Career Profile of

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Date of Birth:

- Born in March 1928

Educational Qualification and Training:

- B. E, Civil, University of Mysore in 1950
- Honorary Doctorate from University of Stuttgart

Professional Experience and Achievements:

- 41 years experience in Gammon India Ltd.
- Managing Director, Gammon India Ltd in 1972.
- Guided a premier construction company ‘Gammon India Ltd’ as Chief Executive for 20 years in the field of dams, tunnels, long span bridges, energy and of short structures, mini hydel works, underwater works, chimneys, cooling towers, industrial structures, etc.
- Many ‘firsts’ to his credit such as long span bridges, bored tunnels, high rise and membrane structures, prepacked concrete, pneumatic sinking, etc.
- Consultancy practice from 1991 in project design, R & D activities and turnkey engineering projects.
- Formulation of codal standards for highways.
- 50 years dedicated commitment to the profession for synthesising professional management and engineering application

Publications:

- Published and presented a number of technical papers, articles, lectures, keynote addresses, panel discussions at several fora of engineers in India and abroad.
Honours and Awards:

- FIB Gold Medal
- International Award of Merit in Structural Engineering from IABSE
- Gaurav Award from ACCF
- Prestressed Concrete Design Award from IE (India)
- Distinguished Service Award by IFAWPCA
- Eminent Engineering Personality status by IE (India)
- ICI-FOSROC Award

Affiliation with Professional Bodies:

- Fellow of National Academy of Engineering
- Past President of BAI, IFAWPCA, Manila, CICA
- Past Vice-President of IABSE and NAE
- Member of FIB and its steering committee
- Fellow of several international and national professional bodies and Institutions such as ICE (UK), I. Struct. E (UK), CS (UK), IEI, ISI, etc
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8 NEW TRENDS IN BRIDGE ENGINEERING

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8.1 Introduction

Innovative methods of design and construction of bridges are being developed to improve infrastructure. As well, bridge management, including additional recent concepts of whole life costing, maintenance strategies, deterioration modeling, replacement, and etc., are being introduced to achieve maximum efficiency and economical design of bridges.

Whole Life Costing (WLC) should be considered in design. The concept of Net Present Value (NPV) is to be used, where all future costs are brought to today’s value of money. Ranking of bridges is necessary. Initial surveys and its projections are often exaggerated. The toll collection is not proportionate with the investment made.

Segmental construction is convenient and economical because of availability of machinery with higher capacity and longer booms for lifting. The new segments of the bridge could be extended from the one already constructed. One need not go down the gorge or valley and erect temporary piers.

Cable stayed bridges is the right solution, when spans exceed 200 m. Individual cables may be sensitive to vibrations. Dead loads are smaller than live loads and hence modal and natural frequency analysis is essential.

New trends in bridges like (a) precast elements for foundations, piers, super structures (b) External prestressing (c) steel pier head system for anchoring cables at top (d) light jacks for each cable precisely and allied recent techniques are being used.

The chapter includes the author’s presentation, in four parts, namely, (1) Whole Life Costing (2) Cable Stayed Bridges (3) Segmental Construction and (4) Illustrations of several bridges through photo-slides to highlight current trends.

8.2 Whole Life Costing of Bridges

Whole-life costing (WLC), sometimes referred to as life cycle costing, is a way of determining the total cost of a bridge structure from its initial conception to the end of its service life. It attempts to quantify, in present monetary terms, the costs arising from all work undertaken on a certain structure. This is referred to as a net present value (NPV) or a single current cost over its entire life. This enables the whole life cost of a bridge to be determined from investment principle. The costs to be included would be those arising from design; construction; repair, maintenance and upgrading; traffic management and delays, and possibly demolition.
Whole-life costing addresses the problem of the future maintenance of bridge structures (both new and existing) and enables designers to consider the future consequences of their present actions in order to get the best value for money.

### 8.2.1 Stages in WLC

The *fig.8.1* shows the stages in the asset life cycle of a typical public sector project in which WLC has application.
8.2.2 Need of WLC

Whole-life costing provides the client with a more realistic estimate of how much a bridge structure is going to cost in the long term. Whole-life costing addresses the problem of the future maintenance of bridge structures, (both new and existing) and enables designers to consider the future consequences of their present actions in order to get the best value for money. The need of WLC is aimed at the following goals.

