

Career Profile of

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Recipient of S.B. Joshi Memorial Award for Bridge & Structural Engineering for the year 2008, cited by Alumni Association of College of Engineering, Pune

Date of Birth:

- 14th May, 1949

Educational Qualification and Training:

- B. Tech, Civil Engg, IIT, Madras – 1970
- M.Tech (Structural Engg ,IIT Bombay) – 1976

Profesional Experience and Achievements:

Associated with the engineering and project management of many civil engineering projects all over the country and neighboring countries.

- Design and construction of several bridges and flyovers like cable stayed bridge over railway at Patna, second Thane Creek road bridge, Parel flyover, Mumbai, etc.
- Design and construction of long span structures, e.g. prestressed concrete cantilever folded plate hangar for IA at Mumbai
- Project management of construction of various hydropower and nuclear power projects.
- Rehabilitation of bridges and other structures
- Design and construction of marine structures
- Computerized FEM analysis and design of various structures like towers, chimneys, cooling towers, etc.

Publication:

- Published and presented over 130 technical papers.

Affiliation with Professional Bodies:

- Associate President, Indian National Hydro Power Association (affiliate of International Hydropower Association).
- Fellow of the Institution of Civil Engineers (U.K.).
- Member of IE, ICI, IIBE, ICFRCC, IRC, ACCE, IIWE, IABSE
- Chaired number of international and national conferences and seminars.

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14 BRIDGES –TOWARDS EXCELLENCE, THROUGH CREATIVE INNOVATION

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14.1 Introduction

Apart from sharing some of the work which the author has done in the field of Bridges and structures and highlighting some of the insights which he has been fortunate to have in this noble field, he will also cite some of the works of the organizations with whom he has worked, with appropriate acknowledgements, to highlight the features of some interesting bridges. He has covered various facets which have been key factors in determining the course of his work over the years, and which he deems to be of significant importance for a good structural engineer.

The visible face of Infrastructure, that backbone of any economy, is composed of Structures, covering Housing, Transportation, Energy and so on. This Field offers endless opportunities for expressing Creativity-- the Infrastructural context and site conditions being different for each Project, and with the variety of possibilities for the forms and functions of the Structures concerned, the parameters for optimizing are different every time with different variables being involved; the methods of realization are again different every time, given the variations in demands from the stakeholders concerned. It is this interplay of diverse forces which offers numerous opportunities to create something different and unique every time. Satisfaction and a Sense of Achievement are the sure rewards to the person who seizes the chance that is offered to realize a creative solution to the challenge thrown at him! In this field of Structures the author has chosen to highlight Bridges as he has done a good amount of work in this field and as Bridges are present more in the public eye than any other structure, with the possible exception of Buildings; and also as a tribute to the great Shri S.B.Joshi with whose name this award has been enriched.

The Innovation is driven by Creativity. And where Creativity is present, there is no boredom, there is a sense of achievement and satisfaction, there is a good amount of optimization and there is an enlargement of the frontiers of Engineering. Innovation can be in Conceptualizing, Analysis, Design, Construction Methods, and Materials, the Bid documents for Design or Construction, in the Project implementation format and so on. Civil Engineering field of work offers tremendous possibilities for Creativity and Innovation. The key person in this endeavour of innovative working could be any one in the entire gamut of Stakeholders - the Owner, the Developer, The Consultant – Consulting Engineer or Consulting Economist, the Designer, the Constructor, the “Proof Consultant”, “Engineer”, “Project Management Consultant” and not in the least in importance, the User. The reason for listing out the many stakeholders is because each of these can affect significantly the manner in which the Structure finally emerges into the public eye. For instance, a tough but fair Bidding document set up by a knowledgeable Owner’s Consultant in a competitive environment can spark off innovative solutions to take advantage of the freedom available within the Terms of Reference and reach the limits of cost economy.

In today's context of Developmental Projects – BOT, BOOT, etc- the Developer is a different entity from the ultimate “Owner” and sets the initial trend, as the Owner may come into the picture only at the end of the Concession period. The term “Constructor” is much more appropriate than the term “Contractor”, which has come to acquire a rather bad connotation in the Indian context and more aptly covers the various skills that this entity has to have to realize the Project for which it would have contracted a mandate for construction. Finally, the User has had a poor deal so far in the Indian context, not having much of a say in what he has to pay for ultimately, except possibly through some public institutions which claim a credit for representing him in a democracy!

14.2 Design

The first topic to be covered would be “Design”- as it has to take into account the very objectives for the structure and evolve the physical form for the intended end use. Typically Design would cover: itemizing the required functional and other objectives to be achieved; the form required for achieving the above and its attendant parameters; the analytical and design algorithms to be employed to ensure adequate strength, stiffness and serviceability; and, conceptualizing the mode of realization. The last activity is important particularly for complex or indeterminate structures where the sequence and method of construction are closely interlinked with the analysis and design procedures.

While the average Designer may restrict his ambit to references to the Request for Proposal Document (or the Bid Document) and the governing Codes of practice, the more enterprising ones will also look at the other parameters- Aesthetics, Cost Economy, Durability, Constructability, etc and go one step further, into the realm of Innovation. The Codes of Practice generally tend to be conservative and restrictive but with the help of a discerning Owner, the Designer can respect the spirit of the Codes and transcend their limits. Such efforts help in the forward revision of the codes. Otherwise we would never have had the much advancement in the Codes – higher strength concrete & steel, partial prestressing, probabilistic methods of analysis and so on! Where the Bid document is unduly and comprehensively restrictive and inflexible, ultimately the Owner only suffers, not being able to take advantage of the possible fruits of innovative solutions. This is where Knowledge plays a part as only the knowing expert can be bold enough to define what exactly he wants!

Many advanced tools are available today for Analysis of Structures, particularly using computer-based methods. The young engineers tend to place too much importance in the use of computers, and often deploy large and complex numerical models or discretizations without understanding the basics of the Structures. Simpler techniques such as the Strut-and-Tie idealization proposed by Prof Schlaich, for instance or the Beam analogy, offer quick and intuitive insights into the behaviour of structures. Similarly the basic understanding one would get from studying Prof Guyon's treatises on prestressing would enable one to tackle uncharted territories in prestressing applications, covering detailing of complex anchorages and so on. Detailed Computerized analysis can only substantiate the results of the basic understanding and supplement for local detailing. Any blind dependence on computerized analysis for complex structures would only lead to disaster! This approach is all the more essential while dealing with new types of structures.

