

# Career Profile of

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Recipient of S.B. Joshi Memorial Award for Bridge & Structural Engineering for the year 2007, cited by Alumni Association of College of Engineering, Pune

## **Date of Birth:**

- 19<sup>th</sup> May, 1933

## **Educational Qualification and Training:**

- BE (Civil), Madras University in 1956
- M.Sc (Structural Engineering), Madras University in 1958

## **Professional Experience and Achievements:**

- Initially 18 years experience of design and analysis of Civil Engineering structures with private consultants like Ove Arup & Partners, London
- Director of Dar Al-Handasah Consultants, London since 1976
- 40 years professional experience in structural design and construction in a wide range of climatic and geotechnical conditions
- World's leading bridge and special structures designer with personal responsibilities for the concept, design and successful implementation of many prestigious projects of highway viaducts, interchange structures, long span river bridges and special structures.
- World record for widest deck structure of Wadi Leban Bridge, Riyadh, Saudi Arabia, carried by a single plane of cables
- Innovative design concept of using precompressed stays and single plane of cables construction by glued segmental method of Shaikh Isa bin Salman bridge, Bahrain which received FIP Award.
- Worli Bandra Sea link bridge, Mumbai, India
- Longest urban viaduct-12.5 km for expressway in Saudi Arabia, with precise segmental design
- Sirsi Circle flyover, Bangalore – precast prestressed segmental viaduct, first in India

- Design of road networks consisting of 12 underpasses
- World's longest cable stayed shell roof – 365m diameter
- Tension cable roof structures, 120 m diameter for the Cairo stadium in Egypt for the African Games
- Stone cutters bridge international design competition, Hongkong 2008
- Lectured to international audiences and professional institutions and University on the subject of Structural Design and Bridge Aesthetics.

### **Publications:**

- Published and presented several technical papers in international conferences and journals.

### **Honors, Awards, Patents**

- MILNE Gold Medal for Bridge Design Awarded by IABSE in 2004
- Supreme Award for the Design of the Sungai Prai Bridge in Penang-Malaysia by The Institution Of Structural Engineers (London) in 2006.
- FIB concrete Award Shaikh Isa Bin Salman Bridge Bahrain

### **Affiliation with Professional Bodies:**

- Fellow of Royal Academy of Engineering (FR Engg)
- Fellow of the Indian National Academy
- Fellow of Institution of Structural Engineers
- Fellow of Institution of Civil Engineers (FICE)
- Chartered Engineer (C Engg)

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# 13 PHILOSOPHY OF DESIGN AND CONSTRUCTION OF CONCRETE BRIDGES

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## 13.1 Introduction

Modern bridge design whilst being the result of unfettered freedom to be creative is also based on numerous factors, including improved material technology, codes of practice reflecting current experience and thinking, and advanced construction techniques. A concept design that is fully responsive to all the requirements of the project is the essential starting point in the design process.

The quality of a design is therefore very much dependent on the understanding and synthesis of all aspects of design and construction by the designer who sets about creating the concept design. Every project is unique in that the controlling criterion governing the design presents the designer with a measured response to satisfy these requirements.

These are varied and include constraints imposed by the client, the biodiversity of the site and its physical effect upon the durability and performance of materials in relation to the structure.

A holistic approach to design is a prerequisite to produce not only an adequate response to this set of guidelines, but which leads to a structure of outstanding merit. The important ingredients in this process however, which the designer must add, are a thorough understanding of the behaviour of structures, an up-to-date knowledge of building methods and materials, and above all the skill and imagination for innovative and creative design. The end result will be clarity in the expression of the structure, optimising the use of materials thus providing strength through its shape and remaining serviceable for the design life of the bridge. The eminent engineer Professor Christian Menn has referred to the visual shaping of a structure as dependent on the 'visual expression of the flow of force'.

That is the corner stone of good structural design and which combines the properties summarised by the three Es, namely:

- Efficiency – concerning the performance of the structural elements and materials
- Economy – reflecting the economies made in design and construction
- Elegance – resulting from the visual expression in harmony with its surroundings and purity of the engineering forms.

Whilst every effort may be made to achieve the desired end result, interaction between the client, consultant and contractor working in close co-operation will be necessary to turn the conceptual design into a successful project.

A successful concept design must employ an appropriate construction method which then forms the basis for detailed design. The designer, in trying to realise the concept design is well placed to determine a construction method consistent with the design and provide adjustments and variations that may be required either to the details of the design or to the construction procedure.

The need to modify or prescribe new construction procedures to suit available expertise, and at the same time produce foolproof methods of construction, has led to many innovations that has made construction simpler, achieving a better quality of workmanship with minimum effort.

Improved material technology, the use of computers in structural analyses and the ability to define complex geometry have contributed to the advancement of modern bridge design.

Concrete technology has also made significant advances with very high strength concrete providing improved durability, performance and the consequent refined appearance of structures.

It should be stressed, however, that technical advances and tools now available to the designer should aid innovation and the realisation of creative thought, rather than dictate it. Innovation in design and construction methods arise from the need for: transfer of technology; to simplify construction procedures, introduce clarity of the structural forms; in the rationalisation of forms and falsework; quality control and finishes; integrated lighting, landscaping and external works; and long span structures.

### **13.2 Transfer of Technology**

The transfer of technology is the process whereby detailed information and expertise is passed from the design office to the contractor and supervision staff on site. For a given design concept, an appropriate method of construction may require to be modified to suit the expertise and resources available especially in developing countries. This should manifestly be made without the need to compromise on the quality of the workmanship or alteration to the design.

