the use of modified concretes, such as fiber-reinforced, regulated-set cement, or latex additions has been advocated (Fig.2).

Coating - Coating can be advantageous in preventing structural surface from direct contact to enviromental condition and in preventing water from entering structural elements. The thin layer of coating can be done by spraying, painting, or hand application. Various forms of manufacturing produce film, felt, paint and so on. Polymer materials such as epoxies, mastic, poly-eurethane ; poly-vinyl chloride, are commonly used. Some modification by adding filler or reinforcement is also available for more strength and more durable. The thermal properties, elongation and permeability have been advocated for some applications.

5. CASE STUDY OF STRUCTURAL REPAIR

Three examples of case study for structural repair have been introduced. Each cases represent different causes of deterioration and of structural damage. After structural evaluation have been made, then repair materials and techniques must be carefully chosen to suit the behavior, field expereinces and estimated durable performance. Figures 3 has shown an examples of material testing for repair work as shear-compression test. Another tests may involve shrinkage, compression, and flexural tests.

Case A : Concrete Chimney

A concrete chimney had been subjected to long-term deterioration from carbonation, especially on the top portion of the structure. The damage at top-most portion of the chimney where exposed to gas effluence, was so great that reinforcing bars were completely corroded; concrete was loosing and falling apart. Larger cracks had been observed at lower levels with large carbonation depth. The reinforcing bar had been corroded to the amount 20-25%. At lower zones, only small cracks have been observed with the maximum width of 0.04 mm and no corrosion on reinforcing bars have been measured.

The repair work involved almost every technique available. Epoxy injection was introduced for small cracks where there was no corrosion of rebars. Polymer modified mortar have been used for pressure grouting of larger cracks where the cavities have been washed out with high presure water jet and the corroded rebars have been inhibited by chemical injection. Topmost portions of the chimney where concrete was unsound and rebars were completely corroded, had been hacked down and then be replaced by a special type of nonshrink concrete with new reinforcement. Localized pathing mortar have been use in several places where small holes or spalling surfaces were inspected. Coating materials were also applied on the outside surface of the chimney in order to protect the concrete from direct contact with carbon dioxide.

Case B : Bridge Deck

An example of bridge deck where concrete was subjected to freeze-thaw deterioration. Concrete slab became loosen and several large cracks longitudinally and laterally had been observed. Slight corrosion on reinforcing bars has been measured and inspected. Unsound concrete can be examined to demonstrate deeper deterioration than mid depth of the concrete deck.

Repair method has been carried out by removing all unsound concretes. Rust has also been removed by sand-blasting. Formwork soffit has been erected by hanging from precast beams, and the polymer concrete has been placed to accommodate service traffic within 3 hrs of repair (Fig.4). This method can minimize traffic blockage and reduce traffic congestion during the repair.

Case C : Building

Small cracks and large deformation as a result of to large cavities in the beam as caused by of heavy reinforcement and improper consolidation. Ultrasonic pulse velocity was used to detect void size and location. Repair mathod has been introduced the epoxy injection to fill the void and to seal the cracks. (Fig.5)

6. CONCLUSION

In accordance with durability problems of structural concrete, the service life can be extended by routine inspection, proper repair and maintanance. Inspection work must be carried out to evaluate the repair work and for decision model of maintenance, repair, demolition or replacement. Tests methods and monitoring system have demonstated the information on decision to satisfy the structural level, safety level, reliability level and cost index. Repair materials and techniques would be essential to warant the durability performance based on properties, proper evaluation, mechanical response and field experience. Excellent repairs can be achieved, only when adequate information, sufficient tests, effective investigation, and reliable operation, have been carried out.

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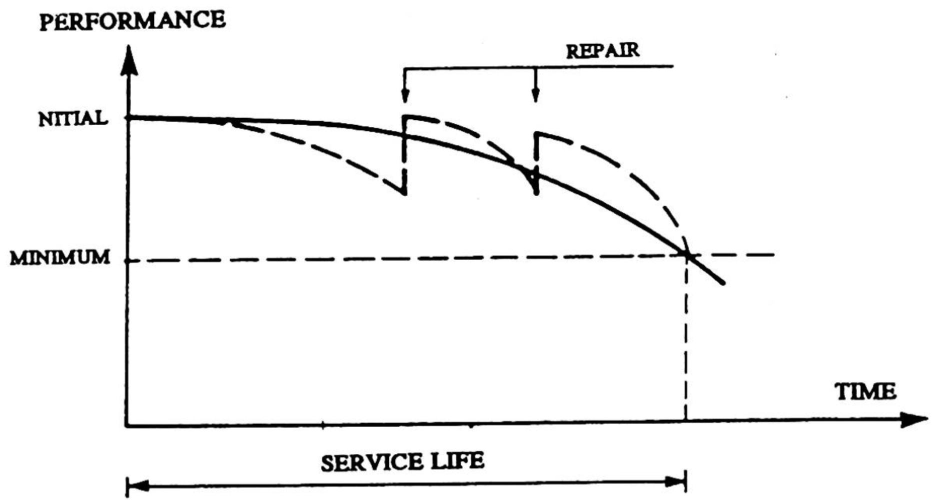

Fig. 1 Durability performance and service life of structures.

Table 1 Checklist for investigation of deteriorated concrete

Item	Description	Investigation check lists
1.	Concrete under inspection	- Concrete structures - Sample from a structures - Lab specimen stored on site - Lab specimen stored on lab - Sampling procedure - Sample storage and treatment
2.	Initial data on Concrete	- Concrete structures (design, load, dimensions) - Concrete specification - Mix design - Tests on materials - Quality control of fresh concrete - Quality in placing - Duration and method of curing - Age at time of attack
3.	Influence from the environment	- Temperature - Humidity - Pressure - Permeability of surrounding media - Sea-Water - Other aggressive substances - Type of contact - Concentration of aggressive substance - Frequency of exposure - Special environmented influences
4.	Visual sign of deterioration	- Erosion - Spalling - Exfoliation - Dusting - Crumbling - Softening - Staining - Pop-outs - Cracks - Liquid gel exudation - Crystallization - Corrosion of reinforcement - Mis-alignment
5.	Laboratory examination and tests	- Visual examination - Chemical analysis - Mechanical test - Physical test - Void location - Rebar location and condition - Water penetration test - Others

Table 2 Strength Testing

Test Method	Principle and Main Application	Test Standard
Core Testing	Determine in-situ strength of concrete. Compressive strength, tensile strength and modulus of elasticity can be obtained. It can be used with N.D.T. for calibration value of lowest strength.	ASTM C 42 ACI-318-89 BS 1881 Part 120
Rebound Hammer	Measures surface hardness by spring driven hammer striking concrete surface and rebound distance is given in R. values. It can be applied for estimation of compressive strength uniformity and quality of concrete.	ASTM C-805-79 BS 1881 Part 202
Pull-out Test	Measures the force required to pull out a steel rod with enlarged heal cast in concrete. It is for estimation of compressive and tensile strength of concrete.	ASTM C-900-82 BS 1881 Part 207
Break-off Test	Measures the force required at the top and at right angle to the axis to break-off the core at the bottom. The flextural strength can be estimated.	BS 1881 Part 207
Penetration Test (Windsor Probe)	Measures the depth of penetration into the concrete. Surface and sub-surface hardness are used to estimate compressive strength, uniformity and quality of concrete.	ASTM C-803-79 BS 1881 Part 207
Ultrasonic Pulse Velocity	Measures the transit time of an induces pulse compressional wave propagating thru the concrete. It is useful to estimate the quality and uniformity of concrete. It can also locate voids in concrete.	ASTM C-597-83 BS 1881 Part 203

Fig.2 Overlaying

Table 3 Test for Void Location

Test Method	Principle and Main Application	Test Standard
Endoscope	Lens and illuminating system which is inserted into a small diameter hole to inspect the interior cavities.. The main application for checking void along grouted prestressed tandons.	
Radiography	Gamma radiation atteñuated when passing thru the concrete. Extent of attenuation controlled by density and thickness of concrete. The location of cracks, voids and internal part (rebars) can be obtained.	BS 1881 Part 205
Radar	High frequency electromagnatic pulse are set into concrete and the reflected pulse are processed graphically Voids as well as reinforcement can be located.	ACI-581-62
Thermography	Measure infra-red radiation and is used to determine the surface temperature differential of concrete member during heating and cooling. It is advantaged in locating delamination and voids.	Ref: Manning D.G. &Holt F.B., 1980
Tomography	Gamma-ray source is collimated to form flat fan of ray that are attenuated as they pass thru the structure to detectors. It is used to locate void and reinforcement.	

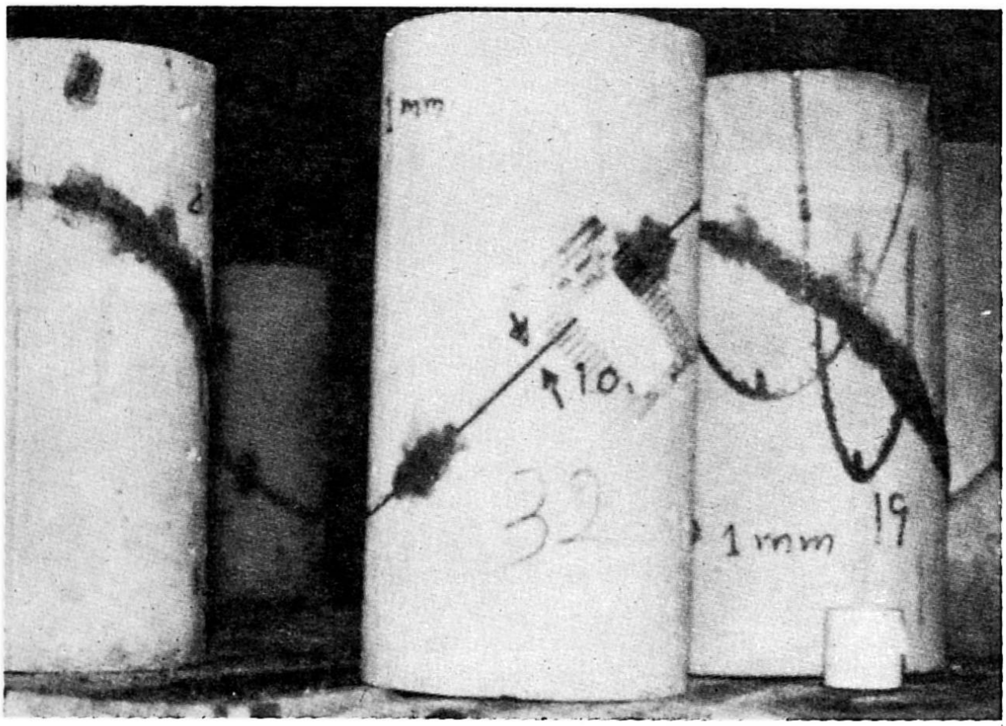

Fig.3 Shear-compression tests

Table 4 Water Penetration Tests

Test Method	Principle and Main Application	Test Standard
Absorption	An over dried specimen of known dimensions is cooled and immersed in water for 30 minutes. The quality and particular the obsorption of concrete in relation to durability can be obtained.	ASTM C 462-82 BS 1881 Part 122
Permeability	Measures the flow rate of water thru the concrete. It will indicate the degree of protection to reinforcement offered by the cover.	NBN 748.18 ISO/DIS 7032
Air Entrainment	By examining a concrete sample impregnate with a dye under the stereo microscope. Effective protection of cement paste from freezing and thawing cycles.	ASTM C 457-82
Initial Surface Absorption	Measures the flow rate of water into the surface concrete. The quality of concrete can be indicated.	BS 1881 Part 211

Table 5 Chemical Tests

Test Method	Principle and Main Application	Test Standard
Cement Content and Aggregate / Cement Ratio	Chemical analysis of the crushed concrete to determine cement content and aggregate to cement ratio.	BS 1881 Part 6 ASTM C 85-620
Water / Cement / Ratio	Measure the combined water present as cement hydrates and the capillary water. The water content can be determined from the sum of combined and capillary water to give the water to cement ratio.	BS 1881 Part 6
Cement Type	Chemical analysis of the crushed concrete sample based upon the dermination of Al_2O_3 and Fe_2O_3 atomic spectrophotometry. If the ratio of Al_2O_3 : Fe_2O_3 is less than 0.9 is SRPC and if the ratio is greater than 1.5 the cement is OPC.	BS 1881 Part 6
Carbonation Depth	Determined by spraying a solution of Phenolphtalene in alcohol and water onto a freshly cut face. An assessment of the time before the carbonation first reaches the level of the reinforcement can be made.	RILEM CPC-18
Choloride Content	Determination of chloride content of hardened concrete enables the corrosion risk to embeded reinforcement to be assessed.	BS 1881 Part 211

Table 6 Tests for Reinforcement Location and Condition

Test Method	Principle and Main Application	Test Standard
Electromagnatic Covermeter	Locates and measures the depth of reinforcement by utilizing an alternating current induced in a secondary coil caused by the proximity and active size of the reinforcement.	BS 1881 Part 204
Eddy Current Techniques	The equipment based on Eddy current techniques, is capable of indicating bar diameter and detecting bar at a greater depth. This is known as the Fe-depth meter.	
Reinforcement Potential	Electrical potential between the surface of the concrete and reinforcement measured. It is applied to determine the condition of reinforcement in the concrete.	ASTM C876-80
Resistivity	A row of four electrodes are held and a current passed between the outer and the potential drop measured between the inner., It provides a inner. It provides a measure of the maximum rate of corrosion affter the reinforcement becomes active.	Ref: Browne and Geoghegan (1978)