In the design process unless a proper mindset has been previously cultivated, the Designer will not be able to look beyond the Box. Here by “Designer” it is meant to cover the main Designer

as well as the “Proof Consultant”, as a less competent proof consultant can undo all the efforts of a good designer and increase the heartburn in the process! The author has been able to achieve good designs many times only with the fair-minded considerations of an understanding proof consultant or Owner’s representative. In one case where computerized analysis of a hyperboloid cooling tower was being done for probably the first time in the country the Owners’ representative refused to go by any calculations and insisted on arbitrary provisions to ensure “safety”! Ultimately the matter had to be resolved by technical arbitration and the designs substantiated.

A good Designer has to have versatility and wide interests so as to have the benefits of cross fertilization between various disciplines of Science and Engineering in his work. The Tacoma Narrows Bridge, though otherwise well designed and constructed, had vital flaws in its stiffness design and collapsed due to aerodynamic factors at practically zero conventional live loading. The designers had overlooked this vital area in design, which was not well-known at that time. Modern long span Bridges employ many advanced features. The Great Belt Bridge in Denmark, shown in *Fig.14.1*, with a free suspended span of 1,624m, is one fine example, where many such features as mentioned below have been incorporated. Strategically designed and positioned frequency-tuned mass dampers counter the effects of vibrations due to wind effects. The steel expansion compensators are masterpieces of fine manufacturing. The steel bridge box deck is not painted on the inside (which has more surface area than the outside) even in the severe marine corrosion environment, taking advantage of in-filled dehumidified air maintained at the correct temperature and humidity (of the order of 40-60%). It was designed and constructed by international teams of consultants and contractors. L&T’s JV partner, Ramboll, was one of the Consultants associated.



Fig.14.1 The Great Belt Bridge in Denmark Bridge



Fig.14.2 Second Thane Creek Road

A good designer studies text books, codes of practices and Journals, visits executed projects and participates in many technical seminars. The last factor is important as interaction with other engineers plays a significant part in learning. Exposure of one’s work to the scrutiny and suggestions of one’s peers helps in streamlining one’s thinking and in identifying new paths for the solutions. A good designer always looks for ways to understand the structures he comes across, learn from them and see how to improve them further.

For the Second Thane Creek Road Bridge shown in *Fig. 14.2* the competitive tender was won using some innovative designs and construction methods. This 1800 m long, six-lane bridge was a landmark bridge incorporating a number of special features. It was the first bridge deck in India to be constructed using cantilever construction method, covering four spans in a continuous deck

with a maximum span of 107 m. It also was unique for the many integral short term and long term durability features incorporated in the various elements. The innovative designs were proof checked by a UK firm of Consultants, apart from the local Government owner agency. The typical deck unit had two intermediate spans of 107m and two end spans of 53.5m, formed by in-situ segmental cantilever construction from the three adjacent piers involved. While the two intermediate joints were made continuous, the two ends of the unit were made to rest on pier caps, instead of having articulated joints as per the then conventional practice (which had been giving problems in many existing bridges). In fact, in order to ensure positive contact, under adverse loading conditions, on the end bearings in the continuous unit, ballasting had to be done in the end spans.

To avoid problems of concreting of the thin and tall webs of the deck (with maximum height of 7m) and to keep the concrete dimensions of the webs small, cables were completely avoided in the webs, being located entirely within the top flange or the bottom flange, unlike traditional solutions for cantilever construction with anchorages on the web faces. This also facilitated good construction as cables did not have curvature in both horizontal and vertical planes and anchorage blisters could be located only at the junctions of the web with the top flange or the bottom flange. A series of computer programs for the design of the continuous superstructure had to be developed and interlinked to try out many alternatives, optimize the solutions and make quick modifications to suit changes in site conditions. The programs for the continuous superstructure were rather unique to cater for the stage construction effects, prestressing effects in the various stages, etc.

For the design of the piers and open foundations under the piers supporting continuous spans, a large number of load cases had to be checked for and the use of a comprehensive computer program was very useful. For the design of a raft foundation under biaxial bending and with partial loss of contact on the rock surface, a specially developed program was used. The design of the piers and foundations for this continuous deck bridge could not be frozen early till the actual founding levels in varying rock conditions were fixed and again, the use of computer programs was very useful to quickly finalise the designs as soon as the founding level was declared by the site. The design of a double-Dee well foundation on one abutment and a spill-through abutment on the other side, under marine clay conditions with very poor properties was again a challenge. Innovative solutions were also found for the bearings, expansion joints, drainage system, inspection walkways, etc. Since this bridge came up after the previous one was found to be ineffective on account of severe corrosion problems, very stringent measures were specified in all stages of design and construction. It was a pleasurable challenge to meet these owner's requirements and satisfy his international proof consultant as well and complete the bridge as desired.

The concept of not having cables in the webs was also utilized for the Vasai creek railway bridges to optimize the design. In this bridge anchoring any cable on the top deck surface of the simply supported girders was avoided for better durability. For maximum economy the thicknesses of the webs and the two flanges were varying continuously along the length, but the establishment of systematic procedures for the precasting ensured that such variations did not pose any problems for construction.

When ten mini flyovers had to be built in Chennai the Owner had a serious problem on hand. The streets were narrow and winding and alternative routes for diverting the traffic during construction were not freely available. There was a pressing need for flyovers at many

intersections and speedy realization without inconveniencing the public was a key issue. Since many projects had to be implemented, finance, and hence cost economy, were also key factors. Here a concept of mini flyovers, with just two lanes had to be developed and the alignment had to follow the winding road below. Considerable standardization was done to facilitate precasting and to get cost economy. Shorter span lengths and precast I-girder decks were seen to be the appropriate solution. Large diameter piles were chosen to minimize interference with services below and to facilitate fast installation. Large diameter rotary piling was adopted to minimize noise and vibrations and for better quality. Single column substructures were adopted to have a smaller footprint and for better aesthetics. I-girders precast elsewhere at a central location and erected at night over the span were the solution for the deck. Once the girders were erected, deck slab construction could go on at the top with staging supported on the erected girders. All concrete was with ready-mix concrete as there was no space available at the sites for storage of materials, etc. Consequently, the traffic below was not disturbed much. Reinforced earth embankments further speeded up the work and also gave an elegant appearance.

An innovative solution for the deck with integral cross beams reduced the overall height, and hence the length of the flyover. Considerable time was saved by precasting the girders while constructing the substructures at the site. Aesthetics were further improved with precast fascia elements, lighter hand-railing, etc. It was possible to realize the flyovers very fast with very good cost economics and good quality. It was a real challenge to complete the entire engineering, comprehensively covering traffic studies, topographic surveys, geotechnical investigations, detailed engineering, good-for-construction drawings and bar bending schedules upto preparation of the tender documents for construction, all within a short period of five months for all these flyovers. The thoroughness of the engineering and the concept of incorporating detailed construction schemes in the tender document itself proved satisfactory as the construction was completed for all the flyovers within the stipulated period.

