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Padma Bhushan Prof Jai Krishna Memorial Lecture

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Background of
Padma Bhushan Prof Jai Krishna Memorial Lecture

Prof Jai Krishna, born in 1912, had a brilliant academic career including a Bachelor's Degree in Science from Agra University, Civil Engineering from Thomason College, Roorkee and a Doctor's degree from the University of London. He studied Earthquake Engineering at the California institute of Technology, USA. Prof Krishna also served as Professor Emeritus in Earthquake Engineering Department, University of Roorkee. He was a pioneer in the field of Earthquake Engineering and established a school for training and research in this field at the University of Roorkee. He provided technical assistance in the country's major engineering projects in earthquake resistant design of structures and equipments. He was the President of International Association for Earthquake Engineering for four years; Founder President, National Academy of Engineering and President of The Institution of Engineers (India). He was conferred Honor's Causa Doctorate by three Universities including University of Roorkee. He was the consultant to major river valley projects, particularly Koyna, Tehri and Narmada Dams. He was the author of a very popular book on “Reinforced Concrete” and a book on “Earthquake Engineering”. Prof Krishna's work focused on the development of methods of strengthening engineering structures against earthquake forces. Some of his contributions include, (i) evolution of simple methods of strengthening buildings, bridges, water towers, dams etc. (ii) design, fabrication and installation of seismic instruments and (iii) evolution of concepts of ISO-Acceleration studies relating to seismic energy distribution. Methods evolved for common brick and stone buildings to resist earthquakes have been widely adopted in India and abroad. Prof Krishna's leadership had been availed by the Indian Standards Organization in preparing codes of practices relating to earthquake resistant construction and by the International Association of Earthquake Engineering in the preparation of the guidelines for Seismic zoning of the countries and determining Fundamental Design Parameters. For his services to Earthquake Engineering studies, he was awarded recognition at the International Conference at Tokyo in the year 1988. He presided over the world body during 1977-80 and assisted UNESCO in developing seismological studies in different areas. He was elected a 'Legend' in Earthquake Engineering at the World Conference on Earthquake Engineering held in China in the year 2008. President of India honoured him with Padma Bhushan in 1972 and he received Bhatnagar Award, National Design Award, Khosla Award, Moudgill Award, Thomason Prize, Cautley Gold Medal, Calcott-Reilly Memorial Gold Medal for his scholarship and research attainments. Prof Krishna's contributions to Engineering span over six decades. In recognition of his life time contributions to engineering, the National Academy of Engineering conferred on him its Life Time Achievement Award on the 10th Anniversary of Establishment of the Academy. A fatherly figure to the engineering community, Prof Jai Krishna lived a full and illustrious life from 1912 to 1999. In memory of his dedicated service, The Institution of Engineers (India) instituted an Annual Memorial Lecture in his name during the National Convention of Civil Engineers.

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Padma Bhushan Prof Jai Krishna Memorial Lecture

presented during **National Conventions of Civil Engineers**

Sustainability in Urban Transportation Projects

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INTRODUCTION

"A city exists, not for the constant passage of motorcars, but for the care and culture of men". With this quote Lewis Mumford, KBE, the renowned American historian, sociologist, philosopher of technology, and literary critic redefined, in a fashion, sustainability in urban transportation projects.

How far removed the current scenario is in Urban Transportation, is visible in the chaotic traffic, overwhelming pollution, road accidents and the downward spiral of quality of life in the urban environment.

The knee-jerk reactions of adding flyovers, increasing lanes, encroaching on pedestrian walks and pavements amply illustrates Lewis Mumford's caustic observation: "Adding highway lanes to deal with traffic congestion is like loosening your belt to cure obesity".

When we talk about sustainability and safety in urban transportation projects the emphasis must be on the co-existence, if not prevailing importance, of non-motorized transport such as cycling and walking along with accessible and efficient public transportation systems.

THE CONCEPT OF CRADLE TO GRAVE

In general terms sustainability can be looked at as being a concept that encourages "Reduce, Reuse, Recycle" in the process of movement of people and goods Several recognised sustainability assessment systems largely applicable to buildings have been evolved during the last two decades. In recent times there have been efforts to propose guiding and/or measuring sustainability practices for urban transportation projects [1-4].

Life Cycle Assessment (LCA) is a comprehensive tool that can be applied to any urban transportation project to asses environmental impact and sustainability, The 'cradle to grave' concept considers design, construction, utilisation, maintenance and its ultimate disposal. It is applicable to both new and existing projects with the objective of seeking ways and means to make them more environment friendly, or, in other words, more sustainable.

MAJOR PARAMETERS FOR URBAN INFRASTRUCTURE PROJECTS

The present Government's two-fold initiatives for cities will give a big boost to sustainability. Under theAtal Mission for Rejuvenation and Urban Transformation (AMRUT) Mission covering 500 cities, of interest in the present context are two of its thrust areas: pedestrian, non-motorized and public transport facilities, parking spaces, and, enhancing amenity value of cities by creating and upgrading green spaces, parks and recreation centers, especially for children [5]. The Smart Cities Mission and AMRUT are complementary [6]. While AM RUT follows a project-based approach, the Smart Cities Mission follows an area-based strategy.

We live on a planet with finite resources the conservation of which is the key to long term survival. Cement and Concrete are energy guzzling, CO_2-belching materials. Optimisation of their quantities in structures, use of more friendly ingredients such as recycled materials like fly ash, blast furnace slag, and, innovative ways of reducing structure and increasing earth ramps, Figs I and 2, are some of the steps that will lead to reduced environmental impact. The retaining of natural features, and monuments as well as water bodies, if any, and landscaping the public spaces, Figs 3 to 5 should be central to any project.

In the urban scenario safety of pedestrians is of paramount concern. Foot Over Bridges (FOBs) must be positioned at strategic locations. Supports should be avoided at the median verge which may reduce cost but can be highly vulnerable to collision from road traffic (Figs 6, 7). Arch bridges, apart from being endowed with aesthetic appeal can safely span across arterial roads without difficulty. The Delhi Government has constructed several such bridges in the span range of70-90m in the city (Fig 8). Fig 9 shows the general structural and architectural concepts that were used in these FOBs. For the safety and comfort of pedestrians, FOBs require special studies concerning aerodynamic effects and pedestrian excitation; the latter being a phenomenon that was realised soon after the opening of the Millennium Bridge in London in June 2000.

New urban transportation structures for Metros, flyovers, roads and the like are almost always required to be implanted in an already crowded urban scenario. It is important to integrate various sustainability issues into the scheme at the very inception when the most important decisions concerning the same are made. Some of the crucial decisions in this regard relating to structures in particular include site selection, selection of materials for various constituents of the project, service design life of the various components, the severity of environmental exposure and the relevant design codes forming the basis of design. The next step is to select the geometrical characteristics, span arrangement, superstructure and substructure arrangements and the type of foundations.

