



SOUVENIR



Seminar on
**Best Practices, Emerging Trends and Technologies in
Planning, Construction and Maintenance of Bridges**

Organised by
Indian Roads Congress
In Association with
Public Works Department, Assam

25th & 26th
APRIL
2025
GUWAHATI

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Guwahati**



RAJ BHAVAN
GUWAHATI

Shri Lakshman Prasad Acharya



MESSAGE

It gives me immense happiness to learn that the Indian Road Congress in association with Public Works Department, Government of Assam is organizing a national level seminar on "Best Practices, Emerging Trends and Technologies in Planning, Construction and Maintenance of Bridges" in Guwahati on 25th and 26th April, 2025. A commemorative souvenir is being published to mark the event.

The Indian Road Congress since its establishment in 1934 has been playing a crucial role in standardizing and promoting best practices for the design, construction, operation and maintenance of roads and bridges across the nation. The Brahmaputra and Barak rivers with their innumerable tributaries crisscrossing Assam in several places, necessitated the need for laying network of bridges capable of addressing the connectivity needs of the people. The bridges therefore, thus laid, are connecting areas, and bringing economic and socio-cultural integration to the far-flung areas of the state. Therefore, Government of Assam, has given unprecedented impetus for laying bridges across the state.

I hope the seminar being held, discusses local issues in the wake of emerging technologies for planning, constructing and maintaining bridges across Assam as well as other North Eastern states. I moreover hope that the delegates attend the seminar discuss and give solutions to various problems and give innovative ideas for the construction of bridges.

I convey my best wishes for resounding success of the seminar. Hope the souvenir being published on the occasion expands its boundaries in materializing the connectivity vision of Indian Road Congress and PWD.

Dated: April 23, 2025


(Lakshman Prasad Acharya)

ড° হিমন্ত বিশ্ব শৰ্মা
Dr. Himanta Biswa Sarma



মুখ্যমন্ত্রী, অসম
Chief Minister, Assam

CMS.7/2024/ 2823
Dispur, 10 Bohag, 1432 Bhaskarabda
April 24, 2025

MESSAGE

It is with profound happiness that I extend my heartfelt appreciation to the Indian Roads Congress for organizing the seminar on 'Best Practices, Emerging Trends and Technologies in Planning, Construction and Maintenance of Bridges', in collaboration with the Public Works Department, Government of Assam, on 25th and 26th April, 2025. The decision to publish a commemorative souvenir to mark the event is equally commendable.

The Government of Assam remains steadfast in its commitment to transformative infrastructure development across the state. The construction of modern bridges is a cornerstone of our strategy to enhance connectivity, drive economic growth and elevate the quality of life for our citizens. Bridges are emblematic of engineering excellence-representing not just physical connectivity, but the very spirit of innovation, efficiency and progress.

This seminar serves as a timely and important platform to spotlight the latest technological advancements in bridge construction. The adoption of best practices is especially critical in Assam, given our unique geographical features, challenging climatic conditions and sensitive ecological zones. The discussions at this seminar will undoubtedly contribute to building a more robust, adaptive and sustainable infrastructure ecosystem tailored to the state's specific needs.

I commend the Indian Roads Congress and the Public Works Department for bringing together a wide spectrum of experts, engineers and stakeholders to foster meaningful dialogue and share cutting-edge knowledge. I am particularly hopeful that the deliberations will address key aspects such as climate resilience, terrain adaptability, ecological sensitivity and innovative design approaches suitable for our context.

My warmest congratulations to all organizers and participants. I wish the seminar resounding success.



(Dr. Himanta Biswa Sarma)

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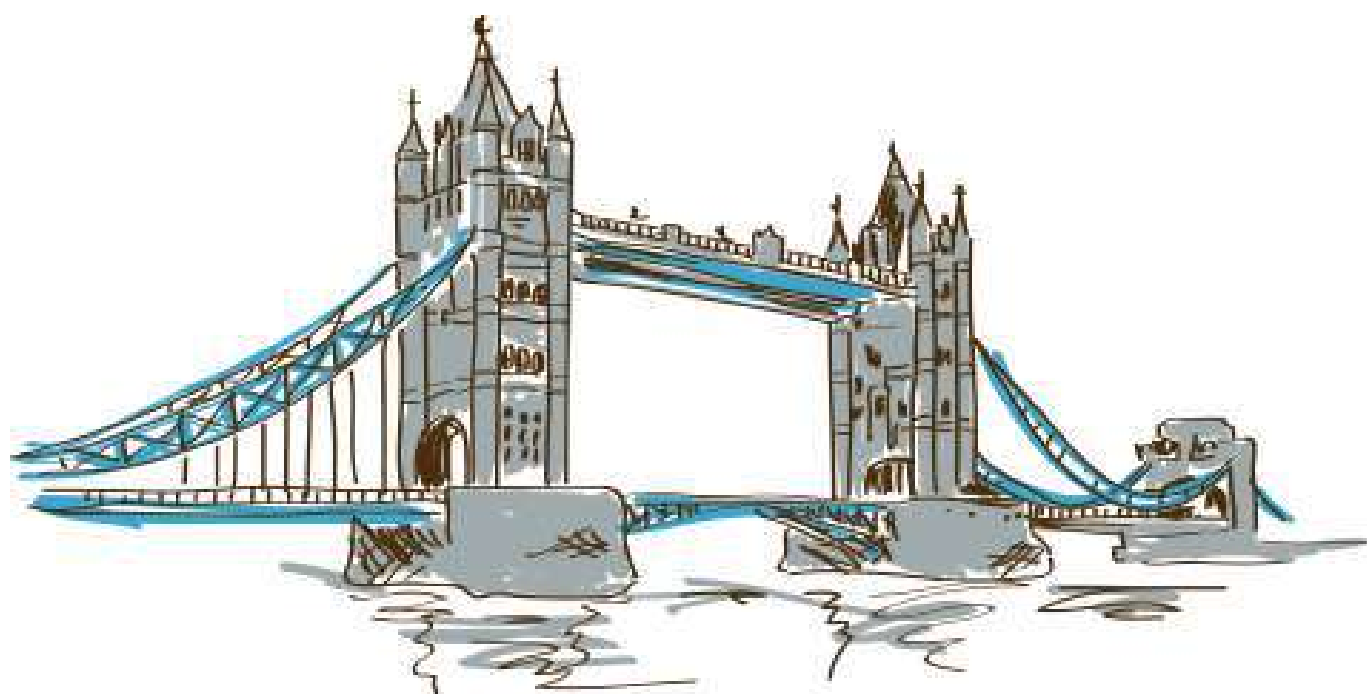
DESIGN AND CONCEPT

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Seismic Performance Evaluation of a Highway Bridge with Fe-based Shape Memory Alloy Retrofitted Pier

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Abstract:

The present study investigates the seismic performance of a highway bridge with Fe-based Shape Memory Alloy (Fe-SMA) retrofitted piers. For this, severely damaged bridge pier scaled models were first rehabilitated using reinforced concrete jacketing, incorporating a plastic hinge relocation technique to restore its lost strength. The relocated plastic hinge region was then retrofitted with a combination of end-anchored and hoop Fe-SMA strips. Pre-strained end-anchored Fe-SMA strips utilized the recovery stress generated during thermal activation to induce pre-compression in the relocated plastic hinge region of the rehabilitated specimen, while Fe-SMA hoops provided active confinement in the same zone. Hybrid simulation of an existing highway bridge in Tripura (India), incorporating scaled bridge pier test models as experimental elements, was conducted to evaluate the seismic performance of the Fe-SMA retrofitted specimen in comparison to a control specimen. Earthquake excitations of varying intensity levels were sequentially applied to assess structural behaviour across a broad damage spectrum. Post hybrid simulation, cyclic tests were performed to determine the ultimate capacity

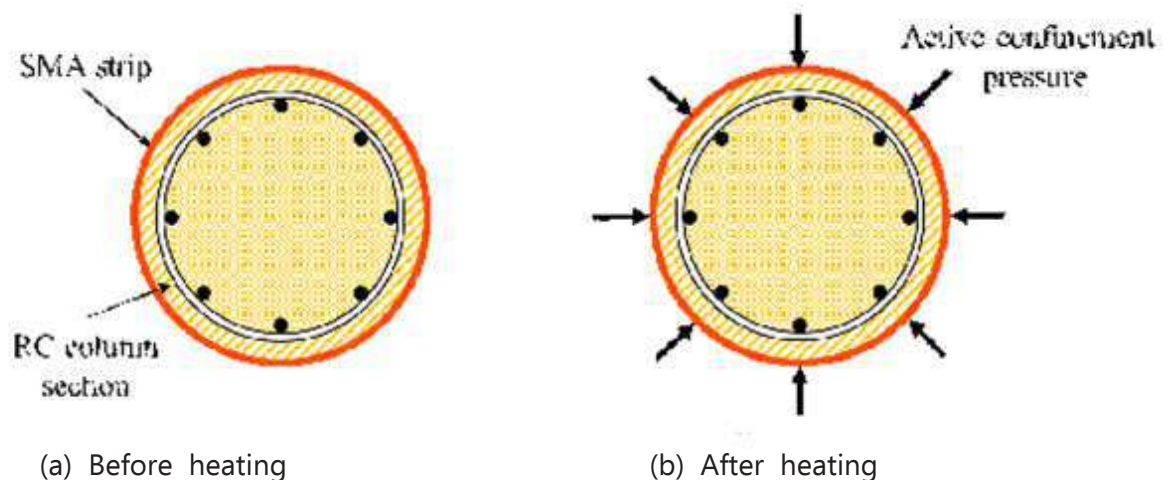
of the specimens. The Fe-SMA retrofitted test specimen demonstrated improved load-carrying capacity, enhanced ultimate displacement, increased stiffness, greater energy dissipation capacity, and minimal damage when compared to the control specimen.

Thereafter, 3D finite element analyses were conducted to simulate the lateral load response of the Fe-SMA retrofitted test specimen, as observed during the experimental investigation. Agreement between simulated and experimental results confirmed the accuracy of the numerical model of the Fe-SMA retrofitted pier specimen.

1. Introduction:

Seismic retrofitting of RC bridge piers aims at improving its seismic performance by increasing its strength and ductility. Most common retrofitting techniques like RC jacketing, steel jacketing, FRP jacketing etc. achieve this objective by addition of lateral confinement to concrete sections. Shape memory alloys (SMAs) have lately gained interest among researchers for its ability to exert active confining pressure on concrete members without mechanical prestressing by virtue of its unique thermo-mechanical property - shape memory effect (SME). If the prestrained SMA is restrained before heating, large

recovery stresses are developed in it, which in turn aids in prestressing/confinement of the structural component against which it is fixed, as illustrated in Fig. 1. Unlike conventional prestressing techniques, this method doesn't require heavy machinery in field. The vast majority of previous studies conducted in the field of application of SMAs to structural elements has focused on Ni-Ti or Ni-Ti-based SMAs (Andrawes & Shin, 2008; Shin & Andrawes, 2011a, 2011b). These studies showcased that SMA-retrofitted columns displayed superior flexural ductility and energy-dissipation capacity compared to their passively confined counterparts, all while being subjected to the same confining pressure. However, the utilization of Ni-Ti-based SMAs for prestressing applications in large structures is limited due to its high material cost, high activation temperature and a relatively narrow thermal hysteresis. Thus, Fe-based SMAs (Fe-SMAs) have emerged as a viable alternative for prestressing applications owing to its lower cost than NiTi-based alloys, higher elastic modulus and a relatively lower activation temperature (Leinenbach et al., 2012). Few studies have been carried out to test the effectiveness of Fe-SMA for strengthening of RC beams (Michels et al., 2018; Shahverdi et al., 2016). However, there are limited studies on use of Fe-SMA for retrofitting of bridge piers (Sarmah et al., 2023).



Prestrained Fe-SMA strips used for application of active confining pressure on RC column section (a) before heating (b) after heating

The objective of the present study is to first carry out rehabilitation of severely damaged bridge pier specimens by RC jacketing to recover its lost strength using a plastic hinge relocation technique. Secondly, retrofitting of a rehabilitated pier using Fe-SMA strips was carried out and seismic performance of an existing bridge with the retrofitted pier was assessed against a control specimen using hybrid simulation. This was followed by cyclic loading tests to determine the ultimate capacities of the test specimens. Lastly, a 3D finite element model of the rehabilitated pier specimen was developed and validated using the experimental results.

2. Specimen Details:

The study focuses on a prototype bridge in Tripura, India, with two spans on roller support and an integrally connected intermediate pier. The pier's vertical load capacity is 54,057 kN, meeting the demands of DL, SIDL, LL, and seismic loads in Seismic Zone-V. One-fifth scaled models of the prototype pier underwent hybrid simulation and cyclic loading test by Kotoky et al. (2018) which resulted in severe damage, including crushed core concrete and ruptured reinforcement. Two damaged pier models were

chosen as test specimens for rehabilitation. The objective of rehabilitation was to repair the original damaged plastic hinge region and to relocate the plastic hinge away from the pier-footing interface, facilitating easier post-seismic repairs. The concept of relocating plastic hinges from the footing, initially proposed by Hose et al. (1997) and later extended by various researchers (Krish et al., 2021; Parks et al., 2016; Rutledge et al., 2014), involves increasing the longitudinal and transverse reinforcement ratio at the damaged plastic hinge region. The rehabilitation procedure, shown in Fig. 2, involved removing loose concrete, restoring the vertical position with a chain-pulley system and the original cross-section with epoxy grouting and micro-concreting. Additional 16 mm dia. dowel bars were installed next to damaged rebars, anchored 150 mm into the foundation with high-strength mortar. After hacking the concrete surface to ensure proper bond, a formwork (diameter 600 mm, height 450 mm) was used, and M30-grade concrete was poured. After 24 hours, the formwork was removed, and water-curing was done for 28 days. This serves as the control specimen (Specimen C). Details of the rehabilitation design and procedure are furnished in Sarmah et al., (2023a) and Sarmah et al., (2023b).