It is not always that post-tensioning is adopted as the solution for bridge decks. For a viaduct across Kune valley on Khandala- Lonavala bypass of the Mumbai-Pune Expressway, pre-tensioned, precast girders were used. Precasting was the preferred method as erecting staging for constructing the deck over the undulating valley would have been very difficult. In order to match the curved geometry of the flyover, considering the large number of repetitions and to facilitate easy handling, 18m span was adopted as the optimum for the I-girders. About 325 girders were produced in a centralized precasting facility with a handling weight of only around 16t. The superstructure was made continuous over four spans, for the superimposed dead loads and live loads, to minimize the number of expansion joints. In order to minimize the prestressing effects near the supports for the straight tendons placed in the bottom bulb of the girders, debonding over some distance near the supports was adopted.

The Designer has a responsibility to the users to ensure durability and longevity for the structures and to ensure that the structure is amenable for future inspection and maintenance. This lesson was particularly learnt while designing the repair and strengthening measures for the Nehru Bridge in Ahmedabad, as well as other structures subsequently. This bridge had long suspended spans between cantilevers projecting from the pier hammerheads and the articulations were not detailed and constructed as per proper corbel theories. A unique system was evolved for supporting the suspended box girder span on a sling formed by prestressing cables anchored over adjacent piers and passing over diversion blocks fixed to the undersides of the cantilevering articulations. The damaged articulation concrete was then dismantled and removed, additional reinforcement added and the nibs re-concreted. The anchorages were projecting on top of the

deck and a system had to be devised for holding them down below the riding surface within the wearing coat using steel boxes, as traffic had to be permitted on this busy bridge while repairing was going on below! This was a very interesting project for actual implementation, without inconveniencing the users. The detailing of articulations and use of appropriate type of bearings were good learnings on the Project.

14.3 The User point of View

Many of us, who have visited developed countries, would have often wondered whenever we came across an interesting structure or a bridge on why we are not able to have more such examples in our own country. It is in this context that the concept of the many Stakeholders was brought out earlier. There is nothing much an enterprising Designer or a Constructor can do if his hands are fully tied by a restrictive demand. The Owner and his representative also have to be aware to demand and accept superior solutions, even if they depart from the conventional, so that the User's interests are properly taken care of- in terms of functionality, aesthetics, less disturbance during construction, etc. Developed countries spend a good amount of money even for erecting noise barriers to shelter nearby residences from the noise of traffic on the bridges or roads!

Taking the example of Bridges, it would be a moot point to see whether the Users have been consulted while finalizing the horizontal and vertical alignment as well as the positioning. The author has seen in one example down South, where a village has been split asunder by a huge bridge embankment going across the main street of the Village! Public hearings for Infrastructure projects is a new concept but one which needs considerable encouragement. Not only have the Users using the Facility but also the people affected by the Facility needed to be consulted.

Rideability is one User aspect which needs to be considered more seriously in our bridges, the lack of which can detract from the otherwise high quality of the structure. The smoothness with which the rider is able to negotiate the entry and exit curves of the bridge, the visibility characteristics and minimal jarring effects of the expansion joints in between, all go into improving the rideability. The structural design and construction play a good extent in determining the rideability. For instance, only an expert Designer would venture into designing continuous structures to minimize expansion joints. The Chennai flyovers had just four joints in the entire length. The Second Thane Creek Bridge and Sirsi flyover also had long continuous



Fig. 14. 3 Integral Cross-beam



Fig. 14. 4 Mini Flyovers at Chennai

lengths. Apart from the expansion joints, the quality of the wearing coat or the riding surface is also important. Many experiments are being made with bituminous concrete, mastic asphalt and

cement concrete. Choosing an appropriate geometry of the structure and a scheme for its construction to minimize disturbance to ground level traffic is a very important factor for flyovers in urban situations. Speedy realization to minimize the overall time duration of such disturbances is also a key factor.

When it comes to land flyovers the cost is affected by the length of the structure, which is governed to some extent by the height of the structure. Integral cross beams at the piers, shown in *Fig.14.3*, reduce the overall height but are more complex to design and construct, and hence not that prevalent in usage here. The mini flyovers in Chennai, as shown in *Fig.14.4*, incorporated this concept to minimize the overall height.

14.4 Construction Methods

As mentioned earlier, for complex and indeterminate structures there is a close connection between the structural concept, the analysis & design methods and the construction procedure/sequence. There is no point in conceiving a structure without being sure of constructing it and, within the desired cost and time limits. As the structural forms become more complex for innovative structures, and the environmental parameters become more difficult, the construction methods also become more complex. It pays to have the involvement of well-experienced Construction Methods Specialists to evolve the appropriate methods and sequences. Such specialists should have detailed knowledge of various types of construction equipment, different methods of construction, typical cycle times involved, requirements of various types of labour, etc. Large construction firms such as L&T have teams of such highly-skilled and experienced specialists in Construction Methods Planning Cells (CMPC). Often bid-winning designs are based on innovative construction methods. Sometimes impossible site conditions also call for specialized and innovative construction methods. In such situations the CMPC experts have to rise to the occasion to come up with winning solutions.



Fig.14. 5 Precast Segmental Const.



Fig.14. 6 Railway Bridges at Aroor-Kumbalam Kerala

Many bridge decks are constructed by using the versatile segmental construction method shown in *Fig.14.5*, with either in-situ or precast segments. Though it has now become commonplace, in the initial stages a number of potential problems had to be solved and design and construction methods developed. Special attention was required in the design stage also to take care of the construction stage effects, shear transfer, etc. On account of the failure of a few earlier bridges there was much trepidation in the minds of the early users to adopt segmental construction and these had to be taken care of by good designs.

For the Aroor-Kumbalam set of railway bridges shown in *Fig.14.6*, on the new Ernakulam-Aleppey broad gauge railway line in the 80's it was seen that adequate land was not available in the already congested construction site. Railways decided to call for bids based on precast segmental construction employing prestressed assembly techniques and totally overhead construction. It was a bold move for Railways, given the state of technology at that time. With good initiatives and inspired leadership from the clients, the Constructor and his Consultant came up with appropriate designs and construction methods to construct the bridge to required specifications. It was the first time that precast segmental construction was adopted in Indian Railways and was one of the earlier usages of prestressing for railway bridges. Each span of about 30 m was precast in seven segments by long-line match-casting technique at a location about 6 km away from the construction site. The precast segments were brought to site on a barge, lifted up by a winch moving on a steel twin rectangular truss spanning between two adjacent piers. The segments were temporarily supported from below on underslung cross trusses spanning between the two longitudinal trusses, joined by temporary prestressing on epoxy-glued joints provided with shear keys and then permanently prestressed. The assembly truss of one-and-half span length was moved from span to span by using a boat to support the front end.

