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THÈME 3

Design for Maintenance

Le projet de la maintenance

Massnahmen für die Unterhaltung

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Design for Maintenance

Projet de la maintenance

Entwurf der Instandhaltung

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SUMMARY

Road structures are not designed primarily to last for ever ; engineers are trained to adopt profitability criteria as applied in construction. This mentality must change and structures be designed as roads themselves, to function reliably for years to come. This will benefit all, even construction firms, if design is based on correct calculation of costs, understood as the global cost (i.e. construction + maintenance). Design must be reviewed accordingly ; one must choose structures and materials suited to last, and above all, use equipment and accessory works facilitating inspection, substitution of consumables and preventive maintenance. An example of this design-for-maintenance philosophy is the recently built motorway between Carnia and the Italo-Austrian border.

RÉSUMÉ

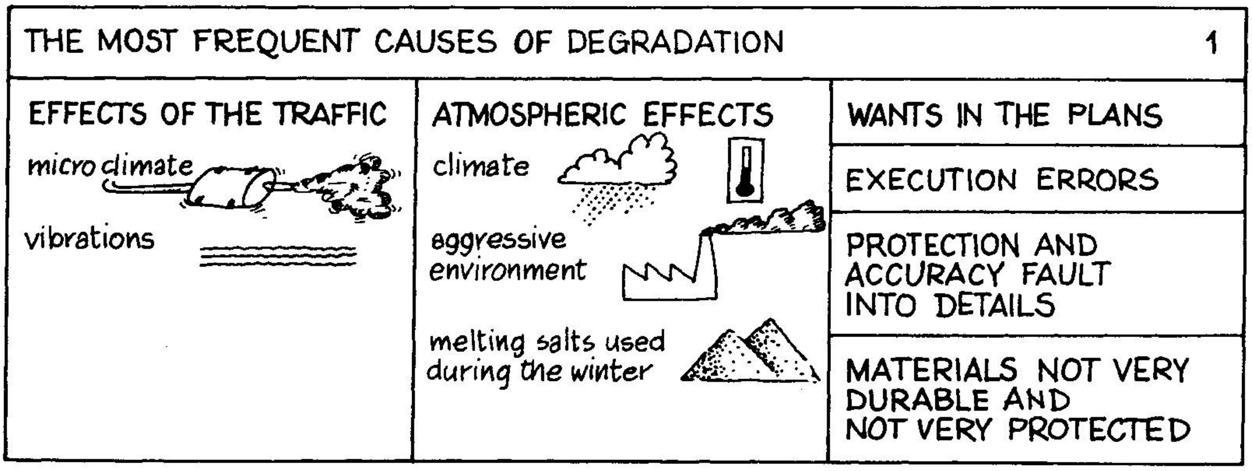
Les structures des routes ne sont pas conçues pour durer éternellement ; les ingénieurs sont éduqués à adopter des critères de profit dans la construction. Cette mentalité doit changer et les structures doivent être projetées comme les routes elles-mêmes, en vue d'une utilisation fiable au cours des années à venir. Cela sera au profit de tous, y compris des entreprises de construction, si le projet est basé sur un calcul correct des coûts, soit le coût global de la construction et de la maintenance. Le projet doit être reconsidéré en conséquence, en choisissant des structures et des matériaux résistants et en utilisant des équipements et des dispositions constructives facilitant l'inspection, le remplacement d'éléments et une maintenance préventive. Un exemple de cette philosophie de projet pour la maintenance est l'autoroute récemment construite entre Carnia et la frontière italo-autrichienne.

ZUSAMMENFASSUNG

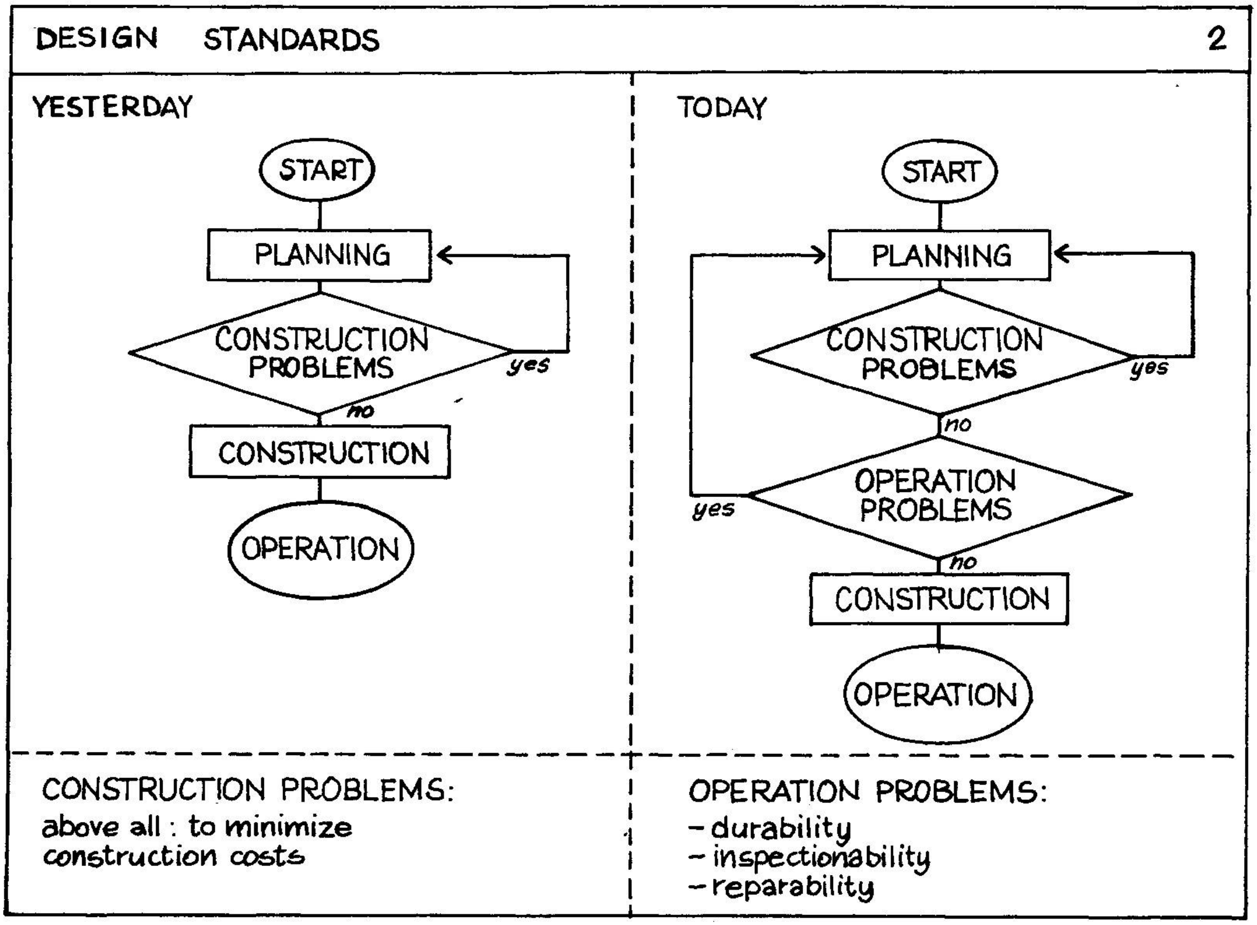
Die Ingenieurbauwerke von Strassen wurden nicht entworfen, um langfristig zu bestehen ; die Ingenieure wurden dazu erzogen, bei der Erstellung von Bauwerken Gewinne zu erzielen. Diese Grundhaltung muss sich ändern, und die Bauwerke müssen nach denselben Kriterien erstellt werden wie die Strassen, nämlich im Hinblick auf eine zuverlässige Nutzung für die Zukunft. Dies wird ein Gewinn für alle Beteiligten sein, auch für die Bauunternehmungen, wenn der Entwurf eines Bauwerks auf einer richtigen Abschätzung der Kosten, der gesamten Baukosten und der Kosten für die Instandhaltung, beruht. Der Entwurf muss entsprechend ausgearbeitet werden unter Berücksichtigung von widerstandsfähigen Tragwerken und Baumaterialien sowie unter Anwendung von Ausrüstungen und konstruktiven Details, welche die Ueberwachung, den Ersatz von Teilen und eine vorbeugende Unterhaltung erleichtern. Als Beispiel dieser Philosophie wird die vor kurzem erstellte Autostrasse zwischen Carina und der italienisch-österreichischen Grenze aufgezeigt.

1. THE MEANING OF A FORMULA

Design-to-maintain is the subject of this note, and the widest interpretation of this summary formula is: design taking into account the durability of the structure as a whole and in its constitutive elements, providing systems to facilitate those repair and maintenance operations which will in any case be necessary.
I would like to dwell for a moment on this last point. It is still all too widely held that road works are intrinsically durable, and when such is not the case, one automatically thinks that they were poorly executed knowingly (with malice). The reality is generally somewhat different; while it is certainly true that road works deteriorate in any case over time (see fig. 1, which summarizes the causes of this phenomenon), it is also true that very often the errors which undermine the durability and maintainability are bound up with the current way the designer thinks, or with his partial view of the problem.



This article and the meeting at which it is to be presented should contribute to changing this mentality, and actually in the course of the last few years there has been an effort to do so. This effort has been generated by the development of road terotechnology, the new science of maintenance which on the one hand defines the special techniques of surveillance and intervention on the different component parts of the road, and on the other provides a series of inputs for the design of new works in such fashion as to foresee and reduce to a minimum the causes of structural degradation, and incorporate devices apt to facilitate maintenance and management.
The designer, on the other hand, as we mentioned, normally has received an education which leads him to give greatest attention to the production stages of the works, i.e. its construction. In fact, in my country, but probably in many others as well, it is the final design which is paid for by the contracting firm, and thus the professional, who works for the firm, tends to optimize all the positive aspects for his direct employer, and hence adopts techniques and equipment which are most valid for his client, but not always up to date or linked to criteria ensuring the durability of the finished works.
Until recently even the shools encouraged "boldness" in solutions, insofar as new possibilities deriving from better understanding of the behaviour of structures and advanced calculation systems were utilized more to reduce the materials used (the famous dead weight, a term which is a program in itself), than to enable it to function with greater durability over time.
Also, the school often does not draw a clear correlation between the training of the structural engineer and that of the materials technologist, which is the basis of the new approach to road structure design.
The consequences of this situation are summarized in fig. 2, under the word "Yesterday". In support of the above, the following table sums up 30 years of



development in Italian motorway construction, divided in periods, types of structures and materials prevalently used.
This evolution has been described many times elsewhere.
Here I would simply recall that at the beginning of Italian motorway construction activity it was not known exactly what types of structures to choose, but decisions had to be made without delay. Each firm proposed what it had done or thought it could do, and each designer gave free rein to his imagination.
Prudence, boldness, banality, geniality: the signs can be seen in those first structures, especially along the customary route of reference, for the Italians, between Bologna and Florence.
Arches, multiple frames, supported beams, cantalevers, continuous beams,... every type is represented and executed with all available materials (except wood).
Those were truly pioneering days (summed up under "1st period" in fig. 3); the majority of the works were constructed with wooden forming constructed on site, but even then we see the first attémpts at industrialization. The centering of the arches, constructed of tubular steel sections for one carriageway, were extended to the second, thus saving a centering (Aglio viaduct, designed by Prof. Morandi); Eng. Zorzi designed and produced the first prestressed beams to be installed (with post-tensioned cables). The economic advantage was immediately evident; following the rule of reducing construction costs, the ten - fifteen years which followed represented the "golden age" of the supported beam: with only minor variations, examples of this type of structure were soon to be found all over Italy ("2nd period" in fig. 3).
But, these bridges were hardly ideal from the standpoint of durability; the many joints characterizing this type of structure are points of entry for degradation agents (in 79% of the cases), and thus the need soon became evident to build with greater attention to durability. Early efforts, maintaining the same

THE MOST USED STANDARDS AND MATERIALS IN THE ITALIAN MOTORWAYS			3
	MATERIALS	STANDARDS	
		isostatic structures	hyperstatic structures
1° PERIOD ('50-'60 YEARS)	REINFORCED CONCRETE PRESTRESSED R.C. STEEL-CONCRETE	RESTED BEAMS (BEARING ON OVERHANG) SPANS < 30 m.	ARCHES FRAMES
2° PERIOD ('60-'70 YEARS)	PRESTRESSED R.C. (ADHERENT WIRES AND POST-STRETCHED CABLES)	RESTED BEAMS SPANS 35÷45 m.	
3° PERIOD ('70-'80 YEARS)	PRESTRESSED R.C. (ADHERENT WIRES AND POST-STRETCHED CABLES)	RESTED BEAMS SPANS 35÷45 m. (ON THE DECREASE)	CONTINUOUS BEAMS CANTILEVERED STRUCT. (DYWIDAG TYPE)

structural types, concentrated on perfecting the joints; originally of rather spartan design, the joint was now divided into two specialized parts, one to provide the waterproof seal and the other to provide continuity to the road surface. Also bridge bearings underwent evolution, as increased efficiency and durability were achieved with the first types of neoprene bearings constructed on site. Starting with brushed-on neoprene vulcanized on site, followed by pot-bearings of encapsulated neoprene, and finally the spherical hinge structures with very low friction sliding surfaces of stainless steel/teflon, there has been an exceptional evolution in these devices, which did not even exist in the earlier bridges or at best amounted to crude metal pieces paid for by the kilogram.

Once the accsessories were perfected, development turned again to the "mature" structure of the motorway bridge: the continuous beam extending over several bays, with movements concentrated on one single point (two, in the case of antiseismic structures), box section, in prestressed reinforced concrete (or more recently in steel concrete, which better resolves the maintenance programming problem), in a structure designed to optimize the global cost (construction + maintenance) of these works which are so fundamental to the existence of the motorway. But typology is only the most apparent aspect of their evolution: protection of the slabs, waterproofing and special pavements, parapets able to contain out-of-control freight vehicles - represent the latest stages in this evolution, together with facilitated inspectability of every "delicate" part of the structure. The future will see the development of global and punctual methods, and ever more sophisticated non-destructive methods to determine scientifically the state of health of the work for maintenance purposes. And what is the guiding element in this evolution? It is simply the increasing determination on the part of the administration responsible for the works that these latter be made more durable, recognizing that the concept of <u>minimizing the global cost</u> (construction + operation) is more valid than that of simply reducing the construction costs.

To do this, however, one must have a strong administration, well prepared to carry out its functions; this means generalist engineers with good management capabilities, able to implement the flow chart shown in fig. 2 under the term "Today" (and I hope also "Tomorrow").

All the concepts set out thus far, even though stated in terms of bridges and viaducts, naturally apply also to all other types of works making up the road (tunnels, pavements, earthworks, etc.).

Let us now attempt to distinguish, again in summary fashion, but in somewhat more detailed manner, the different levels of intervention required in "designing" the maintenance of bridges and viaducts. We have already seen that it is necessary to make decisions regarding:

- <u>type of structure</u> (to resist, but also to last);

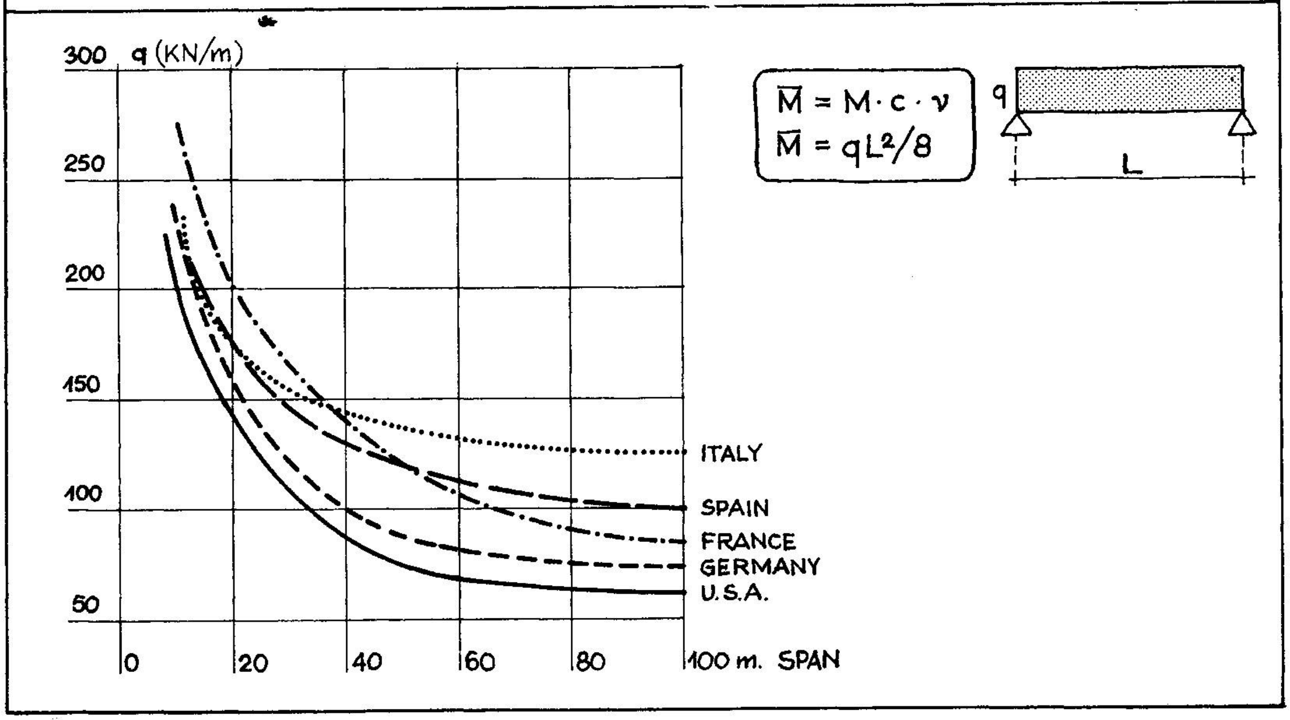
- <u>materials to be used</u> (to construct, but also to protect);
- <u>equipment and accessory works</u> (to function, but also to facilitate surveillance, substitution, etc.).

All of this is aimed at achieving the minimum global cost of the structure; this is a new element, the extra formula to apply when the solution to the problem has not yet been determined. In other words, it is sufficient to choose in such a way that whatever is being built or repaired have maximum operational durability. In fact, even maintenance can be <u>functional</u>, i.e. such as to endow the existing structure with characteristics which it did not have when originally constructed, but would have if it were being built today.
Here we can provide some practical criteria, broken down according to the above three items.

2. SUGGESTIONS REGARDING STRUCTURAL TYPES

The words "structural types" are here understood to mean the various constituent parts of the bridge, i.e. foundations, superstructure, the deck understood as cross-section, and as a complete structural complex. Given the vast range of the subject, it is impossible to give a complete illustation, and it will be necessary to limit ourselves to a few examples intended simply to illustrate the concepts set out in the first section.
To begin with, we must speak of design loads.

DESIGN LOADS (Comparison among different O.E.C.D. countries 4

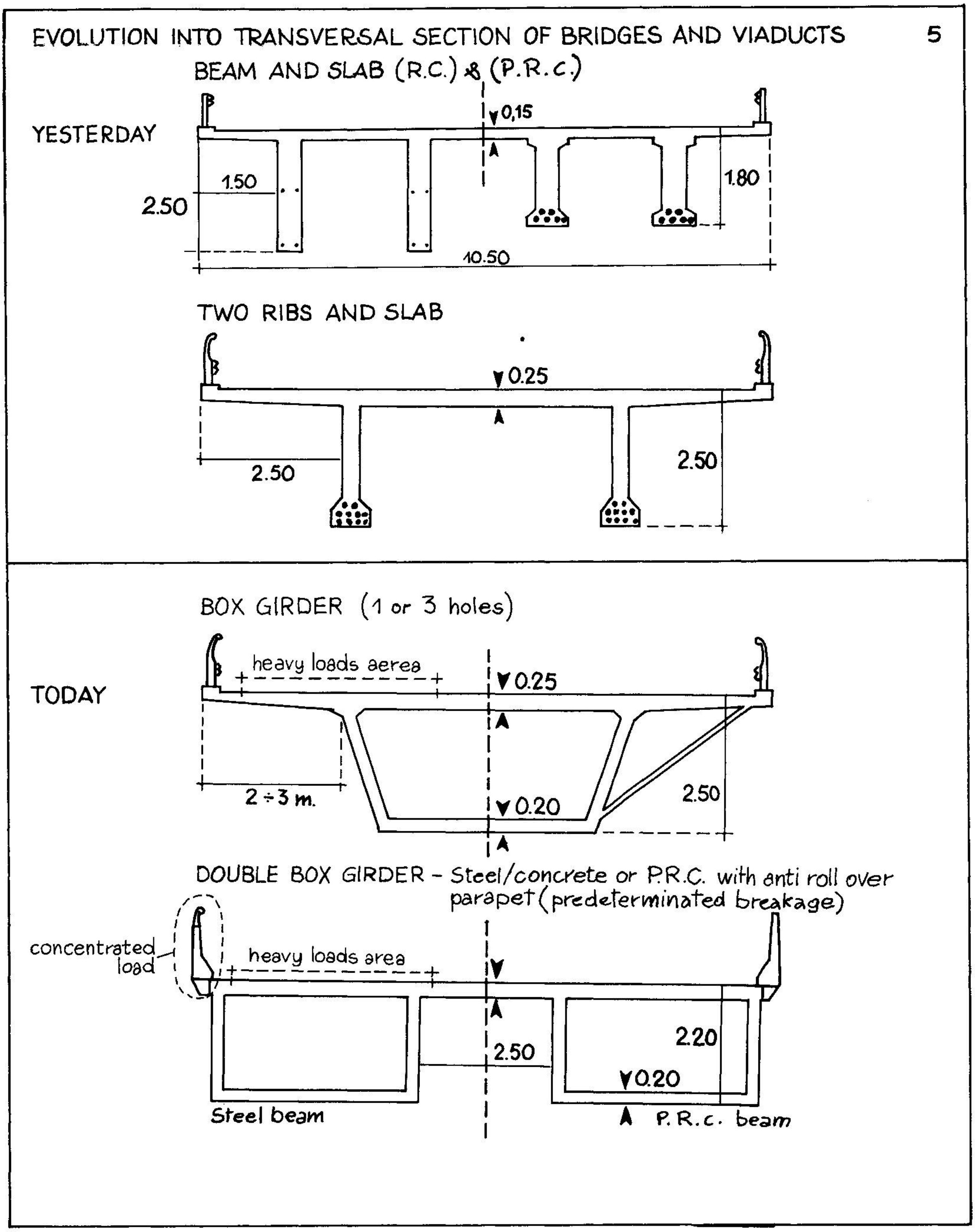


The criterion followed in comparing the various calculation criteria is as follows: start with a simply supported slab (span from 10 to 100 m, width of 7, 11, 15 m); the load is distributed transversally according to the various standards. A hypothetical moment M is calculated, which is derived from the bending moment M_f multiplied by 'C and for V M = M_fC V where C is the dynamic allowance and V is the ratio between the σ of the start of the permanent deformation and the σ allowable in the steel rods. M is then divided into a uniform load q (in KN/m) according to the expression $q = 8M/L^2$. The figure shows one of the diagrams obtained.

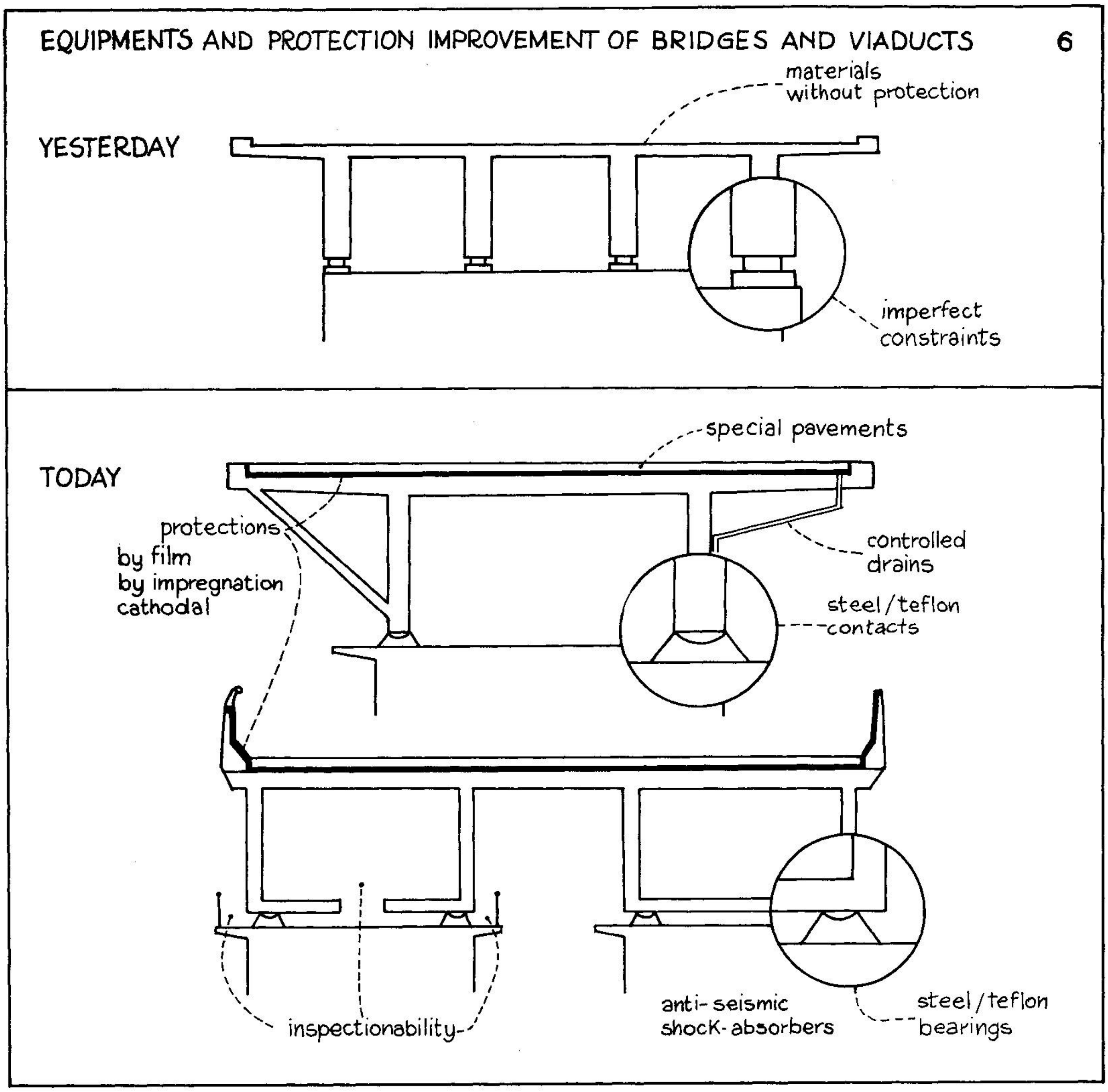
In this regard it is interesting to note that the greater or lesser probabilities of degradation of a structure are linked closely to the greater or lesser initial over-sizing. In fact, it we examine the magnitude of design loads, their transversal distribution, the varying degree of simultaneous presence on the structure and the different dynamic coefficients prescribed in the various countries, we can draw some interesting conclusions.
In a study conducted by the OECD on the bearing capacity of bridges, such a comparison was attempted, using a schematization of the design loads; the results are shown in the diagram in fig. 4.
One can see how the Italian standards (for bridges already constructed) are rather limiting, especially as far as regards structures with spans exceeding 30-35 m.
In countries such as the United States and Germany, on the other hand, the design loads are much more contained, and this leads inevitably to the construction of "lighter" structures. The reason may lie in the tendency in these countries to consider the period of service, i.e. the working life of the structure, as limited in time, in a pre-established manner.
Certainly this approach contrasts with the tendency to minimize the weight of the structures and to consider in their design only the true loads which will act upon them, but by using loads greater than those which would have acted on the structure, one thus corrects (and can still correct) many "errors" or unforeseen developments (increase in loads transported, in transport speed, etc.).
I will not dwell on the matter of foundations; it is sufficient here to recall that today it is possible to avoid costly repair interventions through judicious use of large diameter piles and well-type foundations, depending on the soil and the problem to be resolved. Accurate prior hydrogeological studies permit the design of suitable protection so as to prevent erosion when constructing works in river beds; also in this case it is strictly necessary that the work of the structural engineer be complemented by that of another expert, the hydrogeologist.
The most obvious typological development in the design of bridges for durability is in the bridge deck, the part in most direct contact with the live loads, which represent the essential reason for the structure. I have attempted to outline the evolution and thus the trends regarding future designs in the two figures 5 and 6 below, even though these deal more explicitly with the cross-section and equipment rather than strict typology.
Caisson structures are substituting those made up of series of flanking beams; this facilitates inspectability and improves performance under load. As mentioned, the use of these structures on continuous beams has led to development of the most durable and reliable typology thus far conceived. Also the type of traffic envisaged today has prompted the move to caissons which differ in shape from the traditional trapezoidal form with wide wings; the trend is to adopt the triple caisson center plus wings, as employed on the Carnia motorway, where the greater thermal insulation provided by this type of cross-section and the reduction of lateral action of the cold winds due to the presence of the continuous guardrails, renders winter freezing conditions more homogeneous on the pavement surface, and improves traffic safety.
In the new design of the Bologna-Florence motorway, we will employ a double caisson positioned under the zone travelled by freight vehicles, as well as anti-rollover guardrails designed to contain large trucks, being of such weight (from 875 kg/m up to 1100 kg/m in the two versions from 1.47 m to 1.70 m in height) as to be able to sustain the maximum impacts envisaged.

