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SÉMINAIRE 6

Modern Architecture of Concrete Structures

L'architecture moderne des ouvrages en béton

Moderne Architektur von Betonbauwerken

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The Baha'i House of Worship, New Delhi

Edifice Baha'i, lieu de recueillement, Nouvelle Delhi

Das Baha'i Haus, Stätte der Andacht in Neu-Delhi

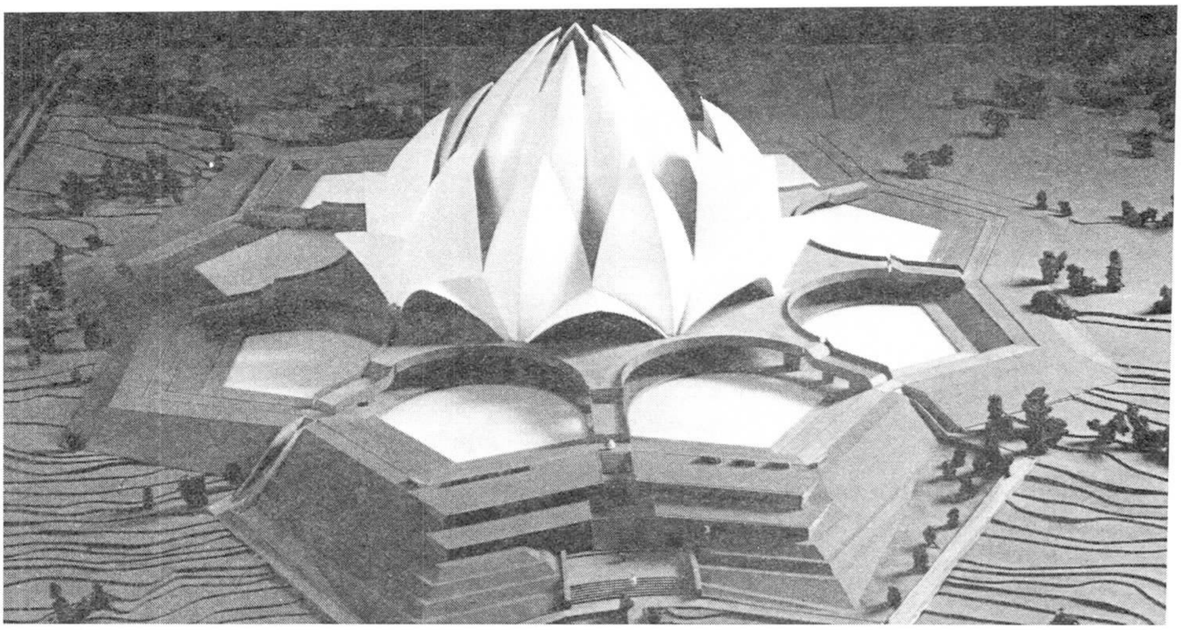
Fariburz SAHBA
Architect
Toronto, ON, Canada

Fariburz Sahba born in 1948, received his Master's Degree in Architecture from Tehran University. In 1975 he was selected to design the Baha'i House of Worship of the Indian subcontinent on which he spent 10 years as architect and project manager.

SUMMARY
In designing the structure, the architect sought a form both expressive of the essential tenets of the Baha'i Faith and responsive to the culture and the people of India. He chose the lotus flower, a traditional and pervasive element in Indian religions and a symbol of purity. At once traditional and modern, the new Baha'i House of Worship is an important example of contemporary religious architecture, its form unmistakably expressing its function as a place of assembly, contemplation and prayer.

RÉSUMÉ
Dans sa recherche pour la forme, l'architecte a cherché à appliquer les principes de la Foi baha'ie et à rendre hommage à la culture et au peuple de l'Inde. Il a choisi le lotus pour son caractère traditionnel largement répandu parmi les religions de l'Inde et pour son symbole de pureté. A la fois traditionnelle et moderne, la nouvelle Maison d'adoration est un exemple important d'architecture religieuse contemporaine ayant adopté une forme exprimant clairement sa fonction de lieu de rassemblement, de contemplation et de prière.

ZUSAMMENFASSUNG
Der Architekt war bestrebt, in seinem Entwurf sowohl die Grundsätze der Baha'i-Religion auszudrücken als auch der Kultur und dem Volke Indiens zu entsprechen. Er wählte die Lotusblüte, ein traditionelles und verbindendes Element und Symbol der Reinheit, als Vorbild. Traditionell und gleichzeitig modern ist das neue Baha'i-Haus ein bedeutendes Beispiel für zeitgenössische religiöse Architektur, mit welcher unverkennbar die Funktion als Ort der Versammlung, des Nachdenkens und Betens ausgedrückt wird.



Design

It is possible to see in the architecture of India, to an extent probably unknown elsewhere, the roots of religion in a most clear and distinct manner. The meaningful, significant, and powerful symbols which can be seen in the buildings and in their ornamentation, and even in the surroundings in which they have been placed, draw their inspiration from the religious convictions of the people, convictions which form an integral part of the Indian way of life.

Against such a background, the Architect finds himself faced with two major questions regarding the design of a Baha'i House of Worship. As per Baha'i Writings, House of Worship should be a symbol manifesting the Baha'i Faith, revealing the simplicity, clarity and freshness of this new Revelation, in distinction to the beliefs of the many divided sects who are clinging to dead, manmade concepts, each desiring to pray in his own fashion, or to display the symbols of his own faith.

On the other hand, in showing respect for the basic beliefs of the religions of the past it must act as a constant reminder to the basic Baha'i principle that all the religions of God are one and that the Baha'i Faith, for all that it may have many new features, is in no way cut off or detached from the life of the Indian people, but rather looks upon them all with respect and love.

Basing our researches on the above sentiments, the Architect undertook a study in the hope that he could prepare a design which, while it would in no way imitate any of the existing architectural schools of India, would remain familiar to the Indian people, and they will accept it as their own temple.

Researches on India and Indian architecture clearly show that, despite the outward dissimilarities to be seen between various temples, one can sometimes discover significant and sacred symbols regarded as holy and divine by all the Indian religions, symbols which have even penetrated to other countries and other religions such as Islam. One of these symbols is the sacred flower of the Indians, the lotus.

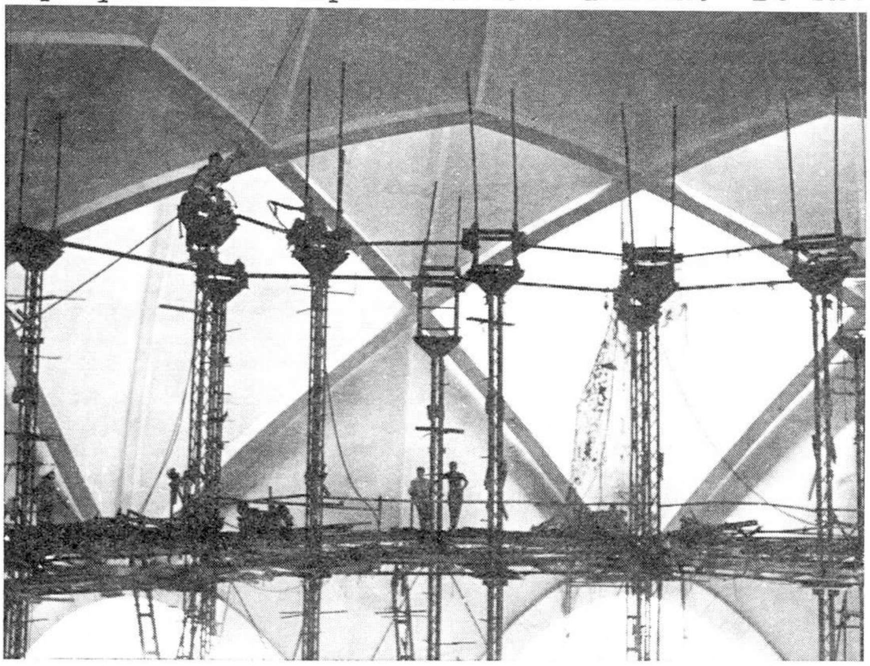
Although it would be preferable to begin a discussion of the Lotus with a survey of the Mandala, one of the oldest religious symbols in the world, we shall move directly into our discussion without such preamble.

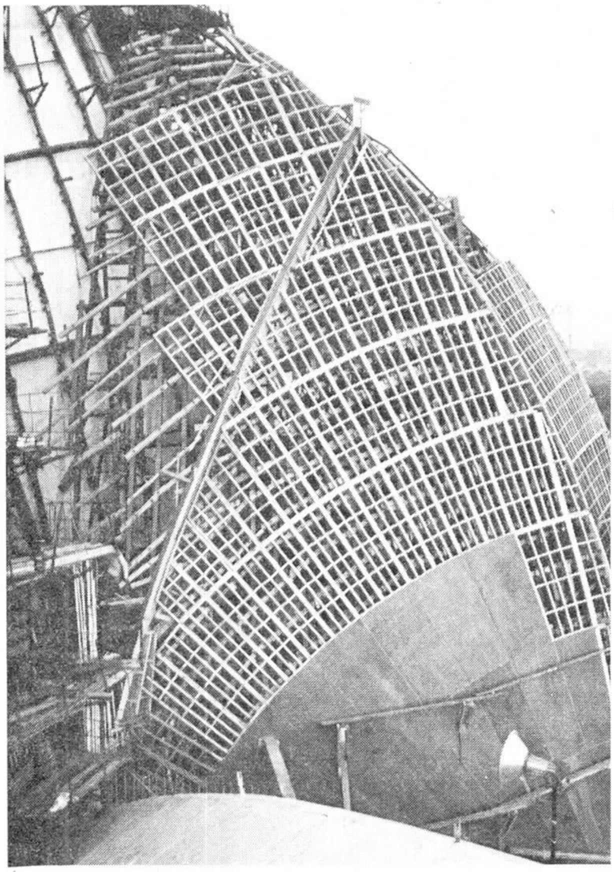
To the Indian taste the lotus has always been the fairest flower; it has enjoyed an unparalleled popularity throughout the length and breadth of India from the earliest times down to the present day, as is shown by its predominance in literature and art. Beginning to be mentioned in the oldest Veda it plays a prominent part in the mythology of Brahmanism. To the later Sanskrit poets it is the emblem of beauty to which they constantly compare the faces of their heroines. The lotus, moreover enters into Indian art of all ages and all religions as a conspicuous decorative element. It appears thus on the oldest architectural monuments of Hinduism as well as later on those of Buddhism and Jainism and Islam all over India.

In the epic poem of the Mahabharta the Creator, Brahma, is described as having sprung from the lotus that grew out of Lord Vishnu's navel when that deity lay absorbed in meditation. In Buddhist folk-lore the Bodhisattva Avalokitesvara is represented as born from a lotus and is usually depicted as standing or sitting on a lotus pedestal and holding a lotus bloom in his hand. Buddhists glorify him in their prayers "Om Mani Padme Hum" Yea! O, Jewel in the Lotus! Amen.

The lotus symbol can be easily traced in Zoroastrian architecture. The carving of Ardashir II at Taq-i-Bustan shows Mithra standing on a lotus flower. In the bas-relief at Persepolis king and most of his nobles each hold a lotus in their hands. The lotus flower is one of the oldest and most beautiful elements used in the patterns of Persian carpets, and it can often be seen in Islamic architecture of Seljuq and later periods. For example the shape of a lotus occur in the design of the perforated plaster work in the mihrab (prayer niche) of the Malik mosque in Kirman.

In the design of the Baha'i House of Worship, lotus has been employed in an unprecedented fashion. It should be said that the most basic idea in the design is that light and water have been used as its two fundamental elements and that these two elements are alone responsible for the ornamentation of the House of Worship, in place of the thousands of statues and carvings to be found in other temples. The structure is composed of three ranks of nine petals each, springing from a podium which elevates the


Interior Dome


Outer Leaf formwork

building above the surrounding plain. The first two ranks curve inward, embracing the inner dome; the third layer curves outward to form canopies over the nine entrances.

The petals, constructed of reinforced white concrete cast in place, are clad in white marble panels, preformed to the surface profiles and to patterns related to the geometry. White marble also covers all the interior floors, while the insides of the petals are bush-hammered concrete. The walkways and stairs in the podium are finished in a local red sandstone.

The double-layered interior dome, modeled on the innermost portion of the lotus, is comprised of 54 ribs with concrete shells between. The central hall is ringed by nine arches, which provide the main support for the superstructure.

The entire superstructure is designed to function as a series of skylights with glazing at the apex of the inner petals, the internal vertical surfaces of the outer petals, and the external side of the entrance petals. Light is thus filtered into the central hall in the same way that it passes through the lotus flower.

Nine reflecting pools surround the building, their form suggesting the leaves of the lotus. External illumination is arranged so that the lotus structure appears to float on water.

Ventilation and cooling are based on techniques traditional to the Indian subcontinent whereby the building itself functions as a chimney. Fresh air, cooled as it passes over the fountains and pools, is drawn in through openings in the basement, up into the central hall, and expelled through a vent at the top of the structure. During the humid season a set of exhaust fans in the basement recycles air from the main hall into the cool basement and back.

Construction

For the Architect and his Structural Consultant M/s Flint & Neill Partnership of U.K. it took nearly 18 months of work with state-of-the-art computer techniques to translate the lotus into structural designs and working drawings.

Translating the geometry of the design, in which there are virtually no straight lines, into the actual structure presented particular challenges in designing and erecting the formwork. Not only was it difficult to align, so as to produce accurately the complex double-curved surfaces and their intersections, but


Manual Excavation

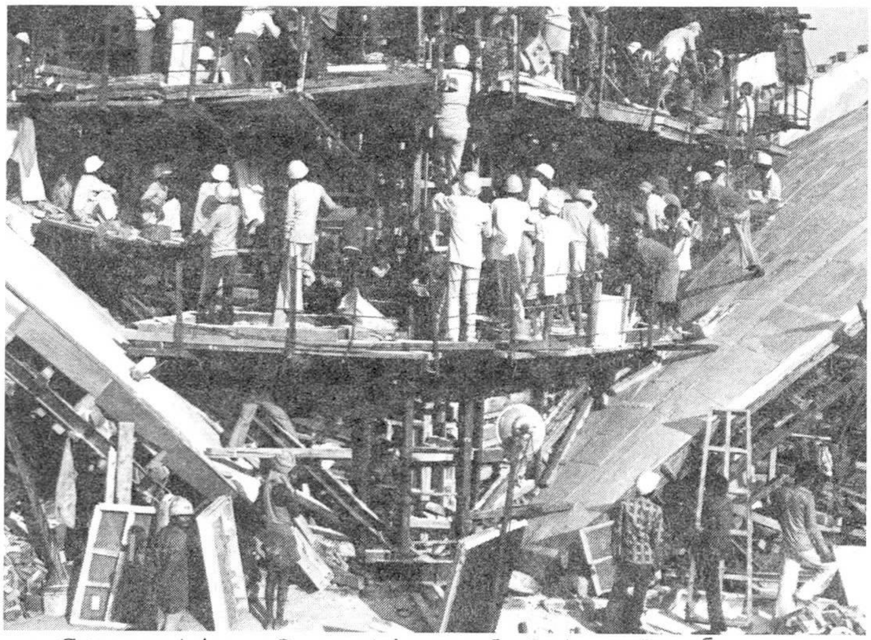
The closeness of the petals severely restricted work space. Nevertheless, the task was carried out entirely by local labourers using traditional techniques.

The inner leaves are a uniform 200 mm in thickness and 33.6 meters high. The outer leaves, 22.5 meters high are 135 mm thick from their cusps to the line of the glazing, beyond which they thicken to 250 mm to enhance their stability. The entrance leaves vary in thickness from 150 mm to 300 mm at their edges and are 7.8 meters high. The shells of the interior dome are 60 mm thick.

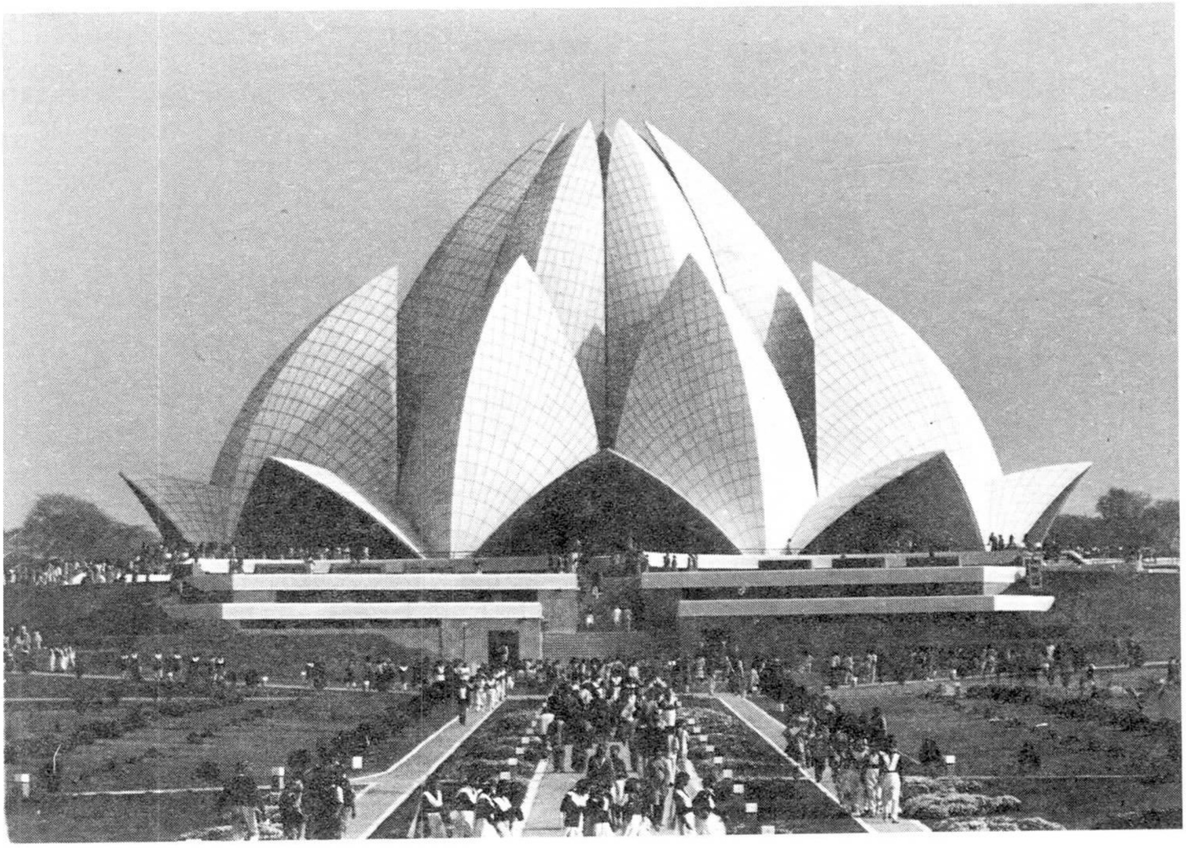
The interior dome - 28 meters high by 34 meters in diameter - was developed from nine intersecting spheres, making a double-layered 'bud'. 18 ribs span between points on the arches and lie on the surface of a base sphere. From each of the 36 intersections, a circular rib springs upward to support the hub to the radial beams between the inner leaves.

Poured-in-place reinforced concrete was selected as the most elegant and cost-effective method of construction. All of the steel reinforcing for the shells were galvanized to avoid rust stains on the white concrete in the prevailing humid conditions.

Before assembling the temporary works for the roofs, a number of full-scale mock-ups were constructed to check the feasibility of the proposed methods of construction, geometric form, practicality of fixing the complex reinforcement, entrance and inner petals, and interior dome elements.


Concreting Operation of Outer Leaf

Numerous trial mixes formwork finishes, concreting procedures and finishing



processes were used to manufacture sample panels of exposed concrete. White concrete composed of white cement, silica sand, and dolomite aggregate, was selected.

Forms and their supports for all the petals were designed to withstand pressures from continuous concreting. Three inner leaves were concreted at a time, generally in only two lifts from their bases to the level of the star beams above. To avoid the construction joints that would ordinarily have been necessary, each entrance and outer petals was concreted in a continuous operation, one at a time, using the removable outer shutter panels for access for concrete and vibrators. Concreting time for an outer petal was approximately 48 hours.

Because ambient temperatures can exceed 46 degrees centigrade, precautions were taken to cool the concrete. Aggregates were cooled by blowing chilled air onto closed stockpiles, and crushed ice was used in the mix. Canopies were erected from the staging to provide shading of the petals being concreted. Systems of horizontal sprinkler pipes were used in curing.