Apart from being one of the earlier instances of the use of prestressed box girders for railway usage for such a large span, it was also the first time for segmental construction (with simply supported spans) and hence the design had to be done in a thorough manner with many reviews. Apart from proof checking by the clients, a scale model test was also carried out by IIT, Madras and the design proved. 38 spans were launched successfully by this method. Many provisions were also kept to ensure durability and good serviceability, often ahead of the codes! In order to support the constructor who was new to such construction, a comprehensive construction procedures manual was prepared and detailed precautionary measures to be adopted were also brought out.

For the long spans of the second Thane Creek Bridge, shown in *Fig.14.7*, the deck was constructed by in-situ balanced cantilever construction method and the cantilevers had to be made continuous during service. Complex computer programming was used to predict the deck precambers to account for the effects of prestressing, creep and shrinkage, so that the deck did not have any kinks during service after establishing continuity. The competitive bid for this bridge was won on the basis of cost economy arising mainly from the use of open foundations for the various piers, which was a unique solution for a bridge in marine conditions! While the material economies could be duly achieved by efficient designs, constructing the RCC foundations under dry condition was a challenge. Two methods were used for the same- one using sheet piles and sinking a concrete caisson inside on sand filling and the other creating an enclosure using twin-wall steel cofferdams assembled in segments on top of a precast concrete cofferdam sunk in position previously. The seating joint of the cofferdam on the rock below was sealed using an innovative method to facilitate dewatering even in marine situation to construct the open foundation in dry condition.

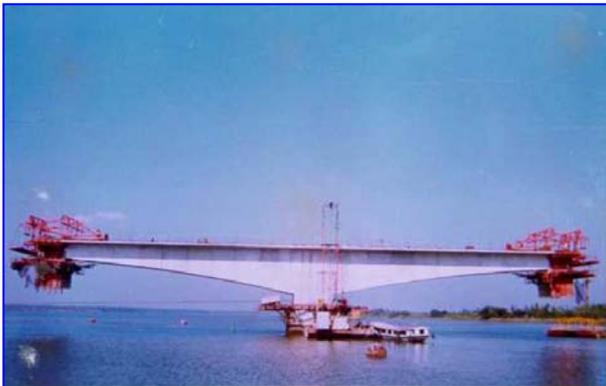


Fig. 14.7 Cantilever Construction



**Fig.14.8 Incremental Launching
Panval Nadi viaduct**

The superstructure of the 600m long Panval nadi Viaduct, as shown in *Fig.14.8* on the Konkan railway was completely precast by L&T on one of the abutments adjoining a steep valley, in segments, and the whole bridge was pushed across the valley, or incrementally launched, in stages. The deck had a forward steel launching nose and as the rear end was pushed using jacks, the forward nose moved over the intervening piers, with sliding happening between PTFE and stainless steel elements. This innovative work earned good recognition when the Government of India launched a postal stamp for Konkan railways depicting this Bridge.

For the superstructures of the railway bridges across Vasai creek in Mumbai show in *Fig.14. 9*, 48.5 m span precast girders weighing about 550t were launched perfectly into position using only tidal power, without any cranes! The girders precast on nearby land and moved onto a jetty, were lifted off the jetty by a pontoon as the tide rose and lowered onto the pier caps as the tide went down. Since it was not possible to carry out any further prestressing operation after launching of the girders at the pier cap locations, the complete prestressing was applied in the yard itself. However, since the tensions induced in the top fibre were of a high order as the full losses would not have been experienced at the launching stage, the girders were loaded with most of the railway ballast before stressing to impose as much of the permanent loadings as possible at that stage. Still there was some residual tension in the top fibre and this was offset by

temporary prestressing cables stressed across the top fibre of the girder between temporary steel anchorages bolted to the deck. After the girders were launched and some more permanent loading was effected, these temporary cables were released. It is a matter of satisfaction that 78 such girders were launched well and positioned with good accuracies using the tidal launching method. This bridge also had a unique design for the bearings, which were designed for seismic conditions. Apart from longitudinal restraints, side restraints were also introduced to ensure smooth functioning even under earthquake conditions.

The Sirsi Circle Flyover in Bangalore, shown in *Fig.14.10*, constructed by L&T is an excellent example of good construction engineering. The horizontal alignment of the bridge had a number of unavoidable curves to suit the congested site location. The continuous superstructure was with a number of precast segments which were mach-cast and assembled at location on overhead travelling trusses using temporary and permanent prestressing. Suitable banking also had to be provided at the curve locations. The large precast segments were subject to creep and shrinkage changes and the casting geometry had to be carefully engineered taking into consideration the above factors to ensure that the segments matched properly after erection and in service.