Existing structures, can often be given a complete metamorphosis with the participation of concerned citizens who bring in untapped zeal and imagination. Two examples from the Maximum City are worth recording here. Tulpule Flyover, located on Ambedkar Road in the suburbs of Mumbai, has been transformed into a 'happening place' and a place to meet, greet, interact and even improve health, Figs 10 and 11. A beautiful and unique 600 m long garden provides a walking-cum-jogging track with greenery and rock formations on the sides. The vacant public space below the flyover has been rescued from a certain fate of misuse as a garbage dump or occupation by slum dwellers, migrants, drug addicts and hawkers, as has been witnessed in other cases, Figs 12 and 13. The credit goes to the initiative and the unstinted efforts by the 'One Matunga' Residents Group for convincing Brihanmumbai Municipal Corporation (BMC) not only to approve but also fund the project (Cost is approx Rs 5 crore).

The second initiative in a similar vein was taken by a group of enthusiastic youngsters going by the name of MAD (Murals and Doodles). Over the last several months, railway stations, streets and derelict walls across the city have been beautified with colourful graffiti and murals, Figs 14 and 15. The founding member, Raashi Raghunath says, "Project MAD was started by me. when/was 17, in order to mobilise fellow college students to clean the city's walls up by giving them a chance to showcase their artistic skills on a large, permanent canvas that we hoped no one would maliciously dirty once it had been painted ". In the process, the collateral advantage that has accrued is that it would discourage defacing of walls by spitting and peeing in public, which seem to have arguably become a favourite past time of our citizens!

The Government must orient policies that encourage initiatives by responsible citizens to reclaim public spaces so that the environment gets a sustainability boost and the cities made more liveable.

EXAMPLES OF SOME SUSTAINABLE INFRASTRUCTURE PROJECTS

It is proposed to depict some major urban transportation structures in which the special care was taken to reduce environmental impact and enhance sustainability.

Three Level Grade Separator of Ghazipur Intersection at NH-24

The 3-level grade separator at the critical intersection ofNH-24 &Road no.56 in East Delhi (Fig J 6) was constructed to the orders of the PWD, Govt of Delhi, for the Commonwealth Games 2010. A flyover is aligned along NH-24 and an Underpass perpendicular to it. The existing rotary at ground level was retained but modified to suit the functional requirements (Fig 17).

All modes of transportations (cars, buses, trucks, two-wheelers, three-wheelers) as well as cyclists and pedestrians have been integrated into the scheme (Fig 18). Also, milder slopes were incorporated in the underpass for cyclists and pedestrians so that they could negotiate it with less effort, Fig 17 and 18. The overall landscaping is awe-inspiring with the existing water body forming a very pleasing feature of the same.

The 800m long flyover consists of 2 separate carriageways of 4 lanes each. The "twin-leaf' substructure is monolithic to the superstructure to constitute an "integral" bridge. Cast-in-situ balanced cantilever construction was adopted to yield 4-span and 3-span modules. Fig 19 shows the free cantilevering of the bridge in progress during construction of the subway.

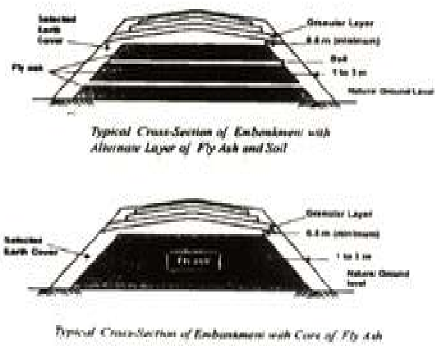

Fig 1. IRC SP 58

Fig 2. Innovative grade separation at Safdarjung-AIIMS, Delhi
• Signal free junction • Landscaping in public spaces
• Reduced structure, increased earth embankments

Fig 3. Badarpur elevated corridor, New Delhi
• minimise structure, maximise embankments
• landscaping
• reduced environmental impact by depressing interchange

Fig 4. Completed structure: Flyover by free cantilever : Underpass by diaphragm wall

Fig 5. Mukerba chowk: Incorporation of archeological monument, burial ground, landscaping in the clover leaf

Fig 6. Typical footbridge in Delhi: Median support is vulnerable

Fig 7. What can happen to median support

Fig 8. FOB crossing Barapulla elevated road near Jln stadium

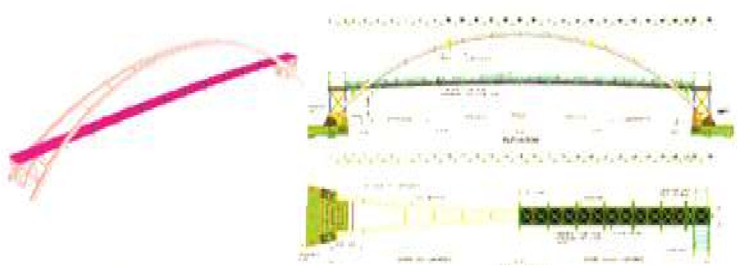

Fig 9. FOB structural concept pedestrian excitation wind excitation

Fig 10. Tulpule flyover, Mumbai
The 'Happening Place' where people meet & greet , walk and jog

Fig 11. Tulpule flyover, Mumbai (night view): reclaiming public space by 'One Matunga' residents group

Fig 12. Underside of flyovers encroached by migrants

Fig 13. Underside of flyovers occupied by slum dwellers

Fig 14. The core team of mad, from left, Shlomoh Samuel, Raashi Raghunath, Tamim Sangrar and Aditi Monde
(Photo: Pratham Gokhale/ht)

Fig 15. A mural outside dockyard road station - Transgender equality mural by mad in Wadala
(Photo: Tamim Sangrar)

Fig 16. Google map of location: Ghazipur-selection of final concept

Fig 17. Ghazipur interchange showing pedestrian path-cum – cycle track and FOB

Fig 18. Ghazipur interchange showing main constituents

Fig 19. Free cantilevering of bridge during construction of subway

680m long underpass (Fig 18) was constructed using diaphragm walls along its periphery in the longitudinal direction. Tension piles were used below the base slab to counteract uplift due to the high water table in the area. The portion of the Underpass crossing the rotary was covered with a deck slab cast into the diaphragm walls.

Pedestrian bridges (3 nos.) consisting of steel arch with a span of 70m suspending the walkway were incorporated for crossing major arterial roads at Ghazipur, Delhi, without support at the median verge (Figs 16,17).