Pentilicon marble from Greece cut to size and geometry in Chiampo, Italy, was shipped to India and fixed to its exact locations like small pieces of huge jigsaw puzzle with the help of carpenters.

After the construction period of six years and nine months about 9000 people from 149 countries took part in the colourful dedication ceremony of the building on 24th December 1986.

Appropriate Language in Visual Concrete

Langage approprié du béton armé

Angemessene Beschreibung des Sichtbetons

Alan HOLGATE
Senior lecturer
Monash University
Melbourne, Vict. , Australia

Alan Holgate graduated from University College London in 1958. His seven years in industry included road construction, tunnelling and design of power stations. At Monash he teaches analysis and design of steel and concrete structures. Research interests include the design process and the interaction between architect and engineer.

SUMMARY
This paper discusses possible reasons and remedies for continuing public hostility to visual concrete. It is suggested that : commitment to the ideal of a single aesthetic for concrete is no longer appropriate ; that designers should develop several "languages" of detail and form, as well as texture ; and that choice of language for a particular building should be made carefully with regard to its location, its function and the sensibilities of those who will use it or see it.

RÉSUMÉ
Cet article examine les raisons et les remèdes éventuels contre l'hostilité permanente du public à l'égard du béton apparent. La notion d'un engagement à l'idéal d'une esthétique est considérée inopportune de nos jours. Les projeteurs devraient développer plusieurs langages de détails et de formes, ainsi que de texture. Le choix du langage pour un bâtiment spécifique devrait être décidé avec soin selon son emplacement, sa fonction et la sensibilité de ceux qui l'utilisent ou le voient.

ZUSAMMENFASSUNG
Der Beitrag behandelt mögliche Ursachen der andauernden Ablehnung des Sichtbetons durch die Oeffentlichkeit und Abhilfen dazu. Es wird empfohlen, die Bindung an das Ideal einer einzigen ästhetischen Erscheinungsform des Sichtbetons zu verlassen. Die Projektverfasser sollten verschiedene Ausdrucksweisen für die Beschreibung von Einzelheiten und Formgebung sowie Textur entwickeln. Die Wahl der Ausdrucksweise für die Beschreibung eines bestimmten Gebäudes sollte sorgfältig getroffen werden und muss in Bezug auf die Lage des Gebäudes, dessen Funktion und die Benutzer oder die Betrachter des Gebäudes abgestimmt werden.

1. REJECTION AND ENTHUSIASM

This paper examines the problem of public hostility towards reinforced concrete, and how engineers and architects might respond to it.

A vast literature already exists on this topic. Most writers acknowledge that concrete buildings have often been finished too cheaply, that traditional detailing for weather has been ignored, and that surfaces have needed more care and attention. Much has been learned of ways to correct these faults, but the best efforts of designers have still not overcome widespread animosity, which has been recorded in popular song and in serious literature [1]. In contrast, designers and builders have shown great enthusiasm for concrete construction since its introduction [2]. Current magazines devoted to concrete demonstrate the continuing strength of this commitment.

A deep commitment to a new material or technique is very necessary in the early stages of its development, but it has disadvantages. Coupled with brutalist functionalism it has led to the claim that *all* concrete buildings must necessarily be beautiful. The "glamour shots" of the professional architectural photographer are taken as evidence, when the perception of the average person is closer to that of the amateur photographer. (Browne demonstrated the difference some years ago [3]). The enthusiast remains confident that public acceptance is only a matter of time. However, much shorter periods have been required for the acceptance of other innovations, admittedly less drastic. These include exposed (unrendered) brickwork inside as well as out; space-frames which have moved from factory to smart international hotel; and mirror-glass buildings which, after initial opposition, are now widely accepted.

Perhaps we could learn from the worlds of industrial design and even fashion. There, the designer does not have as much power as engineers and architects to impose his ideas on the public. Market forces ensure that, while still "showing the way", he remains extremely sensitive to the response of the public.

2. THE NATURE OF CONCRETE

A common theme in concrete design has been to "express the true nature of the material" and thus find *the* aesthetic of reinforced concrete. However, a glance at Figures 1 to 6 shows the wide range of forms successfully adopted for commercially competitive concrete structures.

It can be argued [4] that some uses are simply a display of bravura and are contrary to the true nature of concrete. However if Nervi, for example, won the competition and (presumably) made a profit with his hangars (Fig. 5), how can one say he was wrong? In the final analysis much of the "nature" of the concrete we see around us is the nature of its economics. Cast in situ, its surface is usually flat, and though precasting makes possible more complex shapes, there is a risk of boring repetition. It is difficult to tell from their form alone whether the uprights for the Hull Tidal Surge Barrier (Fig. 7) are of steel or concrete. The same applies to the piers, masts and box girders of many bridges. The framing of Lloyds Bank building in London was conceived in steel, but was largely realized in concrete [5]. In these circumstances, the designer who wishes to "express" the nature of the material is reduced to consciously and artificially emphasizing its surface qualities.

Even when the building form is irregular, it often proves uneconomic to exploit the "plasticity" of concrete. Mendelsohn's Einstein Tower was finally built in rendered brick. The problems encountered with the initial flowing form of the Sydney Opera House roofs (and the solution which utilised precisely spherical segments) are well known (see e.g. [6]).

Thus there seems to be no one true nature and no one true aesthetic of concrete. Commentators write of "languages" appropriate to a material or form

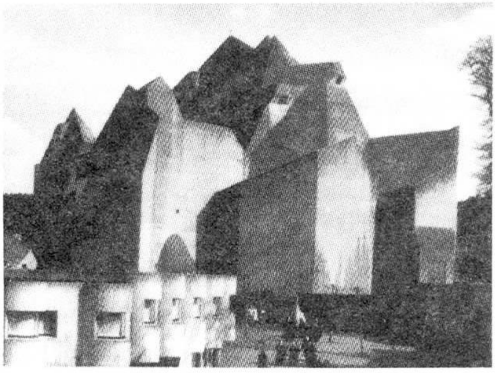


Fig.1 Church at Neviges (Böhm)

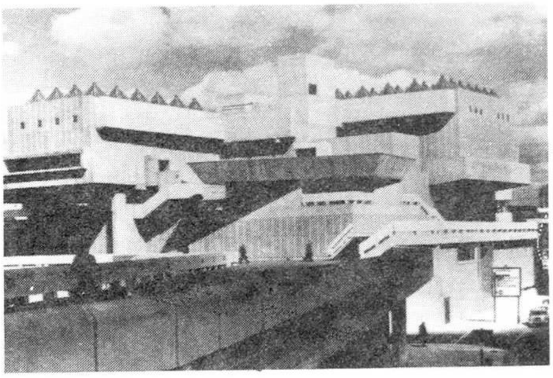


Fig.2 Hayward Gallery (GLC)

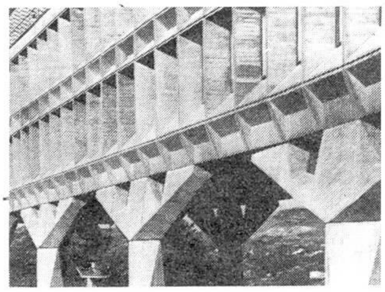


Fig.3 IBM, La Gaude (Breuer)

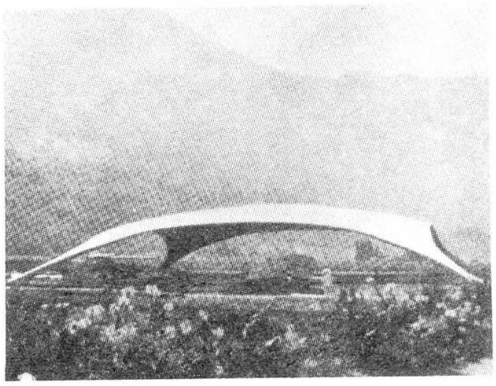


Fig.4 Garden Centre, Camorino (Isler)

of construction. The words of such a language are the common forms and standard details and its grammar is the way in which such elements are combined in buildings. As Marsh [7] has pointed out, if there are not several languages of concrete construction there are at least several "dialects".

3. REVERBERATIONS

There may well be psycho-analytic explanations for public hostility to concrete, but a search will be made here at the level of "appreciation of architecture".

The differences in the formal aesthetics of Figs. 1-6 are evident. It is widely recognized that buildings also stimulate in us memories, metaphors, similes and allegories. We can call these associations or "reverberations" [8]. Obviously, the responses aroused in architects or engineers are rather special. These might be related to: a close familiarity with all aspects of the material; a love of sculpture; a heightened sensitivity to texture, outline and tone; a preference for elegance or parsimony; a preoccupation with order or functional efficiency; a contempt for ornamentation; an enthusiasm to influence society; an interest in historical reference.

The layman's reverberations will perhaps involve similar buildings loved or hated in childhood. Many concrete structures, seen by us as exciting and innovative, may seem to him ponderous, cold and lifeless. Featureless vertical planes may give the impression of a fortress (Fig. 2). Bulky, coffered precast panels framing tiny windows are equally unfriendly. The layman is unaware of the aesthetic and practical reasons for such systems [9]. He is unable to make the necessary abstraction to enjoy primary geometrical forms as the architect would (Fig. 8).

Massive piers, two or three storeys high, at the base of multi-storey buildings are proportioned to harmonize with the total form as seen on the drawing-board or in the model-maker's shop, and overwhelm the visitor on the pavement. Vast concrete staircases are edged with "handrails" in the form of small walls whose proportions relate to the overpowering bulk of the building and not to the person who would expect them to guard and assist him.

The measures taken to avoid weather problems and add interest to the surface often increase its "visual weight" and give it an aggressive appearance. The methods used are often as violent as the resulting surface, and contrast with the care evident in screeding or brick-laying.

4. SOME SUGGESTIONS

We can perhaps learn by looking at other materials. They are no more consistently beautiful than concrete though they may, like stone, have more mellow reverberations. Steel at its best can be elegant and slender [10], but the heavy soot-laden trussed railway bridges near our city centres, bristling with rivets, cover-plates and brackets, show no evidence of this. Steel designers have, however, recently worked out a modern aesthetic that competes with that of nineteenth-century steel. Even the most enthusiastic commentators on Renaissance architecture [11,12] have discussed the problem of the blank masonry wall and the "dreariness" of stucco. Nevertheless, masonry construction may offer us not only tested details, but clues on the aesthetic treatment of massive structures.

The apparent or visual weight of concrete is paradoxically greater than that of steel or masonry. The observer is likely to see a three-dimensional concrete surface as solid rather than void. This tendency has long been recognized in the design of shells, and attempts to avoid it have included turning up the edge or slicing the form. A concrete wall may appear heavy because we know there is no limit to its thickness, but we estimate the thickness of a masonry wall from the size of its blocks. Also, traditional masonry detailing seems designed to concentrate our attention on the surface, giving the wall a two-dimensional quality. On the other hand, the bold projections and deep coffering of many concrete walls give them a strongly three-dimensional and visually heavy quality. Perhaps a new "language" of detail could be developed which would at some points reveal the true thickness (or "thinness") of the panels, and at others, bring the interest forward by the use of surrounds and features in other materials which do not read as heavy as concrete.

If we insist on blank, featureless, truly off-form walls, perhaps we could take maximum advantage of the complexity of building function to arrive at an interest of form which will overcome the boredom and power of a featureless bulk. We could also introduce what might be called "macro-texture" of detail. This would bridge the gap in scale between the "micro-texture" of striation and board-marks on the one hand and the overall building form on the other (Fig. 9).

Definition of scale is a common problem with concrete, because it is a basically continuous material. Precast elements provide clues by which the size of a building can be estimated, but too often at the expense of monotony. On blank surfaces scale has to be consciously introduced by emphasizing formwork joints or panel joints. Sometimes, however, functional requirements provide the basis for a continuous gradation of scale which ties the whole composition together extremely well (Fig. 10).

The fact that reinforced concrete is a modern long-span material permits designers to plan on a grand scale (and in most cases economics or functional requirements demand this). This may lead to unfortunate results, but many aesthetically successful buildings consist of concrete spanning and supporting members infilled with other materials, usually brick or tinted glass (Fig. 6). We must abandon the early ideal that the only good concrete building is an all-concrete building.

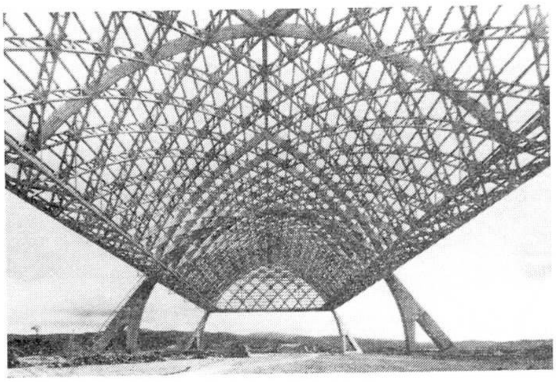


Fig.5 Aircraft Hangar (Nervi)

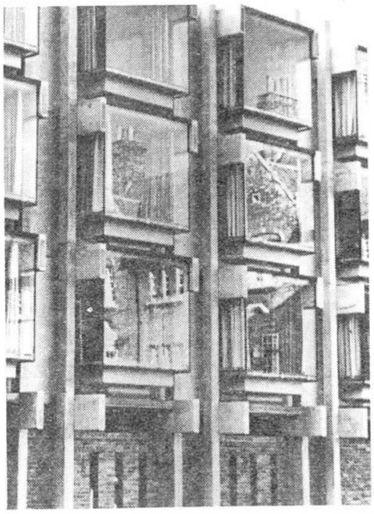


Fig.6 Wolfson Building, Oxford (Arup Assoc.)

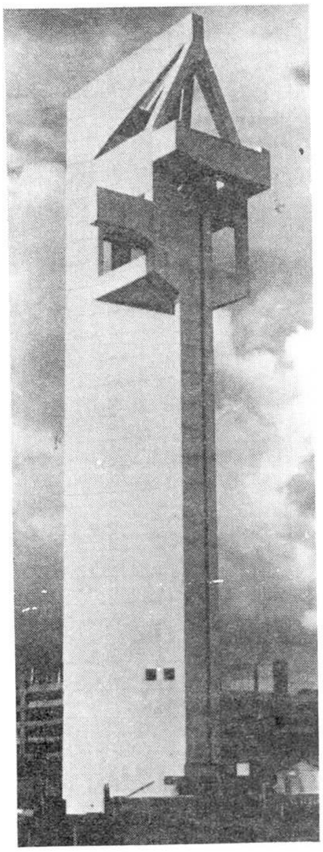


Fig. 7 Tower for Hull Barrier

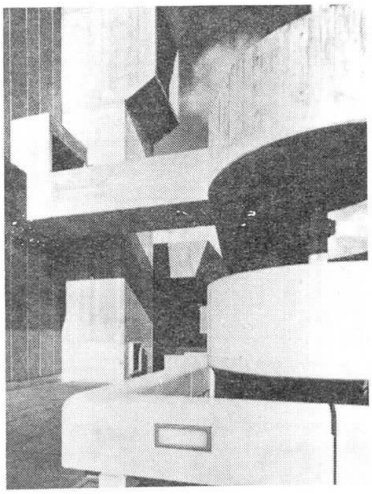


Fig.8 Hayward Gallery, detail

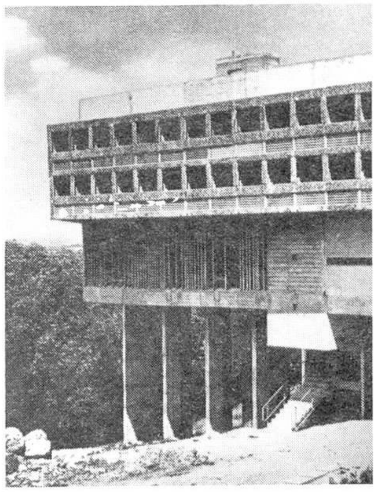


Fig.9 La Tourette (Le Corbusier)

Fig.10 Factory at Thun (Studio 5)

Fig.11 Warehouse (Melbourne)

Some of the suggestions made above may seem like a betrayal of Modern Movement or functionalist principles, but have these principles really served concrete well so far? Most commentators now accept the need for careful thought and extreme care with surfaces and one might ask what is the real difference between the striations on a modern concrete wall and the fluting of a classical column? Such techniques might be a means of introducing visual concrete to the public in a more friendly guise.

5. APPROPRIATE AESTHETICS

The aim of this paper has not been to demolish the concrete aesthetic that is dear to many engineers and architects; the functionalist, "brut" approach. However it is felt that this is best reserved for heavy industrial structures and bridges which are normally viewed from a distance [13]. Elsewhere it should be used with discretion. It is perhaps suitable for a building such as La Tourette where it reflects the austere life-style *chosen* by the monks. Plain untextured panels may be quite adequate for a warehouse on the edge of a factory estate in an outer suburban location (Fig. 11) where nobody cares much about what goes on inside. Such walls serve as an excellent backdrop for medium sized trees. However, banking firms learned several decades ago that they attracted more customers with a glass front than with a classical portico. The fortress image of many art galleries and museums is equally inappropriate. The suggestion is, therefore, that we seek to establish a more "user-friendly" architecture of concrete form and detail, as well as surface, and that this involves searching in every individual case for the *appropriate* aesthetic.

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Olympic Speedskating Oval, Calgary, Canada

L'anneau olympique, stade de patinage de vitesse à Calgary au Canada

Das olympische Eisschnellaufstadion in Calgary, Kanada

Barry LESTER
P. Eng.
Simpson Lester Goodrich
Calgary, AB, Canada

Barry Lester, P. Eng. holds both a B. Sc. and M. Sc. in Civil Engineering from the University of Calgary and was the partner-in-charge for the structural engineering design of the Olympic Oval.

SUMMARY
The design and construction of the Olympic Speedskating Oval for the 1988 Winter Olympics is described. Particular emphasis is given to the design of the long-span roof structure, a unique system of intersecting segmental precast concrete arches.

RÉSUMÉ
Il s'agit de la description du concept et de la construction de l'Anneau olympique où auront lieu les compétitions de patinage de vitesse des Jeux olympiques d'hiver de 1988. Il y a lieu de noter en particulier la conception du long toit voûté, un système unique d'arcs surbaissés entrecroisés en béton préfabriqué.

ZUSAMMENFASSUNG
Es werden Entwurf und Ausführung des Stadions, in welchem während der Olympischen Spiele 1988 die Eisschnellauf-Wettbewerbe stattfinden werden, beschrieben. Besondere Aufmerksamkeit wird der weitgespannten Dachkonstruktion gegeben. Sie besteht aus einem einzigartigen System von sich überschneidenden, vorfabrizierten Flachbögen aus Stahlbeton.

1. INTRODUCTION

In the realm of building technology, it is a rare occassion for the Architect and Engineer to be presented with the challenge and opportunity to design a building for which there is no precedent, for which there are no established rules or conceptions. The Olympic Speedskating Oval in Calgary, however, offered the Designers just such a challenge. The 400 metre covered speedskating track, with a footprint which is significantly different than other long-span recreation or sports facilities, required the Designers to follow a logical step-by-step design process in order to achieve a successful cost-effective solution and to satisfy a very tight budget.

2. BUILDING DESCRIPTION AND USE

Although constructed for the primary purpose of staging the speedskating events during the 1988 Olympics, the Olympic Oval is a multifunctional field house. The building is part of the Physical Education complex at the University of Calgary and includes in its "winter" mode (Figure 1) a 400 metre speedskating track with hockey and figure skating on two Olympic size ice hockey surfaces. The summer mode (Figure 2) includes artificial turf, tracks and facilities for football, soccer, lacrosse, field hockey, tennis, and track and field events. Electrical conduits cast into the floors allow for on the spot measurements of athletes' vital signals with direct transmission to the University's sports medicine computer terminals. The support spaces on either side of the Oval contain locker rooms, class rooms, faculty offices, judges and officials spaces, ice making equipment, Zamboni rooms, turf storage, and mechanical rooms. Total floor area is approximately 26,184 m^2 (282,000 sq. ft.).

The building is fully heated and ventilated, and lighting is provided through a combination of two lighting systems; an indirect natural lighting system around the perimeter and a direct metal halide system for the event floor.

All building finishes, systems and equipment were chosen to be of the highest quality as befits an Olympic building and to provide minimum maintenance and long-life.

3. RESEARCH AND CONCEPTION OF THE ROOF SYSTEM

The design of the roof structure was the key element in the success of the building architecturally, structurally and economically. A substantial amount of research was expended in the review of available structural systems and materials and a great deal of emphasis was placed on conceiving a structural system which would satisfy all of the design parameters of the Owner and the Architect. The Owners parameters included:

- to provide the competition area for the speedskating events at the XV Olympic Winter Games and to accommodate a variety of other sports in either a summer or winter operation mode.
- to create a low maintenance, durable, long-life building.
- to create a warm receptive environment through the introduction of natural light.