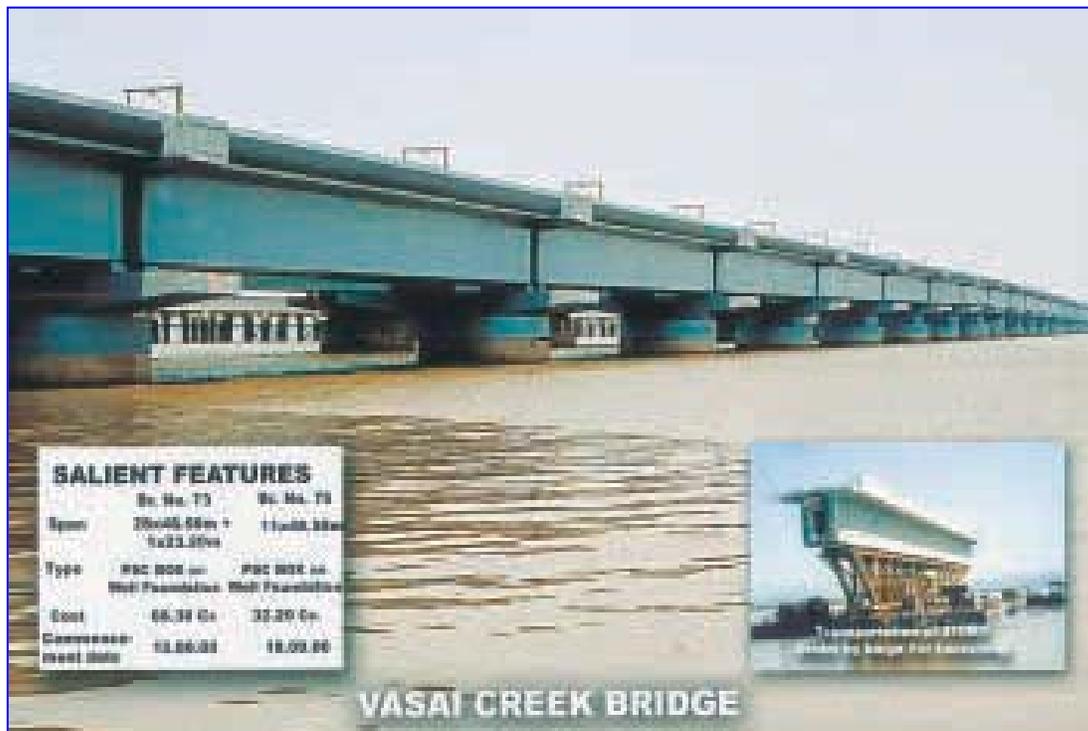


Fig.14. 9 Railway Bridges across Vasai Creek

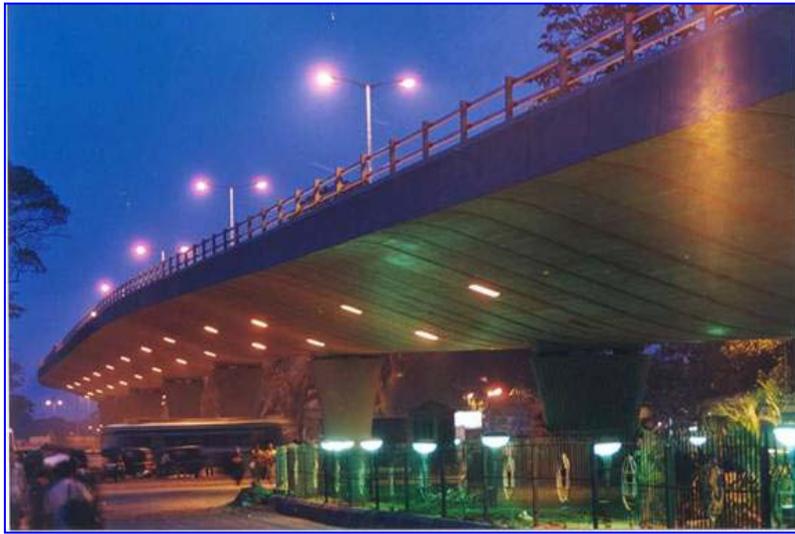


Fig.14.10 An aesthetic view of the Sirsi Circle Flyover, Bangalore

For the Gambhir ghat bridge shown in *Fig.14.11*, on the Jammu-Udhampur railway link , L&T used an interesting technique for launching the steel superstructure.

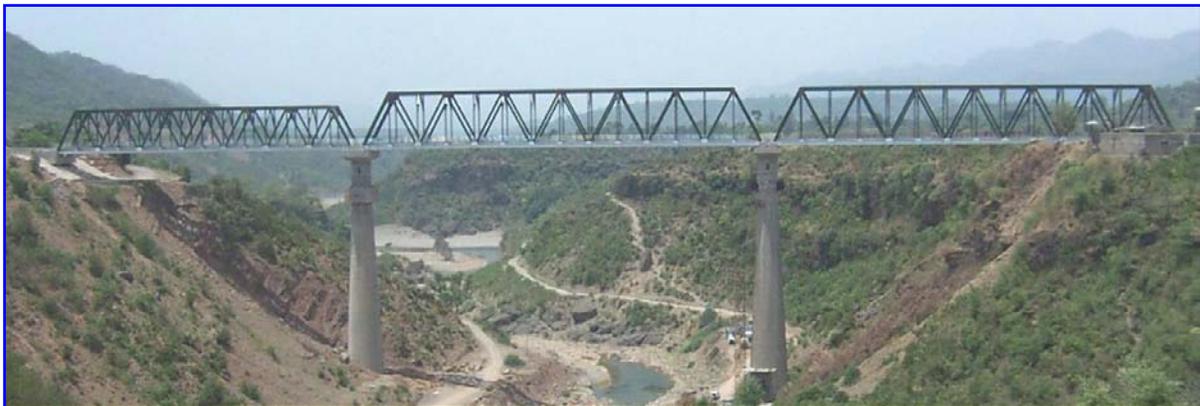


Fig.14.11 Bridge across Gambhir Ghat, Jammu

In the earlier days of construction of deep well foundations, the sinking of the well was always a challenge, on account of tilts and shifts and the lack of good control on the overall sinking process. L&T had developed the Jack-down well system, as shown in Fig.14.12, in which the well was pushed down into the soil using a series of prestressing cables anchored in the soil below and bearing on top of the well steining. This not only increased the speed of sinking but also gave excellent control as the potential tilts and shifts could be controlled by varying the forces on the various cables around the circumference of the well.

When Karnataka Road Development Corporation wanted 100 bridges to be built at a number of distributed locations all over the State, a group of around 40 bridges was constructed by total precasting solution. Apart from the foundations, practically all the other elements were precast in centralized yards in each cluster, transported to the site on trucks and assembled at site. It was

possibly the first example in India of segmentally precast I-girders for the superstructure, assembled at site. Since many sites were not that easily accessible, precasting was adopted as the solution for fast construction, for better quality and for better logistics management by concentrating the infrastructure within centralized yards. The size and weight of each segment were carefully limited to be within those amenable for transportation in conventional trucks and for handling by conventional capacity cranes at site. The abutment and pier column elements were erected inside cavities in the foundations cast in-situ and made monolithic. The abutment cap and pier cap elements were also precast and connected to the column elements by in-situ concreted joints. The I-girder elements were joined by prestressing cables stressed across epoxy-coated joints provided with shear keys. The 20m span girders were assembled at ground level and then lifted up to be in position over the pier caps. The deck concrete was poured in situ over precast shutter planks spanning between the erected I-girders. The construction scheme was led by the design team, with integrated solutions.

In the initial stages of construction of the elevated railway for the MRT system at Chennai, the owner had gone in for a scheme with cast in-situ pile foundations and twin column piers, with the superstructure formed by precast-and-launched whole-span box girders. These were still somewhat early days for utilization of prestressed concrete box girders for railway spans in a big way. From functional utilization point of view, each broad gauge track was supported by an individual box girder, designed for conventional railway loading rather than for any light rail system loading. The resulting heavy girders were precast in a centralized yard, lifted up by strand jack system and transported over previously erected girders on trollies and unloaded over the required span using a launching truss. Since the initial stage of the project was being constructed by a sub-contractor not that well versed in such precast construction, the designer had to evolve the details of the complete construction scheme and help in implementing the same at the site. The girder span lengths were all not alike, as many cross roads intervened along the alignment and each crossing had to be spanned over by a specific-length girder. The lengths of stretches between such crossings varied and many different standard span lengths had to be evolved to build up these stretches. The designs were standardized to the extent possible for the various spans. Stringent measures for durability were also implemented in this project for the superstructure elements.

In a seminar held in Sri Lanka on the possibility of a land link between the two countries, concepts for a bridge link were presented by the author in outline- Lanka by land: a Legend come True! It was an interesting study in the construction of a long bridge on the sea, though in somewhat shallow waters. Many sea links are coming up now in our country and the day may not be far off when we would also be examining international links!