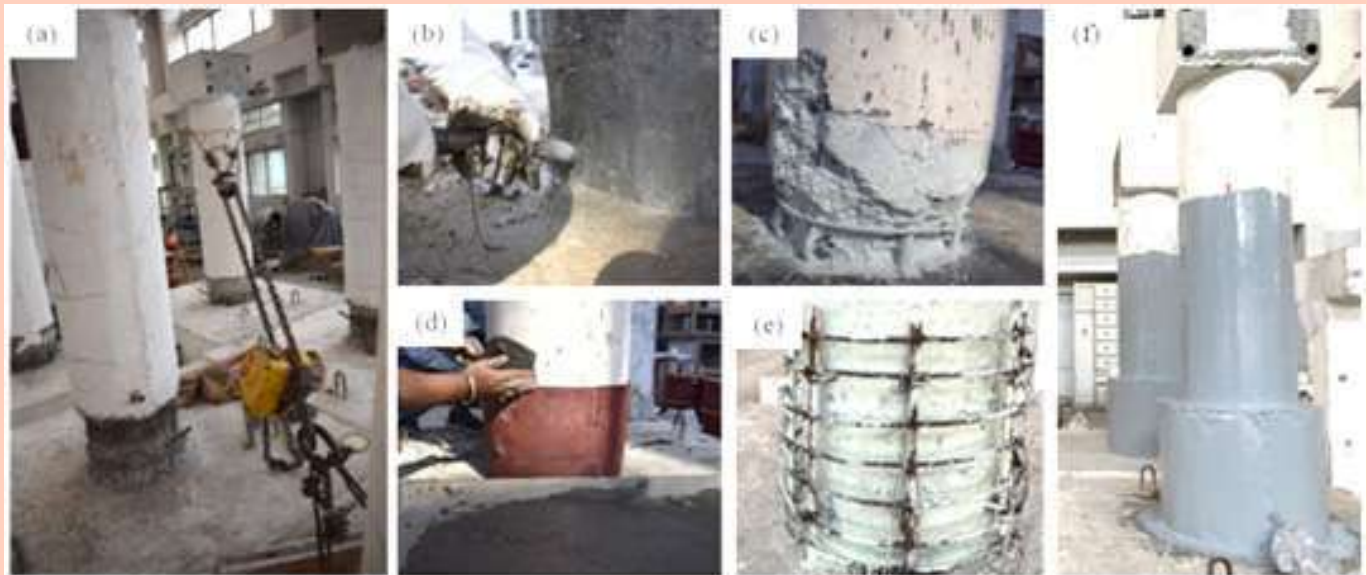


Fig. 2. Rehabilitation methodology (a) bringing the inclined pier to vertical position using chain-pulley system; (b) epoxy grouting; (c) application of bonding agent; (d) micro-concreting; (e) installation of reinforcement cage; (f) test specimens after casting of concrete jacket and application of heat-resistant coating [Sarmah et al. (2023)].

The other rehabilitated specimen was further retrofitting using Fe-SMA strips and is named Specimen R. The retrofitting scheme adopted in the present study used a combination of end-anchored and hoop reinforcements positioned in the new plastic hinge region of Specimen R. For the retrofitting scheme, 2% prestrained Fe-SMA strips having composition Fe-17Mn-5Si-10Cr-4Ni-1(V,C) (mass %) (procured from reFer AG; Switzerland), width 24 mm and a thickness

of 1.5 mm were adopted in the present study. The Fe-SMA strips were fixed on the concrete surface following the procedure shown in Fig. 3 using high strength bolts of 8 mm diameter. These strips were thermally activated at 180°C by resistive heating using a step-down transformer at a current density of 6 A/mm². Recovery stresses of 300–350 MPa were generated after heating the Fe-SMA to 160°C (Sarmah et al. 2023c).

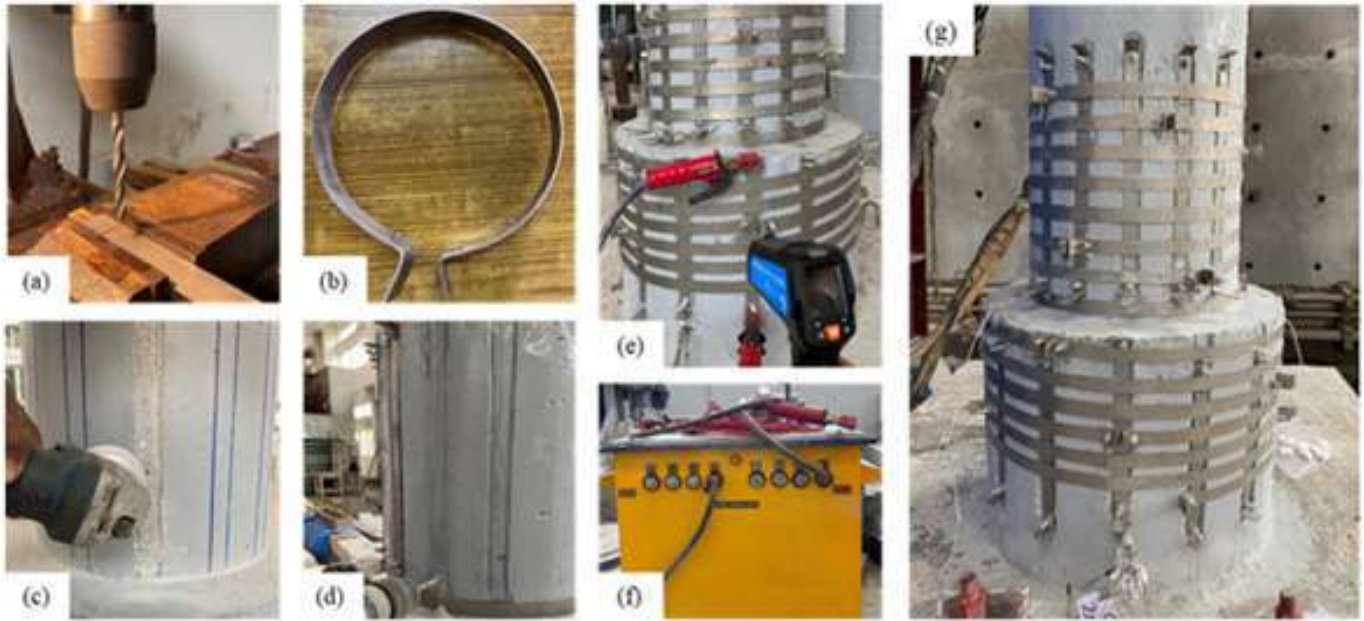


Fig. 3. Fe-SMA strengthening scheme (a) drilling of holes in the cut Fe-SMA strips; (b) representative bent strips; (c) cutting of grooves for end anchored strips; (d) drilling of holes and fixing of strips; (e) thermal activation of Fe-SMA strips; (f) step-down transformer; (g) Specimen R.



3. Experimental programme

To investigate the seismic performance of the Fe-SMA retrofitted RC bridge pier, an advanced testing methodology like hybrid simulation was adopted. The physical test set-up is shown in Fig.4(a). Hybrid simulation of the bridge was carried out with the retrofitted piers as the physical test specimens. Hybrid simulation comprises of two key components, which interact with each other through a controller. The first component is the discrete model of the structure which was computationally analyzed under four scaled segments of the intensity levels: 0.5, 1, 2

and 3MCE of N-S component of El Centro (1940) ground-acceleration history (Sarmah et al., 2024)[Fig. 4(b)]. The second component is the physical specimen that is to be tested in the laboratory. Command signal from the controller, in the form of displacement, is imposed on the physical substructure. Corresponding feedback signal, in the form of spring force generated in the test specimen, is passed on to the numerical model for the next analysis time step. Following the completion of the hybrid simulation, cyclic loading tests were performed at a frequency of 0.025 Hz [Fig. 4(c)] to determine the ultimate load-carrying capacities of the test specimens.

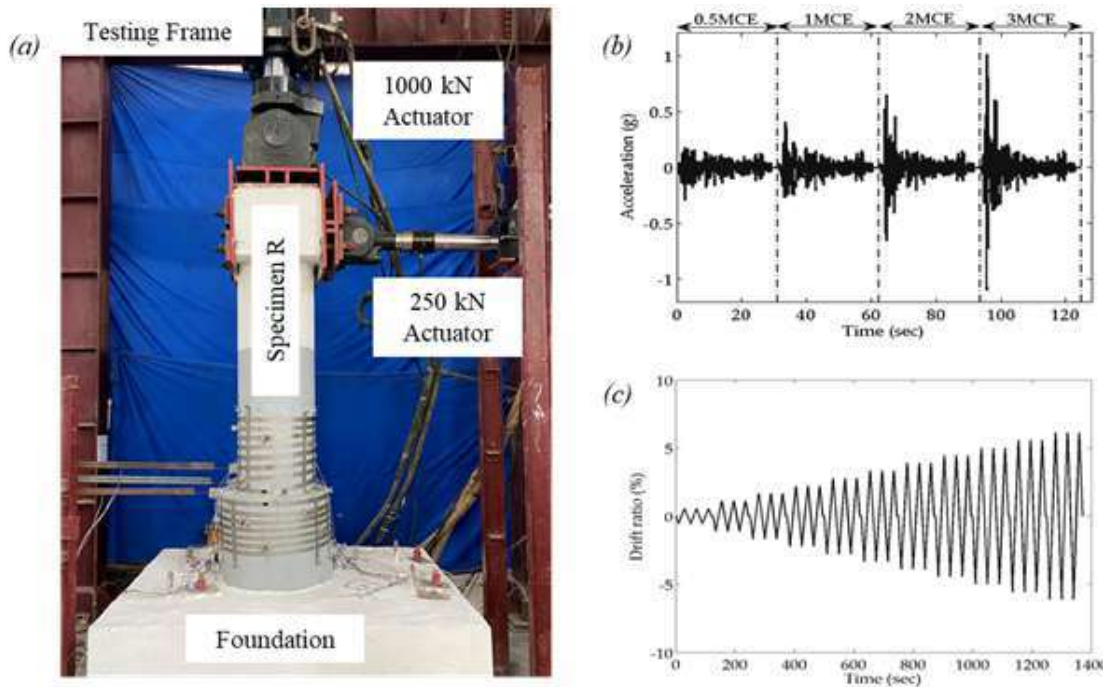


Fig. 4. (a) Overall view of test set-up; (b) earthquake record used in hybrid simulation; (c) cyclic loading history.



4. Test results

The damage states of Specimens C and R at the end of hybrid simulation and cyclic tests are shown in Fig. 5. It may be observed during hybrid simulation Specimen C underwent cracking and jacket-pier slippage at the top end of the jacket as well as around 70-100 mm away from it in the original pier [Fig. 5(a)].

However, in Specimen R cracking was observed only at the top end of the jacket [Fig. 5(b)]. Furthermore, at the end of cyclic test, spalling was observed in the jacketed portion of Specimen C [Fig. 5(c)]. In contrast, the propagation of cracks to the jacket was prevented due to the efficient concrete confinement by the Fe-SMA hoops in Specimen R [Fig. 5(d)].

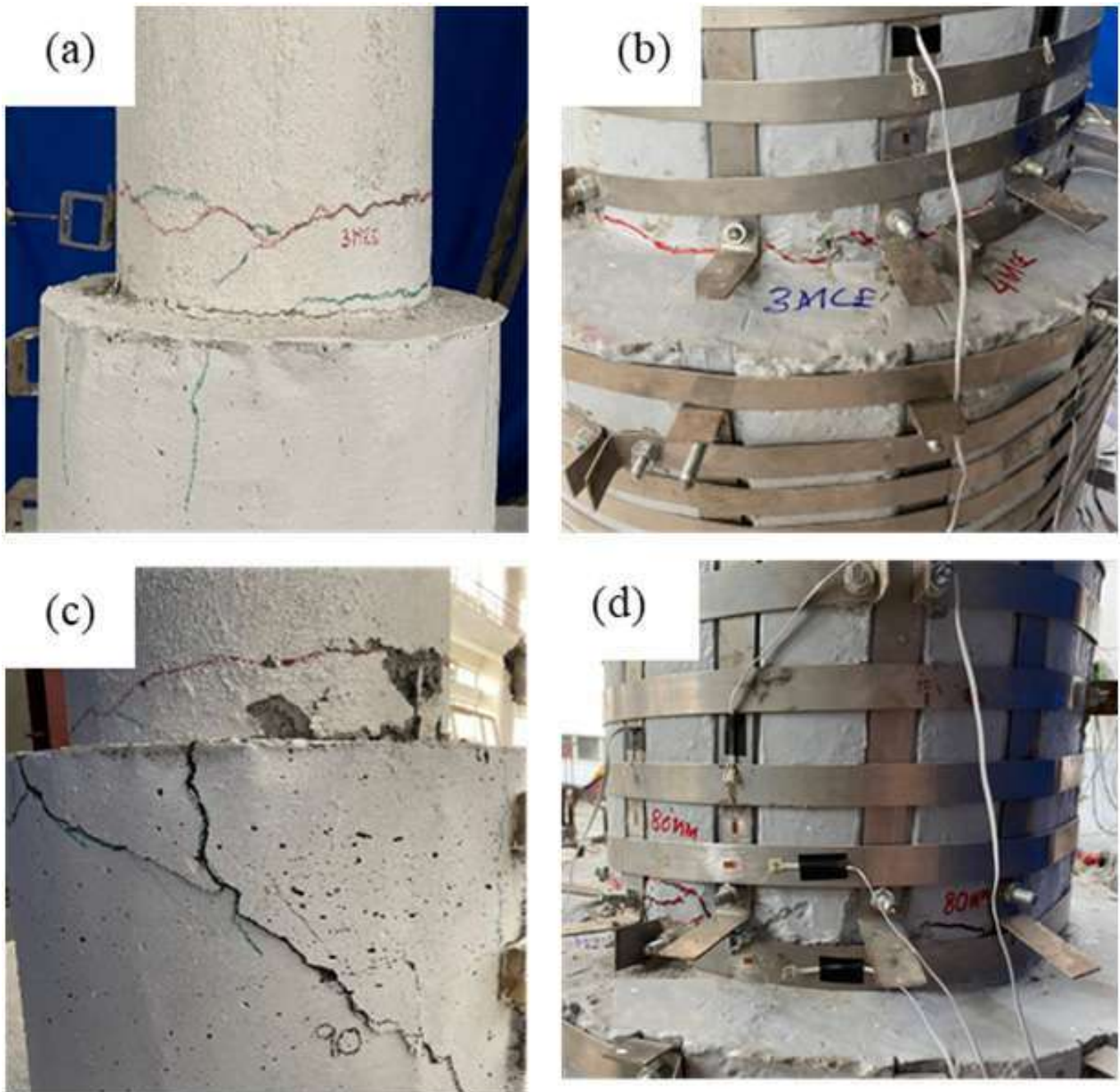


Fig. 5. Damage patterns of (a) Specimen C and (b) Specimen R after hybrid test; (c) Specimen C and (d) Specimen R after cyclic test.