- to provide the complete facility within a maximum building budget of $30 million (Canadian funds in 1985).

Architectural parameters:
- the facility must not overwhelm the remainder of the campus. The profile must be low and, because of its huge size, the building must not be monumental.
- the roof should meet the ground and, through its shape and detail, the spanning system should be visible and expressive.
- the roof must be unadulterated with no penetrations or joints.
- to minimize cost, only those functions which require a long-span space will be included within the Oval itself. All other program requirements will be housed in short-span spaces adjacent to the Oval.

As the conceptual design progressed, the application of these qualitative design parameters evolved into a set of design criteria. First, the need to meet a very tight budget dictated that the minimum building area be constructed and that the structure fit the Oval footprint as closely as possible. This resulted in a preliminary roof plan of approximately 100 m x 200 m with rounded ends and eliminated circular dome solutions.

Next, in order to provide maximum height over the playing surface with minimum perimeter wall height, flat roofs using truss and girder type solutions were eliminated and, due to building code requirements for safety in the event of deflation, inflated fabrics were disregarded because of the height of perimeter wall required.

In order to avoid "monumental" solutions and, again, to adhere to minimum cost requirements, a structure using a large number of small, repetitive elements which were locally available and simply constructed was desired. Further, to avoid roof penetrations and joints it was desirable that the structure be thermally flexible to accommodate temperature changes.

The structure which accommodated all of these requirements was found to be a unique system of intersecting arches. Comparative designs were carried out on this arch system in both precast concrete and structural steel and the costs were comparable. But, since the forces were predominantly compressive and since concrete was the most economical material available in the local market for resisting compression loads, the logical choice for the arches was determined to be concrete.

While arches are one of the oldest structural forms and have long been recognized for their efficiency, the intersecting arch system was found to offer several additional advantages. A high level of structural redundancy occurs as a result of the alternative load paths created by the intersection of the arches and point loads are distributed throughout the structure. Further, the arch grid is stable, both during erection and permanently, without relying on lateral support from the deck. This allows the outer envelope to "float" on the arches and offers the possibility of a large number of external skins including glazing and fabrics.

4. DESIGN

The principal components of the main structure are the intersecting arches; the perimeter roof beam; the perimeter columns and buttresses; and the lateral load resisting foundation system. These components are shown on the building section and plan on Figures 3 and 4. Each of these components will be discussed in detail.

4.1 Intersecting Arch Roof

In order to minimize the initial capital cost and the long term operating costs the plan layout was adjusted to fit the Oval footprint as closely as possible. In fact, at certain locations the perimeter support columns are only 6 mm from the minimum clearance line dictated for international speedskating events. Low roof height and reduced interior volume were accomplished by recessing the event floor 4 metres below grade (deeper penetration was prevented by the presence of the natural water table at 5 metres below grade) and by using a very low rise arch cross-section.

A wind and snow loading study was carried out which dictated roof design live loads varying from .91 kN/m^2 of wind uplift to a maximum 2.5 kN/m^2 of downward snow load in several alternative configurations. The intersecting arch structure was analysed with a computer frame analysis program for a wide variety of loading conditions including erection conditions, dead loads, wind, snow, creep, shrinkage and thermal effects. Using the results of the initial computer runs, cracked section properties were predicted and were used in an iterative P-delta analysis to review the deflection behaviour of the structure.

Maximum compression in a single arch segment is 7700 kN under the worst combination of factored loads. Vertical moments in the arches vary from +860 kN m to -890 kN. m. The arch is very rigid under uniform loads with midspan deflection of less than 100 mm under full dead and live loads. With non-uniform snow loads and wind uplift occuring on opposite sides of the structure, a very likely occurrence during winter blizzards, upward deflections of 100 mm may occur at the quarter point on the windward side while a similar 100 mm downward deflection occurs at the quarter point on the leeward side.

The final arch section is shown in Figure 5. Longitudinal reinforcing ratio is approximately 1%. A closely spaced layout of longitudinal bars and stirrups was used due to the torsion which occurs in the arch segments when unbalanced snow loads occur on either side. Because of the very high positive and negative moments, additional concentric axial compression was provided by post-tensioning with a single duct in each corner of the segment. Each duct contained 7-16 mm strands to provide a total axial compression of 4110 kN. All of the longitudinal reinforcing and post-tensioning is continuous throughout the full length of each arch. The precast arch segments and the cast-in-place intersection "nodes" are poured with a high strength semilightweight concrete mix designed to produce a 28 day compressive strength of 40 MPa at a maximum air dry unit weight of 1770 kg/m^3.

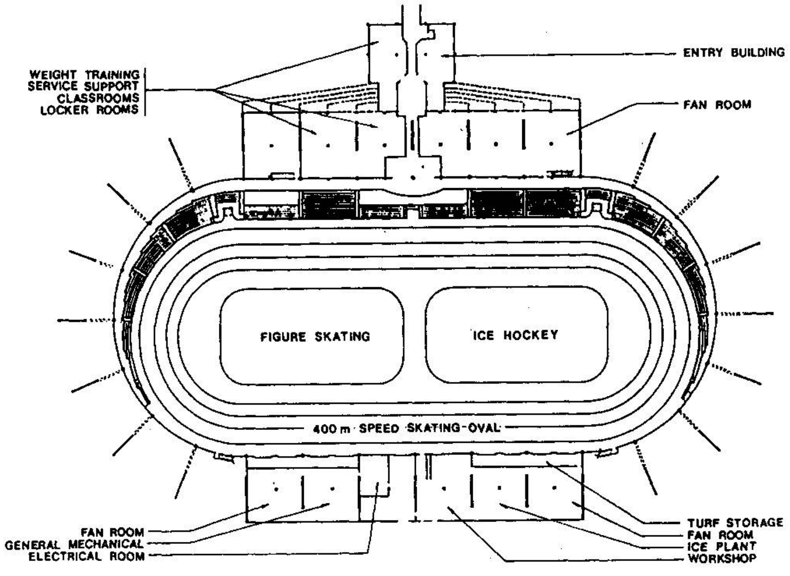


Figure 1 WINTER FOOTPRINT

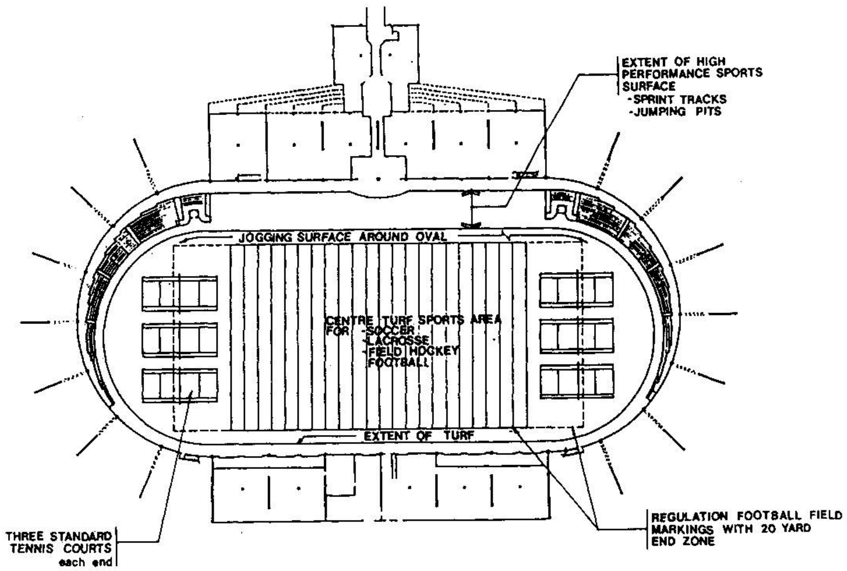


Figure 2 SUMMER FOOTPRINT

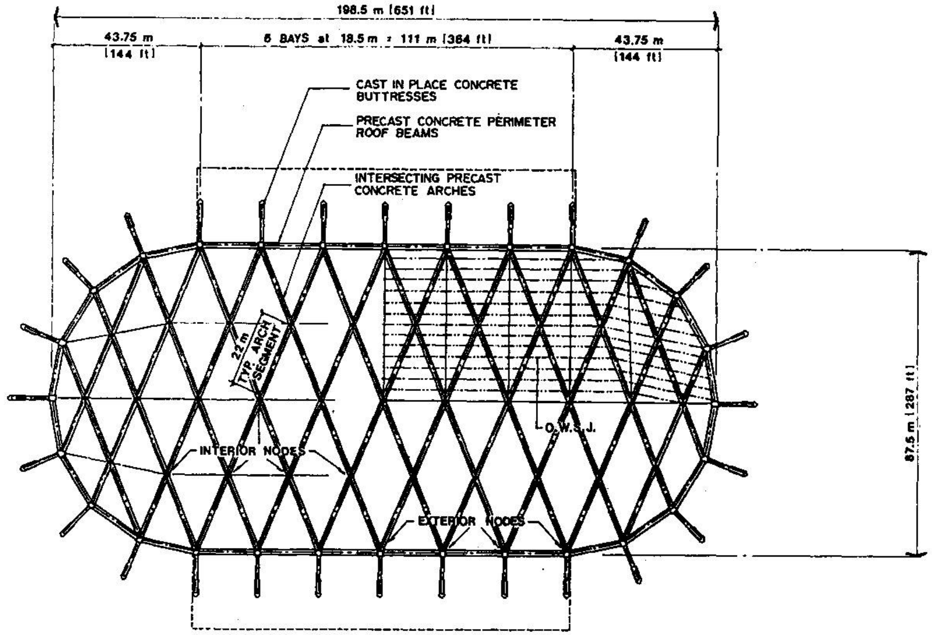


Figure 3 ROOF PLAN
SHOWING ROOF COMPONENTS

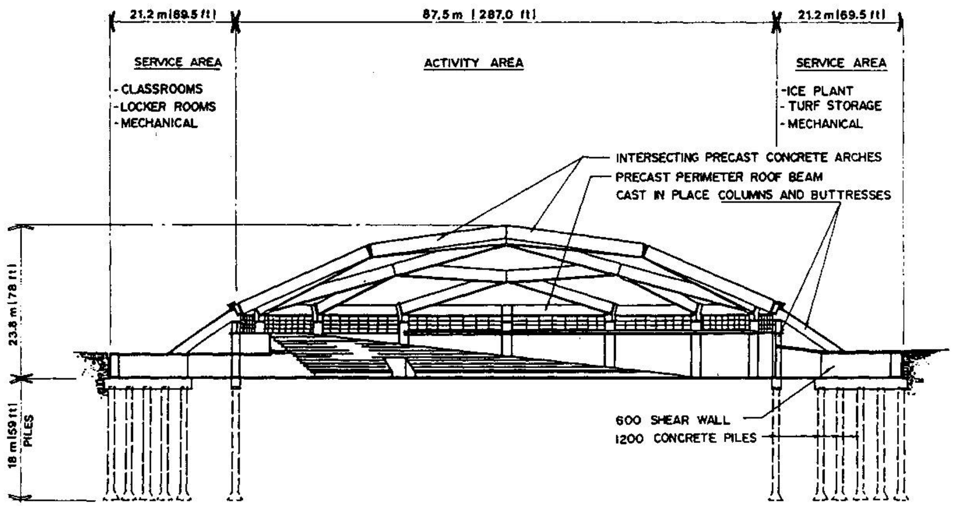


Figure 4 SECTION

4.2 Perimeter Roof Beams

The typical perimeter roof beam is shown in Figure 6.

Due to the fact that the forces in the arch segments vary with each particular loading condition and due to the change in the direction of thrust which occurs between the arches and the supporting buttresses, the perimeter roof beam acts as a tension tie to distribute the offset axial loads from the arches to the perimeter columns. In those bays in which the perimeter beam serves this purpose, a heavy hollow steel section is cast into the hollow concrete beam and attached to the buttress head over the columns with high strength threaded bars. The intersecting arch roof structure is thermally flexible with volume changes due to creep, shrinkage and temperature being accommodated primarily by the rise and fall of the arches themselves. The substructure, however, being over 200 metres long is broken by a series of control joints at every second or third column line. The layout of the building control joints and perimeter roof beam ties is shown in Figure 7.

4.3 Buttresses and Columns

Supporting the arches around the perimeter and spaced at 18.5 m on centre are 1500 mm circular concrete columns and 1000 wide x 1800 deep buttresses. At each buttress "head" a circular multidirectional disc bearing transfers the arch thrust to the buttress. These bearings are designed for a maximum unfactored compression of 8453 kN and a maximum lateral shear of 1495 kN with a rotation of up to 2-1/2%.

4.4 Foundations

The vertical and horizontal components of the arch reactions are transferred by the column and buttresses to a lateral load resisting substructure of large diameter concrete piles. These piles are designed to transfer the horizontal arch thrusts directly into the silty soil through lateral bending in the piles and were determined to be substantially more economical than horizontal ties under the floor of the Oval.

The magnitude of the lateral loads (up to 8000 kN unfactored) at each buttress was far beyond any previously recorded literature on laterally loaded piles and prompted the designers to resort to an extensive load test program in order to define the design parameters for the piles.

In order to minimize the number of piles and also to prevent differential lateral movements from occurring, all of the substructure piles are tied together by the concrete floor slabs of the service areas and are designed to share the lateral roof loads. Lateral load capacities of 1000 kN, 750 kN and 500 kN were assigned to the 1200 mm, 900 mm and 600 mm piles respectively. Further, because the substructure is buried 4 metres below grade, lateral soil pressures against the foundation walls are used to balance the horizontal thrusts due to live loads on the roof.

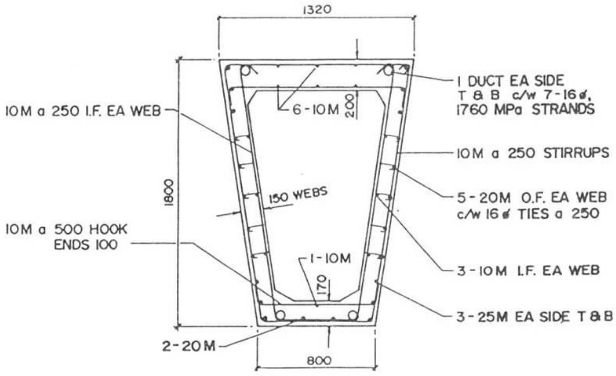


Figure 5 TYPICAL ARCH SEGMENT

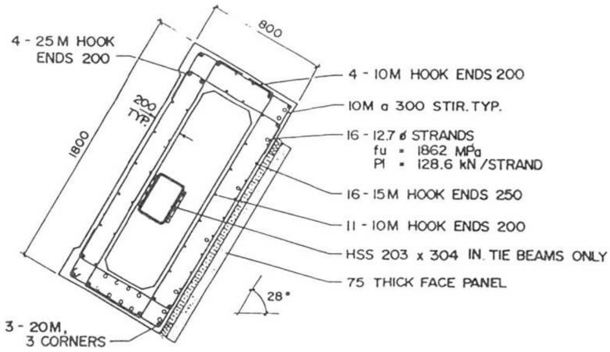


Figure 6 TYPICAL PRECAST CONCRETE PERIMETER BEAM

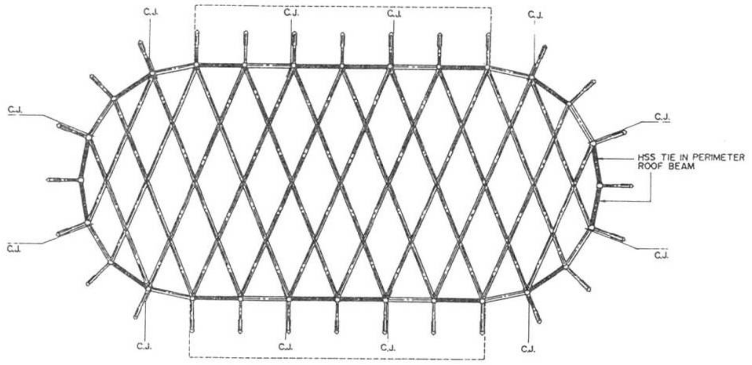
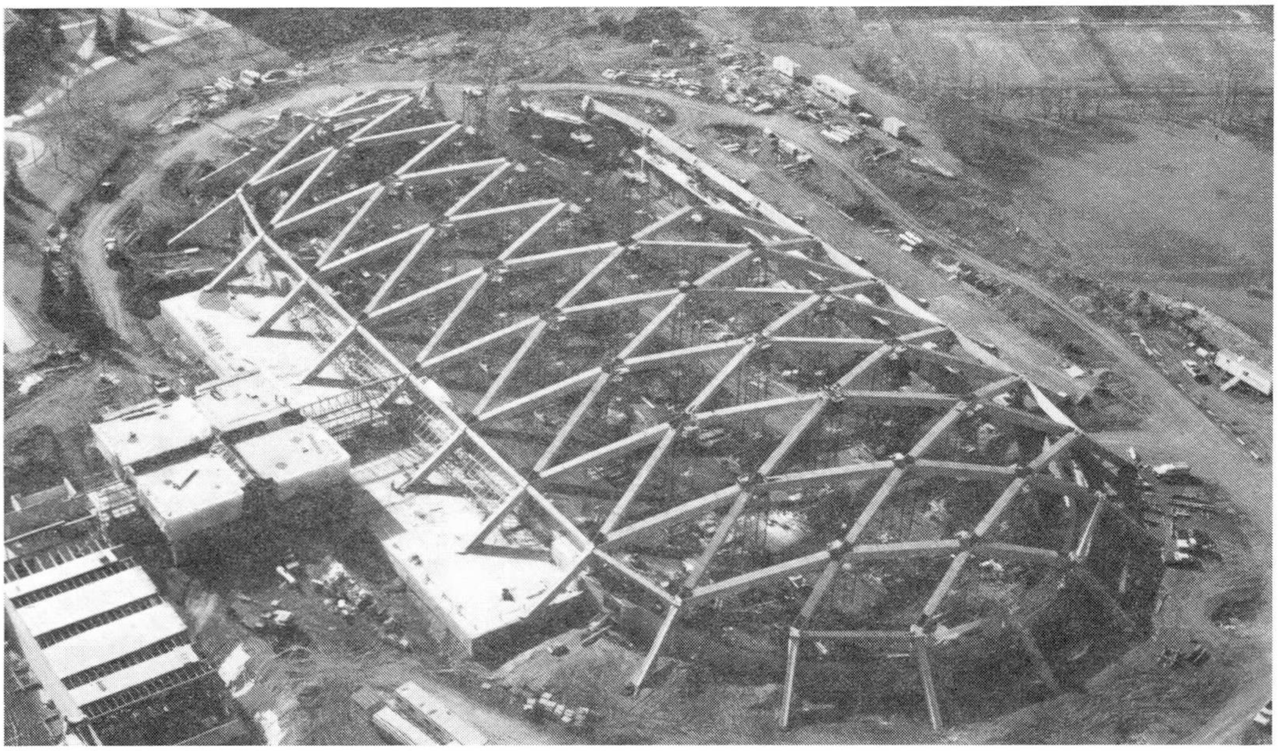


Figure 7 ROOF PLAN
SHOWING TIE BEAMS AND CONTROL JOINTS



5. CONSTRUCTION

Construction commenced in March 1985 and the roof structure was effectively completed by June 1986. Finishing trades and interior work continued until April 1987. Erection of the segmental intersecting arch roof is of particular interest.

The arch segments, each weighing approximately 50 tonnes, were plant cast in a single steel form, trucked to the site, and erected on a temporary scaffolding system consisting of a single steel tower supported by temporary timber piles under each interior node location and a cantilevered steel truss under each exterior node.

Once the arch segments were erected onto the tower, the reinforcing and post-tensioning ducts at each node were coupled together, the sides and soffit of the node formed, and the node cast using the same lightweight concrete mix as the arch segments. Good bond between the precast arch segment and the node concrete was ensured by heavily sandblasting the ends of the precast segments prior to erection. After placing concrete in all of the interior nodes in a single arch, the arch was ready for post-tensioning and, as post-tensioning progressed along the building, the exterior nodes, connecting the arches to the bearings cast into the buttress heads, followed.

Once the concrete in the nodes had reached 75% of its design strength, the General Contractor removed the shoring; first around the perimeter, then under the interior nodes. Because of the inherent stability of the structure it was not necessary to remove all of the shoring simultaneously. Lowering commenced at one end and was carried out in increments of 10 mm with the only requirement being that no tower could be more than 10 mm lower than an adjacent tower. The deflections predicted by the computer analysis during lowering were approximately 30 to 40 mm resulting in approximately 4 increments of jacking being required in order to completely unload a single tower.