All these are some examples of innovative construction methods. For every constraint, a solution must be found, and often original solutions have to be developed! In such cases it is indeed a great pleasure working in a creative team of designers and construction engineers to evolve innovative but practical solutions.



Fig.14. 12 Jack-down Construction of Well Foundations



Fig.14. 13 A Cable-stayed Pipe Bridge at Cochin

14.5 Aesthetics

This is one aspect which is commonly neglected by many stakeholders. The ultimate User often has no choice in this matter, except when a statutory body can intervene, as in the case of Delhi Urban Arts Commission! Ensuring good aesthetics need not cost additional money, if proper attention is paid in all stages of evolution of the Structure. In Developed countries it is common practice of practice to use Bridge Architects to ensure that all elements are designed with good aesthetics. All the elements of bridges are amenable for aesthetic treatment. Essentially good proportions, good surface geometries, good finishes and textures, pleasing colour combinations, superior materials and strategic lighting are the key elements to ensure good aesthetics. Above all, only a passion for good aesthetics from the Owner, the Designer and the Constructor could drive this key factor.

A simple cable-stayed bridge for carrying a pipe in Cochin, as shown in *Fig.14.13*, has given good satisfaction to all the stakeholders on account of the innovation in design and the pleasing aesthetics. It was one of the earlier applications for indigenous cable-stayed designs. While the Developer had many choices for the form of the bridge to carry a simple pipeline, he chose to adopt an aesthetic solution and the result was an elegant cable-stayed structure. An open-formed steel structure was adopted for supporting the pipeline. Every second node was supported by steel cables suspended from the pylon. The bridge came out as a light structure for the overall span of 130 m, with superior aesthetics.

The Sirsi Circle Flyover in Bangalore, as shown in *Fig.14.10*, was one of the earliest examples of high bridge aesthetics in this country. Slender piers in high strength concrete with an aesthetic shape and embellished with pleasing fluting patterns meet the eye at lower levels. The deck soffit above has a pleasing transverse curved shape, again in high strength concrete, with superior finishes. It was designed by Dar and constructed by L&T. Several flyovers in Delhi have been built with good aesthetics, particularly due to the drive of the UAC as well as the Owners. The mini flyovers built in Chennai also have good aesthetics, even though they were conceived, designed and constructed in a very short time period. Considerable efforts were spent for looking at alternative forms and making physical models apart from using computer graphics, with a

view to evolve aesthetic solutions. They were one of the earlier implementations of the reinforced earth technique.



Fig. 14.14 Example of Precast Architectural Fascia



Fig.14.15 Cable-stayed Wadi Abdoun Bridge in Amman, Jordan

As an example of aesthetics in minor elements of bridges, the hand railing and the anti-crash barriers employed in the Princess Street Flyover in Mumbai designed by STUP Consultants several decades ago are good examples and have been emulated several times thereafter. Special precast fascia elements with pleasing patterns, as shown in *Fig.14.14*, are often used to improve the aesthetics of concrete decks. Precast fascia elements which also hide the longitudinal drain pipes behind, reinforced-earth panels with interesting patterns, fluting or grooves on columns, curved shapes on the deck elements, etc are some of the typical design schemes adopted to improve the aesthetics, without increasing the cost. The ornamental structures at the approach of long bridges are also other opportunities for introducing aesthetic elements for bridges.

The Second Vivekananda Bridge in Kolkata and the cable stayed Wadi Abdoun bridge in Amman (designed by Dar), shown in *Fig.14.15*, constructed by L&T are good examples for long span bridges. The Great Belt Bridge in Denmark mentioned earlier, is a very interesting example of superior bridge aesthetics.

14.6 Some Other Important Aspects

Apart from the above, there are a few other aspects pertaining to Structures which need some attention, as dealt with below. Though the following section does not directly influence innovative working, it is felt that that the younger engineers should have a proper perspective on these factors.

14.6.1 Materials: With advancements in Science and Technology, many new and innovative materials are making their advent in the field of construction. The Designer and the Constructor should take advantage of these to realize the structures in a more effective manner. High Strength/ High Performance Concrete of very high strengths is being used for a variety of applications to minimize structural dimensions, to improve durability, etc. Self Compacting Concrete has facilitated considerably the concreting of congested or inaccessible zones. Thinner members are now possible to be concreted satisfactorily using this material. Fibre- reinforced Concrete has improved the ductility and strength as well as wear resistance of concrete elements. Heavy concrete of density of 4.65 t/cum has been used in nuclear containment structures at

Tarapur Nuclear Power Project for radiation protection and techniques for pumping this heavy concrete with abrasive properties through pipe lines has also been well developed. Ready Mix Concrete has now become quite common and for the smaller sites in urban areas this application ensures high quality concrete with standard properties. Further, coloured concrete has also made its advent and aesthetics can be improved using this material judiciously. High Tensile Steel strands of larger diameters are now being manufactured to facilitate higher capacity prestressing cables. Corrugated polyethylene sheathings have improved durability of prestressing cables considerably. Advanced admixtures have improved grouting methods, further improving the durability of prestressing cables.

14.6.2 Constructability: Constructability is a key issue. Designers should pay good attention to ensure that their structures can be constructed with ease, with good speed and quality, particularly for innovative concepts. Reinforcement detailing should be done carefully to minimize congestion to facilitate easy concreting. Acute corners should be avoided. Construction joints should be pre-planned and preferably shown on the construction drawings. Dimensions of members should be adequate to permit easy concreting, duly considering the placement of reinforcement and any embedments. Precast elements should have optimally located lifting/handling points, properly identified. The Designer should have a practical idea of how the structure is to be constructed before releasing the drawings for construction. Mock-ups of some key elements are also carried out in special cases to ensure constructability and to test out the design conditions.

14.6.3 Durability: Durability or longevity of the structures is another moot issue for the Designer and the Constructor. While carrying out the Design, good materials should be identified and specified. Reinforcement detailing is a key parameter in this respect. Adequate concrete cover is essential for the reinforcement. The Constructor should ensure good concreting, as a smaller but denser cover is often more effective than a larger but poorly concreted cover. Large unreinforced surfaces should be avoided to minimize crack formation in concrete. Minimizing crack widths and ensuring proper spacing of cracks should be looked into in design. Good quality coatings are often used in highly corrosive areas to promote durability. Surface drainage should be ensured on bridge decks and run-off water should be conducted off the bridge deck as speedily as possible. Many recent bridge decks incorporate downspouts, longitudinal runner pipes and downtakes to convey the run-off water into the ground without impinging on the structure. The design should facilitate inspection and maintenance of all key elements during service. Typically, for bridge decks the bearings should be amenable for inspection and arrangements should be provided for lifting up the deck and replacing the bearings in service. Notwithstanding any measures taken in design and construction, systematic inspection and maintenance of bridges is still very much required. Use of systems such as the Bridge Management System (DanBro) of Ramboll enables the monitoring of a large number of bridges in a database.