The lateral force-displacement hysteretic responses of the test specimens under seismic excitation of intensity level 3 MCE are presented in Fig. 6. It can be observed that Specimen-R showed an increase of 30.03% as compared to the control specimen C. Additionally, Specimen

R exhibited a decrease in the drift at the top of the pier corresponding to the peak lateral load by 19.92%. This may be attributed to the increased stiffness and confinement at the relocated plastic hinge region due to the presence of end-anchored and hoop Fe-SMA.

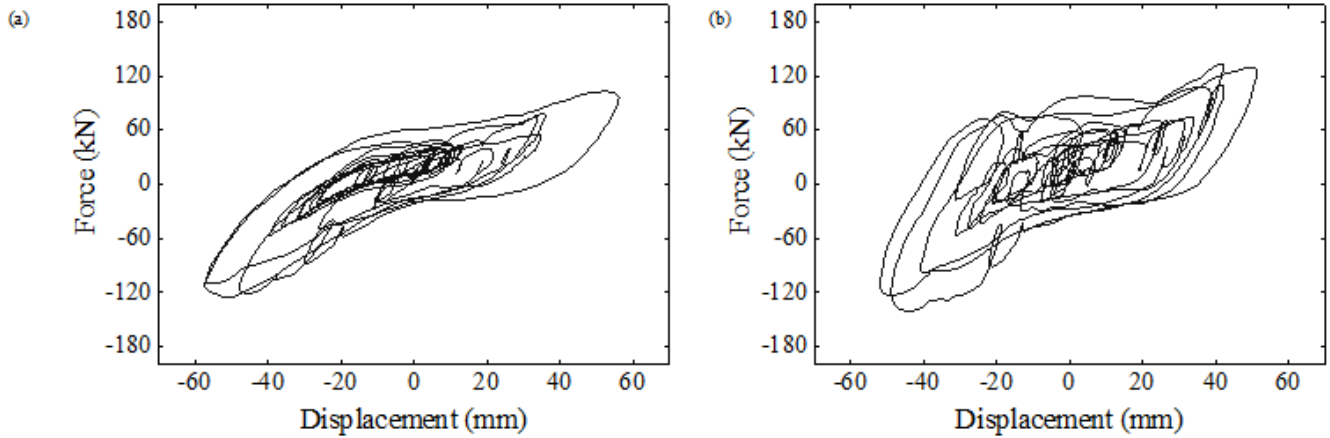


Fig. 6. Force-displacement hysteresis of specimens (a) C and (b) R at an intensity level of 3 MCE.

Force-displacement behavior and backbone curves of the test specimens at the end of the cyclic loading test are shown in Fig. 7 and Fig. 8 respectively. The peak lateral load carrying capacity of Specimen R showed an increase of 35.6% as compared to that of the control Specimen C. Additionally, percentage increase in failure displacement of Specimen R was 33.3% as compared to Specimen C. The synergy of vertical prestressing with active hoop confinement, achieved through the combination of Fe-SMA hoops and end-anchored reinforcement, led to improvements in both

lateral load carrying capacity and maximum drift at failure.

Fig. 9 shows the cumulative energy dissipation capacities of the test specimens during cyclic test conducted after hybrid simulation. The cumulative energy dissipation capacity of Specimen R exhibited an increase of 134% as compared to Specimen C. This increase is due to the increased peak load and reduced slope of the load-displacement curve of Specimen R leading to higher area under the load-displacement curve as compared to Specimen C.

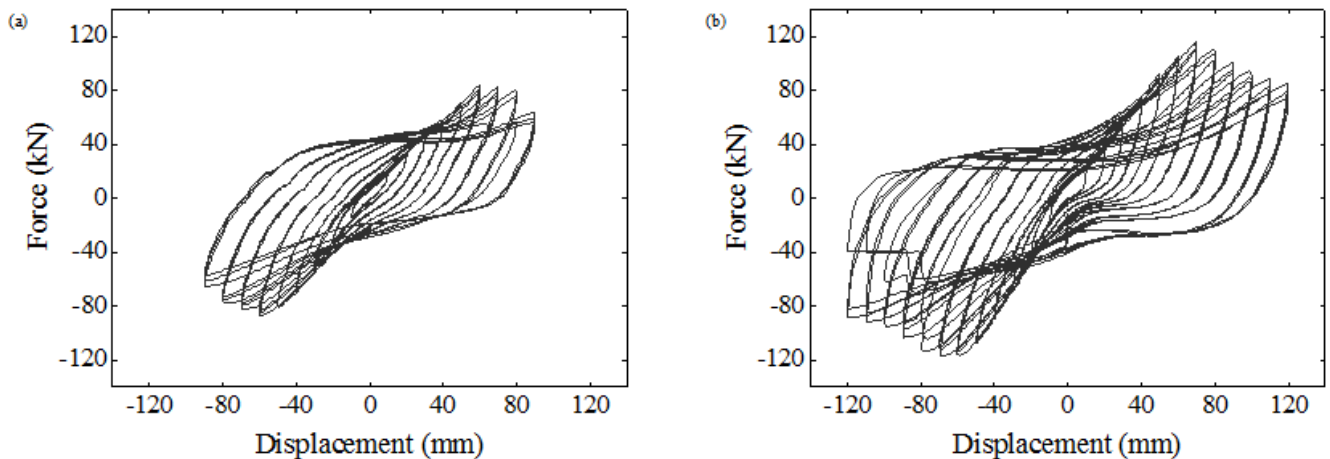


Fig. 7. Force-displacement hysteresis of specimens (a) C and (b) R at the end of cyclic test.

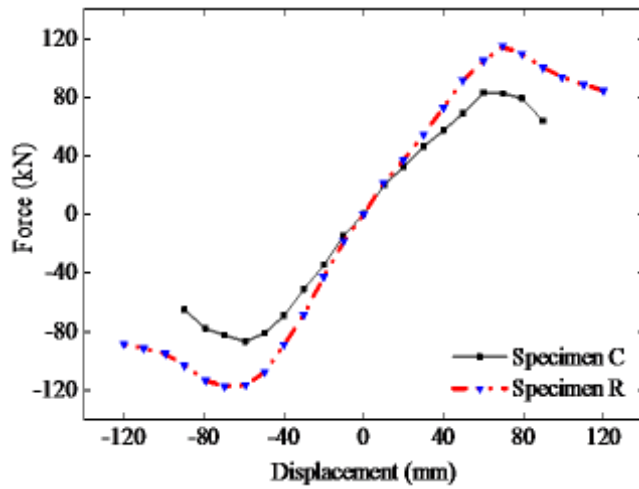


Fig. 8. Backbone curves of test specimens.

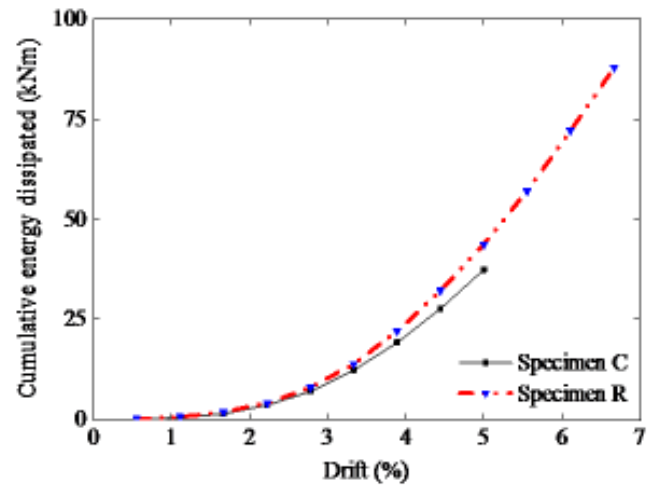


Fig. 9. Energy dissipation curves of test specimens.



5. Finite Element Modelling

A 3D nonlinear finite element (FE) analysis was performed using ABAQUS/CAE 6.20 to study the behaviour of Fe-SMA retrofitted test specimen under hybrid simulation and lateral cyclic loading. The model incorporated material nonlinearity, bond-slip behaviour of reinforcement, and pier-jacket interface properties.

5.1. Material Constitutive Models

The concrete damaged plasticity (CDP) model was used for modelling concrete, incorporating isotropic elasticity and plasticity. Mohr-Coulomb criteria with a shape factor $K_c = 0.667$, and stress-ratio parameter = 1.16 were adopted. The dilation angle was 32° , and viscosity parameter was set to 0.0001. The Mander et al. (1988)'s model was used for compressive behaviour

[Fig.10(a)], and Wahalathantri et al. (2011)'s model for tension stiffening [Fig.10(b)]. Residual strengths (10% of peak) were introduced to ensure stability. Damage parameters were as per Yu et al. (2010), and default recovery factors from ABAQUS Manual were used.

For steel reinforcements, bond-slip effects were included using a modified rebar model by Dehestani and Mousavi (2015). This bi-linear model [Fig.10(c)] adjusts yield stress and modulus based on bond-slip characteristics.

Reinforcements were modelled using a kinetic hardening plasticity model.

U-shaped shear connectors were modelled using a bilinear elasto-plastic stress-strain curve with Young's modulus of 200 GPa and Poisson's ratio of 0.3. For Fe-SMA strips, the linear segment of stress-strain curve of the Fe-SMA coupon specimen after thermal activation [Fig.10(d)] with a modulus of 175 GPa was assigned to the Fe-SMA strips in the FE model in an isotropic hardening plasticity model.

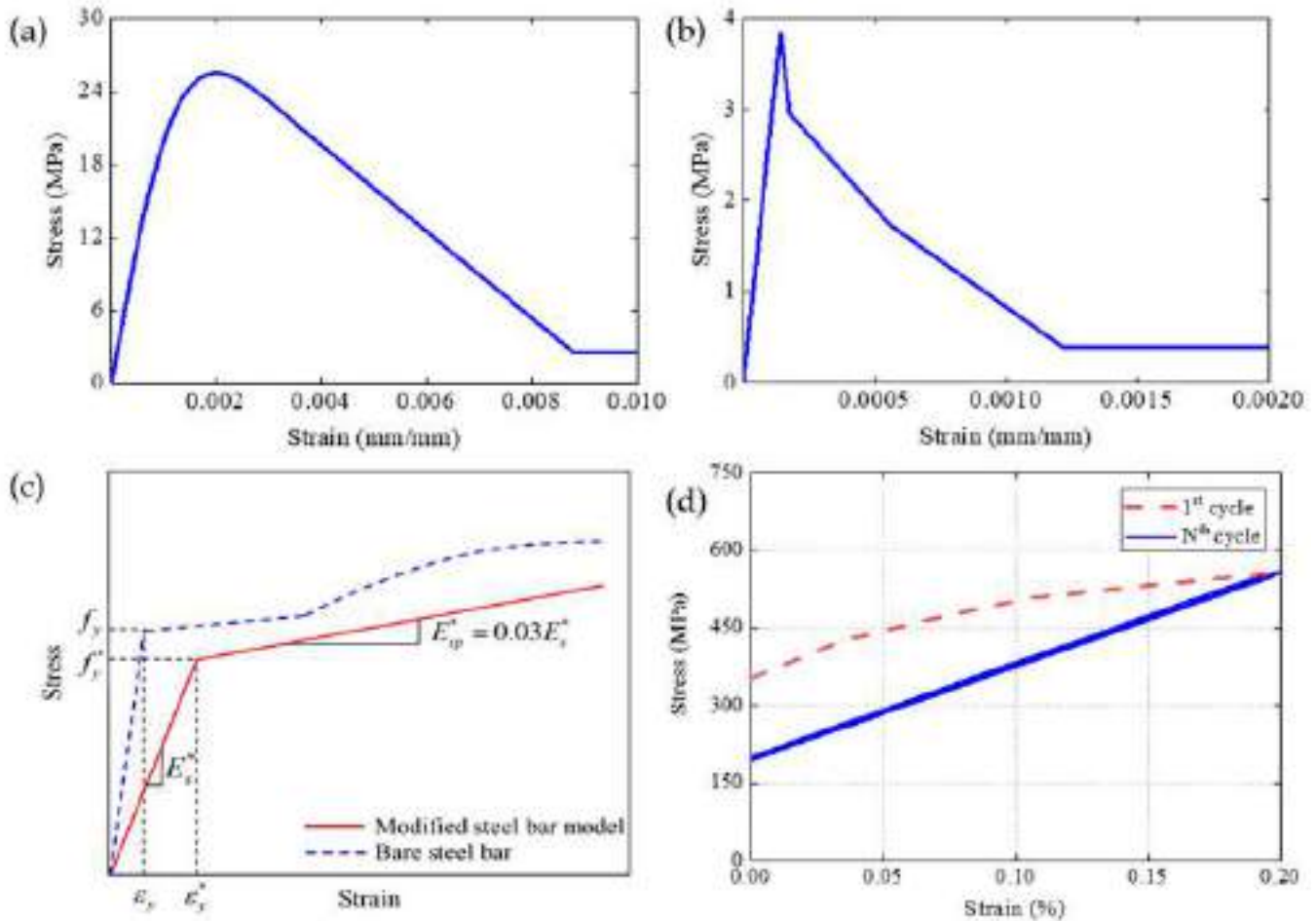


Fig. 10. Material models (a-b) Concrete in compression and tension respectively; (b) Steel reinforcements and (b) Fe-SMA strips.