6. CONCLUSION

The total construction cost of the Olympic Oval including one of the largest refrigerated ice plants in the world; artificial running tracks and sprint tracks; broadcast level lighting systems; fixed and moveable bleacher seating; acoustical systems and surface treatments; and a "permanent" porcelain enamel steel panelled roof envelope is only $27.2 million Canadian ($19 million U.S.). Through the design stage, low cost and maximum operating life were the two most important criteria used in every decision. The low construction cost achieved through the use of the concrete arch structure allowed the highest quality and minimum maintenance factor to be achieved in other building components, a benefit which will accrue to the Owner through lower operating costs in the future. Yet the final building is anything but low-cost in appearance. The intersecting arch roof structure, exposed on the inside of the building and visibly expressed by the faceted roof on the outside, results in a unique, aesthetically pleasing addition to the campus of the University of Calgary.

Approche architecturale de la ligne nouvelle TGV Atlantique

Architecktonische Einfügung der neuen Linie des TGV – Atlantique

Architectural Considerations for the New TGV Atlantique Railway line



Etienne CHAMBRON
Directeur Ligne Nouvelle
TGV Atlantique
Paris, France

Jacques ESCARON
Ing. Princ. Adj.
TGV Atlantique
Paris, France

Jean-Claude PRANGE
Ing. E.T.P.
TGV Atlantique
Paris, France

RÉSUMÉ
Cet article présente la démarche suivie par la SNCF pour l'insertion dans l'environnement existant, urbain et rural, de la ligne nouvelle TGV Atlantique, puis montre le traitement architectural retenu dans les sites les plus caractéristiques.

ZUSAMMENFASSUNG
Es werden zuerst die von der SNCF unternommenen Anstrengungen für die Einbettung der neuen Hochgeschwindigkeitslinie des TGV Atlantique in die bestehende städtische und ländliche Umgebung beschrieben. Dann wird die architektonische Gestaltung der charakteristischsten Abschnitte gezeigt.

SUMMARY
The article describes the steps taken by the SNCF to accomodate the new high speed railway line TGV Atlantique to the existing urban and rural environments. It then presents the architectural features of typical sections.

1. LE PROJET

La ligne nouvelle TGV ATLANTIQUE a été conçue pour améliorer la desserte ferroviaire de l'Ouest et du Sud-Ouest de la France. Réservée au transport des voyageurs à grande vitesse (300 km/h), elle permettra de relier PARIS au MANS et PARIS à TOURS en 1 heure, puis par sa compatibilité avec le réseau existant BORDEAUX à 556 km de PARIS en 2h 58 mn, BREST en 4h 16 mn.

D'une longueur totale de 263 km en site propre, elle se compose d'un tronc commun de 124 km (dont 20 km en Région Parisienne) de PARIS à la bifurcation de COURTALAIN (Loir-et-Cher) puis d'une branche BRETAGNE de 52 km vers LE MANS et d'une branche ATLANTIQUE de 87 km vers TOURS.

Le relief, relativement plat des territoires traversés permet de n'atteindre qu'exceptionnellement des rampes de 25 ‰, la rampe normale ne dépassant pas 15 ‰.

De PARIS à MASSY, la ligne emprunte en site urbain l'ancienne plateforme de la ligne ferroviaire PARIS à CHARTRES par GALLARDON, puis franchit les contreforts du Bassin Parisien par un tunnel de 5 km de long à VILLEJUST. Avant de rejoindre le plateau de la BEAUCE, elle est jumelée avec l'autoroute A10 sur environ 24 km.

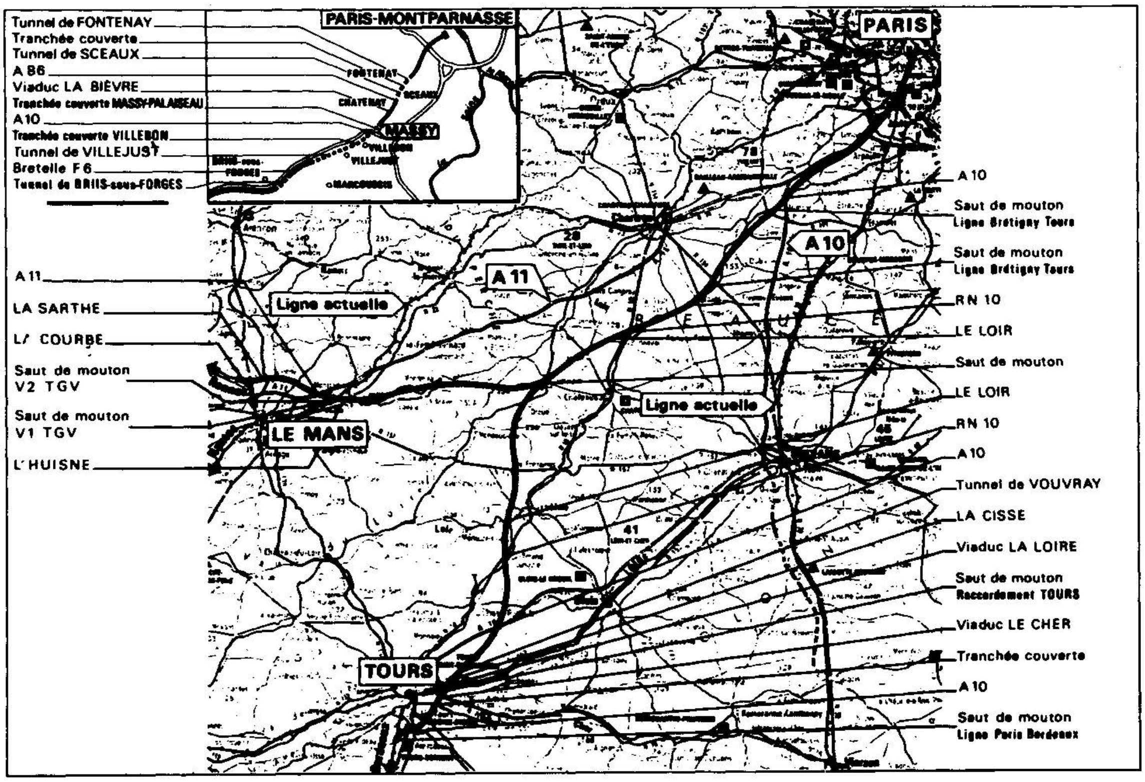


Fig. 1.1

La ligne se poursuit ensuite vers TOURS dans un site rural au relief calme marqué principalement par les franchissements de l'autoroute A10 à ST-MARTIN-DE-BRETHENCOURT, du LOIR à BONNEVAL et à NAVEIL, de l'autoroute A10 une nouvelle fois à AUZOUER-EN-TOURAINE pour rejoindre, par la vallée de la BRENNE et le tunnel de VOUVRAY, la large plaine de la LOIRE et du CHER où sont réalisés les viaducs les plus importants.

Sur la branche BRETAGNE un site caractéristique, celui de la Vallée de l'HUISNE qui est coupée par les raccordements de la ligne nouvelle TGV avec la ligne existante PARIS - LE MANS.

Le tableau ci-après (Fig. 1.2) précise les caractéristiques des principaux ouvrages de franchis-

VIADUCS

Voie rapide F6	220 m.	
le Loir (Bonneval)	108 m.	
le Loir (Naveil)	173 m.	
Vouvray	387 m.	
la Cisse	312 m.	
la Loire	431 m.	estacade 296 m.
Rochepinard	315 m.	
le Cher	370 m.	estacade 456 m.
Total :	2 316 m.	estacade 1047 m.

TUNNELS

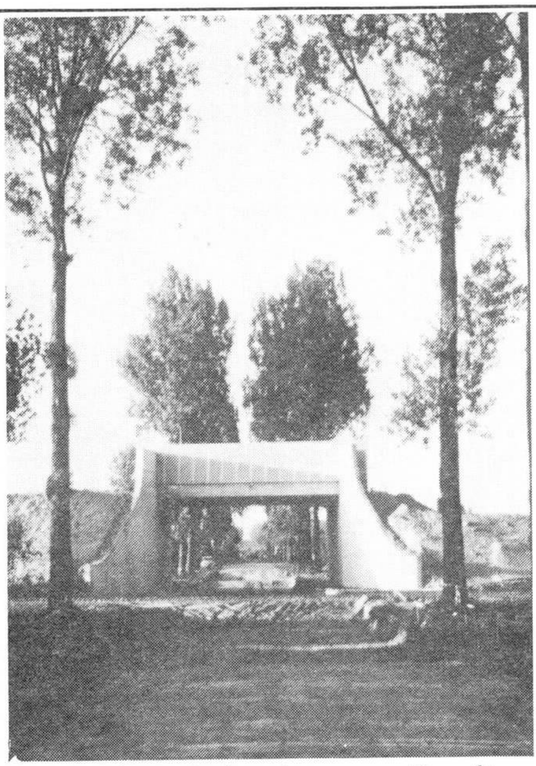
	Double voie	Voie unique
Fontenay	474 m.	
Sceaux	827 m.	
Villejust		2 x 4 800 m.
Vouvray	1 496 m.	
Total :	2 797 m.	9 600 m.

TRANCHÉES COUVERTES

Fontenay	306 m.
Fontenay	460 m.
Sceaux	216 m.
Chatenay-Malabry	1 047 m.
Antony	969 m.
Verrières-Massy	1 280 m.
Massy	2 014 m.
Villebon	650 m.
Briis-sous-Forges	1 273 m.
Larçay	203 m.
Total :	8 418 m.

Nombre d'ouvrages d'art courants

— ouvrages routiers	ponts-rail	83
	ponts-route	181
— autres ponts-rail		48
— buses ou dalots		488



sement et des ouvrages souterrains, mais il faut noter que les ouvrages courants : ponts-rails, ponts-routes ou passages hydrauliques ont également fait l'objet d'attention vis à vis de l'environnement (Fig. 1.3)

2. SENSIBILITÉ DE L'ENVIRONNEMENT

Le cadre légal de construction d'une voie nouvelle en France s'est trouvé récemment transformé par la loi sur la protection de la nature du 10 juillet 1976.

La SNCF a donc procédé, pour la ligne nouvelle TGV ATLANTIQUE, à une étude d'impact complète permettant de faire connaître à tous les interlocuteurs intéressés la consistance du projet et les mesures prises pour réduire son impact sur l'environnement. L'aspect paysager et architectural du projet y était bien entendu présenté.

Fig. 1.3 Pont-rail

Ce dossier n'était qu'une première étape : à partir du moment où le tracé a été pratiquement fixé par les résultats de l'Enquête d'Utilité Publique ainsi que par trois enquêtes complémentaires portant sur des variantes locales de tracé, il a été procédé à des études détaillées sur tous les domaines touchant à l'Environnement. C'est ainsi qu'ont été entreprises des études paysagères des franchissements des points sensibles, comprenant notamment l'étude architecturale des ouvrages d'art.

3. APPROCHE PAR LA SNCF DE L'ARCHITECTURE DES OUVRAGES D'ART

De même que la désignation des points sensibles, les grandes options de leur traitement ont été définies de façon collégiale, sous l'égide des Ministères des Transports et de l'Environnement, et en liaison étroite avec les autorités régionales et locales responsables de l'Environnement.

Compte tenu de la diversité des sites traversés, la SNCF a fait appel à plusieurs cabinets d'architectes. Ceux-ci ont été associés très tôt à la définition des projets d'ouvrages et ont pu ainsi participer à la mise au point des structures, et en intégrer toutes les contraintes.

En particulier, il a été tenu le plus grand compte des contraintes technico-économiques notamment en matière de choix et de dimensionnement des structures de choix des matériaux, de topographie, d'hydraulique et d'acoustique.

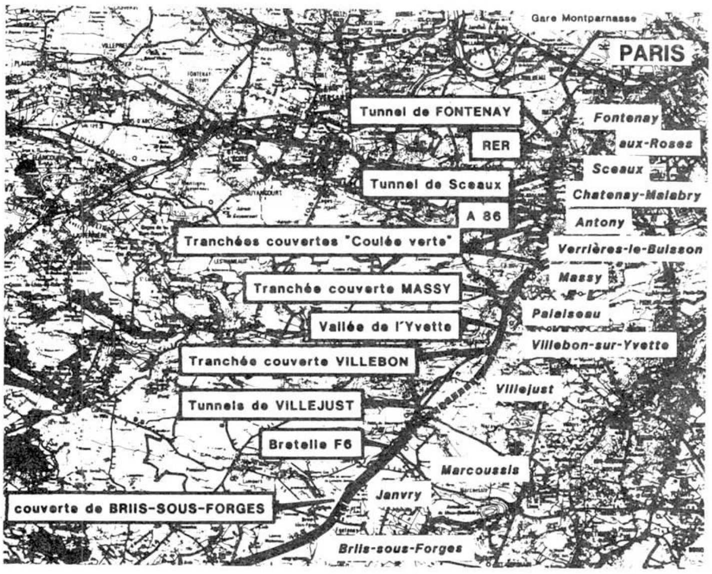


Fig. 4.1

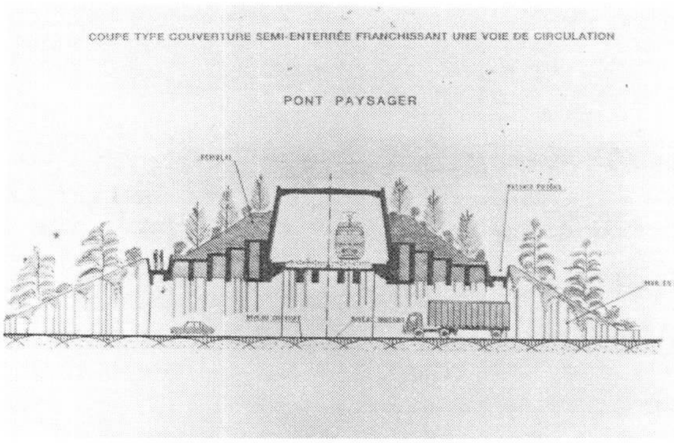


Fig. 4.2

Les chapitres suivants décrivent la démarche architecturale retenue dans quelques sites caractéristiques.

4. TRAVERSÉE DE LA BANLIEUE PARISIENNE DE FONTENAY AUX ROSES A MASSY

Le tracé de la ligne nouvelle utilise une ancienne plateforme ferroviaire autour de laquelle s'était organisée l'urbanisation entre les communes de FONTENAY AUX ROSES et MASSY.

Il ne se posait donc pas problème d'acquisition d'emprise mais de vives appréhensions sur les nuisances sonores ont été exprimées par les riverains qui s'étaient quelques années auparavant opposés avec vigueur à un projet d'autoroute sur le même site.

La SNCF a donc élaboré un projet ferroviaire à ciel ouvert mais avec de très importantes protections phoniques latérales. Les associations et les élus locaux avaient par ailleurs envisagé sur ces terrains des aménagements d'espaces verts a priori incompatibles avec le projet de ligne nouvelle. Appuyée par les ministères de tutelle et la région Ile de France, une coopération étroite entre la SNCF et les collectivités intéressées a permis une adaptation réciproque des deux projets, qui a abouti à une opération exemplaire appelée "Coulée Verte".

Grâce au concours de ce "projet d'aménagement d'une Coulée Verte du Sud Parisien" plusieurs tronçons de la voie de la ligne nouvelle seront couverts pour permettre la réutilisation de l'emprise. Dans d'autres tronçons qui restent à ciel ouvert pour des raisons techniques les dispositions du projet initial ont été maintenues et la plateforme est encadrée d'écrans antibruit de hauteur au moins égale à

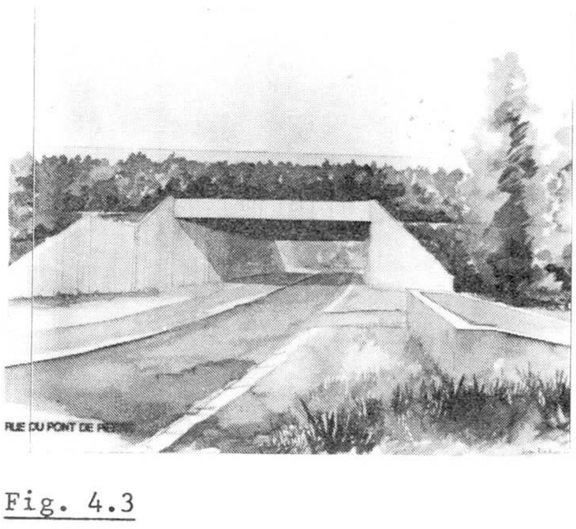


Fig. 4.3

2,5 m pour assurer également un rôle de clôture et de protection antivandalisme. L'intégration à l'environnement urbain de ces écrans est assurée par une animation de leur parement et améliorée par l'aménagement paysager du Projet de Coulée Verte.

De VERRIÈRES à MASSY les ouvrages de couverture de la ligne ne seront pas complètement enterrés pour des raisons topographiques. Le parement apparent (2,50 m supérieur) de ces ouvrages préfabriqués en béton armé est de bon aspect.

Le franchissement des routes de ce tronçon SUD est l'occasion de la construction d'ouvrages de conception architecturale originale qui s'inscrit tout à fait dans l'objectif de la Coulée Verte. En effet, la continuité des ouvrages de couverture du TGV par dessus les routes est accompagnée par la continuité du talus latéral grâce à l'aménagement d'accotements spéciaux permettant la végétalisation de l'ouvrage. (Fig. 4.2).

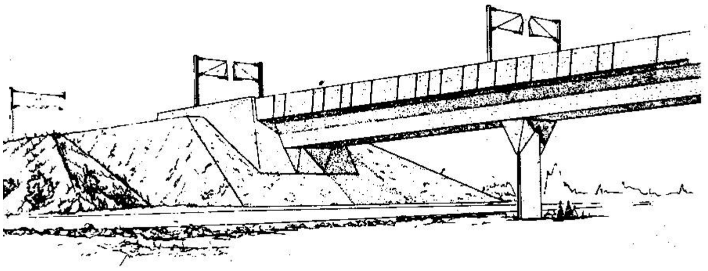
Ici, l'architecture se fait donc discrète dans un souci de symbiose entre les ouvrages de la voie nouvelle et les plantations de la Coulée Verte qu'ils permettent de réaliser (Fig. 4.3).

5. JUMELAGE AVEC L'AUTOROUTE A10 SITE DE FRANCHISSEMENT DE L'ÉCHANGEUR F6 A MARCOUSSIS (ESSONNE)

Ce site de la vallée de la SALMOUILLE fait la liaison entre la tête SUD du tunnel de VILLEJUST et le franchissement des bretelles de l'échangeur F6 avec l'autoroute A10. La ligne nouvelle – parallèle à l'autoroute le franchit par un remblai de grande hauteur et deux viaducs.

Dans ce cadre très contraignant, le parti de l'architecte a été le suivant :

- pour la tête Sud du tunnel, évènement important de la pénétration dans la banlieue parisienne, exprimer simplement la technique de l'ouvrage en évitant les décorations arbitraires,
- pour la traversée de la vallée, aménager les formes du remblai là où peut être montrée la technicité de celui-ci à savoir au raccordement avec le viaduc en dégageant la structure interne du bloc technique (Fig. 5). Ainsi est assurée la meilleure continuité possible entre béton et ouvrage en terre,
- pour les viaducs de conceptions différentes (l'un à caisson en béton précontraint, l'autre à poutrelles enrobées), le rapprochement des formes des piles, culées et garde-corps, affirme l'unité de l'ensemble.



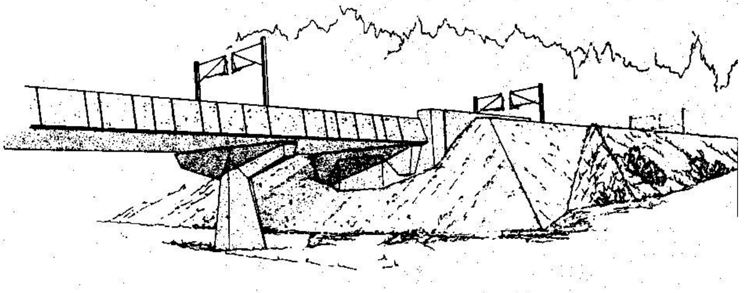


Fig. 5

La dynamique du franchissement est obtenue par les formes fondamentales des structures vu l'échelle du site déjà traversé par l'autoroute A10.