It should be borne in mind that the cost to be considered should be the life-cycle cost, covering both the initial cost as well the cost of maintenance and operation. Hence the structure should have good durability, with least requirements for maintenance costs.

14.6.4 Quality: Quality is an omnibus key element which is a function of serviceability, aesthetics and longevity /durability, keeping the cost as an invariant, and would be more or less taken for granted for innovative structures. Quality is an important requirement for structures

constituting the Infrastructure, in view of long-term service demands. Quality generally does not cost anything more but only demands more attention to details and proper systemization of all relevant activities. It can be said that the end Quality is a function of the demand for the same! Eternal vigilance is often the only price for Quality! All large projects run by good organisations have their well-built Quality Systems. The Bid document of the Owner is the place where the intent has to be specified, backed up by detailing the requirements for the various systems. Ultimate Quality has to be kept in mind at all stages: the Design stage, Specifications stage, Bid document drafting stage and the Construction stage. All the relevant stakeholders have to take care of their parts adequately to ensure overall quality.

14.6.5 Role of Owner's Representative: As mentioned earlier, the role of the Owner's Engineer is critical to ensure the realization of the main objectives at various stages. Key roles of this stakeholder would cover formulating the Bid documents, encouraging and proof checking the main Designer and ensuring the due observation of the Quality systems during construction. The Bid document is a key document which drives the contract for Design as well as for Construction. While it should be comprehensive, there should also be adequate flexibility to encourage innovation and value engineering at various stages. A fair-minded approach rather than the Owner-takes-all approach should be adopted in the document in a demonstrative manner to ensure an enthusiastic participation from the Constructor.

14.6.6 Codes of Practice: Generally all Codes of Practice make it clear that they are recommendatory and not mandatory, thus giving some flexibility and room to the practicing Engineer. However, many Owner's Engineers take them as literal mandates and place severe restrictions. A pragmatic approach based on sound knowledge and due observation of the spirit of the codes is important to realize outstanding structures. The people responsible for developing the codes keep in continuous touch with the latest developments in Technology and make sure that the codes are forward-looking and duly reflect the state of technology.

14.6.7 Cost Economy: Cost is a very important parameter for structures forming a part of the Infrastructure, particularly in the Public domain. Cost economy is a function of several parameters. Design can primarily influence the quantities of materials and thus control the cost of materials, which in India is a substantial fraction of the total cost. Material specifications, time period available for construction and bidding format are other key parameters, and influenced more by the Owner. On the part of the Designer, ensuring good constructability and providing Standardization in the various members can reduce construction costs. Ultimately cost of the structure is a function of optimization between various elements controlled by the Owner, the Designer and the Constructor and hence close cooperation between these stakeholders is required to drive down the costs.

14.7 Some other Interesting Structures

The author would also like to take this opportunity to share with the readers details of some other interesting structures he has worked on.

14.7.1. Tall Structures - RCC Chimneys shown in *Fig.14.16* Apart from bridges, another fascinating field of structures is that of tall structures. The RCC Chimneys employed in thermal power plants going upto 275 m height, as for instance the one in Anpara Thermal Power Project, are an interesting example. For these structures the wind effects are rather special. Apart from in-wind response, the cross-wind oscillations are interesting. Special elements called strakes have been developed empirically through wind tunnel tests to minimize the effects of

the cross-wind vibrations. The stage-wise design of the chimney as it gets built and later in-filled with the refractories and supporting structure calls for specialized applications. These chimneys are usually built using the slip-form technique and new contractors have been supported with construction methods assistance for developing the techniques.



Fig 14.16 Tall Structures – Chimneys, NDCTs

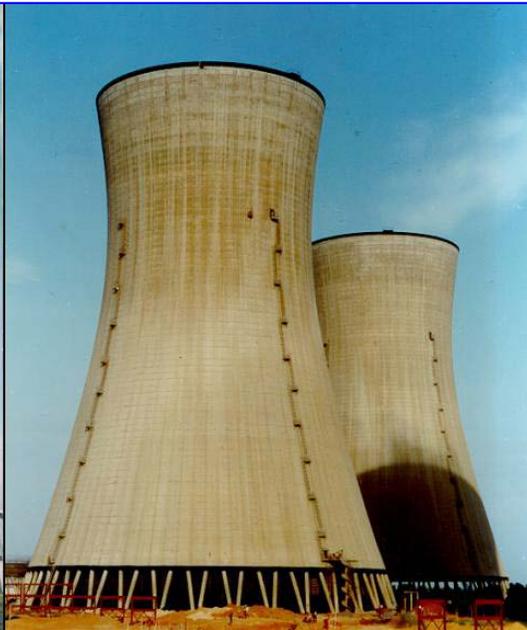


Fig 14.17 Construction of Hyperboloid Cooling Tower

14.7.2 Hyperboloid Natural Draught Cooling Towers: As shown in *Fig.14.17*, for re-cooling the hot water used in the condensers of thermal or nuclear power plants Cooling Towers are used. The Natural Draught Cooling Tower (NDCT) traditionally has a hyperboloid shape for structural efficiency. The dimensions are huge, as for instance the tower at Kakrapara is 123 m tall and over 90 m in base diameter. The minimum shell thickness in many cases is just 175-200 mm! Along the meridian the diameter, the meridional slope and the shell thickness all vary continuously making this structure a real challenge for both design and construction! The design and construction of these towers are both specialized jobs, calling for considerable expertise. Specific purpose computer programs employing the axi-symmetric finite elements and thin shell elements were developed indigenously in early 80's for such purposes! The designs were also checked by SERC among other agencies. The shell is supported on a series of relatively thin (“matchstick-like”) diagonal columns, which are generally precast and erected. Towers with open foundations as well as pile foundations have been designed. The whole system has to withstand high wind forces as well as seismic effects. Unlike the smaller diameter chimneys, the wind pressure variation around the NDCT is complex and the distribution of the meridional forces around the circumference is also complex. The open foundation is cast on the ground in a number of pours around the circumference. The basin wall, which is also a part of the shell-supporting structure, is built up on top of the same. The diagonal columns, which are cast in pairs with a portion of the shell-bottom ring beam connecting the pair at the top, are erected inside pockets in the basin wall and bonded monolithically through in-situ concrete joints. The shell ring beam is then cast with supporting staging from the ground level or using

precast concrete formers supported between the erected diagonal column tops. After the lower lifts are cast, the systematic construction of the shell using hydraulic climbing scaffolding system starts. A large number of climbing units operate around the circumference supporting the formwork in a number of panels and the form is lifted up using the hydraulic system from pour to pour. The control of the geometry along the meridian as well as circumferentially is very critical for these thin shells, as towers are known to have failed on account of bad geometry.