BarapulJa Elevated Road: The Fast-track "Village" to "Venue" Project

Commissioned by the PWD Government of Delhi for the Commonwealth Games (CWG 2010), the elegant design of Phase I of the Barapulla Elevated Road (Fig 20) was envisaged as a dedicated signal-free access to transport participants from the Games Village to the Main Venue (Jawahar Lal Nehru Stadium). Located along and above the existing Barapulla Nallah drain, the 4.5 km long viaduct consisting of two separate structures of 10m width each for the up and down traffic has an important legacy value for the city for the east-south traffic, Fig 21. While Phase 2 is nearing completion, construction is in full swing for Phase 3.

The innovative design concept was geared for high speed construction (time available: 20 months) using precast prestressed segmental techniques (no. of segments 3000), Fig 22, for most of the alignment including obligatory spans (up to 85.0 m), employing Balanced Cantilever construction. Standardisation was the key to cost-optimisation while decreasing the expansion joints in the deck led to increased riding comfort. Flexibility in design for accommodating modifications in alignment, span arrangement and foundation configuration contributed greatly in avoiding relocation of underground and overhead utilities during construction. The erection techniques by launching girder as adopted for Standard Spans in the range of 25m-37m is depicted in Fig 23. For the large Obligatory Spans the erection was effected by the versatile equipment called 'Segment Lifters' which avoid any disturbance at ground level during transportation as well as lifting, Figs 24 and 25.

Interestingly, Phase3 of the Elevated Road, 2×3.4 km long, crossing the River Yamuna, incorporates an Extradosed Bridge of 85m + (127.5m $\times$ 3) + 85m $\approx$ 553m length, which is proposed to be provided with solar panels to generate enough power to light up the bridge.

The cabling will connect to the city grid so that it can draw power at night and pass it back during the day.

Delhi is a city of archaeological monuments and a highly sensitive approach is required to be taken for their preservation. Each of the major crossings presented difficult challenges. For instance, the block-time for the Northern Railway tracks was limited to a mere 2 hours on alternate days, (Fig 25), while the deck level had to be raised to 20m to provide an uninterrupted view of the Khan-i-Khana Tomb on Mathura Road (Fig 26). Sharp curvatures and skew crossings characterised the alignment to avoid crossings above the ancient Barapulla Bridge and to ensure that the elevated corridor can be built without slowing on shutting down traffic.

Fig 20. Barapulla elevated road (Phase 1) : Completed view

Fig 21. Alignment of elevated viaduct of Barapulla nallah (drain) showing

- **Signal free route: CWG village to Nehru stadium**
- **Location of major crossing**
- **The three phases of the projects**

Fig 22. Barapulla stacking yard for segments

Fig 23. Erection technique for standard spans

Fig 24. Simultaneous progress of both carriageways by cantilevering

Mukarba Chowk Grade Separator to Disperse Traffic at Delhi Border

The path-breaking 8-lane main flyover (Fig 27) consisting of a continuous steel box girder with a composite concrete slab was constructed to the orders of PWD, Delhi Govt at the junction of Outer Ring Road and NH 1, (Fig 28). The superstructure was widened to 10-lanes to incorporate bus-stops at deck level that cater to facilities like ramps, stairs and escalators for vertical movement and underbridges for cross-overs for passengers, Fig 29.Seemless and safe movement of pedestrians and cyclists at the subway level was ensured by innovative concepts, Fig 30.

The Mukerba Chowk intersection which was conceived as a green project threw up design challenges in the form of the city's garbage dump and several nallahs at the site. Use of flyash, blast furnace slag cement, segregation of motorized vehicles from cyclists and pedestrians, integrating the existing features at site, Fig 31, (city's garbage dump, archeological monument, burial ground, and substation) and the creation of innovative and aesthetic structural designs were some of the highlights of project. The aesthetically designed (Fig 32) integral concrete bridge construction, permitted the elimination of bearings and expansion joints. The structures have specially designed features for earthquake resistance as well as those that cater to poor soil conditions that have a high liquefaction potential.

Parvati Bridge

372 m long bridge with a main arch span of 120 m in concrete, and 7 nos. end spans and 5 nos end spans on either side, was constructed near Kulu, to the orders of the Govt of Himachal Pradesh PWD. The arch supports a 2-lane deck slab by special suspension cables and rests on 11 m dia well foundations at each end. The completed bridge and the structural concept are shown in Figs 33 and 34.

The method of construction adopted was free cantilevering, Fig 35, so that no disturbance was created in the flowing stream.

The selection of the geometry, shape and span of the bridge and its method of construction was truly commendable from the point of aesthetics and environmental considerations.

Bangalore - Hosur

The 10 km long Bangalore - Hosur Elevated Road on NH-7 from Silk Board Junction upto the Electronic City which houses the major players of the IT Industry was one of the most heavily trafficked sectors (1,25,000 PCUs/day) in the country. The NHAI decided to augment the 4-lane highway to 10 lanes of which 4 lanes would be an elevated toll road (Fig 36). The 16. 3m wide deck of the bridge superstructure consists of State-of-the-Art precast prestressed segmental2-cell box girder construction, erected by launching truss, Figs 37, 38. Aethetics was given the utmost attention in this long structure which would be viewed from various angles both during day and also at night. The pier shape, Fig 39, and the texture of the outer surface of the superstructure, Fig 40, require special mention in this regard. Lighting of the flyover at road, on ground, below the deck and of the superstructure, Fig 41, itself were other highlights of the design. Several complicated interchange structures and ramps connect to the main elevated expressway. The typical span arrangement between the expansion joints of the main bridge is 29.0 m + (6 × 34.0 m) + 29.0 m = 262.0 m. Underground Pedestrian crossings (4 nos.) were constructed using 'box pushing' techniques to avoid inconvenience to existing traffic at ground level during their implementation. Additionally, two flyovers crossing the alignment at different locations were also included in the project.

Fig 25. The Railway crossing under construction operation midnight: 2 hrs, alternate days