5.2. Element Types, Boundary Conditions, Prestressing in Fe-SMA Strips and Loading

The concrete was modelled using C3D8R elements; reinforcement with T3D2 truss elements; Fe-SMA strips with B31 beam elements. Mesh sensitivity analysis ensured accuracy and computational efficiency. The base was fixed with an Encastre condition; superstructure load was applied as equivalent pressure. Reinforcements and connectors were embedded; Fe-SMA strips were tied to the concrete surface for full load transfer.



Shear resistance of the jacket-pier interface was defined by cohesion, friction, and shear connector action. A traction-separation law with 1 mm cohesive thickness was used. Normal contact was set as hard, while tangential friction (penalty formulation) used values from Eurocode 2.

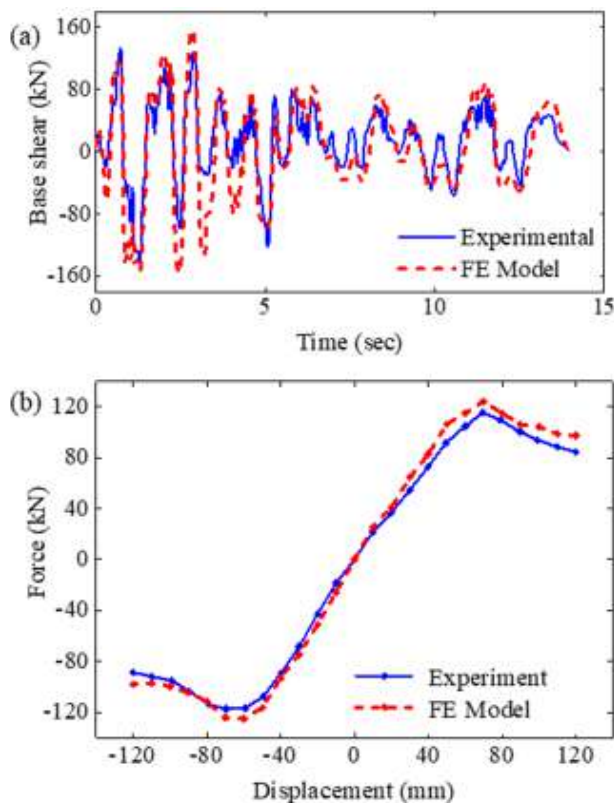
For simulation of prestressing effect in Fe-SMA strips an initial recovery stress was applied in the axial direction in the first FE step. A second step without any loading allowed redistribution of stresses to ensure equilibrium.

5.3. Loading Conditions

The experimental displacement-time history from hybrid simulation was scaled using similitude laws (Harris & Sabnis, 1999). The FE model underwent four sequential displacement-time segments (0.5–3 MCE) followed by cyclic loading. Explicit central-difference time integration was used to compute dynamic response.

6. Validation of FE-Model of Fe-SMA Retrofitted Specimen R

The validation of the FE model of Specimen R was carried out by comparing the FE results with



the corresponding experimental outcomes. The base shear-time responses of Specimen-R at earthquake intensity levels of 3 MCE is shown in Fig. 11(a) while the envelope curve from cyclic loading test is shown in Fig. 11(b). It can be seen that the base shear response predicted by the FE model was in close agreement with the experimental results. Additionally, the envelope curve for Specimen R closely matched the experimental curve, accurately capturing strength gain due to Fe-SMA confinement as well as post-peak softening behaviour.

Fig. 11. Comparison of (a) experimental base shear-time histories and (b) envelope curve of cyclic tests with the results obtained from FE analyses.

The contour plots of the DAMAGET parameter obtained at the end of the hybrid simulation and cyclic are presented in Fig. 12. In Specimen R, damage was observed to concentrate at the top end of the RC jacket at the end of hybrid simulation and cyclic tests, with no significant damage propagating below this level. This

localization of damage was also evident during the experimental program. The accuracy of the FE model in capturing both the damage initiation and propagation patterns supports the effectiveness of the traction-separation interface and material nonlinearities considered in the modelling approach.

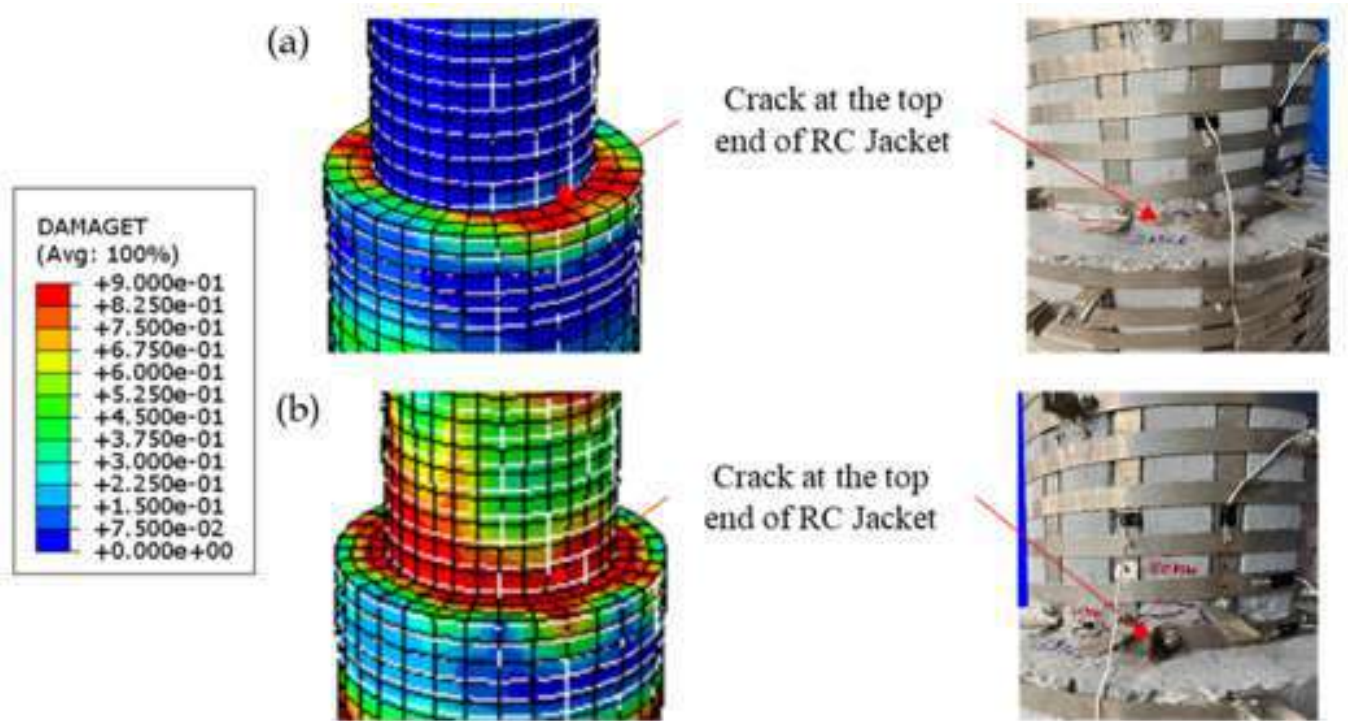


Fig. 12. Comparison of experimental damage patterns at the end of: (a) hybrid simulation and (b) cyclic test with that obtained from FE analyses of Specimen-R.

7. Conclusion

A set of two severely damaged scaled bridge pier models of a prototype bridge located in Tripura, India were first rehabilitated by RC jacketing. This led to shifting of the plastic hinge region from the pier-foundation interface of the original pier model to the top end of the jacket in the rehabilitated pier model. The relocated plastic hinge region of one rehabilitated pier model was further retrofitted using Fe-SMA strips as a combination of end-anchored reinforcement and hoop reinforcement. Hybrid simulation of the bridge with the test specimens as experimental elements was carried out to determine the effectiveness of the Fe-SMA retrofitting scheme under seismic loading followed by cyclic loading to evaluate the ultimate capacities of the test specimens. Test results demonstrated that the Fe-SMA retrofitted pier specimen exhibited enhanced peak lateral load as well as improved ductility. Additionally, noteworthy improvement was observed in the cumulative energy dissipation capacity of the retrofitted specimen, signifying a substantial enhancement in seismic performance. Thereafter, the Fe-SMA retrofitted bridge pier specimen was simulated using ABAQUS and was subjected to the same loading history as the experimental scheme. The resulting base shear-time

The validated FE model can therefore be further utilized for parametric studies and to optimize retrofitting strategies for similar bridge piers in seismic zones.

histories and damage patterns obtained from FE analyses were compared with experimental results. It was seen that the FE model could reasonably simulate the experimental behaviour.

The validated FE model can therefore be further utilized for parametric studies and to optimize retrofitting strategies for similar bridge piers in seismic zones.

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New and Sustainable Materials for Bridge Construction



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Introduction

New and sustainable materials are adopted day by day on a larger scale in construction of roads while their uses have been found to be limited in construction of bridges. The extensive experience of using conventional materials and technologies, and the in-depth knowledge of their behaviour has made industry players hesitant to use new/alternative materials. The conventional material and technology have shown various issues such as excessive use of natural resources, rapid depletion of aggregate, inadequate durability, poor riding quality, long hauls of construction material and excessive pollution etc. In order to redress these challenges, there is a pressing need

to adopt new/innovative materials, technologies in bridge construction sector in a big way.

Recycled Materials

Recycled materials such as reclaimed asphalt pavement (RAP), crushed concrete, recycled steel and fly ash, are increasingly being incorporated into bridge construction. Utilizing these materials reduces waste and conserves natural resources. For instance, recycled concrete aggregate (RCA) can replace natural aggregates in bridge decks, offering similar performance while reducing environmental impact. Studies show that bridges using 30-50% RCA can maintain their structural integrity over long periods.

Geosynthetic Materials

Geosynthetics, including geotextiles, geomembranes, and geogrids, are increasingly used for soil stabilization in Road and bridge embankments. These materials improve load-bearing capacity, reduce erosion, and enhance drainage, particularly in flood-prone areas. The Stonecutters Bridge in Hong Kong effectively uses geosynthetics to support its massive load.

High Performance Concrete (HPC)

High performance concrete (HPC) may be defined as one whose ingredients, proportions and production methods are specifically chosen to meet special performance and uniformity requirements that cannot be always achieved routinely by using only conventional materials, like, cement, aggregates, water and chemical admixtures, and adopting normal mixing, placing and curing practices. These performance requirements can be high strength (70 to 140 MPa at 28 to 91 days), high early strength (20 to 28 MPa at 3 to 12 hour or 1 to 3 days), high workability (up to 200mm), low permeability (500 to 2000 coulombs), high modulus of elasticity (more than 40 GPa) and high durability for severe service environments, etc. or combinations thereof. High-performance concrete has been primarily used in tunnels, bridges, pipes carrying sewage, offshore structures, tall buildings, chimneys, and foundations, and piles in aggressive environments for its strength, durability, and high modulus of elasticity.

Self-Compacting Concrete (SCC)

Self-Compacting Concrete (SCC) is a concrete that fills uniformly and completely in every corner of formwork by its own weight and fluidity without application of any vibration, without segregation, whilst maintaining homogeneity. It is suitable in situation where;

- Reinforcement is very congested,
- access not available for vibration,
- complicated geometry of the formwork,
- pouring is possible only from a single point,
- speedy placement is required,

It has also the other advantages of no noise due to vibration and no requirement of finishing.

Indian Roads Congress (IRC) has published IRC: SP: 70-2016 "Guidelines for the Use of High

Performance Concrete in Bridges" which provides for use of High Performance Concrete/Self-Compacted Concrete up to M90 grade. It is, however, observed that use of High Performance Concrete/Self-Compacted Concrete (M60 to M90 grade) is limited to a few long span extradosed/ cable stayed bridges only.

Ultra-High Performance Fiber Reinforced Concrete (UHPFRC)

Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) is one of the most modern concretes developed during the last decade. It is generally characterized by high compressive strength above 100 MPa having high-stiffness, self-consolidating, and ductile material formulated by combining Portland cement, various mineral and chemical admixtures, water, and steel or organic fibres. Compared to Reinforced Concrete, it eliminates uses of aggregate and instead of steel uses steel fiber as reinforcement. Properly designed Ultra-high-performance fiber reinforced concrete (UHPFRC) which have following superior characteristics as follows--

- i) Concrete Grade 150 and above
- ii) With usable structural tensile strength (> 8 MPa) and ductility
- iii) At least 4-6 times stronger than normal concrete (in compressive strength)
- iv) At least 100 times more durable than conventional concrete
- v) Longer service and design life
- vi) Lower carbon footprint

Of late, in India the use Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) technology has been adopted in the construction and rehabilitation of bridge, flyover, viaducts, vehicular overpasses etc. by MoRTH, NHAI, MSRDC, Maharashtra PWD etc. in the span ranging from 20m to 100m.

For promoting use of UHPFRC Technology in National Highways in India, Ministry of Road Transport and Highways, Govt. of India published guidelines encouraging various implementing agencies, DPR Consultant, Contractor/ Concessionaire to use the technology in the construction of elevated corridors/ viaduct sections and long span bridges for span length varying from 50m to 100m. Although, there is no

guidelines published currently by Indian Road Congress (IRC) for use of UHPFRC Technology in Indian condition, however, MORTH has prescribed French design standard and material specification(NF P18-710- "National addition to Euro code 2- Design of concrete structures: specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC) & NF P18-470- "Concrete-Ultra-High Performance Fiber-Reinforced Concrete-Specifications, Performance, Production and Conformity") for manufacturing UHPFRC components.



India's First Major Bridge Construction using UHPFRC Technology at Km. 42+050 on Sole River, Latur Nilanga Aurad Section of NH-752K, Maharashtra. Executed UHPFRC Long span configuration (02 x 56m). Source: Long Span Structures Pvt. Ltd., India.