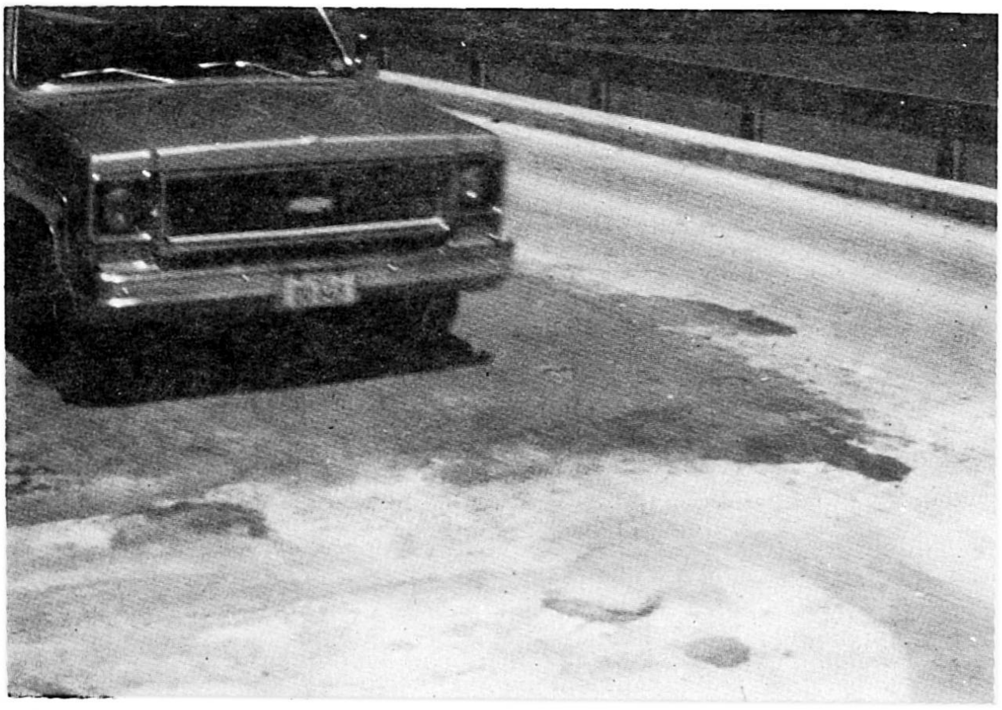

Fig.4 Bridge deck repaired by polymer concrete

Table 7 Repair Materials and Techniques

Repair Techniques	Material	Application
Injection	Epoxy resins Polymer modified	Fine Cracks
Pressure Grouting	Portland cement mortar Polymer mortar Putties and caulks Cement paste with filler	Large cracks Small holes/cavition Joints
Normal Grouting	Portland cement mortar Latex modified mortar Polymer mortar	Large Holes/cavition
Patching	Rapid setting mortar Polymer rasins Portland cement mortar (set control)	Localized area shallow
Placing	Portland cement concrete Polymer concrete Expansive cement concrete Latex concrete Epoxy concrete	Replacement
Overlaying	Asphaltic concrete Polymer concrete Expansive cement concrete Latex concrete Epoxy concrete	Thin layer surface
Coating	Polymer modifier Paints Mastic fult	Surface coating

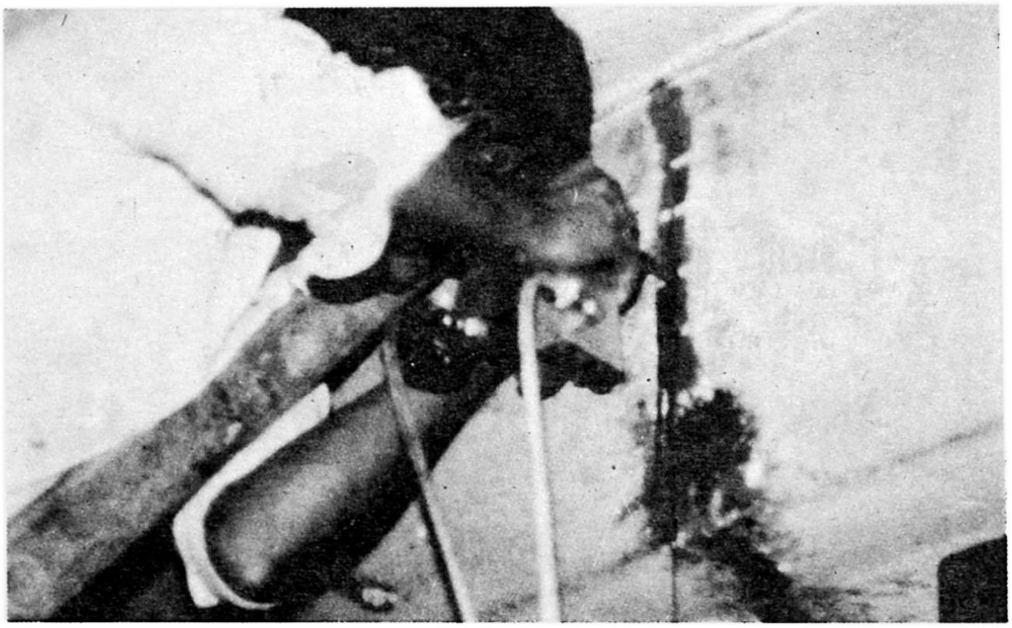

Fig.5 Building frame repaired by epoxy injection

DESIGN FOR DURABILITY

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SUMMARY

Durability of concrete structures, from both *technical* and *economic* aspects has become one of the basic civil engineering tasks. In order to achieve durable concrete structures, *measures* should be taken for *prevention, decrease* or *slow-down* of their *deterioration* processes. The *measures* should be taken in *all phases* of *creation* and *life* of the structure. A *long service life* of the structure could be achieved by high level of *design* and *construction*, by adequate *operation*, regular *maintenance* and due *repairs* and *rehabilitations*. The basic *factors* of concrete structure *deterioration* are: presence of *water* and *moisture, environmental aggressivity, compactness* and *thickness* of the *concrete cover, compactness* of *grouting* for the protection of prestressing wires and the *width* of *cracks*. The analysis of these factors leads to the *measures* that should be taken during the *design, construction, operation* and *maintenance* of concrete structures.

GENERAL

Following the current principles, *concrete structures* , either reinforced or prestressed, should have the corresponding *reliability* at every moment of their operation. It means that the concrete structures should have the sufficient *safety*, the required *serviceability* and the necessary *durability*.

From the historical point of view the analysis of concrete structures *durability* is the youngest one. The reasons not to sufficiently seriously consider the durability of concrete structures since the time they have first appeared can surely be found in the fact that they are very *durable*. At the beginning, many people have wrongly taken them for eternal thus considering their maintenance not necessary.

Nowadays, however, when numerous concrete structures are of considerable age or at the end of their service life, durability problems are paid great attention to. Unfortunately, in the near past sudden unexpected catastrophic failures of poorly maintained structures took place. *Durability, maintenance, rehabilitation* and *strengthening* of the existing concrete structures, especially of bridges, of numerous structures subjected to aggressive effects, has become one of the basic civil engineering tasks. Scientists and experts all over the world are engaged in studying those problems from both *technical* and *economic* aspects.

SERVICE LIFE

The *service life* of a concrete structure is a period of time during which it has the sufficient *safety* and the required *serviceability*.

The *designed service life* can be achieved with different scope of rehabilitations, Figure 1.

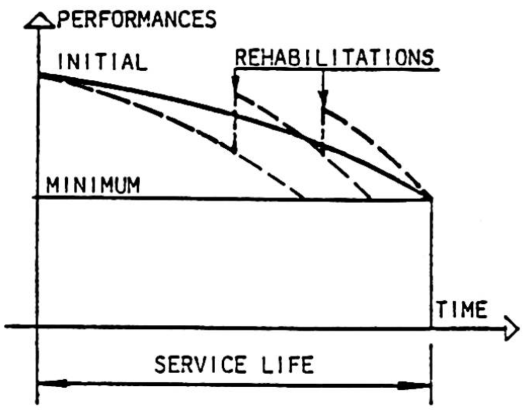

Fig. 1 - SERVICE LIFE

The better the quality of structure which is subjected to regular maintenance, the lower the decrease of its performances from the initial to the minimum required values at the end of the service life.

In order to achieve the same service life for a lower quality structure which is not regularly maintained as for the higher quality, regularly maintained, more frequent rehabilitations are necessary. That, certainly, requires *higher* total *expences*.

A *long service life* of the structure could be achieved by high level of design and construction, by adequate operation, regular maintenance and due repairs and rehabilitations.

During the *design* , it is difficult to establish the *service life* of a structure because the requirements that it has to meet during the operation period are increased with time. It is not easy to rightly assess the future development of the technology many years in advance.

The service life of a concrete structure is much longer in comparison with the service life of the equipment and vehicles transmitting their effects onto it. It is realistic to expect the structure to last a number of generations of the equipment and vehicles with possible adaptations and strengthenings of the structure.

A structure reaches its *real service life*, which due to numerous unpredictable factors does not equal the design service life, when the expenses of its further maintenance in the condition of sufficient safety and the required serviceability exceed the expenses of maintenance which, during the operation period, have been considered acceptable.

It is absolutely clear that the concrete structure, when it *reaches* its *service life* should *not be immediately replaced* . That is, however, the moment when it should be analyzed in detail and estimated if the indispensable rehabilitation including the future maintenance is technically justified and economically more favourable then the construction of a new structure. That is the time when the *decision* should be made on *future destiny* of the existing structure.

DURABILITY

Although they are very durable, concrete structures, sooner or later, start showing the signs of *deterioration.* The appearance and the development of the deterioration process come as a consequence of very *different causes.*

The most dangerous form of concrete structures deterioration is the *deterioration of steel.* Full attention must be paid to the *permanent corrosion protection* of the reinforcement and prestressing wires. In the highly-alkaline mass of concrete, they are fully protected by *passivation.*

Deterioration of concrete, physical, chemical or biological, is less dangerous. However, it can significantly influence the increase of the deterioration of steel.

The required *durability* of concrete structures should be achieved by taking a series of *measures.* They refer to *prevention, decrease* or *slow-down* of the *deterioration process*, as well as to due *repairs* and *rehabilitations* of the damages.

In order to achieve the purpose, in the best way possible, but from engineering and economical points of view, a series of measures should be taken in *all phases* of *creation* and *life* of each structure:

- During the *design* (gathering of the detailed relevant data on the location, the selection of an adequate structural conception, the selection of the corresponding structural materials, the application of the appropriate computation models, dimensioning according to all limit states, correct solving of the structural details);

- During the *construction* (selection of adequate construction methods, realization of the structure in accordance with the design, realization of the required preciseness of the structural geometry and the position of reinforcement and tendons, the application of the designed quality of the materials, the selection of adequate composition of concrete, correct mixing, transportation, placement and curing of concrete in order to obtain the required quality, realization of the concrete cover of the required thickness and compactness, good grouting of tendons, correct continuations of concrete placement);

- During the *operation* (provision of the design use of the structure, protection from overloading and undesigned actions);
- During the *maintenance* (regular follow up of the condition and behaviour of the structure, due repair and rehabilitation).

The *designer*, the *contractor*, the *owner* and the *user* should take care of the execution of those measures.

WATER AND MOISTURE

The presence of *water* and *moisture* make the most dangerous cause for the appearance and development of the deterioration process of concrete structures. Practically, in all deterioration processes, water can be found and it plays a very important role.

In order to provide *durability*, measures should be taken to prevent or to decrease retaining of water on the surface and its penetration into the concrete. Water should be drained off as soon as possible.

During the *design*, a secure *waterproofing* and efficient *draining system* should be planned.

The *shapes* of concrete surfaces exposed to atmospheric waters should be selected so as to prevent retaining of water and to enable its quickest possible draining, Figure 2.

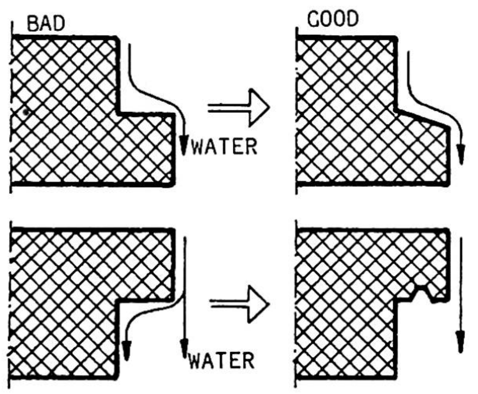

Fig. 2 - SHAPE OF CONCRETE SURFACES

Smooth surfaces are much better than the rough ones.

If possible, concrete should be *protected* from direct *splashing* by water due to passing vehicles, Figure 3.

During the winter, such water can even contain defreezing salt. Easy *replacement* should be designed for the members which are difficult to protect.

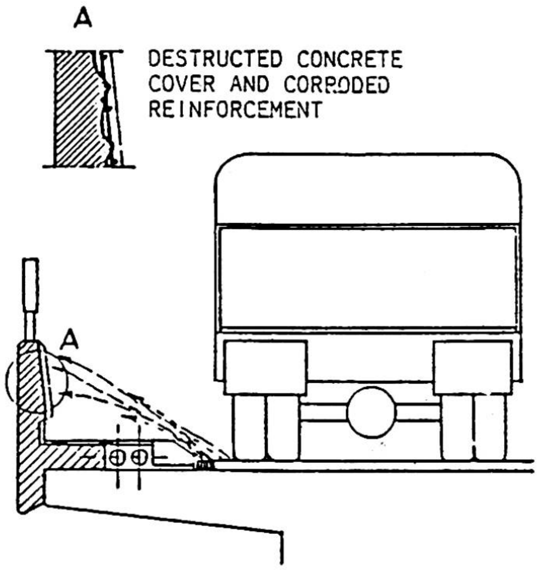

Fig.3 - SPLASHING DUE VEHICLES

Asphalt pavement on concrete bridges is not, as it has been thought earlier, sufficient to prevent the penetration of water, containing defreezing salt during the winter, to the deck, and, if it is cracked through it, too, Figure 4.

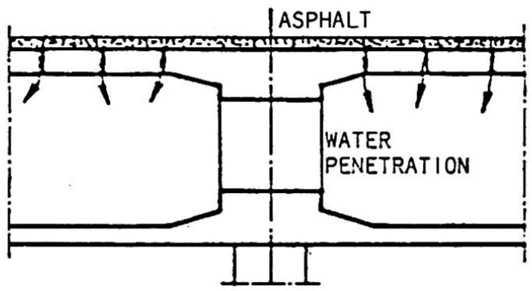

Fig.4 - BRIDGE DECK WITHOUT WATERPROOFING

It is indispensable to make *waterproofing* between the pavement and the deck.

The *draining system* should be so designed as to safely and quickly drain the water and to be easily accessable for maintenance. The draining tubes should not be embedded into the concrete mass, Figure 5.

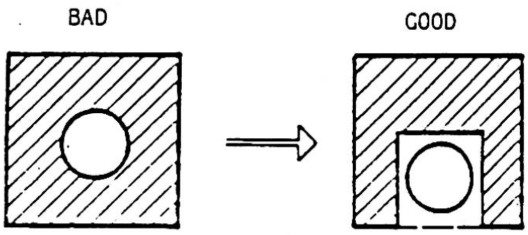

Fig. 5 - DRAINING TUBES

Beside good *construction* and correct *operation*, regular control of waterproofing and draining system functioning should be undertaken during the *maintenance*.