Nevertheless, contractors have been very keen to adopt and learn new methods of construction, and work in close collaboration with the design team. In addition to providing the contractors with complete construction engineering, the design of the prefabrication yards, gantries, launching girders and temporary works are all major elements designed to complement and aid the construction process.

Enormous strides have been made recently in the design and construction of urban viaducts in India, where contractors have used precast segmental construction for the first time on a large scale and have achieved outstanding results.

This was introduced against great odds by the author in the Sirsi Circle Viaduct in Bangalore. The author's firm provided the design and construction engineering for the project. The viaduct is 2.3 km long and consists of match cast precast segments 16.2m wide and cast in 3m lengths. The deck was assembled on shaped piers at 36 m centres. An integral ramp also with precast segments formed part of the viaduct. The segments were cast by the long line method to avoid any problems in the precision required to match the segments.

The deck was erected using a launching girder specifically designed for the project. The project was completed in 1999 and was the forerunner of precast segmental bridges being built in India. The IRC codes had to be revised following the successful completion of the project, to allow the use of precast segmental bridges and the effective use of high strength concrete.

This project was followed by the design and construction of the Second Narmada Bridge for which our firm provided the design and construction engineering and temporary works design. The project consists of 93m spans with variable depth bow girder. Designed and built using the precast segmental match cast, long line method. All form work, falsework and erection gantries were designed by the designer.



**Fig.13.1 JJ Flyover, Mumbai, India- Pier Head and Soffit Lighting Finishes Detail**

The JJ Flyover, along Paltan Road, Mumbai, India completed in 2002, is the first major urban viaduct for the city. The 2km long viaduct has a precast trapezoidal spine with precast side frame cantilevers stitched and transversely prestressed with the spine. Spines are match-cast and erected using an underslung launching girder, upon which line and levelling is carried out prior to gluing and prestressing. Side cantilevers are erected from the completed spine by the use of an overhead hanger system. The shaped piers and deck soffit are cast with a fine fluting creating an overall appearance of harmony and elegance, as shown in *Fig.13.1*.

### **13.3 Simplicity in Construction**

The construction method often dictates the economics of the structure, but with the emergence of the privatisation of infrastructure projects some of the criteria hitherto ignored are assuming greater importance. In particular, the construction time should be as short as possible, quality should be guaranteed and above all the structures should be constructed with simplicity and minimal risk.

In arriving at the total cost of the project, the material cost has to be considered together with the time required for construction. Thus the material cost of structures taken alone is not of overriding significance now that market forces have also placed the engineer in a

managerial role to conceive and deliver a complete project on time and on budget. An appropriate construction method must be chosen with this objective in mind at the concept stage.

Where construction is largely a repetitive process in viaduct and bridge design, a precast concrete segmental approach satisfies all of the criteria deemed necessary to achieve this through standardisation of the bridge's main structural components.

The choice of concrete is a natural one that lends itself to be moulded to produce exciting forms and textures combined with performance and durability to fulfil the desired requirements of the design.

Construction methods developed by the author and now universally adopted include the span-by-span method of construction using glued precast, prestressed segments. The system was pioneered in Saudi Arabia in the late seventies for the construction of the elevated 12.5km long, dual three lane, Jeddah-Makkah Expressway, at that time the longest urban viaduct in the world. Each carriageway consists of a prestressed concrete box girder with curved soffit on discrete piers and 16 on-off ramps in total. A remarkable feature of the project is that the entire structure including the ramp-viaduct bifurcations were precast and completed in 3 years in 1984.

### **13.4 Clarity of The Structural Forms**

The forms of structural elements adopted for any particular project are integral with and inseparable from the concept design. The development of the type of bridge deck, supporting pier, rationalisation of long span structures, precasting for achieving quality, economy and durability and construction technology are then all considered at the concept stage.

Theoretical analysis of the bridge structure is best studied through a breakdown of the structural elements into a model composed of smaller components to aid simplicity of design.

Similarly this is true of the construction process where smaller components are match cast and installed, with consequent greater ease of construction and handling during erection.

The deck which is composed of a spine box girder and cantilevered side frames is an example. This method of splitting a wide precast concrete deck was developed by the author in the mid-1980s and has been successfully implemented with resulting quality of finish and ease of construction making substantial savings in cost and time.

The Qurashiyah Viaduct, Riyadh, Saudi Arabia, shown in *Fig.13.2*, completed in 1991 after a 24 months construction period, uses a fully precast segmental superstructure 484m in length, with a double-cell variable depth spine box girder and cantilevered side frames giving an overall deck width of 26.5m. The high quality finishes obtained are as vibrant today as when constructed and illustrate the degree of detail that can be achieved when the refinement level of the finished structure is perceived and considered at the concept design stage.