3. MATERIALS TO BE EMPLOYED

This is the sector which in my opinion has seen greatest development and presents the widest range of possibilities and implications with regard to designing for durability. It has been a quiet revolution, often overlooked by the



structural designer, even though the more advanced criteria for strucural reliability are always more closely linked to the <u>real strength characteristics</u> of the materials used in the works.
Here I cannot supply more than a simple and incomplete list; it is necessary to consider two major categories:



- materials which serve in the construction of the structures;
- materials which serve for the protection over time of the former.

The more advanced tendency among designers is to choose materials which combine the two characteristics mentioned above, but this is not always possible.

My opinion, in all cases, is that it is better to "overdo it" in the matter of protection.

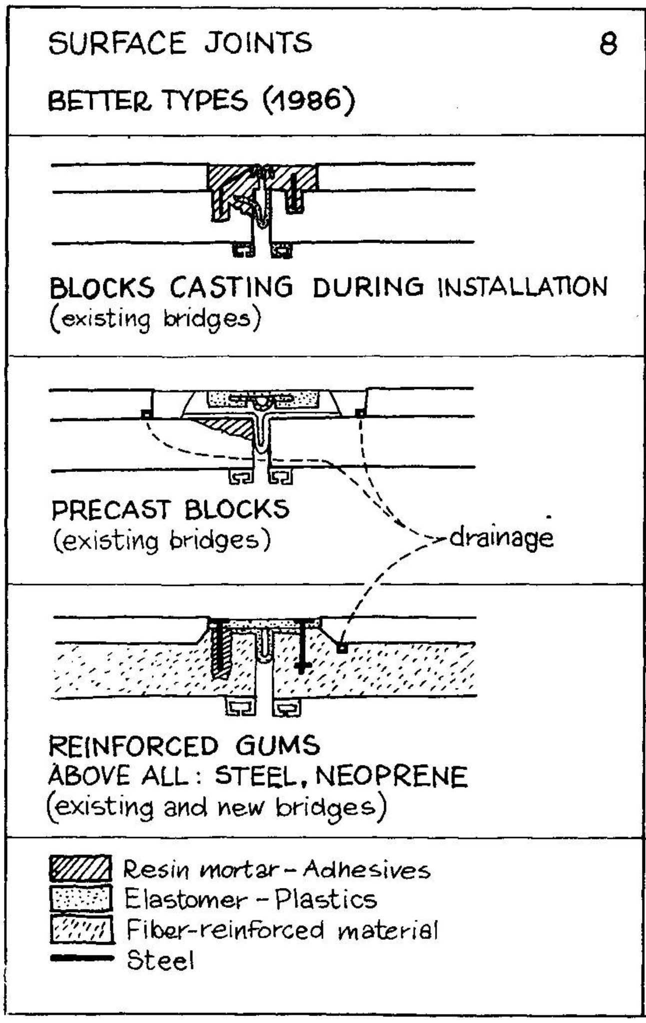
Of the various self-protecting and structural materials, I would first mention concrete with low water/cement ratio and high workability, in certain cases also non-shrinking (in Italy we call it "rheoplastic non-shrink cement"; our technical standards include concretes which must satisfy not just certain strength characteristics, but also durability prescriptions with indications of the types of cement and the water/cement ratio (w/e 0.42 and slump 18 cm). In parentheses I have indicated the values for class 1 - maximum durability. These can be obtained with superfluidizers and foamer additives.

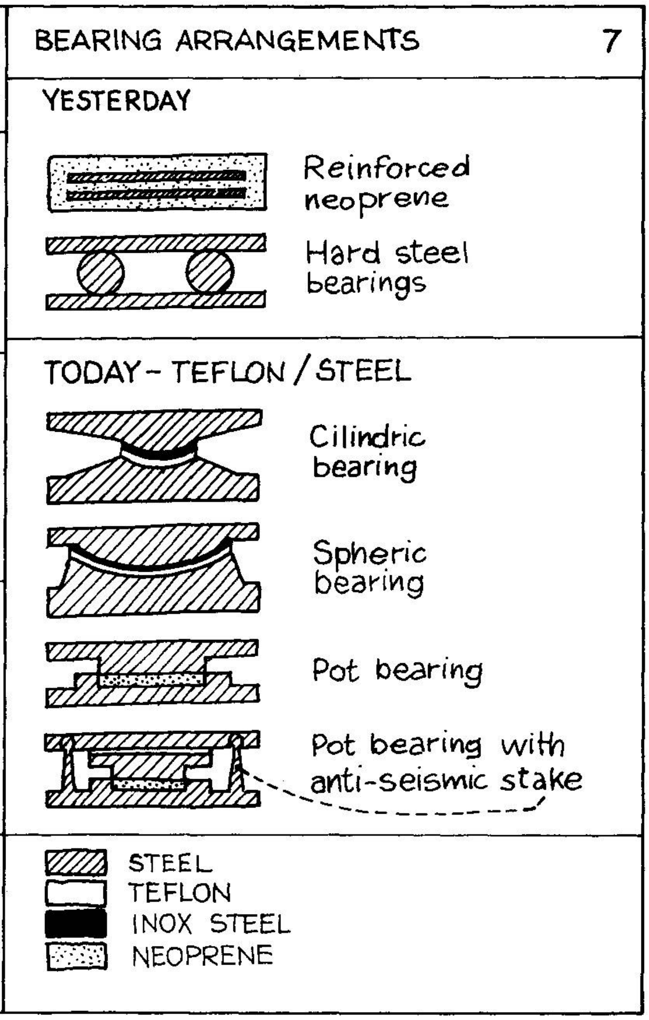
The first category should also include the highly protected prestressing steel (in bars or toroids) coated with epoxy resin films. These permit resolving the most common problem for maintenance design: the generalized use of cathodic protection also for works in prestressed reinforced concrete. The reason why

protection also for works in prestressed reinforced concrete. The reasón why this material is so important in prestressing is that the great development of protective materials (used mainly in slabs) has led to a rise in costs in this sector. Preparing a durable concrete, impregnating it with resin after pouring, then waterproofing it with synthetic polyurethane film and finally covering it with a durable and non-deformable pavement under these conditions (with the water remaining in it because it cannot drain rapidly through the waterproofed deck) costs at least as much as a sound active cathodic protection of the reinforcing steel. This latter procedure, however, generates nascent hydrogen during operation, which in turn may attack the prestressing steel.
Thus in order to have good protection, one must either avoid prestressing, or protect the prestressing steel from the H^+.
One of the most insidious enemies of durability, however, is the carbonation of the cement overlay, which in a matter of a few decades can destroy the protective concrete envelope around the reinforcing steel.
Possible solutions include corrosion inhibitors (calcium nitrites, $Ca(NO2)2$) in the casts, the use of microsilicates, ("silica fume" derived from steel processing), protective paints and also, of course, rheoplastic concretes. Each of these materials merits a discussion apart, and in any case one can truly say that there are too many to choose from.

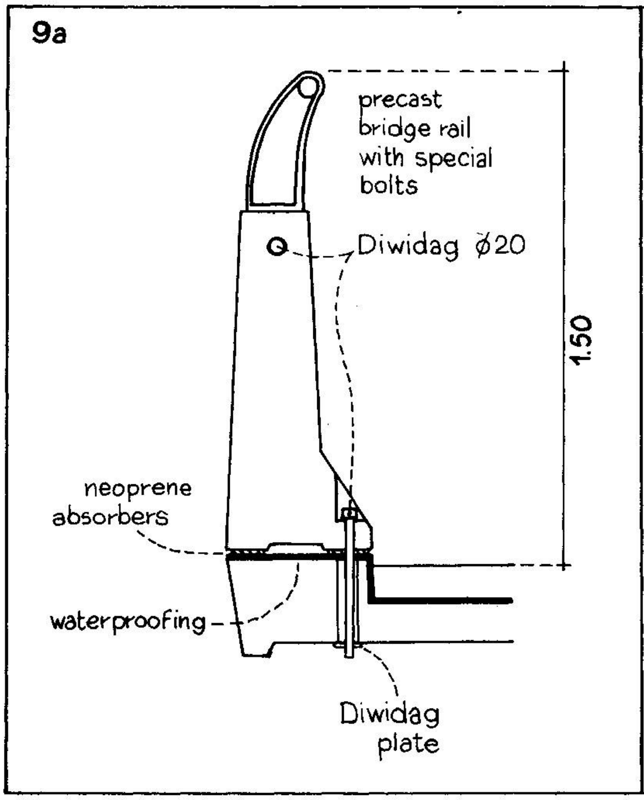
4. EQUIPMENT AND ACCESSORY WORKS

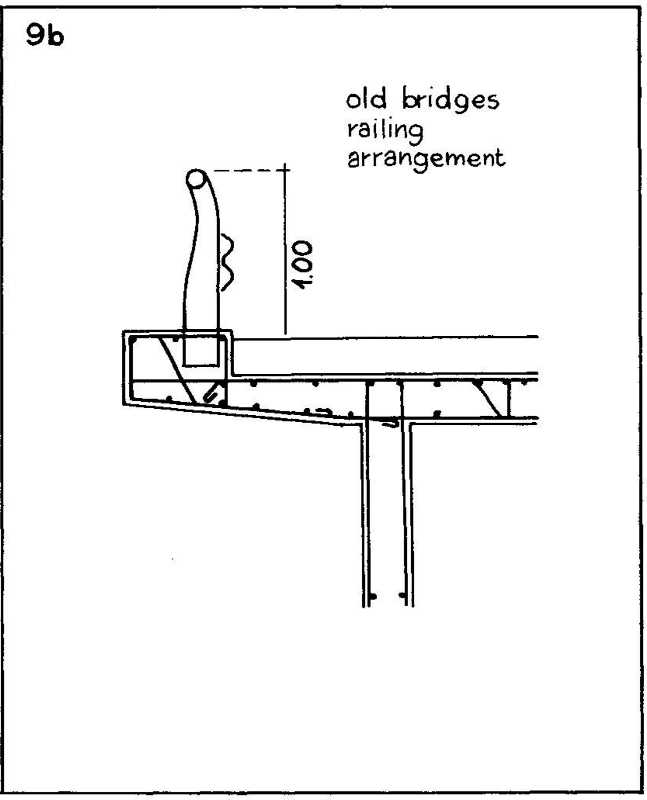
These are the consumable parts of the works, and also here there have been significant developments such that I will limit myself to a simple list.
In the case of <u>bearings</u> (fig. 7), steel/teflon has had very rapid development.





Problems have been encountered in works affected by severe traffic vibrations due to the accelerated "chewing" phenomenon (consumption linked with very small but rapid oscillating movements, and not due to the larger, slower expansion/ contraction movements).
There has also been great progress in counteracting seismic actions (on both new and existing bridges). The more advanced devices (in fact, of recent days) contain steel hinges which yield under the actions of an earthquake (but in the direction and with the forces desired); these were developed out of neoprene and lead bearings used in New Zealand.
Joints have reached a stage of stability, with the widespread use of neoprene/ steel devices on reinforced concrete blocks, which in most recent installations have also been reinforced with fibre (the full name is rheoplastic, sulpho-resistant, fibro-reinforced anti-shock joints)(see fig. 8) But the most recent developments on which full-scale tests are just now underway have to do with the anti-rollover, double-duty (against both cars and trucks), prefabricated bridge guardrail (see fig. 9). Also in this case we have an innovation concealed under a traditional form: the system of attachment to the bridge deck and of resistance to collision is designed and calibrated in such a way as to avoid transmitting excessive forces to the bridge structure itself (the impacts of trucks may reach 75 to 100 tonnes, even though only for microseconds). The





impact strength of these devices is a mixed function of beam and bracket, based on a dywidag ∅ 20 horizontal bar and attachments, of a strength varying according to the reinforcing present in the structure, at the foot of the wall, which has a New Jersey profile. An additional steel handrail or the wall itself extended to a height of 1.70 m from the road surface comprises the upper part of the structure. In cases of collision, maintenance is immediate, as the element can be replaced in minutes.

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Design for Maintenance

Projet de la maintenance

Entwerfen für die Unterhaltung

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SUMMARY
Maintenance-oriented activities are not only regarded as technical problems, but also under cultural aspects. This is especially necessary for future concrete structures. There are two main problems to be solved : future maintenance of contemporary structures and maintenance of structures to be designed for future demands. General conclusions are drawn for future-oriented maintenance activities. Special recommendations are formulated for the maintenance-oriented design of future concrete structures.

RÉSUMÉ
La maintenance des ouvrages d'art ne peut pas être considérée comme une activité technique exclusivement, mais elle doit tenir compte d'aspects culturels. Cela est particulièrement nécessaire pour les constructions en béton de l'avenir. Deux problèmes doivent être résolus : la maintenance future des structures contemporaines et la maintenance des structures devant répondre à des besoins futurs. Des conclusions générales sont tirées pour les activités futures de maintenance. Des recommendations particulières sont faites en vue du projet orienté vers une maintenance adéquate des structures en béton de l'avenir.

ZUSAMMENFASSUNG
Die Unterhaltung von Bauwerken wird nicht nur als eine technische Aufgabe gesehen, sondern unter Einbeziehung kultureller Aspekte diskutiert. Dies ist für zukünftige Betonbauwerke besonders notwendig. Zwei Aufgaben sind zu lösen : Die künftige Unterhaltung von bereits bestehenden Bauwerken und die Unterhaltung von Bauwerken, die unter Beachtung zukünftiger Anforderungen zu entwerfen sind. Es werden allgemeine Schluszfolgerungen für zukunftsorientierte Bauwerksunterhaltung gezogen. Für den auf die Bauwerksunterhaltung orientierten Entwurf von zukünftigen Betonbauwerken werden spezielle Empfehlungen gegeben.

1. THE FUNDAMENTAL QUESTIONS

Some weeks ago I was strolling through the ruins of buildings the Romans passed on to us two thousand years ago.

Some years ago I was admiring the pyramids and the temple of Abu Simbel the Egyptians passed on to us more than four thousand years ago.

Some months ago I was staying in the caves of Lascaux in front of the outstanding pictures our ancestors passed on to us some ten thousand years ago.

My feeling were always the same:

GREAT RESPECT AND DEEP ADMIRATION

But there were also some thoughts I could not put aside:

- Those works were done for eternity and have been endangered by ignorance, negligence and even destruction in our time.
- Those works have only been maintained in the last historical second of our man-related "eternity".

Mankind now, only five minute before twelve have developed consciousness of cultural responsibility and started maintenance-oriented activities to protect outstanding cultural values.

Bearing this in mind I considered and reconsidered the theme I have to deal with and the questions I have to answer in this presentation.

At the first glance it seems to be very easy to deal with

DESIGN FOR MAINTENANCE

only by answering the questions

- WHAT to maintain?
  and
- HOW to maintain?

Such a point of view leads straight to a technically oriented confrontation and to only technically oriented answers.

Those answers can be found more or less easily by running the chain of maintenance activities from field inspection, inspection with visual, destructive or non destructive examination, damage evaluation, damage assessment up to damage qualification and -quantification and so starting the decision-making-process to ensure an optimal maintenance concept.

Considering the theme a little bit deeper, one can add two more questions:

- WHY to maintain?
  and
- WHETHER or not to maintain?

By asking such questions one goes beyond technical aspects and enters into a greater, more demanding and more culture-oriented field of considerations. One is passing from maintenance of STRUCTURES into maintenance of ENVIRONMENT, from RESTORATION of structures to their DESTRUCTION.

I would like to ask you to follow me in that direction and to deal with our problem not only out of the classical technically-oriented attitude of repair and reconstruction, but to also incorporate cultural and human aspects into our consideration.

That means it is taken for granted in this presentation that engineers are able to handle the technical aspects of maintenance of concrete structures using effective methods to improve damaged concrete surfaces, to repair cracked concrete structures and to strengthen such structures, if their load capacity is insufficient for further usage or structural safety.

Maybe we should also modify the theme a little bit and not only deal with design FOR maintenance but also with design AGAINST maintenance.

2. THE FUNDAMENTAL PROBLEMS.

In dealing with our subject in the frame of this symposium we have to consider three terms:

STRUCTURE FUTURE MAINTENANCE .

And we have to answer two questions:

- What is the future of the contemporary concrete structures ?
  or more precise:
- What is the future of concrete structures already built?
  and
- What are the characteristics of concrete structures to be planned, designed, constructed, used and maintained in the future?

We are therefore confronted with two MAIN TASK:

- the FIRST one is to maintain contemporary concrete structures,
- the SECOND one is to design concrete structures for the future based on our contemporary experience.

To fulfill the FIRST TASK we have to thoroughly analyze concrete structures, to evaluate their damage level and to synthesize effective methods of classical maintenance:

REPAIR, RECONSTRUCTION, STRENGTHENING.

To fulfill the SECOND TASK we have to deal with methods of technical, economical and social forecasting and we have to develop future-oriented, non classical attitudes.

So there are different features which characterize the two task:

Maintenance of CONTEMPORARY concrete structures can mainly be based on classical engineering quality and contemporary maintenance methods and tools.

Maintenance of FUTURE structures is challenging engineer's future-oriented imagination, his social responsibility and his creativity.

There are therefore different capabilities one has to develop to meet these demands:

Three of them I would like to highlight:

- The FIRST one is the

  CAPABILITY TO THINK

  in order to recognize and to formulate the present trends of development of society, technology, public demands and human needs,

- The SECOND one is the

  CAPABILITY TO DREAM

  in order to draw conclusions from the development of mankind and their needs and to formulate the demands, which concrete structures have to meet in the future,

- The THIRD one is the

  CAPABILITY TO ACT

  in order to create concrete structures which not only meet technical demands but ensure and possibly even upgrade the cultural level and the harmony between men and structure.

Our activities and our responsibility have to be evaluated by CRITERIA not only valid in our time but also in the future.

Let me propose three groups of such criteria:

- criteria out of interaction between

  STRUCTURE AND FUNCTION,

  that means: technical-economical criteria

- criteria out of interaction between

  STRUCTURE AND ENVIRONMENT,

  that means: sociological-ecological criteria

- criteria out of interaction between

  STRUCTURE AND MEN,

  that means: esthetical-ergonomical criteria

Maintenance of structures in the past was often only understood as the avoidence or repair of structural failures and damages.

More and more engineers are and will be confronted with additional future demands.
Those demands will not only be technically oriented but will include requirements resulting out of cultural considerations.

Additional demands result out of:

- Change of

  USERS' DEMANDS

  and therefore change of interaction between structure and function,

- Change of

  PUBLIC DEMANDS

and therefore change of interaction between structure and environment,

- Change of

  PEOPLES's DEMANDS

  for safety and convenience and therefore change of interaction between structure and men.

3. THE FUNDAMENTAL MAINTENANCE ACTIVITIES.

There are a lot of studies dealing with sources of failures and damages of concrete structures. Summarizing the conclusions of such studies one can find some main relationships between specific types of maintenance activities and decisions made during the process of preparation, construction and use of concrete structures (table 1).
Maintenance activities can be minimized by proper preparation of such activities.

INSUFFICIENT QUALITY OF:	MAIN INFLUENCE ON MAINTENANCE ACTIVITIES		
	REPAIRING	REDESIGNING	REMOVING
TENDERING		XXXXXXXX	XXXXXXXX
CONTRACTING	XXXXXXXX		
DESIGN	XXXXXXXX	XXXXXXXX	
CONSTRUCTION	XXXXXXXX	XXXXXXXX	
UTILIZATION	XXXXXXXX	XXXXXXXX	XXXXXXXX

Table 1: QUALITATIVE EVALUATION OF RELATIONSHIP BETWEEN INSUFFICIENT QUALITY OF PREPARATION, CONSTRUCTION AND UTILIZATION OF STRUCTURES AND MAINTENANCE ACTIVITIES.

A proper system of quality assurance and quality control has to be planned and exercised in all of these phases to minimize the necessity of maintenance activities.

With some restrictions, it seems to be possible to find some relationship out of interaction between structure, function and environment on the one hand and important types of structural failures and damages of concrete structures on the other.
Table 2 demonstrates those relationship taking into account:

- impacts of media
- temperature impacts
- dynamic impacts

resulting out of interaction between structure, function and environment under performance- and hazard condition.

IMPACTS	MAIN TYPES OF FAILURES AND DAMAGES			
	DEGRADATION	SPALLING	CRACKING	DESTRUCTION
MEDIA				
- AIR/GAS	XXXXXXXX	XXXXXXXX		
- LIQUIDS	XXXXXXXX	XXXXXXXX		
- MOISTURE	XXXXXXXX	XXXXXXXX	XXXXXXXX	
- SOLIDS				XXXXXXXX
TEMPERATURE				
- CONSTANT			XXXXXXXX	
- VARIABLE	XXXXXXXX	XXXXXXXX	XXXXXXXX	
- VERY LOW				XXXXXXXX
- VERY HIGH				XXXXXXXX
DYNAMIC				
- PERIODIC	XXXXXXXX	XXXXXXXX	XXXXXXXX	
- TRANSIENT	XXXXXXXX	XXXXXXXX		
- BLASTWAVE				XXXXXXXX
- IMPULSE				XXXXXXXX

Table 2: QUALITATIVE EVALUATION OF RELATIONSHIP BETWEEN IMPACTS AND MAIN TYPES OF DAMAGES.

The main activities to prepare maintenance of

CONTEMPORARY structures are:

- field inspection
- visual examinations
- non-destructive and destructive examinations
- damage assessment, - evaluation and - quantification
- evaluation of residual bearing and performance capacity
- updating users-, public- and men's demands
- optimization of life-cycle behaviour of structure.

The main activities to prepare maintenance of

FUTURE structures are:

- Future-oriented evaluation of users', public and peoples' demands
- Tendering and design on a full-life-cycle-basis instead of an initial-cost-basis
- Development of future-oriented maintenance concepts to adapt concrete structures on future structural demands
- Development of future-oriented maintenance concepts to adapt concrete structures to future cultural demands or to remove concrete structures.

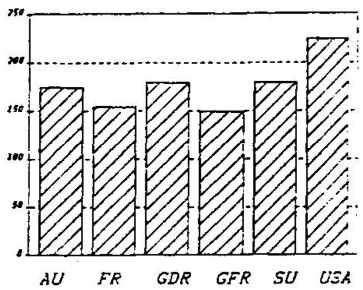
One of the most important task to carry out a maintenance-oriented design is to evaluate and to describe loads and impacts concrete structures have to withstand.

Norms, codes, regulations and recommendations give an initial orientation in this regard.

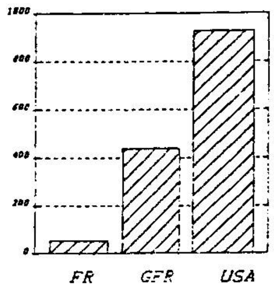
As it is shown in table 3 even in this basic and most traditional field of engineering activity one is confronted with quite different points of views and different orientation.

LOADS AND OTHER IMPACTS

SILO PRESSURE calculated by SILO NORMS of AU, FR,GDR,GFR,SU, USA (Cementsilo)



AIRCRAFT CRASHES upon CONTAINMENTS recommended by REGULATIONS of FR,GFR,USA

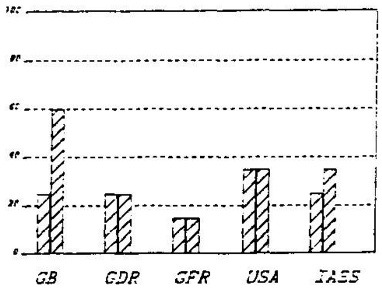


STRUCTURAL DETAILING OF COOLING TOWERS

MAIN STEEL PERCENTAGE

MINIMUM CONCRETE COVER

given by NORMS and RECOMMENDATIONS of GB, GDR, GFR, USA,IASS



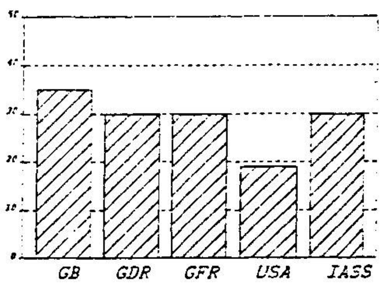


Table 3: EXAMPLES OF DISCREPANCIES IN INTERNATIONAL NORMS AND RECOMMENDATIONS

The same situation is given for some basic orientation concerning structural detailing, as it is also shown by examples in table 3.

This is one of the reasons, why even in such a most classical field of civil engineering like SILOS maintenance of different type and intensity is often necessary.
Table 4 shows results of a damage-oriented study comprising about two hundred grain concrete grain silos.
The damage level are defined as follows:

- Level 1: isolated cracks and small local deficiencies, TO BE INSPECTED
- Level 2: cracking patterns and concrete spalling, TO BE REPAIRED
- Level 3: serious cracking patterns with widespread concrete spalling and local compression failures TO BE RECONSTRUCTED

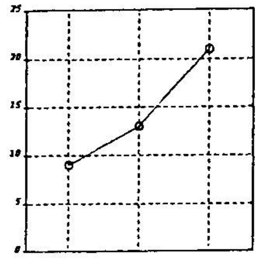
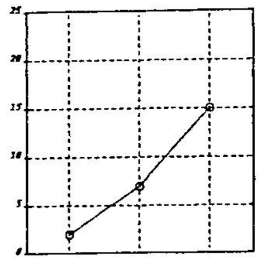
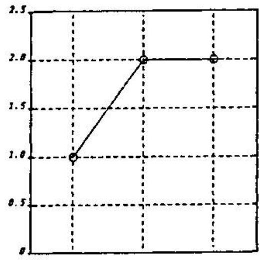
DAMAGE LEVEL	DAMAGED SILOS AFTER 1o, 15,25 YEARS	MAINTENANCE ACTIVITIES
1 (SMALL CRACKS)		OBSERVATION
2 (CRACKING PATTERN)		REPAIR
3 (HEAVY DAMAGES)		RECONSTRUC-TION

Table 4: EXAMPLES OF SILO DAMAGES DEPENDING ON SILO LIFE-TIME

Those examples demonstrate that even in the most classical and fundamental fields of civil engineering engineers are confronted with decisions which greatly can influence the necessity of maintenance activities.

Often enough engineers are not given support by norms and recommendations when they need it mostly.
That is especially true for structures with high risk potential and structures which have to meet special users demands.

It is therefore always necessary not only to respect regulations but to analyze and to evaluate the full life-cycle of structures to meet the demands of optimal maintenance.