Possible *damages* or *cloggings* should be immediately removed. The penetration of water from damaged gullies and draining tubes to the box girder was one of main causes of damages, for a concrete bridge, Figure 6.

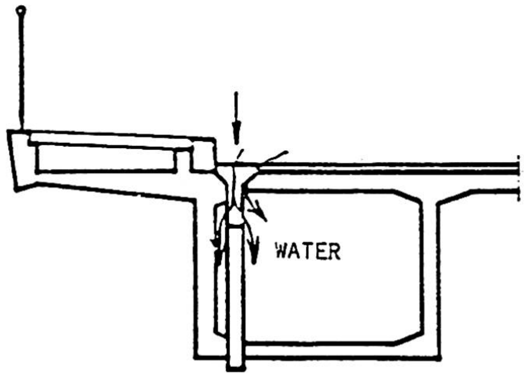

Fig. 6 - DAMAGED DRAINING SYSTEM

In the box girders, *openings* for quick draining of possibly penetrated water, as well as for aeration should be designed.

AGGRESSIVE ENVIRONMENT

The deterioration process of concrete structures is highly influenced by *aggressive environment*.

The most frequent is *chloride aggressivity* . It is caused by the presence of *defreezing salt* on bridges during the winter, or due to presence of *sea salt* on the structures in coastal regions. Chloride ions decrease alkalinity of concrete so depassivation takes place together with the corrosion of steel.

In industrial structures, concrete can get into contact with very aggressive *inorganic acids* (hydrochloric, sulphuric, nitric) or with *organic acids* (lactic, acetic). During the production of fertilizers, concrete is endangered by *ammonium salts*. Such aggressive substancess as well as *magnesium salts* from the sea and ground waters including *soft water* chemically react with *all calcium components* of the hardened cement creating expansion comound which are washed out from the surface of the concrete causing its deterioration.

Sulphate aggressivity on the concrete causes chemical reaction of sulphate ions with *aluminate component* of the hardened cement, creating expansion compound resulting in the appearance of cracks.

Alkalies in contact with concrete *silicates* and *carbonates* from aggregates. *Alkali-silica* and *alkali-carbonate* reactions lead to expansion, resulting in appearance of cracks.

In the box girder of a concrete bridge, into which the entrance of birds through the openings without doors or wire networks was not prevented, thick layers of birds excrement, eggs and similar impurities were found, Figure 7.

The lower chord of that box girder especially in the vicinity of incorrect draining tubes, was so damaged that it was inevitable to replace it, Figure 8.

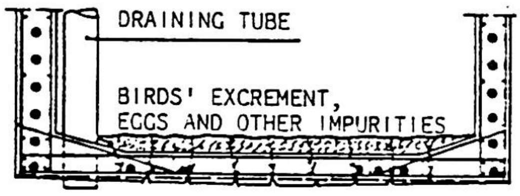

Fig. 7 - PRESENCE OF BIRDS IN THE BOX GIRDER

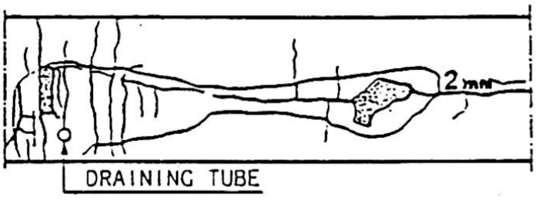

Fig. 8 - VERY DAMAGED LOWER CHORD

The prestressing wires taken from that lower chord were very much corroded and even completely broken, Figure 9.

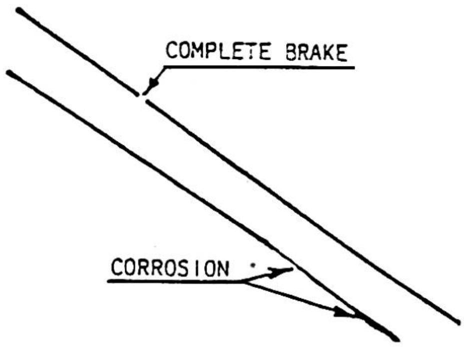

Fig. 9 - VERY CORRODED PRESTRESSING WIRES

Very much corroded reinforcement and an outstanding taking off of concrete on poorly made ceiling in very wet aggressive surroundings of a swimming pool in a spa are shown in Figure 10.

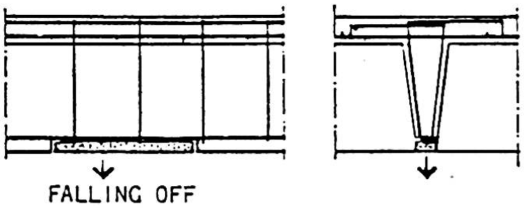

Fig. 10 - VERY MUCH DAMAGED CEILING

During the *design* and *construction*, it is necessary to take measures to permanently *protect* the concrete structures from aggressive environment. Depending on the kind of aggressive environment, the corresponding kinds of *cement* and *aggregates* should be selected - their deterioration resistance should be higher.

During the *operation*, measures should be taken to *decrease* the aggressivity, and during the *maintenance*, measures should be taken to *control* the structures together with the measures to *remove* the deposited aggressive substances.

·CONCRETE COVER

An essential influence on the concrete structures deterioration has the state of the *concrete cover*, as well as the state of *grouting* for prestressing wire protection.

Porous, thin, poorly made and *damaged concrete cover* directly influences the *corrosion* of the reinforcement.

Moisture containing aggressive substances penetrated through porous and thin concrete cover causes reinforcement corrosion visible by the appearance of rust spots on the concrete surface. The corroded reinforcement swells causing longitudinal cracks and falling off of the concrete cover. The process is a progressive one as longitudinal cracks and separation of concrete intensify the penetration of moisture containing aggressive substances to the reinforcement.

Porous and *poorly* made *concrete cover* enables *physical deterioration* of concrete structures, due to *frost, erosion* or *cavities*.

Porous, poorly made and partly *not placed grouting* for the protection of prestressing wires directly influences their *corrosion*.

Poorly grouted and partly not grouted tendons of the box girder of a bridge were the causes of intensive corrosion of prestressing wires, Figure 11.

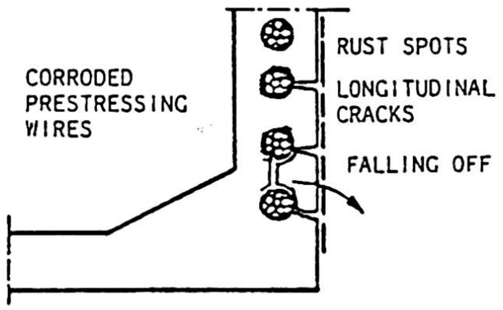

Fig. 11 - POORLY GROUTED TENDONS

In the past, prestressing wires were frequently conducted through the inside of the box girder, with a good concrete protection along its length. However, it was difficult to achieve a good protection at its entrance to the deck. Poorly made concrete protection, beside lack of waterproofing and the cracked deck of a concret bridge, has caused the penetration of water containing defreezing salt, intensive corrosion and the complete brake of all prestressing wires of one of four existing groups, Figure 12.

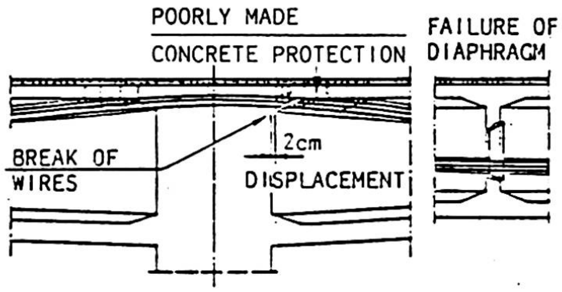

Fig. 12 - POORLY MADE CONCRETE PROTECTION

That had caused a serious rehabilitation of the bridge.

Poorly sealed grouting control tubes of the prestressed hangers of a concrete bridge have enabled the penetration of water along the tendons, Figure 13.

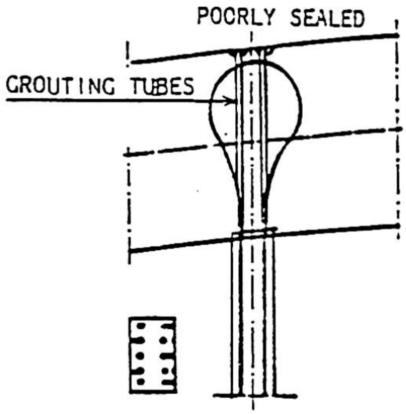

Fig. 13 - POORLY SEALED GROUTING TUBES

Very aggressive corrosion of prestressing wires took place together with the longitudinal cracks in the hangers. This later led to the rehabilitation of the bridge hangers.

It is essential for *durability* of concrete structures to realize, during their *design* and *construction*, the best possible *compactness* and the necessary *thickness* of the *concrete cover*. *Grouting* for the protection of prestressing wires should be *compact* and *well made* during the *whole length* of the tendons.

Achievement of the necessary *compactness* of the concrete cover depends on a series of factors regarding the *technology* of concrete as are kind, quality and quantity of cement, kind and grain size distribution of the aggregates, water cement ratio, kinds and quantities of possible admixtures, methods of mixing, transportation placement and curing of concrete.

During the *maintenance* , it is very important to *control* the concrete cover and the grout for the protection of prestressing wires.

The appearance of *rust, lime* or *water spots* on the concrete surface, as well as the appearance of *blistering, separation* and *falling off* of the concrete cover, require urgent establishment of the *causes* and *degrees* of *damages* and their *removal*.

Carbonation of concrete cover is also one of the causes of deterioration. By diffusion of *carbon dioxide* from the air to the surface layers of concrete, the alkalinity is decreased causing *depassivation* and the reinforcement *corrosion*. However, the process penetrates into the depth of concrete very slowly, and its progress can be easily established by measuring pH values.

CRACKS

The state of *cracks* is also an essential cause of concrete structures deterioration. In the cracked areas, the penetration of aggressive substances into the concrete is much easier.

It is indispensable to keep the real *width* of the cracks within the coded values. Cracks of lower width, frequently full of deposits of lime, dirt and rust, have significantly lower influence on the deterioration process.

During the *design*, it is necessary to analyze, as precisely as possible, the expected values of the crack widths. Through structural measures, concentration of stresses and the appearance of unexpected cracks should be avoided.

Unforseen cracks arising during anchoring the prestressing tendons without necessary overlapping are shown in Figure 14.

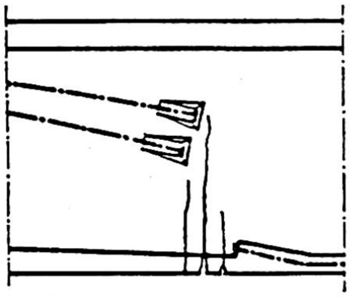

Fig. 14 - TENDONS ANCHORING WITHOUT OVERLAPPING

During the *construction* it is necessary to achieve the designed structure, with regards to the system, geometry, quality of the materials and of the executed works.

During the *operation*, the structure should be protected from overloading.

During the *maintenance* , it is necessary to regularly control the crack widths. If they are not within the design limits, the causes should be immediately established and removed, as well as the cracks of excessive widths sealed or injected.

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Curing of Concrete Surfaces

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Abstract

Curing of concrete is mainly understood to be measures to maintain a satisfactory moisture content in concrete during its early stages so that desired properties may develop. This paper gives an overview on basic aspects and principles of curing. The effects of curing on the structure of concrete are summarized on the basis of a literature review. Various commonly accepted methods of curing are listed and their effectiveness is delt with. Furthermore, relevant recommendations and codes on curing and in particular on the estimate of the duration of curing are concisely presented and compared with each other. Finally, some comments are given on test methods to be applied on the construction site to determine the effectiveness and required duration of curing.

1 General considerations

After placing and compaction of the concrete, adequate measures have to be taken in order to obtain the expected properties from hardened concrete, in particular strength, impermeability and durability. In that context curing of concrete is understood to be measures to avoid premature drying of the concrete and to provide the cement paste in the concrete with a sufficient amount of water over a sufficiently long period of time to achieve a high degree of hydration within its mass and particularly in its surface layers. In addition, curing includes measures against environmental effects such as direct sunshine or wind and comprises also measures to prevent cracking due to early shrinkage.

In contrast to curing protection is understood to be a measure against other external effects which may harm the young concrete such as leaching due to rain or flowing water, rapid cooling or freezing, thermal stresses due to heat of hydration, vibration or impact [1].

Carefully curing is an important contribution to obtain a high quality concrete and durable concrete structures. This results from the fact that the durability of concrete members is primarily controlled by the properties of the surface layers. If concrete is adequately composed, sufficiently curing results in an impermeable and strong surface layer with a high resistance to the ingress of aggressive media which may exert an attack to the concrete and/or to the embedded steel. While insufficient curing strongly impairs the surface layers,

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it often has only a minor effect on the strength development of the concrete in the structure with the exception of thin sections because the core of a thicker concrete section maintains a sufficiently high moisture content for a prolonged period of time even without curing. It is essential that curing and protection start immediately after compaction of the fresh concrete.

2 Effect of curing on the structure of concrete

The hardening of the concrete is the consequence of the hydration of the cement, i.e. the reaction between the cement and the mixing water forming solid hydration products. To achieve a complete hydration of the cement and an impermeable structure of the concrete a certain amount of mixing water is necessary but the water-cement ratio has to be sufficiently low. An early loss of water from a young concrete may prevent further hydration. This may occur, e.g. in the surface region of a structural member if early drying is possible due to insufficient curing. As a consequence this region obtains a low strength and a high permeability. This results from the pronounced effect of the prevented hydration on the pore structure of concrete. The relations between the pore structure of concrete surfaces and the duration of moist curing have been investigated in [2]. Some of the test results of this study are shown in Fig. 1.