6. FRANCHISSEMENT DE L'AUTOROUTE A10 A ST-MARTIN DE BRETHENCOURT (YVELINES)

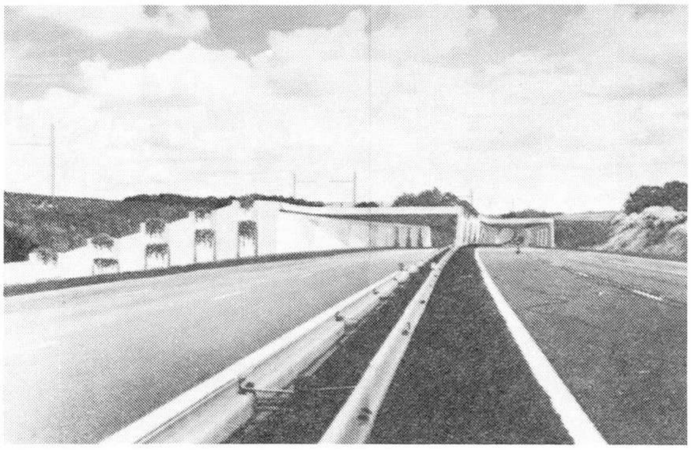


Fig. 6

Les contraintes d'environnement de ce tronçon ont imposé au franchissement de l'autoroute A10, un biais très accentué (angle de 12 grades) et un tablier de très faible épaisseur. La structure de l'ouvrage s'est donc imposée et consiste en un tablier à poutrelles enrobées reposant sur des appuis de grande longueur (210 m y compris les murs en aile). L'architecte a donc travaillé à minimiser pour l'usager de l'autoroute l'impact de cet ouvrage qui doit rester discret dans ce site très doux du plateau de BEAUCE. Des évidements dans les appuis contribuent comme les formes du tablier à alléger l'ouvrage. Les parements ont reçu un traitement d'animation. Les murs en aile ont été aménagés pour accueillir à mi-hauteur et à intervalles réguliers des plantations ornementales. (Fig. 6)

7. FRANCHISSEMENT DE LA VALLÉE DU LOIR A BONNEVAL (EURE-ET-LOIR)

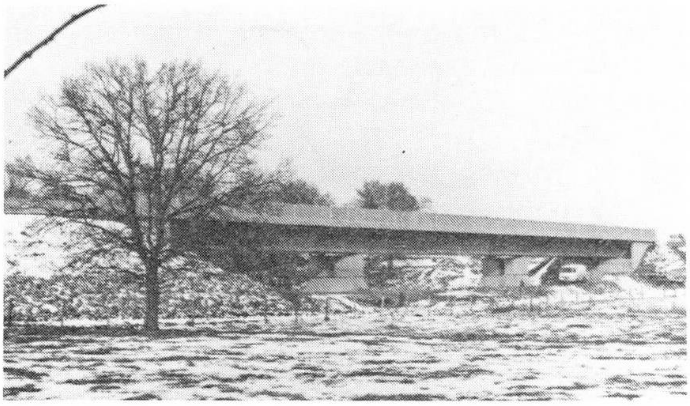


Fig. 7

Le site correspond à une petite vallée rurale dont la brèche est d'environ 300 m entre 2 coteaux peu marqués où la voie nouvelle se trouvera encaissée.

Le parti structural ayant été défini à la suite d'études hydrauliques, (ouvrage unique de 3 travées permettant de dégager une ouverture de 108 m) le problème posé était l'intégration dans le site d'un ouvrage du type caisson en béton précontraint avec une hauteur de franchissement réduite.

La réponse apportée est basée sur des piles travaillées sans caractère monumental et sur l'utilisation d'un garde-corps au parement coloré et rustique en agrégats locaux apparents. (Fig. 7)

8. INSERTION D'UN ÉCHANGEUR FERROVIAIRE DANS LA VALLÉE DE L'HUISNE A CONNERRÉ (SARTHE)

Le projet se caractérise par 3 lignes de remblais de hauteurs différentes qui franchissent la vallée à partir du versant EST jusqu'à se raccorder à la voie ferrée existante vers LE MANS.

Le traitement paysager de ce site a été confié à un architecte régional qui avait en charge également la définition architecturale des ouvrages d'art de franchissement de la rivière. L'architecte, associé à la définition structurale des ouvrages, a été amené à présenter une variante de balancement remblais - ouvrages tout en respectant les impératifs définis par les études hydrauliques (Fig. 8.1)

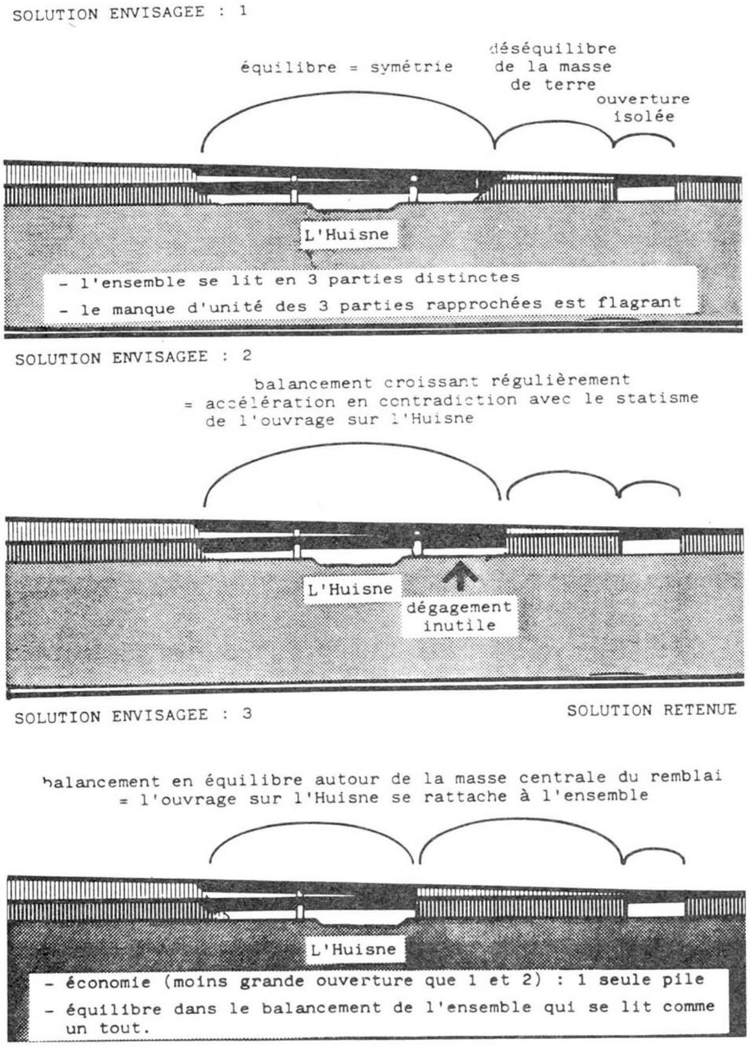


Fig. 8.1

Le traitement des ouvrages qui a porté sur les culées, les piles et les garde-corps autour de la structure courante en caisson béton précontraint s'est orienté de manière marquée vers l'indication d'une dynamique de la ligne à grande vitesse. Ce traitement sera complété par des plantations paysagères pour accompagner les remblais importants encadrant les ouvrages. (Fig. 8.2)

9.FRANCHISSEMENT DU LOIR A NAVEIL (LOIR-ET-CHER)

La proximité de l'agglomération de VENDOME a accentué la sensibilité de la traversée de cette vallée ouverte sans accroche bien marquée de la rivière.

Une concertation importante s'est déroulée pour définir le projet avec les collectivités locales tant dans sa consistance technique : réalisation d'une maquette pour l'étude de dimensionnement hydraulique des ouvrages par exemple, que dans son traitement paysager : réalisation de photomontages.

L'étude paysagère et architecturale de l'intégralité du franchissement de la vallée a été confiée à un même cabinet d'architectes.

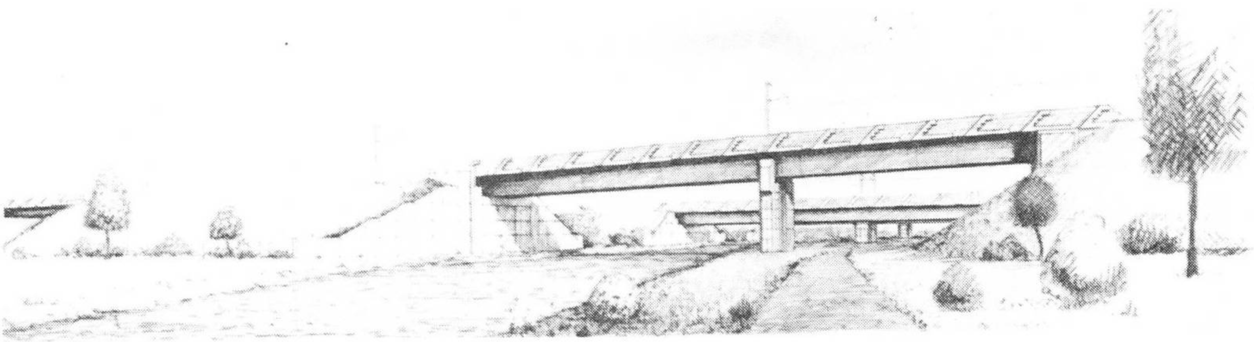


Fig. 8.2

Le viaduc sur le LOIR présente la particularité d'être calé au ras des plus hautes eaux conformément au souhait des élus, et l'architecte a dû trouver équilibre et transparence pour la structure du tablier type caisson en béton précontraint mis en place par poussage. (Fig. 9.1)

L'architecte a donc travaillé la forme des appuis et du garde-corps qui grâce à son inclinaison et sa matière (béton de ciment blanc) attire dynamisme et finesse.

C'est à partir des éléments caractéristiques du viaduc sur le LOIR qu'ont été déterminées les lignes directrices du traitement des autres ouvrages de la vallée (ouvrages de décharge et ouvrages routiers) et des écrans antibruit sur remblai qui ont été intégrés à cette étude globale. La linéarité des éléments retenus participe à la dynamique du franchissement de la vallée.

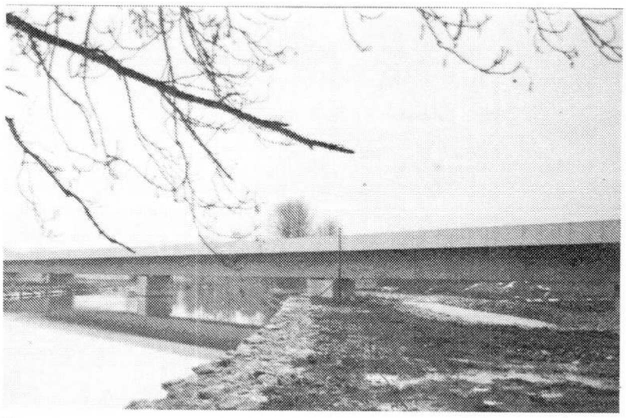


Fig. 9.1

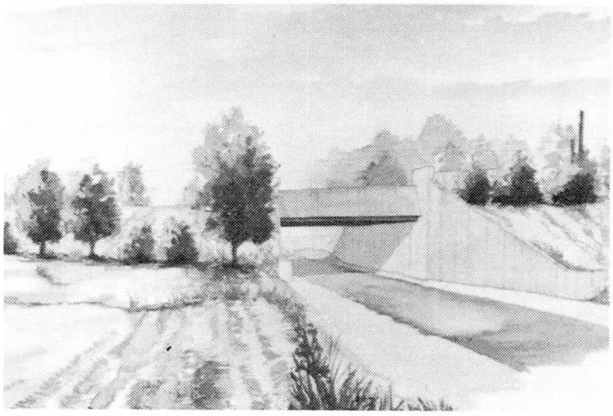


Fig. 9.2

Sur la rive Sud de la vallée, le paysage de la ligne aurait, sans précaution particulière, découpé dans le coteau une brèche détruisant l'harmonie du paysage.

L'architecte a saisi l'opportunité du rétablissement d'une ligne ferroviaire existante sur la ligne de crête pour masquer cette brèche par le choix d'un ouvrage de type cadre sur lequel s'arrête le traitement paysager de la vallée.

10. FRANCHISSEMENT DES VALLÉES DE LA LOIRE ET DU CHER (INDRE ET LOIRE)

L'étude d'impact présentée par la SNCF lors de l'enquête préalable à la Déclaration d'Utilité Publique définissait la consistance du projet issue des études techniques, des études paysagères préalables et de la première concertation.
L'importance des ouvrages conduisait à prévoir un deuxième stade d'études paysagères et architecturales détaillées prenant en compte les observations recueillies lors de l'enquête publique.
En concertation avec les Services Départementaux de l'Architecture, il a été décidé de faire appel à 2 cabinets d'architectes locaux auxquels était associé un cabinet de paysagistes. Une équipe pluridisciplinaire regroupant architectes paysagistes, ingénieurs de structures, hydrauliciens, acousticiens, topographes et géologues a aussi été constituée.

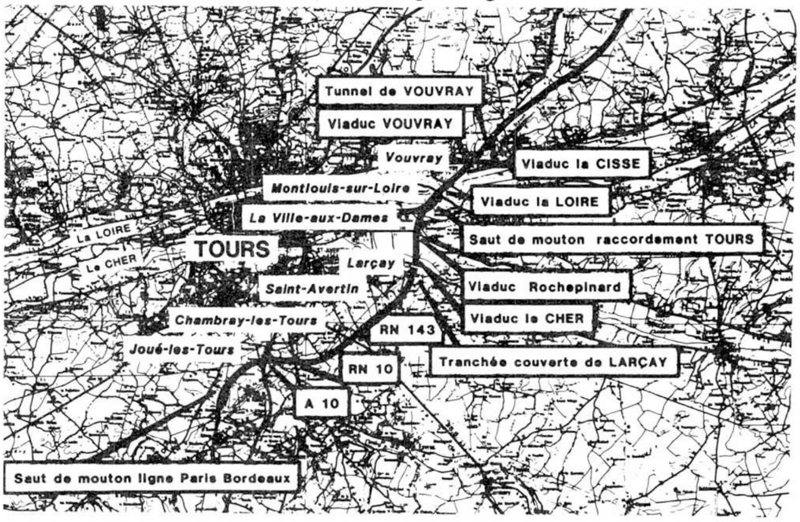


Fig. 10.1

Dans une première approche les principes d'une meilleure répartition entre les remblais et les ouvrages ont été définis pour :

- améliorer la séquence des remblais et des viaducs,
- dégager les vues intéressantes à proximité des voies de communication.

Après une étude de l'ensemble sur les 10 km de la zone sensible les deux bureaux d'architectes ont été chargés d'étudier, plus particulièrement :

- l'un, la traversée de la LOIRE et l'aménagement de sa rive droite, avec les ouvrages de la vallée de la BRENNE et de la CISSE, et les têtes du tunnel de VOUVRAY,
- l'autre, la vallée du CHER et la pénétration dans le coteau de LARÇAY.

Analyse des partis retenus

Tête SUD du tunnel (Fig. 10.2)

La sortie SUD du tunnel de VOUVRAY s'effectue dans le coteau dominant le Val de CISSE là où existent des murs de soutènement construits en terrasse. Le parti retenu consiste :

- à affirmer l'effet de taille créé dans le rocher par le passage en biais du TGV,
- à conserver le caractère aux façades du coteau situées de part et d'autre du tunnel, et en particulier à sauvegarder l'habitat troglodytique dans son état naturel.

Des arcs boutants nécessaires à la structure de la tête du tunnel assureront la transition entre la zone de lumière du Val de LOIRE et la zone d'ombre du tunnel.

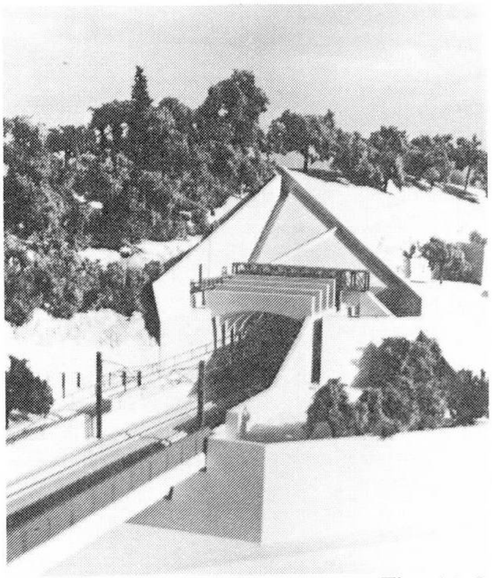


Fig. 10.2

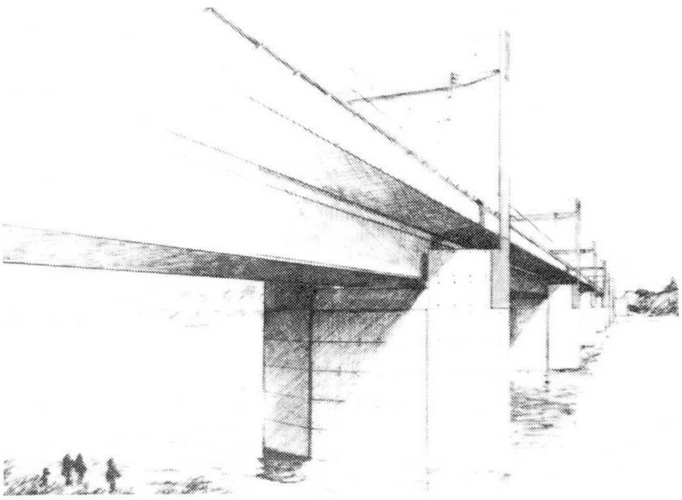


Fig. 10.3

Vallée de la LOIRE (Fig. 10.3)

L'architecte fait apparaître dans les viaducs sur lesquels débouche le tunnel des lignes pures, des volumes sobres où la couleur vient souligner l'effet de vitesse tout en atténuant visuellement la hauteur des protections antibruit. L'ouvrage de franchissement de la LOIRE, construit suivant la technique du poussage, se caractérise par des piles prolongées de becs enserrant le tablier pour réduire l'épaisseur visuelle de celui-ci et servant d'ancrage aux supports de caténaires. Les culées très marquées sont dessinées à l'échelle du paysage.

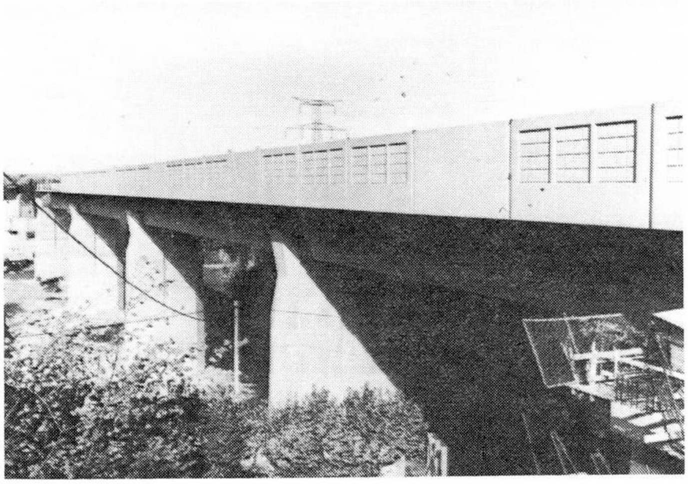
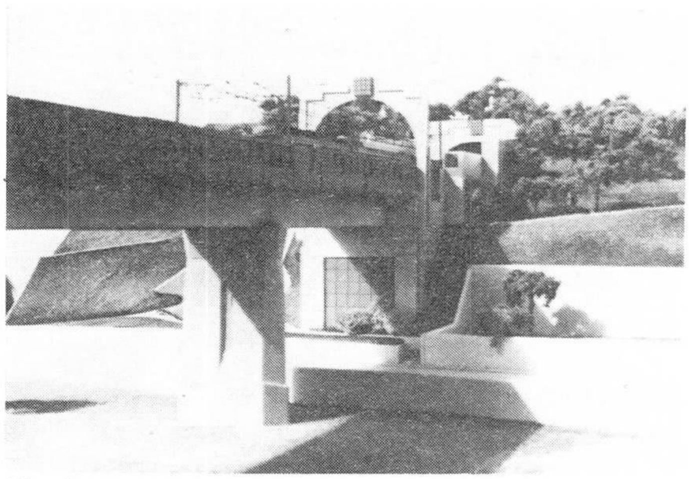


Fig. 10.4

Vallée du CHER (Fig. 10.4)

Cet ouvrage est également construit suivant la technique du poussage.
L'architecte a souhaité affiner l'ouvrage pour tenir compte de ses dimensions importantes : le traitement des garde-corps antibruit permet de réaliser une accroche visuelle qui "fait oublier" le tablier. L'architecte joue sur des décaissés permettant de faire jouer la lumière et de faire varier l'aspect du béton teinté ocre rouge. Les piles ont été dessinées en les affinant le plus possible par un pincement en partie haute, pour en accentuer leur verticalité.