- Long term durability.
- Design for maintainability.
- Design for min. Repair & related costs.
- To decide on option:
  - Alternative bid proposals
  - Repair & rehab priority amongst a stock of bridges’
  - Anticipatory member life & preparation for repair or replacement.
   - Get most from money available.
- Cost evaluation of alternatives during service.
- Prerequisite for a proper br. Mgt. System of entire bridge stock of a road network.
- Very necessary for bot projects.

8.2.3 Costs Involved In Evaluation of WLC

Whole-life costing enables the exercise of sound financial management in respect of initial design and construction costs, and ongoing maintenance costs. Evaluation of WLC involves the following costs.

- Initial costs of design / construction
- Initial costs of design / construction
- Inspection & maintenance costs
- Repairs during lifetime
- Strengthening / replacement / br. Modification costs
- In service failure costs
- Redundancy & disposal costs

\[ \text{INSPECTION & MAINTENANCE COSTS} \]
\[ \text{REPAIRS DURING LIFETIME} \]
\[ \text{STRENGTHENING / REPLACEMENT / BR. MODIFICATION COSTS} \]
\[ \text{IN SERVICE FAILURE COSTS} \]
\[ \text{REDUNDANCY & DISPOSAL COSTS} \]

- TENDENCY AMONG OWNERS TO PREFER LOW INITIAL COST PROPOSALS: IS LEAST COST BR. TO BE PREFERRED
8.2.5 Issues Involved In WLC

The choice between initial design and construction costs and ongoing maintenance costs is very often reduced to that between lower initial cost structures with higher maintenance costs, and higher initial costs structures with lower maintenance costs. Additionally attempts are made to consider the future cost to the community if there are delays, accidents etc.

Issues in WLC are given as follows:
- Alternate cost models
- Traffic delay costs with low initial cost model (inconvenience)
- Political impacts & variation in discount models in consequence.
  evaluation of env. Costs at every stage of life of a bridge as
  - design life
  - economic life
  - physical life

Life dependency of WLC is illustrated graphically as shown in fig 8.2 and fig 8.3.

Fig 8.2  Life dependency of WLC
8.2.6 Evaluation of WLC

The need for a NPV analysis in bridge management is the fact that options need to be considered on an equal basis. Principal $P$ invested for $n$ years at an interest rate $r$, compounds to a sum $C$. This can be expressed another way to mean that the net present value $P$ of an expenditure $C$ in year $n$ at a discount (or tests discount) rate $r$ is calculated. This then allows for the comparison of different schemes on an equitable basis, and generally the scheme with the least NPV is the preferred one. This process of calculating the NPV is known as discounting and the terms interest rate and discount rate are interchangeable.

The whole life cost of the project is then the sum of the initial (capital) costs and long term negative discounted costs of subsequent inspection, maintenance and repairs.

Mathematical equations for evaluation of costs are as follows:

**EVALUATION OF COSTS:**

- **SIMPLE PAY BACK** $P = \frac{1}{R}$.
- **PRESENT VALUE** $P = C \left(1 + r\right)^n$; $r =$ INTEREST RATE / DISCOUNT RATE.
- **INFLATION IMPACT CAN BE BUILT INTO THE ABOVE EQUATION BY SUBSTITUTING.**
  $ndr = \left[\frac{100 \times \text{interest rate} - \text{inflation rate}}{100}\right] \times 100$ in % terms
- **NET PRESENT VALUE** $NPV = \sum_{t=0}^{N} \frac{B_t - C_t}{(1 + r)^t}$
  $B_t =$ Estimated benefits in year 't'
  $C_t =$ Estimated costs in year 't'
  Discount factor $= \frac{1}{(1+r)^t}$
  $N =$ Period of analysis in years
- **INTERNAL RATE OF RETURN (IRR).**
  - O.K. FOR BOT/ NOT FOR PUBLIC SECTOR
8.2.7 Concluding Points of WLC

8.2.7.1 WLC and Management

- WLC is part of a total bridge mgt. System
- Helps prioritisation & ranking of br.
- Provides a quick ref to deterioration modelling in regard to cost, time & other factors
- Helps standardize deterioration
- Stores maintenance cost data base by use of the Markhov process
- A reliable admin tool: helps analyze various options and reach the most beneficial decision.