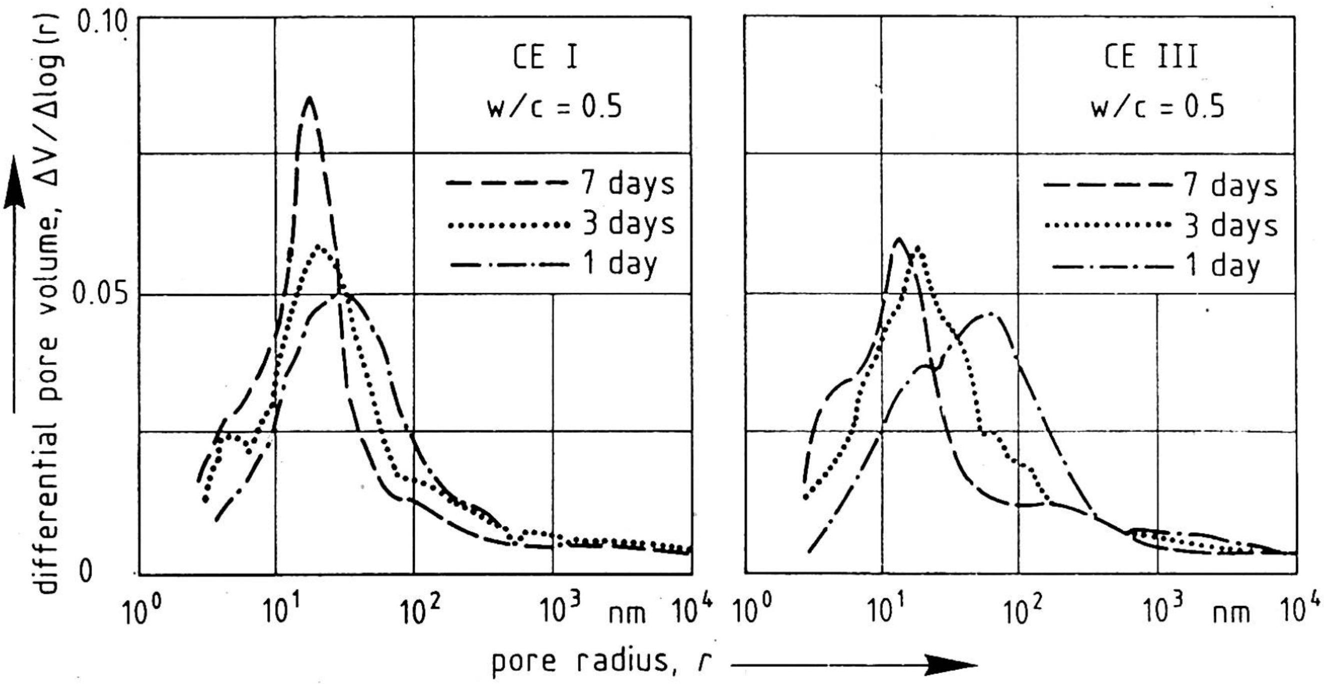

Fig. 1: Effect of the duration of curing on the pore size distribution of concretes made with Portland cement (CE I) and blast furnace slag cement (CE III) [2]

The diagrams represent pore size distributions which were obtained by differentiating the curves of the cumulative pore volume measured by mercury intrusion porosimetry. The investigated concretes have been made with an ordinary Portland cement (CE I) and a blast furnace slag cement (CE III), respectively. Both concretes have a water-cement ratio of w/c = 0.5. The specimens have been moist cured for 1, 3 and 7 days and afterwards stored at 20°C and 65% relative humidity. The tests have been carried out at the concrete age of 28 days. It is apparent from Fig. 1 that for both concretes the pore size distribution is shifted to smaller pore radii if the duration of curing increases. The pore volume measured by the mercury intrusion porosimetry is only little affect by the duration of curing for both concretes (mean value: 0.070 cm^3/g). From the diagrams it is also evident, that the concrete made with the cement type CE III is more sensitive to curing. The peak of the pore size distribution for 1 day of curing is found to be at a significantly larger pore radius for a concrete made with a CE III cement than for a concrete made with a CE I cement. However, after 7 days of curing the structure is found to be slightly more dense for the concrete made with the CE III cement.

These findings agree very well with the results of permeability tests (Fig. 2) conducted in [3]. The storage of the investigated concrete specimens corresponds to that reported above for the experiments of [2]. The air permeability tests have been carried out at the concrete age of 56 days. It is apparent from Fig. 2 that the air permeability decreases with decreasing water-cement ratio and increasing duration of curing. Also in these tests the curing sensitivity of a concrete made with a CE III cement is very pronounced compared to a concrete made with a CE I cement both having a water-cement ratio of 0.45. The results found for the air permeability can easily be understood in view of the pore size distributions obtained for different durations of curing shown in Fig. 1.

Furthermore, the strength class of the cement and in particular its hardening behavior have a significant effect on the development of the pore structure and therefore on the curing sensitivity of corresponding concretes. Fig. 2 shows that the air permeability of concretes after a duration of curing of 1 day is considerably lower if the concrete is made with a rapid hardening cement of a high strength class (CE I, 42.5 R) compared to a concrete having also a w/c ratio of 0.45 but made with a cement of a lower strength class (CE I, 32.5 R). This difference vanishes if the duration of curing increases. These test results are confirmed by a similar investigation in [4]. In summing up, Figs. 1 and 2 clearly indicate the pronounced effect of the duration of curing on the porosity and permeability of surface regions of concretes.

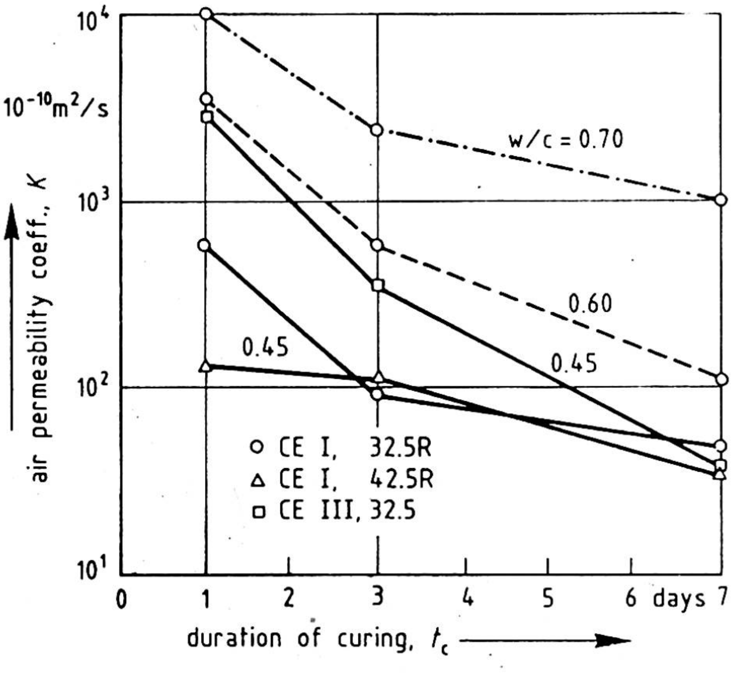

Fig. 2: Effect of the duration of curing on the air permeability coefficient of various concretes [3]

3 Parameters affecting the duration of curing

The required duration of curing of concrete depends on various parameters. First of all, the *composition of concrete* itself is of major importance in that context. As has been shown in the preceding section, the water-cement ratio and the type and strength class of the cement exert a tremendous effect on the hydration rate, i.e. the pore structure and its development, respectively, and thus on required curing durations of concretes. Furthermore, additions such as e.g. fly ash may lead to prolonged curing periods if a sufficient impermeable surface of concrete shall be achieved. Another parameter affecting the duration of curing is the *concrete temperature*. The heat of hydration increases the concrete temperature and thus accelerates hydration. Hence, thin concrete sections exposed to low ambient temperatures during curing where the concrete is made of cements with a low heat of hydration need a very careful curing. The *ambient conditions during and after curing* have a relevant effect on the required duration of curing. Under the conditions of low relative humidity of the ambient air, sunshine and high wind velocity prolonged curing is required. Finally the *exposure conditions of the finished structure in service* have to be taken into consideration. The more severe the exposure conditions are, e.g. chemical aggressive environment, the longer is the required duration of curing. Some of the mentioned parameters are interrelated particular with regard to the concrete temperature. This interrelation also contributes to the complexity of the problem of estimating required durations of curing. Some detailed guidelines on the estimation of the duration of curing will be presented in section 5.

4 Methods of curing and their effectiveness

The various methods of curing may be subdivided into two principal groups. The first group includes those methods of curing which decelerate drying of the concrete, such as:

- keeping the formwork in place
- covering the concrete surfaces with plastic films
- application of curing compounds which form protective membranes.

In contrast, the second group of curing methods includes those procedures where the concrete surface is kept moist by the application of water:

- placing of wet coverings on the free concrete surface
- storage of the concrete under water
- sprinkling the concrete surface with water.

The individual curing methods can be applied either separately or in combination. They are not equally effective; in particular the methods where water is applied are more effective than other methods provided that thermal shocks, e. g. by using cold water on a concrete surface which is warm due to the heat of hydration, are avoided. However, the effectiveness of curing methods is significantly affected by the composition of the concrete, see e. g. [4], [5].

Besides the test methods mentioned in section 2, the effectiveness of curing methods has also been evaluated on the basis of strength tests and from testing the rate of carbonation. However, it has been repeatedly observed that the standard compressive strength is not a suitable measure of curing effects, whereas the rate of carbonation has proved to be more sensitive.

Fig. 3 shows the influence of various curing methods on the depth of carbonation observed at an age of concrete of 6 months. The investigation has been carried out on structural concretes, having a water-cement ratio w/c = 0.55 and made of different types of cement. After demoulding at the age of 1 day, some of the specimens have been water or wet cured for 6 days before being stored in the air at 23 °C and 50 % relative humidity. Comparing the effects of the curing methods "wet covering" and "air", there is only a minor difference between the measured depths of carbonation if concretes made with rapid hardening cements (CE I, 32.5 and CE I, 52.5) are under consideration. This is not observed for the concrete made with a CE III cement. Obviously the curing compound No. 4 strongly reduced the diffusion of CO_2 by sealing the concrete surface. The experimental results indicate that the effectiveness of curing methods, i.e. the progress of carbonation clearly depends on the composition of concrete.

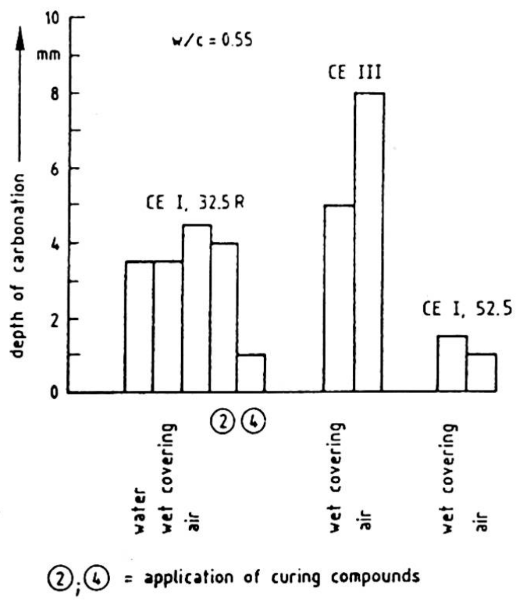

Fig. 3: Effect of various curing methods on the depth of carbonation at a concrete age of 6 months [5]

In practice the choice of a particular curing method often depends on the facilities given on the site. With respect to the effectiveness and practical aspects the following general guidelines on curing methods are given [7]:

The storage under water may be regarded as the most effective curing method. It has mainly a positive effect on concretes with a low water-cement ratio as well as on concretes made with a rapid hardening cement. However, on the construction site this method is hardly feasable for practical reasons.

Covering the concrete surface with wet burlap in combination with plastic films is considered to be as effective as curing under water. This curing method may often be applied on the construction site. For architectural concrete surfaces attention has to be paid to the fact that efflorescences may occur.

Keeping the formwork in place is a favourable method of curing because it starts working just after compaction of the concrete. A wooden formwork which may suck water has to be kept moist.

The covering with plastic films is a simple, practicable and in many cases sufficient curing method; however, they should be so placed, weighted or fastened that the wind is prevented from getting under the film and removing it.

The application of membrane-forming curing compounds has been proved for curing of horizontal concrete surfaces; in addition, they may be of advantage for structural components which can be cured only for a short time period, e.g. due to the construction process [6].
The curing compounds may have an adverse effect on the bond behavior of a coating which is applied on the concrete surface; hence the chemical compatibility of curing compound and coating material has to be checked. At temperatures below the freezing point it is recommended to apply dissolved curing agents instead of emulsions.

Curing by sprinkling with water may result in cracking of the concrete surface due to differences in temperature between the concrete and the water. Generally, temperature differences of more than 15 K between the concrete core and the surface have to be avoided.

It is essential that curing commences not later than the time the concrete surface looses its sheen. Any delay or interruption of the curing can hardly be compensated by an extension of the duration of curing. Additional information on commonly accepted curing methods and materials may be found in [11].

5 Estimates of the duration of curing

The required duration of curing depends on the time needed of the surface zone to reach a sufficient resistance to the penetration of gases or liquids into the hardened concrete.

According to [8] the duration of curing shall be determined from the following criteria:

- parameters which determine the maturity of concrete
- local requirements
- minimum standard curing periods.

The standard curing times as required by various recommendations or building codes are based on the following parameters which influence the rate of hydration essentially:

- concrete composition, in particular the strength class of cement and the water-cement ratio
- ambient conditions during and after curing
- temperature of concrete.

Table 1: Minimum duration of curing in days for T > 10 °C according to [1]

Rate of development of impermeability of concrete		Very rapid	Rapid	Medium	Slow
Expected ambient conditions during and after curing	I No direct sunshine, rel. humidity of surrounding air RH > 80 %	1	2	3	4
	II Exposed to medium sunshine or medium wind velocity or rel. humidity RH: 50 % < RH < 80 %	2	3	4	5
	III Exposed to strong sunshine or high wind velocity or rel. humidity RH < 50 %	3	4	6	8

Table 2: Rate of development of impermeability according to [1]

Rate of development of impermeability	w / c	Class of cement
Very rapid	0.5 - 0.6 < 0.5	RS RS; R
Rapid	0.5 - 0.6 < 0.5	R N
Medium	0.5 - 0.6 < 0.5	N SL
Slow	All other cases	

Table 1 gives in combination with Table 2 the minimum durations of curing for concrete temperatures T > 10 °C as proposed in the CEB-FIP Model Code 1990 [1]. The values are valid for concretes made with Portland cements (CE I), where the cements are subdivided into the classes RS = rapid hardening high strength cement, R = rapid hardening cement, N = normally hardening cement, and SL = slowly hardening cement. In ENV 206 [8] a very similar approach to estimate the duration of curing is chosen. However, with respect to the concrete temperature there is a more detailed classification into three different temperature ranges.