**Fig.13.2 Qurashiyah Viaduct, Riyadh, Saudi Arabia- Pier Head and Soffit Finishes Detail**

In Wadi Leban Bridge, Riyadh, Saudi Arabia completed in 1999, as shown in *Fig.13.3*, pile caps to the piers have been constructed as cellular prestressed rafts where post-tensioning has been used for the first time in foundation construction. The piers are cast *in situ* in 3m high lifts and the hollow box construction reduces in cross-section with elevation and becomes solid at its neck 20m below the deck soffit. At this level the pier branches into four arms to carry the *in situ* pier head or diaphragm equivalent to six deck segments. The shape of the pier head forms an elegant, dynamic limb, which not only provides a stable support for the cantilevered deck, but also allows a platform for the subsequent transfer of the crane to the higher level for construction of the tower



**Fig.13.3 Wadi Leban Bridge, Riyadh, Saudi Arabia- General View of The Bridge Looking North**

Another innovative structural element occurs in the cable stay design where steel saddles are housed within the tower and allow for the load transfer of the stay cables to occur in a natural compressive state applied radial to the axis of the saddle and virtually along the axis of the tower. This arrangement offers several benefits over the use of traditional tower cable anchors. Importantly, it allows for a slender tower with sculpted surfaces as less mass is required to resist the forces found in the stays of a conventional cable stay design. It also allows flexibility in the range of tower shapes, and is cheaper to build and maintain. The bridge deck is composed of a trapezoidal spine box girder with triangular side frames precast in one 3m long segment, 35m wide and 5m deep and cast using the short-line method it is equivalent to the span of a typical motorway over-bridge. The maximum weight of the precast segment adjacent to the tower is approximately 250t.



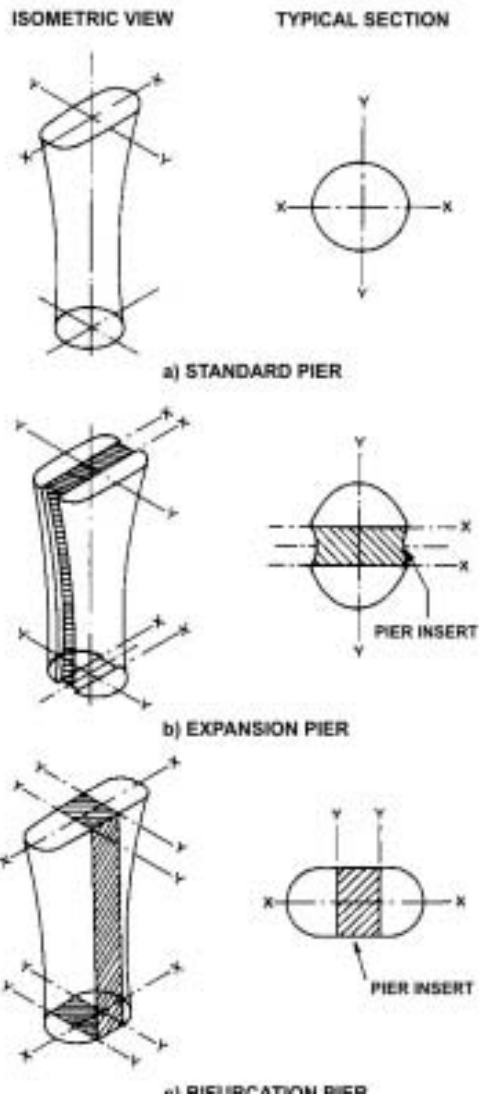
**Fig.13.4: Wadi Mujib Bridge, Jordan- Elevation of the Bridge at the Mouth of Wadi Mujib; and Detail of ‘Sails’**

Wadi Mujib Bridge, Jordan shown in *Fig.13.4* is a concrete cable stayed bridge which has its stays in compression by using conventional prestressing strands in a highly unconventional way but making savings over the cost of typical stay cables. The stays were prestressed to increase their durability and eliminate problems associated with fatigue and further economies were achieved by the use of normal prestress anchorages. The use of precast prestressed concrete was considered desirable to resolve the diverse requirements of its location and in particular controlling the effects of the extremes of the environment. The structure forms an imposing portal to the mouth of the Wadi Mujib as it enters the Dead Sea, contrasting against the impressive backdrop of the rose coloured rock face.

### **13.5 Pier and Tower Forms**

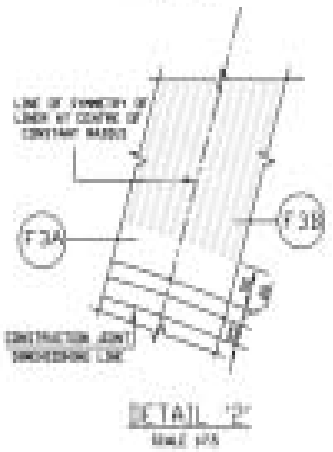
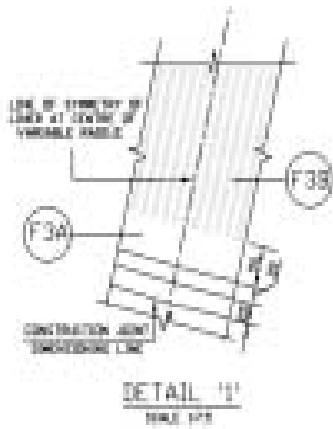
Rationalisation of the forms and false work, is introduced at the design stage to minimise the number and types of forms, maximise their use and as far as possible standardise the bridge’s components. Forms are invariably lined with a purpose deigned elastic polymer or reinforced plastic liners which produce an immaculate concrete finish without the need for introducing mould oil. These liners will last several hundred uses if taken care of.. Standard pier forms, shown in

*Fig.13.5*, involving a variable geometry which may need to be deshuttered after 24h, are generally made in two halves, each consisting of smaller units, so that the forms can be moved away radial from the cast without causing damage to the projecting ribbed surface. These types of forms also facilitate the casting of an expansion pier or wider pier for an increased deck width. An expansion pier is formed by moving the formwork outward along the pier/carriageway axis, and perpendicular to this axis to form the bifurcation pier. The resulting modified pier inserts will be given the same surface treatment to maintain appearance and continuity of the structural forms throughout the family of piers.