8.2.7.2 Benefits From a Proper Assessment of W.L.C.

- Saving in vehicle operating costs
- Saving in vehicle operating time
- Traffic delay impact
- Traffic flow detour impact
- Many others.

8.2.7.3 Sensitivity Analysis

- Discount rate
- Inflation rate
- Initial costs
- Inspection costs
- Maintenance costs
- Repair costs
- Br. Deterioration rate / remaining life
- Traffic vol. Variation
- Detoured traffic vol.
- Impact of collapse
- Possible changes in road network.

8.2.7.4 Problems Involved In Implementing WLC

- Difficulty in predicting deterioration rate & remaining life
- Uncertainty of traffic volume
- Uncertainty of discount rate & inflation
- Difficulty in using subjective & qualitative criteria
- External influence
- Difficulty in predicting long term economic conditions.

8.2.7.5 The Indian Scenario

- Started & stopped
- Not initiated for new projects even on the golden quadrangle
- No repair & maintenance data for deterioration modeling available
- Funding and priority compulsions.
- WLC is a cradle to grave concept.
8.3 Cable Stayed Bridges

8.3.1 General

A noteworthy development in bridges is that of cable stayed bridges, widely adopted all over the world since the 1960s because of their elegance as well as economy. Traditional suspension bridges evolved into cable stayed bridges that eliminated the need for strong anchorages of the suspension cables thereby reducing the impact on environment. Cable stayed bridges are generally considered advantageous for spans of about 100 – 500 m; however, larger spans over 1000 m are not uncommon. Cable stayed bridges require high pylons, generally span / 5, to support the long span girders, leading to large inclination of cables, about 30° to 80°, with the bridge axis. The large inclination of the cables results in significant variations in the cable tension due to deck deformations under live load. The deck system of a cable stayed bridge is supported by the inclined cables anchored to the towers, resulting to the reduction in the stiffening girder moments and resulting in smaller sections of the girders leading to overall economy. The moments in the girders and supporting pylons can be controlled by a suitable choice of stay cables; uniform distribution of forces in pylons and deck girders results in efficient material utilization.

The primary advantage of cable stayed bridges is the reduced stresses in the main girders due to the support from stay cables. Numerous alternatives possible for the deck, pylons and stay cables render the structural system suitable to any landscape, and allow the formulation of an economical and elegant bridge profile for the given constraints.

Stay cables carry most of the vertical loads on the deck, usually about 85 – 95 percent. The vertical component of the cable force supports the girders, and reduces bending stresses, while the horizontal component provides longitudinal prestress. Both these effects reduce forces and deflections in the girders.

Cable stayed bridges rest on a limited number of supports (abutments, and pylons), which can absorb the differential displacements during seismic action.

Consequently, earthquake tremors and wind forces have little effect on cable stayed bridges. They dissipate earthquake shock energy efficiently because of large deflections, the deck oscillations, and differential lengths of cables. The vertical component of seismic loading is taken up by pylons and stays. The deck being suspended at a multitude of points, local deformations are restrained from exceeding the elastic limits. However, the response of the structures to horizontal excitation may be critical.

8.3.2 Design and Construction

The salient features of layout, design and construction of a cable stayed bridge are pointed out and illustrated as follows:

(a) Layout
   • Composition of a typical cable stayed bridge is shown in Fig.8.4
Fig. 8.4  Composition of Cable Stayed Bridge  Fig. 8.5  Different Pylon Types

Fig 8.6  Stay cable layout  Fig 8.7  Stay cable sections
Pylon types as shown in Fig. 8.5, is dictated by cable arrangement and side or spinal in plan
Stay cable layout may be fan / harp / mixed (in elevation), as shown in Fig. 8.6.
Stay cable sections may be as shown in Fig. 8.7.
Deck sections are shown in Fig. 8.8.
Arrangements of pylon head and stays are illustrated in Fig. 8.9.
In multi span bridge, pylon stiffness may be high/balanced/low
Connection of pylon to deck is shown in Fig. 8.10.
(b) Design