Fig 26. Tomb of Abdul Rahim Khan-e-Khana (1556- 1627AD): View from Mathura road

Fig 27. Mukerba chowk: continuous steel box girder with composite concrete slab

Fig 28. Google map and model Mukarba chowk interchange at Delhi border

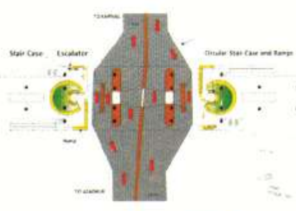

Fig 29. Bus stop and pedestrian & vehicular movements

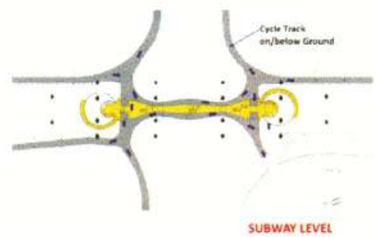

Fig 30. Pedestrian & cyclist movement

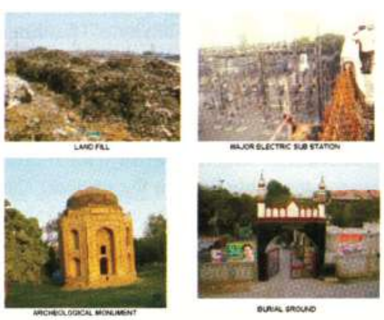

Fig 31. Existing features at site

Fig 32. Mukarba chowk architectural views

Fig 33. Bridge over Parvati at Jia on Nh21 arch bridge with suspended deck

Approach Structure of Signature Bridge at Wazirabad, New Delhi

Designed and Constructed to the order of the Delhi Tourism and Transportation Development Corporation Ltd, the project involves 'open' portion of 51000 m^2, 'closed' portion of 25000 m^2 and embankment portion of90,000 m2, making a total of 6 km length flanking both sides of the Signature Bridge over river Yamuna. (Fig 42). The viaduct includes precast prestressed segmental box spine girder, integral (monolithic) with the pier, Fig 43. The unique aesthetic appeal of the structure is enhanced by precast curved ribs supporting the edges of the deck. (Fig 44, 45).

The pier is especially shaped to follow the flow of forces from the deck without the intervention of bearings which are always the fragile components of bridges. (Figs 44 and 45). Self-compacting concrete of M60 and M65 grade was extensively used in the project. The western approach had highly variable rocky strata and both 'open' foundations and bored piles were used. Since the eastern bank is susceptible to liquefaction during earthquake deep well (caisson) foundations were adopted for the entire eastern viaduct and were sunk by jack-down technology.

Fig 34. Parvati bridge: Structural concept

Fig 35. Parvati bridge: Arch construction by free cantilereing

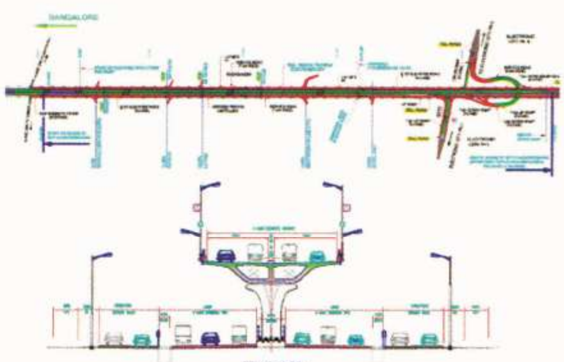

Fig 36. Bangalore-Hosur expressway: Single support on median verge

Fig 37. Bangalore Hosur expressway: Precast segmental construction erection by overhead launching truss

Fig 38. Precast segments suspended from main truss during erection

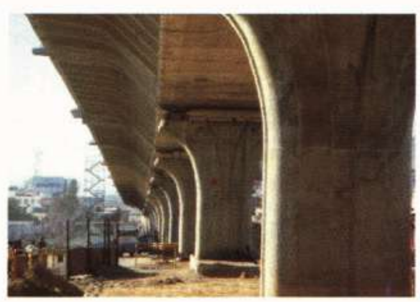

Fig 39. Pier shape and structure: Bangalore-Hosur

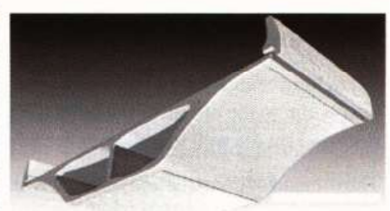

Fig 40. Superstructure form & texture: Bangalore-Hosur

The complex geometries of the alignment along with loops, ramps and flyovers as well as merging and demerging lanes make up the fairly complex design of the structures.

Sharply curved superstructures require careful handling of the structural systems. As many as four structures of such description, all of them simply supported, have toppled in Surat, Mumbai, Kolkata and at the Border roads (near Shimla), Fig 46 in recent times. The solution lies in the adoption of Integral and Continuous Bridges (Fig 44) or ensuring by other means that there is adequate factor of safety of Stabilising Moment against Overturning Moment.

Fig 41. Traffic lanes and lighting design

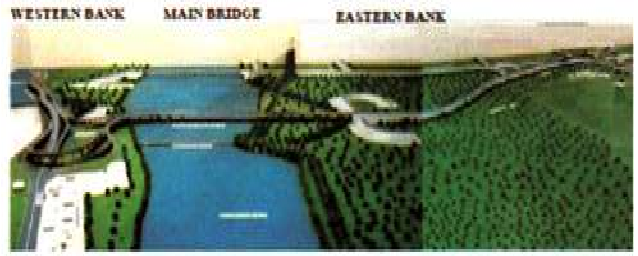

Fig 42. Approaches to signature bridge

Fig 43. Sharply curved structure

Fig 44. Spine beam with curved ribs supporting the deck cantilevers

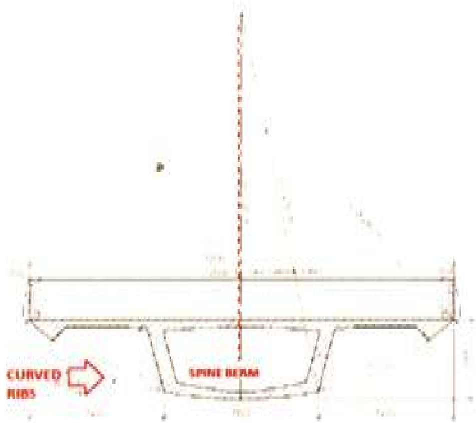

Fig 45. Typical section of approach structure

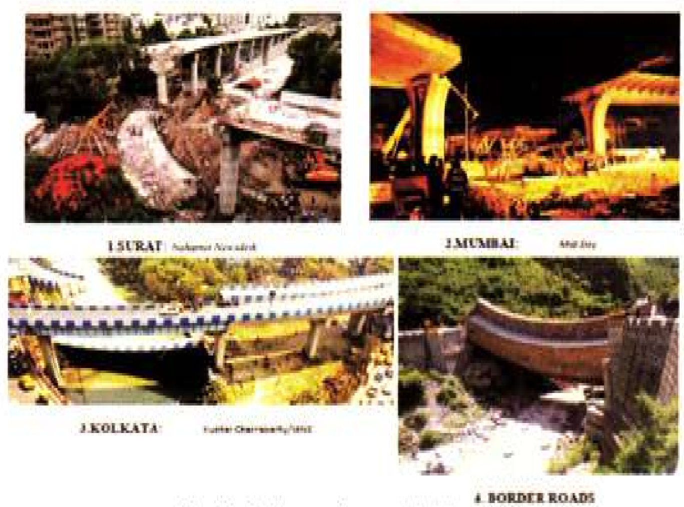

Fig 46. Collapse of curved bridges

CONCLUDING REMARKS

Large cities in India are speedily losing their soul. We are forced to live in crowded, polluted and aggressive environments for which the bad planning of transportation projects are hugely to be blamed.