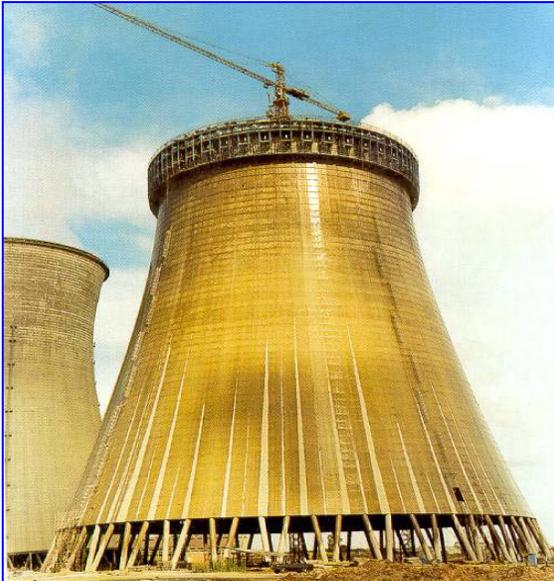


Fig.14. 17 Construction of Hyperboloid Cooling Tower



Fig.14. 18 TV Tower at Rameswaram

Inside the tower the cooling medium, or “fill” as it is called, is supported on a series of wall blocks resting on a grillage of beams over tall columns. Traditionally the entire series of elements inside are precast as there are large repetitions and to save time for their construction, which can commence generally only after the outer tower is constructed. Here again the stage-wise effects are important as the structural behaviour is different in different stages of construction/ service. While the earlier traditional system of supporting the concrete laths on relatively unreinforced wall blocks was acceptable for non-seismic cases, for the Kakrapara tower more rigidity and strength were required in view of the higher seismicity specified for design. A special precast RCC beam element for supporting the laths was developed and this was also amenable for fast and reliable construction. Unlike the traditional cases this system also facilitated replacement of the laths at any time during the construction.

14.7.3 RCC TV Towers - In the earlier days tall TV towers in India were constructed with structural steel elements. AIR found after optimization studies that hybrid towers with most of the height being in RCC could be more economical. A series of tall RCC TV towers were then constructed with the top 45 m only being with a steel mast, with a provision for another 23 m high antenna mast above that. The 100 m tall tower at Bangalore, the 150 m tall towers at Varanasi and Ahmedabad and the 323 m tall tower at Rameswaram, as shown in *Fig. 3.18*, are interesting examples for their design intricacies. Apart from other wind effects, the P-Delta effect for these very slender structures was relevant for design. The lateral deflection at the top due to wind effects had to be contained from transmission point of view. The design of the raft foundations was also critical. Cellular raft foundation was adopted in some cases for the sake of

economy. These towers have very good aesthetics and the difficult construction was carried out using the jump form technique.



Fig. 14.19 Aircraft Hangar at Mumbai

14.7.4. Long span Aircraft Hangar - Aircraft hangars are special structures having requirements for large column-free spaces for parking aircraft during maintenance. A concrete hangar at Mumbai, as shown in *Fig. 14.19*, is a very interesting structure with a cable-stayed cantilever folded plate roof. While an earlier hangar at this location was constructed with designs developed in the past, the extension was designed indigenously using Indian codes. The hangar had a cantilever of 62 m length and the average thickness of concrete was only 200 mm! This highly aesthetic hangar roof had to be designed for some special load cases and the construction sequence was very critical. The entire roof between expansion joints had to be supported on staging. The various cable ties supporting the roof had to be stressed in a particular sequence and the decentering sequence for the staging below had to be carefully controlled.

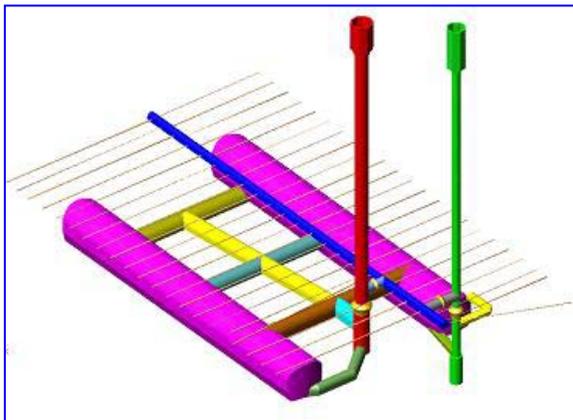


Fig. 14.20 Schematic View of the LPG Storage Underground



Fig. 14.21 View of the

14.7.5 Underground Cavern - A special technique based on hydraulic containment has been adopted for storing inflammable liquids, such as LPG or crude, underground in unlined rock caverns. A large cavern with a capacity of 125,000 cum has been built at Vizag, as shown in *Fig.14.20 & 14.21* to store LPG at a depth of 200 m below ground level. A surface installation of this size would be prone to fire and sabotage hazards and would also suffer from high costs for

the structures, distribution piping and controls. Water made available in the rock pores above the cavern from a series of horizontal holes drilled from a gallery about 15m above the top of the cavern helped in containing the evaporations from the stored liquid. The cavern was constructed using only two small diameter shafts of 4.5 and 6 m diameters in a rather short time. Extensive use of machinery and use of innovative construction methods and project management were the key factors for the successful completion, with a very high safety record.

14.7.6 Marine Structures - Marine structures are another class of interesting structures with emphasis on construction methods in view of the difficult site conditions normally encountered. In the early 80's ten large caissons were precast in a dry dock at Mumbai and launched off into the sea, towed for about 10 km and sunk into position as part of the Fourth Oil Berth at Butcher Island. The design had to take into account the construction methods and sequence adopted and to provide for good durability under severe corrosive conditions. The construction methods were an important aspect for this interesting type of project carried out for the first time in Indian conditions.

Some of illustrations are shown in the *Fig 14.22, 14.23, 14.24* given below.



Fig. 14.22 Cantilever Construction for Second Thane Creek Bridge



Fig.14.23 View of the Second Thane Creek Bridge, with the earlier Bridge in the Background



Fig. 14.24 View of the deck of Second Thane Creek Bridge

14.8 Conclusion

The need for an approach to Bridges and other Structures, based on a quest for Innovation, has been brought out adequately. While Innovations have to be driven mainly by the creative Designer or the Constructor, the other stakeholders also have a responsibility to foster the spirit of innovation and nurture the same. Only then can outstanding structures be realized in our country. Above all, a passion for excellence is what sets the trend and it is hoped that all young engineers would keep their passion for excellence duly stoked at all times in their career! That would make our country really great and ensure its due place amongst the developed nations.