4.CONCLUSIONS AND RECOMMENDATIONS

4.1 General conclusions

To optimize maintenance activities of structures the following GENERAL CONCLUSIONS can be drawn:

- Maintenance-oriented attitudes have to be developed and exercised during all phases of preparing, construction and using structures.

- Tendering and contracting have to ensure assessment of risk during construction and utilization and to define levels of duties, responsibilities and quality control.

- Maintenance activities should be minimized by establishing a system of quality-assurance and quality-control valid in all phases of preparing, constructing and using of structures.

- Tendering and design activities have to be carried out taking into account the full life-cycle-costs of structures and overall costs instead of only the initial costs.

- Criteria to evaluate the necessity and type of maintenance activities should be determined not only out of technical but also out of cultural demands and should consider interaction between structural behaviour on the one hand and future oriented users-, public- and men's demands on the other.

- Concepts of maintenance activities have to take into account that performance requirements, environmental conditions and public attitude may change in a wide range during the life-cycle of the structure.

4.2 Recommendations for concrete structures

DESIGN FOR or AGAINST maintenance of CONCRETE STRUCTURE should take into account characteristics of concrete structures. For the layout, analysis and structural detailing of concrete structures the following recommendations may be useful:

- Design has to consider change of structural systems, loads and other impacts as well as concrete properties during the erection of the concrete structure.

- Design has to consider that concrete is a material with long-term-deformation the intensity of which is time-, environment-,stress- and temperature-dependent.

- Design has to consider that long- and short-time deformation of concrete structures must not be restricted without taking into account possible redistribution of internal forces and development of cracks.

- Design has to consider that cracks not only may cause corrosion of steel but also can influence the stiffness, the stability and the dynamic behaviour of concrete structures in a wide range.

- Design has to consider that structural supports and interconnections of structural elements mostly are strongly idealized in structural analysis and that therefore great differences might be between assumption and reality.

- Design has to consider that behaviour of prestressed concrete structures is greatly influenced by the exactness of prestressing and that such structures are more sensitive against incorrect assessments of loads and other impacts and of restriction which may result out of restricted deformation or unrealistic assessment of structural stiffness.

- Design has to consider that maintenance activities in the future can make it necessary not only to repair, strengthen or reconstruct but also to demolish and replace concrete structures in order to maintain or restore harmony in natural or built environment.

To orient our design activities in such a direction may contribute to our general aim:

Development of CIVIL ENGINEERING
into
CIVILIZED ENGINEERING

Design of Bridges for Optimum Construction and Maintenance Costs

Conception de ponts en vue d'une optimisation des coûts de construction et d'entretien

Brückenkonzepte für optimale Herstellungs und Instandhaltungskosten

Klaus H. OSTENFELD
Technical Director, Bridges
Cowiconsult,
Virum, Denmark

K.H. Ostenfeld, P.E. , born 1943, M. Sc. in Civil and Structural Engineering from Technical University of Copenhagen and registered professional engineer in the USA, has worked as bridge engineer in the United States and France for many years. Since 1977 he has been with Cowiconsult in Copenhagen, responsible for the design of several long span bridges.

SUMMARY

The design for low maintenance of bridge structures begins at the conceptual design stage. A quality strategy shall be part of the design criteria serving as a basis for the selection of optimum structural concepts, configuration, and materials. Quality assurance systems are necessary in all phases during design, construction and service life. Systematic inspection and maintenance procedures, as well as monitoring systems will be required. Lately computerized bridge management systems have been developed to assist owners and bridge administrations in data processing and economical calculations for establishement of decision alternatives.

RÉSUMÉ

Le projet de la maintenance pour un entretien minimal des ponts commence au stade du concept de projet. Une stratégie qualitative doit permettre le choix des critères de projet et servir de base à la sélection de concepts structuraux, de la forme et des matériaux de construction. Des systèmes d'assurance de la qualité sont nécessaires à tous les stades du projet, de la construction et de l'exploitation. Des procédures d'inspection et d'entretien systématique ainsi que des systèmes de contrôle sont requis. Récemment, des systèmes de gestion informatisée ont été développés afin d'aider les maîtres d'ouvrage et administrations des ponts dans le traitement d'informations et le calcul des coûts, leur permettant ainsi de comparer plusieurs solutions.

ZUSAMMENFASSUNG

Der Entwurf für die minimale Unterhaltung von Brückenbauten beginnt bei dessen Konzept. Eine Qualitätsstrategie soll die Wahl der Entwurfskriterien erlauben und als Basis für eine Auswahl von Tragwerksystemen, der Form und den Baumaterialien dienen. Qualitätssicherungssysteme sind während dem Entwurf, Bau und Betrieb der Brücke notwendig. Systematische Kontroll- und Unterhaltungsverfahren wie auch Ueberwachungssysteme werden benötigt. In der letzten Zeit wurden computergestützte Brückenmanagementsysteme entwickelt, um Bauherren und Brückenverwaltungen in Datenverarbeitung und in Kostenberechnungen zu helfen, verschiedene Lösungen zu vergleichen.

1. INTRODUCTION

The optimum design for lowest overall cost during the intended service life begins already at the initial design stage. Decisions are made at this stage which, although not always realized, have a fundamental influence on the overall life cycle costs of the structure.

In the post-war years the main concern of the owners was to rebuild and further develop the total infrastructure and transport system. Little - if any - attention was spent on maintenance aspects and durability of the structures and how to repair, rehabilitate, strengthen, and possible expand them. These problems were left for the future generations to solve.

However, as the infrastructure systems in the industrialized world is now nearing completion and adequate capacity, and the total volume of existing infrastructure has increased drastically, in terms of replacement value, a growing burden of maintenance has been accumulated for the administrations and owners.

Budgets previously primarily allocated to new construction are now directed towards maintenance and rehabilitation projects for existing infrastructure elements. This has lead to an obvious need for greater awareness with regard to maintenance of any new or rehabilitated structure forming part of our substantial investments of society.

Numerous examples exist around the world where very high rehabilitation and repair costs have incurred by lack of proper consideration of maintenance aspects, in the design phase. Situation which in many cases could have been reduced considerably, and generally at no additional cost if maintenance had been a design parameter at the time of construction.

2. KEY ELEMENTS IN LOW MAINTENANCE

The key parameters for overall low and predictable maintenance cost are the following:

- Overall quality strategy
- Structural concepts and configuration
- Materials
- Quality assurance in design and construction phases
- Systematic inspection and maintenance procedures, and monitoring
- Management and budgetting systems for data management and generation of decision alternatives

Each of these parameters are contributary to the overall concept of maintenance and by proper consideration of these parameters can reliable maintenance prediction and planning be made.

3. QUALITY STRATEGY AND AWARENESS

In the initial planning stage the overall quality strategy must be determined with due consideration to the intended use of the structure.

Performance criteria must be determined, as well as design life, frequency of use, importance, built in reserves for future development in use etc.

Technical, economical, sociological, and other consequences of poor performance, break down and/or major maintenance operations must be considered when establishing quality standard.

If performance inferior to intended leads to very high additional user costs, complicated maintenance and repair under use, high risks, and if long service life is required, a high quality standard would be warranted.

On the other hand temporar structures with short intended service life and limited use requires lower quality standard. However, lower overall quality standard should not be confused with lower safety standard. This fact has been recognized relatively late, and most newer codes of practice requires same structual safety (partial coefficients) for short life structures as for permanent structures.

If a key bridge is taken out of service on a major high capacity highway due to rehabilitation works, and traffic due to this must be diverted and rerouted via major detours causing unacceptable congestions and consequently very high additional user costs dublication of the facility may be necessary, e.g. 2 parallel and independent structures which can be taken out of service one at a time for rehabilitation, strenghtening or rebuilding without affecting the other.

It is generally accepted that high initial quality leads to high initial cost and generally minimizes maintenance costs. Likewise it is believed that low initial cost invariably leads to high maintenance costs.

This is, however, not always the case as shall be demonstrated in the following.

The real challenge to the designer is to obtain the best of the two worlds - low initial and maintenance costs by selection of proper structural concept and configuration, use of best suited materials, and innovative ideas based on experience and feed-back from past performance of similar structures.

Correspondingly high initial cost does <u>not</u> necessarily lead to low maintenance costs! - if the high initial cost is caused by inexpedient selection of structure type and materials for the use intended.

4. STRUCTURAL CONCEPT AND CONFIGURATION

The selection of the structure concept and configuration will have a significant influence on the later maintenance requirements of the structure.

Structures like bridges are a complex combination of materials and mechanical components exposed to very severe environment, and it is generally considered unacceptable to temporarily interrupt their use for servicing.

It is thus required that service and replacement of worn out components is minimized, and where unavoidable, that such replacement can take place with minimum influence on the use of the facility.

Bridge components may be categorized in primary main components like the roadway deck, girders, columns, and foundations, whos life will determine the actual life span of the structure.

These components have in common that they are very difficult, if not impossible, to replace during service life. Main cables of large suspension bridges also belong to this category.

Other components are rather short lived, and provisions for replacement one or several times during the service life must be considered. Such items are components subjected to wear and tear, corrosion, or fatigue, as well as other forms of deterioration. Like bearings, expansion joints, road pavements, surfacing, painting, sealing, and cable stays and hangers on cable supported bridges.

Innovation of bridge technology for low maintenance must, therefore, be directed towards:

- reducing the number of short life components to a minimum,
- protect the components from premature deterioration and wear
- provide for easy access for regular inspection and servicing
- prepare for scheduled replacements

By the use of unconventional methods it is possible to minimize both initial cost and maintenance requirements.

For the Farø bridges in Denmark, use of a low cost dehumidification system in the bridge box girder has saved about 8-10% of the initial superstructure cost by eleminating the cause of steel corrosion - humidity - instead of specifying painting of the interior of the girder.

The use of such a system which is made of standard components also reduced net present value of maintenance costs over the service life.

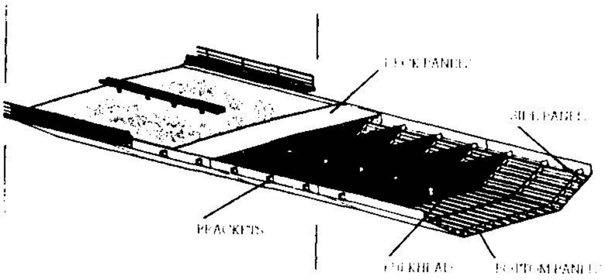


Fig. 4.1 Farø Bridges. Box Girder

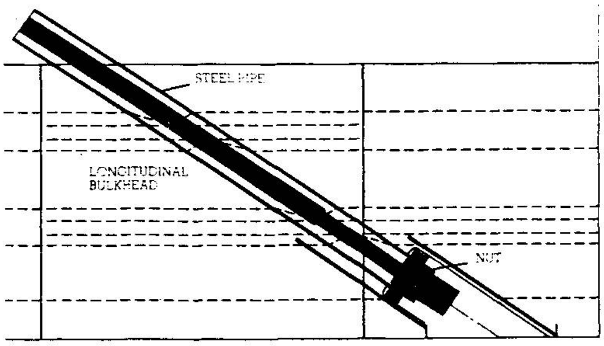


Fig. 4.2 Farø Bridges.
Stay Anchorage in Girder

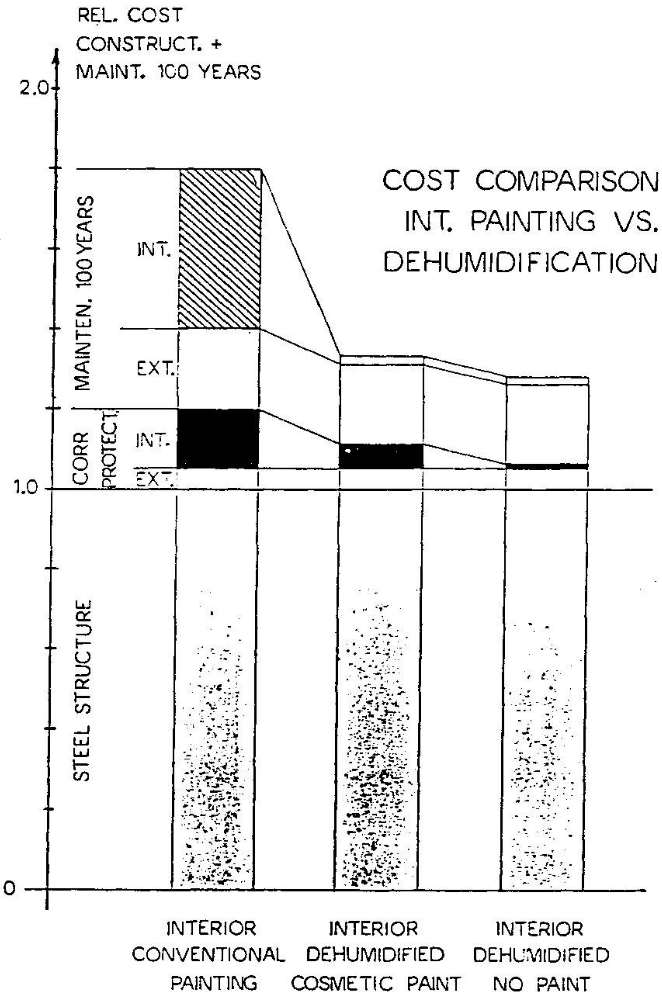


Fig. 4.3 Steel Box Girder.
Cost Comparison

Due to placement of all stiffeners in the interior dehumidified air space, only 20% of the total, 400,000 m^2, steel surface is exposed to the exterior environment, and due to smooth surface easy to inspect and maintenance.

The interior congested by stiffeners, corners and inaccessible areas, and voids as well as machined parts like cable stay anchorages, electrical equipments etc. is safely and permanently protected by the dry environment. The initial cost amounts to DKK 5.00/m^2 and net present value of 100 year maintenance DKK 20.00/m^2 using an interest of 4% p.a.

Easy acces to components requiring inspection and maintenance shall be provided. Expansion joints and bearings must be accessible during operation. It is a well known fact, that if access is difficult, the necessary inspection and maintenance will not be executed as planned.

New ideas can further cut down on maintenance.

For the Farø bridges the number of maintenance intensive expansion joints have been cut to a minimum. The bridge girders have been made continuous from coast to coast, in fact 2 bridges each continuous for 1600 m and 1700 m, respectively. Expansion joints capable of up to 1 m respiration have been installed only at the abutments.

Easy access has been provided by stairs and cellar space and platforms allowing amble space for inspection, maintenance - work and replacement in full upright position of expansion joint parts and abutment bearings.

On the pier tops is provided via electrically powered monorail through the box girder from the abutments to each pier via easy access manhole with hinged and counterweight balanced lid. Workers can work in an upright position for lubrication and other maintenance of the sliding bearings. Long life is ensured by protecting the movable parts by dust seals and bellows.

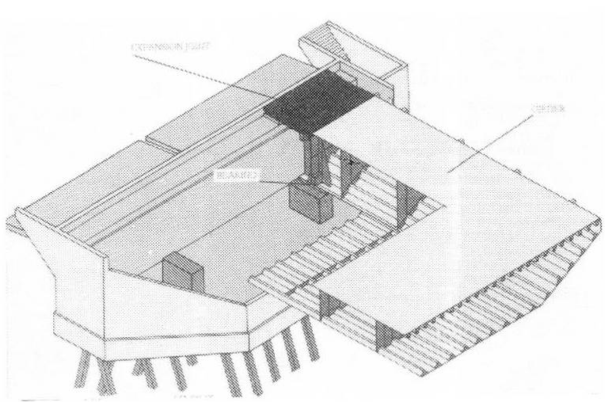


Fig. 4.4 Farø Bridges. Abutments

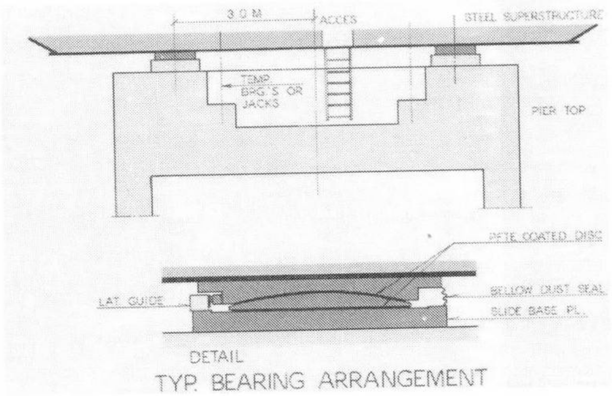


Fig. 4.5 Farø Bridges. Pier Top

The accummulated travel of bearing part, (temperature expansion etc.) as recorded for calibration of optimum inspection intervals and provisions are made for easy replacement of bearings under service by local strengthening of the box girder and extra plinth on the pier top designed for jacking. Bearing replacement can take place without interruption of traffic.

Another maintenance saving feature is the use of hydraulic cylinders for restricted and controlled support and movement of the bridge girder at the main towers. The system is extremely robust and maintenance free as compared to a system of vertical and horizontal sliding bearings and mechanical linkage which would otherwise have been required.

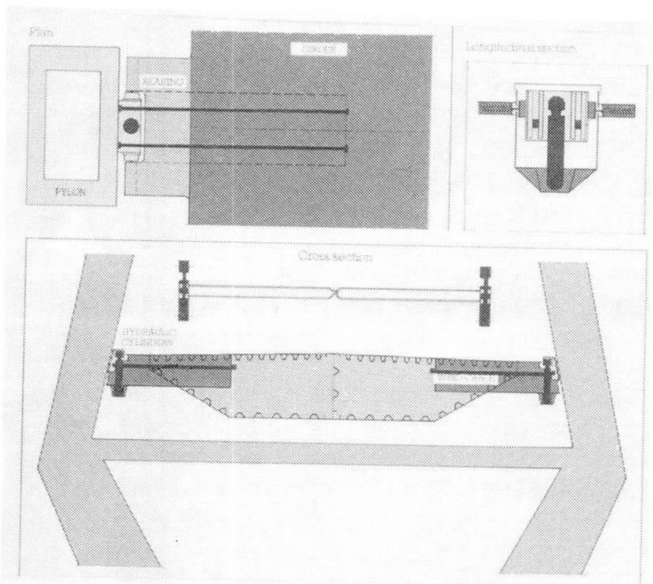


Fig. 4.6 Farø Bridges.
Bearing between Pylon
and Girder

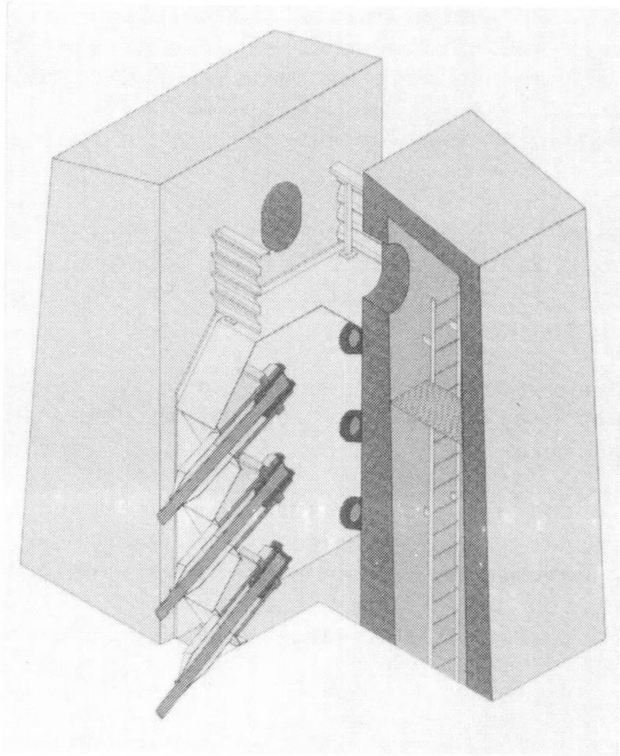


Fig. 4.7 Farø Bridges.
Stay Anchorage in
Pylon Top

The cables for the stayed portion of the bridge are anchored in the top of the pylons into a robust bearing walled steal box structure posttensioned to the concrete tower legs by bars. Due to the rather difficult access on the outside, the box has received a thorough protection by zincspraying and 4 layer paint system which should ensure a very long life before new treatment will be required.

Easy access is provided by elevator in the tower legs to the complicated interior with cable anchorages, stiffeners, shims etc. This space is efficently and inexpensively protected against corrosion by dehumidefication.

The stay cables are spaced closely to allow replacement one at a time under service. The traffic only being limited locally by a local single lane shut down for working area during replacement. Cable stresses in neighbouring stays will only increase marginally due to the close spacing and girder stiffness.

The replacement of roadway pavement is foreseen in the the girder shall remain stable on its bearings during removal of all pavement on one side of the bridge even under strong wind conditions. Traffic may then temporarily be directed to one side of the bridge during repaving without impairing safety.

5. MATERIAL SELECTION

In addition to the normal structural strength criteria the most important criteria in the selection process is durability for the intended use, environmental exposure, and desired lifetime.

Environmental deteriorating forces are severe for transportation infrastructure being unprotected and exposed to aggressive atmosphere, sea water, de-icing salts, high winds, and pounding traffic. Therefore, durability is most often the governing criteria.

Many attempts have been made in recent years to improve durability of concrete. These attempts have been encouraged by increasing concrete deteoriation problems experienced in many countries after the hectic building and construction activity in the late sixties and early seventies.

The most significant improvements have been directed towards:

- use of non-reactive concrete aggregates to avoid alcalic reactions,
- avoid initial cracking of the concrete by controlled temperature gradients during the cement hydration process,
- production of dense low permeable concrete by minimizing w/c ratio using additives like superplastifiers,
- addition of silica fume and/or fly ash, partly in substitution for cement, in order to improve homogenity (reduce bleeding), density permeability and minimize hydration heat generation and thereby temperature gradient induced initial cracking,

Further, intensive research is being carried out for extra high strength concretes using normal weight or even lightweight aggregates primarily for use for deepwater platforms in the North Sea and for longspan bridges.

Traditionally, Danish bridges are equipped with waterproofing bituminous membranes applied in hot liquid asphalt for 100% adhesion and a multilayer asphaltic pavement on top. Such systems are expensive, and the excellent 100% quality is difficult to achieve under normal practical circumstances, leading to often premature leakage and accellerating deterioration.

The encouragement to avoid such protective systems or develop new technologies is, therefore, high.

For two experimental bridges built by the Danish Road Directorate, the pavement and waterproofing has been omitted all-together, and silica fume and fly ash concrete developed in research projects in close collaboration between client, designer, contractor, readymade concrete supplier, as well as testing laboratories. Concrete mixes with various silica and fly ash contents, as well as other parametric variation have been tested by accellerated methods in laboratory. The bridges have now been in service for some years and behaviour is promising.

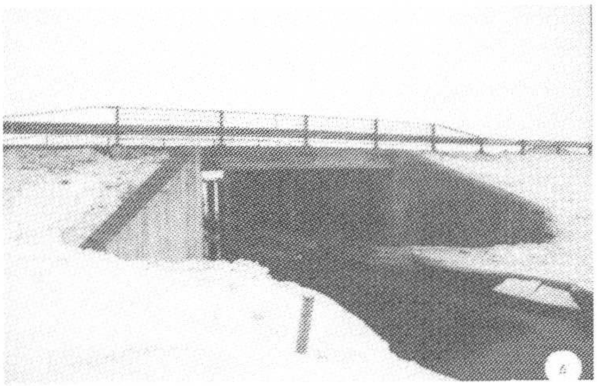


Fig. 5.1 Ry Å. Experimental Bridge.

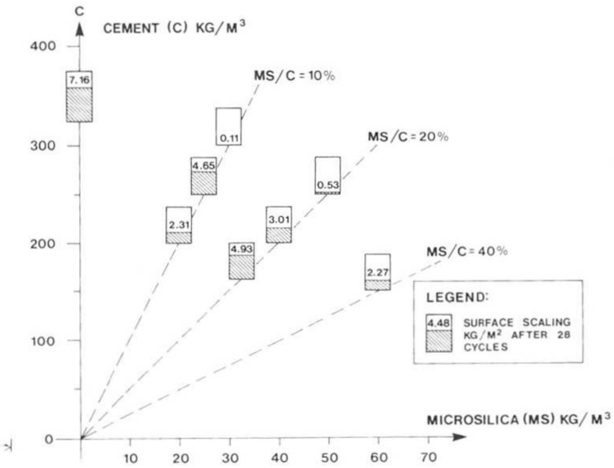


Fig. 5.2 Freeze-thaw tests. Concrete with different amounts of microsilica and no air entrainment

Other possibilities under investigation are the substitution of the bituminous membrane techniques by latex or polymer modified overlays. Such method could be of particular interest for rehabilitation of existing bridges as an alternative to replacement of the traditional pavements.

6. QUALITY ASSURANCE IN DESIGN AND CONSTRUCTION PHASES

Once a durability and maintenance strategy has been selected for a given structure it is important to ensure that this strategy is implemented in all phases from conceptual design through construction and operation.

This should be assumed by a quality assurance system in accordance with modern QA-principles by means of which the inspection and maintenance objectives are defined along with other criteria. A policy of access, durability of individual primary and secondary project elements, replaceability and adaptibility shall be defined as a basis for conceptual design and ensuing phases of the work. The QA system specifies procedures and staff requirements to be followed and requirements to checking and documentation.

For the construction phase a transfer of the project to the contractor takes place via tender documents and the contract. It is fundamental for the continuity in the quality assurance that the quality strategy and objectives is likewise transferred to the contractor through tender documents and for major complicated jobs also by quality conferences with the contractor responsibles at all levels. The contractor, thus motivated, should be required to demonstrate and document his own quality assurance programme to ensure the job is done right in the first place, and that proper documentation is produced.

Such QA programmes has consistently been used for the Farø bridges in Denmark, resulting in generally very high quality of design and construction at competitive cost.

7. INSPECTION AND MAINTENANCE

The aim of the system of inspection and maintenance procedures is to maintain the level of service by a minimum of cost. An example of systematical inspection programme is given below for the Farø bridges:

To control the inspections and maintenance works a system of manuals is used:

- o Inspection plan including organization diagram
- o Inspection, instructions
- o Maintenance, instructions
- o Report, instructions

The inspection plan includes routine inspections by local personnel and principal inspection by trained inspectors. Based on the reports from these inspectors, decisions are made whether maintenance works or further special inspections by selected inspectors are necessary.

The frequency of routine inspections varies from daily (road surface) to every six month, while principal inspections take place every 3-6 year.

The reports on inspections and maintenance works give information by which both remaining life and future costs for different parts of the construction can be estimated.

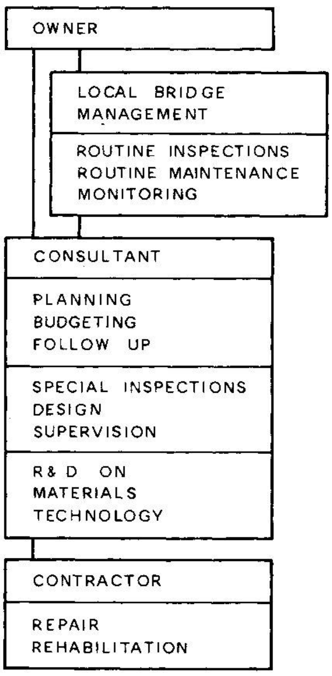


Fig. 7.1 Diagram of typical maintenance organization

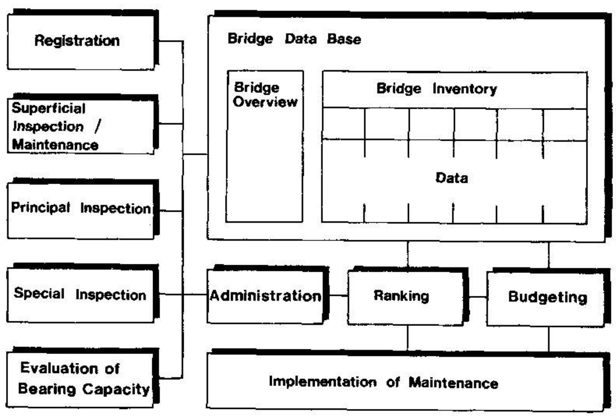


Fig. 8.1 Diagram Bridge Management System

8. BRIDGE MANAGEMENT SYSTEM

The growing quantity of maintenance implies a large number of inspection reports and construction data. To get a comprehensive view or to analyse the consequences of alternative maintenance proposals, an efficient data handling system is needed.