In the old days, building was everything and that was indeed the ultimate aim. This is no longer acceptable to the public. Now, we must build without shutting or showing down anything. For achieving this, not only do we require technology but also a sensitive, creative and imaginative approach so that the present and future generations feel proud of the acquisition of the new urban infrastructure projects that have been implanted in their midst.

Infrastructure projects like bridges, flyovers, underpasses and major traffic interchanges invariably occupy large spaces in the urban environment. Unlike buildings, their need is the greatest where the scenario is most crowded.

Green-field projects under the circumstances are rare. Both on-ground obstructions and underground utilities require to be diverted or crossed in a manner that induces minimum disruption to life as it existed at the time of the inception of the project.

A sustainable bridge can be defined as the one that is "conceived, designed, constructed, and maintained, and eventually put out of service in such a fashion that these activities demand as little as possible from the natural, material, and energy resources from the surrounding community" (Whittemore, 20 I0).

The built environment has great impact on the natural environment, economy, and human health. By incorporating green strategies, a large number of environmental, economic, and social benefits would be clearly visible. Therefore, sustainable applications for urban transportation projects that can reduce environmental impact need to be developed and implemented. The social, economic, environmental criteria combined with the coherence with other existing and planned projects become the most important criteria. Nonmotorised transport must receive a high importance in a sustainable urban project.

Finally, sustainability is all about the life cycle concept of cradle- to- grave assessment and must include considerations such as the siting, design, construction, operation, maintenance and the final demolition of the urban transportation project.

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Growth of Civil Engineering & Infrastructure is Synonymous

Dr Prem Krishna

Introduction

Infrastructure has been a 'buzz' word globally for many decades and in India too, for the last couple of decades. Those developed countries which built-up a major part of their required infrastructure some 50 years ago, need to upgrade and enhance the same now. On the other hand, the developing countries need to apply themselves to bridge the yawning gap between 'What is' and 'What is needed' in terms of infrastructure, in order to support industrial and economic growth and raise the standards of living for their populations. It is best to count India amongst the latter category. One way to describe infrastructure is to associate the same with its purpose, i.e., for healthcare, for education, for defense, for traffic & transportation, for communication, for habitat, and, so on. In broad terms though, infrastructure consists of power, water, transport in different ways through road, railways and waterways, ports & harbours, housing, and so on. None of these, singly or collectively, are an end in themselves, but are catalysts for economic growth and social wellbeing. It can be said with little debate, that developments in infrastructure are inter-twined with primarily those of civil engineering, while drawing due support from other disciplines, such as, Architecture, Electronics, physics leading to miniaturization, enhanced computing capabilities, robotics, and, other allied branches of engineering.

How much infrastructure is needed to be created in a country for a projected standard of living is related also to the size of a country and its population and the present level of available infrastructure and facilities. How much of this long-term goal can be achieved, depends very strongly upon the economic health, technological preparedness and the educational 'back-up' prevailing at a given point in time and its future projections. There are several other factors too that are relevant to infrastructure development and growth, such as, material resources, disaster-resistant construction, energy efficiency, governance, environment related issues, and, so on. It is also pertinent to say that all these factors are closely inter-related and, this is a complex matrix, making it difficult to create a long-range scenario of infrastructure needed or even what can actually be achieved. Never-the-less, this is an inescapable exercise. This alone can lead to an assessment of the gaps in the various areas, and, therefore provide the directions of thrust in infrastructure development.

It is interesting first to look at the historical perspective, followed by the current status, and, what the future projections are, related to infrastructure. Next, it will be in order to trace the growth of various aspects of Civil engineering, particularly the over-arching issue of technical education, and other allied issues, which together provide the backbone for infrastructure development.

The text of this paper covers the subject in general terms, but has kept the Indian scenario particularly in view. Examples from abroad have been used where relevant.

Infrastructure

Historical: Infrastructure has always been a basic need for humans to live - only its form has continued to evolve with the times. In primitive times a fallen tree, or, vines and creepers served the functions of a bridge, which later evolved into a suspension bridge with the use of timber, stone and ropes made from creepers. Likewise, the shelter was provided by caves, or, huts made from vegetation, or, a tent made from animal skin. In the more recent times, still much before formal technical education and training started, there is more than adequate evidence of very formidable development of habitat, bridges, and, irrigation systems based on nonmetallic material. To find infrastructural development in the modem sense, one goes back about a couple of centuries to see the growth of habitat, transportation systems, and, irrigation systems, and, so on.

Financial Resources: The economic factor is obviously most important in determining the quantum and course of infrastructure development. A simple way to assess the economic resources that a country can invest in infrastructure (as also any other facet of its development) is the percentage of its GDP (Gross Domestic Product) that it can afford to use for this purpose from public or private sources, besides the support that may be forthcoming in a certain situation from richer countries for fulfilling humane or political obligations.

In a report from the "Organization for Economic Co-operation and Development", it has been mentioned that in the period up to the year 2030, the average of about 3.5% of GDP will be invested into infrastructure. Typically, the GDP for India grew from 15,37,966 million US$ in 2010 to 27,77,280 in 2016. Although the system of 5-year plans has now been discontinued, it is of some interest to note that, whereas in the x" 5-year plan an investment made for infrastructure was 5% of GDP, in the XIth plan it was projected as 7.55% of GDP. For the XIIth plan, it was announced to be 8%. The projected break up for the major sectors it was (as a percentage of the total) - Power 33, Roads 16, Railways and Irrigation 13 each, Telecommunication 10, Water supply & Sanitation 7. The average annual budgetary commitment for the period 2016 -2020 is approximately Rs 8 lac crore, but needs to be almost doubled if projected development till 2025 is to be achieved. Deficiencies in infrastructure come at a high cost. For example, deficiencies in city infrastructure for traffic & transportation alone may be costing the Nation a huge sum of Rs. two lac crores annually. It augers well for the future that this is being realized, and, there are signs of commitment to overcome these shortcomings.

Current Scenario &Future Projections:

There are numerous studies and reports which give an idea of the oncoming challenge of the infrastructure needs of this country. Several studies, some of which are listed amongst the references, have recently attempted to make such an assessment. The following sections are based on the same. Only four sectors are covered since these run a common thread through most other sectors too, and, are currently the major areas of focus. The related status as presented gives a fair idea of the oncoming scenario. Energy: India has the third largest commercial energy demand after China and USA. The Indian electric power generation market is the fourth-largest in Asia and the sixth- largest in the world, and, it is the fastest growing component in the power sector. The largest primary energy source has been coal with a share of approximately 40%, biomass and petrochemical crude at approximately 25%, and natural gas at 7%. The 2006 integrated energy policy formulated by the Government of India projected a growth rate of 8% until 2031-32 to sustain the overall economic development. The current generation capacity is of the order of 250GW. By 2025 the generation of power is projected to grow to 460 GW. The role of advanced engineering and innovative technologies will increase significantly in coming years for harnessing renewable energy in India and to make the transition to low carbon energy economy more sustainable. Solar energy can shift about 90% of daily transportation needs from petroleum to electricity by increased use of hybrid automobiles.