Fiber-Reinforced Polymers (FRP) Bars

During the last few decades, fibre-reinforced polymer (FRP) bars have emerged as an alternative to carbon steel bars in bridge construction, repair and rehabilitation. It consists of high-strength fibers such as Glass, carbon, basalt, or aramid fibers, embedded in a polymer matrix. They are used to reinforce concrete structures, providing resistance to corrosion and fatigue. The use of FRP in bridge construction also leads to lighter, more durable structures, cost-effective in long-term (lower life cycle cost) due to lower maintenance needs.

Four common types of FRP bars:



(a) GFRP bars



(b) CFRP bars



(c) AFRP bars



(d) BFRP bars

Indian Roads Congress (IRC) has come up with the State-of-the-Art Report and Guidelines-IRC:137-2022 on use of Fibre Reinforced Polymer Bars in Road Projects (Part 1: Glass Fibre-Reinforced Polymer Bars) on National Highways work. The code prescribes for use of GFRP reinforcing bars in bridge approach slabs, bridge decks, walkways of Foot Over Bridge, Slab and Box Culverts, Retaining Walls, Noise barriers, Crash Barriers & Bridge Parapets, mechanically stabilised Earth Wall Panels and Copings etc. Currently, the GFRP reinforcing bars are available in India from few of the manufacturers for diameter ranging from 4 mm to 40 mm. The use of this material in road projects therefore may not require it to be imported from another country. The use of FRPs for road and bridges located in coastal areas, high rainfall and flood prone regions is expected to give high returns and sustainably in long-term due to their corrosion free characteristic.

Conclusion

For promoting use of new/alternative material and technology in Road and Bridges of National Highways, Ministry of Road Transport & Highways, Govt. of India has been issuing various policy circulars from time to time to ensure adoption of best practices, value engineering in planning, construction and maintenance of bridges. Indian Road Congress (IRC) has also come up with various State-of-the-Art Report and Guidelines in this endeavours. IRC has also accredited new materials/techniques/equipment/product etc. for use of which contractor/concessionaire need not require further accreditation from the Authorities. Contractor/concessionaire have also been allowed for use of new/alternate material/ technology for which international standards such as AASHTO, ASTM, Euro Code and British Codes, FHWA guidelines are available. Despite, all the above efforts, significant achievement have yet to be seen and

the use of new materials and technologies is observed to be limited to a few long span structures and innovative bridge projects in India. The need of the hour is to review and take further efforts to incentivize implementation agencies, DPR Consultants, Contractor/ Concessionaire to adopt sustainable and best practices by way of providing training, workshops, bonus, subsidies, tax-benefits, and certifications etc. for implementation of the projects using new, alternative materials and technologies.

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SUSTAINABILITY DIMENSION IN URBAN TRANSPORTATION STRUCTURES

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Transport infrastructure consists of the fixed assets that concern mobility of people, goods and services. Multilevel traffic interchanges and major flyovers are an integral part of a city's growth. The challenge that exists today is how to retain the essential cultural and social characteristics of the urban environment and still give the city an efficient transportation network.

The sustainability dimension in the design of urban transportation structures is of recent origin, ever since the specter of Climate Change has made its importance felt throughout the world and life as it exists today. The impact of a "green" transportation structure may be judged less by statistics and more by whether it blends into the environment satisfactorily.

The important parameters that can be short listed to form sustainability criteria for urban infrastructure projects could include the following:

- exceeded from code specified values, do not result in structural collapse.

- Retain essential cultural and social characteristics of the existing environment,
 - Encourage pedestrians, cyclists and public transport. (FIG 1)
 - Ensure signal-free movements of traffic to avoid atmospheric pollution from stationary vehicles.
 - Incorporate landscaping at the concept stage itself for new projects (FIG 2).
 - Safety of road users is retained as being of paramount during construction.
 - Aesthetics of structures is important for people to 'own' the project. (FIG 3).
 - Use blended cements and recycled aggregates by proper planning and where possible to reduce carbon footprint.
 - Reduce concrete quantities to enable reduction of carbon footprint.
 - Employ more embankments and less structure to reduce carbon footprint, (FIG 4).
 - Employ technologies which reduce construction period and minimize on-site work.
- Use waste material and industrial by-products like flyash and blast furnace slag in concrete

In most cases existing important buildings and other major landmarks have to be incorporated both physically and visually as part of the overall scheme in the conception of the transportation structures.



FIG 1. Steel Arch FOB of 90m span. concept comprises a steel arch bridge. No support at the central verge, provides enhanced safety from errant vehicles.

FIG 2. The flyover is aligned along NH-24 and the Underpass perpendicular to it. The existing rotary at ground level and water body was retained with minimal changes necessary to suit the structural arrangement. Integration of traffic of pedestrian and cycles.



FIG 3. The flyover aesthetics emulate the human vertebrae.

FIG 4. More embankments, Less structure





Future Challenges & Opportunities in BRIDGE ENGINEERING

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This paper will focus on advancements in Bridge Design and Construction that we are currently seeing globally and also some of the future challenges and

opportunities in Bridge Engineering that we are likely to see in the not-so-distant future.



Bridges are vital components of our modern highway/railway systems, often serving as crucial lifelines in our nation's infrastructure. They not only connect places but also connect people, communities, and societies. They play a significant role in improving our quality of life.

Bridge Engineers have now started to realise that there is a need to look at structures from a life-cycle perspective. The life cycle approach envisages affirmative actions toward a sustainable solution, starting from the project planning and feasibility study stage and going to decommissioning and end-of-life management. It is from cradle to grave consideration. Traditionally, Bridge Engineers were focussing only on few parts of the life cycle.

They were not thinking about the whole process holistically. The new generation of Bridge Engineers need to have widespread knowledge on many aspects of bridge design, other than mere structural engineering. And of-course they have to have deep knowledge on structural design aspect. The following are the core aspects of Bridge Engineering that are undergoing important changes in Bridge Engineering :

1. Upgrading Codes and Standards
2. Materials
3. Engineering, Analysis & Design
4. Construction Techniques
5. Monitoring and Maintenance
6. Aesthetics & Sustainability
7. BrIM/BIM Based Design
8. Embracing Emerging Technology
9. Collaborative Design

1. Upgrading Indian Codes & Standards to built in sustainability framework : In the context of urgent sustainable development, codes of practice could play a crucial role in advancing sustainable solutions. Indian Codes for Bridges (IRC Codes as well as BIS codes) currently in use are all developed at a time when the issues of climate crisis, issues of sustainable development were not under consideration. These codes requires urgent upgradation so that the sustainability aspects are built in the planning, design and execution of Bridges. Fortunately there are international references and codes which can help the codemakers to bring out these revision in the code. Recently published fib model code MC2020 for concrete, is a good example as reference code. Unique in its blend of academic excellence and practical rationality, the fib model code 2020 aims to drive innovation amidst rapid technological advancements. To serve as a catalyst for mainstreaming innovative practices, it provides comprehensive provisions for design, construction, operations and circular usage in concrete engineering. The concepts can be made equally applicable for other materials, like steel. The sustainability framework of the model code facilitates the integration of cutting-edge concepts and technologies - such as new material solutions, advanced structural models, data-informed assessment, and integrated life-cycle management - into sustainable practices for both new and existing structures. This code

can be taken as the bench-mark for re-writing our Indian codes.

2. Materials : There are several innovative and New materials which are finding market space, due to their lower life cycle cost and due to their low GHG emission. Efforts are also made worldwide to decarbonise concrete and steel (which are two major material of use), by changing its constituent materials, by improving method of production. New materials will supplement and compliment concrete in Bridge Engineering. Low Carbon construction is expected to be a multi-material scenario integrating novel concepts in which many new interactions will arise. We are already seeing application of FRP Rebar, Stainless Steel rebars in construction in India.

3. Engineering, Analysis & Design : In terms of Engineering, Analysis and Design, there has been a huge change in the way SE's work, in recent years. Some of the digital tools now available to us were unthinkable even just a few years ago. The pace of change is phenomenal. Present practice in analysis of bridges is to de-couple the structure and carry out separate analyses for the Superstructure, substructure, and Foundation. This practice is now being replaced by modeling the whole structure, including the Foundation in one integrated model and analyze in one go.

4. Construction Techniques : Construction Techniques for Bridges have been changing at a very rapid pace. Accelerated construction with added measures of safety is the trend.

5. Monitoring and Maintenance : Design and Construction takes only 2 to 5 years, while maintenance and monitoring is for 100 years. So the focus in future will see improvements in the management and maintenance of existing bridge structures. Better methods will emerge for fast bridge damage detection and bridge health assessment.

6. Aesthetics & Sustainability : The construction sector plays a key role in sustainable development, and bridge engineering is no exception. At every stage of bridge design and construction, environmental impacts will be given greater consideration than ever before. At the end of a bridge's life, repurposing and reusing

the structural components is another way to reduce CO2 emissions.

7. BrIM/BIM Based Design : BrIM/BIM is a game changer. It allows a Bridge Engineer to foresee issues, access information and minimise re-work. BIM gives a general methodology for coordinating activities through the whole project lifecycle. The application of (BIM) in the construction sector is expanding every day. It has wide applications starting from planning, design, construction, maintenance, monitoring, and in Bridge Management Systems.

8. Embracing Emerging Technology : Smart technology is tremendously impacting the construction industry. This is because the likes of artificial intelligence (AI), Augmented / virtual reality (AR/VR), drones, site robots, and other construction techniques are now the new norm at every construction site. Bridge construction is no exception.

9. Collaborative Design : The future will see a new breed of engineers, different from what we have in the past. They will be engineering leaders, who are more creative, innovative, collaborative, more willing to work on cross-disciplinary problems and be leaders for society. Future Structural and Bridge Engineers need to have breadth in technical and non-technical issues and the ability to work across multi-disciplines and bend any degree in various disciplines. At the same time, they have to have specialised and deep knowledge in their specialised field.

Concluding Remarks

In the future, a bridge won't be just a bridge anymore. It will move the goalposts for the future of civil engineering, and what the civil engineers of the future will become.



Emerging Trends and Technologies in Planning, Construction and Maintenance of Bridges- Implementation on Palashbari Project



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Abstract

The rapid expansion of infrastructure in India necessitates innovative solutions for efficient bridge construction, maintenance, and longevity. Emerging technologies such as faster construction using precast technology with larger equipment as an advanced construction methodology and real time structural health monitoring systems (SHMS) are transforming bridge engineering by enhancing cost-effectiveness and better planning considering the life cycle of cost of the project and safety.

Structural Health Monitoring Systems (SHMS), enables real-time monitoring, predictive maintenance, and disaster prevention, significantly extending bridge lifespans while minimizing operational disruptions.

Additionally, application of BIM modelling, and geometric control using software (ABES Etc.) ensure more accurate and faster bridge construction with minimized project delays. By integrating these cutting-edge technologies, India is setting new benchmarks in sustainable and resilient bridge infrastructure, optimizing resources while ensuring safe and efficient transportation networks for the future.

Keywords:

Precast, Larger Equipment, Building Information Modelling (BIM), Structural Health Monitoring Systems (SHMS)

1 Introduction : Bridges are critical infrastructure components that ensure connectivity and economic progress. Advances in technology, construction methods, and materials are transforming how bridges are planned, constructed, and maintained. This paper explores the latest trends and best practices in bridge engineering, highlighting real-world examples over the India including the showcase of recent on-going project in ASSAM, Palashbari Project and its successful implementations.

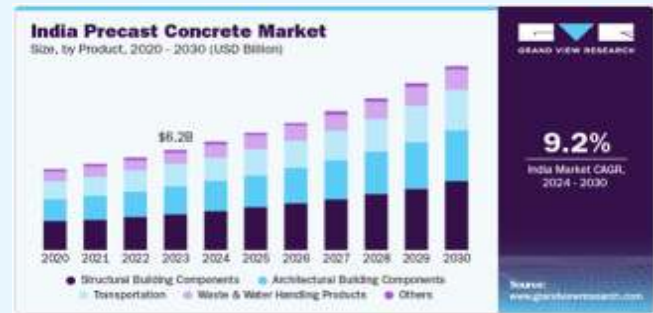
2. Emerging Trends in Planning and Construction

2.1 Focusing on Faster Construction

2.1.1 Precast rather than Cast-in-Place Construction methodology

Precast construction has revolutionized bridge engineering by offering a faster, more efficient alternative to traditional cast-in-place methods. This approach involves manufacturing bridge components—such as girders, deck slabs, and segments—in controlled factory settings before transporting them to the construction site for assembly. This off-site fabrication ensures consistent quality, reduces construction time, and minimizes environmental disruptions at the site. In India, the adoption of precast technology is accelerating, driven by the need for rapid infrastructure development to support urbanization and economic growth. The India precast concrete market was valued at USD 6.16 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of 9.2% from 2024 to

2030, reaching USD 11.33 billion by 2030(Source: www.grandviewresearch.com)



This expansion is fuelled by government initiatives aimed at enhancing the country's transportation network, including roads, highways, and bridges. The adoption of precast technology aligns with these initiatives by facilitating faster construction timelines and improved structural quality.

Speed of Construction : Precast elements can be produced simultaneously while site preparation is underway, leading to significant time savings. For instance, precast segmental construction can achieve construction speeds as high as 7~9 days per span of segmental superstructure. Full span launching methodology (FSLM) for precast span can be achieved even in single day per span.

Quality Control : Factory-controlled environments allow for stringent quality assurance, resulting in components with superior strength and durability compared to those cast on-site, where variables such as weather can affect quality.

Reduced On-Site Labor and Environmental Impact :

With much of the work completed off-site, there is a decreased need for on-site labour, which is particularly beneficial in areas with labour shortages. Additionally, this method reduces noise and air pollution at the construction site, contributing to a smaller environmental footprint.

In conclusion, the shift towards precast construction in India's bridge projects reflects a strategic move to meet the demands of rapid urbanization and infrastructure development. By leveraging the advantages of precast technology, such as accelerated construction schedules, enhanced quality control, and reduced environmental impact, India is poised to deliver durable and efficient bridge structures that will serve its growing population for decades to come.