It is the objective of bridge management to maintain the functioning of every single structure and ensure an optimum life of its different elements. This objective must be fulfilled in due consideration of technical, economical, aesthetic and political lines.

A management system could be divided into three modules:

- Registration

  Bridge data are stored in a data base whose structure ensures updating and avoids double registrations. The users can choose fixed ouput forms such as bridge overviews or create individual output forms containing selected data.

- Inspection

  The system ensures that regular inspections are started at the right time and made to standards as detailed in the manuals. The necessary data - the "working basis" - are printed out to the inspection engineers, who will report their findings including condition marks and remaining life for the bridges and the elements.

  Bridges are divided into elements and sub-elements depending on the conditions of the bridges - elements are introduced when damages occur and deleted after repair.

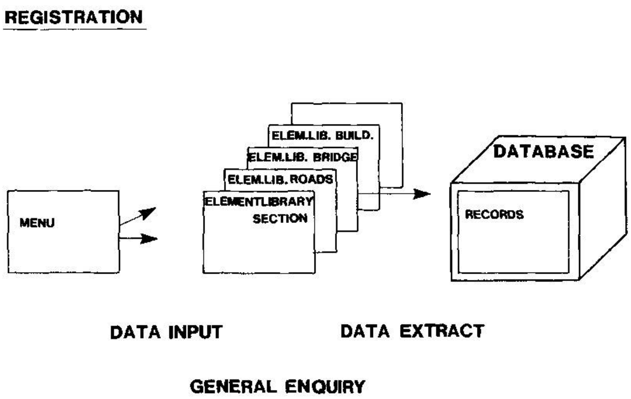
  The amount of inspection data is by this dynamic element structure kept to a minimum.

- Ranking and Budgeting

  A ranking point is calculated for each bridge on the basis of the condition marks for the elements. All bridges are subsequently arranged according to their condition.

  Repair schemes are made for the bridges which are placed higher in the priority list. The preferred repair scheme for a bridge is based on a net present value comparison.

  The overall budget needs are calculated and adjusted to budget limitations, when the maintenance strategies for the individual bridges are finally adjusted.



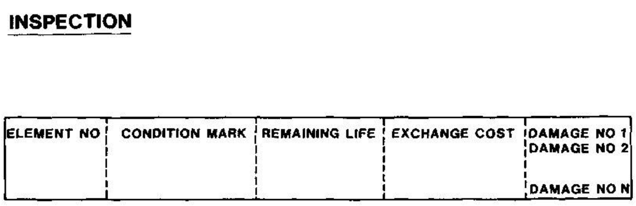


Fig. 8.2

Fig. 8.3

To make sufficient maintenance plan and corresponding cost estimates, an assessment of remaining life of the construction or parts thereof is necessary.

Reliable methods for the assessment of remaining life of bridge elements are difficult to establish and a definitive settlement of the lifetime is only possible at the time when the bridge elements are replaced or condemned. Therefore, the system takes full advantage of this acknowledgement and thus comprises two components:

- Marking System for the registration of the present condition combined with an estimate of the remaining life and the cause of deterioration.

  The closer one gets to the end of the lifetime, the shorter inspection intervals and the more correct is the estimate.

- Log System for the registration of the actual development.
  The accepted conditional marks and the inspection date for each bridge element are kept in the system. This log forms the background for statistic analysis together with information on materials, surroundings and loads. Lifetime estimates are thus supported by these logs.

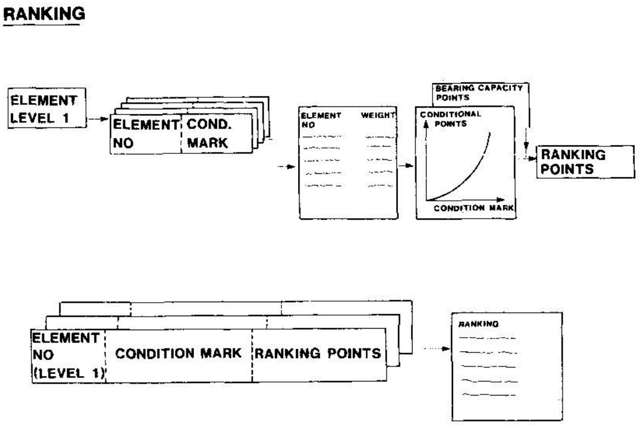


Fig. 8.4

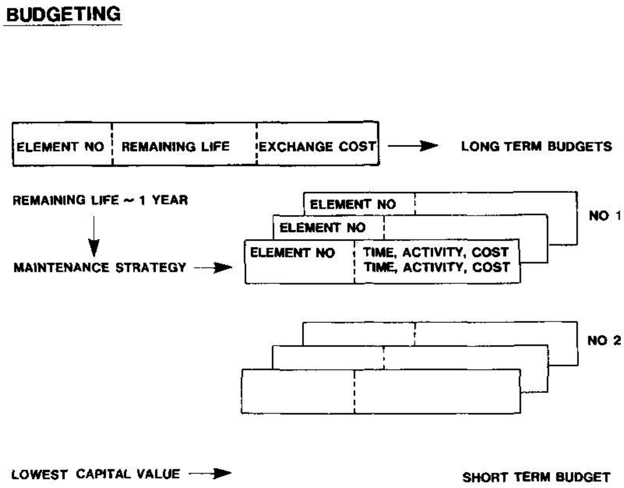


Fig. 8.5

The priority and budgeting system is based on inspection results - visual, such as damage registration, condition marks, remaining life and estimated repair costs - and special, such as detailed repair schemes.

The regular bridge inspection provides data detailed to an extend which corresponds to the actual condition of the bridges: A bridge may be registered by one element with 1) conditional mark of say 1, 2) remaining life of say 50 yeas and 3) estimated costs for replacement of the element (- bridge) after 50 years of say 7 mill. DKK.

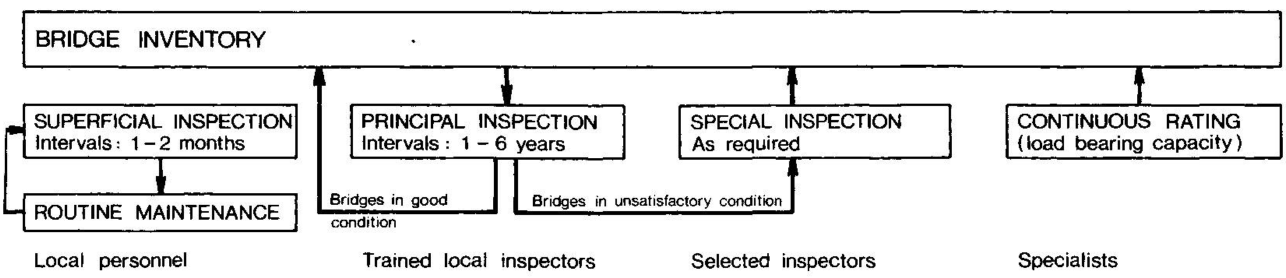


Fig. 8.6

If from experience the inspector is aware that some of the bridge elements have a remaining life of less than the above mentioned 50 years, he introduces these elements (expansion joints, membranes etc.) and corresponding 1) conditional mark, 2) remaining life, and 3) estimated costs.

During the following inspections, the number of elements are increased and conditional marks, remaining life and estimated costs are adjusted. The closer to remaining life of 0, the more correct predictions.

Elements of the bridges have been assigned a factor reflection its contribution to the overall function of the bridge. Bridge condition points are then calculated based on the condition mark of each element and its factor.

A ranking of all bridges is performed on the basis of the condition points and the remaining life.

Bridges having top priority are highlighted and detailed investigations are called for. These investigations may lead to adjustments of the condition marks, remaining life and costs or alternatively to repair schemes.

The system analyses the repair schemes and calls attention to the scheme with lowest net present value.

Budgets are available at any time with relation to latest inspection records. Short term budgets are usually based on the detailed repair scheme provided by the special inspection and long term budgets are normally based on estimated remaining life and replacement costs.

Maintenance des ouvrages d'art à la SNCF

Bauwerksunterhaltung bei der SNCF

Maintenance of Structures at the French National Railways

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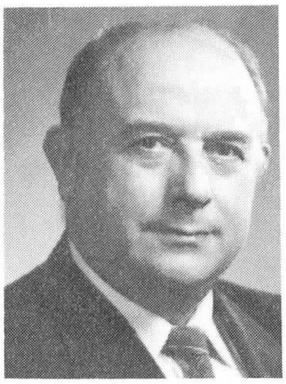

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RÉSUMÉ
L'analyse des travaux d'entretien courant effectués par la SNCF sur ses ouvrages en béton montre que ces travaux peuvent être réduits et n'occasionner qu'une moindre gêne aux circulations ferroviaires si des mesures sont prises dès le stade de la conception des ouvrages et pendant leur construction. Après avoir rappelé l'organisation SNCF de la surveillance et de l'entretien, l'article indique les mesures déjà prises ou envisagées pour la construction de nouveaux ouvrages sur lignes à vitesse normale ou sur lignes à grande vitesse.

ZUSAMMENFASSUNG
Die bei der SNCF durchgeführten Überprüfungen der laufenden Unterhaltungsarbeiten an den Betonbauwerken haben gezeigt, dass diese Arbeiten vermindert werden können und dass sie nur eine kleine Störung des Bahnverkehrs verursachen, wenn gleich bei der Konzeption der Bauwerke und während ihrer Ausführung die richtigen Massnahmen getroffen werden. Der Beitrag zeigt schon durchgeführte und für Neubauten in Betracht kommende Massnahmen.

SUMMARY
The study of routine maintenance works carried out by the French Railways on its concrete structures shows that these works can be reduced, thus lessening interference with rail traffic provided that these steps are taken at the design stage of the structures and throughout their construction. After reviewing the French Railway's organization of inspection and maintenance, this article points out the measures already taken or envisaged for building new structures on normal speed lines or high speed lines.

Le patrimoine de la SNCF en ouvrages d'art est considérable. Il se compose en effet de 39 000 ponts-rails, 10 000 ponts-routes ou passerelles auxquels viennent s'ajouter 1 500 tunnels représentant une longueur cumulée de près de 600 km, 52 000 petits ouvrages sous voie et 10 000 000 m2 environ de perrés et murs de soutènement. Un bon nombre de ces ouvrages sont plus que centenaires.

Pour les maintenir en service, des opérations d'entretien sont nécessaires et si pour des raisons évidentes de sécurité il y a lieu d'intervenir au moment voulu, pour des raisons non moins évidentes de bonne gestion il y a lieu de ne faire que les réparations qui s'imposent.

Cet article traitera de l'organisation actuelle de la surveillance et de l'entretien à la SNCF.

A la lumière de l'expérience acquise en matière de surveillance et de contrôle, il évoquera également les mesures préconisées pour la construction des ouvrages nouveaux en béton armé ou précontraint afin de réduire le plus possible les charges d'entretien ultérieures et induire le minimum de gêne pour le trafic du fait des opérations de maintenance.

1. ORGANISATION DE LA SURVEILLANCE

Pour assurer la maintenance de son patrimoine la SNCF dispose d'une organisation très décentralisée de la surveillance.

Le premier échelon, l'échelon local, est composé de chefs de district et de chefs de section. Un chef de district est responsable des installations de son parcours s'étendant sur plusieurs dizaines de kilomètres de voie. Une section regroupe 3 ou 4 districts.

Le second échelon, l'échelon régional, situé au siège de la région SNCF, comprend des agents d'études et de contrôle. La SNCF est divisée en 25 régions territoriales.

Le troisième échelon, l'échelon direction, est le département des ouvrages d'art de la direction de l'équipement. Il regroupe des agents d'études et de contrôle spécialisés dans les différentes techniques.

1.1 Principes fondamentaux

C'est à l'échelon local que les agents doivent surveiller toutes les constructions au cours de leurs tournées réglementaires sur leurs parcours.

Pour ce qui concerne les ouvrages d'art, une surveillance plus systématisée est mise en place et elle comporte :
– des visites annuelles,
– des inspections détaillées.

1.2 Visites annuelles

Elles sont faites par le chef de district. Pour les ouvrages comportant des fondations en rivière, la visite a lieu en période de basses eaux favorable pour l'examen des fondations. L'assistance de scaphandriers peut être demandée.
En dehors de ces visites annuelles, des visites exceptionnelles peuvent être déclenchées après des crues, des tempêtes ou des périodes de froid inhabituelles.

1.3 Inspections détaillées

Les inspections détaillées, tous les cinq ans, ou d'une périodicité moindre si l'état de l'ouvrage l'exige sont effectuées sous la direction du chef de section.

Pour des ouvrages importants faisant l'objet de consignes particulières le chef de section doit demander la participation d'un inspecteur "ouvrage d'art" de la région et dans des cas particuliers, l'assistance d'un spécialiste du département des ouvrages d'art de la direction de l'équipement.

1.4 Moyens spéciaux de visite

Pour faciliter la tâche des échelons locaux, des moyens et engins modernes sont mis à leur disposition. Actuellement sont en service :
- 4 plates-formes descendantes sur rail,
- 1 plate-forme ascendante sur rail,
- 3 plates-formes ascendantes sur route.

2. ENTRETIEN ET RÉNOVATION

L'entretien des ouvrages d'art est nécessaire pour assurer la sécurité des circulations mais de plus un entretien bien conduit permet de prolonger la durée de vie des ouvrages.

Pour tous les ouvrages et particulièrement pour les ouvrages anciens, l'entretien a des conséquences sur la régularité des circulations. De plus, compte tenu des impératifs budgétaires, les points de vue de l'ingénieur, de l'exploitant et du financier sont parfois contradictoires et un compromis doit être trouvé prenant en compte bien évidemment, en priorité, la sécurité des circulations.

L'ensemble des constatations faites lors des visites annuelles et des inspections détaillées, consignées par écrit, permettent d'établir un programme d'entretien mis à jour chaque année.

Dans un souci de bonne gestion, la décision finale qui aboutira soit à des travaux d'entretien, soit au renouvellement de l'ouvrage ne sera prise qu'au vu :

- des constatations objectives formulées par le contrôleur et après analyse de ses conclusions,
- de la vérification par le calcul de la force portante résiduelle des ouvrages, et le cas échant :
- d'essais sur les matériaux constitutifs de l'ouvrage (métal, pierre-béton),
- d'essais de chargement de l'ouvrage avec mesures concomitantes de contraintes et de déformations.

Un bilan comparatif des réparations et du renouvellement de l'ouvrage est établi en tenant compte, pour les réparations, de la durée de vie probable de l'ouvrage ainsi conforté.

3. OUVRAGES EN BÉTON – CAUSES PRINCIPALES DES RÉPARATIONS – ENSEIGNEMENTS TIRÉS POUR LES OUVRAGES NOUVEAUX

3.1 Causes principales des réparations sur les ouvrages en béton

Indépendamment du vieillissement accéléré des structures en béton dû à l'augmentation des charges et des vitesses, l'examen des travaux courants d'entretien montre que les principales causes d'intervention sont dues :
- à l'oxydation des parties métalliques, garde-corps, poutres des ponts à poutrelles enrobées,
- au mauvais fonctionnement et au remplacement des appareils d'appui,
- aux réparations des épaufrures et éclatements du béton,
- aux étanchéités défectueuses et à la collecte des eaux.

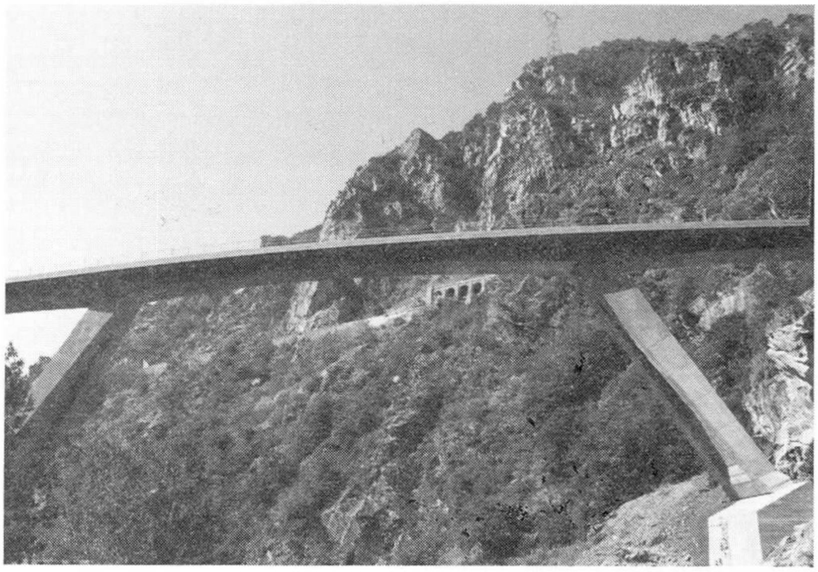

Photo 1 – Ligne de Coni à Vintimille Viaduc de Scarassoni – Caisson en béton précontraint, Long. 117 m

3.2 Conception des ouvrages neufs sur lignes existantes ou nouvelles

Compte tenu des constatations faites sur les ouvrages en service, des règles ont été prescrites pour la conception des ouvrages nouveaux, pour qu'une fois exécutés, leur entretien n'ait qu'une influence très réduite sur la régularité des circulations ferroviaires.

C'est ainsi que, outre le choix raisonné du type d'ouvrage qui conduit par exemple pour les ouvrages courants à retenir des structures rustiques en béton ou à poutrelles enrobées les dispositions particulières ci-après sont prises :

3.2.1 Parties métalliques

Les garde-corps et les fermettes des auvents de protection caténaire pour les ponts-routes sont en alliage d'aluminium. Les grillages de protection sont galvanisés. Les joints de dilatation des ponts-rail sont en inox et les poutrelles des ponts à poutrelles enrobées sont métallisées et peintes.

3.2.2 Appareils d'appui

Le choix des appareils d'appui source de difficultés à terme fait l'objet de soins particuliers.

A titre d'exemple pour les ponts-routes à 3 travées, ponts-types pour franchir l'emprise du domaine ferroviaire, les appuis intermédiaires sont des articulations "Freyssinet" ne nécessitant aucun entretien et les appuis d'extrémité sont des appareils en élastomère fretté dont le remplacement éventuel peut se faire sans interruption du trafic ferroviaire compte tenu de leurs positions par rapport aux voies.

3.2.3 Dégradation du béton

Pour tout ce qui concerne les parties enterrées, emploi de ciments spécifiques (CLK – CHF – CLC) afin d'éviter d'éventuelles agressions chimiques du milieu environnant.

Contrôle sévère de l'enrobage minimal des aciers afin d'éviter les éclatements du béton par oxydation des armatures.

Contrôle strict de la cure des bétons pour les parties en élévation.

3.2.4 Étanchéité

Mise en œuvre d'étanchéité de type agréé suivant des techniques ayant fait leurs preuves.

Pour tous les ponts-rails et viaducs, l'étanchéité mise en place est ainsi composée d'une chape en bitume armée, protégée par une contre-chape en asphalte porphyré.

3.2.5 Buses métalliques

Pour ce qui concerne ces ouvrages sous voie, les tôles ont une épaisseur majorée par rapport à celle que donne le strict calcul résistant et la protection contre la corrosion est renforcée par une galvanisation épaisse.

De plus ils sont dimensionnés de façon telle, qu'en cas de désordre un chemisage en béton puisse être mis en place tout en conservant le débouché minimal requis.

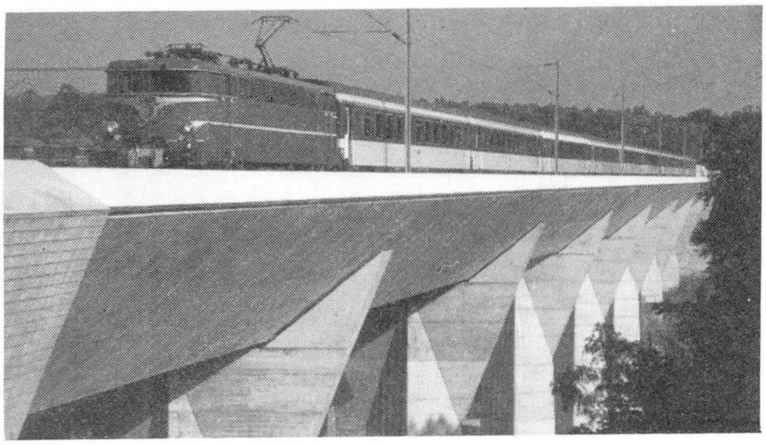

Photo 2 – Ligne de Paris à Lille, Viaduc de Commelles – Caisson en béton précontraint pour 4 voies, Long. 400 m

3.2.6 Grands viaducs en béton précontraint

Pour leur conception et leur exécution des dispositions particulières sont prévues :

- augmentation du ferraillage passif,
- étude de la précontrainte de façon que la tension initiale des câbles soit limitée à 0,7 FRG,
- étude de dispositifs spéciaux permettant la mise en œuvre d'une précontrainte complémentaire ultérieure,
- équipement de certaines sections sur appui et en travées avec des témoins à corde vibrante,
- mise en place sur appuis de blocs-contraintemètres permettant à tout instant de connaître les valeurs des réactions d'appui. Les valeurs relevées associées à celles des témoins sonores du tablier renseignent sur l'évolution des contraintes dans le temps.
- injection par la méthode dite "sous vide" des gaines de précontrainte. Cette méthode permet un remplissage quasi parfait des conduits,
- auscultation gammagraphique des gaines par sondages pour vérifier leur remplissage et la compacité du coulis.

4. SOUHAITS D'UN "CONTROLEUR-GESTIONNAIRE" D'OUVRAGES D'ART

Tout ce qui vient d'être exposé ne peut conduire à une modification profonde de l'organisation de la surveillance et de l'entretien des ouvrages d'art à la SNCF, organisation qui a montré depuis plusieurs décennies son efficacité, mais les prescriptions nouvelles relatives à la conception, l'exécution, l'instrumentation peuvent modifier profondément la gestion du patrimoine pour les ouvrages construits récemment et pour les ouvrages futurs.

Compte tenu de l'aide apportée par l'informatique, les projets arrivent à un haut degré de perfection du point de vue théorique et les projeteurs peuvent être légitimement satisfaits de leur réussite. Mais ces projets élaborés ne tiennent pas toujours compte des imperfections et des difficultés inéluctables de l'exécution et ils ignorent parfois des dispositions constructives élémentaires nécessaires à une bonne réalisation.

Sur le terrain ce ne sont pas les concepteurs qui construisent et mettent en place le ferraillage, ce ne sont pas eux non plus qui mettent en œuvre le béton, mais ce sont des manœuvres peu spécialisés et de moins en moins spécialisés. Cela devrait conduire les concepteurs à plus de réalisme et pour que les aléas de chantier soient les plus réduits possibles, une concertation est nécessaire pendant l'étude de l'ouvrage, entre le projeteur, le contrôleur et le gestionnaire futur.

Cette concertation éviterait que ne se renouvellent les difficultés rencontrées par le passé lors de la construction de certains ouvrages :

- tracés de gaine de précontrainte parfaits théoriquement mais peu compatibles par endroit avec le ferraillage passif,
- positionnement des gaines rendant difficile localement la mise en œuvre correcte du béton. (les systèmes DAO et CAO devraient pouvoir résoudre aisément ces problèmes).
- plans de ferraillage prêtant à interprétation ou difficilement réalisables sans modifications importantes,
- absence de "cheminées de bétonnage" dans le ferraillage,
- réduction trop importante des épaisseurs d'âme en béton dans un souci d'économie.

Pour ce qui concerne la concertation entre le concepteur et le gestionnaire futur de l'ouvrage il y aurait également beaucoup à faire. Aux journées de l'AFPC en 1983, M. l'Ingénieur Général BELTREMIEUX souhaitait que les visites des ouvrages ne soient pas de véritables "parcours du combattant".

Malheureusement c'est un vœu qui ne se réalise que très progressivement. Des efforts non négligeables ont été faits mais des progrès restent à faire qui sans obérer les coûts d'investissement devraient permettre d'éviter certaines erreurs passées :

- trous d'homme pour l'accès à l'intérieur de caissons dimensionnés vraisemblablement en fonction de la corpulence du projeteur (des projeteurs obèses seraient les bienvenus!),
- passages d'entretoises demandant des qualités acrobatiques de la part des inspecteurs,
- visites des appareils d'appui sur piles élancées de grande hauteur rendues difficiles par l'exiguité de la surface disponible. Absence de garde-corps de protection jugés inesthétiques par les architectes.
- visites des perrés de grande hauteur qui relèvent plus de l'alpinisme avec cordées de rappel que d'une visite technique spécialisée,
- caissons en précontraint de trop faible hauteur libre.

Ces difficultés résolues, la recherche d'inspecteurs qui devaient jusqu'alors répondre au profil suivant :

"Guides de haute montagne, ni trop gros, ni trop grands, ayant de très bonnes connaissances techniques en ouvrages d'art",

deviendrait alors plus facile.

Design of Bridges for Inspection, Maintenance and Repair

Dispositions constructives des ouvrages d'art en vue de l'inspection, de l'entretien et de la réfection

Bauliche Durchbildung von Brücken zur Besichtigung, Wartung und Instandsetzung

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SUMMARY
The report stresses the importance of inspection, maintenance and repair for the long-term reliability of bridges and gives some information about requirements of structural design and the organization of bridge inspection in the Federal Republic of Germany. Guidelines for practical design for the purpose of facilitating inspection and maintenance are explained, including economic aspects.

RÉSUMÉ
Ce rapport fait ressortir l'importance que revêtent l'inspection, l'entretien et la réparation pour la fiabilité à long terme des ouvrages d'art. Il donne en même temps quelques renseignements au sujet des exigences de la construction et en matière d'organisation de l'inspection des ouvrages d'art. Des dispositions constructives visant à faciliter la gestion des ouvrages d'art sont expliquées à titre d'exemple et évaluées du point de vue économique.

ZUSAMMENFASSUNG
Der Bericht betont die Bedeutung von Prüfung, Unterhaltung und Reparatur für die Zuverlässigkeit von Brücken auf lange Sicht. Er gibt einige Hinweise zu konstruktiven Anforderungen und über die Organisation der Brückenprüfung in der Bundesrepublik Deutschland. Richtlinien für die bauliche Durchbildung zur Erleichterung der Brückenerhaltung werden erläutert und in wirtschaftlicher Hinsicht bewertet.

1. INTRODUCTION

Bridges must be properly designed, calculated and constructed. But this is not sufficient to guarantee longevity and long-term reliability. The most important causes are:

- Bridges are expected to achieve a life time of about 80 years. But nobody can predict the changes that may occur during this time, e.g. in terms of environmental conditions or service load.
- It is often not only economical but even necessary to make use of new developments in material, structural design and technique. But despite careful considerations in advance it is not possible to calculate the long-term behaviour of the structure precisely.

Therefore safety and durability of bridges can be ensured only by regular inspection and maintenance and also repair measures if necessary. From that follow particular requirements on design on the one hand and on personnel and equipment of road authorities on the other hand.

2. REQUIREMENTS OF STRUCTURAL DESIGN

It is an essential principle to be employed whenever possible to design in such a way that the structure will not suddenly collapse. Instead a possible failure should be noticeable in time by visible indications which can be detected by bridge inspection. Such indications can be extraordinary deformations or cracks whose width is increasing. In the Federal Republic of Germany it is required of prestressed concrete structures [1] that every cross section of the structure must contain several tendons. If one tendon were to fail, the others would have to be able to prevent collapse.

Usually we employ post tensioning. We have been trusting in this method, but we have also restricted the tensile stress of tendons in service to a relatively low level (55% of tensile strength). In our opinion this restriction is advantageous in order to limit the relaxation of the prestressed steel and to lessen the danger of crack corrosion. We believe that we in this way properly serve the longevity of the structure. The planned low level of the tensile stress offers also the possibility of overstressing the tendons in cases of extraordinary friction losses. These aspects should be taken into account when the allowed tensile stress is finally harmonized by the Euro Code 2.