- Main span to side span
- Pylon to span: preferred 0.25 to 0.30

**Fig 8.11  Apparent Modulus of Cable**

- Cable stay spacing: equipment dependent
- Impact of live load: effective span
- Apparent modulus of cable, as shown in fig. 8.11
- Wind on structure: vibration / damping, as shown in fig. 8.12
Fig 8.12  Wind on Structure : Vibration / Damping
**Fig 8.13  Force absorption: Long: Braking & Trans: Seismic or Wind**

- Force absorption: long: braking & trans: seismic or wind, as shown in fig. 8.13
- Temp effect: conditioned by pylon to deck system proposed
- Fatigue of stay cables: affected by many factors, stress limited to 0.45 guts
- Abutment layout: dead weight, force absorption, temp. Freedom
- Accidental failure of cables: higher stress limits proposed 0.6 to 0.56 and traffic control
- Deliberate replacement of Cables: higher stress limits proposed 0.6 to 0.56 and traffic control

(c) **Construction Methods:**

- Pylon to abutment & to span on either side: in insitu: Akkar bridge.
- Precast segments + extrados cables: Worli Bandra Link Bridge.
- Stability during construction: to vibration: Normandy, ting kau solutions
- Ground / water transport of segments: Ting Kau bridge
- Construction from one end: 2\textsuperscript{nd} Hoogly bridge.
- Concreting of deck in situ for composite decks: 2\textsuperscript{nd} Hoogly bridge. deflection control.

**8.3.3 Different Cable Stayed Bridges**

Various cable stayed bridges are presented through photo-slides as figures, highlighting only the specific features, as follows.
The first cable stay bridge at Akkar in Sikkim is shown in Fig. 8.14 & 8.15. The spans are symmetrical of 77-77 meter length. The stay cables were manufactured at site under controlled conditions. The cable stay design was tested for dynamic performance at Stuttgart before being incorporated in this bridge (cable stays patented by SBP, Germany).

These two views as shown in fig 8.16 and fig 8.17 of the Second Hoogly bridge show the main span of 457m under construction. The deck is of composite construction with steel segments placed in position as seen in fig 8.17. The segments were transported by river, lifted to position and riveted to the previous section. After the entire span was completed the deck slab was laid. The side spans are 152m.
The views of the second Hoogly bridge are shown in fig 8.18 and fig 8.19. They show the mobile gantry used for concreting the deck with specially made jacks for lifting and lowering the deck centering plus a schematic view of the systematic erection of the deck elements.

The fig 8.20 shows the Ting Kau bridge in Hongkong where the deck is supported on the longitudinal axis by centrally positioned cable stays. The main spans are 457m. Of particular interest is the manner in which the central pylon is stabilized from the adjacent pylon junction with deck. Again, mast mobilizing cables are provided transversely over each pylon. The bridge is located in a cyclonic belt and hence these precautions. The fig 8.21 shows the second longest cable stay bridge at Normandy in France. The main span is 867m. It is also exposed to strong North Sea Winds. The main span deck is partially in concrete and partially in composite construction for weight reduction and balancing.
The *fig 8.22* shows the Evripos bridge in Greece with a span of 230m and a deck thickness of only 0.67m. It is a high strength all concrete deck and one which commends itself to easy casting because of its solid deck section. The *fig 8.23* shows the Kelheim foot bridge in Germany with the pylon placed outside the deck. The manner in which the suspension cables support the deck is of interest.

The *fig 8.24* is a cable stay bridge blending beautifully with the locale and with a short pylon height. The *fig 8.25* shows a view of the longest span cable stay bridge in the world at Shikoku in Japan with a span of 999m. There are two planes of cable stays for this wide bridge located in cyclonic area.
The \textit{fig} 8.26 and \textit{fig} 8.27 of cable stay bridges in Japan show the beautiful variation in pylon concepts referred to earlier.

Again, cable stay bridges lend themselves too many types of cable stay placement. Here are two examples in Japan, \textit{fig} 8.28 shows straight bridge with a single pylon and spread back cables and \textit{fig} 8.29 shows how cable stays can also be adapted for a curved bridge.