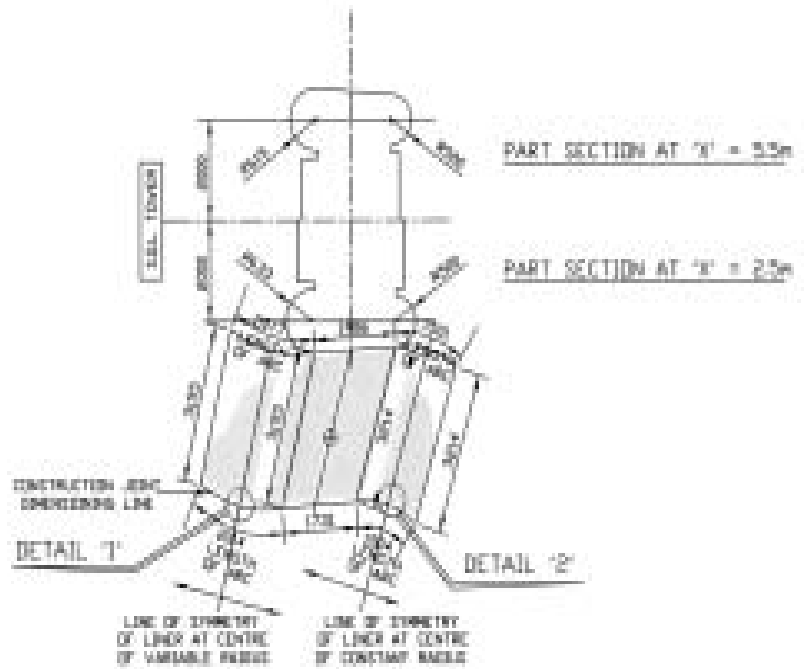


**Fig.13.5 Sirsi Circle Flyover, Bangalore, India- Rationalisation of Pier Forms**

In the case of the Wadi Abdoun Bridge, Amman, Jordan, as shown in Fig.13.6, pier and tower forms must accommodate a constantly changing profile which diminishes in cross-section over the full height of the towers. The variable shaped concrete sections optimise the stresses in the concrete and effectively prestress the sections to resist the forces due to torsion in the deck. They vary in shape from a modified straight-sided ellipse at the base 45m below deck level, to a circular section 26m above the deck at the top. Slenderness is achieved by the elimination of tower anchors in favour of a saddle system for the stays and placing mass where it is required the most. This variable geometry requires that different formwork was needed for each 3m lift, but each formwork section was used four times per pair of towers, and twelve times in total, providing economy in their use. The formwork is designed in 3m high sections using an innovative concept in the fabrication of variable sections. Thin sheet steel is cut to the developed shape of the geometry and controlled by the use of steel diaphragm stiffeners, a similar process employed in the shipbuilding industry.



CONCRETE FINISHES TO TOWER



TYPICAL DEVELOPMENT OF FORMWORK  
LINED AT TOWER TOWERED SEGMENT



**Fig.13.6 Wadi Abdoun Bridge, Amman, Jordan- Development of tower forms & Finished tower**

## 13.6 Deck Forms

A high degree of workmanship is similarly required to achieve a satisfactory structural design of the formwork to be adopted. Generally speaking, in span by span bridge construction plan curvature and super-elevation are governed by the requirements of the road profile. The alignment of precast segments in the finished works can be easily replicated on the ground. To make up for the expertise required in casting deck segments by the shortline method, greater flexibility can be obtained by match-casting using the long-line method on the ground and re-assembling in the final position. Steel moulds capable of being flexed transversely and vertically to take up any variation in alignment and profile, and incorporating an allowance for camber are used to cast a complete span of segments (Al-Khaleej Viaduct).

For a bridge deck on the straight including bifurcations, uniform soffit profiles can be cast in forms cut into consolidated ground which has been concrete lined to approximate finished profiles. The final segment arrangement is achieved using cement mortar and framed timber templates at close intervals. Polyester reinforced plastic liners are glued to this surface and the deck segments then cast with relative ease giving a high quality ribbed finish (Qurashiyah Viaduct).