Roads : Road Transport is vital to India's economy. As a part of the country's transportation sector, it is estimated to contribute 4.7 percent of India's GDP. The total length of classified road networks in India was at 4.7 million km at the end of March 20 11, of which only 53.8% were paved. India's road density averages about 1.42 km of road length per square km accounting for 85% of passenger traffic and 65% of freight traffic in India. According to McKinsey Report, 2.5 billion square meters of roads will have to be paved - 20 times the capacity added in past decade. Present length of National Highways is 17,000 km and is expected to become 26,000 km by 2025.

Railways: Currently more than 90% of the inter-regional traffic is carried by Rail and Road. The Rail, in spite of being environment friendly, is losing its market share. The share of Rail in Freight Traffic has come down from 89% to 30% since 1950-51 and for the Passenger Traffic, it has reduced from 69% to 15%. Thus, there are efforts through policy directives and otherwise to improve the share of environment friendly Rail mode. It is planned to develop the Golden Quadrilateral (connecting four metro cities of Delhi, Kolkata, Chennai and Mumbai) and its two diagonals. Further, the existing axle load capacity has been enhanced on some selected routes. The Dedicated Freight Corridors are being designed to take axle loads of30.0t. For the present 25.0t axle load wagons are proposed to be run for which Feeder Routes, now carrying axle load of 22.9t, are also being upgraded to enable carriage of 25. Otaxle load wagons. Further, construction of additional 10,000 km of railway lines are planned. The area in which large expansion is expected is of the Metro lines. Currently the length of Metro lines stands at 347 kms but is expected to become 1923 km by 2025.

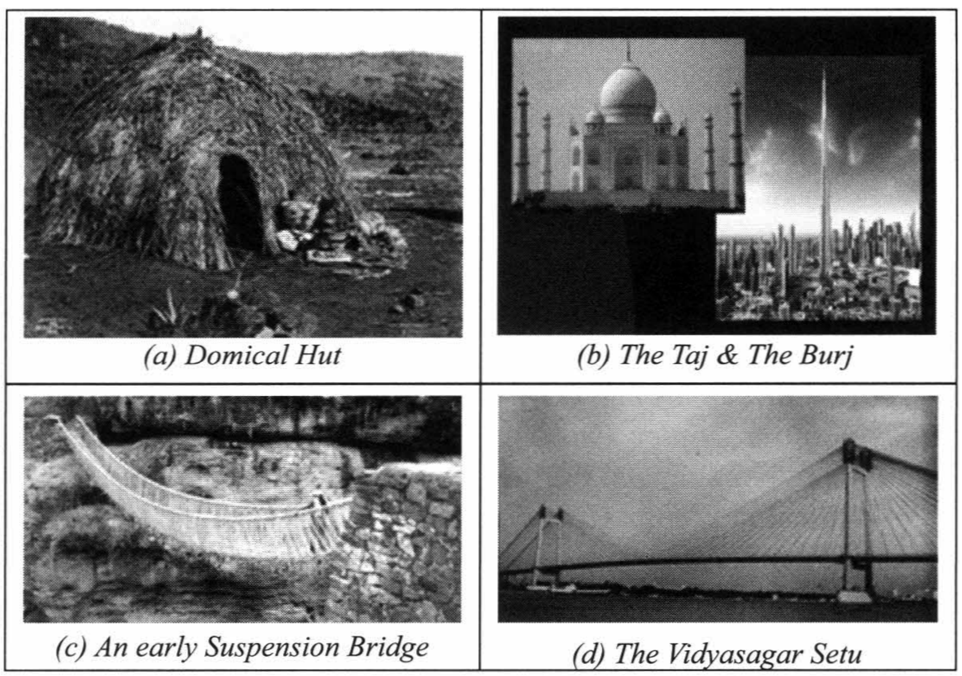
Habitat: Europe and Americas experienced intense urbanization during the middle of 20th century. The trend has now shifted to the developing economies of Asia and Africa. The urban population of India is likely to grow from 2853 million in 2001 to 360 million in 2010, 410 million in 2015,468 million in 2020 and 533 million in 2025, as per the projections based on past trends. Studies project that by 2030, the total urban population of India will be 590 million i.e. 40 per cent of the Indian population would live in urban areas (Mckinsey report). The expanding size of Indian cities will be created in many cases through a process of peripheral expansion with large villages, with smaller municipalities surrounding the core city, becoming part of the large metropolitan area. The position of the housing stock is reflected below.

According to the 2011 Census, the total housing stock of the country is 245 million for 247 million households and the housing stock in urban area is 78 million for 79 million urban households. As per numbers from census held in 2001 and 2011, there has been a growth of 50% in the number of Urban Housing Stock. According to the projections of the Government, there will be housing for all by 2022. It is necessary to point out that the volume of infrastructure development envisaged in India is so large that finding the required quantity of construction materials for it, besides the manpower resources, is always going to be a challenge.

Growth of Engineering :

As mentioned earlier in this paper, infrastructure in the primitive form was created by man for his survival, well before any formal engineering practice (as we understand it now) was employed. This is evidenced by examples of civil engineering application perhaps in 2000 BC, and, later in the Roman era, arches made from stone, as also domical structures made with mud bricks or stone. These have gone on evolving with time and later burnt bricks were used too. Suspension bridges, using stone, timber and ropes of vines and creepers, were seen in early times. Later, the Qutub Minar built in 13thcentury, Madurai Meenakshi temple in 14thcentury, the Taj Mahal in the 17thcentury, are examples of Civil engineering practice. It is obvious that this earlier engineering development would have been based on ingenious commonsense and intuitive understanding of mechanics.

Formal engineering using mainly, steel, cement concrete and bricks, took roots only about 200 years ago. If one focuses thus, on the last couple of centuries, the status of infrastructural development today (the collage in figure 1 has been presented to show the impressive status of achievements), and, all that we can project for the future, is directly related to the growth of different aspects of engineering. That Civil Engineering leads the pack should not come as a surprise because it was not too long ago that there were only two broad disciplines in engineering - Civil and Military. The section that follows therefore addresses the growth in Civil Engineering.