L'entrée Nord de la Tranchée couverte de LARÇAY se justifie elle aussi par le souci paysager de reformer la crête du coteau dans lequel pénètre la ligne nouvelle. Située en retrait de la route nationale 70, elle est annoncée par un arc symbolique placé à l'extrémité sud du viaduc.

Fig. 10.5

CONCLUSION

Les contraintes de tracé imposées aux lignes à grande vitesse, les contraintes d'exploitation qui requièrent des structures éprouvées et durables ont des implications sur les paysages traversés par ces infrastructures linéaires.

Toutefois, ces implications sont peu visibles dans la majorité des sites où la voie ferrée, par sa faible largeur d'emprise et son absence de pollution, s'intègre facilement et avec discrétion.

Pour les grands ouvrages qui restent inévitables dans certains cas, et qui deviennent alors les éléments majeurs de la ligne, il est au contraire souhaitable de marquer la modernité du TGV tout en conservant particulièrement en site rural l'ambiance de l'environnement existant. Ce nouvel environnement technique reste à la dimension des espaces traversés.

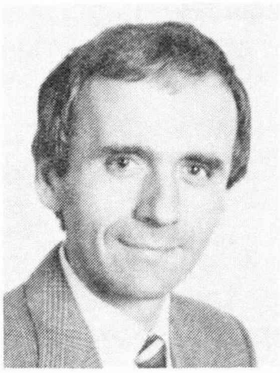
L'association de l'Architecte et de l'Ingénieur relativement tôt dans l'étude des projets permet de réaliser ce pari en réussissant une bonne insertion de la ligne nouvelle dans les sites sensibles et même dans certains cas en apportant un enrichissement incontestable du patrimoine local.

L'architecture aérienne du Métro de Marseille

Die oberirdische Architektur der U - Bahn in Marseille

Architectural Aspects of Elevated Structures of the Marseille Subway

Michel CROC
Directeur Technique
Société du Métro
Marseille, France



Michel Croc, né en 1948, est ancien élève de l'École Polytechnique de Paris et Ingénieur des Ponts et Chaussées. Après avoir été maître d'œuvre de projets portuaires, il est actuellement responsable technique de la construction des lignes de métro de Marseille.

RÉSUMÉ
Trois des quatre terminus du Métro de Marseille sont aériens : La Rose, Sainte Marguerite - Dromel et Bougainville. L'article expose la recherche architecturale – tant pour les viaducs que pour les stations – qui a abouti à des ouvrages de qualité dont l'apport à leur environnement est important.

ZUSAMMENFASSUNG
Drei der vier Endstationen der U - Bahn in Marseille sind oberirdisch : La Rose, Sainte-Marguerite - Dromel, und Bougainville. Der Beitrag beschreibt die architektonischen Anstrengungen, die für die Gestaltung der Viadukte und der Stationen unternommen worden sind, und welche zu qualitativ guten Bauwerken in ihrer Umgebung führten.

SUMMARY
Three of the four terminal stations of Marseille's Metro are above ground : La Rose, Sainte-Marguerite - Dromel and Bougainville. This paper presents the architectural research both for bridges and the stations as well – which resulted in high quality structures and a positive contribution to environment.

1. INTEGRATION DES LIGNES DE METRO DANS LA VILLE

1.1 Influence du tissu urbain sur le choix des ouvrages

Le tissu urbain dense des centres-villes ne laisse aucune place à l'implantation de lignes de métro en surface et la seule possibilité est le passage en souterrain.
En revanche, dès que l'on gagne la périphérie des agglomérations, on rencontre un tissu urbain de densité plus faible, soit dans des zones en dépérissement tendant vers la rénovation, soit dans des zones d'urbanisation récente plus ouverte. Il est alors possible de rechercher des implantations de lignes en viaducs, avec stations aériennes, participant à l'architecture de la ville et jouant un rôle dynamique dans la régénération du tissu urbain.

1.2 Le cas du Métro de Marseille

La ville de Marseille n'échappe pas à cette règle et les lignes de métro qui la desservent actuellement, souterraines dans un centre-ville très dense, deviennent aériennes dès qu'elles abordent la périphérie, à l'approche des terminus.

C'est ainsi que trois extrémités de lignes ont été réalisées en viaducs, la quatrième, en centre-ville, ne pouvant être que souterraine:

- sur la ligne n° 1, le viaduc avec station terminus de la Rose, au Nord-Est de l'agglomération,

- sur la ligne n° 2, le viaduc du stade Vélodrome, avec la station terminus Sainte-Marguerite - Dromel, au Sud-Est, et le viaduc de Bougainville avec sa station terminus au Nord.

Dans un souci d'homogénéité architecturale entre viaducs et stations, une mission de conseil a été confiée, dès les études d'exécution du génie civil, aux architectes des stations, et on ne peut que se féliciter d'une telle procédure au vu des excellents résultats obtenus.

Nous allons décrire les trois stations terminales dans l'ordre de leur contruction et le lecteur pourra suivre l'évolution dans la mise en œuvre, en particulier dans l'aspect et la qualité des parements de béton.

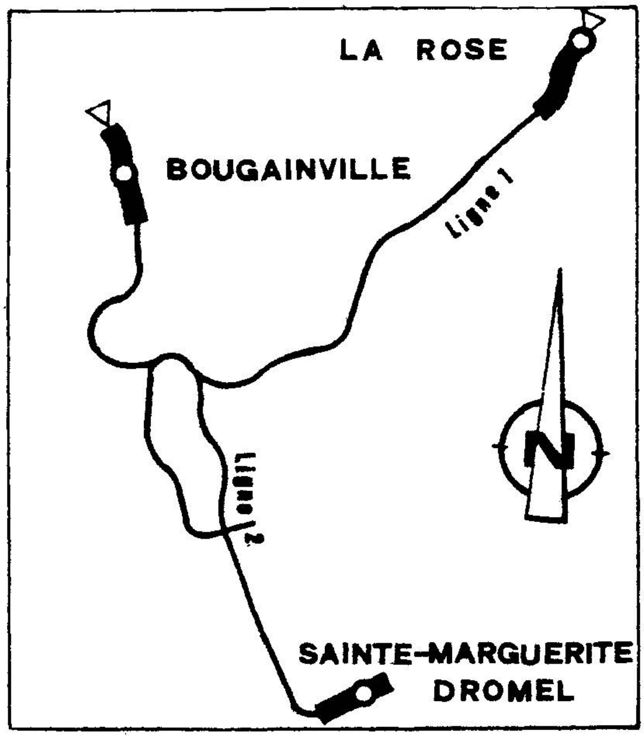


Fig. 1 - Les extrémités aériennes du réseau

2. LE TERMINUS DE LA ROSE

2.1 L'ensemble de l'ouvrage

Mis en service en 1977, le terminus de la Rose est le premier en date des ouvrages aériens du Métro de Marseille. Situé à l'extrémité Nord-Est de la ligne, le viaduc terminal a une longueur totale de 680 m – dont 116 m pour la station – et s'inscrit en s'élevant progressivement dans une large trouée préexistante entre des groupes d'urbanisation récente.

2.2 La station

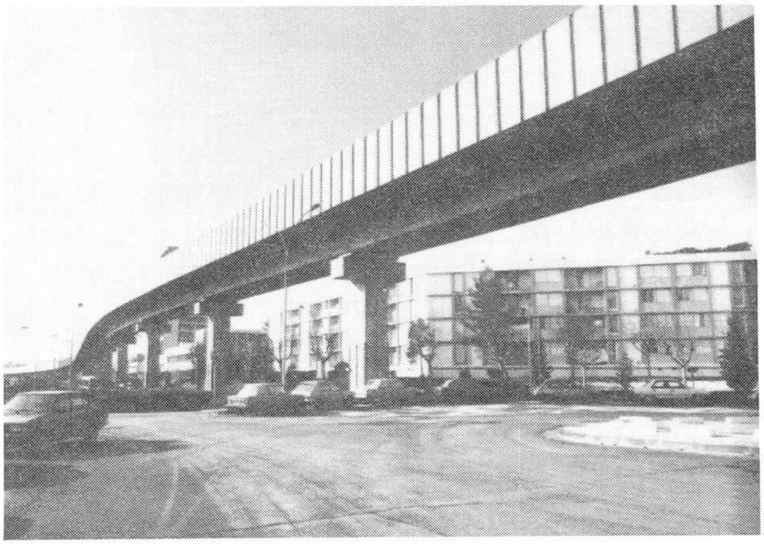


Fig. 2 : Le viaduc de la Rose

Celle-ci est située à l'extrémité du viaduc, à la jonction avec le dépôt. Epaulée contre le mur de culée de celui-ci, elle est caractérisée par la superposition de deux grands volumes orthogonaux donnant à l'ensemble une grande simplicité. Le tout s'inscrit sur un terre-plein bordé par les voies de desserte des autobus, paysagé et agrémenté de sculptures de galets au sol.

La qualité architecturale de l'ensemble découle du choix de juxtaposer le béton massif du génie civil et de légères structures métalliques aux couleurs claires et largement ouvertes. Le volume supérieur des quais, dont le tablier en double caisson précontraint avec encorbellements repose sur des portiques en béton brut de décoffrage, est habillé d'auvents de quais en bardages métalliques de teinte claire et perforés, autant pour en alléger l'aspect que pour amoindrir les effets du vent. Par opposition à l'aspect purement linéaire et aérien des quais, le volume inférieur se développe en plan, bien posé sur le sol. Il reçoit le Hall des Voyageurs, les locaux techniques de la station et une unité de service occupée par des commerces et un commissariat de police. La couverture, en structures tridimensionnelles, repose sur un minimum de points porteurs. Ce qui permet de largement dégager façades et surfaces couvertes. Structures et points porteurs sont peints en rose clair s'harmonisant avec le gris du béton brut de décoffrage.

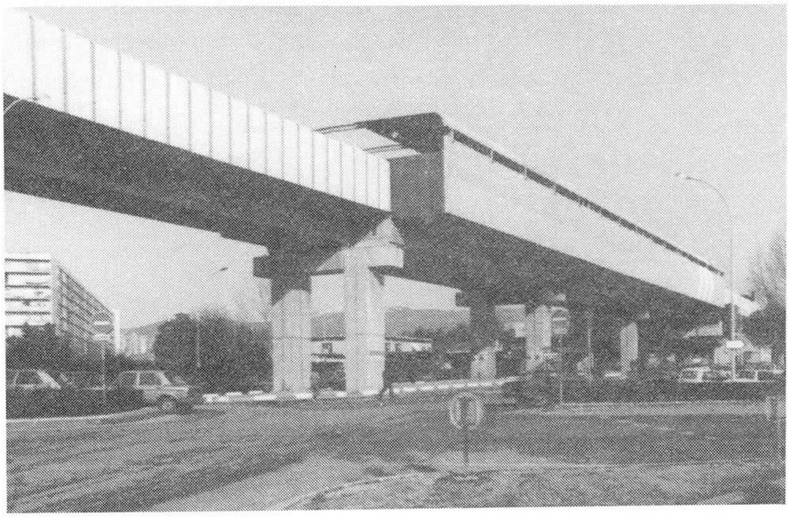


Fig. 3 : La station de la Rose

Aucun traitement de surface particulier n'a été appliqué au béton brut clair du génie civil mais, afin d'alléger l'aspect massif des piles et poteaux, ceux-ci comportent une modénature en creux.

3. LE TERMINUS DE SAINTE-MARGUERITE - DROMEL

3.1 L'ensemble de l'ouvrage

Le tronçon Sud de la ligne n° 2 a été mis en service en 1986 et le viaduc de Sainte-Marguerite - Dromel en constitue la section terminale au Sud-Est. D'une longueur totale de 620 m y compris les culées – dont 70 m pour la station – le viaduc sort de terre en bordure Est du stade Vélodrome, franchit en s'élevant progressivement les terrains de sport – sous lesquels a été réalisée la station d'épuration de la ville – pour enjamber ensuite un large boulevard puis gagner la culée du terminus en bordure de la rivière de l'Huveaune.

3.2 La station

Celle-ci est située en bordure du boulevard, à proximité d'un carrefour d'importantes voies périphériques. Le terre-plein qui l'environne, gare d'échange pour autobus et parking, recouvre en partie la rivière cuvelée. Le hall du public et les locaux techniques sont au niveau du terre-plein, le hall étant relié par deux batteries d'escaliers, fixes et mécaniques, aux quais qui surplombent le boulevard.

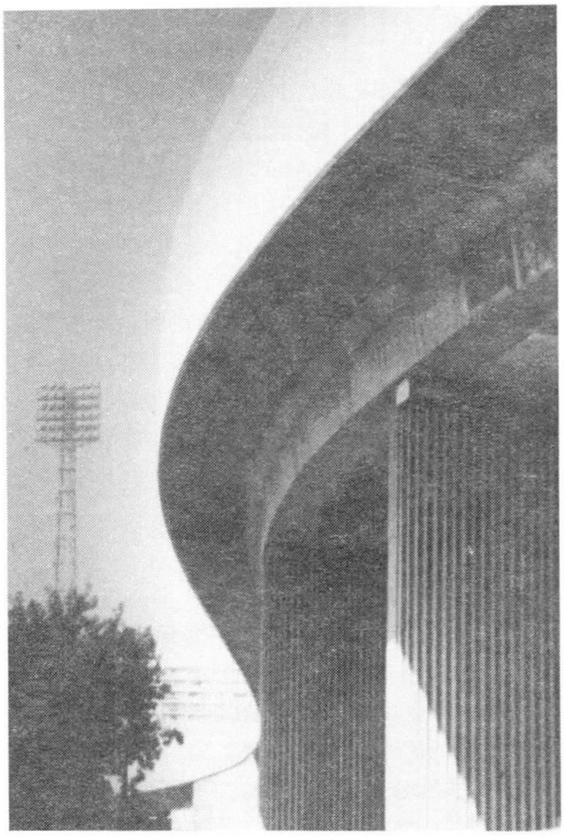


Fig. 4 : Le viaduc de Sainte-Marguerite

L'enchaînement entre le volume horizontal du hall, les volumes obliques des escaliers, encadrant le viaduc et aboutissant en tête des quais au volume linéaire de ceux-ci donne une architecture à la fois simple et très affirmée, exprimant clairement le fonctionnement de la station. Cette architecture joue également sur l'opposition entre la légèreté des structures métalliques largement ouvertes et de couleurs claires – blanc et vert – du hall et des auvents de quais, et la masse du béton des accès aux quais.

Le parti choisi pour les parements du béton a été, ici, d'œuvrer à partir d'un béton naturel (ciment gris et agrégats courants). Pour les tabliers, celui-ci a été simplement laissé brut de décoffrage, alors que, pour les piles et autres ouvrages verticaux, dont la surface est cannelée, les agrégats sont rendus apparents par lessivage après désactivation. Enfin, un traitement anti-graffiti et anti-affiches fonce légèrement la teinte du béton. Les garde-corps anti-bruit, quant à eux, sont réalisés en béton de ciment blanc.

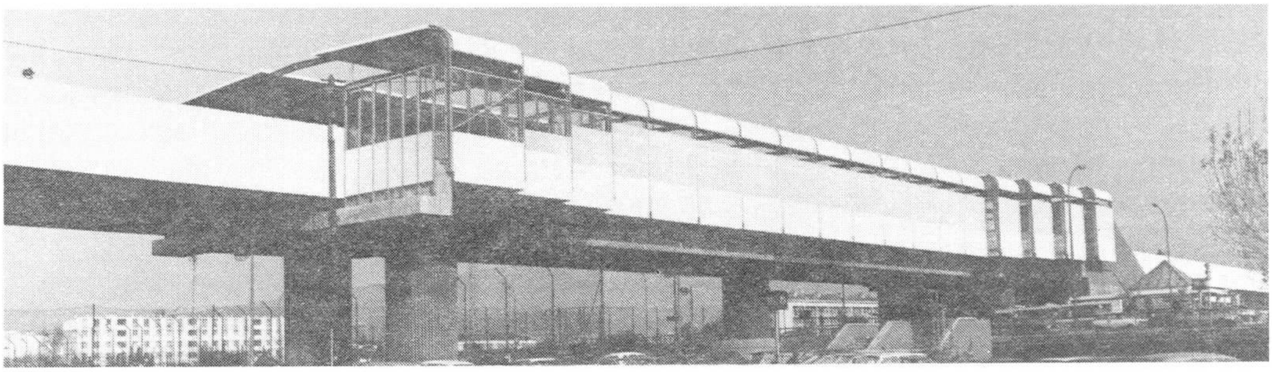


Fig. 5 : La station de Sainte-Marguerite – Dromel

4. LE TERMINUS DE BOUGAINVILLE

4.1 La section en viaduc

Le tronçon Nord de la ligne n° 2 vient d'être mis en service, en Février 1987. Le viaduc de Bougainville, d'une longueur totale de 670 m – dont 90 m pour la station terminus située environ au quart du parcours – franchit une large dépression, passant au-dessus d'un grand boulevard de pénétration, en bordure duquel se trouve la station, puis gagne en pente douce le dépôt de Zoccola, constituant dans cette zone et sur 329 m un ouvrage commun avec la canalisation d'une rivière et une voie routière ainsi créée.

4.2 La station

Celle-ci est caractérisée par son volume pratiquement cubique composé de quatre tours encadrant le viaduc et, partiellement, les quais au niveau supérieur et, au niveau intermédiaire, le Hall des Voyageurs. Ce hall est desservi par deux accès latéraux – escaliers mécaniques et fixes – dont l'un comporte une passerelle franchissant le boulevard pour la desserte du quartier environnant et d'un parking. Au sol est aménagé un important complexe d'échanges avec les autobus et un deuxième parking.

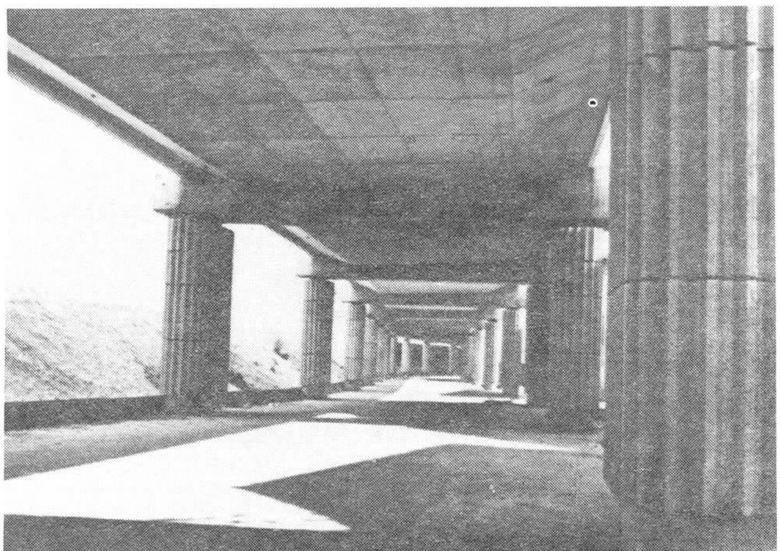


Fig. 6 : Viaduc et voie routière de Bougainville

Située à l'autre extrémité de la ligne par rapport à Sainte-Marguerite – Dromel, la station Bougainville marque une large cohérence avec celle-ci en même temps qu'un progrès par l'utilisation de bétons teintés dans la masse dont la couleur est obtenue par l'utilisation de ciment blanc et d'agrégats ocres, sans addition de produits chimiques, dont la tenue dans le temps n'est pas assurée. C'est ainsi qu'aux masses des tours, habillées de panneaux préfabriqués en béton ocre clair, cannelés et aux agrégats apparents, se juxtapose la légèreté des habillages métalliques des auvents de quais et gaines d'accès à ceux-ci laqués blancs, nervurés de violet et grandes baies vitrées.

Alors que le tablier du viaduc est en béton naturel brut de décoffrage, les piles et portiques le supportant sont également habillés de béton cannelé ocre clair – coques préfabriquées dans lesquelles ont été coulés les ouvrages – et les garde-corps anti-bruit sont en béton blanc.