The recommended standard curing times have to be extended in certain cases. According to [8], the curing times should be substantially increased if the concrete is exposed to severe abrasion or to severe environmental conditions. It is also mentioned that longer curing times may be appropriate for other types of cement than CE I. More detailed information is given in [1] and [9]. For example, the curing time has to be extended in the following cases:

for concretes made of cements containing high amounts of constituents other than Portland cement clinker and concretes containing latent hydraulic and pozzolana additions in high amounts, for 1 to 2 days beyond the values given in Table 1 if concrete is exposed to conditions II and III [1];

where concrete is exposed to severe abrasion or to severe environmental conditions, for 3 to 5 days [1];

- when the temperature of the concrete surface drops below 0 °C, for at least by the number of days with $T < 0$ °C [9];
- for concretes containing set retarding admixtures, for the time of retardation [9];
- for concretes containing fly ash in combination with reduced cement contents, for 2 days [9].

With respect to the concrete temperature, the duration of curing may be determined more accurately on the basis of the maturity concept given in the CEB Model Code 1990 [1]. The temperature adjusted concrete age may be calculated from eq. 1:

$$t_T = \sum_{i=1}^{n} \Delta t_i \cdot \exp\left[13.65 - \frac{4000}{273 + T(\Delta t_i)/T_0}\right] \qquad (1)$$

where: t_T = temperature adjusted concrete age [days] if the concrete temperature deviates from T = 20 °C;

$T(\Delta t_i)$ = concrete temperature [°C] during the time period Δt_i;

T_0 = 1 °C;

Δt_i = number of days where a concrete temperature T prevails.

Eq. 1 is valid for temperatures $T > 0$ °C. If the required duration of curing is calculated from eq. 1, then t_T has to be considered as the duration of curing at T = 20 °C and $\Sigma \Delta t_i$ is the required duration of curing if the temperature T deviates from 20 °C.

Presently, a working group within CEN TC 104 is preparing a revised approach to estimate the duration of curing [12]. According to this approach the following relations have to be used to estimate the duration of curing:

$$t_c = \Sigma \Delta t_i \qquad (2)$$

$$\Sigma \Delta t_i \cdot T_i = k \cdot 20 \cdot MH \qquad (3)$$

where: t_c = actual curing time for an applied curing method;

Δt_i = time interval [hours] during which a temperature T_i [°C] prevails;

T_i = concrete temperature [°C];

k = coefficient which depends on the method of curing;

MH = required maturity hours [hours · °C].

The required maturity hours MH are defined as the required curing time for a constant concrete temperature of 20 °C. Values of MH are given in a table for the exposure conditions indoor, outdoor and severe abrasion and for various curing sensitivity classes of the concrete. The curing sensitivity of the concrete depends on the type of cement, the strength class of cement, the water-cement ratio of the mix and the type of additions. This approach [12] which is still under discussion allows a considerably more precise and comprehensive estimation of a required duration of curing than [8]. In particular, the effects of curing methods, types of cement and additions as well as variable concrete temperatures are taken into consideration.

6 Test methods for the application on the construction site

Generally the estimation of the effectiveness of a curing method is possible only indirectly, i.e. through testing such concrete properties which are affected by curing.

In various studies the compressive strength of companion specimens has been used as a parameter to evaluate the effectiveness of curing methods. The experimental investigations showed that the compressive strength often undergoes only a little reduction when curing is deficient. Sufficient curing results in an impermeable and strong surface zone of the concrete which contributes only minor to the compressive strength of concrete measured on standard specimens. However, the porosity and thus the permeability of the surface zone of concrete is significantly affect by the curing procedure (see section 2). Hence, test methods which determine the resistance to the penetration of gases or liquids into the surface zone of the concrete in view of the evaluating the efficiency of curing but also with respect to durability considerations became an important subject of the recent research.

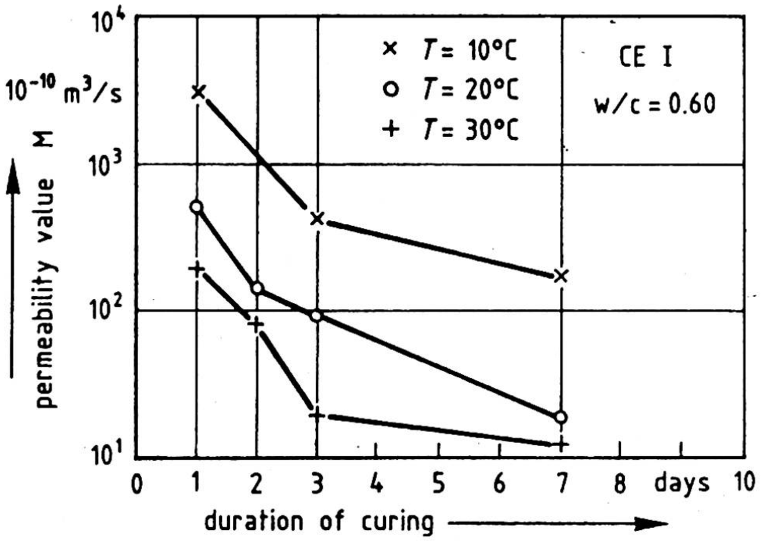

Fig. 4: Effect of the duration of curing on the permeability value at various concrete temperatures [3]

Suitable test methods to be used in the laboratory for a characterization of the structure and permeability of concrete are the mercury porosimetry and the methods of measuring the gas permeability and the water penetration. In contrast, for the time being there are no generally accepted methods for a rapid determination of concrete porosity and permeability which may be used on the construction site. In particular, the aim of the research in this area is to develop a non-destructive test method in order to assess the effectiveness of curing and to determine the end of curing time on the construction site. A promising test procedure has been developed e.g. by Schönlin [3].

He uses a suction device which is placed directly on the concrete surface. This instrument allows to exert an underpressure generated by a connected vacuum pump on a circular surface area of 50 mm in diameter. After the pump is removed, the air pressure inside the vacuum chamber of the suction device will rise to a certain amount within a fixed time period depending on the porosity and air permeability of the concrete, respectively. As the penetrated area and the path of the penetrating air cannot be determined exactly a permeability value M is defined and obtained from corresponding tests. However, this permeability value M may be correlated to the permeability coefficient K. As it is apparent from Fig. 4 the permeability value M of concrete surfaces depends pronouncedly on the duration of curing and concrete temperature. However, also the moisture content and the moisture history of surface regions tremendously affect the measured values. Hence it is difficult to obtain reliable test values on site. For further details and test methods see [10].

Further research work is mendatory to arrive at a test procedure being reliable and operational for application on the construction site. In summing up it has to be stated that presently there is no commonly accepted rapid test method to determine the effectiveness and duration of curing on the construction site.

7 Concluding remarks

The significance of curing on the impermeability of concrete surfaces and thus on the durability of concrete structures has been demonstrated in numerous experimental investigations. As a consequence, nowadays many efforts are undertaken to give more detailed and more substantiated proposals for curing requirements in recommendations and codes on the basis of these findings. In view of the connection between curing and durability the measures for curing and protection should be a separate item of the construction contract to be agreed upon prior to the commencement of the construction work.

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Controlling Durability during Construction
- Examples, Case Studies

Dr. Rolf Dillmann

1. Introduction

One substantial problem of the durability of reinforced concrete structures is the protection of reinforcement against corrosion, This protection is normally ensured by the basic (that is: hydroxyl ion concentration) nature of the concrete. However, this basic environment surrounding the reinforcement bar can be destroyed by carbonation, i. e. the reaction of atmospheric carbon dioxide with the calcium hydroxide of the concrete.

In the face of this fact two outstanding factors have emerged as protection against corrosion:

- the thickness of the concrete covering and
- the density of the concrete covering.

The concrete covering is the concrete layer between the surface of the reinforcement bar and the outer surface of the concrete. In addition to securing a sufficient protection against corrosion of the reinforcement the covering also serves in

- taking up bond strength
- providing an effective fire protection.

2. Measures for increasing the durability of the concrete structure by increased protection against corrosion during construction

2.1 Thickness of concrete covering

The thickness of concrete covering is, generally speaking, influenced by the following factors:

- measurements of the bent and suspended reinforcement
- clearing width of the form work
- amount of dislocation of the reinforcement cage during concreting.
- height/thickness of spacers

On the basis of a research projekt it became evident that, provided the influencing factors are independently and normally distributed, a standard deviation of concrete covering of approx. 8 mm is to be expected.

Consequently, on construction sites the following checks are carried out routinely or at least randomly:

- inspection of the measurements of bent and suspended reinforcement and rejection of those reinforcement bars that deviate in their lengths from the values of table 1.

- inspection of form work struts and rechecking of the clearing width of the form work immediately prior to concreting.

In order to avoid dislocation of the reinforcement cage during concreting a sufficient number of spacers must be used. The spacers must have sufficient bearing strength and be resistant against deformation and tilting. Their height/thickness must correspond to the minimum concrete covering and include an allowance that takes into account all inevitable deviations.

2.2 Density of the covering

The density of the concrete covering is largely influenced by the following two factors:

- the water/cement ratio of the concrete
- the degree of hydration, i. e. the curing of the concrete

By using concrete plasticizers it is nowadays no problem to produce and use a concrete with a sufficiently low water/cement ratio.

Because of the greater human factor involved it is definitely more difficult to achieve sufficient curing under site conditions. However, when using a minimum of discipline there are enough curing methods on hand today to suit every specific site and purpose.

The effectivness of curing can be checked under site conditions. This may be done either by testing the permeability towards air by means of a vacuum or by the rate of water absorption of the concrete near to the surface.

3. Summary

The two parameters, thickness and density of the concrete covering, are the determining factors for durability of concrete structures as far as corrosion of reinforcement is concerned. Defect preventing methods are recommended that explain how the two parameters can be controlled during construction.

In the long run so-called "Trade-off-methods" may become feasable. These methods pre-suppose that quality is a constant while the two factors concrete thickness and concrete density can have variable values.

Stablänge l (m)	≦ 5,0	> 5,0
Abmaß Δ l (cm)	± 1,5	± 2,0
bei Paßlängen Δ l (cm)	± 0,5	± 1,0

Biegeform						
Stab Ø (mm)	bis 14	über 14	bis 14	über 14	bis 10	über 10
Abmaß Δ l (cm)	+ 0	+ 0	+ 0	+ 0	+ 0	+ 0
	− 1,5	− 2,5	− 1,0	− 2,0	− 1,0	− 1,5
bei Paßlängen Δ l (cm)	+ 0	+ 0	+ 0	+ 0	+ 0	+ 0
	− 1,0	− 1,5	− 1,0	− 2,0	− 0,5	− 1,0

[1]) Bei Festlegung dieses Maßes Abmaß der zugehörigen Bügel beachten (Passung)

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AN OVERVIEW OF CURRENT TOOLS FOR DEVELOPING KNOWLEDGE–BASED EXPERT SYSTEMS

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Summary

Knowledge–based expert system (KBES) technology was presented to the international structural engineering community in the early 1980's and experienced an exponential growth of application to Civil Engineering problems in the latter part of that same decade. The intent of this paper is to discuss what has happened since Fenves, Maher and Sriram described this technology in IABSE Periodica in 1985. Several more recent methods for building and using KBES are discussed: object–oriented modeling, model–based reasoning, case–based reasoning, and inductive machine learning.

1. Introduction

The purpose of this paper is to present a brief overview of some of the current methods and techniques being used to develop knowledge–based expert systems. Because these systems began as pure rule–based systems, this form is briefly described in the first section. Following this discussion, other more recent KBES technologies (or more general programming paradigms) are discussed. These technologies include: (1) object–oriented methods, which are now being used to represent the structured knowledge within a domain; (2) model–based reasoning, which is used to reason qualitatively about the solutions of complex problems; (3) case–based reasoning, which is used to reason from past solutions to form solutions to new problems; and (4) inductive machine learning, which is used to acquire more general problem solving knowledge from past solutions to problems. Together, these techniques provide increased capability for today's KBES in the areas of representation, inference, and knowledge acquisition.

2. Traditional (Rule–based) Knowledge–Based Expert Systems

Although the concept of knowledge–based systems is actually "old" by today's software time–scale (it came on the computer science scene in the early 1970's), it has taken the engineering community several years to understand and grasp the potential of this technology. In 1985, Fenves, et al., authored a paper within the IABSE Periodica describing the nature of, possible application of, and implications of this technology[3]. At that time, the technology was predominantly a rule–based technology, where they described the main components of a KBES as:

- a knowledge–base — a collection of IF–THEN rules that represent pieces or "chunks" of decision–making knowledge that are applied during the development of a solution to a problem;
- a context or working memory — a formal data structure for representing the initial information known about the problem as well as the evolving solution being developed through application of the rules in the knowledge base; and
- an inference engine — a pattern–matching program for applying the "chunks" of knowledge in the knowledge base to the problem (and its partial solution) described in the context.

A knowledge–based system has several key qualities that differentiates this form of computer program from its procedural counterparts that all stem from its separation of knowledge from its usage: transparency of the knowledge applied, transparency of the solution being developed, and a capacity for incremental development.

Because the rules are developed and represented as separate "chunks" of knowledge, each hopefully specifying the preconditions under which it is applicable, those pieces can be individually observed and understood thus leading to the claim of transparency of knowledge applied. In a procedural program, the pieces of knowledge used are inextricably intertwined with the control of these pieces of knowledge and thus one must look at the entire program to get a sense of the knowledge within.

Because the inference engine of a knowledge–based system searches over this set of rules and keeps track of what rules match the context at what points in the solution process, it is possible to reconstruct the evolution of the solution process thus leading to the claim of transparency of solution. A procedural program normally does not keep track of the path it followed during the solution of a problem and only issues a final answer.

Finally, because the knowledge that is represented within the knowledge base can be both general and much more specific and one can rely on the inference engine to "figure out" which to apply, it is possible to develop a knowledge base that consists mostly of general rules in the early stages of system development that is later augmented with more specific rules as the knowledge acquisition process matures. Thus, the system will perform at a reasonable level of proficiency, but not expertly, in the early stages of development. It will not be capable of more expert problem solving capabilities until the more specific, exceptional pieces of knowledge have been added to its knowledge base. This represents the concept of incremental growth capability. Most procedural programs do not allow for more than one level of problem solving knowledge.