**Fig.13.7 Elevated Expressway, Kuala Lumpur- Malaysia. Family of Pier and Deck Forms**

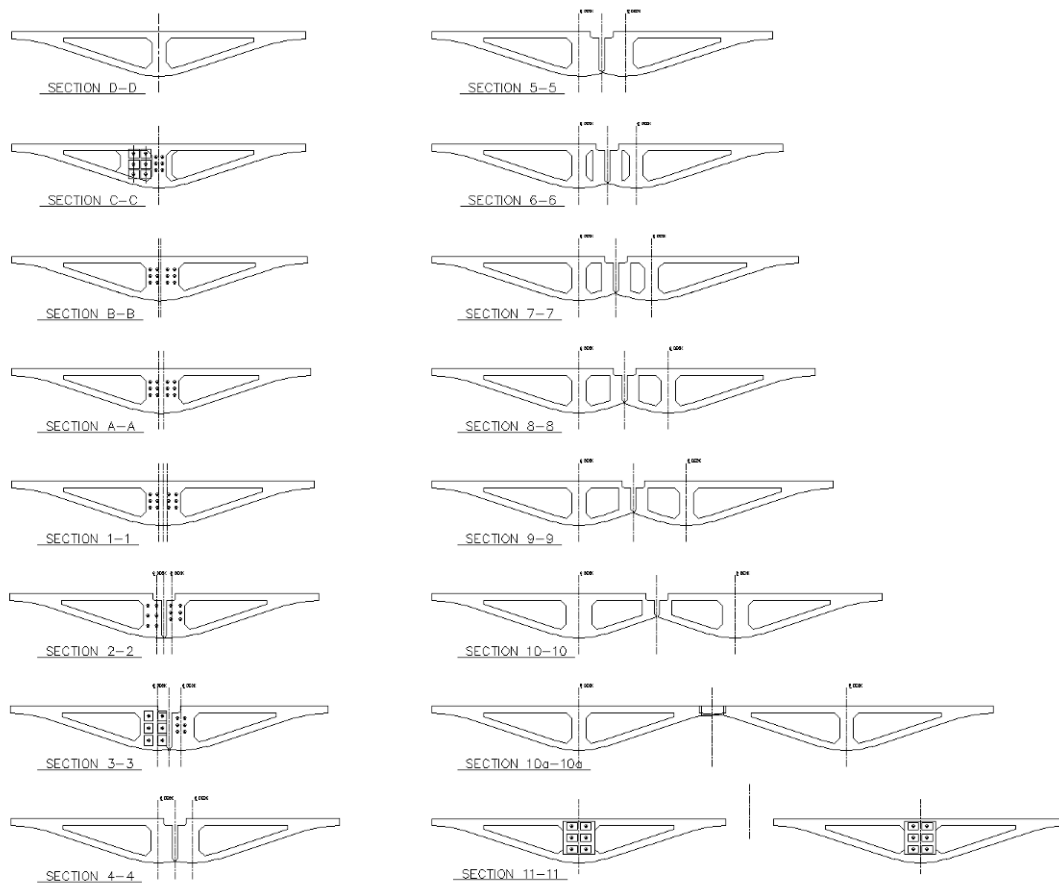
The modular design for the proposed Elevated Federal Expressway in Kuala Lumpur, Malaysia, 1997, shown in *Fig.13.7*, rationalises both deck and pier forms to suit the variations in carriageway widths and heights in viaduct and ramp arrangements. The system also uses a trapezoidal spine box girder with cantilevered side frames to great effect.

This systematic choice of deck and pier shapes will automatically lead to economies in repetitive use of formwork and enable shapes to be modified with relative ease, without the need to resort to a re-design of forms.

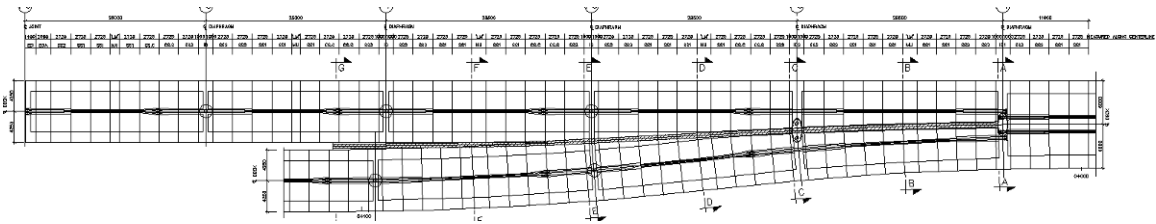




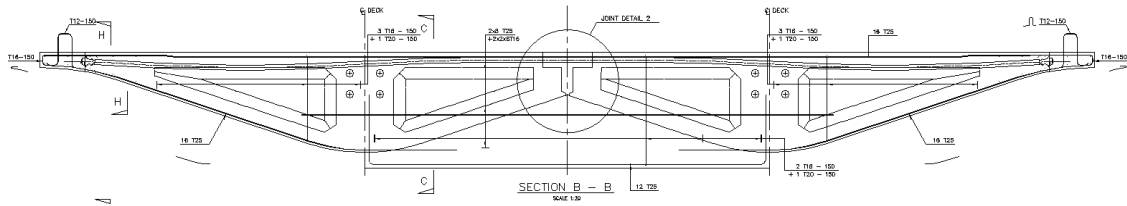
**Fig.13.9 Bifurcation Detail on the Sungai Prai Bridge, Malaysia (Top: Segment Setting out and evolution; prestressing layout. Left: Construction. Right: Finished Bifurcation**