2.1.2 Larger Block Erection Methodology : Larger block erection is a key innovation in modern bridge construction, significantly reducing project timelines while improving structural integrity and safety. Instead of assembling numerous small precast segments on-site, larger prefabricated blocks—such as full-span girders, orthotropic steel decks (OSDs), and large pier caps—are cast off-site and transported for rapid installation. This method is widely used in metro rail projects, expressway viaducts, and long-span bridges to minimize on-site work, reduce traffic disruptions, and enhance construction efficiency. Increased use of hybrid precast-steel structures for lightweight, high-strength solutions in long-span bridges. Automation and robotics in precast production to enhance quality and consistency.

Faster Construction Timelines: Larger blocks eliminate the need for time-consuming on-site segmental connections, accelerating bridge erection. Full-span precast girders allow for the completion of bridge spans in a matter of days rather than weeks.

Improved Quality Control: Factory-controlled casting ensures superior concrete quality, reducing variability due to weather conditions and on-site errors.

Reduced Traffic Disruptions and Environmental Impact: Since a major portion of the work is done off-site, on-site activities such as formwork, reinforcement tying, and curing are minimized. Ideal for congested urban areas where on-site construction needs to be minimized.

Enhanced Safety: By reducing the number of lifting operations and on-site labour, the risks associated with manual handling and high-altitude work are significantly lowered.

Some case of notable Applications of Larger Block Erection in India is briefed below.

Mumbai Trans Harbour Link (MTHL)

This 21.8 km sea bridge is India's longest and features orthotropic steel decks (OSD)—large, prefabricated steel segments measuring up to 180 meters (weighing around 2700 Tons).

The use of large block erection methodology for OSDs enabled rapid erection over the marine sections, reducing construction time to 7 days per span (more than 150m)

Mumbai-Ahmedabad Bullet Train Corridor (MAHSR)

Full-span precast girders (40m long, weighing 1000tons) are being installed using Full-Span Launching Gantries (FSLG).





The adoption of large precast blocks has significantly accelerated the project's execution compared to traditional segmental construction.

Larger block erection is transforming India's bridge construction landscape, enabling the completion of complex infrastructure projects at unprecedented speeds while maintaining high safety and quality standards.

2.1.3 Larger Diameter Drilled Shafts for Faster Bridge Construction

Completion of foundation work is most crucial activity to achieve the construction schedule on time. Drilled shafts (bored piles) are a foundation technique for large-scale bridge projects, offering high load-bearing capacity, stability, and durability. With increasing bridge spans and heavier superstructures, larger diameter drilled shafts even more than 3.0m are becoming the preferred choice for reducing the number of piles required, thereby accelerating construction timelines and enhancing structural performance.

By utilizing advanced drilling technologies, high-capacity drilling rigs, and specialized reinforcement cages, larger diameter shafts ensure that deep foundations can be installed faster, even in challenging geological conditions such as marine environments, riverbeds, and urban settings with limited workspace.

Reverse Circulation Drilling (RCD) Technology is used for fast and efficient drilling of large-diameter piles in marine and river environments. Improves penetration rates in hard strata, reducing time delays. Some case of notable Applications of Larger Diameter Drilled shaft done in India is briefed below.

Mumbai Coastal Road Project (MCRP)

One of the first projects in India to adopt 3.3 meter diameter piles for marine bridge foundations.



This approach reduced in-terms of the total number of piles, significantly cutting down construction time.

Larger diameter drilled shafts are revolutionizing bridge construction in India by enhancing speed, load-bearing capacity, and durability. As infrastructure projects grow in scale and complexity,

the adoption of larger diameter bored piles, advanced drilling rigs, and innovative foundation techniques will continue to drive faster and more efficient construction, ensuring the successful delivery of mega bridge projects across the country.

3 Focusing on Quality Control During Construction

3.1.1 Building Information Modelling (BIM)

Building Information Modelling (BIM) has revolutionized bridge construction by enhancing quality control, reducing project delays, and improving collaboration across multiple disciplines. Traditionally, construction projects faced challenges related to design conflicts, rework, and miscommunication between structural, geotechnical, and MEP (Mechanical, Electrical, and Plumbing) teams. With the adoption of BIM technology, these issues can be addressed before actual construction begins, ensuring smoother execution, reducing costs, and enhancing project efficiency. Authorities can review 3D digital models for faster clearance of designs and safety checks. Reduces delays due to regulatory bottlenecks.

3D Clash Detection and Resolution

BIM enables real-time clash detection between structural, civil, and MEP components. Advanced tools like Autodesk Revit, Navisworks, and Tekla Structures help identify conflicts before construction, preventing costly rework.

Streamlined Coordination Between Stakeholders

BIM creates a common data environment (CDE) where engineers, contractors, and consultants can collaborate. Helps reduce miscommunication and ensures that everyone works on updated models rather than outdated 2D drawings.

Efficient Material and Resource Planning

BIM integrates with 4D (time) and 5D (cost) models, optimizing construction schedules and budget tracking.

Reduces material wastage and enhances just-in-time delivery of components.

BIM is transforming bridge construction by minimizing design clashes, improving quality control, and accelerating project execution. With widespread adoption, BIM will continue to enhance accuracy,

safety, and efficiency in India's mega infrastructure projects, ensuring timely and cost-effective delivery.

3.1.2 Geometric Control Using Advanced Software

Geometric control is a critical aspect of bridge construction that ensures precise alignment, levelling, and positioning of structural elements such as piers, girders, precast segments, and bearings. Any deviation from design specifications can lead to structural instability, safety hazards, and costly rework. To enhance quality control and minimize project delays, ABES software is increasingly being used in India's major infrastructure projects.

ABES software provides real-time monitoring, automated geometric adjustments, and digital verification of bridge components during erection, significantly improving accuracy and reducing manual errors.

This ensures accurate installation of bridge components without the need for dismantling and rework.

Geometric control using Geometric Control software is transforming bridge construction by enhancing precision, reducing rework, and accelerating project timelines. By ensuring real-time alignment monitoring, automated adjustments, and integration with BIM, this technology is setting new benchmarks in quality control, making bridge construction in India more efficient, safer, and cost-effective.

4 Emerging Trends for Bridge Maintenance

4.1.1 Life Cycle Cost of Bridge

While initial construction costs are a critical consideration in infrastructure projects, modern bridge design and maintenance strategies increasingly prioritize long-term life cycle cost (LCC). The shift from traditional designs to low-maintenance, durable structures is driven by the need to reduce frequent repairs, minimize disruptions, and extend bridge lifespan. In India, major bridge projects are now integrating monolithic integral structures, reducing expansion joints, and eliminating bearings to lower maintenance expenses and ensure structural longevity.

Minimizing Expansion Joints for Reduced Maintenance:

Expansion joints are one of the most vulnerable components of bridges, requiring frequent inspections, repairs, and replacements. They allow

for thermal expansion and contraction, but over time, they deteriorate due to:

Continuous vehicular loading and vibrations, causing cracks. Water ingress leading to corrosion of reinforcement and deck slab failure. Debris accumulation and joint failure, resulting in structural instability.

By minimizing expansion joints, bridges experience less frequent maintenance issues and improved durability.

Avoiding Expansion Joints in the Middle of the Span:

Mid-span joints are highly susceptible to structural movement-induced failures. Avoiding them reduces long-term repair and maintenance costs.

Monolithically Integral Structures – Eliminating Bearings for Enhanced Durability:

Monolithically integral bridges eliminate bearings by rigidly connecting piers and decks and thereby eliminating the requirement of future maintenance of bearing and reduce the life cycle cost of the bridge.

Optimizing bridge maintenance through life cycle cost analysis is a critical emerging trend in modern infrastructure projects. By reducing the number of expansion joints, avoiding the joint in the middle of the span, and adopting integral structures without bearings, engineers can enhance structural longevity, reduce maintenance costs, and improve operational efficiency.

These best practices are now being widely adopted in India's mega infrastructure projects, ensuring cost-effective and sustainable bridge networks for the future.

4.1.2 Ultra-High-Performance Concrete (UHPC)

Ultra-High-Performance Concrete (UHPC) is revolutionizing bridge construction and maintenance due to its exceptional strength, durability, and resistance to environmental degradation. As infrastructure demands grow, the focus has shifted from reducing initial construction costs to optimizing long-term life cycle costs (LCC). UHPC offers extended service life, lower maintenance needs, and improved structural resilience, making it a preferred material for modern bridges in India and globally.

Exceptional Strength and Load-Bearing Capacity:

UHPC has a compressive strength of 150-200 MPa, significantly higher than conventional concrete (~40-60 MPa). Enhanced flexural strength (~20 MPa) reduces cracking under repeated vehicular and environmental loading. Reduces section thickness, allowing for lighter and more efficient bridge designs.

Reduced Maintenance Due to Crack Resistance:

Self-healing microstructure prevents water ingress, reducing corrosion of reinforcement. High tensile strength and fibre reinforcement minimize micro-cracking and fatigue damage. Significantly extends bridge service life to over 100 years, reducing periodic repairs.

UHPC is redefining bridge maintenance by offering unparalleled durability, crack resistance, and low maintenance costs. With its superior mechanical properties, resistance to harsh environments, and extended service life, UHPC is a game-changer for India's next-generation infrastructure. By integrating UHPC in bridge decks, piers, and joints, India is ensuring more sustainable, long-lasting, and cost-effective bridges for the future.

4.1.3 Structural Health Monitoring Systems (SHMS)

Structural Health Monitoring Systems (SHMS) have become a critical component in modern bridge maintenance to enhance safety, longevity, and cost efficiency. With the increasing number of aging and high-traffic bridges, proactive maintenance using SHMS ensures early detection of structural issues, minimizes unexpected failures, and optimizes repair schedules. In India, where infrastructure projects are rapidly expanding, SHMS is being integrated into mega bridge projects to enhance monitoring and reduce long-term maintenance costs.

Early Detection of Structural Issues:

Real-time monitoring sensors detect stress, strain, displacement, and cracks in bridge components. Prevents sudden failures by identifying minor damages before they escalate.

Remote Monitoring for Reduced Maintenance Costs:

SHMS allows continuous remote monitoring, reducing the need for frequent on-site inspections. AI-driven predictive analytics suggest maintenance interventions before major damage occurs.

Improved Safety and Disaster Prevention:

SHMS helps in earthquake monitoring, extreme weather impact assessment, and overload detection. Real-time data ensures quick response in case of structural weaknesses.

Extended Bridge Lifespan and Reduced Downtime:

SHMS ensures preventive maintenance, which extends a bridge's service life by detecting corrosion, fatigue, and material degradation. Reduces bridge closure periods for repairs, minimizing traffic disruptions.

Data-Driven Decision Making for Efficient Maintenance Planning:

SHMS collects long-term performance data, helping engineers plan cost-effective maintenance strategies. Optimized maintenance reduces life cycle costs (LCC), ensuring better resource allocation.

The adoption of SHMS in bridge maintenance is transforming India's infrastructure by providing real-time insights, reducing maintenance costs, and improving safety. As India continues to build mega infrastructure projects, SHMS will play a crucial role in extending bridge lifespan, preventing failures, and ensuring long-term sustainability. The future of bridge maintenance lies in smart, AI-driven monitoring systems that enhance efficiency, reduce risks, and optimize maintenance strategies.

5 Case Study: Best Practices Implemented in the Palashbari Project

On behalf of the State Government, Assam Public Works Roads Department has proposed the design and construction of the Palashbari Bridge over the river Brahmaputra, which, together with its approach structures and roadways, will connect Palashbari to Sualkuchi on the eastern edge of Guwahati in the State of Assam.

The proposed four-lane extra-dosed PSC bridge over the Brahmaputra River for a length of 3600 metres has multi-span extra-dosed units of PSC superstructure, a 216 metre viaduct, a 5387 metre approach road with one traffic junction at NH-17 with a service road on the Palashbari side, an 864 metre elevated road, and a 1927 metre approach road with a service road and a rotary at the end that meets at Bongsor Sualkuchi Road on the North Bank. The total project length is 12.21 km. The main bridge is a four-lane carriageway with an overall width of 28 metres. The project starts at Kaita Sidhi on NH-

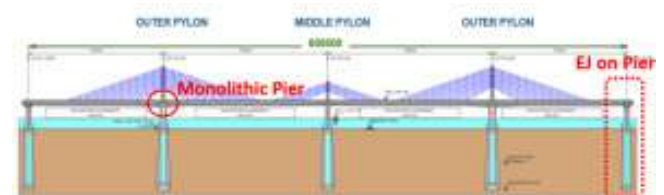
17 (near Mirza) on the South Bank, crosses the Brahmaputra River, and terminates at Bongsor Sualkuchi Road on the North Bank.

The site location of Palashbari-Sualkuchi Bridge Project is shown in Figure.



5.1.1 Structural Design

Superstructure for main bridges is proposed as Prestressed Concrete Single Cell Box Girder with internal struts constructed by Balanced Cantilever Method. The main span superstructure is an Extradosed superstructure. The unit block of the main bridge adopted is a 3-pylon Extradosed bridge type, with a span of $(135\text{m}+165\text{m}+165\text{m}+135\text{m}) = 600\text{m}$. The superstructure is composed of the concrete girder with bonded prestressing tendons, and Extradosed cables. The girder has a typical depth of 4.75m at mid-span. And at pylon locations, the depth of the girder is 5.75m for the outer pylon and 5.45 m for middle pylon. Total width of the deck is 28.0m with (3+3 lanes with Footpath) divided carriage way.



No Expansion Joints in the Middle of the Span which will eliminate any maintenance cost for the expansion joint in the middle of the span if provided.

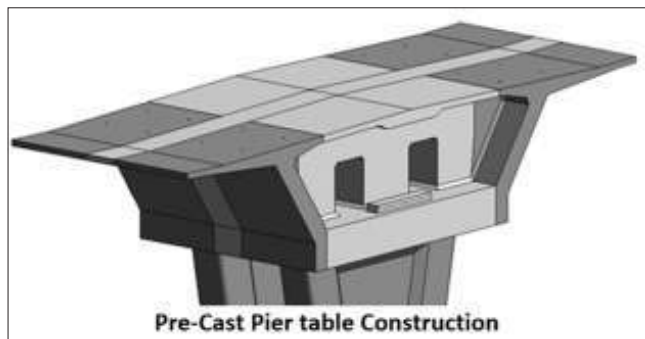
Monolithically integral bridges eliminate bearings by rigidly connecting piers and decks and thereby eliminating the requirement of future maintenance of bearing and reduce the life cycle cost of the bridge.