(a) Domical Hut

(b) The Taj & The Burj

(c) An early Suspension Bridge

(d) The Vidyasagar Setu

Figure 1

Civil Engineering: The growth of this discipline of engineering can be best viewed in terms of some key aspects such as, education facilities, development of analytical tools, materials, computing facilities and those for experimentation, realization of the importance of natural forces of seismicity and wind, construction technology. It is worth noting that this is a very wide spectrum subject and therefore only a few important issues are addressed.

Education : It has been pointed out in this paper earlier that there existed an innate understanding of the principles of Civil Engineering much before formal education programmes were set up, and, the achievements were quite impressive. However, one should not get away with feeling that perhaps the world could have done without formal education, because the results that have accrued therefrom are for all to see. The pedestal on which infrastructure development stands today has moved places in the last two centuries after formal education programmes were launched.

The first college to impart Civil Engineering education was established in 1847 in Roorkee, followed by three others in the span of about 20 years. These were colleges at Sibpur, Guindy and Pune. Thus, the foundations for Civil Engineering foundation were laid. The College at Roorkee became a University in 1949 and an lIT in 2001. In all these years, Civil Engineering has remained the forte at Roorkee, and, it has played a leadership role by producing excellent monographs, writing of books by the faculty, and by its students serving to built the infrastructure both within India and abroad. Amongst the specialties that were developed at Roorkee as part of the growth in Civil Engineering, many would be seen to have a direct bearing with the growth of sustainable infrastructure. Out of these, four that are particularly worth mentioning are, Water Resources Engineering, Geotechnical Engineering, Earthquake Engineering, and, Wind Engineering. The latter three belong to the post-independence (1947 onwards) era. Prof. Jai Krishna, in whose memory this paper is being presented at the Civil Engineering Convention of the IEI, served on the faculty of the Institution at Roorkee from 1939 to 1999, and made a large contribution to this development.

In the 170 years that have elapsed, the number of Institutions has grown into thousands, including twenty plus IITs, and, the number of persons, who come through the portals of these institutions with a Civil Engineering graduate level qualification, has grown from 06 in 1850 to over a lac today. With this growth the capability of the Country to deliver the needs of developing infrastructure has gone up substantially, though not exactly in proportion to the numbers. It must be pointed out that of late, the quality of technical education has been a matter of concern, while the numbers are still short of requirement.

Analysis and Design : This can be viewed in two parts. One is the development of theories based on mechanics, whose principles were no doubt understood for centuries. The other is the development of capabilities in computing through the evolution of high speed digital computers, which in turn owe their dramatic growth in the last 50 years to the developments in Physics and Electronics (and miniaturization). Both these have influenced the design of structural systems. Examples can be given here of the classical developments of the 'Deflection Theory' for suspension bridges, and, approximate closed form or numerical solutions to overcome partially the handicap of not having fast computing facilities that became available in the post 1950 period. Later, the 'Matrix Methods' of analysis and the 'Finite Element Method' developed primarily in the wake of the digital computers.

From the viewpoint of computing, it can be said that it was a challenge to solve 06 simultaneous algebraic equations in the 1950s. Today that number can be in hundreds of thousands with the equations being nonlinear too if necessary. Whereas one had to travel kilometers to use a mainframe computer located in a huge room in the 1950s, today you carry this facility in the palm of your hand, and, it will be farcical to compare the memory and speed of operation with that of the computers of the 1950s. Thus, in the 1950s, cable stayed bridges were being designed with very few cable stays in order to minimize the degree of indeterminacy, and the resulting equations to solve. Today, long span cable stayed bridges can be seen to have hundreds of stays. Now, a steel space truss or a network of cables with thousand members, can be analyzed without any difficulty- Use of the Matrix method or the FEM for the analysis of frames, plates or shells does also indeed lend itself to a large number of equations to solve.

Disaster Resistance : The growth of this aspect of engineering is vital to the sustainability of the infrastructure that has been built and that which is still to come. India is beset with natural hazards of earthquakes, floods and wind storms, and suffers huge losses of life, property, industrial production and agricultural output year after year. While the Governmental system, and, often primarily the Defense forces, do a commendable job in minimizing the disasters and providing relief, it is imperative that all systems (including the Civil engineering structures) required to safeguard or develop infrastructure are made disaster resistant to the maximum possible extent. Facilities for necessary studies, both theoretical as well as experimental, have developed well in the country in the past 70 years. Experimental studies related to these hazards and their effects require, among other implements, 'Shake Tables', 'Wind Tunnels', and facilities for 'River Engineering'. However, it needs to be mentioned that whereas this development has produced a plethora of literature, its utilization and implementation of codes and standards is still quite limited.

Furthermore, there is a very important need for health monitoring of existing infrastructure, some of which is very old. Likewise, measures are necessary to monitor the health of new important additions. This aspect of engineering development is still in a rather nascent stage.

Materials & Implications: The materials that have a lion's share in modem civil construction are, Brick, Stone or Block Masonry, Concrete in different forms, and, Steel also in various ways. All the other developments in materials have served special but limited needs, or, have been used for finishing and nonstructural purposes. The growth has kept pace fairly well with the demand. Technology for higher strength concretes has been in focus over the last 75 years, and, the concept of 'High Performance' has evolved. Understandably, there has been great emphasis on durability of concrete structures. Alongside, there has been the up gradation of strength in reinforcing steels, with the one major breakthrough being the evolution of twisted reinforcing bars, which has virtually replaced plain bars.