External prestressing has been used in rare cases of strenghtening or repair of existing bridges, but not as a previously planned measure in order to facilitate future repair. Concerning new structures there are some considerations here and there to locate unbonded tendons outside the cross section so that they can be exchanged. But such solutions have not come into practice yet. We also have reservations about building in empty prestressing ducts to have the option of introducing additional tendons later on, because hollow spaces in concrete can be detrimental.

3. ORGANIZATION OF BRIDGE INSPECTION

Facing the significance of maintenance of existing bridges the road authorities of the FRG have been setting up a well thought out system of bridge inspection. Each federal state employs well trained inspection groups. The staff must meet high requirements, because the correct interpretation of observations, possibly indicative of dangers, needs expert knowledge and wide experience.

The general rules of bridge inspection are laid down in DIN 1076 [2]. There are three basic types of bridge inspection:

- Superficial inspection
- Principal inspection
- Special inspection

Superficial inspections are carried out at least four times a year in connection with the normal observation of the road by road maintenance personnel without special training. The purpose is to report obvious deficiencies which can be found without special means.

Intervals of principal inspections are three years. Every six years even hardly accessible areas have to be inspected by means of special equipment or scaffolding. Principal inspections are made by inspection groups led by a trained inspector under the general supervision of a bridge engineer.

Special inspections are required after particular events like extraordinary traffic accidents, high water or fire.

4. PRACTICAL DESIGN FOR FACILITATING BRIDGE INSPECTION AND MAINTENANCE

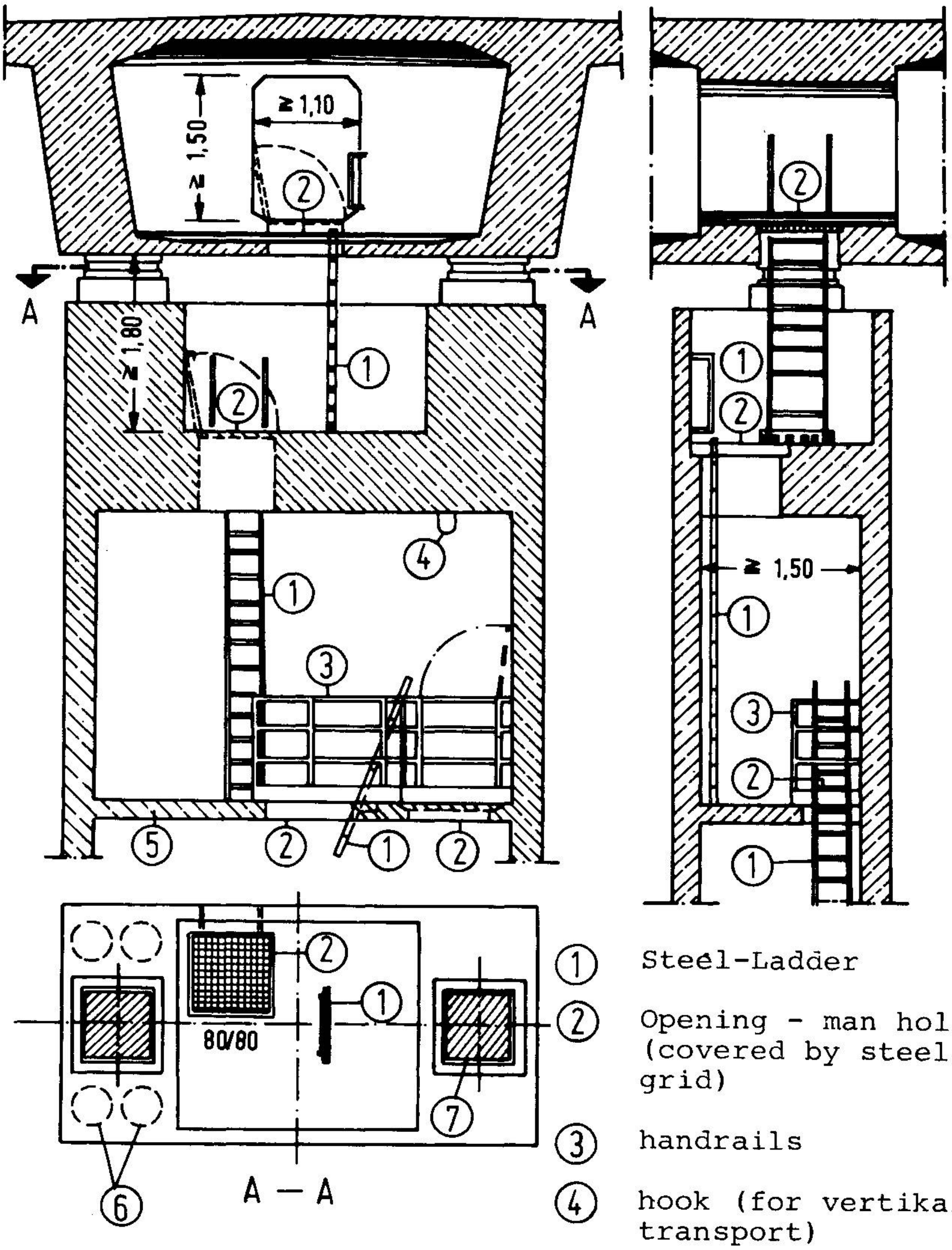
The inspection groups have all equipment needed to reach the critical zones of the structures. They are even equipped with snoopers (investigation cars) working from the ground or from the surface of the bridge grasping at the soffit. But this kind of equipment is costly. Snoopers can not carry heavy loads and are susceptible to dirt arising from repair work. Therefore it is economical and efficient to design in such a way that inspection and maintenance can be done without special equipment as far as possible.

In the Federal Republic of Germany guidelines [3] in this field were elaborated. We have learnt that they must be respected at all stages of the design process. These guidelines are to ensure that inspection as well as foreseeable repair work can be performed whenever necessary, as easily as possible, with due regard to the safety of the staff and without significant hindrance of traffic. The objective is a design which enables the bridge inspector to reach every point of the surface of the structure with his own hands using means as simple as possible.

Special value is attached to accessibility of bridge bearings, transition joints, drainage pipes and other components which are particularly exposed to wear and tear. According to our experience an inspection tunnel should be provided below transition joints. Drainage pipes along the web of a T-beam need to be accompanied by a foot-bridge for the inspecting crew. All hollow spaces must be accessible.

Necessary repairs must not be delayed because of lacking infrastructure. Therefore driveways to the ground below the bridge and also basic installations for electrical lighting in the hollow spaces must be taken care of when the bridge is built.

As an example of practical design fig. 1 reveals the access to the head of a high hollow pier from the box girder and within the pier. The box girder is accessible from each abutment, the pier from the ground by a door. Within the pier platforms (at intervals of 5 m) and ladders are installed. This is especially significant in case of drainage pipes within the pier. All steel parts are hot-galvanized. The platforms can carry loads usually occurring during repair work. Material can be lifted by a winch through openings in the platforms. All arrangements are made to install jacks on the pier head so as to lift the superstructure and to exchange bridge bearings if necessary.



(1) Steel-Ladder

(2) Opening - man hole (covered by steel grid)

(3) handrails

(4) hook (for vertikal transport)

(5) platform (r.c. or steel grid, 5 m c/c)

(6) seats for jacks

(7) bridge bearings

Fig. 1 Access within pier and from box girder to pier head.

5. ECONOMIC CONSIDERATIONS

Appropriate practical design to facilitate bridge inspection, maintenance and repair undoubtedly requires special care and to some extent extra costs. On the occasion of the erection of the bridge over the Kiel Channel near Brunsbüttel (2831 m long, 21 m wide, up to 45 m high, structure partly of steel, partly of prestressed concrete, completed in 1983) these extra costs were figured up. The costs of the structure amounted to 150 million DM, the additional costs of the measures derived from the principles explained in chapter 4 amounted to 4.4 million DM, which is 3%. Considering the importance of all these measures for reliable and durable bridges we are convinced that an expenditure of this order, with respect also to smaller bridges, is worth-while.

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Measures for Maintenance of Concrete Structures

Mesures à prendre pour la maintenance des structures en béton

Massnahmen für die Unterhaltung von Betonbauwerken

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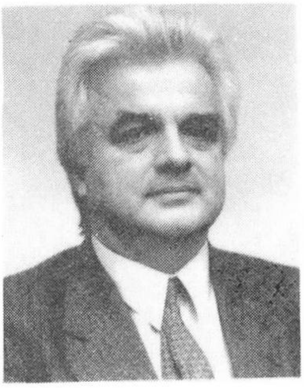

Aleksandar Pakvor was born in 1934. B. Civ. Eng. , Master of Engineering and Doctor of Science from the University of Belgrade. After five-years' work at the Institute CERNI in Belgrade, he started working at the Belgrade University. As Professor for Concrete Structures he is engaged in teaching, scientific, research work and professional activities.

SUMMARY
Provision of sufficient safety, the necessary serviceability and the required durability of concrete structures during the service life is both a technical and an economic problem. Maintenance of existing concrete structures requires considerable financial resources. On the basis of experience, the improvement of concrete structures' quality and the reduction of maintenance expenses provide the most convenient solution. For easy and economic maintenance, a series of measures should be taken during design, construction, exploitation and maintenance. Regular and preventive maintenance, systematically organized with planned financing, has many advantages.

RÉSUMÉ
L'assurance d'une sécurité et d'une durabilité suffisantes des structures en béton en cours d'exploitation est un problème technique et économique. La maintenance des structures existantes exige des moyens financiers importants. D'après les expériences faites jusqu'à présent, l'amélioration de la qualité de futures structures en béton et la diminution des frais de maintenance constituent la solution la plus favorable. Pour une maintenance facile et économique, il faut prendre une série de mesures lors du projet, de l'exécution, de l'exploitation et de la maintenance même. L'avantage est donné à une maintenance régulière et préventive qui est systématiquement organisée et financièrement planifiée.

ZUSAMMENFASSUNG
Die Garantie genügender Sicherheit, nötiger Gebrauchsfähigkeit und geforderter Dauerhaftigkeit von Betonbauwerken im Laufe ihrer Anwendung ist ein technisches und ein wirtschaftliches Problem. Die Unterhaltung bestehender Bauwerke fordert merkliche finanzielle Mittel. Den bisherigen Erfahrungen nach ist eine Qualitätsverbesserung von Betonbauwerken und eine Verringerung der Unterhaltungskosten die günstigste Lösung. Für eine leichte und wirtschaftliche Unterhaltung sind zahlreiche Massnahmen erforderlich : beim Entwurf, der Ausführung, der Anwendung und der Unterhaltung selbst. Den Vorrang hat eine regelmässige und eine präventive Unterhaltung, die systematisch organisiert und planmässig finanziert ist.

Nowadays, when concrete structures are widely applied in civil engineering, their *maintenance* has become a very present *technical* and *economic* problem. Recently, sudden unexpected catastrophies of failure due to poor maintenance have been witnessed and, on the other hand, considerable financial resources are required for the maintenance of the existing concrete structures. Great interest of experts in this field is not accidental, neither are numerous professional and detailed discussions on a series of scientific and professional conferences. When selecting the most convenient solutions for the new concrete structures, in the process of comparing the possible alternatives, care must be taken on the anticipated future maintenance costs.

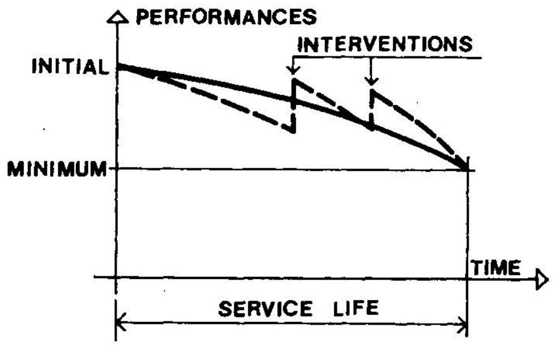

Fig. 1. SERVICE LIFE OF CONCRETE STRUCTURES

The designed *service life* of concrete structures can be achieved with different scope of interventions Fig.1. The better the quality of the concrete structures, the lower the decrease of their performances from the initial to the minimum required values at the end of the service life. More frequent interventions are necessary to make the service life of the lower quality concrete structures match the service life of the higher quality concrete structures. That certainly requires higher expenses.

Due to technical and economic reasons there should be a tenedency to make the future concrete structures of the *best quality* possible, to make *maintenance operations easy* with the *minimum expences*. Beside correcting the designing, construction, exploitation and maintenance defects and errors, many future inovations will be necessary in order to increase the quality of concrete structures.

The very fact that the requirements with regard to the safety and serviceability of the concrete structures are most frequently increased during the exploitation period makes it difficult to establish the required service life. When designing, it is not easy to realistically establish, many years in advance, all future requirements connected with the increase of loading and actions together with technological and functional requirements.

It is quite clear that concrete structures, when they reach their service life, *should not be immediately replaced*. That is, however, the moment when it should be *analyzed* and *assessed* if the future increased expenses of the maintenance would be *economically more favourable* than the expenses of building a new structure. That is when *the decision should be made on further destiny* of the existing concrete structures.

Maintenance should cover *all the elements of the strucutures* regardless of whether those elements, in the strict sense of the word, belong to the concrete structures themselves or not. Poor maintenance of the *equipment* of the structures can greatly influence the decrease of concrete structures reliability. As such equipment is, as a rule, of *significantly lower durability*, great attention must be paid to its maintenance. *Control, repair, rehabilitation* and *replacement* of the equipment should be much *more frequent*.

It is extremely important that all the elements of concrete structures and of the equipment are absolutely *accessible* for control and interventions. This especially refers to the parts which are subjected to great stresses or to stresses which are difficult to be precisely anticipated including the parts exposed to aggressive actions. The easiest possible replacement should be provided for the lower durability elements of the equipment. This should be taken care of already during the stage of designing. Special attention must be paid to those elements of the concrete structures which must remain difficult to access.

Maintenance of concrete structures should be *regular* and *preventive*. Irregular maintenance, especially if it is initiated by the damages which are, when observed, in most cases, in an advanced stage, causes far greater total expenses.

The maintenance of concrete structures and of the equipment depends on a series of technical and economic factors. In order to make the maintenance *easy* and *economical a series of measures* should be taken at *designing, construction, exploitation* and the *maintenance* itself. The specific measures depend on the basic *purposes of the maintenance*: to achieve *safety, serviceability* and *durability.*

The first group of measures refers to securing the sufficient *safety* of concrete structures during their service life.

The real *safety factor* of the concrete structures in relation to the ultimate limit state should correspond to the prescribed *limit values.* At the design stage, on the basis of the real data regarding the location, loadings and the possible action with the introduction of the realistic properties of the applied materials, the expected values of the safety factors, should be determined as precisely as possible. Attention should be paid to the selection of geometrical forms and the details to be constructed. Concrete structures should be of simple shapes, not too indented, and filgree forms, they should not include sudden changes of geometrical forms, the distribution of reinforcement and tendons should enable regular casting of concrete. There should be no high concentration of reinforcement but the concrete should be sufficiently filled with reinforcement especially on the places on which tendons are anchored and the places subjected to the action of concentrated forces. During the construction stage, it is necessary to fully attain the requirements of the design especially with regard to the materials used and the executed works, with regard to the preciseness of geometrical form including the position of tendons and reinforcement, with regard to the boundary conditions and the way of the loading transmission. If possible, during the exploitation, it is necessary to protect the structure from overload and unforseen actions especially if they are uncontrolled. During the maintenance, it is necessary to control and prevent all changes that could cause decrease of the safety factor below the permitted values. It is also necessary to control bearings, expansion joints, displacements of supports, uneven settlements, scour of the foundations, damages and unevenness of the pavements damages of thermal insulations and the like. Supplementary analyses of real safety factors is indispensable in cases of changes which are difficult to prevent. If required, rehabilitation of the structure should be done.

The second group of measures refers to securing the necessary *serviceability* of concrete structures and the equipment during the service life.

Real *defelctions,* and *widths of the cracks* and *vibrations* of concrete structures should correspond to the coded or adopted *limit values.* Thereby, the required function is provided together with the influence on *durability, aesthetics* and *psychological safety* . During designing, the expected values of deflections, widths of cracks and vibrations should be determined with maximum preciseness. Concentrations of stresses and unforseen cracks, should be avoided by the application of the corresponding construction measures. During maintenance, the real deflections, the widths of the cracks and vibrations should be controlled. If they are not within the design limits the causes of the excess should be immediately established and removed together with injecting of all cracks of excessive width and, if necessary, the rehabilitation.

During designing, construction, exploitation and maintenance, a series of measures should be taken to provide *serviceability* of the equipment of the structure. Its correct functioning could significantly influence the serviceability of concrete structure.

The third group of measures refers to the provision of the required *durability* of concrete structures.

The required measures are related to prevention, decrease or slowing down the *deterioration processes* in concrete structures as well as to the repairs and rehabilitation of the damages.

The most serious form of the concrete structures deterioration is the *deterioration of steel* arising due to the *corrosion of reinforcement* and the *corrosion of tendons*. Full attention must be paid to the permanent corrosion protection of the steel. In concrete, steel bars are corrosion protected by *passivation*. Due to the decrease of alkalinity of concrete, because of carbonation or environmental aggressivity, the passive oxide film on the surface of the steel bars becomes unstable and its dissolution takes place. Due to depassivation the corrosion protection of steel bars in disturbed.

Deterioration of concrete which can be *physical, chemical* or *biological* is less frequent compared with deterioration of steel. However, deterioration of concrete can significantly influence the increase of deterioration of steel.

Deterioration of concrete structures is highly influenced by the processes of the *combined transport of moisture, heat and chemical substances* within the concrete itself and in the interaction with the environment.

The presence of *water* and *moisture* in concrete structures during the service life is the most dangerous factor for the appearance and development of the deterioration processes. In order to increase durability, all measures should be taken to decrease or prevent retaining of water on concrete structures and its penetration into the concrete. Water should be drained off the concrete as soon as possible. Therefore, secure *waterproofing* and efficient *draining system* should be designed. When selecting the shape of the concrete structures, the possibilities of direct course or water retention on the surface of concrete should be avoided, especially on the places on which elements are connected and on the operation joints. Smooth concrete surfaces are better that the rough ones. Concrete should be protected from direct splashing especially when it is caused by traffic of vehicles due to possible presence deicing salt. Easy replacement should be designed for those elements which are difficult to protect. Openings for quick draining of possibly penetrated water should be designed on box girders together with the aeration of the boxes. The draining system should be so designed as to provide safe and quick draining of water and to be easily accessible for maintenance. The tubes should not be embedded into the concrete. During maintenance, permanent control of waterproofing and of draining system should be conducted. Possible damages or blocking of the draining system should be immediately removed. The drifted trash, dirt, dust and weeds should be regularly removed from the concrete structures.

The deterioration processes of concrete structures are significantly influenced by the *environmental aggressivity*. In most cases, concrete structures are placed in *chloride* aggressive environment due to presence of sea-salt on coastal structures or deicing salt on structures intendend for traffic. Industrial concrete structures can frequently be subjected to *chemical action* of various *aggressive substances*. During the designing and construction, measures of permanent protection against environmental aggressivity should be taken; during exploitation, measures directed to decrease environmental aggressivity should be applied; the maintenance should include control and repair of the existing protective coatings and covers together with the removal of the drifted aggressive substances.

Climate conditions also make one of the factors of concrete structures deterioration. *Rainfall, snowfall* and *air humidity* are the main sources of possible water and moisture in concrete structures. The *increased temperature* influences the acceleration of the concrete deterioration processes. *Considerable temperature differences* that cannot be forseen can cause cracks in concrete while *thermal shocks* due to freezing and possible short-term fire can damage the concrete cover. Wind drifts drops of sea water or sea-salt sedimented on the coast to coastal concrete structures. *Rainfall* and *wind* together with dust and dirt can cause erosion of the concrete surface and they can block the draining systems. Beside already listed measure, *thermal insulation* should be designed, following the requirements. It should be controlled and repaired during the maintenance of the structures.

The state of *concrete cover* and the state of *tendon protection* which is most frequently achieved by cement grouting make an essential factor of the concrete structures deterioration. Porous, thin, poorly made and damaged concrete covers and porous, poorly made and on some places the missing groutings for tendons, directly influence the corrosion of reinforcement and tendons. The process is progressive as the corroded steel bars cause further damage of the concrete cover. During the designing and construction, the *compactness* and the required *thickness* of the concrete cover should be secured that are, depending on environmental aggressivity, defined by the codes. The groat should be compact and well applied along the whole length of the tendons. During maintenance, it is very important to control the existing concrete covers and the grout for tendons. The appearance of rust stains, calcium or water on the surface of the concrete, 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.

The state of *cracks* is also an essential factor of concrete structures deterioration. In the cracked areas, the penetration of aggressive substances into the concrete is much easier and the process of concrete carbonation is more intensive. To secure durability of concrete structures it is necessary that the width of the cracks does not exceed the limited values defined by the codes which is achieved by already mentioned measures. Cracks of the lower width, frequently full of calcium, dirt and rust deposits, have significantly lower influence on the deterioration processes.

Carbonation of concrete is also one of the basic factors of concrete structures deterioration. The progress of carbonation process into the concrete is very slow and the level of concrete carbonation can be easily established by chemical indicators.

The maintenance of concrete structures should be *systematically organized* with the *planned financing*.

The *maintenance design* should, depending on the kind of the structure, its quality and the degree of danger, anticipate the required *measures of maintenance* to be applied to concrete structures and the equipment, reasonable *frequency* of the relevant works and the *responsibility* for their performance. However, it is difficult to anticipate all the details in advance, especially after accidental actions, the alteration of the exploitation conditions and the discovery of the unknown failures and errors made during the construction.

All the data on the anticipated and the realized maintenance make an integral part of *technical documentation* on each concrete structure and must be carefully taken care of.

The purpose of *organizational forms of maintenance* is to *establish the condition and behaviour* periodically or against the requirements or they can mean higher or lower *interventions*.

Initial observations should be permanent and do not require any particular professional skill. The basic purpose of initial observations is to provide *permanent general, visual follow up of the condition and behaviour* of the concrete structures and the equipment in order to reach *due observation of the arisen changes* and to take the necessary actions.

Routine inspections of concrete structures should be carried out periodically, after time intervals which are established in advance. It is thought that the most endangered concrete structures (the structures in aggressive environment, bridges) should be subjected to such inspections once a year. Routine inspections cover *professional visual control of the condition and behaviour* of concrete structure and the equipment.

Periodical inspections are less frequent compared with the routine inspections but they are more detailed and more comprehensive. It is thought that the most endangered concrete structures should be subjected to such inspections every five years. Periodical inspections include the *detailed professional visual control of the condition and behaviour* of the concrete structure and the equipment including the *control measurements* of the quantities required for the establishment of the real reliability of the concrete structure.

Special inspections are carried out only following the requirements. They are performed on the highest professional level, only by specialized professional organizations or institutes, in many cases using the services of experts.

Against requirements, various *special investigations* can be carried out in order to establish the causes or levels of damages.

Correcting of small defects are the smallest but not unimportant interventions (removal of scrap, mud, weeds, salt and aggressive substances, cleaning, washing, prodding free of the draining system ....). Special skill is most frequently not required for such operations. However, it is especially important to carry out such operations *in time*. Delyed removal even of smaller defects can initiate further progressive damages of concrete structures.

Repairs are applied when damages of the equipment or the elements of concrete structures are relatively small. They are performed by professional individuals or services. No special designs are necessary for repairs although the corresponding technical documentation can be made.

Rehabilitations are applied to larger damages of the equipment or the elements of concrete structure. They are carried out according to specially produced main designs which contain, on the ground of the established cause and level of the damages, the detailed elaboration of the methods for their correction. Such designs also indicate the ways of rehabilitation of the damaged equipment or the elements of the concrete structure.

Reconstructions are the greatest interventions on concrete structures. Often, they are connected with *adaptations* for which there are requirements regarding significant increase of static and dynamic loading and actions or the new functional and technological demands.

In case it is found necessary, the replacement the equipment or individual elements of the whole concrete structure takes place.

Finally, the *great importance of correct maintenance of concrete structures* should be emphasized once again. Regular and systematic maintenance is technically the most efficient and economically the most favourable solution. By the establishment of the changes of conditions and behaviour on time, as well as by due correcting of the observed deffects and damages, significant contribution is made to sufficient safety, necessary serviceability and the required durability of concrete structures.

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Inspection and Maintenance of Post-Tensioned Tendons

Inspection et entretien des câbles de précontrainte

Inspektion und Unterhaltung von Vorspannkabeln

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SUMMARY

The paper discusses the inspection and maintenance of post-tensioned tendons in existing and future prestressed concrete structures. It includes brief presentations of current post-tensioning techniques with internal / external and bonded / unbonded tendons as well as the possibilities of non-destructive and destructive inspection.

RÉSUMÉ

L'exposé traite de l'inspection et de l'entretien des câbles de précontrainte dans des structures existantes ou futures. Les différents systèmes de précontrainte avec câbles intérieurs ou extérieurs sont brièvement décrits, qu'il s'agisse de précontrainte injectée ou sans adhérence. En outre, les possibilités d'investigation par le biais de tests non destructifs et à la ruine sont mentionnées.

ZUSAMMENFASSUNG

Der Beitrag handelt von der Inspektion und der Unterhaltung von Spannkabeln in heutigen und zukünftigen Spannbetontragwerken. Er schliesst kurze Erläuterungen zu den existierenden Spannverfahren mit internen bzw. externen Spanngliedern, sowie mit Spanngliedern mit und ohne Verbund ein. Ausserdem werden die zerstörungsfreien und zerstörenden Untersuchungsmethoden erwähnt.

1. INTRODUCTION

The first applications of the prestressing technology in modern times are now about 50 years old and most of them are still in service.

After 1945 prestressed concrete gained general acceptance very rapidly as it proved to be an ideal technique for rebuilding the infrastructure of post-war Europe. Later on prestressing was successfully introduced on the other continents.

Due to its inherent economical and technical advantages prestressing found applications in almost all fields of civil engineering structures such as:

- Bridges (spans ranging from 20 m to over 450 m)
- Buildings (slabs, beams, etc.)
- Circular Structures (reservoirs, silos, pressure tunnels, safety containments)
- Geotechnical Structures (foundations, ground slabs, anchored walls for excavations and numerous applications of prestressed ground anchors).

It is no exaggeration to say that prestressed concrete has revolutionized the civil engineering world. To illustrate this, it can be mentioned that today in many countries over 60 % of all existing bridges (related to the bridge deck area) have been built with this technique. At the same time considerable savings in money in the order of 10 to 20 % could be achieved by using prestressed concrete over other materials.

For many years engineers believed that concrete is virtually maintenance-free. Because of this, the design for maintenance was neglected. This is, however, on the verge to be changed. A comparatively small but nevertheless growing number of prestressed concrete structures show signs of minor or major destress.

The reasons for these unsatisfactory behaviours are the same as for other structural materials and can be summarized as follows:

- Design: Errors in planning, analysis, detailing.
- Execution: Unsatisfactory technology, human inadequacy.
- Service: Change of service conditions, e.g. environmental impacts (de-icing salts, etc.), increase in traffic loads.

It was Rüsch who rightly pointed out the inherent "system reserve" and the "cleverness" of reinforced and prestressed concrete structures. This on the other hand can also be a disadvantage because it takes a long time to recognize deficencies and to introduce the required improvements into future practice [1].

In this situation it is essential to follow two paths. We must continue to implement effective inspection and maintenance programs and if needed properly repair and strengthen our structures. At the same time, it is necessary to learn from errors for the design, execution and maintenance of future structures.

In the following, this paper will only deal with the inspection and maintenance of post-tensioning tendons.

2. PAST AND CURRENT POST-TENSIONING TECHNIQUES

Even if we concentrate only on post-tensioning and leave out other techniques, such as pre-tensioning and wire winding, we are still faced with a multitude of different prestressing steels and systems.