Optimizing bridge maintenance through life cycle cost analysis is a critical emerging trend in modern infrastructure projects. By reducing the number of expansion joints, avoiding the joint in the middle of the span, and adopting integral structures without bearings, engineers can enhance structural longevity, reduce maintenance costs, and improve operational efficiency.

5.1.2 Construction Best Practices

Precast Pier Table Construction:

Speeds up construction while maintaining high quality. Precast pier tables are constructed at cast yard while foundation and pier construction progress simultaneously, leading to concurrent execution and reduced overall project timelines. By applying precast technology in the pier table work, significant reduction of in-situ construction is envisaged more than 4 month per pylon. Furthermore, it will ensure the better accuracy of the construction as the precast part of the pier table will be constructed under the controlled area, i.e., casting yard. Therefore, better quality geometry control can be also achieved.

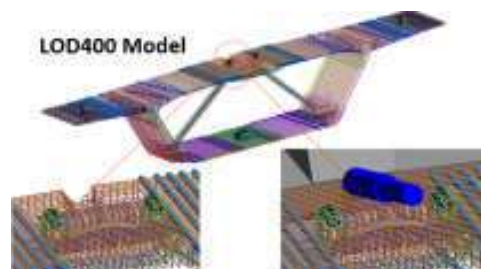


5.1.3 BIM Implementation

BIM was Implemented for the Extradosed bridge which will help prevent design clashes, ensuring

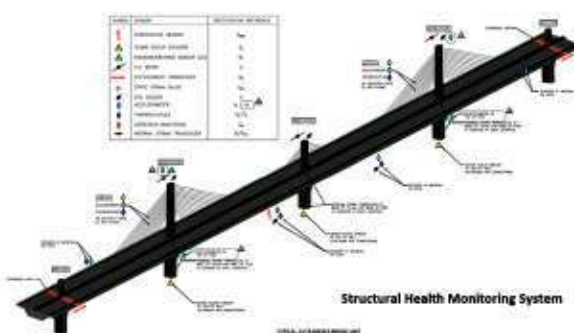
smooth project execution at site.

LOD 400 Models are developed for well foundation, lower pylon and superstructure deck stay and non-stay segments.



5.1.4 SHMS Implementation

Proposed SHMS in the EPC for the Main Bridge as per below details for getting real-time structural health monitoring which will ensures long-term sustainability and safety.





The Evolving Scenario in Bridge Engineering

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INTRODUCTION

The article traces the salient points of developments in bridge engineering from early times to the present, with bridges already presenting a formidable picture. Further identified are some of the ongoing technological advances as well as the challenges ahead. The article also shares information about two iconic bridge projects currently in the starting stage of construction in India. While the focus is essentially on bridges, the emerging scenario is just as applicable to structures in general.

Early History

Bridges, in one form or the other, have been part of the human civilization. Perhaps these were first indicated by a tree falling across a rivulet or by monkeys using vines and creepers to jump around the jungle. Even the more formal early bridges used only natural material (Figs. 1,2) such as timber, creepers and stone, had small spans and were obviously meant for very light traffic. Romans showed their intelligence by doing some clever engineering sense. (Fig.3 and 4). These bridges (and structures) were in complete harmony with nature - no issues of sustainability!

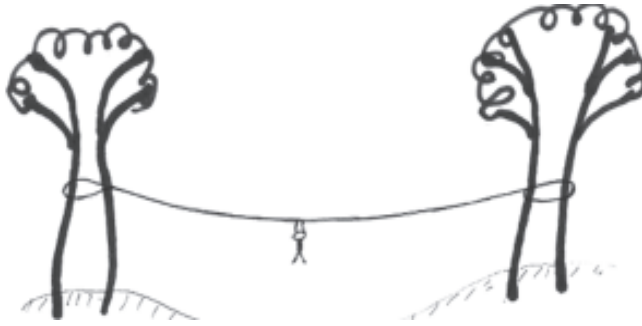


Figure 1: Primitive Suspension Systems



Figure 2: Stone Bridge



Figure3: The Pantheon at Rome using 'Hot mixed' pozzolanic concrete, with incredibly high strength



Figure 4 : Remarkable Aqueduct with semi-circular arches

Modern Era

The middle nineteenth century should be considered to have ushered in modern structural engineering, as also indeed bridge engineering. The one main reason for venturing into this era of bridge engineering was the availability of structural steel, followed a little later by concrete. The human spirit of adventure, innovation and greater achievements truly took wings, and today the world can boast of having bridges with spans of over 2 km, carrying six lanes of traffic (Fig. 5 and 6). Inadvertently though, the seeds of the problem of sustainability were sown, and the same human race is grappling today with a fully grown problem of sustainability.

”

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”



Figure 5: Russky Bridge, Longest Cable Stayed Bridge in the world (1104 m central span)



Figure 6: 1915 Çanakkale Bridge, Longest Suspension Bridge in the world (2033 m Main Span)

It is nevertheless interesting to look at the key factors that lay behind this stupendous change of scenario in bridge engineering (in structural engineering in general) in the last couple of centuries.

THE KEY FACTORS

The above Section points out that modern bridge engineering began to take roots in earnest in the mid Nineteenth century. The pace of growth has been on the upward curve ever since, with



the last 50 years having seen achievements which would have been hard to imagine even in the 1950s. The key factors mainly behind this evolution are described below:

Key Factor 1: Demands for Additional Infrastructure.

It is easy to understand that increasing demand for additional and improved infrastructure is behind the above growth. One important factor leading to this demand is well established fact of *Increasing Urbanization*. Whether good or bad, this is irreversible, and it is obviously demanding, and will continue to demand, additional civil infrastructure related to transportation (metro rail with new challenges), communication, habitat, energy, recreation, to state a few aspects. An assessment made about 10 years ago indicated that India will require to add a new Chicago year after year.

Key Factor 2: Appropriate combination of form and material.

The current materials in use primarily are Concrete, PSC, Aluminium alloys, Steel, and, a range of composites. Steel wires of tensile strength of upto 1860 Mpa, structural steels with 800 Mpa and ultra-high performance concretes with compressive strengths touching 200 Mpa (tensile strength upto 15 Mpa), besides Carbon fibre based wrapping materials, have all given the structural engineer a wide range of possibilities for their application, including repair, retrofitting and rehabilitation work for existing structures.

Appropriate choice of form to utilize the material in primarily direct tension or compression, as per the case in point, helps to consider longer spans or taller heights. Furthermore, materials with higher strength-weight ratio make it possible to reduce dead loads and enhance the possibility of taller structures, and, bigger spans. This is almost a necessity for longer cable bridges.

Key Factor 3 : Improved understanding of loads, analytical and experimental techniques, particularly driven by the Electronic revolution.

A better assessment of loads and effects, particularly those created by the natural phenomena such as seismicity and wind, has been a very redeeming feature of the developments post 1950.

Furthermore, conventional hand-calculation Methods gave way to Matrix methods, FEM, CFD etc. and their applicability received a great fillip

from computer based coding. Analytical received much needed support from greatly improved facilities for experimental investigation due to developments in sensors as well as automation. See an outstanding example in Fig. 7 showing a 1/100 scale wind tunnel model of the Akashi Kaikyo bridge (960+1991.6+960m) in Japan. The advent of computerization and its tremendous growth has made a huge difference to the developments described above.



Figure7: 1/100 scale Wind Tunnel model of the Approximately 4 Km long Akashi Kaikyo Bridge.

Other Key Factors :

- Evolutions in construction technology, in fabrication, lifting, installation. See an outstanding example in Fig. 8 showing a 80m diameter caisson for the tower foundation of the Akashi Kaikyo bridge.
- Growth of allied disciplines - conventional as well as new

All the above factors have given great confidence to engineers and architects to create the challenging the structures around. Figure 9 is clearly indicative of related growth in bridge structures



Figure 8: 80 m diameter steel caisson fabricated onshore being floated to the location of the pylon for the Akashi Kaikyo bridge

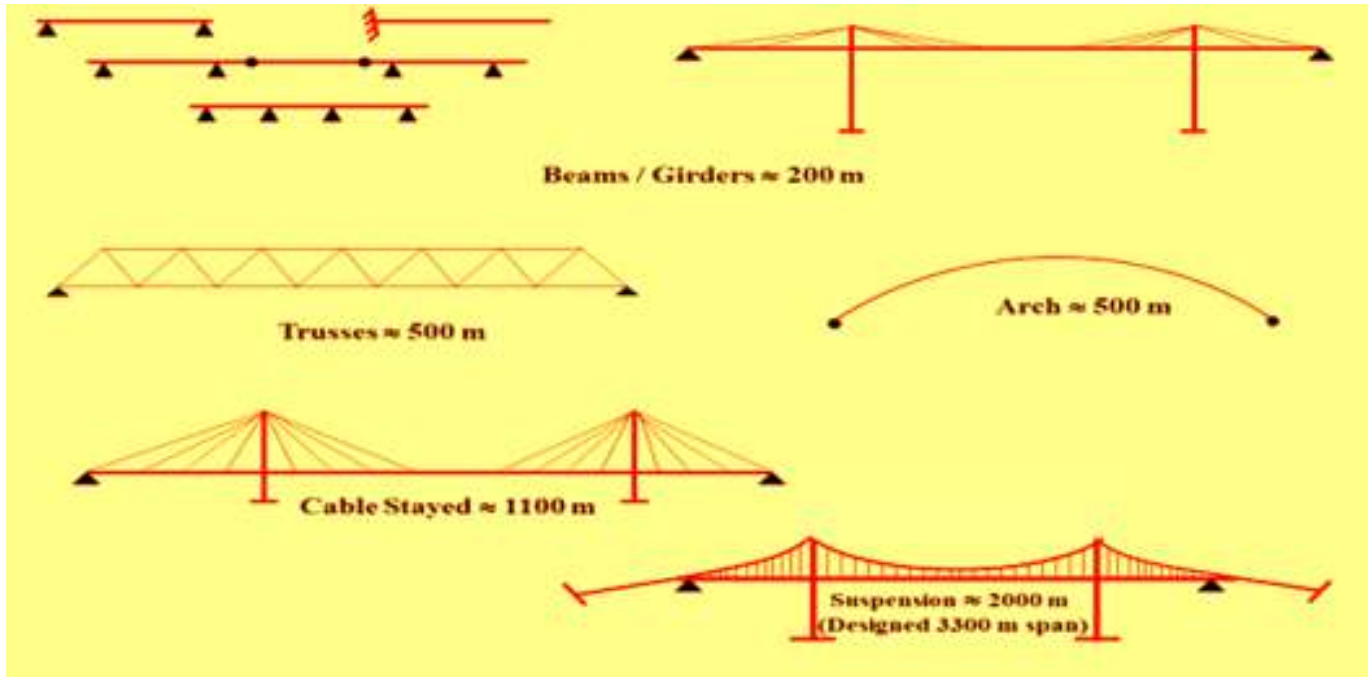


Figure 9: Notional Span Ranges for Various Bridge Forms

INDIAN SCENARIO

The developments in India, though modest compared to the International ones, have been commendable to. The examples of outstanding arch and cable supported bridges, particularly the latter, are clearly pointing to a bright future. See fig.10 to 13.



Figure 10: Chenab Railway Bridge - The highest in the world, Above bed level at 359 m



Figure 11: Haridwar Bridge - First in India



Figure 12: The Iconic Vidyasagar Setu



Figure 13: Okha-Bet Dwarka Signature Bridge-Longest Main span in India (500m) Completed 2024.

In terms of cable bridges alone, the progress in the last couple of decades has been impressive. Table 1 gives the approximate numbers:

Table 1: Cable Supported Bridges in India

	Cable Stayed Bridges	Extradosed Bridges
Completed	20	15
Ongoing	10	20
Span Range	20-500m	50-230m

Features of two iconic bridges under design and construction are described below in brief:

The longest span cable stayed bridge under construction at Kapurthala.

A cable stayed bridge with a main span of 700m which will be the longest main span in India is proposed over river Beas to establish the connection of Amritsar with Delhi-Amritsar-Katra

expressway from Junction with Kapurthala-Sultanpur Lodhi Road (NH-703A) near Isharwal Village to Dhunda Village. The location of the bridge is an important tourist and pilgrimage destination due to the nearby attractions such as Golden Temple, Amritsar and Radha Soami Satsang Beas.

The bridge has an overall length of 1300m (excluding viaduct of 810m length) and deck width 38.24 m to accommodate 8 lanes of vehicular traffic. The bridge configuration consists of 4x50m+100+ 700m+ 100m+4x50m.

The main pylons having 174m height have a security deck having plan area of 779 m² at 74m height and the other a viewing gallery with Restaurant having plan area of 738 m² at 168m height. As shown in Fig. 14



Figure14: An overall view of the Kapurthala bridge.



The pylons have well foundations with a diameter of 16.5m, and steining thickness of 2.5m, which is being constructed by using jack down method. The back spans have well diameter of 6.4m. Fig. 15 shows the construction and progress.

The superstructure consists of steel concrete composite deck in part of the main span, and rest of the deck is made in concrete. The cables are spaced typically 12m apart having the longest cable length of approximately 380m and maximum diameter of 200mm.

The contractor of the bridge is SP Singla Constructions PVT. LTD., and the authority engineer of the bridge is Rodic Consultants PVT LTD, New Delhi in JV with Sapatagon Asia Consultants PVT LTD. which comes under the charge of NHAI - PIU Amritsar.



Figure15: View of Under construction main pylon well foundation.

The 3.6 KM under construction extradosed bridge at Guwahati Assam.