\section*{8.4 Segmental Construction}

\subsection*{8.4.1 Preamble}

Technological advances using the material ‘concrete’ the last century has enabled us to forge ahead with structures which could not be forecast even five decades ago. The birth of prestressing gave a Philip to these advances since it enabled passive concrete to be energized and
accept force adjustment with time. This led to nearly 50% saving in concrete material, which had a snowball effect on construction technology and long span concepts. These have been augmented by the use of high strength concrete combined with external prestressing, leading to member sizes being substantially reduced. The reduction in weight of the members in consequence has led to large precasting of prestressed concrete elements, transporting and placing them in position at location, with high capacity mechanical devices. The author’s presentation is about this aspect of segmental construction and the many ways human ingenuity has made it possible and achievable. The presentation is only a small revelation of the many facets of this fast developing and fascinating type of construction. The presentation is mainly related to segmental bridges and Indian applications and some innovative foreign applications.

Segmental construction can be realized both in concrete and steel but it has a greater application to concrete structures on account of its inherent durability characteristics. Segmental construction is today evident in simply supported and continuous spans, cable stay bridges and arch bridges, marine and offshore projects, hydraulic structures, building components and the like. Segmental construction of steel bridges consists of prefabricated steel segments and in-situ concrete segments for deck.

Segmental construction is characterized by application of longitudinal force either through prestressing or by component of self weight to develop a pressure across joint. The joint material may be dry or epoxy.

The location of prestressing forces may be within the member depth (external cables) or within the webs (internal cables) or below the member.

Casting must match to fine tolerance (short and long line). Casting yard may be at site or elsewhere. Segment weight is generally 150 tons. Actually there is no limit. But it depends on equipment harnessing.

**8.4.2 Construction Methods**

Segmental construction can be both insitu and precast type and is becoming increasingly popular in most parts of the world since the related equipment for lifting and placing such segments is now readily available. Precast segmental work requires casting of elements to fine tolerances and transporting them on low bed trailers to site. In India, we have erected precast segments up to 150 tonne but abroad up to 2500 tonne weight complete span and pier components have been placed in position to accelerate work and minimize joint interfaces.

The supporting system required for precast generally consists of

- Bed gantry
- Truss supporting the soffit below the member
- Truss above suspending the elements
- Truss within telescoping out each time
- Gantry / crane on finished deck
- Mobile tower cum cable stay system on finished deck
- Floating crane
- Fixed tower cum cable from pier or bed for arch construction
- Slide projection corresponding with the
8.4.3 Illustrations

The various erection methods are illustrated in this presentation through photo-slides as figures, as follows.

**Fig 8.30  Barak Bridge**

The two bridges shown in **fig 8.30** and **fig 8.31** are the first cast in situ segmental bridges constructed in India (*Barak and Lubha Bridges, 1964-1968*). The in situ units are 3m in length and the centering system consisted of a mobile cantilevered gantry. The spans are 120m for Barak and 135m for Lubha. They are situated in acute seismic areas and have been designed appropriately. The 135m span is a continuous deck, extending into the adjacent rock formation and counterweighted by it. The 120m span has a central pendulum hinge bearing to accept longitudinal movement and transfer vertical shear.

**Fig 8.31  Lubha Bridge**

**Fig 8.32  Bassein Creek Bridge-general view**  **Fig 8.33  Bassein Creek Bridge-under construction**

**Fig 8.32** and **fig 8.33** are two views of the Bassein Creek Bridge reveals cast in situ construction of 115m span made continuous over a length of 360m. This is the first prestressed long span continuous bridge in India. During the construction process, the stability of the cantilevers was ensured with the help of short columns supported on the well cap and carrying a sandjack atop for easy later day removal. The sand jacks are used for lowering 800t partly completed deck onto bearings, which arrived later.
Fig 8.34  Tapi Bridge at Idgaon  

Fig 8.34 shows Tapi Bridge at Idgaon and fig 8.35 shows Zuari Bridge which are reflective of the variety of spans that can be generated using insitu segmental construction. The spans vary from 90m for Idgaon to 120m for Zuari. The span are continuous having pendulum bearings at centre of span.