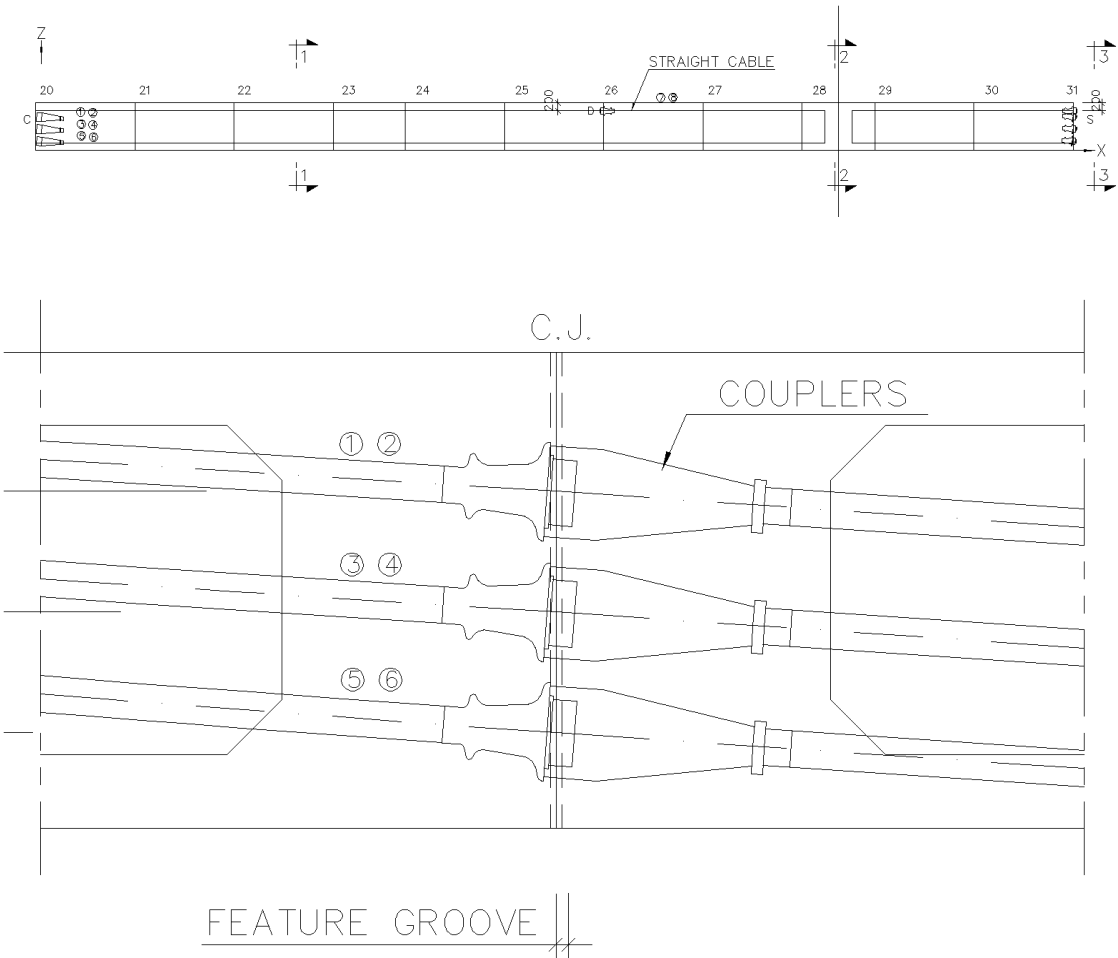
**Fig.13.10 Bifurcation Detail, University Circle Flyover, Pune- Family of Deck Sections**



**Fig.13.11 Bifurcation Detail, University Circle Flyover, Pune -Segment Plan GA**



**Fig.13.12 Bifurcation Detail, University Circle Flyover, Pune- Transverse prestress at Bifurcation**



**Fig.13.13 University Circle Flyover, Pune- Deck Prestressing. Coupler and Coupler Detail**

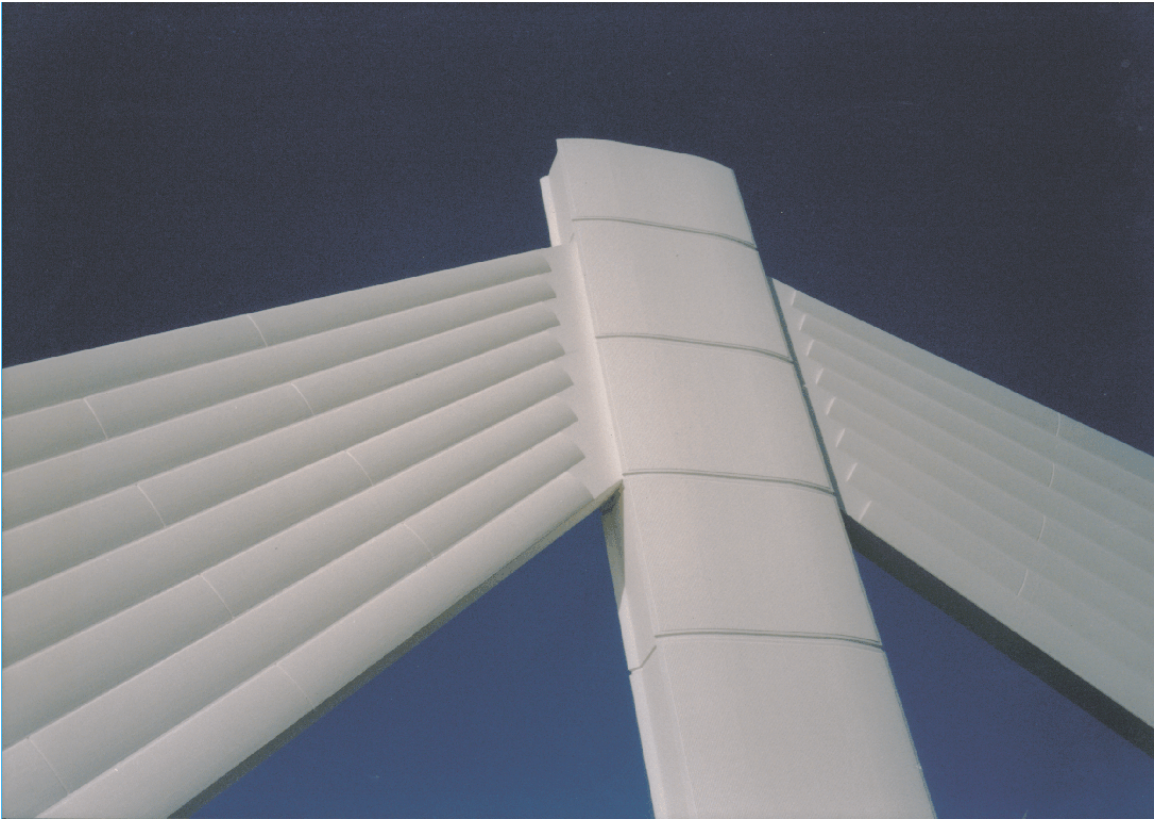


**Fig.13.14 University Circle Flyover, Pune- Construction of Bifurcation.**





**Fig.13.15 Bifurcation Detail, University Circle Flyover, Pune- Top Left: Stitch Detail.  
Top Right: Construction. Bottom: Root of Bifurcation.**