For the sake of completeness the definition of post-tensioned tendons is repeated here. A pt tendon consists in principle of four elements: prestressing steel as tensile member, mechanical anchorages, duct providing the void in the hardened concrete for the prestressing steel to move during stressing, filler material for the remaining void inside duct and anchorages (cement grout, grease, wax). The prestressing steel is stressed after sufficient hardening of the structural concrete and fixed in the anchorages. The filler material protects the steel against corrosion.

Especially in the beginning, engineers have been extremely innovative in creating pt systems. In the course of the years more than 100 different systems appeared on the market of which many, however, had a rather short life.

In addition some variations can be noticed throughout the years within an established pt system with regard to applied materials and field procedures.

Looking only at the main stream of current pt technology, we can first distinguish between internal and external tendons (tendons either inside the concrete or outside the concrete only connected at the anchorages and possibly also at deviation points). The bulk of applications has doubtless been with internal tendons.

After having been used in the initial phase of prestressed concrete (e.g. Dischinger Bridge at Aue, Saxony, GDR built 1936/37 [2]), external tendons however have recently seen a certain revival [3] with applications primarily in the USA (e.g. Long Key and Seven Mile Bridges in the Florida Keys designed by Figg & Muller), in France (after 1980 under the auspices of SETRA many bridges have been designed and built) and in the UK (Exe and Exminster Viaducts designed by Freemann, Fox & Partners).

Another important distinction must be made between bonded and unbonded tendons. Bonded tendons are those which are cement grouted after finishing the stressing operation.

The purpose of cement grout is two-fold; it provides sufficient bond between the prestressing steel and the surrounding concrete and protects the steel against corrosion.

The prestressing steel of unbonded tendons remains free to move along the tendon axis. It is only fixed to the concrete at the anchorages or couplers. The ducts can either consist of ordinary corrugated steel ducts or plastic sheathing (polyethylene or polypropylene either smooth or corrugated). As filler material suitable greases or waxes are normally used.

Practically all possible combinations of the above mentioned techniques are in existence and if properly designed and executed they perform as intended.

3. INSPECTION AND MAINTENANCE TODAY

In the civil engineering world the need for regular inspection and maintenance of concrete structures is generally accepted. There exist national or international standards indicating inspection intervals depending on criteria such as type of structure and environment [4].

Even if the principle is introduced, we can note in practice the full range between no tendon inspection at all which is by far the normal case and thorough, regular inspection for special structures only. For the latter the nuclear industry can be mentioned. From the early stages in the planning of prestressed concrete safety containments and pressure vessels, various regulatory bodies specified unbonded tendons. This concept allowed the monitoring of tendon forces, the possibility to adjust the tendon forces and to detension, remove and thoroughly inspect a particular tendon. For each US-containment in prestressed concrete a comprehensive and detailed surveillance program for pt tendons is in existence. For some earlier containments, inspection results over a period of more than 15 years are now documented.

Compared with other prestressing applications such an extensive surveillance program is exceptional. It was introduced because in the USA nuclear engineers were not familiar with this technique and therefore wanted to convince themselves of its reliability even more that pt tendons are absolutely vital for safety containments. It is interesting to note that later on, the French Electricité de France (EdF) for their 900- and 1300 MWe-Nuclear Power Station Program decided to use traditional cement grouted tendons because they are obviously more economical (lower initial costs and no expenditure for regular inspections) and because French engineers did not need to be convinced of their reliability.

It is a fact that except in some special applications as described above, pt tendons of prestressed concrete structures have not been designed for inspection. Everybody was convinced that the available concrete cover and the cement grout inside the ducts was sufficient for eternally protecting the steel against corrosion.

On the other hand pt tendons are a major element in assuring the required behaviour and safety of a structure both in service and ultimate conditions. In accepting this principle, also pt tendons must be inspected and maintained.

In order not to complicate the issue and to remain sufficiently practical, we <u>concentrate in the following only on longitudinal pt tendons in bridge superstructures</u>.

As the responsible engineer, we would like to know the actual status of the tendons. Let us assume that we have a ductile structure with more than one <u>bonded tendon</u>. In such a case the inspection engineer would primarily look for signs of destress or deteriorations such as unusual cracking, excessive deformations, wet or soaked areas, signs of rust, etc. In the presence of such defects and especially if the structure in question has been left unattended for many years, more thorough investigations are needed. We would like to know whether the prestressing steel has already been impaired by any form of corrosion.

What are the inspection methods theoretically available today? We can distinguish between non-destructive and destructive methods. For obvious reasons the client prefers non-destructive methods. Their essential disadvantage is that, if at all, they only show changes of certain properties in time.

We are not able to check directly the actual mechanical properties such as the ultimate tensile strength, but we measure some auxiliary value which is hopefully related to what we want to know. Methods in this category are gammagraphy, ultrasonic testing and potential measurements. Without going into detail, it must be mentioned, however, that these methods have unfortunately so many limitations, that they can only be recommended for special cases. Let us hope that in the future, researchers will come up with suitable non-destructive methods.

In order to apply destructive methods reasonably, it is advisable to look for potential weaknesses such as tendon high points, tendon couplers, construction joints, etc. First the tendon must be located inside the concrete. Then a hole is drilled carefully. The drilling must be stopped automatically when touching the tendon duct. In case the investigated area is not filled with cement grout (e.g. because of inadequate grouting procedure during execution) it is possible to visually inspect the prestressing steel with the help of an endoscope. The area can also be photographed.

Should corrosion be detected, it is generally up to the specialist to judge the situation and recommend measures. As a minimum requirement such detected voids must be properly filled with grout. If necessary, larger openings must be made and maybe even steel samples have to be cut out for testing the degree of deterioration in the laboratory.

Depending on the outcome of these investigations, proper maintenance, repair or strengthening measures can be decided. It is obvious, that the inspection methods available today are rather cumbersome. They are furthermore not entirely satisfactory, as they give us only results at some locations and not continuously over an entire structure.

4. OUTLOOK

In my personal view I see two main options for improvement. Also in this outlook I restrict myself to pt bridges. The reasoning can however be applied accordingly to other types of structures.

The first option is to retain the traditional technique of internal, bonded tendons. We primarily have to learn from past mistakes such as insufficient concrete cover, substandard concrete quality with regard to durability (carbonation, etc), incomplete duct injection with cement grout (e.g. voids at high points) and non-effective or even missing bridge deck insulation (in presence of aggressivity such as de-icing salts).

Furthermore quality assurance systems can help us to achieve the goal for better structures. The construction industry must profit from the good experiences of other industries. In particular any serious prestressing firm should have introduced by now an adequate quality assurance system [5].

All these measures and strategies will improve the quality of future structures. The principle that structures should be regularly inspected will still be retained. We will therefore still look for a method to qualitatively and quantitatively determine any harmful change of the entire pt tendon invisibly buried in the concrete. To my knowledge no method is available at present. It is known that specialists are currently working at it. The ideal solution would certainly be to measure the response of the tendon, longitudinally from one anchorage point to the other, to a physical impulse. Based on the result of a zero-measurement, any subsequent change could be detected. As a minimum requirement for the validity of method, the location of the actual damage should be given sufficiently precise and maybe also its nature.

The second option is to expand the application of external tendons. As mentioned in Chapter 2, the use of external tendons for bridges is increasing. In the context of inspection and maintenance of pt tendons the concept to arrange the tendons outside the concrete offers positive aspects. The "glassy" tendon inspectable at any stage seems theoretically possible. Due to several restrictions this is not true in its full extent; what is left however, is still considerable:
- the tendon force can be monitored
- the tendon force can be adjusted by restressing or detensioning
- the protective envelope of the tendon (steel or plastic tube) can be inspected and maintained without too much difficulties
- the tendon can be replaced.

Past and current designs do not fully utilize the potential possibilities that external tendons offer. More efforts are needed in this respect. It goes without saying that remarks made for the first option regarding the need for quality assurance, etc. are likewise valid.

In concluding, it is necessary to say that the involved parties in the design and construction process for prestressed concrete structures should realize the possibilities for improvement by introducing into new design ways to allow proper inspection and maintenance of pt tendons.

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Combatting Road Salt Corrosion in Concrete Bridges – the Way Ahead

Propositions pour la lutte contre la corrosion des ponts en béton

Tausalz-Korrosion von Betonbrücken – Massnahmen für die Zukunft

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SUMMARY
The paper identifies de-icing salt generated corrosion as currently the most damaging threat to the integrity of our concrete bridge stock, requiring ever increasing expenditure on future maintenance. Examples are given of typical salt attack zones. A package of measures is proposed for the design, detailing and specification of future concrete bridges to improve their resistance to this insiduous form of attack.

RÉSUMÉ
La corrosion due aux sels de déverglaçage constitue le plus grand danger pour notre patrimoine de ponts en béton. Ce problème demandera à l'avenir des dépenses croissantes pour la maintenance. Dans cette contribution, les zones tout particulièrement menacées sont décrites. L'auteur propose un certain nombre de mesures concernant le projet, le dimensionnement et l'exécution de détails constructifs qui permettront aux futurs ponts en béton de résister mieux aux attaques des sels de déverglaçage.

ZUSAMMENFASSUNG
Tausalzeinwirkungen und die dadurch erzeugte Korrosion stellen für die Dauerhaftigkeit unserer Betonbrücken die grösste Gefahr dar. Sie werden in den nächsten Jahren stark steigende Kosten für die Instandhaltung verursachen. Besonders gefährdete Zonen für Tausalzangriffe werden aufgezeigt. Für die Betonbrücken der Zukunft werden Massnahmen auf dem Gebiet der Planung, der Projektierung und der Ausführung vorgeschlagen, um den Widerstand gegen Tausalzeinwirkungen zu erhöhen.

1. ROAD SALT CORROSION

1.1 Road Salt De-icing & Concrete Bridges

It is a tedious fact that most of the highly industrialised nations lie in the winter snow and ice regions of the northern hemisphere. These nations are very dependent upon sophisticated highway networks which must be kept clear during winter, when the common remedy of spreading road salt for de-icing is applied.

Unfortunately, winter salt spreading operations are inevitably accompanied by melting ice or snow and the water run-off from the treated roads turns into a harmful sodium chloride solution. In the form of spray or run-off the deposit can penetrate the exposed faces of concrete bridges carrying or crossing the treated roads, causing weakening corrosion of embedded reinforcement bars and/or prestressing cables in those bridges.

Where the salt penetration is very random & there is not much free oxygen available at reinforcement or cable level, the lower ferric variety of corrosion develops. This is characterised by a local pitting of the attacked steel leading to a soft black corrosion deposit. With cover concrete of a reasonable strength, this deposit will not expand with sufficient force to break away the concrete. Typical local pitting black corrosion is shown in Figure 1. If more oxygen is present, the corrosion process is the more familiar variety with a general red surface rust. Inevitably the concrete cover is forced off by this harder & more expansive corrosion product, allowing more oxygen & moisture penetration along the bar, giving the more familiar progressive visible and red corrosion.

Thus, black corrosion is a potentially much more dangerous phenomenon as loss of reinforcement or prestressing cable is proceeding unseen under the surface. The accompanying reductions in structural integrity give no visible early warning such as cracking and spalling.

In addition, the rapid heat withdrawal from salt treated concrete surfaces can cause a sudden local surface temperature drop of up to 10^{o}C within one minute after application, or thermal shock. This can cause

Fig. 1 Black Corrosion

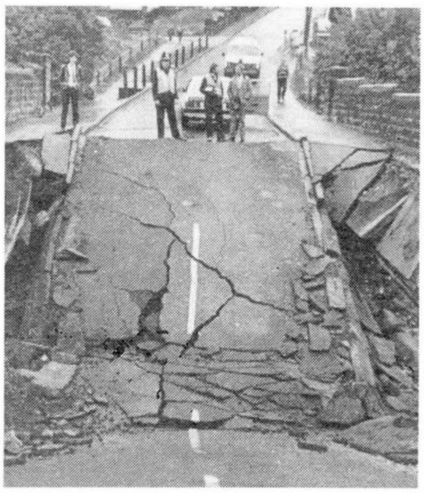

Fig. 2 Bridge Collapse

early surface cracking, leading to surface water penetration, ice formation and the familiar freeze-thaw surface spalling and concrete disintegration.

Concrete bridge corrosion damage arising from the winter salting of UK roads has become more evident of late, possibly because of the considerable increase in the stock of potentially vulnerable reinforced and prestressed concrete bridges which have dominated construction over the past three decades, combined with some recent severe winters and a massive increase in road salting of up to fifteenfold in the same period. It is also possible that the UK specification emphasis on concrete strength rather than impermeability has contributed to the apparent greater vulnerability of these more recent bridges.

The demolition of a 25 year-old prestressed concrete flyover in Berlin because of road salt damage was well publicised in 1985. Events moved uncomfortably closer to the UK in 1986 with the demolition of one bridge, and the collapse of another, (Figure 2).

1.2 Typical Salt Attack Zones

Figure 3 shows a typical concrete bridge unfortunate enough to be suffering all the winter de-icing salt attack zones which are commonly met with in bridge inspections. The vulnerable zones are indicated as subject to ponding, rundown, spray or direct penetration. The most troublesome areas are deck joints, parapets & piers. It should be emphasised that corrosion attack can be particularly rapid in local areas where the shelter of overlying structures prevents the beneficial cleansing actions of rain & salt-free spray.

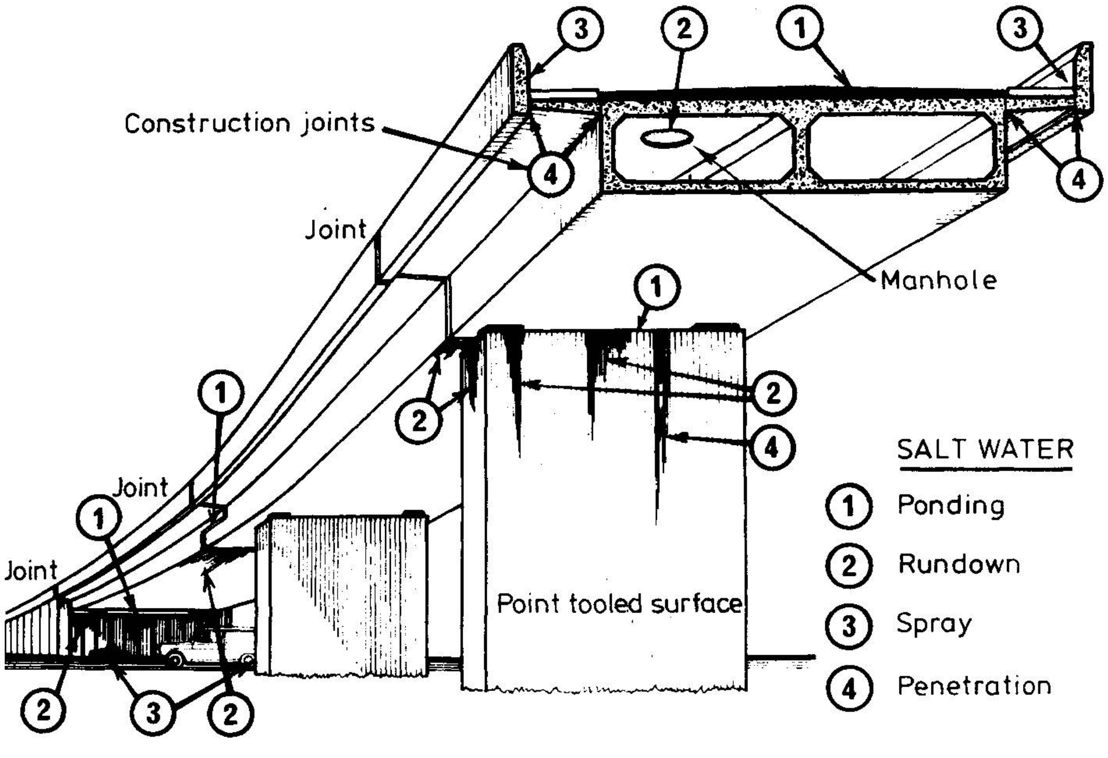

Fig. 3 Typical Salt-Vulnerable Zones

2. PROPOSED MEASURES TO REDUCE FUTURE VULNERABILITY OF BRIDGES TO SALT ATTACK

2.1 The Way Ahead

It is possible, with very little extra effort, to considerably reduce salt attack vulnerability in the design, detailing and specification of new concrete bridges. In addition, several new construction materials and techniques have offered varying degrees of protection to improve the salt resistance of new, existing or repaired bridges. These should be considered in conjunction with the design, detailing & specification procedures to reduce the future salt attack vulnerability of concrete bridges. Some of these are described.

2.2 Design for Deck Continuity

Bridge deck expansion joints are particularly vulnerable to salt attack, not only affecting the surrounding concrete but also the underlying piers and abutments. It therefore appears logical that deck designs should set out to minimise the number of expansion joints. These occur at deck ends over the abutments, with intermediate joints if multi-span decks are designed as a series of simply supported spans or, worse, with cantilever & drop-in span half-joint arrangements. The end abutment joints may always be with us, except in the case of very short built-in single span decks. Intermediate joints are generally unnecessary if deck continuity is adopted for multi-span bridges & flyovers. Continuity possesses many other beneficial features, such as reductions in deck construction depths and pier bearings, widths & foundations, in addition to a better running quality. A major proposal is therefore that multi-span deck continuity should be mandatory, unless soil conditions dictate otherwise, and that cantilever and drop-in spans should never be permitted. Fortunately, deck continuity is now commonplace and is encouraged by several national bridge authorities. The technique of building precast beams into prestressed insitu crossheads has been used successfully to form continuous decks on several large flyovers, (Figure 4). It can readily be adapted to avoid drop-in arrangements, (Figure 5).

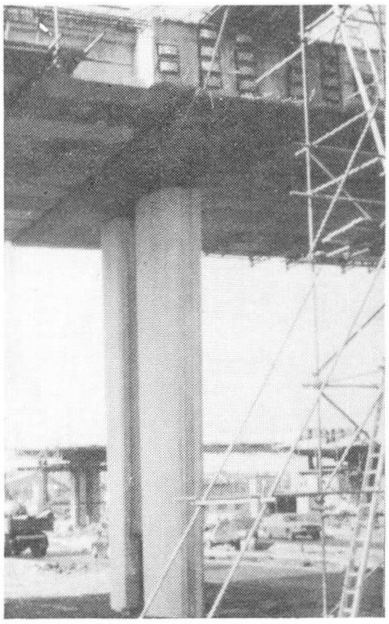

Fig. 4 Precast Beam Deck Continuity

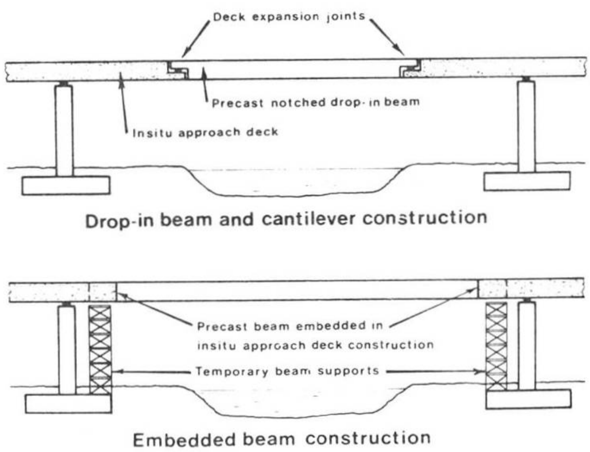

Fig. 5 Avoiding Half-Joints

2.3 Detail Accessible End Deck Joints

Figure 6 shows a proposed treatment to an end abutment expansion joint to avoid some of the common rundown & access problems. The ballast wall is set back and the abutment shelf dropped as necessary to provide sufficient access way at the back of the deck for future inspections & maintenance. Concrete corbels cantilever from the deck and the ballast wall to contain the expansion joint. The deck waterproofing is carried down the vertical/inclined edges of this joint and tucked into a drip formed under the corbel, providing rundown protection. The remaining soffit of the corbels and the deck vertical edge are treated with a thick bitumen paint or silane impreganation. This is particularly important in prestressed decks, where anchored cables lie just under the surface. Similar waterproofing treatment is provided on the ballast wall and abutment shelf, all applied from the access way. A drip is provided to the rear of the bearings to prevent any moisture migration across the deck soffit, which might occur due to failure of the drainage arrangements or excessive condensation within the access chamber. Adequate falls are provided to a substantial drain at the back of the abutment to prevent any rundown on the abutment face.

2.4 Detail Pier & Parapet Protection

It is not difficult to design adequate protection for bridge piers & parapets subject to salt splash corrosion. Splash tends to concentrate its attack just above the adjacent road surface and dogs often use columns as a tree-substitute, promoting further attack! Figure 7 shows typical treatments to a circular column pier and a parapet. The lower vulnerable zone of the pier is treated with a tough black bitumastic paint. To protect the bearings at the top from any salt laden mist, which may collect under the deck soffit, a matching black removable plastic collar is added. The overall effect can add aesthetic interest. The parapet can be treated with silane impregnation or grp sheeting.

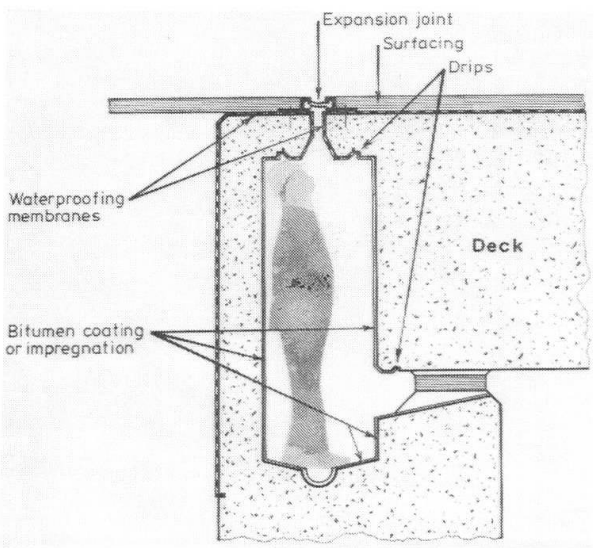

Fig. 6 Deck End Treatment

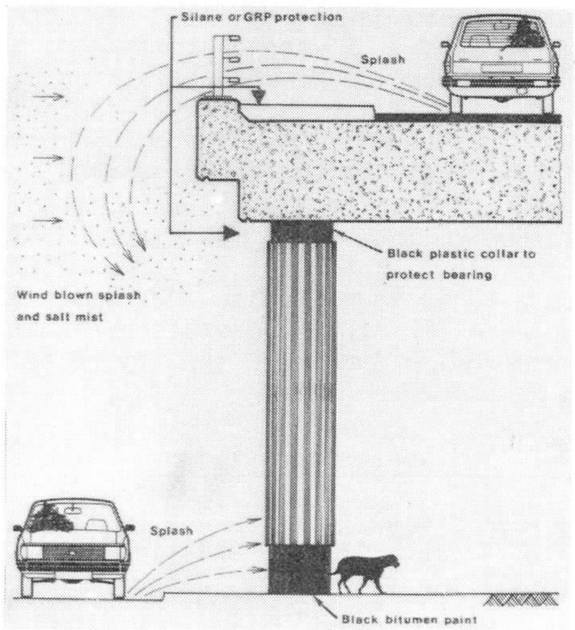

Fig. 7 Pier & Parapet Protection

2.5. Specify Durable, Less Permeable Concrete. Add Quality Assurance

Concrete durability is generally vested in the outer 50mm or so of cover, because most long term attack comes from the surrounding environment. It would be useful if permeability could be monitored, with concrete permeability testing included alongside conventional strength testing. Quality Assurance procedures are recommended to ensure this concrete durability attainment. QA also includes providing maintenance manuals.

3. NEW MATERIALS & REPAIR TECHNIQUES

3.1. New Materials

In recent years, with the realisation of the growing problems of maintenance, there has been a quickening development, particularly in Germany & America, of materials which can be used for protecting concrete bridges from salt attack. The more promising are described.

Prefabricated sheet materials rely on relatively inert and impermeable material bonded to vulnerable concrete surfaces to form a barrier to salt penetration. A familiar example is the bridge deck waterproofing membrane, which cannot be used on visible vulnerable areas. More acceptable is grc or grp sheeting, which can be colour matched & bonded in to the surrounding concrete. These materials have been used on bridge parapets, also fulfilling the role of permanent formwork.

Liquid surface coatings can be applied to vulnerable surfaces by spray, roller or brush. They dry to form barrier coatings resistant to salt and other forms of attack. Their very success in acting as an impermeable one way barrier to the concrete can sometimes prove a weakness, as they may be susceptible to blistering from the inevitable moisture vapour seeking to get out from the concrete. Some materials offer a 'breathing' property to minimise this risk.

There is little doubt that silane and siloxane surface impregnations applied to a depth of 2-4mm form a water-repellent pore lining material which acts as a strong barrier to salt penetration. The material also allows some concrete breathing, is more or less invisible and is claimed to last at least the life of the concrete structure.

The inclusion of polypropylene or steel fibres in the concrete mix adds a crack arresting function & toughness throughout the whole body of the structure including, most importantly, the environment - resisting cover concrete. The use of ground granulated blast furnace slag as a partial cement replacement also adds impermeability. An effective last line of defence is to use corrosion resistant epoxy coated reinforcement, much in evidence in America & shortly to be produced in the UK.

3.2 New Repair Techniques

Several techniques are now available or under consideration for improving the durability of existing structures, including cathodic protection & patch repairs using vacuum or cooling panel formwork to minimise restrained early thermal shrinkage effects and associated cracking.

Design and Construction of Double-Decked Prestressed Concrete Bridge

Conception et construction d'un pont mixte à deux étages en béton précontraint

Planung und Ausführung einer Spannbetonbrücke mit zwei Fahrebenen

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SUMMARY
On the Island of Yoshima, as a part of the Honshu-Shikoku Bridge Project, a viaduct with tall piers was built using prestressed concrete girders in consideration of maintenance, noise and vibration. A multi-span continuous structure was adopted in view of a reduction in the number of expansion joints and resistance to earthquakes.

RÉSUMÉ
Sur l'île de Yoshima, desservie par les ponts Honshu-Shikoku, un viaduc à piles surélevées a été construit en béton précontraint en tenant compte de la maintenance, du bruit et des vibrations. La superstructure de ce viaduc est constituée d'une poutre continue sur plusieurs travées afin de réduire le nombre de joints de dilatation et d'améliorer la résistance aux séismes.

ZUSAMMENFASSUNG
Auf der Insel von Yoshima wurde, im Rahmen des Brückenprojekts Honshu-Shikoku, ein Viadukt auf hohen Pfeilern erstellt, unter besonderer Berücksichtigung von Unterhaltung, Lärm und dynamischer Einwirkungen. Den Ueberbau bildet eine durchlaufende Spannbetonkonstruktion, um die Anzahl von Dilatationsfugen zu verringern und den Widerstand gegen Erdbeben zu verbessern.

1. INTRODUCTION

The Yoshima Viaduct has been constructed on the Island of Yoshima as part of the Kojima-Sakaide route of the Honshu-Shikoku Bridge Project. The Viaduct is a 717 m long prestressed concrete bridge with high piers, adjacent to a suspension bridge to be built over the international navigation as shown in Figs. 1 and 2.

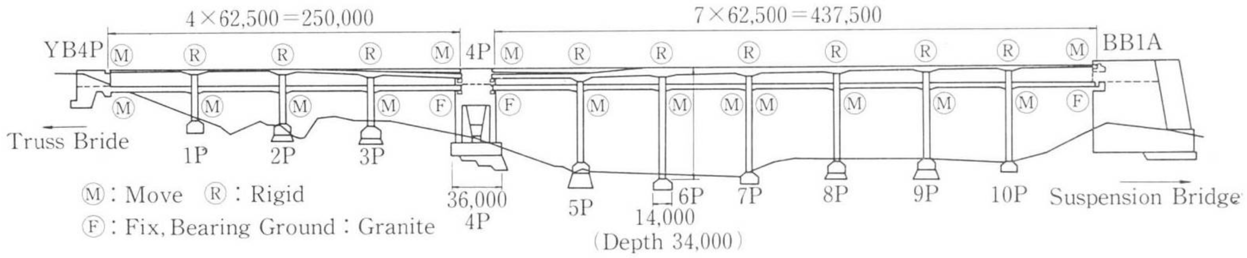

Fig. 1 General View of Yoshima Viaduct

This viaduct has the following features:

(1) It uses prestressed concrete girders for the highway (upper) and railroad (lower) decks.