Fig 8.35  Zuari Bridge

Fig 8.36  Jawahar Setu in Patna  

Fig 8.36 and fig 8.37 shows views of Jawahar Setu in Patna having 46 spans of 120m across the Ganges, which is essentially in precast segmental construction. The erection of precast segments weighing nearly 80 t, 25m above the water level, using floating equipment is of interest.
Fig 8.38  Jawahar Setu in Patna - Transfer of Precast Unit  

Fig 8.39  Jawahar Setu in Patna - Short Distance Transportation

Fig 8.38 shows the erection of the segmental units of the Patna Bridge over the dry bed portion, the transfer of the precast unit from the stacking yard to a low bed trailer and fig 8.39 shows the short distance transportation of the precast unit by the gantry to location.

Fig 8.40  Ganga Bridge at Buxar - Mobile Shuttering  

Fig 8.41  Ganga Bridge at Buxar - Stacking of Precast Units

The bed for Ganga Bridge at Buxar for prestressing deck units, as shown in fig 8.40, is different to what is practiced today. It consisted of a complete bed for one span with mobile shuttering. This is somewhat a cumbersome approach and is now not popular. The stacking of precast units, as shown in fig 8.41, without causing distress to the bottom unit, upto two high, following transportation, is also important at worksite to provide space for movement.
Fig 8.42  Sirsi Flyover  

Fig 8.42 of Sirsi Flyover shows the precast segment which is being lifted, as shown in fig 8.43, by a bed gantry at location and the finished work sneaking through the road network at Bangalore. The units weighed upto 75 t and they were perfectly matchcast in a special form work which could accept the radius transitions, wuper elevation and several other features. It is high strength concrete that made this concept realizable in a simple and elegant manner.

Fig 8.44  GM Flyover at Bombay - Precast Spine Unit  

Fig 8.44 shows the precast spine unit of the GM Flyover at Bombay and fig 8.45 shows the side segmental units erection in progress. This type of concept is well suited for a congested locally and requires little space for transporting and erecting the spine unit.
Fig 8.46 and fig 8.47 shows the erection process of the GM flyover. Following the erection of the spine unit, transported from a casting yard 5km away, you will note the positioning, as shown in fig 8.46, of the precast side units to make up the total carriageway width. The side units are erected from the deck as shown in fig 8.47.

Fig 8.48 and Fig 8.49 show the erection of precast segmental units for the Delhi Ring Road network. It was possible to have a simple truss system, as shown in fig 8.48 for this work for erection purposes. The units weighed upto 30 tonne maximum and were transported over 5 km mostly at night, for being suspended from the truss and prestressed as usual. The span configuration is 26-31-42-32-26m. The work was rapidly executed with least disturbance to traffic.
Fig 8.50  Noida Flyover  

Fig 8.50 and Fig 8.51 show views of Noida Flyover which evidenced excellent workmanship. Only external cables were provided for the work. The segments were supported on trusses as, shown in Fig 8.50, raised on brackets from the piers. After completion of erection of segments of each span using a simple cantilevered gantry, the units were stitched with an epoxy interface. All segmental bridges in India, as of today, have an epoxy interface, although abroad some bridges have been constructed without it. This later development has been the outcome of external cable usage.

Fig 8.52  Godavari Bridge –Cantilevered Construction Using Cable  

Fig 8.52 and fig 8.53 show the views of Godavari Bridge. The construction procedure adopted for insitu segmental construction of the arch using cable stays is shown in fig 8.52. Although the construction methodology is somewhat complicated, the solution has minimum weight per sq.m of deck and economical when a no. of spans are to be constructed.
**Fig 8.54  Godavari Bridge**

**Fig 8.55  Teesta Bridge in N. Bengal**

*Fig 8.54* shows the elevation of one span of Godavari bridge with the hangers and deck in position, suspended from the insitu cast arch by the cantilever method. The span is nearly ninety meters. *Fig 8.55* shows beautiful coronation bridge across Teesta in N. Bengal. This arch was also segmentally cast during the Pre war years and has several notable technical features especially in the foundations. The central portion of the arch was completed using a MELAN type steel concrete integrated solution. This method was necessitated because the cableway used for concreting could not accept the full load of the arch in this segment.