**Fig.13.16 Shaikh Isa Bin Salman Bridge, Bahrain- Precast Concrete Sail and Tower Head**

This consideration of the bifurcation, ramp and main line as being part of one family of a deck design works if the whole problem is considered together, rather than starting with a main line deck and considering ramps and particularly bifurcations at a later stage. On the Sungai Prai bridge in Malaysia, as shown in *Fig.13.9*, where there were a number of bifurcation and ramp details, this idea was taken to a high level with repetition and skew symmetry used and the resulting detail was extremely efficient, economic and visually stunning.

On a smaller scale the University Circle Flyover in Pune, India, shows this in a simple manner. The growth of the segment section in the bifurcation is shown in *Fig.13.10* and the plan geometry is shown in *Fig.13.11*. At the wider sections transverse prestressing in the deck is used, as shown in *Fig.13.12*. The deck is also longitudinally prestressed and the cables are made continuous with the use of couplers, as shown in *Fig.13.13*. The construction of the viaduct and bifurcations is shown in *Fig.13.14*.

*Fig.13.15* shows the stitch detail and the completed structure. The simplicity of the design allows for accurate work on site and a superb visually attractive finish.

### 13.7 Quality Control and Finishes

The finishes to any concrete structural element of the bridge have always played a significant part of the design process and is considered at concept stage as integral to the overall harmony of the finished product. Similarly the detail of the finishes to retaining walls, abutments, facings and ancillary elements play an important role in determining the total quality of the project. A textured finish to exposed inclined concrete surfaces will not only allow uniform weathering and reduce streaking but will also enhance and maintain its long term appearance. The juxtaposition of plain and textured surfaces using high quality tactile finishes, as shown in *Fig.13.16*, moreover contributes to the vibrancy of the completed structure and engages all of its users .The aesthetics of dividing what would otherwise be a large plain surface by texture is well known and this can also conveniently be used to express the form of the structural element.

Occasionally, even introducing a dummy construction joint line on a segment may be necessary to reduce the scale even further or maintain symmetry. For example, on the free form deck soffit of the Al-Khaleej viaduct the heavier, deeper segments were cast in 2.5m widths while lighter segments were cast in 5m modules having a dummy construction joint line mid-way. The final quality of finish could not be achieved of course without good workmanship and quality control at all stages. This requires the designer to be in control of the project throughout its construction and to approve the results of trial segments, which must form part of the specification, irrespective of whether they are pier, tower, deck or parapet segments. Initial trials may be carried out at the yard of the form manufacturer before shipment to site and again at the pre-casting yard on site to satisfy both the designer and contractor that the specified high quality finish will be achieved. These trial samples are carried out not only as a means to train the local workforce and to test various work procedures, but also to clearly establish a benchmark for acceptance of further casting work on site.



**Fig.13.17 Wadi Leban Bridge, Riyadh, Saudi Arabia- Elevation of South pier and tower**



**Fig.13.18 Sungai Prai Bridge, Penang, Malaysia - Computer generated image of the River Crossing**

Consideration is given where the bridge is constructed in a hostile environment and to add a final protective layer of acrylic anti-carbonation paint which is tested for colour and method of application before rendering all exposed concrete surfaces. A stunning effect is created by the finishes clearly visible on the pier and tower of Wadi Leban Bridge when the scale is chosen correctly even though the structure rises to 175m overhead This is shown in *Fig. 13.17*.

The Sungai Prai Bridge, Penang, Malaysia, *Fig.13.18*, is a cable stayed bridge with a centre navigation span of 185m giving a clearance of 22m above high water level and an overall river crossing length of 485m. The dual three-lane deck is 29m wide and consists of precast prestressed concrete segments made up of a central spine with side frame

cantilevers. The spine is constructed as a first stage and stressed longitudinally. The side cantilevers are launched from the constructed spine and erected as a second stage and transversely prestressed. The bridge concept allows the ramp forms to be derived entirely from the main viaduct forms in such a way that all the ramp/viaduct junctions provide a logical and elegant transition from one to the other. The project was the winner of the Institution of Structural Engineers (UK) Supreme Award for Structural Engineering in 2006 and the Award for Transportation Structures. The judges' citation: 'The Sungai Prai Bridge is an excellent example of structural engineering, and bridge engineering in particular. And is a superb example of bridge engineering at its most effective and imaginative - a landmark structure for the 21<sup>st</sup> Century'.

### **13.8 Integrated Lighting, Landscaping and External Works**

The impact which lighting can have over a structure cannot be overstated and the opportunity to integrate a well thought out scheme is very much part of the concept process. Lighting equipment, parapet handrails, location of drainage and other utilities which require access for installation and subsequent maintenance should be incorporated into the initial design, not plucked out of a catalogue or regarded as a later appendage. Lighting specifically required for the illumination of the carriageway that can provide a dual function and the opportunity of raising the elevation of a structure into a night-time landmark and visitor attraction should not be squandered.