(2) It is a three-dimensional frame in which the upper deck is rigidly connected to the horizontal beam of each pier.

(3) The piers are very high (max. height: 79 m) and slender (max. depth: 4 m).

(4) The piers are mixed structures in which a steel frame is encased in reinforced concrete.

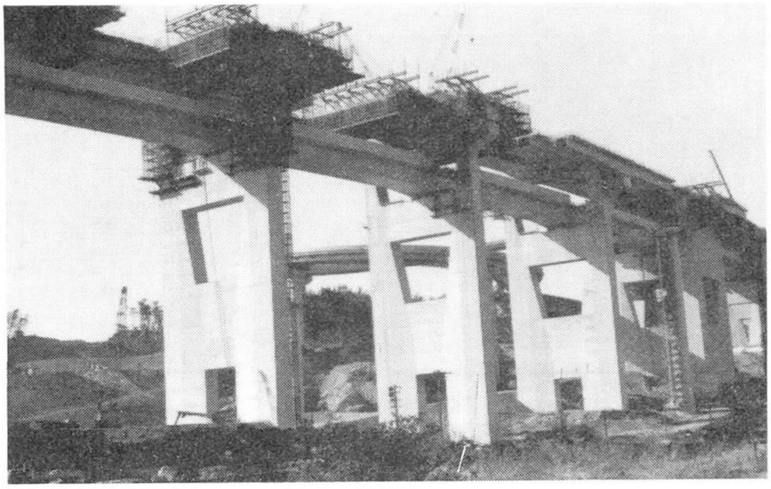

Fig. 2 Construction of Yoshima Viaduct

At present, the prestressed concrete girders for the highway deck are under constructin for scheduled completion in the spring of 1988.

2. PLANNING OF THE BRIDGE

A prestressed concrete structure was selected as the superstructure in consideration of maintenance, noise and vibration. A multi-span frame structure was employed for better traffic running characteristics and seismicity. As a result, the total weight of the superstructure is very heavy, and the influence on the substructure during an earthquake is dominant. Therefore, the selection of a structural type that excels in seismicity became a major factor in the bridge planning.

The railroad girders are fixed at the massive substructure, and are movable at the other supports to reduce the horizontal force on the high piers during an earthquake (see Fig. 1). Stoppers are introduced at the movable supports to prevent the girders falling from the bridge.

As the highway girders are heavier than the railroad girders because of their greater width, it is difficult to employ the concentrately fixed support method used for the lower deck. Therefore, a multi-rigid frame method, that reduces the restraints on the rigid piers, was employed by considering the viaduct as a higher pier bridge.

3. DESIGN OF THE VIADUCT

Fig. 3 shows a general view of a pier. The highway deck is designed to accommodate 4 lanes of traffic (22.5 m in width). Two conventional railroad lines will be constructed on the railroad deck, and provision is made for the future addition of double Shinkansen tracks.

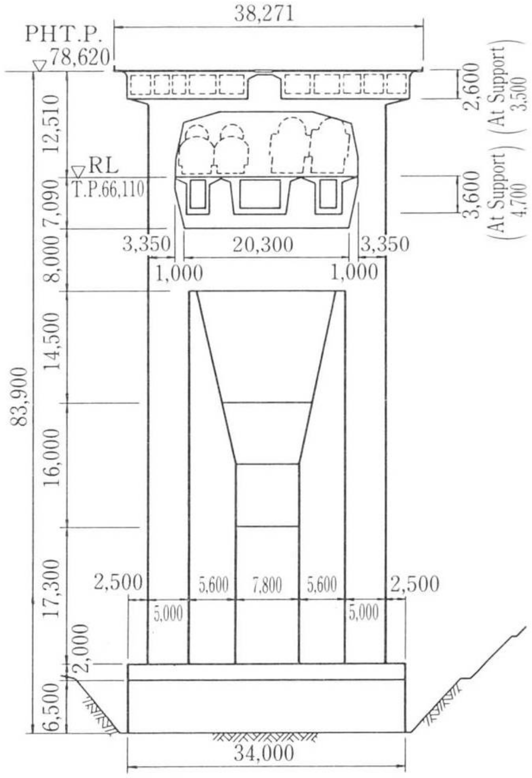

Fig. 3 General View of Pier (7P)

3.1 Design of the Pier

A spread foundation was adopted for this viaduct, because of the existence of granite under a thin layer of soil. As the piers are very tall and slender, the earthquake resistant design was performed by both ordinary methods and a dynamic analysis (spectrum response analysis).

The seismic coefficient in the direction at right angles to the bridge axis is K = 0.19, and in the axial direction is K = 0.17 for 1p - 3P, and K = 0.08 for 5P - 10P (natural period: 2.6 sec).

A long-period system structure that minimizes the pier thickness to the extent possible was needed in the bridge axial direction, and a highly rigid structure in the direction at right angles to the bridge axis was required in view of the running characteristics of trains. Thus two or three layer rigid-frame piers were adopted.

A mixed structure in which a steel frame is encased in reinforced concrete was adopted as the cross-sectional structure of the pier in consideration of its resistance to earthquakes and ease of construction (see Figs. 4, 5, 6).

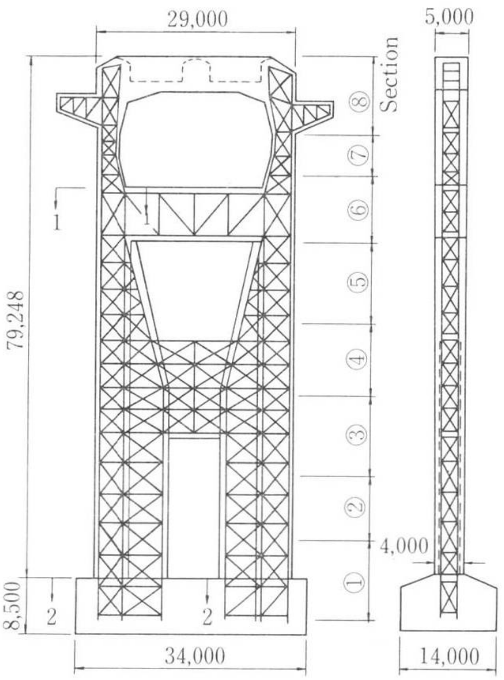

Fig. 4 Steel Frame (6P)

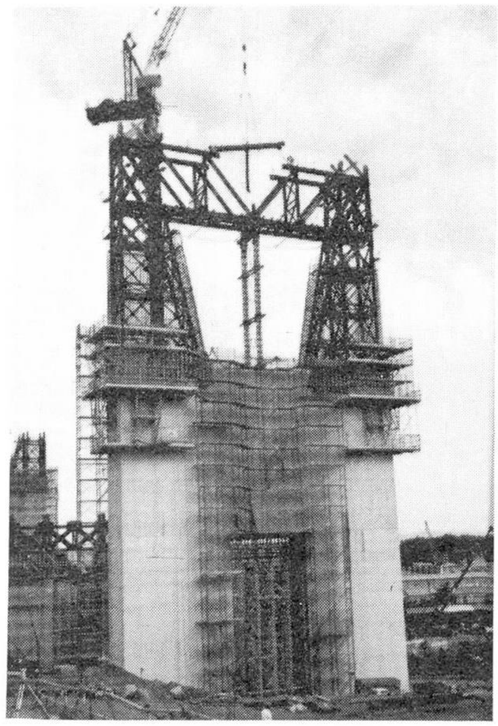

Fig. 5 Construction of Pier

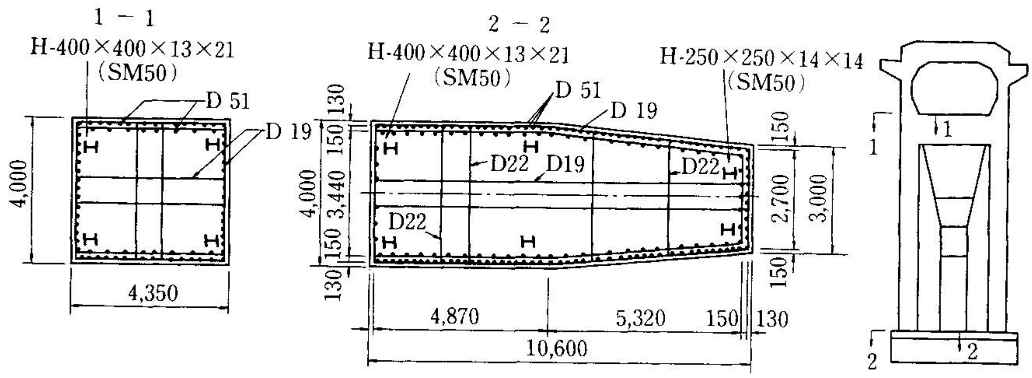

Fig. 6 Cross Section of Pier (6P)

The piers were designed by the same procedure as for ordinary reinforced concrete structures, and the relatively short span members, such as the intermediate beam and railroad supporting beam, were designed as deep beams. Stud connectors were buried directly in the steel frame anchor section to assimilate with the anchoring method of reinforcing bars in the outer part. Fig. 7 shows details of the steel frame embedded in the footing. To secure the concreting work, a steel frame with a large cross section was used and a closed structure was adopted to increase the ductility of the piers. H-section steel was used to construct the main frame (max. 458 x 417 x 30 x 50), and channel steel and angle steel were used as brace members.

At the pier base, the steel to concrete ratio is 1.1 to 1.4%, and the steel frame ratio to total steel is roughly 20%. In consideration of the durability of the structure, a depth of covering over reinforcing bars of 10 cm was adopted.

A 1/10 scale model test was made to find the ductility of the piers in both directions (see Figs. 8, 9 and 10).

Fig. 8 shows the representative Load-Deflection curves. It was confirmed that the safety level of the piers during an earthquake is very high and that a mixed structure has greater ductility than a reinforced concrete structure.

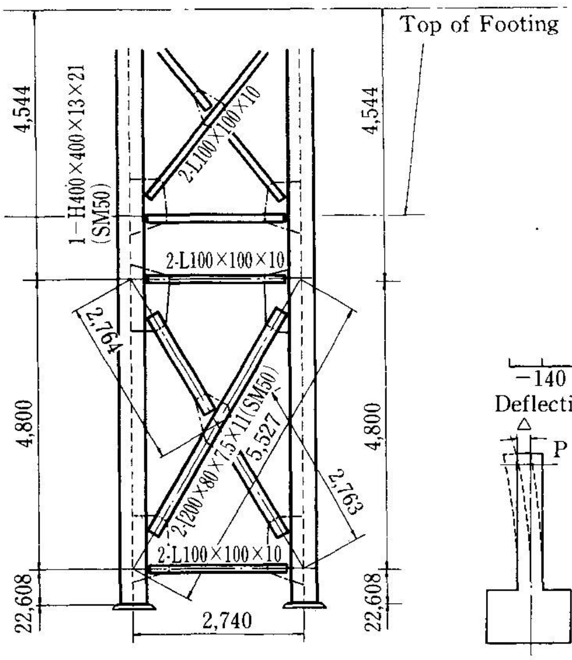

Fig. 7 Steel Frame Anchorage

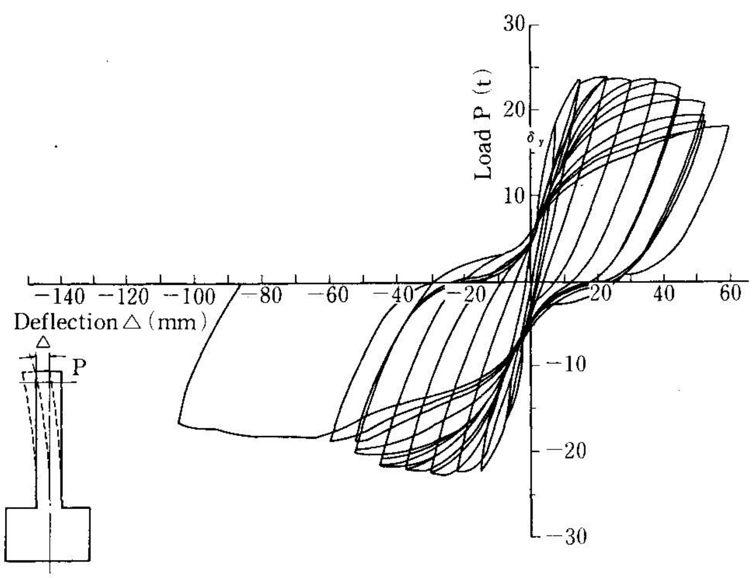

Fig. 8 1/10 Model Test of Mixed Structure in Bridge Axial Direction

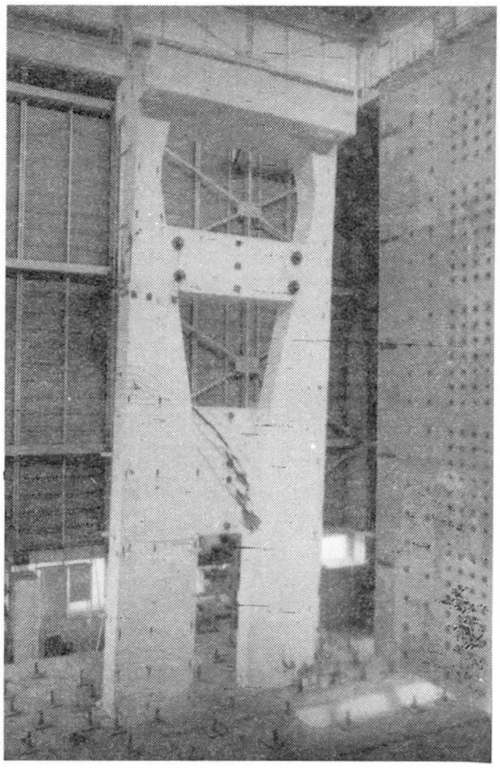

Fig. 9 1/10 Model Test in Direction at Right Angles to Bridge Axis

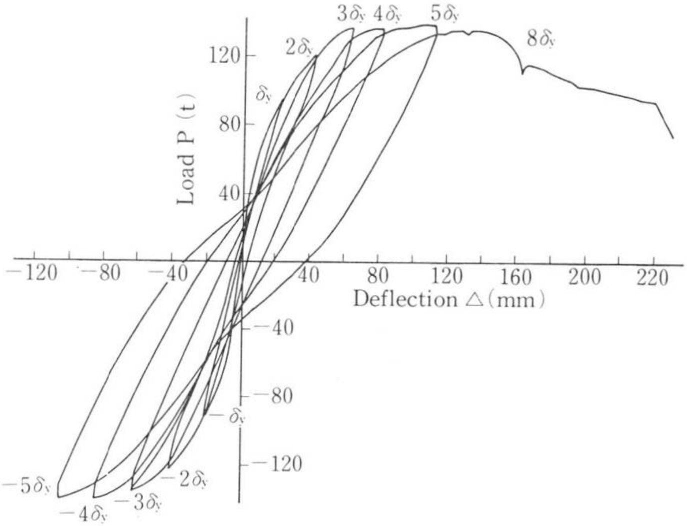

Fig. 10 Relation of Load-Horizontal Deflection at Upper Beam

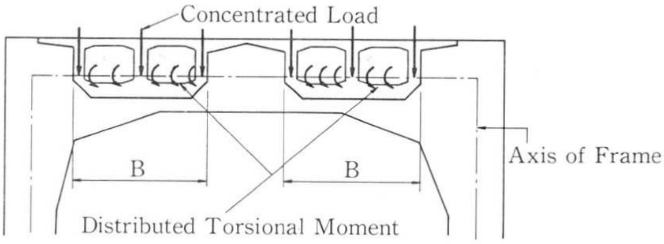

Fig. 11 Loading Condition at Pier

3.2 Superstructure Design

The highway girder of this viaduct is a solid rigid frame structure connected rigidly to the horizontal beam of each pier. As the highway girder axis line does not coincide with the pier post axial line because of restrictions imposed by construction limits of the railway section below, combined flexure, shear and torsional stresses are applied by both dead loads and seismic loads (see Fig. 11).

Thus, the following design methods were applied by utilizing the result of a basic experiment on torsion with respect to a short torsional span, and a 1/10 model test of this structure.

(1) A prestressed concrete structure was adopted for the upper horizontal beam on the assumption that it will suppress the development of cracks under the design load conditions, including an earthquake.

(2) Under ultimate load conditions, it is designed as a reinforced concrete member, disregarding the influence of prestressing.

(3) For the rigid-frame corners, a two dimensional analysis by finite element method was made and reinforcing bars provided to cope with the tensile force generted.

The prestressed concrete box girders for the highway and railroad decks have been erected by the cantilever erection method. Thus, those were designed by the same procedure as for ordinary prestressed concrete box girder bridges. The depth of cover over the reinforcement was increased to 5 cm for the outer faces of the box section (cover of the inner part of box: 3 cm).

In order to enable inspection and repair under the main girders and floorbeams whenever necessary, anchor bolts were inserted in advance into the girder so that an inspection car and suspended scaffolding may be supported (see Fig. 12).

4. CONSTRUCTION

As the piers of the viaduct are very tall and their width in the bridge axial direction is small, a high level of accuracy is required. Therefore the steel frames were fabricated in the same manner as for a truss bridge and provisional assembly was also made.

The most important of all accuracies in steel frame erection is that of perpendicularity, and the inclination of each member and the structure as a whole was controlled below H/1000 or H/2500 + 10 mm. The control of the height in the first section was extremely important as it forms the base for the steel frame erection.

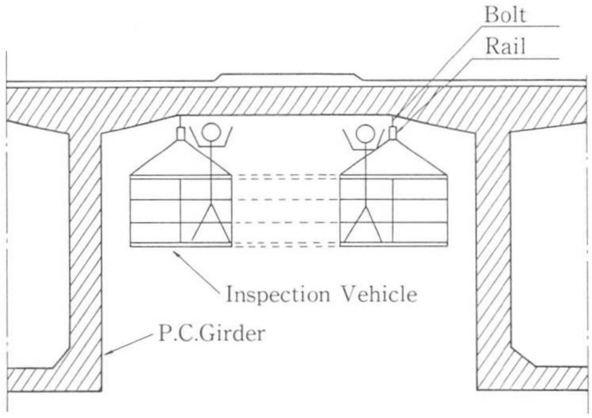

Fig. 12 Inspection System of P.C. Girder

Reinforcing bars were assembled by utilizing the steel frame as a ruler (see Fig. 13). The standard concrete lifts for the footings, columns and beams are 1 m, 3 m and 2 m, respectively. In summer, cooling water of roughly 5°C was used as mixing water to lower the concrete temperature for placing.

The average compressive strengths of the footings and piers was 38 and 41 MPA, respectively.

On completion of the substructures, the railroad girders in the lower deck were erected by the cantilever erection method. The highway girder in the upper deck then erected, also by the cantilever erection method. During the construction of the highway girder, the railroad girder was fixed temporarily for structural stability, as shown in Fig. 14. Average compressive strength of the prestressed concrete girders was 49 MPA.

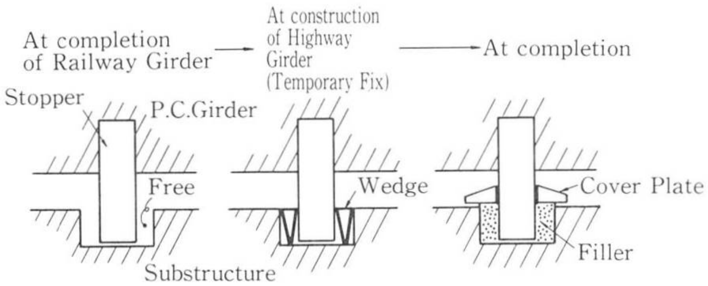

Fig. 14 Railroad Girder Stoppers at Piers

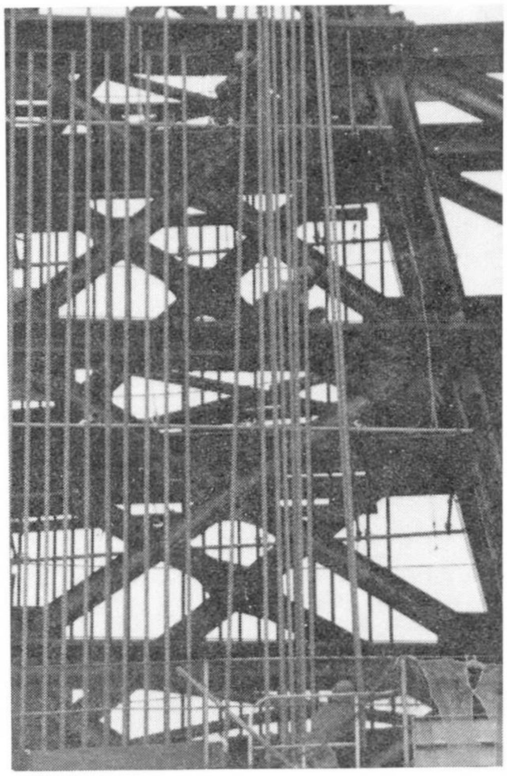

Fig. 13 Assembly of Reinforcing Bar

5. CONCLUSION

Several considerations for maintenance were made in the design of the viaduct on Island of Yoshima. After completion of the structure regular inspections will be made to maintain its condition.

Design for Reconstruction and Maintainability

Conception en vue d'une reconstruction et d'une maintenance faciles

Projektierung im Hinblick auf Instandhaltung und Wiederherstellung

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SUMMARY

Replacement or modification of medium span bridge decks has become necessary with increasing regularity. The reasons include the need for greater width or strength and reconstruction because of deterioration. Two case studies are presented which highlight these causes, describe the methods of replacement and illustrate improvements made to facilitate easier maintenance. The need to minimise traffic disruption during reconstruction makes a strong case for designing the majority of short and medium span bridges in the form of longitudinal strips and with detailing to facilitate reconstruction.

RÉSUMÉ

Le remplacement ou la modification des tabliers de ponts de portée moyenne est devenue nécessaire avec une régularité sans cesse croissante. Parmi les raisons, il y a le besoin d'une plus grande largeur ou résistance, et la reconstruction à cause de détérioration. Deux études de cas sont présentées. Elles mettent en évidence ces causes, et les méthodes de remplacement y sont décrites. Elles illustrent, en outre, les améliorations apportées pour en faciliter la maintenance. La nécessité de réduire au minimum le dérangement de la circulation pendant la reconstruction, renforce l'argument en faveur de concevoir la majorité des ponts à portée courte ou moyenne sous la forme de bandes longitudinales, avec détails pour en faciliter la reconstruction.

ZUSAMMENFASSUNG

Der Ersatz oder die Wiederherstellung der Fahrbahnplatten von Brücken mittlerer Stützweiten wurde mit steigender Regelmässigkeit erforderlich. Die Gründe liegen unter anderem am Bedarf an grösserer Breite oder Tragfähigkeit sowie an der Verschlechterung des Zustands. Es werden zwei Fallstudien vorgestellt, die diese Ursachen unterstreichen und die Verfahren für den Ersatz beschreiben. Es werden Verbesserungen vorgeschlagen, um die Instandhaltung zu erleichtern. Die Notwendigkeit, während des Neubaus Verkehrsunterbrechungen auf ein Mindestmass zu beschränken, spricht für eine Konstruktion in Form von Längsstreifen mit konstruktiven Details zur Erleichterung von Erneuerungen.

1. INTRODUCTION

1.1 Background

During the last decade there has been a rapid increase in the number of modern bridge decks which have required replacement. This has been due largely to the effects of water ingress and the dissolved salts carried by it. The provision of wider roads and motorways has also necessitated the modification of superstructures.

The primary user of a highway must be considered when replacement or modification is required. It is essential that the highway is maintained during the contract period even though it may be of reduced width. For this reason it is suggested that the potential need for replacement or modification should be considered at the design stage, at least for small and medium span bridges and viaducts.

1.2 Reasons for reconstruction

The possibility of reconstruction can arise as a result of many causes. The following list, which applies mainly to concrete bridges, includes known examples of modification necessitated by:

- Widening to increase traffic capacity.
- Renewal to provide greater strength.
- Renewal or repair following major damage from vehicle or other impact.
- Renewal or repair of piers and abutments.
- Deterioration caused by chloride attack after using de–icing salts.
- Deterioration caused by alkali aggregate reaction.
- Deterioration caused by high creep or shrinkage effects or by corrosion of reinforcement or prestressing tendons.
- Increase in span or in superstructure level to accommodate alterations below.

Many bridge reconstructions become necessary as a result of highway improvements, the development of urban light rail projects and the renewal of railway overbridges. In addition, the greater priority now given to inspection and maintenance has tended to identify deterioration at earlier stages in the potential life of a bridge.

2. CASE HISTORIES

2.1 Widening of a motorway viaduct

This example concerns a motorway viaduct which was opened to traffic in 1961. A continuous increase in traffic volume has made it necessary to widen each carriageway so as to provide 3 lanes plus hard shoulder instead of 2 lanes plus verge.

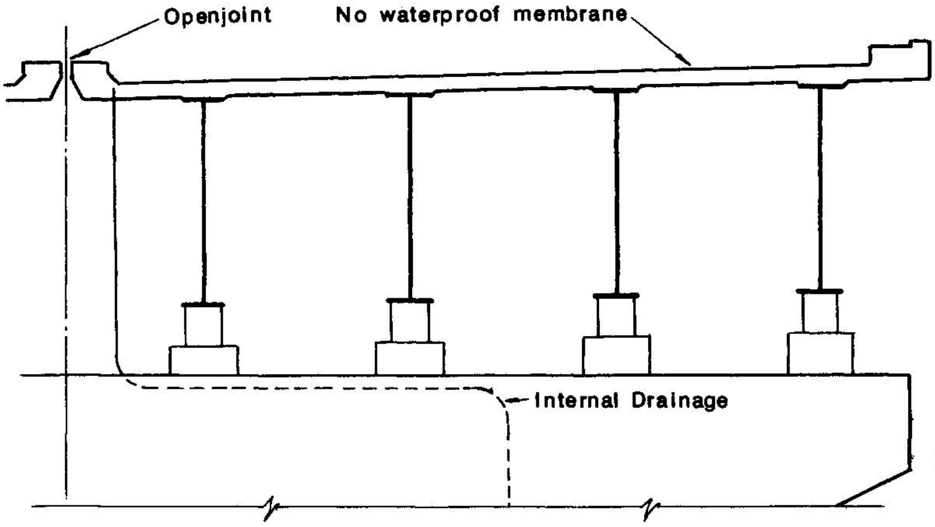
The superstructure consisted of 18 spans each comprising 8 rivetted plate girders acting compositely with the reinforced concrete slab. Widening is being achieved by adding a single welded plate girder to each side and extending the slab.

It was originally intended to retain the existing slab if this was in good condition. To confirm this, 118 cores were taken to provide samples for testing the concrete strength, carbonation depth, chloride content and cement content. Test results indicated adequate strength but high (up to 0.52%) chloride contents in the top 30–60mm of the slab. It was clear that this had accumulated during the early years of use when de–icing salts had been used prior to a waterproof membrane being installed.