**Fig 8.56  Panval Nadi Viaduct**

**Fig 8.57  Panval Nadi Viaduct - Push Launching**

*Fig 8.56* and *fig 8.57* show the Panval Nadi viaduct. Of particular interest is the push launching, as shown in *fig 8.57*, carried out for a broad gauge railway bridge for the first time in India. The segments are precast at the rear end of the bridge in segments and pushed forward with the help of winches and guide rollers. A small casting yard is all that is required for this type of work and the solution is highly economical where tall piers are necessitated by ground configuration.
Fig 8.58 and fig 8.59 show a push launched bridge over the river Markanda on the Delhi-Chandigarh expressway and represents the first road bridge to be so constructed. The push launching system is similar to that of Panvel nadi but the span is much more heavy.

Fig 8.60 shows the first push launched bridged with a radius. It reveals the flexibility of the launching system. Works of this nature demand very high precision and good construction engineering. Fig 8.61 shows the Brenner bridge in the Austrian Alps. The bridge was constructed without any access from the surrounding terrain. After each deck was completed and prestressed, the next foundation and pier were executed using equipment mobilized on the completed deck. The superstructure was then executed segment wise up to the next pier and the work proceeded. This reveals an aspect of sustainable engineering so rarely witnessed.
The Thane Creek Bridge completed in 1971 reflects current thinking of incorporating large bridge elements into a bridge structure for rapid construction. 98% of the bridge was precise 3 km away, transported to site and placed in position over 2.5m diameter bored piles also precast and anchored into rock. This represents transportation of units upto 200 tonnes of this bridge, lifting them in position and lowering them into their final location taking advantage of tidal variation at site.

These views represent transportation of the precast units for the pier and bringing them into position.
These two views represent the Confederation bridge in Canada where the entire bridge was precast and placed into position. These views shows one entire deck unit being lifted. The maximum weight lifted was 2500 t and reflect the manner in which major bridges are likely to be executed using heavy equipment for rapid construction.

These two views shows the piers which were cast in two halves in the casting yard. The size of the units may be noted as also the fluted mating arrangement. The funnel in the pier is a ice-breaker.
The view (left) shows the casting yard with the pier and deck units precast before they are towed and placed in position. The view (left) shows the Oestersechelde storm surge barrier in the Netherlands meant to keep off sea incursion and develop a fresh water lake behind using the Rhine delta water. It has a storm return period of 72 years and connects several islands in the delta, all with the intention to shelter the delta areas from the North Sea storms. The entire work is precast and placed on the sea bed over a non-erodible mat and resists the sea impact by sheer dead weight. It is one of the largest precast systems ever launched. The view (right) shows a view of the longest span cable stay bridge in the world at Shikoku in Japan with a span of 999 m. There are two planes of cable stays for this wide bridge located in a cyclonic area.
Bahrain causeway, erection of bridge from fully precast installation of a ‘short’ span between two cantilever ends in spans of two different types: supporting spans and the Bahrain causeway.

Drop-in spans: (a) installation by floating cranes of a supporting span; (b) installation by floating cranes of a supported span on two supporting spans; (c) installation of a new supporting span.

### 8.5 Conclusion

The following current trends are observed in bridge engineering practice:

- **Large unit casting**
- **Light wt concrete**
- **High st. Concrete**: (m 100 will become popular) (presently m 60 & upto m 75 in India)
- **Kevlar & aramid cables**: non corrosive / very high st. / high cost / very light
- **More precasting**: high capacity & expensive machinery
- **More composite decks to reduce wt.** Of long spans
- **Very large spans mixed cable system + comp & mixed decks**: (2km already achieved. Expect 3-4 km spans before long).
- **Durability / environmental acceptance / aesthetics / speed / cost main objectives**
- **Procurement based contracts** based on W.L.C. And societal criteria may emerge.
- **Rapid computer aided solutions**: knowledge based expert system in pipeline.

It is concluded that:

- Segmental construction has progressed globally, providing economic quality controlled structures with quick completion tenure.
- The bridges constructed in India and elsewhere should provide and inspiration for their adoption in India in greater measure, not forgetting their sustainable engineering benefits during construction and later during their life cycle.