3. Additional Methods and Technologies for KBES

Many successful applications of the more traditional rule–based KBES technology have been described in the literature and employed [1][9]. However, while developing these systems, and many others like them, the KBES community has come to realize several important limitations of the knowledge–based technologies of the last decade:

- knowledge is not homogeneous in structure and many different knowledge representation paradigms (frames, rules, procedures, formal logic, neural networks, etc.) are needed in order to adequately represent the problem solving knowledge brought to bear on a particular problem;
- knowledge is not homogeneous in level of abstraction and knowledge at various levels of detail is needed in order to develop preliminary, high–level solutions to problems, as well as more detailed solutions, at various stages in the problem solution process;

- knowledge acquisition is an enormously difficult, time-consuming, error-prone task, is the most important task in developing a knowledge-based system, and is one area in which tools for assistance are most needed; and
- most current knowledge-based systems are only static "snapshots" of the knowledge used in problem solving and must be made capable of self-modification over time and as more experience is gained.

Hence, KBES developers have looked toward researchers in AI and other fields of Computer Science to help them solve these limitations. There are several methodologies and technologies that are receiving a lot of attention and represent some of the advancements that will eventually find their way into mainstream knowledge-base system development: object-oriented knowledge representation, model-based (qualitative) reasoning, cased-based reasoning, and inductive machine learning. The following sections describe each of these emerging technologies in more detail.

3.1. Object-Oriented Modeling

Object-oriented methods are now being used for organizing and representing various forms of knowledge. The basic building block of an object-oriented representation is the *object* — a modular, self-contained collection of descriptive attributes and the methods (procedural or rule-based) for manipulating those attributes. Representation in an object-oriented environment first requires the description (declaration of attributes and methods) of the general types of objects that populate the domain (class objects), and then requires the generation of instances of the class objects to describe the particular entities being modeled.

In object-oriented representations, everything is an object. Objects can represent concepts, physical objects, processes, etc. In all cases, objects possess a set of attributes and relationships, both of which are represented as slots in the object. Attributes represent descriptive pieces of information about the object and may be represented by either a static value or a method, where a method describes how the value of an attribute is computed. Methods may also cause side-effects in other objects. Relationships, also represented using slots, represent links to other objects. For example, an object may have a "next-to" slot that is filled with the name of another object representing the fact that the two objects are next to each other. Other objects can access the attributes and relationships of an object by *sending a message* to the object that "owns" the attribute or relationship.

While, the most popular way to represent domain-dependent behavior is with production rules, they alone are inadequate for representing domain object definitions and their static relationships. It is common today to use an integrated approach to knowledge representation, where objects represent the natural structure of the physical objects and abstract concepts within the domain that are to be reasoned with, and rules are used to represent the decision-making knowledge (i.e., the derivation of object attributes that are conditional in nature). Objects provide a powerful foundation for a rule-based inference by providing:

- a powerful language for describing domain objects that can be used within rules,
- a set of inference mechanisms (inheritance and ValueClass/cardinality checking) that can automatically reach a lot of conclusions that are needed by a rule, such as class membership and default values, and
- a powerful and flexible language for defining the rules themselves.

The advantages of an object-oriented representation are: 1) the methodology greatly aids in structuring the knowledge; 2) it enables rules and procedures to be more generic making the knowledge–base easier to understand (one can write rules based on a class of objects and have them apply to all subclasses); 3) it compartmentalizes the knowledge, thus reducing the complexity; and 4) through graphical display of attributes and relationships, the knowledge base is more understandable. For more information on object–oriented modeling, see [10].

3.2. Model–Based Reasoning

Model–based reasoning, also known as qualitative reasoning, provides developers of knowledge–based systems with a tool for assisting both knowledge acquisition and reasoning at multiple levels of abstraction. Model–based reasoning is based on the way in which humans initially develop causal models for, or initially reason with, complex systems. We do not start with the detailed descriptions of the causal relationships about the components of a system. Rather, we reason qualitatively about the way in which these components (or larger groups of components) interact to get a sense for how the system will behave. Hence, model–based reasoning first involves building a qualitative model of a complex system, consisting of a set of identified subcomponents and their qualitative causal interrelationships (e.g., A causes B to increase). Next, this model is used to: 1) qualitatively reason about effects given observations about existing symptoms (causes); 2) qualitatively reason about possible causes given observations about existing conditions (effects); or 3) developing more detailed causal relationships between causes and effects that can be used to predict values of quantities instead of just qualitative trends thus guiding the knowledge acquisition process. When the more detailed causal relationships are known, the qualitative model is not discarded, but remains as a more abstract description of the system which can be used to reason about the system in earlier stages of system development when many of the system details are yet to be determined. The existence of both qualitative and detailed descriptions of causal relationships thus provides the multi–level reasoning capability described as the second deficiency of current knowledge–based systems. There are many different directions being taken by researchers in this field (Harandi and Lange [6], Forbus [5], Kuipers [8])

In summary, such a model is useful for performing diagnostic causal reasoning. Once the set of components have been properly connected, it can be used to reason from causes to effects or from effects to causes. When an expert reviews the results from either of these reasoning exercises, he may discover inconsistencies, or the inability of the model to reason from opposite changes in inputs, and at that time may modify the causal equation for a component. In this way, the model is refined and thus also assists in knowledge acquisition.

3.3. Case–Based Reasoning

Case–based reasoning, also known as reasoning by analogy, provides developers of knowledge–based systems with an alternative to the traditional distillation of knowledge into a set of static rules. Case–based reasoning is based on the way in which experienced humans sometimes solve problems, i.e., by determining which of the myriad of past experiences is closest to the current problem and modifying the former solution to develop a solution to the current problem. Hence, the case–based reasoning paradigm takes a large collection of previous experiences, called cases, and determines which case is most similar to the current case. Having determined which case is most similar, and having identified which aspects are similar and which are different, the case–based reasoning system then transforms the past solution into one that is viable for the current situation. Having the ability to reason about the similarity of previous cases (and their solutions) with the current case being addressed and then to develop an analogous solution offers a dynamic problem solving paradigm that begins to address the fourth limitation of current knowledge–based systems (namely, their "snapshot" nature).

Kolodner describes three steps in performing a simple case–based inference: 1) recall a previous case that is similar to the current case; 2) focus on the appropriate parts of that previous case as it relates to the current situation; and 3) use the appropriate parts of the previous case to derive an appropriate solution to the current case [7]. More than one case may be employed in developing a solution to the current problem; different cases may be similar to the current situation in different ways and together the subset of past cases provides enough past knowledge to solve the current problem [7].

In order to make effective use of past experiences and to determine the degree of similarity between past cases and the current situation, it is not sufficient to only represent the final design solution. What is needed about past cases are: the goals and subgoals of the past problem, the constraints imposed on that problem at the goal and subgoal levels, the solution derived for each of these goals and constraints, and the rationale or plan behind the solution derived for the goals and subgoals. It is usually the case that the goal hierarchy, constraints and rationale are represented using an object–oriented representation such as that described in section 3.1. Kolodner defines a past case to be similar to a current situation if the past case has many of the same goals and most important constraints [7]. There is no currently agreed upon definition of similarity.

Once a past case has been identified as being similar to the current case under consideration, the next step is to determine what about the past case can be used in solving the current problem. There are several ways in which the successful solution of a goal from a past case can be employed in the development of a solution to a similar goal in the current case [7]: 1) the solution used in the past case can be directly transferred to the new case; 2) the solution used in the past case can be modified for the new case based on the differences in constraints and subgoals between the past and current case; and 3) the method by which the solution in the past case was derived can be transferred directly to the current case and used to derive a solution for the current case. Hence, using the design representations and plans of past cases, a design plan and solution for a new design problem can be constructed.

Case–based reasoning systems provide an alternative to the traditional, static rule–based systems. One can easily see that as the case–base is built up with descriptions of past experiences encountered and successfully, or unsuccessfully, resolved, the performance of the system will drastically improve — a characteristic that is also present in systems capable of learning, some of which are described in the next section.

3.4. Inductive Machine Learning

Learning is a generalized term denoting the way in which people (and computers) increase their knowledge and improve their skills. Machine learning has been a goal of AI researchers since beginning of AI, where researchers strived to understand the process of learning, and to create computers that can be taught rather than programmed. Two methods for machine learning are described below: induction from symbolic rules and neural network–based mappings.

Induction is one type of machine learning (of which there are many) that has received a lot of attention and presents valuable solutions for some of the limitations of current knowledge–based systems. Induction is the process of learning how to perform a task (and recording this knowledge in the form of if–then rules) by being presented with examples of how it should behave. The most common inference process used for learning from examples is *generalization*. We say that rule A is more general than rule B, if rule A applies in all situations that rule B does and then some more. For example, "5 cards that are all of the same suit is a flush" is more general than "5 cards that are all hearts is a flush. [2]" Often description A is more general than description B because description A places fewer constraints on any relevant situations for which the rule applies. Specific rules are generated from examples and then generalized by modifying the specific rules, while maintaining their validity for the given cases. Thus, the representation chosen for the rule space is important and must be able to support generalization. For example, predicate calculus supports generalization by permitting the following: 1) turning constants into variables, 2) dropping conditions, and 3) adding conditions, to name a few of the operations.

There are currently several problems plaguing such induction systems. Some of the rules induced are incomprehensible. A knowledge engineer still plays a major role in inductive learning by instructing the system as to what attributes are important and what attributes are not. If the attributes are not filtered by a knowledge engineer, the noise might be so great (in the form of unusable, or extremely specific rules) that the program will never perform efficiently and at an expert level. The rules induced from a set of cases is very dependent on the scope of the test cases. If the test cases do not represent a broad set of situations, the rules will be incomplete and possibly over-generalized. The programming of a learning system lies in the selection of test cases or the breadth of the experiences fed into the learning systems. Hence, inductive learning systems will only work for domains where a large body of experience exists, and will not learn any principles not embodied in the experiences presented to them.

4. Summary

The purpose of this paper was three-fold: 1) to briefly review rule-based knowledge-based system techniques; and 2) to briefly describe some of the newer techniques being used to develop current knowledge-based systems. Due to space limitations, several other interesting subjects, such as machine learning and neural networks, were left out of this review. Many of the systems currently being developed are still using technology that is 20 years old. However, many others are being developed that incorporate various forms of machine learning, use more descriptive, flexible models of the domain, and make much greater use of past performance for improving their performance on new problems. While knowledge-based systems are still in their "formative years", the prospect of having a system that 1) acts as a knowledgeable colleague capable of providing advice when asked, 2) grows in capability as it experiences various problems and their solutions, and 3) serves to record in much more detail the evolution of problem solutions, is still very exciting and deserving of more research attention.

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Development of Expert Systems In Structural Engineering

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1.0 Introduction

Computers are increasingly being used in all facets of architecture, engineering, and construction (AEC) industry. Early application centred around the tasks of structural analysis, -later high speed batch mode computations, man-machine interaction with Graphic user Interfaces and logic programming with fifth generation languages took over the scene.

The availability of new computer technology is responsible for initiating significant changes in the AEC industry. For example, the development of Artificial Intelligence (AI) techniques during the 1970's have provided a new set of tools for supporting the analysis and design of structures. AI techniques are being used to develop expert systems which differ from conventional programs in their ability to process non-numerical data and express procedures in more understandable 'English' like rules. This potential of expert systems was initially used to develop an expert system MYCIN (Buchanan and Shortliffe, 1983) for medical diagnosis.The diagnosis and interpretation problems in structural engineering open up possibilities that were not conceivable with conventional programs. The potential impact of expert systems is in providing advice in the areas of design process where conventional computer aids fail.

Engineering process is basically a decision making process. The engineer must be creative, imaginative, using his judgement, intuition and experience. Knowledge-Based Expert System (KBES) are "interactive computer programs incorporating judgement, experience, rules of thumb, intuition and other expertise to provide knowledgable advise about variety of Tasks".

The reasons for using expert systems in structural engineering are the same as for using any type of automation: using less skilled personnel, quicker and more reliable solutions.

Knowledge Based Expert System being developed in the field of structural engineering may be broadly categorised as systems dealing with :

- Design of structures dealing with either one or more of the following tasks :

  a) layout or configuration design
  b) structural design conforming to particular standards or practices
  c) design detailing

- Assessment of strengh of structures and recommendations on strengthening/repair
- Modelling of structures for analysis (say, analysis by using the finite element method)
- Construction Management

The salient features of the above mentioned types of KBESs have been brought out in the lecture notes through a brief description of a few typical systems developed. Development of expert systems for engineering applications can be facilitated by efficient data base management techniques and other software tools. It may be noted here that engineering data bases consist of both graphical and textual data which are interrelated.

In order to improve the productivity of the construction industry as a whole it is necessary to have an integrated approach in the development of computer software spanning the area of Architecture, Engineering, and Construction. Efforts are being made to develop knowledge based systems for structural engineering to meet this need.

To start with the basic architecture and components of a typical expert system are presented.

2.0 Main Components Of A Typical KBES

A schematic of the basic architecture of a typical KBES is given in Fig. 1. (Aravind et. al 1988)

The main components of a typical KBES consist of the following :

- Knowledge base
- Context
- Inference Mechanism
- User Interface Module
- Explanation facility
- Knowledge Acquisition Module

3. Steps In Expert System Development

The six main stages of building of an expert system may be stated as follows:

- Initial Problem Assessment
- Establishing a structure
- Prototype Building
- Evaluation, model refinement
- Tests with end users
- System adjustments and end release

3.1 Tools For KBES Development

A broad classification of the tools that may be used in the development of an expert system is given below (which includes examples).

Logic Programming (PROLOG),
Production system Programming (OPS5, EMYCIN),
Object Oriented Programming (Smalltalk, Flavors, C++),
Hybrid language programming (ART, KEE, LOOPS), and
Shells (VP Expert, Insight II, M.1, Deciding Factors).

In addition, for an engineering design database, the system must be able not only to manage effectively the design data, but also model the objects composing the design. Therefore tools are required for management of complex engineering objects in a sharable, relational framework.

4. EXPERT SYSTEMS IN STRUCTURAL ENGINEERING

4.1 Structural Design

The structural design process starts with the definition of need to transmit loads in space to support or foundation subject to cost, geometry and other criteria. The final product of design is a detailed specification of structural configuration capable of transmitting these loads at appropriate levels of safety and serviceability. The design process (Fenves 1981) may be viewed as a sequence of three distinct steps namely preliminary design, analysis, and detailed design. Both preliminary design and detailed design belong to class of ill-structured problems as they require engineering heuristics and different problem solving strategies at different levels of design, hence they are more amenable to the use of expert system. Two early developments in this area are briefly discussed below.