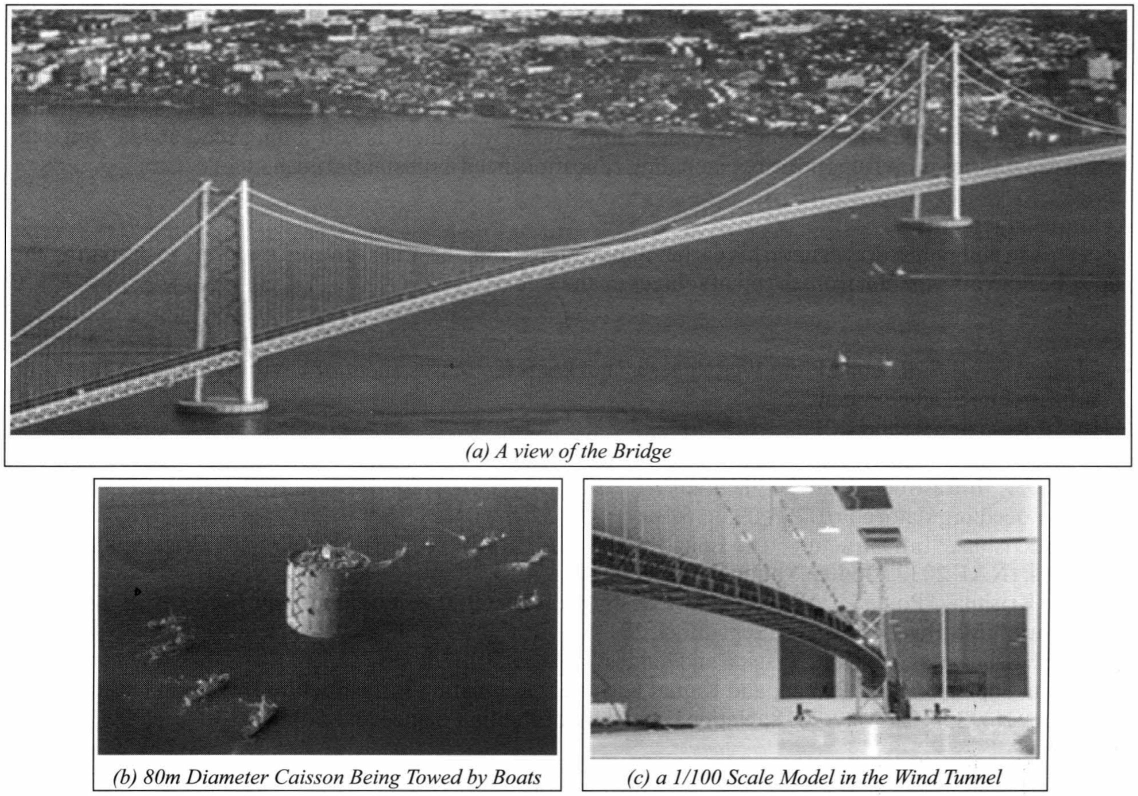
The other major development is through the use of metals, particularly steel- ranging from mild steel to super strength steels particularly used for cables. This has given great impetus to the construction industry in adopting large or tall buildings, or, slender long span structures. One very great advantage that steels have afforded is through their higher strength-weight ratio which leads to reduced dead weight, saving in usable space, lighter load on foundations. As a structure gets taller or longer in span, the live load to dead load stress ratio becomes smaller. This implies that the structural system begins to be utilized increasingly by its own dead weight. It is therefore imperative to use materials with high strength weight ratios to keep the dead weight to a minimum. In the context of a tall building, the column cross sections will become un-manageable with materials of low strength, and useful floor space will be wasted besides increasing the load on the foundations. With the use of high strength steels this problem is overcome effectively. In the case of large covered spaces using arches or space frames, the same logic is applicable. The deployment of suspended/tension systems further enhances this advantage. However, one needs to be cautioned that unduly reduced mass of the structural elements, or increased slenderness, can give rise to the structure becoming prone to unacceptable instability problems - aerodynamic or otherwise. Some typical relative strength weight ratios are given below:

Mild steel	20
Higher strength structural steel	80
High strength wire steel (1800 Mpa)	240
Aluminium alloys	60
Medium strength concrete (M30)	04

Construction Technology: The conceptualization of infrastructural systems, analysis and design of structures needed, preparation of drawings and construction sequences, must indeed finally be translated to ground. This is where the appropriate back up of construction technologies comes into reckoning. As far as the need for delivering rapidly, the infrastructure for habitat, transportation, power generation, communication, and, so on, this will broadly imply capacity of producing and in-situ pouring of large quantities of concrete, curing and finishing; transporting large precast elements of concrete; fabricating large quantities of steel, and, assembly and erection of elements. Though the world has taken big leaps in evolving construction techniques, India is still not that advanced. However, it is heartening to see enough evidence of advancement taking place in our country as well, in large and good quality concrete construction, in computerized analysis, designing and drafting, and, computer - controlled fabrication of skeletal steel structures, increasing use of drones for geometric control in road construction. The outlook is becoming increasingly modern.

According to the author, the Akashi Kaikyo bridge (Fig. 2a), opened to road traffic in Japan in 2001, represents the cutting edge of technology in Civil Engineering in general and Bridge engineering in particular. Briefly, the features of the bridge are given as under.

The bridge was conceived almost 10 years before its opening to the traffic. It has spans of 960m, 1991m, and, 960m. The towers rise 216.2m above the deck. The bridge is designed for 6 lanes of traffic. Higher strength steel was developed (1800 N/mm^2) for the wires in the cable, which has a diameter of 1l00mm. 3,00,000 km length of wire was used in the cables. The accuracy achieved in obtaining the cable profile was 1/20,000 (approximately 10 mm in a 200 m sag). The substructure used 9,67,000 m^3 of concrete, and, the capacity for pouring concrete was 180 m^3/hour. The quantity of structural steel used, mostly in the superstructure, was 2,24,000 tonnes. The foundation caissons were 80 m in diameter. These were fabricated and towed into position by boats (Fig. 2b). A wind tunnel was specially designed, fabricated, and, instrumented with the most sophisticated equipment, to test a 11100 scale model of the full bridge. The tunnel was 41.5m wide, 4m high, and the largest such tunnel in the world. Figure 2c shows the model being tested. Each one of the aspects of construction and technology brought out above are in the nature of setting up new bench marks.



(a) A view of the Bridge

(b) 80m Diameter Caisson Being Towed by Boats

(c) a 1/100 Scale Model in the Wind Tunnel

Figure 2. The Longest Suspension Bridge in the World: The Akashi Kaikyo, Japan

Conclusions:

The paper has attempted to trace the growth of infrastructure from early times and the manner in which the developments of Civil Engineering have kept pace with it As expected, humans required infrastructure from the early times, and primitive forms of Civil Engineering practice would have served their requirements. In a modern sense, the rapid pace of this development can be seen to have occurred in the last two centuries. Education in Engineering and Technology has grown in parallel In the Indian context, there would appear to be two other watersheds - India's independence in 1947, and the liberalization of its economy in the 1990s. The achievements of Civil Engineers already made, both in India as well as abroad, are monumental, and, deserve to be recognized by the society. However, in as far as the levels of the Indian infrastructure are concerned, despite vigorous efforts underway, there is still a long road ahead, and, the Indian capabilities in civil engineering, including education, need a substantial push.

Acknowledgements:

The author has drawn upon his earlier publications, and, the other referred material, in preparing this paper, besides information from the open sources on the web.

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- Advanced Construction Technologies
- Tunnel Boring
- Mechanization in Construction Industry
- Cost Effective and Eco-friendly Construction Technology
- Influence of Large Dams
- Rapid Transit System for Medium Cities
- Save Water Campaign
- Liveable City
- Urban Flood Management
- Utilization of Construction & Demolition Waste in Construction Industry
- Utilization of Polythene Waste in Highway Construction
- Reducing of Carbon Footprint in Construction
- Energy Efficient High Rise Structure
- Fire Safety in High Rise Buildings
- Retrofitting & Rehabilitation of Old Buildings
- Climate Responsive Vernacular Construction Technology
- Future of Civil Engineer with Rapid Change in Technology
- Sustainable Development and Legal Issues

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