A special feature of the Al-Khaleej Viaduct in Riyadh, as shown in *Fig.13.19*, for example, lies in the integration of deck soffit lighting and landscaping with the structural form and finish. This is particularly significant at the three-tier interchange where the roundabout has been scooped out to form a theatre-in-the-round of landscaped terraces with planting, fountain and waterfalls. Spectacular views of the curved soffit of the 130m main-span viaduct are seen from beneath as it sweeps over both the busy Airport Road underpass and at-grade roundabout creating a fitting entrance to the city.

The Shaikh Isa bin Salman Bridge shown in *Fig.13.20*, linking the Manama and Muharraq islands of Bahrain has successfully bridged the gap between old and new. The 'sail' structure resembles the sailing dhows historically associated with Bahrain and the Gulf region and gives an exciting panorama when viewed from the shore or bridge crossing. The appearance of the unblemished finish gives the impression that the bridge has been sculpted in marble rather than poured in concrete. The night time view is equally spectacular as the integrated lighting features take effect delineating the bridge's length, emphasising its simple but powerful outline by casting pools of light on the towers and sails creating shimmering reflections in the sea. The project has been widely hailed as a success eminently suited to its setting and was the theme of a set of commemorative postage stamps issued by the State of Bahrain on the inauguration of the bridge in 1997.



**Fig.13.19 Al-Khaleej Viaduct, Riyadh, Saudi Arabia - Three-Tier Interchange Showing Deck Soffit Lighting**



**Fig.13.20 Shaikh Isa Bin Salman Bridge, Bahrain - Bridge Illumination**

The Wadi Abdoun Bridge shown in

Fig.13.21, constructed for the Municipality of Greater Amman and completed in December 2006, undoubtedly presented one of the most challenging projects. It is set in a dramatic landscape between the neighbouring mounts of Jebal Abdoun and Jebal Amman in a Grade 2 seismic zone, in close proximity to the major Jordan Valley fault. The ‘S’ curve horizontal alignment was dictated by existing highway constraints but this has been used to great advantage to heighten the drama of the location with a four-span continuous cable stayed structure. The computer generated image of the illuminated bridge serves to highlight the aesthetics of the highly sophisticated design and

further confirms that structural efficiency and aesthetic excellence work in harmony when combined judiciously.



**Fig.13.21 Wadi Abdoun Bridge, Amman, Jordan.**



**Fig.13.22 University Circle Flyover, Pune.**



**Fig.13.23 Complex highways geometry at University Circle Drives a Flowing Structural Solution**



**Fig.13.24 Agricultural College Flyover, Pune**



**Fig.13.25 Bandra-Worli Sea Link Project, Mumbai, India - Computer Generated Image of The 500m Span Cable Stayed Bridge, and Viaduct Under Construction.**

### 13.9 Challenging Projects of Bridges in Urban Areas

The University Circle and Agricultural College Flyovers lie at crucial junctions in the city of Pune.

The structural solution is a family of structures. The complexity is to allow for a highly unusual and varying highways alignment in a manner than suits the location.

As was noted earlier, the wholly precast structures feature complex bifurcations.

The structures are efficient, economic, safe and visually attractive in an urban environment. Spans are arranged so that the deck depths are to a human scale, in tune with the surrounding buildings and the local environment. This is shown in *Fig.13.22*, *Fig.13.23* and *Fig.13.24*.

Long span bridges have naturally resulted from the physical limitations imposed by the site whether they are required to span a wide wadi (dry river course) or expanse of water. The contract for the Bandra-Worli Sea Link Project, Mumbai, comprising a 500m main span cable stayed bridge with single support tower, as shown in *Fig.13.25*, was awarded in early 2003 for redesign and construction supervision. The project now under construction consists of a twin four lane deck, 5km in length linking the western suburbs of Worli and Bandra across Mahim Bay.



**Fig.13.26 Long Span Cable Net Structure in Excess of 2km, Concept 1988**

The visually exciting structural form of the long span cable net structure shown in *Fig.13.26*, is as relevant today as when the concept submission first graced the front cover of the 1988 *New Civil Engineer*, and voted runner-up in its sponsored international ‘Bridge Image’ competition. The landscaped dual carriageway spans the major axis of the elliptical envelope which carries a high-speed rail link at the lower level. The technology is available to construct spans in excess of 2km, but there needs to be a gigantic leap of faith on the part of clients and authorities to believe in the benefits of such a structure, truly belonging to the 21st century.

### **13.10 Conclusion**

Having established the correct solution for the concept design in terms of satisfying all the available design constraints, it has been a challenge to ensure that the initial concept is correctly translated. Moreover, there remains an overriding responsibility to the client, who has seen and approved these concepts, to deliver what has been shown, apart from the contractual obligations. It is the translation of WYSIWYG. The close cooperation with the contractor will always be a vital component in this process and while it is always pleasurable to be able to create innovative designs, there is also great satisfaction when the contractor actually enjoys building them and taking pride in what has been accomplished. There has never been a conscious attempt to produce what today may be called a signature or landmark structure. What has been conveyed above all is that the design and construction of modern concrete bridges is borne out of a passion for design combined with the synthesis of governing requirements and not out of any preconceived notions. It is a natural response to these requirements with one principal objective - quality.