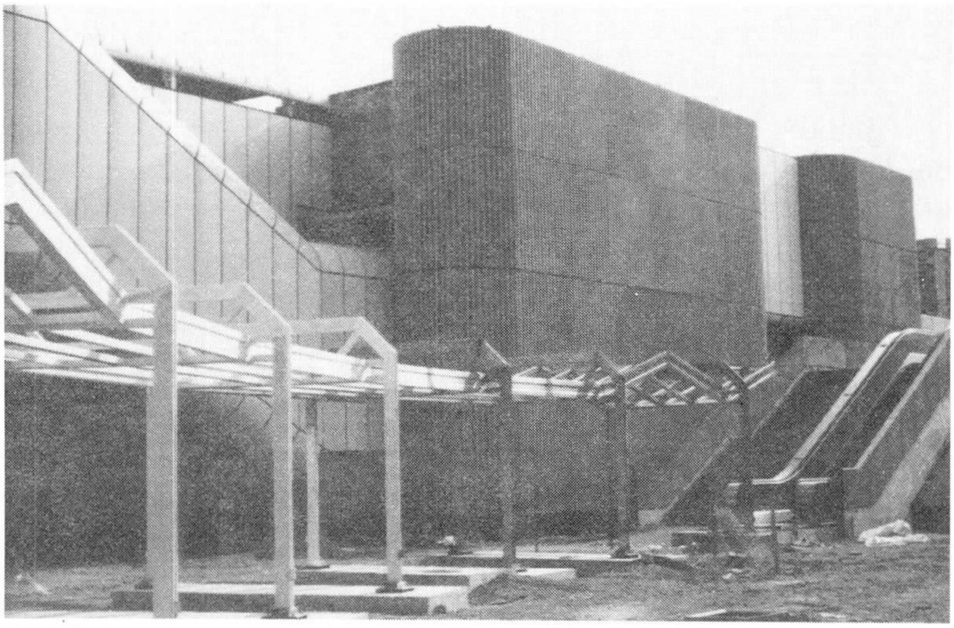


Fig. 7 : Les tours de la station Bougainville

5. CONCLUSION

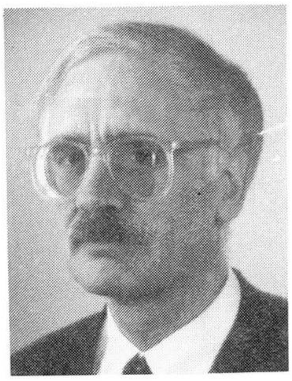
Implantées, ainsi que les viaducs qui les desservent, dans des zones largement dégagées, ces trois stations terminus occupent une grande place dans le paysage urbain qu'elles valorisent et embellissent tant par leur qualité architecturale propre, jouant avec bonheur sur la composition des parements en béton et structures métalliques, que par celle des aménagements urbains périphériques qu'elles ont entraînés.

The Wind Barrier along the Caland Canal near Rotterdam

Pare-vents en bordure du Calandkanaal, près de Rotterdam

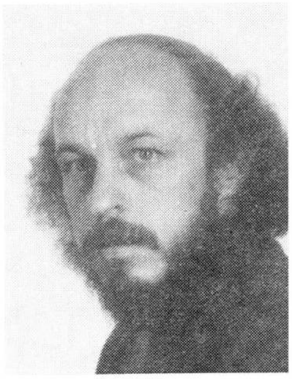
Der Windschirm am Calandkanaal bei Rotterdam

Jopp SCHILPEROORD
Design Engineer
Rotterdam Public Works
Rotterdam, The Netherlands



Joop Schilperoord, born in 1939, completed his studies in 1959 at the Rotterdam College of Technology. In 1983 he graduated in general economics at the Erasmus University in Rotterdam. The focus of his work is in the design and preparation of special constructions.

Maarten STRUIJS
Architect
Rotterdam Public Works
Rotterdam, The Netherlands



Maarten Struijs, born in 1946, trained as an architect at the Rotterdam Academy for Architecture. Since 1971 he has been practising as an architect. The scope of his work lies in the design of public buildings and artefacts, with emphasis on theoretical premises.

SUMMARY
This publication gives and insight into the design process for the wind barrier along the Caland Canal, near Rotterdam. The aim of this structure is to reduce the wind pressure on passing ships. The design involved a close collaboration between the three parties involved, the architect, the (wind-engineering) advisor and the designer. A finite element method program was used for calculating the details of the concrete barrier. A characteristic feature of the barrier is the employment of semi-circular shells.

RÉSUMÉ
Cet article présente la réalisation d'un pare-vents en bordure du Calandkanaal, près de Rotterdam. Cet ouvrage d'art contribuera, par sa présence, à réduire l'impact des vents sur le trafic fluvial. La réalisation de ce projet a été marquée par un esprit d'étroite collaboration entre les différentes parties concernées : l'architecte, le conseiller (spécialiste des vents) et le constructeur. Le développement de l'ouvrage en béton, caractérisé par une composition d'écrans cintrés, a été conduit à l'aide d'un programme d'éléments finis.

ZUSAMMENFASSUNG
Es wird ein Einblick in den Entwurf des Windschirms am Calandkanal bei Rotterdam vermittelt. Zweck dieses Bauwerkes ist die Verminderung des Winddrucks auf vorbeifahrende Schiffe. Beim Entwurf gab es eine enge Zusammenarbeit zwischen den drei am Projekt Beteiligten : dem Architekten, dem (windtechnischen) Berater und dem Konstrukteur. Bei der Bemessung der Betonabschirmung wurde vom Finite-Elemente-Programm Gebrauch gemacht. Die Verwendung halbrunder Schalen ist ein charakteristisches Merkmal der Abschirmung.

1. INTRODUCTION

1.1 Geography

The port and industrial area, also known as Europoort, situated between Rotterdam and the North Sea, is in its present form a product of a 30-year evolution. It is a narrow strip of ground, bounded by Nieuwe Waterweg, the shipping communication with Rotterdam, and a scenic area formed by the Brielse Maas with adjacent built-up (residential) areas. In this area is found a lot of (petro-)chemical industry, in addition to (container) transshipment firms and oil storage. A prerequisite for all this industry is good communications with the hinterland by means of rail and road links (fig. 1).

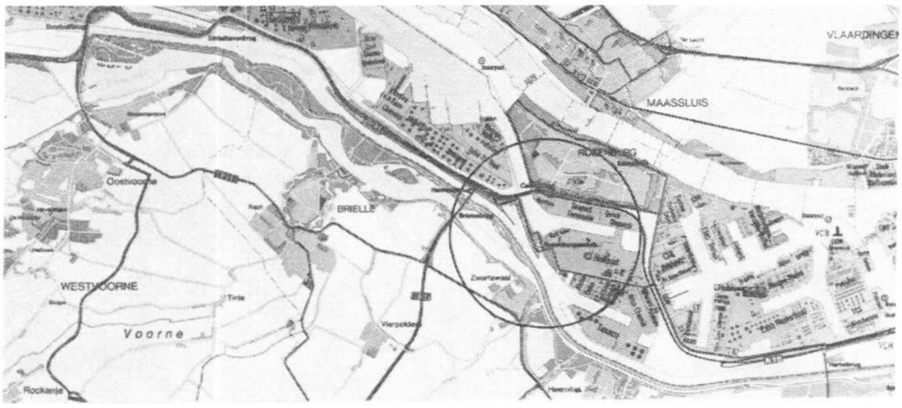


Fig. 1 The Europoort area, Brittanniëhaven is indicated by a circle.

1.2 Changed environmental requirements

These roads were constructed during the very first phase of the development of the Europoort region. At this time, it was envisaged that almost only petrochemical companies would be established, but times have changed.
About half-way along the Europoort area, right next to the residential district of Rozenburg, is Brittanniëhaven. This harbour was designed on the implicit assumption that petrochemical industry would be established around it (see fig. 2). This conviction was so strong that the Caland Bridge, which enables road and rail traffic to cross the Caland Canal (the link between Nieuwe Waterweg and Brittanniëhaven), was dimensioned such that only relatively small ships could pass this bridge without problem on their way to Brittanniëhaven.

1.3 Shift in use of Brittanniëhaven

With the emergence of container transport and car transhipment (Ro-Ro), a possibility emerged to give this harbour an environmentally safe use. In 1981 Quick Dispatch established itself with a car terminal on the northern side of the harbour. In addition, Seaport started up a new multi-purpose terminal. These companies frequently receive ships with a large windage.
Practice has shown that these ships cannot pass the Caland Bridge without problem under all conditions. Beyond a certain wind strength, these ships were therefore not allowed to pass the bridge in order to reduce the risk of damaging it to a minimum.

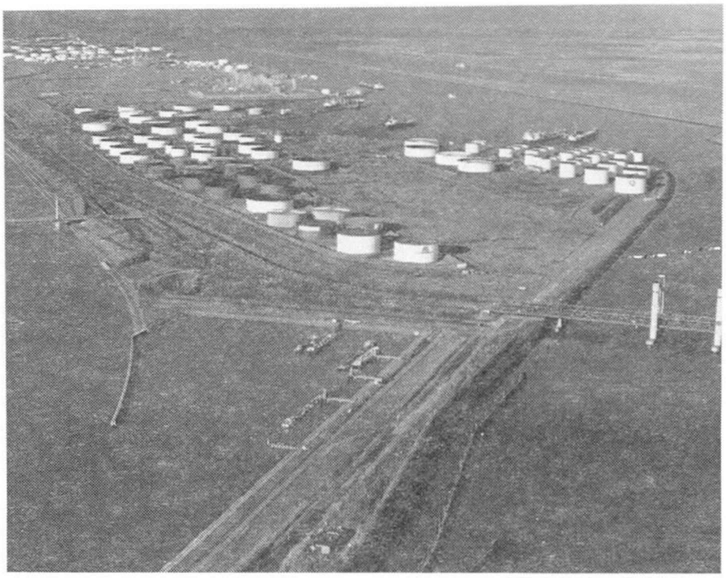


Fig. 2 The situation before 1985.
In front the Caland Bridge.
photo: Bart Hofmeester

This restriction resulted in waiting times, which was a nuisance for the companies in question. The infrastructure would have to be changed if Brittanniëhaven was to remain economically attractive. The most obvious solutions, such as widenening the bridge passage or even replacing the bridge by a tunnel, were out of the question on financial grounds.

1.4 Necessity for improving wind climate

The only remaining solution was the erection of a structure to change the wind climate, especially at the Caland Bridge to such an extent that there would be no significant waiting times.
The management of the port area, the Municipal Port Authority, requested TNO to carry out wind tunnel research in order to determine how these requirements could best be met.

2. ARCHITECTURE OF THE WIND BARRIER

2.1 Architect's contribution necessary

As the project developed, people began to realize just how great the impact on the landscape would be. The Port Authority then asked Public Works to put the further elaboration of the barrier in the hands of an architect, with the additional request that a number of models be developed in order to provide a choice. Since no comparable projects had been undertaken anywhere else in the world, reference could not be made to existing models.

2.2 Architectural design process

The architectural design process began with an investigation into the architectural means. Preliminary wind research had first of all examined the fine meshed "seive model". But it also appeared possible to consider the barrier as a series of large-scale elements with relatively large gaps between them. Bearing these two possibilities in mind, the architect developed four models by approaching the wind barrier from four different architectural design starting points.
The development of a number of architectural variants is based on a theoretical model developed by Maarten Struijs and which has been described in a number of publications. This model is based on the assumption that architecture is a specific form of knowledge.
The field of knowledge opens out into three directions:

* The empirical direction, this takes "experience" as its starting point
* The rationalistic direction, takes a discipline of science as starting point
* The idealistic direction takes an ideal picture as starting point

A specific category of knowledge is characterised by two structures, viz. the internal and the external structure. Ideas based on the internal structure - how does the discipline itself work - are called "autonomous" ideas. Realistic ideas are those based on the external structure: how is the discipline related to other knowledge and experience. They are based on a different reality than the discipline itself.
From the model for knowledge in general, viz. the empirical, rationalistic and idealistic fields of knowledge on the one hand, and the model for a specific field of knowledge (knowledge category, discipline) viz. the autonomous and the realistic ideas, on the other, arises the specific knowledge model for the discipline of architecture.

* Autonomous architecture ideas
* Empirical-realistic architecture ideas
* Rationalistic-realistic architecture ideas
* Idealistic-realistic architecture ideas

In order to arrive at the various architectural models, it was decided to

develop an ordering principle from each idea (see fig. 3). The models developed from this were considered from the wind-technology, constructional engineering and cost points of view.
In addition, the models were submitted to the municipality of Rozenburg, the Urban Development Department and the Rotterdam Building Inspectorate. The almost unanimous opinion was that the design now implemented the empirical order model, was the best choice from among the models presented.

2.3 Wind barrier design

Figure 4 shows the completed wind barrier. The characteristic feature of the barrier is the use of semi-circular shells 25 m high, having a radius of 9 m at the southern side and placed every 12 m. The central part consists of half shells with an internal radius of 2 m and a separation of 1.33 m. The design of the central part was made in close collaboration with the sculptor Frans de Wit. The presence of road intersections meant that it was not possible for the central section to extend to ground level at all points. A heavy torsion-resisting bridging beam was therefore employed over the entire length of this section in which the shells are anchored at road intersections.
The convex sides of the shells are directed towards the water, the most effective orientation from the wind point of view.
The third, northernmost barrier section is a combination of a 15 m high, wind-breaking embankment, on top of which are 10 m high wind-breaking flat slabs.
The division of the barrier into three sections, which was in fact made necessary by local conditions, meant that the overpowering and massive character of the structure could be toned down. The final result of these architectural efforts is one of the few examples in The Netherlands of an entirely architect-designed civil engineering project. It has an enormous impact on the landscape, a post-modern architectural monument.

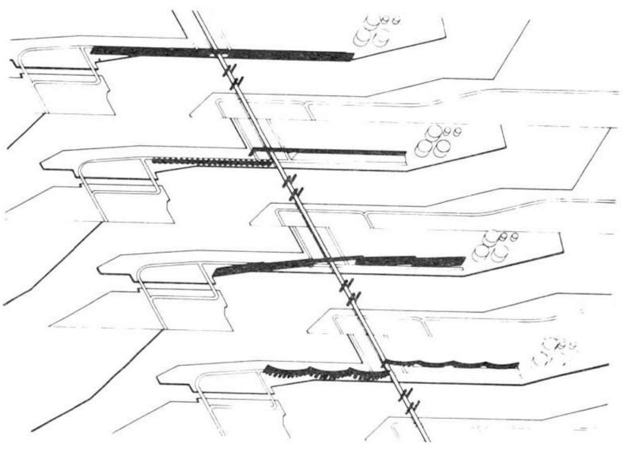


Fig. 3 The 4 models considered.

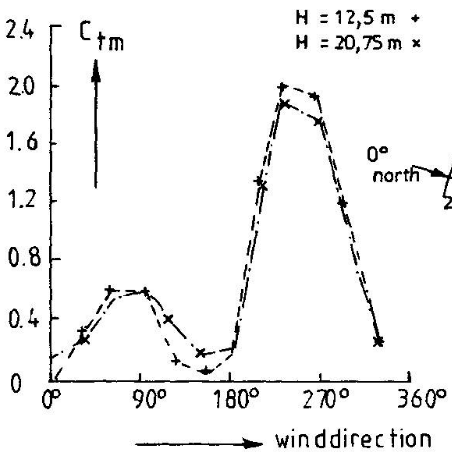

Fig. 4 Situation nowadays.
photo: Bart Hofmeester

3. CONSTRUCTION OF THE WIND BARRIER

3.1 Wind tunnel research

The wind tunnel research was carried out in two phases. The TNO research first of all concentrated on an approximate determination of the optimum barrier height and also looked at the effect of the permeability. This exploratory research showed that a 25 m high barrier with a 25% permeability would be the best solution to the Port Authority's requirement in respect of the reduction of the wind pressure, measured at the navigation line.
On a basis of these rough starting points, the architect determined the exact shape. The final choice was for semi-cylindrical shells with 25% permeability,

which was achieved by spacing the shells. The three sections of the barrier (southern, central and northern part) partly overlap each other.
The length of this overlapping part was determined empirically.
The choice for the semi-cylindrical shape was made primarily on architectural grounds, but also had definite wind-effect advantages. The measurements made by TNO showed that the half shells were so effective that their separation, which had originally been put at 6 m, could be increased to 12 m.



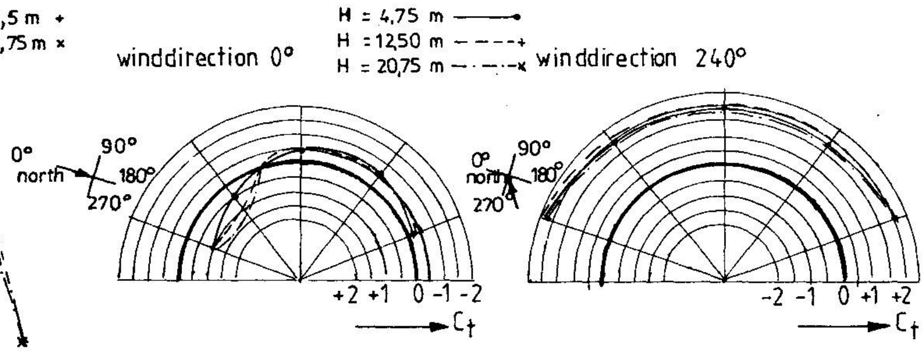


Fig. 5 The C_t value as a function of the wind direction.

Fig. 6 The detailed wind distribution for two significant wind directions (0° and 240°).

The effectiveness was determined in a second series of wind tunnel tests, in which a part of the barrier (southern part) was measured. Thirty Pitôt tubes were positioned both at the inside and the outside of the scale model (1 : 250), which enabled the total C_t value of one shell to be determined as a function of the wind direction.

3.2 Some constructional aspects of the southern barrier section

The shape of the shell is ideal from the constructional point of view: maximum rigidity for a minimum of material used. The choice of concrete for the material was never really in question.
Thanks to the great rigidity of the structure, tensile forces are only very localised and not too great and can easily be coped with by mild steel reinforcing.
Each shell is built on foundations consisting of 11 pre-stressed prefabricated piles. The centre of gravity of the pile arrangement coincides with the centre of gravity of the shell, so that no uneven pile loading will occur for resting load. Locating the piles as far as possible from the centre of gravity produced a maximum rigidity (for a minimum number of piles). The thickness of the shell was fixed at 250 mm, determined mainly by the casting aspects (sliding shuttering, double reinforcing mesh).
Due to the boundary conditions, or rather due to their absence (no constraint, no thickened edge, no through shell), it was not possible to calculate the structure purely theoretically. Calculation of a discretised structure and the structure itself was the most that could be hoped for. It was therefore decided to calculate the structure with the aid of the finite element method. For some time now, Rotterdam Public Works has at its disposal the DIANA program developed by TNO-IBBC.
This extremely advanced program can draw from a wide range of element types, including the super-parametric, double-curved shell element with 40 degrees of freedom (CQ40S), which was used in this case. It can accommodate bending, perpendicular and transverse forces, as well as twisting forces. At the bottom

of the shell, the piles were inserted as triple two-node elements, resilient in the three major axis directions. This enabled the shell behaviour as a result of a wind load varying over the surface, to be accurately determined.
The importance of this research became evident when it was found that large movements could arise locally (near the top angles) as a result of the wind load which increased strongly towards the tips. This was only discovered after the second series of wind tunnel tests had been carried out.
As the constructional work had already been started, it was no longer possible to thicken the shell further. The only solution for reducing the bending moments in the top cross section was to fit a tension joint at the top of the shell. In the determination of the wind load, the dynamic aspect was translated into the allowance factor φ_1 calculated as a function of the lowest Eigenfrequency. This was about 0.7 Hz (see fig. 7), which resulted in an allowance factor φ_1 = 1.15. The critical wind velocity for the shell is $V = (1/s) . f D_m$.
In case of complete working of the shell (which is brought about by the tension connection), D_m can be taken as 18 m. Given the factor S (Strouhal number) which can be taken as 0.02 for this type of construction, the critical wind velocity is 60.3 m/sec. Only at this speed there is a risk of the construction being excited at its lowest Eigenfrequency. This value is far above the design velocity of 40 m/sec (145 km/h).
The design wind loads varied between 0.3 and 3.1 kN/m^2, depending on wind direction and point on the shell surface.

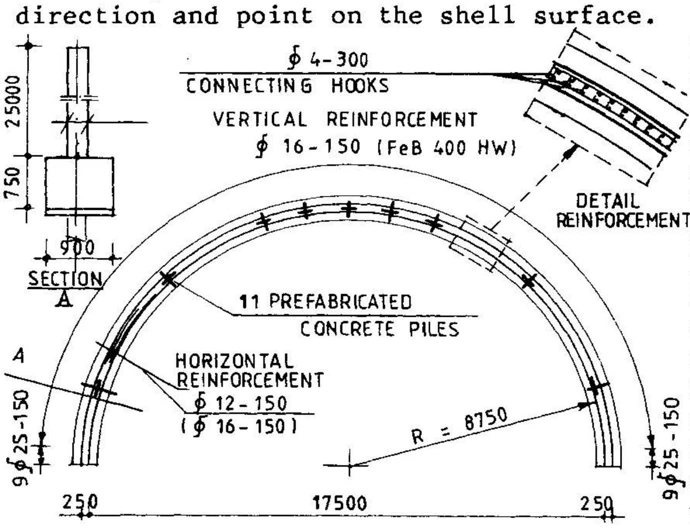


Fig. 7 Horizontal cross-section over southern shell.