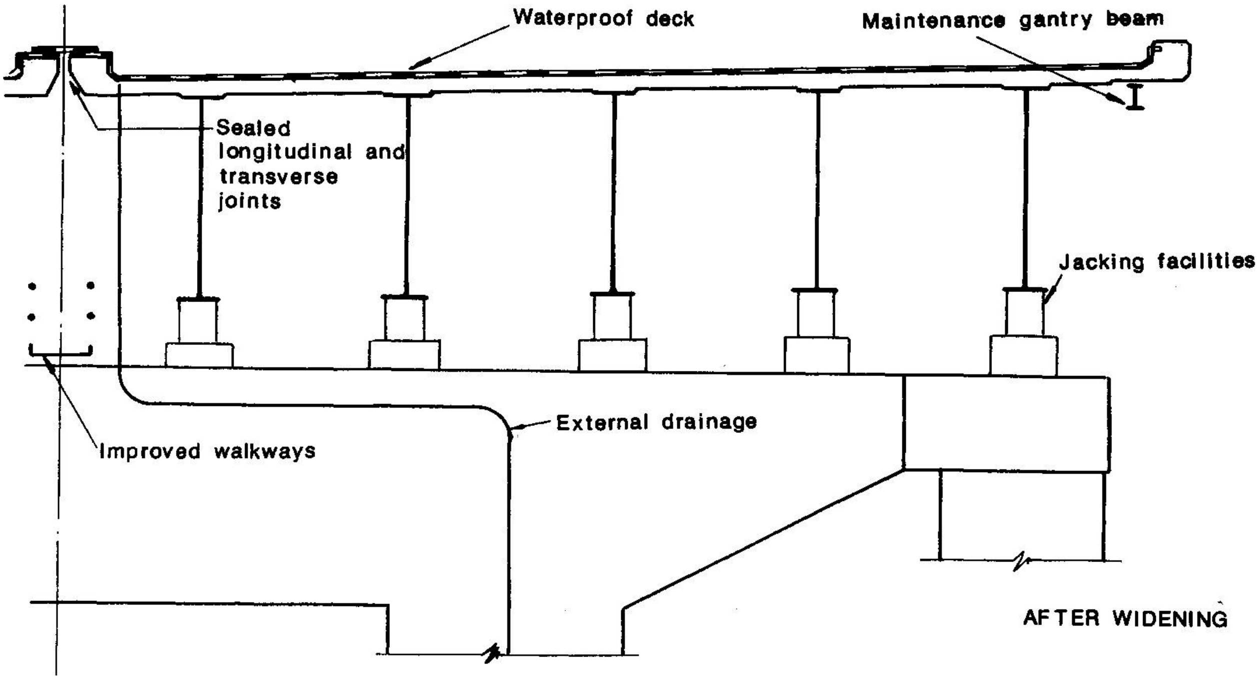
This situation made the risk of future corrosion in reinforcement and shear connectors, and of concrete deterioration too high to accept. It was then decided to remove and replace the existing slab as part of the widening contract. By defining the traffic management stages in conjunction with demolition and reconstruction phases, it was possible to maintain two lanes of traffic in each direction during the majority of the contract period. The key to this process was to work in a series of longitudinal strips (which included construction of new abutments and additional pier columns) extending for the 726m length of the viaduct.

Deterioration of the surface water drainage system had caused chloride laden water to enter the joints at the end of each span and to collect on the pier tops below. This in turn overflowed down the faces of the piers where high chloride concentrations were again found. However, in this case a half-cell potential survey indicated only small areas where corrosion of reinforcement might become a problem. A further difficulty was the discovery that the aggregate was potentially subject to alkali aggregate reaction. This led to a decision not to encase the existing piers with a new "jacket", extended at its upper level so as to provide cantilever support for the new girders. Instead, additional independent columns were built, thus leaving the existing piers intact so that inspection, height adjustment by jacking, and even future replacement could be carried out.

During design and reconstruction, very careful attention was paid to the control of surface water and the need for improved access to all parts of the superstructure. The provision of a waterproof membrane covering the whole area of the deck was an obvious requirement but this had to be carefully integrated with both transverse and longitudinal deck joints to ensure that chloride laden water would not reach the new slab. In addition, all surface water was piped to ground level in such a manner that failure of a pipe would not cause uncontrolled discharge of water to the interiors of piers but would be clearly visible by external inspection only. This latter activity would be facilitated by the provision of additional transverse and longitudinal permanent walkways below the superstructure slab and by runway beams to support a full-width travelling gantry for inspection and maintenance. Existing and future cross sections are shown below.



ORIGINAL CONSTRUCTION



AFTER WIDENING

This example illustrates the relative simplicity with which a bridge having a number of main members spanning longitudinally can be modified or replaced while maintaining the flow of road traffic using it. The same is unlikely to be true of a superstructure which consists of a single main member supporting secondary transverse members, or a structure which is dependent on transverse load distribution to adjacent members for its strength.

2.2 Replacement of Motorway Overbridge Superstructure

This second example describes a two span bridge originally built between 1969 and 1971. In 1983 it was discovered that the deck and central pier were severely affected by Alkali-Aggregate Reaction (AAR).

The bridge deck was an insitu beam and slab, and had been designed to accommodate mining subsidence which actually took place 1974 to 1976. The design was two 27 m simply supported spans. Articulation was provided by 1.8 m high rocker columns at abutments and with beams dowelled to the pier to provide fixity and carry braking forces.

An AAR investigation was commenced in 1984 and concluded that: concluded that:

- The central pier corbel required immediate strengthening.
- Even a strengthened pier could have only 5 years life under its heavy loading.
- The deck was in danger of becoming an unpredictable hazard within 5 years.
- The abutments should have 20 years life, but the tops needed strengthening.

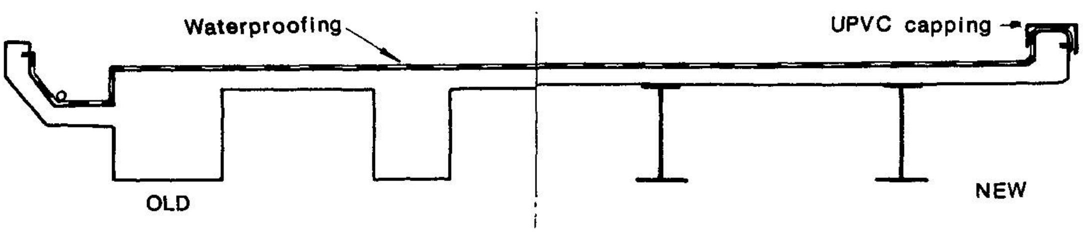
A decision was made to replace the deck during a planned 14 week carriageway reconstruction programme commencing in 1985.

The new design was to incorporate a lighter composite steel beam/concrete deck slab. Each span would be separately fixed to each abutment via rocker bearings attached to new precast bearing shelf units. Compact sliding bearings on the strengthened pier were necessary to reduce the eccentricity of loading on AAR affected corbels. By this means the remaining AAR concrete parts of the pier could be given the probability of an additional 15 years life. The transfer of braking forces to the abutments, coupled with reduced deck self-weight still enabled a forecast that the abutments should remain serviceable for over 20 years, although, as with the pier, frequent monitoring, (every 6 months), is recommended for the foreseeable future of the AAR affected parts.

Provision had to be made for possible future replacement of the central pier and refacing the abutments, some time after the new deck had been built. This was done by providing stiffeners in the deck steelwork, (adjacent to the pier and abutment), corresponding to 'convenient' positions for military trestling, that would support the deck while the substructure was reconstructed. Many options were considered for the sequence of construction; such as constructing one span at a time or in two longitudinal strips. The former was chosen as there was an alternative route for traffic on the side road and it could be easily phased in with the contractor's possession of the site for the major roadworks. Schemes for launching a new deck from an abutment or for building a new superstructure alongside the old and sliding it into place were investigated but had fewer advantages in this case.

In the detailed design of the new deck it was felt that special measures were justified to achieve a high degree of protection to the new concrete which would necessarily contain potentially reactive aggregates; albeit with a much reduced cement alkali content. Efforts would also be made to protect the old parts of the structure from surface water run-off.

A comparison between the old and new deck cross-sections is shown below.



OVERBRIDGE CROSS SECTIONS

The major differences between the protection given to the two structures is shown below:-

Item	Old Deck	New Deck
Waterproofing	Mastic Asphalt between inside faces of copings	Heavy Duty Flexible sheeting full width including over and down coping sides
Deck Edges and Copings	Standard Concrete mix Exposed sloping tops	Air Entrained Concrete Preformed UPVC covers fixed over top
Service Bays	Deep troughs with Limestone fill, drained by perforated pipes and weepholes in slab	Services in Footways, with light-weight rounded fill
Expansion Joints	Cantilevered bolted plates	Flexible bedded and bolted 'sealed' type, in short sections
Deck Ends	Exposed Concrete	GRP Sheets and angles, resin glued
Drainage	On bearing areas to fall to pipes within abutments	Collected in gutters and exposed pipes at both abutments and pier.

3. DESIGN FOR EASE OF MAINTENANCE

The following improvements are commended for consideration:

- Accept that joints will leak and therefore waterproof the concrete or steelwork below. Plastic sheets, 3mm thick have been successfully resin glued to deck ends and abutment headwalls, but access to both sides of expansion gaps is necessary.
- Design joints so they can be replaced without closing more than one lane. Continuous joints seem attractive but if the fixings corrode it can necessitate total carriageway closure for remedial works. See advice on protection in item above.
- Do not put road gullies on bridge decks unless it is necessary to prevent flooding. They invariably leak and bring chlorides into the structure leading to pitting corrosion of reinforcement. Likewise, do not put drainage channels along decks, especially grooves recessed into the structural concrete.
- Do not leave holes or cast pipes into structures where they cannot be maintained or problems are out of sight.
- Avoid half-joints and hinges, both of which are vulnerable to chloride ingress and reinforcement corrosion.
- Design bridge bearings for easy inspection and replacement. Have a standard range of bearing heights to enable new ones to be slid in without plinth or downstand reconstruction.
- Where possible include with the bridge design equipment to ease maintenance and inspection. Smaller structures may not justify permanent cradles and runway beams, but portable, 'over the side' inspection and repair platforms can save scaffold erection and be moved as required.
- Ensure that all materials are of a quality and finish not to require frequent renewal. Be sure that the work force has the necessary expertise in the use of the materials.
- At the design stage, consider how the bridge deck could be replaced while maintaining reduced traffic flow.

Some 20 years experience of maintenance of modern highway structures should be used to avoid future problems by better design for durability.

4. CONCLUSIONS

Bridges are always likely to require modification as a result of changes in highway requirements. They are also likely to need repair when the concrete or steel materials fail under severe loading, or deficiencies in their construction become apparent. Examples of degradation have included:-

- deterioriation of high alumina cement precast concrete.
- deterioration of concrete from alkali-aggregate reaction.
- deterioration of concrete by chloride attack from de-icing salts.
- corrosion of prestressing cables caused by inadequate protection or grouting.
- break down of waterproofing, joints, fixings and repairs.
- fatigue damage.

We must assume that while new developments will bring undoubted advantages there will also be disadvantages which will be unsuspected at the time of their adoption.

It seems clear from rapid repair and reconstruction work already carried out, that confining areas of working to longitudinal strips of a bridge will enable improvements or essential maintenance to be completed with the minimum of disruption to traffic. It is therefore proposed that serious consideration should be given to the potential need for reconstruction at the conceptual design stage and that this can be most effectively provided for if the bridge deck consists of a number of longitudinal beams each supporting approximately one lane of traffic. Such a concept is relatively easy to adopt for the majority of short and medium span bridges.

5. ACKNOWLEDGEMENTS

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A Bowstring Railway Bridge Designed for Durability

Réalisation d'un pont-arc ferroviaire projeté en vue d'une haute durabilité

Eine Eisenbahn-Bogenbrücke, entworfen für hohe Dauerhaftigkeit

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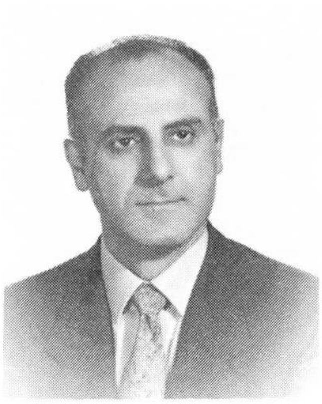

Remo Calzona, born 1939, Full Professor of Technique of Constructions, University "La Sapienza", Rome, Italy. Designer and consulting engineer. Member of numerous scientific councils.

SUMMARY
The paper describes a railway bridge, overpassing a highway, which serves a new double track railway Udine – Tarvisio, in an area of severe climatic and seismic conditions. The layout is designed mainly to meet the needs of durability and maintenance : structural shape and construction techniques were selected in order to keep concrete mainly under compression and well protected. The construction of the bridge has been recently completed and tested.

RÉSUMÉ
La contribution traite d'un pont-arc ferroviaire à deux voies, enjambant une autoroute, sur la nouvelle ligne Udine – Tarvisio. Il est construit dans une région à conditions climatiques sévères et situé dans une zone sismique. Le projet est étudié principalement pour satisfaire les exigences de durabilité et d'entretien : la forme et la technique d'exécution sont choisies de façon à solliciter le béton essentiellement en compression et à le protéger des influences climatiques. Le pont vient d'être achevé et soumis à des essais de charge.

ZUSAMMENFASSUNG
Der Beitrag beschreibt eine Eisenbahn-Bogenbrücke über eine Autobahn der neuen, zweispurigen Verbindung Udine – Tarvisio. Das Bauwerk liegt in einer Erdbebenzone und ist strengen, klimatischen Bedingungen unterworfen. Das Brückenprojekt wurde ausgearbeitet unter besonderer Berücksichtigung von Dauerhaftigkeit und Unterhaltung : durch die gewählte Form und die Art der Ausführung sollte der Beton geschützt und vor allem durch Druckspannungen beansprucht sein. Die Brücke wurde vor kurzem beendet und durch einen Belastungsversuch geprüft.

1. INTRODUCTION

The durability of a structural work is generally defined as its ability to resist weathering action, chemical attack, abrasion and other processes of decay.
From a structural point of view, this means the ability to preserve optimum service conditions, during its economical lifetime, without any decay of mechanical and physical properties that would demand expensive maintenance operations.
The principal phenomena related to bridge durability are the following:

- Cracking and porosity of concrete.
- Fatigue of materials.
- Deformability related to dynamic actions.

Thus, to be durable, reinforced or prestressed concrete structures must have:

- Low tensile stresses.
- Compression stresses < 0.5 fck under concentrated forces.
- Concrete of low permeability and large steel cover.
- Low deformability under live loads.
- As few as possible factors that can cause impact load, such as structural joints.

Therefore design for durability means to choose structural shape, materials, and construction procedures that reduce or eliminate the phenomena affecting durability negatively,so that maintenance will be unnecessary; i.e. the best way to plan durability is to design structural works with no maintenance needs.

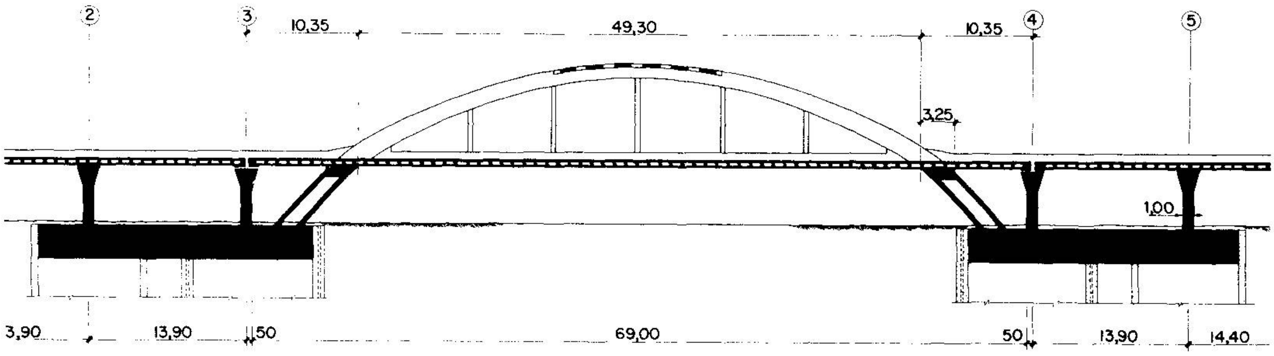

Fig. 1 - Longitudinal section of the bridge.

The bridge, as sketched in figure (1), is a modern interpretation of the classic scheme of a 1930's through arch bridge. Modern because, on one hand, safety and durability requirements are much more strict today than in the past, and on the other, new possibilities are provided by modern concrete and construction technologies, especially precasting and prestressing.
Design layout was devoted mainly to meeting the needs of durability and maintenance. Thus, structural scheme and construction techniques were selected in order to give low deflection and to keep concrete mainly under compression and well-protected.
In fact, arches and deck are composite members of cast-in-situ concrete and well-compacted prefabricated structural moulds, whereas the open surface of the cast-in-situ concrete is protected by layers of waterproof products.

2. DESCRIPTION OF THE STRUCTURE

The bridge serves a new double track railway line (Udine-Tarvisio), in an area of severe climatic and seismic conditions.
The bridge has a total length of 70 m and is composed of twin arches, sustaining the deck by means of five concrete hangers each (fig.2).
The reinforced concrete arches have a parabolic profile following the dead-load static line. The arch span is 64 m and the rise 15 m.
The rectangular arch cross-section above the deck has a constant 1.20 m width, with depth varying from 1.90 m to 1.20 m at the crown.
Below the deck, the arches are connected by two flanges, forming a single box element 1.90 m deep and 11.20 m wide.
Over a length of about 15 m the two arches are shearbraced in the crown area by a 0.2 m thick frame which follows the arches' upper profile. See fig. (1).
The deck is composed of: two longitudinal girders lying in the plane of the arches; the transverse track-support slab ; cantilevered slabs for sidewalks. Each girder (0.90 x 1.50 m) is prestressed over its full length by four cables of 25 0.6" stabilized strands lying in approximately straight lines; there are also two 'cap' cables, at each intersection with the arches, of 9 0.6" strands.
The reinforced concrete transverse slab support has a clear span of 8.9 m. It is made up of an upper and a lower flange, connected by a series of in-situ-poured reinforced concrete ribs (0.35 x 0.45 m) spaced 1.25 m. The lower flange, 0.1 m thick, is made of precast reinforced concrete; the upper one, varying in thickness from 0.15 m

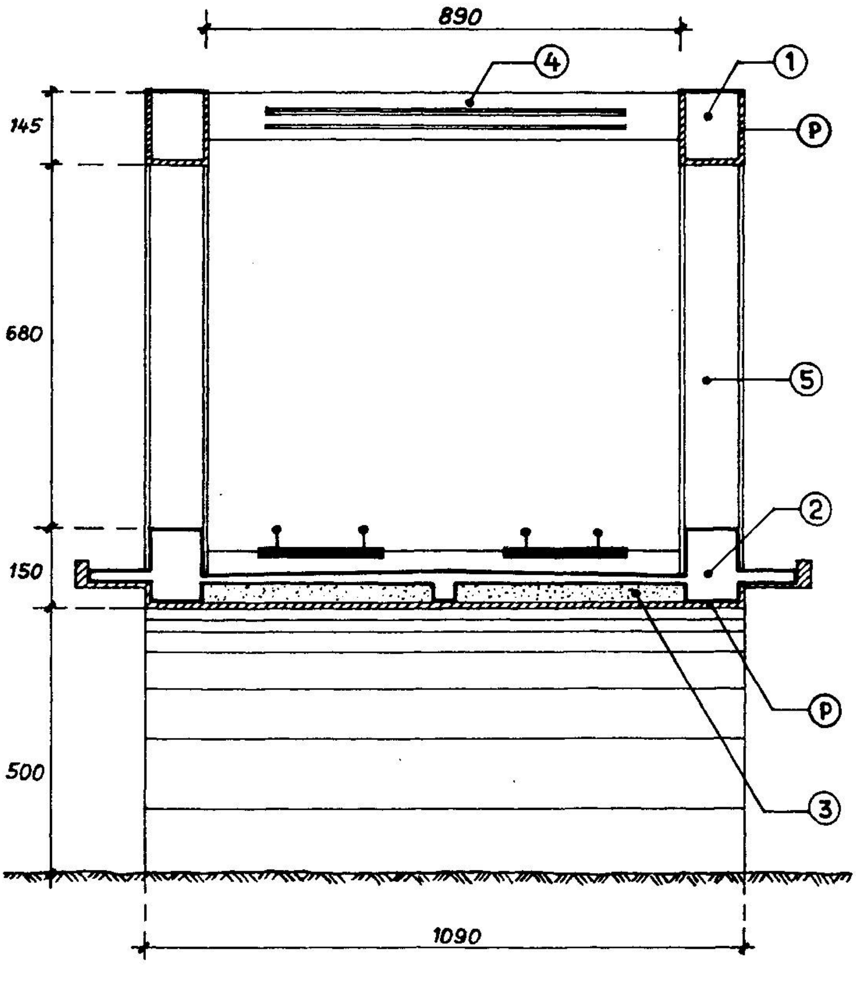

Fig. 2 :

Transverse section

LEGEND

1- Arch.

2- Longitudinal girder.

3- Transverse track support slab.

4- Frame.

5- Hanger.

6- Prefabricated units.

to 0.25 m, is cast-in-situ. The hangers have a rectangular rectangular cross-section of 0.40 x 0.90 m, prestressed by two two straight-line cables of 10ϕ0.6" strands. The caisson type foundations are laid on a gravel bed at 12 m below the site plane.

3. CONSTRUCTION PROCEDURES

The cast-in-situ concrete of arches and deck was poured in prefabricated moulds, which also work together to provide structural strength.
Several reasons dictated this choice:
- Durability, since the concrete of the prefabricated moulds, of higher strength (fck > 45 N/mm^2) and waterproof, provides high resistance to weathering and therefore a surer durability.
- Perfect finish of the fair-face surface.
- Saving in formwork and scaffolding, further speeding up the work.

The structural elements were built according to the following construction procedures:
- Arch lower part

The box-section of the arches, below deck level,were poured in 0.06 m thick prefabricated moulds.
- Deck

Considering the bridge's low level above ground, scaffolding was not used. An earth embankment was raised and the precast elements forming the lower part of the deck were laid upon it. Polystyrene blocks were positioned on the precast elements to realise the slab'sn box cross-section.
The reinforcing and prestressing steel was then placed, and the complete deck was poured.
After 14 days of curing, the cables were tensioned.
During this phase structural continuity between deck and arch was effected for one side only, the other being given a temporary sliding bearing. This was done by setting two graphite-clad steel plates below the deck girders and by sheathing the reinforcing bars of the lower part of the arch. Crossing through the girders, these bars would later provide continuity with the upper arch.
This expedient was necessary in order to prestress the deck in isostatic conditions.
Once prestressed, the deck was left free to deform due to creep, shrinkage, and temperature changes, from June, when the cables were tensioned, through October, when temperatures were running below 10°C.
- Arch upper part

The arches were poured in a mould of 0.06 m thick precast plates (fig. 3).
Continuity between the upper part of the arches and the girders was now realised by grouting the sheathed reinforcing bars; the joint between the girders and the lower part of the arches was sealed with high resistance , non shrink, reoplastic mortar. This phase was carried out while temperatures were running below 10 °C.
- Hangers

The hangers were poured prior to the upper arches, and prestressed after the arches had been cured. As the cables were tensioned, the weight of the deck began to be shifted from the embankment to the arches. The full weight was transferred when the earth embankment was removed.

4. SPECIFICATIONS

The Railway Administration had laid down the following specific design requirements for durability:
Prestressed elements: no concrete tensile stresses
Reinforcing elements: allowable stress for steel = 180 N/mm^2
For the maximum service load the design stresses in the concrete and steel of different structural elements were respectively :

- Deck-girder:	σc min.	= 0.1	N/mm^2	(compression)
	σc max.	= 13.8	N/mm^2	(compression)
- Deck-slab :	σs	= 175.0	N/mm^2	
- Arch :	σs	= 15.3	N/mm^2	
- Rods :	σc	= 2.2	N/mm^2	(compression)

The measured deflection under test with 440 kN/m loading resulted: δ = 9.1 mm = (1/7000) of span .

5. CONCLUSION

The structure was designed to meet safety and durability requirements on the basis of prescriptions as to service and use conditions, and, at the same time, to take into account architectural appearance and environmental impact.
Within this overall picture, importance was given not only to construction techniques, careful execution, and proper design of the structural members but , above all, to the structural shape, which governs the structure's behaviour and the stress state of the materials.
Durability, which in a concrete structure is of most concern in the tensile zones, is especially well satisfied. Owing to its shape, in fact , the arch is prevalently under compression, as are the main girders and hangers, due to their being prestressed.
Construction technique and careful execution of the design thus had a greater influence on durability than on safety. In fact, pouring concrete in precast concrete moulds means both a better, more perfectly finished concrete exposed to the weather, and a better-protected reinforcement.

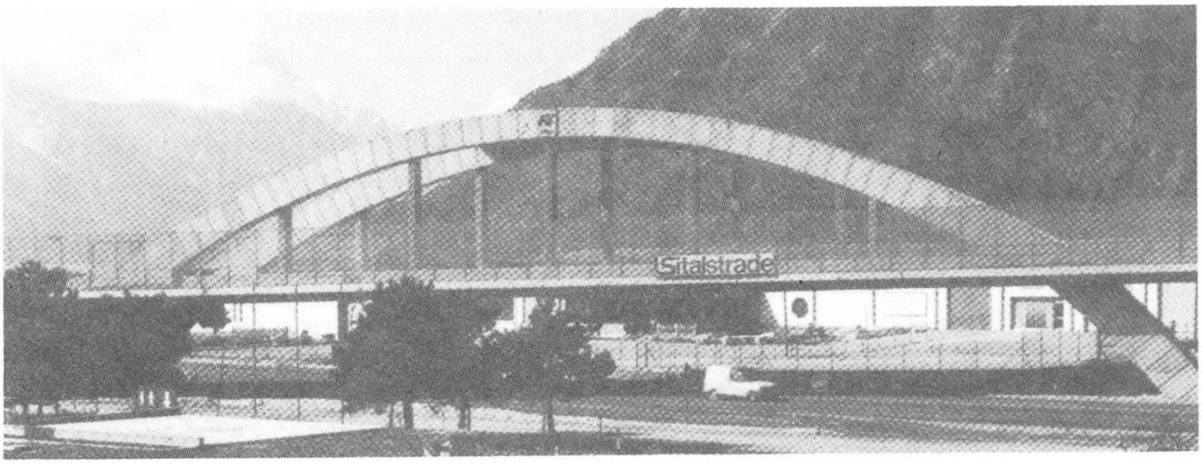

Fig. 3 - View of the bridge.

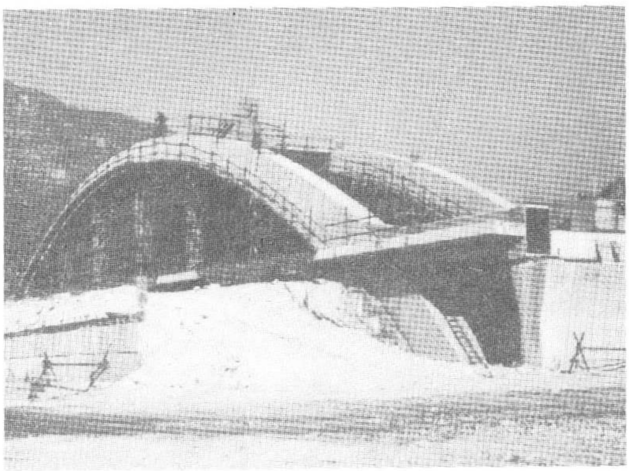

Fig. 4 - Bridge under construction.

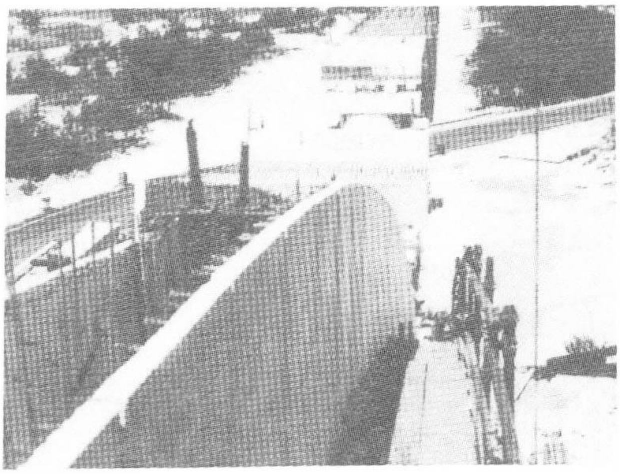

Fig. 5 - Detail of prefabricated units of arch.