4.1.1 *HI-RISE* (Maher Fenves 1986) is an expert system for preliminary design of high rise residential and commercial buildings which are rectangular in shape.

HI-RISE configures and evaluates several alternative structural systems for a given three-dimensional grid. The expertise in HI-RISE is derived primarily from a book on preliminary structural design (Maher and Zhao 1986) containing approximate analysis techniques and applicable design heuristics. The knowledge incorporated in HI-RISE is appropriate for buildings between 5 and 50 storeys (Garret and Fenves 1987)

4.1.2 *SPEX* (Standards Processing Expert) (Garret and Fenves 1987) is an ES for component design. SPEX can only design components that are highly constrained either by the requirement of design standards or externally specified constraints. It can design nonprismatic structural components and connections.

4.2 Expert systems for diagnosis

An expert system IRAS (Insurance/Investment Risk Analysis System) has been developed at Stanford University, USA., to assess seismic risk of buildings and structures. Evaluation of the hazard (earthquake) potential, vulnerability of the exposures (buildings and structures) to the hazard and evaluation of the risk of exposures based on their responses to the hazard, constitute the three basic phases of this system.

4.3 Expert systems for analysis

Analysis is a process of determining response of a fully specified structure to its environment. The most highly developed method of the analysis is the finite element method (FEM). There is a need for modelling an increasingly wider range of physical performance phenomena in all stages of system design. The primary functions of the analyst is to model the problem. KBES shows the promise of providing a methodology for such FEM modelling. The expert system for FEM modelling can be viewed as an intelligent pre- processor, in the sense that it acts as a knowledge-based front to the algorithmic programs. An early precursor of analyst expert system is SACON (Bennett and Englemore, 1979).

4.4 Expert systems in construction management

Construction management addresses planning, scheduling, and control of construction activities as well as deciding on legal, behavioral, and other nonphysical elements of the construction process. An application in this area is described below.

4.4.1 *TIME* (Gray and Little 1986) Predicting Time and Cost of Construction During Initial Design. The construction industry is somewhat unique in that the process of design and manufacturing are separated. Generally speaking, the ease of manufacture and assembly of a building is not considered in the design process, because the designer may not have the knowledge needed for consideration. In addition, evaluation of different methods of design requires prompt feedback regarding their time and cost implications. This expert system was developed to help designers evaluate different construction methods, designs, and processes to determine their effects on time and cost of construction.

5. Expert Systems development at SERC

Structural Engineering Research Centre (SERC), Madras has been involved in the development of software for analysis and design of structures. Realising the need for knowledge-based tools in structural engineering, SERC has initiated projects in this direction. The following knowledge-based systems have been developed :

a) EXTASY (EXpert Tower Analysis and design SYstem)
b) KASTLE (Knowledge-based Analysis and Synthesis of Transmission Line towErs)

An expert system on design of cooling towers is being completed. A brief description of these systems is given in the following.

5.1 *EXTASY* (Murlidharan, et.al. 1991a,b) is a system built using some of the knowledge-based programming concepts. To capture heuristics of design experts, KBES methodology was found appropriate. EXTASY's domain of expertise is configuring and design of free-standing steel lattice microwave towers based on the Indian Standard Codes of Practice (IS:800-1984, IS:802-1974). The scope of EXTASY is limited to design of microwave towers. EXTASY has several Knowledge Modules (KMs) which communicate through a Blackboard (Nii, 1986) and are controlled by an Inference Mechanism. The Blackboard of EXTASY is divided into three segments, namely the Coordination segment, the Working segment and the Decision segment. The knowledge base is divided into several levels and these levels provide a methodology for organizing the problem solving activities. These levels are comprised of knowledge modules which perform various tasks in providing a solution to the problem. In EXTASY, knowledge modules are classified as i) Configuration Processor; ii) Analyser; iii) Designer; and iv) Critic. Given a particular design problem EXTASY will generate alternative feasible designs. Also the system will provide the following information about the designs which will be displayed to the designer: i) Profile of the tower indicating the number of changes in the slope of a tower; ii) number of different types of standard sections required; iii) number of joints; and iv) the types and sizes of the bolts adopted. The designer can then finalize his decision based on weight of steel involved, fabrication cost and ease of construction. KASTLE (Raman et. al. 1989) is a similar system where the domain is design of transmission line towers. Both the systems are implemented on IBM PC-AT with MS-DOS. The languages used are PROLOG, FORTRAN and BASIC.

5.2 Cooling Towers

The development of an Expert System for the Design of Natural Draught Hyperboloid Cooling Towers has also been initiated (Pandian and Appa Rao, 1991). The KBES makes use of the results of statistical analysis of the data relating to the geometrical details of different existing cooling towers. Adequate knowledge is also incorporated for thermal design of the tower. Computer programs for analysis and design of cooling tower shell and its foundation, support the KBES to arrive at the preliminary design of the cooling tower. The codal provisions related to the structural design such as wind load distribution on the tower, minimum thickness and reinforcement details have been incorporated in the knowledge base. Graphic routines have also been integrated with the KBES to visualize the geometry of the tower, the plots of stress resultants and reinforcement details. The KBES will give the quantity of concrete and steel for the finalized design. The KBES is built around the VP-Expert shell.

6.0 Scope for Future Work

There is considerable scope for developing special purpose software tools such as shells to facilitate development of expert system for structural engineering applications. It is essential to develop efficient DBMS techniques to deal with graphical and textual information. There is considerable scope for research to formalize knowledge sharing between architecture, engineering, and construction activities.

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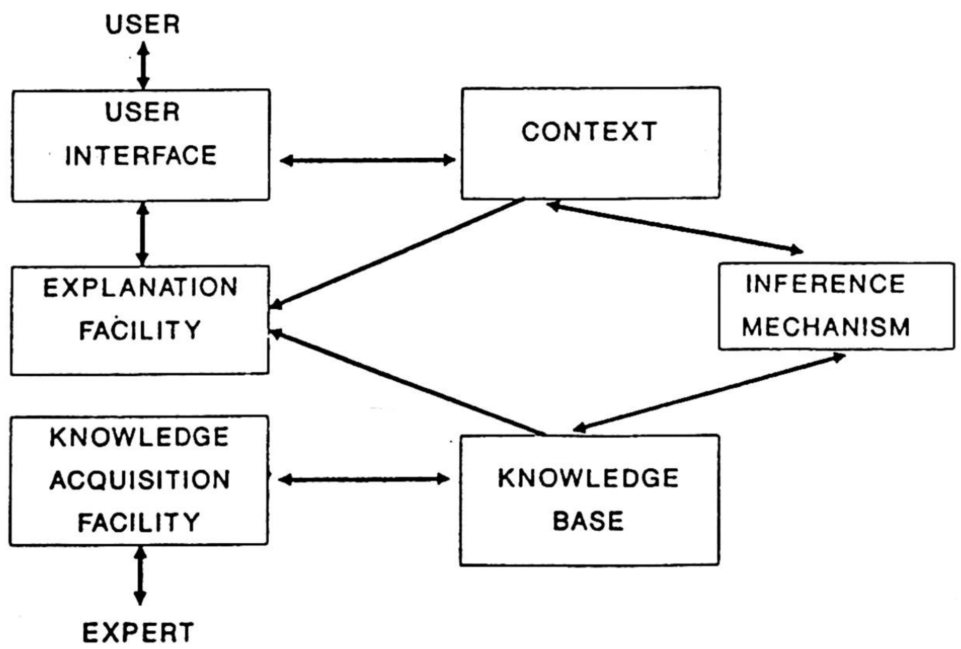

Fig. 1 ARCHITECTURE AND COMPONENTS OF A KNOWLEDGE-BASED EXPERT SYSTEM

Closing Ceremony of the 14th IABSE Congress

Cérémonie de clôture du 14e Congrés de l'AIPC

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Final Comments

Commentaires finals

Schlussbetrachtungen

T. N. SUBBA RAO
Chairman, Scientific Committee
New Delhi.

Mr. President, Delegates to the Congress, Ladies and Gentlemen.

We have now come to the end of the 14th Congress of the IABSE. It is now my pleasant task to offer some brief comments on this Congress.

When the title for the Congress was proposed, it was the intention that the Congress should highlight the role played by the civil engineering discipline in promoting the welfare and progress of human kind. I have pleasure in acknowledging before you, that this laudable objective has been, by and large, fulfilled.

The format of the scientific content of the Congress, laid an emphasis on:

Emerging structural horizons,
Structures and environment,
Natural disaster reduction,
Bridge design, construction and management,
Renewable energy concepts,
Project financing,
and Continuing Education

as prime issues. Around this broad spectrum, several sessions were articulated, which were termed Plenary Sessions, Special Sessions, Seminars, Teach-ins and Design Workshop. All these Sessions have been widely attended. The perception and understanding of global developments in structures through a two-way interaction, has been truly realised. I hope the Scientific Committee will endorse these views when it meets in September '92 and IABSE will use the output of this Congress in disseminating information to all those who did not have the benefit of attending this Congress.

For several reasons, the delegate participation has not been as large as originally envisaged but it is to be acknowledged, that it was nevertheless substantial with over 600 members attending. What matters is the sustained interest in the subjects chosen for the delegates; in this respect there is no second opinion. The Indian participants in particular, were keen to learn and be informed of progress elsewhere and they constituted nearly 60% of the total strength.

The Sessions were essentially field oriented and the information fall out is certainly of great value to the profession.

A total of 110 Papers have been presented, divided into invited Lectures from Specialists who gave the state-of-the-art reports, selected paper contributions and Poster Sessions. This Congress has been a unique opportunity for us in India to fuse our thoughts and ideas with those worthy delegates from abroad, and thereby hope to provide in the coming years, a much better service to society.

The Scientific Committee for the Congress, had as members, persons whose experience in their respective fields is widely acknowledged. Several of the members were chosen to organise the Sessions, after the topics had been identified by the Scientific Committee. They in turn assessed the papers received, and took pains to identify and invite specialists from various countries to speak on current topics. In this manner, each one of the Sessions projected distilled information and current status, worthy of the Congress.

I would like to record in brief the coverage of the Sessions:

Emerging Structural Horizons: The most important problem of this planet Earth is one which concerns the rapid growth of the developing nations and those related to the affluence of the developed nations. The moral is that the developing nations should not follow the environmental track record and societal structures of the developed but take a course-correction now itself. Yet, with all this philosophy repeated in many fora, the path followed by the developing countries, under political, social and economical compulsions is the same as that of developed countries, disregarding potential adverse effects in future not only to its citizens but also to everyone globely. There is, therefore, an imperative need for the affluent nations to provide the necessary financial input and statistical evidence to enable the poor countries to pursue policies which do not hurt those beyond their frontiers.

The concentration and migration of population to urban areas, the demand for safe and adequate energy, water, sewage, transport and other infrastructure far beyond what can be practically provided and managed, has given rise to social tensions and psychological frustrations everywhere. New and improved economical solutions need to be evolved by society to meet the growing demands. Human ingenuity and skills appear to be the answer to meet this challenge.

In a rapidly deteriorating environment, the preservation and rehabilitation of existing assets, especially those with a historical and aesthetic record is an obligation today's society owes to future generations. This protection of our heritage calls for new solutions and techniques backed by research and analysis. The Engineers role in this respect is universal and must be proactively responsive to the preservation of civilization.

New forms of power generation, the reduced dependence on fossil fuels, the accelerated exploitation of renewable energy sources (though currently expensive), improvement in the safety levels of nuclear, transport, public health, civil works, etc., are all related synergical systems, wherein the civil engineer's presence and participation for improvement in the quality of life is pivotal. They have much work ahead of them, must develop imaginative solutions, and be more modest in evaluating the consequences of their contribution to the well being of man.

The Sessions covering the above thoughts, related themselves to the many sided structural facets of the problem, often citing case studies of real situations to drive home the point.

The very first Session (P1) dealt with some of the issues I have referred to as a part of this wide ranging philosophy. Specific areas of interest to the structural engineer in this emerging scenario were confined to High rise, Off-shore & Tensioned Structures.

The Seminar (S1) on practical applications of creative design was complimentary to the first session. The specific areas discussed were new materials including Aprapree fibres for prestressing, high strength and high performance concrete, use of thick rolled-steel members, application of robots in construction, architectural realisations, safety levels in nuclear secondary containers and others. Much information and discussion was generated during the Seminar.

The Session (R4) on **Highrise Buildings** highlighted the latest construction techniques in vogue in the USA, Japan and India, the use of computers for analysis, maintenance and comfort management, new advanced structural system concepts, urban massing considerations and other informative data.

The Session (R2) on **Offshore Structures** illustrated brilliantly the application of civil engineering on offshore projects covering floating islands for leisure parks, communication through submerged tunnels, wave energy generation, gravity anchors for floating vessels, offshore oil platforms (fixed and semi-submersible type) and the Japanese experience with flexible breakwaters. The increasing use of the oceans for cooling purposes, the incorporation of presentday information technology for quality assurance and life cycle prediction were the other aspects covered. It became evident that oceans are an inspiring environment for the civil engineer. One speaker concluded: "Let your thoughts be as deep as the ocean and as light as foam".

The Session (R1) on **Tensioned Structures,** provided many examples of roof and open area coverage by these light, retractable and quick erection structural forms and their analysis. The availability of durable flexible roof coverings and their easy erection techniques have made them popular. The Japanese, German and English experience were notable. The applications included sport arenas, swimming pools, supermarkets, atrium coverings, concert pavilions and others, each incorporating its own distinct method of erection. Their use in future appears guaranteed for semi-permanent needs, as they are competitive in cost and facilitate quick erection and removal.

Structure and Environment: A major input of the Congress from Seminar (S7) has been an effort to identify environment as an undeniable parameter in the concept and realisation of several types of projects, since several constructions have a far reaching influence on nature and thus on Man's life. The need to provide education in this discipline to the engineer within the bounds of reasonable economic parameters, as also to realise a new role for him as an important constitutent in the global effort to reach a **sustainable environmental balance,** is an important outcome.

The Session (P3) dealt with the problems and solutions when structures have to be built to meet national demands like tunnels, dams, harbours, bridges, nuclear power stations, urban transport structures and the like. The cry for **'Structural art'** in the search for economy and elegance, the need to redefine perspectives as embodied in codes, regulations, education and practice, a preaudit and surveilance environment programme for any project, maintaining bio-eco system equilibrium in harbours, criteria for safety factors in nuclear containers and transmission systems and finally the integration or urban bridges into the cityscope as a thing of beauty and art with a built-in environmental consistency, are some of the important issues discussed at the seminar. What is most satisfying is the awareness and conviction engineers are showing by way of pooling their efforts with other specialists, so that today we all act as trustees for tomorrow's society.