The shells are reinforced with a double crossing mesh ϕ12-150 Feb 400 HW, locally thickened to ϕ16-150. The horizontal rods are situated in the outer layer.
To prevent the reinforcing from springing apart, the two meshes are linked to each other by "bacon hooks". A 40 mm coating of concrete was employed in order to reduce the risk of corrosion (see fig. 8). Particular attention was paid to the concrete mixture, especially the fine fraction. To this end, fly-ash was added. Since the cracking moment would only be exceeded at an exceptionally high wind load, a surface coating was not applied.

4. CONCLUSION

The wind barrier along the Caland Canal is clearly an example of an amalgamation of engineering and aesthetics leading to an optimum result. The architect's demands could be met almost completely, and this was thanks in no small part to the facilities available to the designer, comprising a sophisticated computer program (DIANA finite element method), which enabled model research to be performed as it were without additional costs. As Public Works always had this program (implemented on a Geminix/Microdutch microcomputer) at its disposal, it was possible by means of "fine tuning" to put the design fully in the architect's hands. In addition, it was also possible to achieve an economic design, since the required reinforcing could be determined precisely. The possibilities open to the architect were considerably enhanced by the computer, while there was also more scope for the designer, since he did not always have to turn down a seemingly extravagant request by the architect. The wind barrier will certainly not be the last project to be realized in consequence of this trend.

Concrete in Contemporary Architecture

Le béton dans l'architecture contemporaine

Beton und zeitgenössische Architektur

Giulio PIZZETTI
Professor
Turin Politechnico
Turin, Italy

Giulio Pizzetti, born in 1915, Civil Engineer degree in 1937, doctorate in Strength of Materials in 1943. Professor of Structural Design, Faculty of Architecture, Turin Politecnico, since 1960. Visiting professor at M.I.T. – Berkeley University of Buenos Aires. Active in consulting and design of many relevant works in Italy, Argentine, South Africa.

SUMMARY
After introductory considerations on the evolution of architectural trends and on the controversial evaluation of contemporary achievements, the author debates the meaning and architectural personality of concrete, the only material capable of fulfilling the most dreamed of aspirations of architects for space handling. Some examples of significant Italian constructions where the expressive power of concrete is enhanced, are illustrated.

RÉSUMÉ
Après une introduction sur l'évolution de l'architecture moderne et sur la controverse des réalisations contemporaines, l'auteur disserte sur la personnalité et l'expression créative du béton, le seul matériau capable de satisfaire les aspirations les plus poignantes des architectes en ce qui concerne l'expression spatiale. Des exemples de réalisations italiennes illustrent les possibilités d'expression du béton.

ZUSAMMENFASSUNG
Nach einführenden Betrachtungen über die Evolution der modernen Architektur und die kontroverse Akzeptanz zeitgenössischer Bauwerke werden die Bedeutung und die architektonische Ausdrucksweise des Betons erörtert. Der Beton ist das einzige Rohmaterial, das dem Architekten die höchsten Wünsche betreffend die räumliche Gestaltung erfüllt. Einige Beispiele italienischer Bauwerke veranschaulichen die Ausdrucksmöglichkeiten des Betons.

1 - INTRODUCTION

To evaluate the meaning of a building material - concrete in our case - in the Architectural world, we can not avoid a few considerations on the uneasy, controversial life of modern Architecture.
"All sensible and sensitive people - says the writer Paul Johnson - know that "moderne architecture is bad and horrible.
On the other hand another Johnson, the famous american architect Philip Johnson still creative at 80, taking a telescopic view of present trends within an historical perspective, considers moderne Architecture "extremely rich and exciting" Statements like these prove - to my opinion at least - that we are living one of the most creative and controversial periods in architectural history. Never we had such a great public interest in - and hostility to - what has been built in recent years - and that for sure means the great vitality of modern architecture.
We realise how true are the words written by Artur Koestler in his fine book "The act of creation".
"The act of discovery has a destructive and constructive aspect:it must disrupt "rigid patterns of mental organisation to achieve the new syntesis. Only by "escaping the popular frames of reference and critically examining conventional "methods and techniques can new ideas be developed and implemented.
"Desorder appears to be a necessary part of the creative sequence and uncer- "tainty goes with it.
Which is then the genesis of such desorder and uncertainty?
To answer this question, we may usefully turn to two fundamental moments in the history of architecture. The first of these came when the Renaissance accorded recognition to the analogy between chords appreciable by the ear and proportions by the eye, thus setting the seal on the entry of architecture into the universe of numbers erected by the Pythagoreans to bear witness to their faith in the harmonic and mathematical structure of the whole of creation.
According to an unbroken tradition stretching back to antiquity itself, arithmetic, geometry, astronomy and music constituted the quadrivium of the "mathematical" or "liberal" arts.
Painting, sculpture and architecture were, by contrast, classed as "manual" arts. Their elevation to a superior level required that they be endowed with a firm foundation, in other words a mathematical basis.
This transformation was the "great leap forward" achieved by the architects of the 15th century. It need come as no surprise that they turned to music as the only liberal art capable of answering their needs, capable, in other words, of supplying those laws of harmony, proportion, symmetry and tonality that would provide the key to the solution of their problems.
From this time onwards, therefore, the canons of harmony and the hierarchical, arithmetical and geometrical proportions that strictly governed the relations between lines, areas and volumes became the benchmarks for every work of architecture. It was unconceivable that there could be any other world of architectural composition other than that of harmony.
The second of these fundamental moments of history occurred during the 19th

century, when the concepts of harmony and proportion succumbed to a shattering revolution. On the one hand, changes in mathematical thought demolished reference to Euclidean geometry as the only geometry possible, thus unmasking a world of possible alternatives. On the other hand, a cultural revolution of enormous compass conferred artistic citizenship on all forms of expression that lay outside the pale of harmony, symmetry and proportion, thus sanctioning the total uncoupling of the liberal arts from their erstwhile mathematical foundations.

The whole structure of classical aesthetics was systematically upheaved. It was not by chance that atonal and dodecaphonic music were accompanied by the appearance of cubist and abstract painting and sculpture. Architecture, too, was completely freed from the restraints imposed by the mathematical relationships of formal harmonies, from coherence and the recurrence of expressive themes.

The birth-pangs of this evolution are with us yet. A hardship compounded by the absence of limits and "rules of the game", so that the way lies open to tremendous risks and brazen speculations that are particularly dangerous in the domain of architecture.

Yet it is one we must accept and learn to live with.

2 - CONCRETE AND ARCHITECTURE

What place can be assigned to building in reinforced concrete in this picture of a changing, mutating architecture?

It came on the scene when the fragmentation of harmony was already in progress, albeit it at the embryo stage.

The great unease that moved artistic sensibilities immediately divined that a material capable of satistying architecture's most recondite aspiration now lay ready to hand.

The opportunities reinforced concrete offered of defining both interior and exterior spaces and volumes, whether concluded or continuous, were first appreciated by poets and artists. As "Paul Claudel put it: ... L'Architecture cesse "d'ètre enfermée dans sa prison cubique... ...le ciment armé n'est pas un mate- "riau rigide, c'est un tissu souple, un epais feutre, de la matière coulante. "Il est a estamper d'un seul coup de l'imagination...

The totally different personality displayed by this new material when compared with stone, wood and iron was immediately apparent: the possibility of expression in plates or bulks, linked to or free from geometrical references and rich in a new fundamental connotation, that of a continuity of expression and modelling unthinkable before; the possibility of forming space anew, as Riegl was later to declare ..."A mature vision which extols space: in the beginning, "static and cubic space, then fluid, dynamic, formless space emancipated from "geometric constraint".

Later, however, the exciting connotations that emerged during the infancy of reinforced concrete became cloudy and lost their substance: economic reasons, production logics and poor scientific support shattered the manigificent continuity in flat, linear members - beams, columns, slabs - conceived by analogy with typical building elements in wood and iron.

This magnificent continuity, along with the high charge of architectural expressiveness inherent in the new material, remained a latent feature. At the beginning of this century and in the Twenties, they appeared yet, in works with a strong structural personality.

It was, indeed, the masterpieces of the great pioneer, Maillart, followed by Edoardo Torroja and Pier Luigi Nervi, that opened the way to that structural expressionism, soon to become a mighty architectural patrimony.
So much has been written about these masters that any further comment might appear superfluous. Since my paper is particularly directed to Italian achievements, however, I would ask to be allowed to say a little more about Nervi.
In addition to being a designer, he was a building contractor, of necessity constrained by the iron laws of competition and the economic running of a business.
Yet he succeeded in extracting from these constraints the inspiration for a highly personal architectural interpretation of concrete that connotates the constructional features of his structural inventions.
In his works, indeed, the static stance of the whole is purposely simple and - in general - decidedly classical, obedient to the laws of harmony and symmetry. The whole of his invention lies in a parting of the structures into a sapient play of prefabricated parts, subsequently assembled on the site into a scheme capable of recreating a faultless continuity in a framework of luminous logic (fig. 1).
It was perhaps this two-sidedness of Nervi's personality, his blending of the designer and the building contractor, that deprived him of disciples. Ho thus remains and will continue to remain an unique figure in the history of structural architecture.

3 - EXAMPLES OF ITALIAN ACHIEVEMENTS

Another figure of great import in the field now being examined is the Italian engineer, Riccardo Morandi, who always managed to express in his very many works the architectural force inherent in creations of great structural distinction.
Unlike those of Nervi, his works are always marked by a desire for structural invention capable of throwing into elegant architectural relief a static equilibrium that plays the leading role, underscored both by the shape of the members and sections and by the presence of nodes, supports and hinges whose interpretation is not open to doubt.
In addition to this strictness of expression of his, Morandi will be remembered as the man whose greater courage overcome the limitations inherent in the nature of reinforced concrete since he invaded the field of structural shapes from which concrete itself was physiologically barred, extracting from it fully independent architectural motifs.
The hangars at Fiumicino (fig. 2) offer an example of a reinforced concrete hanging roof. By exploiting prestressing in a highly personal manner, Morandi has succeeded in giving an impeccable picture of the equilibrium of the forces involved, though with an architectural expression totally different from that which would have emerged had he used simple steel cables instead of concrete stays.
Another interesting example of the special architectural effects that can be obtained thanks to the use of prestressing is offered by Morandi in the FATA

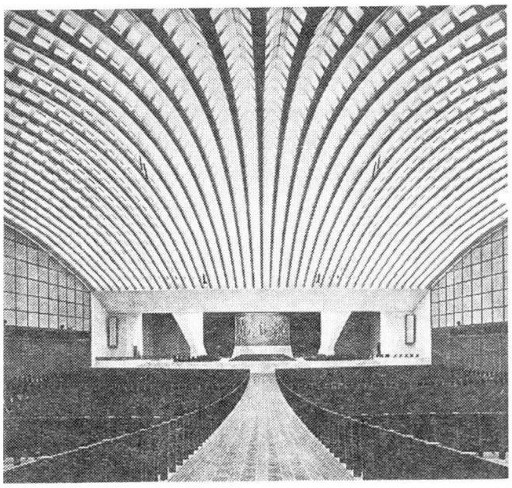


Fig.1 Roma - Vaticano Audience Hall   Design and Construction: P.L.Nervi

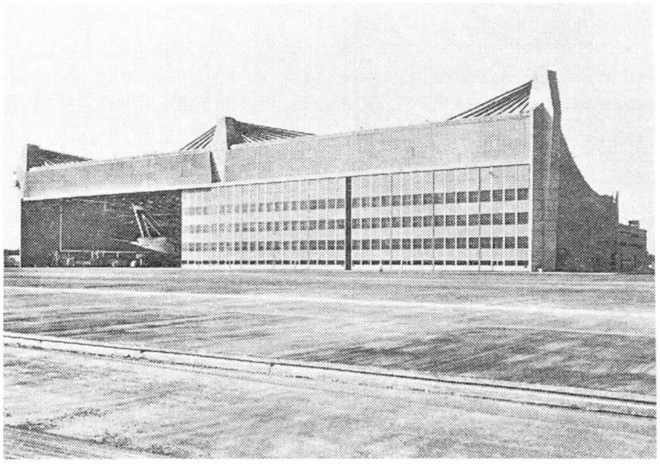


Fig.2 Roma - Fiumicino Airport Hangar   Design: R. Morandi

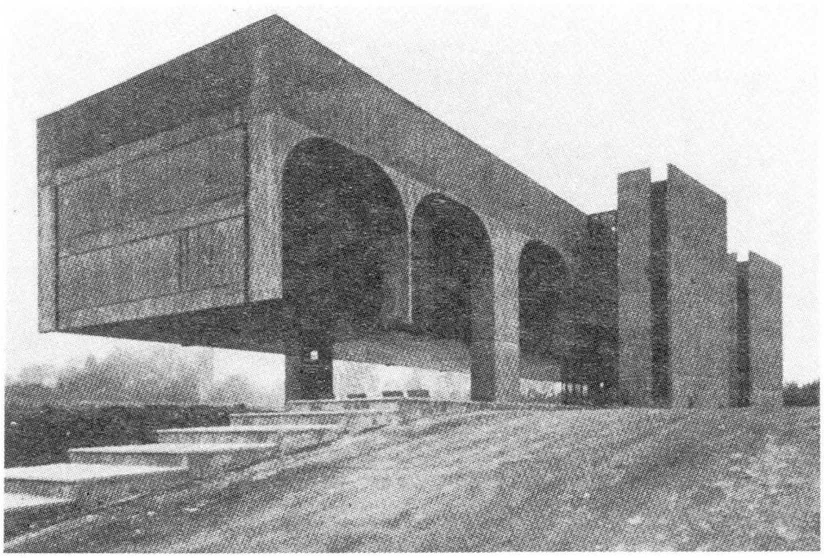


Fig.3 Torino - F.A.T.A Offices Building   Design: O. Niemeyer - R. Morandi

office building, Turin (architect: O. Niemeyer). The formula adopted to bring out the presence of the stays in ideal reference to the column-arch layout, makes it one of the most unusual and elegant example of a suspended-floor building (fig. 3).
In effect, we can realise that today's concrete architecture has rediscovered and put to their best use those characteristics of the material that had been sensed from its earliest days: the possibility of breaking out of the "cubic prison" and forming continuous, dynamic spaces with multiply curved three-dimensional surfaces, closed, pierced or even gaping: the possibility of splitting spaces, whether modularly or irregularly, with assortments of flat slabs rendered continuous thanks to geometrical repetitions or free patterns: and the possibility of exalting the power conferred by the mass of this material, spreading it and shaping it in ways sometimes deliberately cumbersome and so devoid of all harmony as to even appear a contradiction of the logic of static flows.
The picture is one of a new freedom, a territory awaiting exploration, where speculation and the most anomalous fancies may flourish. This is even more true now that computerised procedures have eliminated nearly all the difficulties posed by analytical investigation, while new materials and new techniques make it possible to mould this "cast stone" into shapes that would have been unthinkabel only a few years ago.
The moment is thus a weighty onde, pregnant with the weighty responsibility that lies on reinforced concrete architecture, which is called upon to discipline this abundance of freedom.
At this point, it may be of interest to see what is happening in a sector peculiar to reinforced concrete, namely that of shell structures.

Shell structures are surfaces whose strength lies in their form, and those best capable of fulfilling Claudel's prophecy.
They aroused considerasble interest in the engineering and design world when Maillart first stressed the possibility of confiding the task of providing strength not to cross-section mass, but to the global shape of suitably curved thin plates.
Architecture became aware that it was presented with an extraordinary chance of finally creating that "fluid, formless space emancipated from geometric constraint" imagined by Riegl at the beginning of the century.
Much creative effort was devoted to this sector, many, indeed, were the sound results obtained. Yet, in the long term, one fact became evident. Reference to a set geometric shape or "constraint", inevitable for calculation and construction purpose, slowly but inexorably suffocated the exceptional architectural force inherent in shell structures. Works of great architectural significance could not appear until some way was found of breaking free from this constraint.
In this connection, the last ten years have provided instances of great worth, partly thanks to sugestions stemming from the sphere of hanging roofs (albeit no more than partly applicable to shell structures) and from surfaces with a minimal spatial development between given borders. It has thus proved possible to head towards notions of new shapes and outlines statically more economical for the edge members, though difficult to fit within geometrically established surfaces and curves.
Italy has offered a magnificent example of the interpretation of these notions

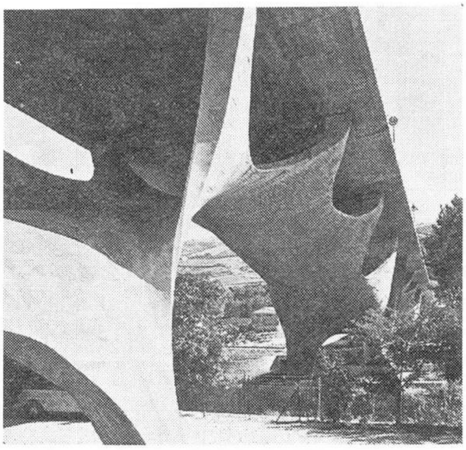


Fig.4 Potenza - Shell bridge over Basento River   Design: S. Musmeci

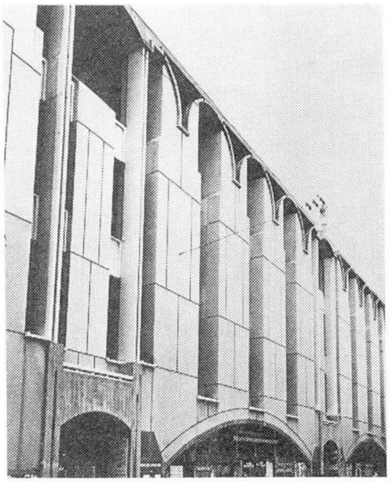


Fig. 5 Padova - Bank of Italy Building
Design: G. Samonà - G. Pizzetti - A. Chiorino

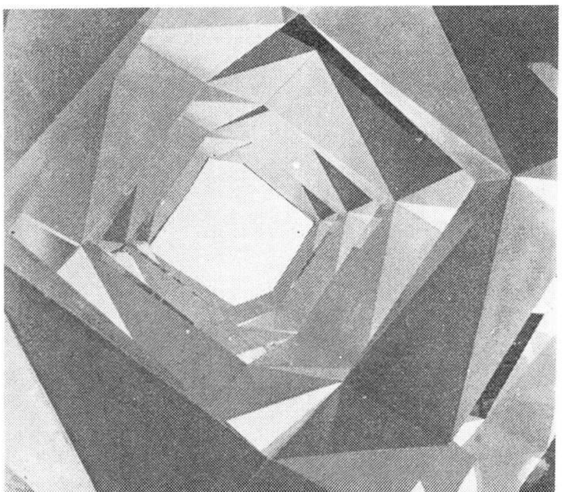


Fig.6 Roma - Space Structure (Exhibition Model)   Design: S. Musmeci

in the shell bridge designed and built by Prof. Musmeci over the River Basento (fig; 4).
This consists of four 70-metre bays, each formed of a 30 cm thick plate, shaped in accordance with multiple-curved surfaces, either positive or negative depending on the static reference pattern,and designed so as to achieve pure longitudinal and transverse compression stress conditions, without edge disturbances.
The static flows are conveyed to the curved plate and then discharged to the ground thanks to zones of support for the runway, and zones of support on foundations obtained by piercing the plate. The effect is to define truly unique inner and outer continuous curved spaces that blend in perfectly with the landscape.In the other building sectors, the panorama of Italian accomplishments in reinforced concrete in recent years is both extensive and varied, rich in works of undeniable architectural personality, yet also burdened by much capricious ballast. A balance cannot be drawn, nor even a reasoned recognition be offered, owing to the limits placed on this paper.
All the same I remember, as an example of using concrete in a well balanced blending of structural elements and decorative motifs, the Bankitalia building in Padua (fig. 5).

To close, I would like to observe how the new-born "special concretes" (hyperplastified, polymerized) can enriche and enhance the possibilities of architectural expressions of reinforced concrete,thanks to their high strenght and fine elastic behaviour.
Polymerized, or synthetic resin impregnated concrete for instance (strenght up to 130-140 N/mm^2), opens a world of new forms and shapes both in shell structures as in space frames.
As far the last are concerned, we could think in terms of space lattices according geometric patterns quite new as to the structures typical of the architecture of steel.
Fig. 6 shows a space structure of this kind, in polymerized concrete,with rigid tetrahedral nodes studied and presented by Prof. Musmeci at the "Week of Architecture" in Roma (1979).
A new world to explore, a safe guarantee of riches and vitality in concrete Architecture for the years to come.