Natural Disaster Reduction: The current decade has been dedicated by the United Nations as the period for focussing world attention in preventing and mitigating disasters caused by natural forces, so that humanity can feel safe from the recurring calamities being faced. In harmony with this laudable mission, the Sessions (P2 + S3) covering this subject, have evoked much interest and discussion. The impact of storms, cyclones, tidal waves, earthquakes, wind and others have been discussed at length, and economic and novel solutions for damping through passive and active controls and/or for developing substantial safety against damage, were projected.

The need for good quality control during construction, conscious detailing and connections and a measure of ductility were emphasized. The fact that the science of natural disaster prognosis, mitigation and control, extended beyond the realm of civil and design engineers to scientists, meteorologists, seismologists and others involved in information technology was effectively focussed, in order that a co-ordinated endeavour could result for the protection of 'wealth' on our plantet.

Renewable Energy: India is a country with much sunlight and fairly good winds. The importance of utilising these natural phenomena, as an alternative source of energy, was seriously discussed in Session (R3) and the possible solutions of various types and their limitations were dealt with. These types of energy, if properly harnessed though plants of small magnitude, could, when widely used, result in cumulatively large power generation and help reduce the demand on non-renewable source of energy and rapid depletion of global inventory.

The engineering discipline is now aware of the fact that several other types of energy such as the OTEC approach are actively under research and that it is not long before renewable energy systems will become a major source of power supply everywhere.

The speakers brought out that photovoltaic systems and solar chimneys are the answer for medium and large solar energy conversions and that this form of energy, widely available, is the answer to large scale local and isolated power generation. The statistical assessment that power consumption, living standard and population control are related parameters was highlighted as general information input into the discussions.

Bridge Design, Construction & Management, Urban Transport Structures: The Seminar (S2+S5+S6) dealt with large span cable-stayed bridges and their aesthetics, construction techniques used in India for floating complete spans into position, solutions for foundations in water, special urban transportation systems, rehabilitation and finally inservice management of structures from a optimised and economical standpoint. The participants felt that condition assessment, data collection and research on bridge rehabilitation should be elevated to an international level. The concept that assets should be protected consciously over their service life and how, was the topic of discussion covering different problem areas.

A special feature of the presentations on bridges was aesthetics as related to cablestay bridges, a reflection on how complicated and highly sensitive quality controlled fabrication coupled with simple erection techniques, is realised in India. Thermogradients in segmental box type decks and other case studies were presented.

An insight into duo-mode o-bahn system adopted in Essen, monorail systems in steel and concrete, multi-voided boxes and box girder units for dual rail tracks and road networks, have been the main contributions. They reflect innovation, architechnical sufficiency and different solutions conditioned by economy, each tailor made to suit specific locations and functional demands.

Project Financing: Several projects around the world are now given industry status, inasmuch as they are conceived, planned and executed by promoters through self-financing schemes and the cost thereof recovered through tolls, advertisements and other types of mechanisms. Many innovative methods have gained currency and major projects like the Euro-Tunnel Project, the Great Belt Crossing in Denmark, the North-South Highway in Malaysia have all been privatised. Methods and practices followed in developing such self-financing schemes to ensure their viability have been the subject matter of intense discussion. A panel discussion held also gave the participants some idea of the state-of-the-art status to guarantee lender's recovery of investment and ensure success of such ventures.

The legal aspects involved in meshing complicated financial networks, the responsibility of the sponsoror vis-a-vis the promoter and eventual owner and vice-versa, and many other intricate facets of this fast growing financing mechanism were debated at length. The question of government guarantees to lenders, concessions to the sponsoring agencies and their legal character, were among several other important criteria in project funding, it was stated. This subject is very relevant to India; at present statutory laws are being enacted to encourage this funding process.

Continuing Education: This has been one of the main aims and objectives of IABSE. The Session (S4), including the panel discussion held, generally debated the many avenues available to keep the knowledge of engineers up-to-date and help disseminate such information through distant education processes, inhouse training, workshops, well defined short term courses and other modes. The practice in Poland to stimulate this recurring educational process was most impressive and could well serve as a model.

A few of the various views expressed during the panel discussions were:

- IABSE Centres everywhere should be a repository of data on various subjects, stock audio visuals, provide library facility etc.

- Short courses, workshops and Teach-ins, conducted in less developed countries with the help of international experts would help in knowledge sharing on topics most vital to the profession and industry locally.

- Recognition with a qualification title would act as a catalyst in attracting talent and interest, as is evident from distant learning courses in the U.K. and such courses need to be prepared indepth beforehand by experts.

- Inhouse training programmes by industry would meet specific demands and they need to be pursued on a continued basis.

The Teach-in Session (T1+T2+T3), which are a part of this ongoing objective, were widely attended, and endorsed the view of the Sub-Committee to include Teach-ins in the Technical Programme. They covered a updated insight of stress flow and related visualisation of Truss systems as simplified analytical tools, a design and construction basis to assure longterm durability, and the emerging development of expert systems. associated with rapidly expanding computer facility. In brief, these Sessions served their intended purpose admirably.

Design Workshop: Keen interest was evinced in the Design Workshop, with quite a few participants taking up the challenge. I am sure this provocation to creative thinking will, in the years to come, help attract the interest of young engineers. In order to ensure that the competition is among equals, it would perhaps be appropriate to let this Design Workshop be thrown open for two or more age groups and judged accordingly.

The exhibition projected mainly some of the equipment and products used at work sites and manufactured in India. The Poster Session was well laid out and provided an excellent forum for interaction with the authors of some selected projects. Both were sufficiently visited by the delegates.

It should not be concluded that a Congress will instantly promote a quantum jump in engineering applications around the world. It is perhaps the best forum for witnessing the profound developments that have taken place or envisaged in different countries, with a view to build more efficient, durable and liveable structures. I am sure the subjects dealt with in the Congress will be discussed in greater detail in appropriate fora by the member countries and thereby enhance the knowledge and information on the subjects.

I would not like to continue more with regard to the scientific content of the Congress. I fervently hope the delegates from abroad have found their coming to New Delhi of great value. They sure have gained not only technically but socially. Many social events that were organized for the delegates and their accompanying persons seem to have been well received. On behalf of the Indian National Group of IABSE, I would like to thank the President and the Executive Committee of the IABSE for having accepted to hold the Congress in India and give us this privileged occassion to host you all in the customary Indian manner. I trust you are satisfied with our earnest efforts to make your visit as comfortable as possible. I would imagine many of you would take advantage of the post-Congress tours and return home with a good impression of what India can offer.

I take this opportunity to gratefully thank the organizers of the various Sessions for giving so much of their valuable time in preparing the Sessions and conducting them during the Congress. I wish to also express my heartfelt thanks to Mr. Alain Golay, Mr. Ninan Koshi, Mr. S.P. Chakrabarti and their backup teams, who have given much thought and effort for the success of this Congress. There are several others, who have contributed silently and I am obliged to them all for their assistance. It is indeed difficult for me to express how I feel towards you delegates at this moment. There are perhaps moments in life when silence conveys deep gratitude more eloquently than words.

I wish you all happy days in India and good tidings when you return home. Thank you all again for attending this fourteenth Congress.

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Closing Speech

Discours final

Schlussansprache

NINAN KOSHI
Chairman, Organising Committee
New Delhi

The President of the IABSE, Prof. Von Gunten,
Chairman of the Scientific Committee, Dr. T.N. Subba Rao,
Chairman of the Technical Committee, Mr. J. Brozzetti,
Secretary of the Organising Committee, Mr. S.P. Chakrabarti, and fellow delegates,

On last Sunday evening I welcomed you all to this Congress at the Inauguration Ceremony. Today, four days later, I stand before you to say a few words as we come to the closing moments of this 14th Congress of the IABSE. A host of activities had been compressed into these four days. Many subjects have been discussed, many lactures delivered, many new ideas exposed, much knowledge exchanged, many associations renewed and many friendships found. On looking back at these four days of intense activity, I feel a sense of satisfaction that we have, in large measure, achieved the goals which we had set ourselves. I have had an opportunity to talk to fair cross section of the delegate and it is very heartening for us to learn from them that the Congress has progressed smoothly, the things have generally been under control and that there have been very few causes of complaint. If at all there have been some shortcomings, I am sure you will be generous enough to forget them and remember only the warmth of welcome and the sincerity of our purpose. I take this occasion also to express my appreciation and thanks to the large number of people who have worked untiringly behind the scenes to make the organisation of this Congress a success. Their numbers are too large to be mentioned individually but I would like to mention the names of Mr. S.P. Chakrabarti, Secretary of the Organising Committee and Mr. Krishan Kant, Deputy Secretary of the Indian National Group for their commendable efforts. I would also like to thank the state Governments, various Institutions and Organisations and our friends from the profession all over the country who have contributed generously both financially and otherwise towards the organisation of this Congress. I close by wishing you all a safe journey back to your homes and with the fond hope that the happy memories of this Congress will remain with you for long time to come.

Thank you.

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Invitation to the 15th Congress of IABSE

Extract from the Invitation Adress by the chairman of the Danish National Group of IABSE, Professor Niels J Gimsing at the closing session of the IABSE Congress in New Delhi:

The very successful 14th Congress of the IABSE has come to an end, so it is time to look ahead to 1996 when the next of the large IABSE Congresses will be held.

On behalf of the Danish National Group of IABSE it is a privilege and a great honour for me to invite you all to come to Denmark in 1996 for the 15th Congress of our association.

For the 1996 Congress it is proposed to use the motto:

ENGINEERING - ENVIRONMENT - ENERGY - ECONOMY

to emphasize these important aspects that should be integrated in the the work of structural engineers as we move into the 21st Century. It is, however,, not the intention to deal with these aspects in a general, talkative way but - where appropriate - to let them form an integral part of the specific sessions on structural engineering and science.

The congress will in 1996 be held in June close to midsummer so you will experience long days and short nights. Thus, at that time of the year there will be almost 18 hours from sunrise to sunset in Denmark. So you can enjoy plenty of daylight even if you are attending all of the technical and scientific sessions of the congress.

To give you an idea of the country you are going to visit in 1996 it could initially be mentioned that Denmark is the oldest Kingdom of the world as there has been a continuous row of sovereign kings - and a few ruling queens - for more than one thousand years, not even interrupted by the Thirty Years War, the Napoleon Wars or the two World Wars.

To-day the history of the kingdom is reflected in the large number of castles spread out throughout the country, but concentrated in North Zealand within reach on a one day tour from the capital, Copenhagen.

In Copenhagen the tourist will, however, also find more modest sights than large castles - such as the famous Little Mermaid at the waterfront.

As most other European capitals Copenhagen has an old city center, and here *the pedestrians have the priority as motor cars are either completely abandoned or subject to strong restrictions.*

In 1996, Copenhagen will - besides hosting the IABSE Congress - also be the Cultural Capital of Europe so there will be many opportunities to combine the technical activities inside the conference halls with cultural experiences outside. However, the coincidence between hosting the IABSE Congress and being the Cultural Capital also gives the opportunity to emphasize that the large buildings and structures of our time form a very important part of the culture in the 20th Century.

As in many other countries this fact is illustrated in Denmark by many modern buildings and structures that are designed not only to be functionally efficient but also to be acceptable in the visual environment, as it can, e.g., be illustrated by some of the recent power plants in the vicinity of Copenhagen.

When you come to Denmark you should of course also try to get outside the Copenhagen area to see the countryside with small villages, old churches, farms, fields and forests.

If travelling around you will soon realize that Denmark is a country surrounded by the sea, as you cannot find a spot in Denmark with over 50 km to the sea. Also, despite the fact that the longest distance from one point in the country to another hardly exceeds 400 km, the total coastline is close to 7000 km long.

Being composed of a peninsula and numerous islands separated by water, the Danes have from ancient times been forced to rely on transportation by sea to get from one part of the country to another. Famous were the vikings (that did not really confine themselves to the internal waters) but the seafaring traditions have been kept alive to our times, and when you come in 1996 you will still be able to experience the ferries that have been an important part of the infra-structure for more than a century but are now rapidly being substituted by fixed links in the form of bridges and tunnels.

In Denmark bridges have been built for many centuries, first across narrow streams and small rivers and later across the straits separating the different islands. Initially, these strait crossings were built as pontoon bridges, but in the 1930.es a major bridge building programme was initiated to substitute a number of ferry routes by fixed road and railway links.

The first major bridge from this period was the Little Belt Bridge, opened in 1935, between the island of Funen and the peninsula Jutland. Two years later, the 3.2 km long Storstrøm Bridge, at that time the longest bridge in Europe, was completed to connect the main island of Zealand with the islands of Falster and Lolland to the south, and to improve the traffic route from Scandinavia to the

The prewar bridges were generally constructed with steel superstructures but after the war prestressed concrete became the preferred material for most of the strait crossing bridges. Only when large spans were required, steel superstructures were still used, such as in the Second Little Belt Bridge constructed as a suspension bridge with a 600 m main span or in the Farø Bridges with a 290 m cable-stayed span.

The final link in the Danish infrastructure, the Great Belt Link, will be nearing completion in 1996 when the IABSE Congress takes place in Denmark - so the construction site of this link will certainly be on the list of technical excursions.

The Great Belt Link will comprise

- *the second longest underwater railway tunnel in Europe, the 8 km long East Tunnel, that will be surpassed only by the Channel Tunnel.*
- *the longest combined road and railway bridge in Europe, the 6.6 km long West Bridge.*
- *the longest road bridge, the 6.8 km long East Bridge, with the longest free span of 1624 m in Europe.*

But the Great Belt Link is not going to be the only major bridge and tunnel project to be under construction in the area at that time. Thus, in 1996 Sweden and Denmark are about to establish a fixed link across the 18 km wide Øresund (The Sound) between Copenhagen and Malmö. This link will comprise both an immersed tunnel, a low level bridge and a high level bridge, all for both road and rail traffic.

So it is believed that it will be wortwhile for all members of IABSE to reserve June 1996 for a trip to the 15th Congress of IABSE in Copenhagen, and as chairman of the Organizing Committee I can assure you that we will do our utmost to make your attendance a memorable experience.

Niels J Gimsing

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