Extra dose bridge with a main span of 165m having total length of 3.6km with 24 nos. of total spans is proposed over river Brahmaputra to establish the Connection between Palashbari and Sualkuchi. The bridge will reduce the travel distance between Palashbari to Sualkuchi from ~38 km to 12.21 km. The bridge will de-congest the city of Guwahati and increase transport efficiency, thus helping in cutting down travel time for daily commuters from Nalbari, Barpeta and Baksa traveling to Guwahati from ~100 mins to ~25 mins. The bridge will facilitate direct connectivity to the internationally-renowned silk town of Sualkuchi and the industrial region of Amingaon with Guwahati and the international airport.

A 3.6 km long extradosed bridge is proposed to cross the Brahmaputra River at the project location. Two 216 m long precast beam and slab approach viaducts are proposed at the approaches to the main extradosed bridge on both the north and south bank of the river. A 756 m long and a 108 m long elevated viaduct are also proposed on the northern approach road to traverse two environmentally sensitive wetland areas.



Figure 16: An overall view of the Palasbari bridge.

The height of outer pylon is 30m and inner pylon is 17m. The outer pylon has Twin D type well foundations with a diameter of 19.35m, and a steining thickness of 3.6m which is under construction. The middle pylons have circular type well foundation having diameter of 11.4m and steining thickness of 2.6 m.

The superstructure is box girder type having depth of 5.75m at pylon location and 4.75m at middle. The no of cable in outer pylon is 13 and middle pylon is 5.

The contractor of the bridge is L&T constructions Transportation Infrastructure, and the PMC of the bridge is Rodic Consultants PVT LTD, New Delhi in JV with ICT Consultants PVT LTD which comes under the charge of PWRD Assam and the project is funded by the New Development Bank.

UPCOMING CHALLENGES & DEVELOPMENTS

Bridge and structural engineering are on a very strong platform with the possibility of creating even the unthinkable, but new challenges are

thrown up which have to be catered to. Basically new challenges are thrown up by the need to maintain the existing structures as well as to continue to meet the huge scale of demand for additional infrastructure (which includes bridges) in the Changing Environment. Global warming is leading to effects such as rising temperatures, changing climate patterns, rising water levels, possibilities of increasing frequency and intensities of natural hazards and raising the all-important issue of sustainability.

For these challenges to be met, civil / structural engineers have to continually upgrade their competencies through education, training and practice, besides, being aware of improvements in technologies, such as 3-D printing, developments in software, growth of allied disciplines such as biotechnology, information technology, artificial intelligence, machine learning, robotics, automation and forensic engineering.

Furthermore, in order to address concerns for sustainability, it is required to,

1. Optimise/ minimise use of the materials with significant carbon footprint, by adopting improved design methodology, ensuring re-cyclability, design for longer life, and ensure easier constructionability and maintainability
2. Research for new improved materials, which will have lower carbon foot print. The latter is being pursued quite extensively. Some of the emerging developments are, carbon composites for new as well as for repairs of the existing bridges, Ultra High Performance Concrete (UHPC).

In the design of bridges, folded web steel girders, butterfly webs for extradosed bridges of long span (300m to 400m) (see figs. 17 and 18) , and seismic isolation using rocking piers (New Zealand and Japan development) offer some new ideas.

Folded Steel Plate Girder Bridges offer the same advantages as Closed steel box girder bridges. Opening in the bottom allows easy inspection of the bridge. Elimination of any bracing (internal or external or top lateral bracing), significantly enhances the service life and reduces the cost. These bridges are economical for short span bridges.

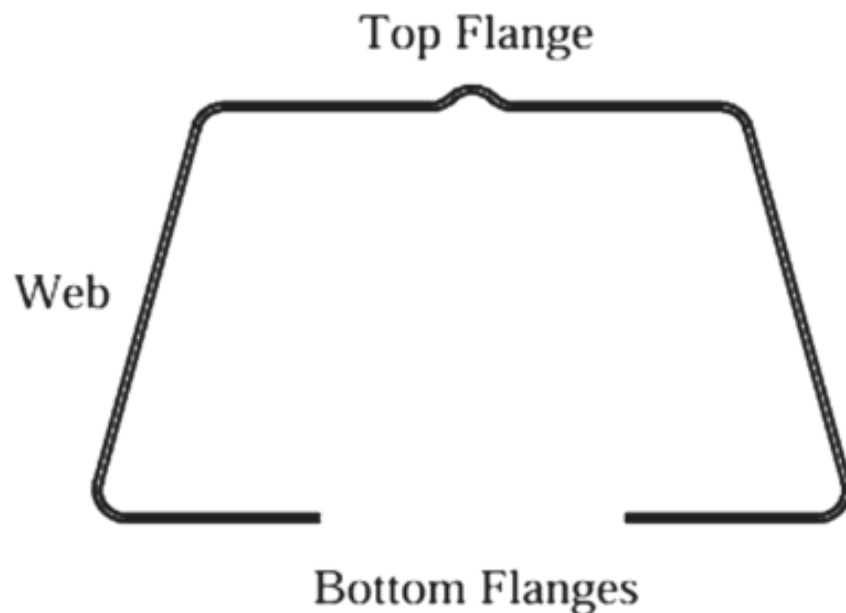


Figure17: Folded Steel Plate Girders

Besides more innovative efforts in design there are engineering developments such as the greater and ready use of Artificial Intelligence and Information Technology, and, in monitoring and rehabilitation, use of drones, robotics and automation.

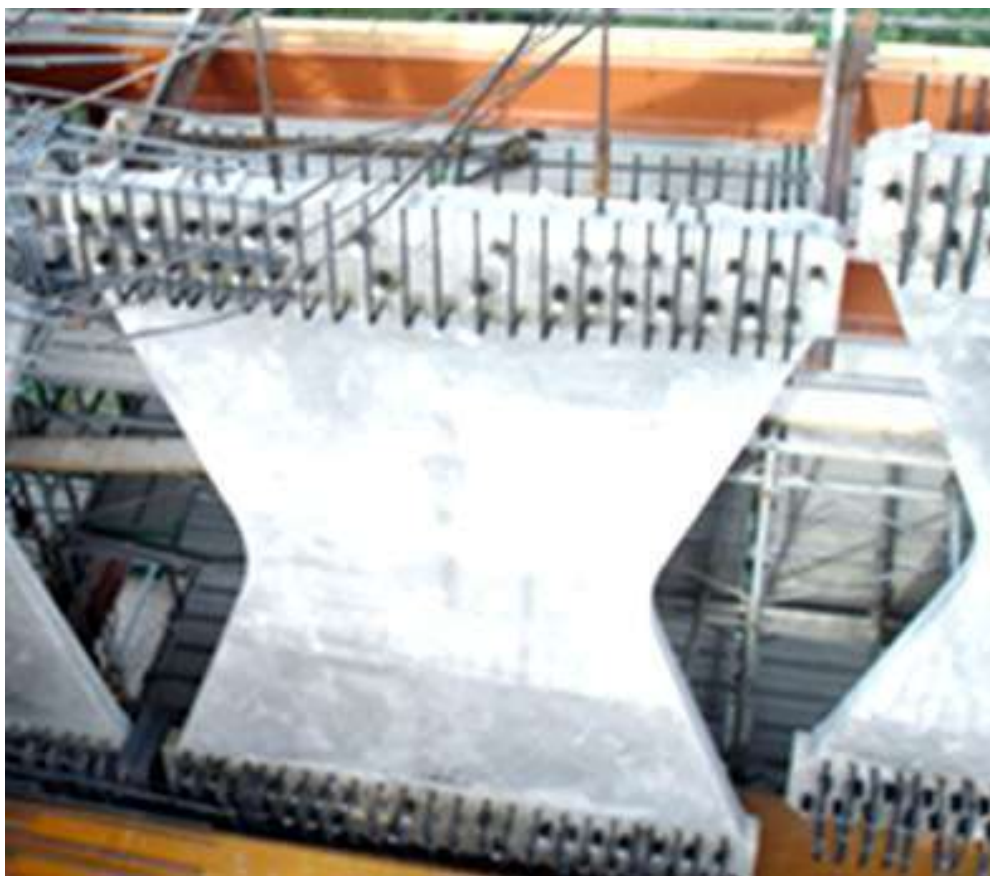
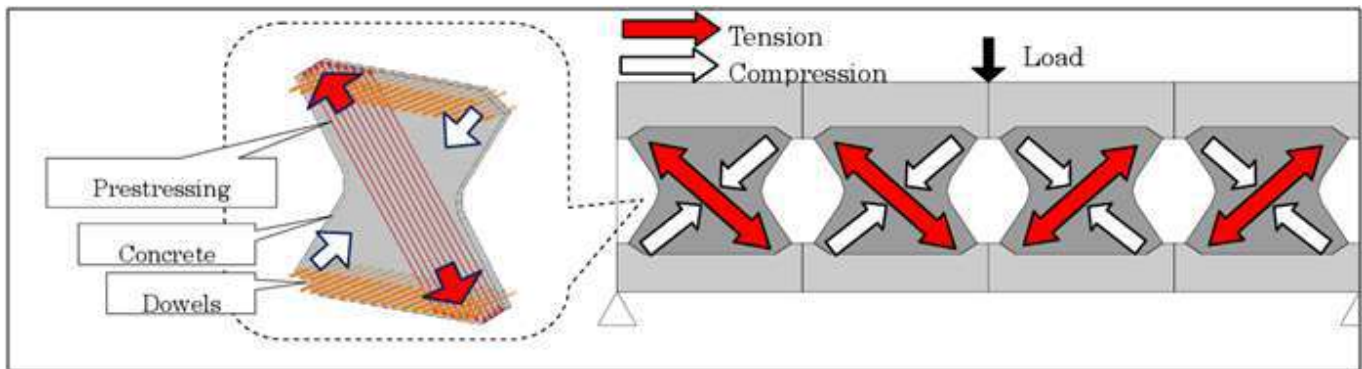


Figure 18: Typical Details of Butterfly panels for Webs of the Main girder

CONCLUSION

There have been continuing contributions of high quality from structural engineering, covering a wide spectrum of needs for the growth of the society. However, the all- round change of scenario in engineering and technology, changes in environment, and the huge additional demands related to civil infrastructure, throw up new

challenges.

The future of structural and bridge engineering will therefore require continued innovation and collaboration. It is an exciting time for our profession, and with the right approach, we can create structures that will stand the test of time and serve as a testament to human ingenuity and innovation.



Design/Construction of Cable Stayed/Extradosed Bridges

Assystem Stup

Mrs. Mousumi De, Joint Principal Manager 'Assystem STUP

Abstract

Extra-dosed bridges, often perceived as an intermediate structural design between cable-stayed bridges and cantilever constructed box girder bridges, have emerged as a compelling engineering solution. In this Article the details regarding Geometric arrangement & Analysis of Jabalpur Extradosed Bridge are stated.

I. Introduction

An Extradosed bridges are categorised as "in-between" cable-stayed and girder bridges. Although extradosed girders resemble cable-stayed bridges in appearance, they behave more like pre-stressed concrete girders due to their stiff deck and shallow angled cables. Only a small percentage of the live load is directly carried by the extradosed cables due to their shallow angle. This is how an extradosed bridge behaves in its basic form.

For spans between 100 and 250 metres, extradosed bridges provide a competitive substitute for more conventional forms like arches, girders, and cable-stayed systems. Concrete or composite girder bridges are the most popular option for spans up to 100 metres. However, for spans over 100 metres, the depth of the boxes above the piers is becoming less and less acceptable due to cost and constructability issues. In most cases, cable-stayed bridges are the most cost-effective option for spans exceeding 250 metres. Widespread publications have detailed the conceptual and structural designs for this type of bridge, which has bridge decks composed of steel, concrete, or a mix of the two materials. The three bridge types discussed above are depicted along with their typical dimensions in Fig. 1.1. The features of a normal Extradosed Bridge become clear when comparing them.

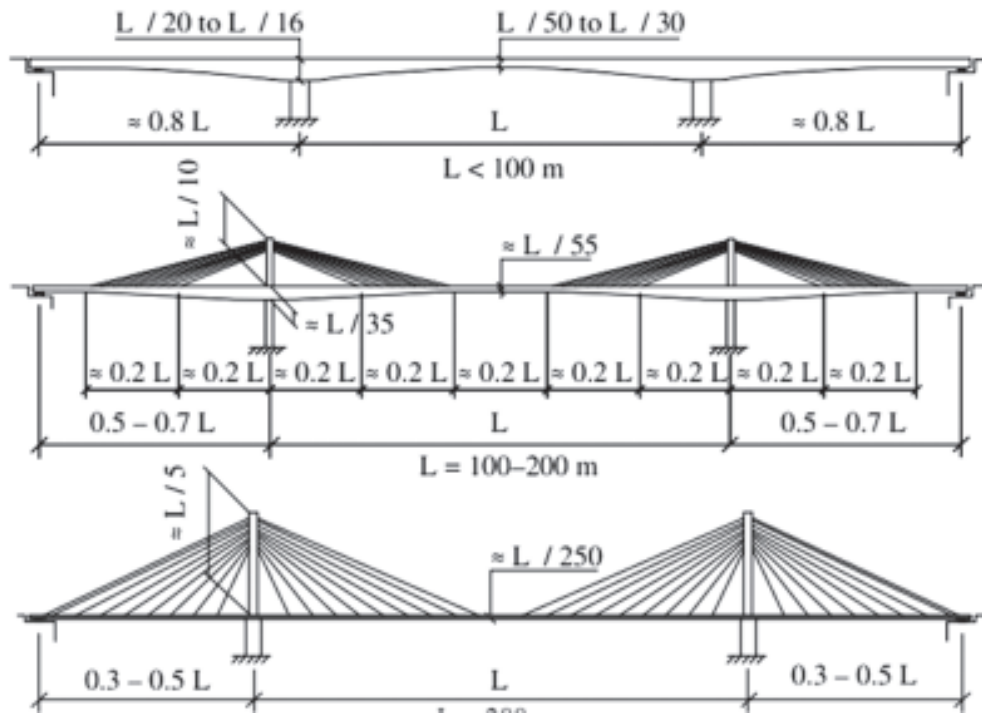
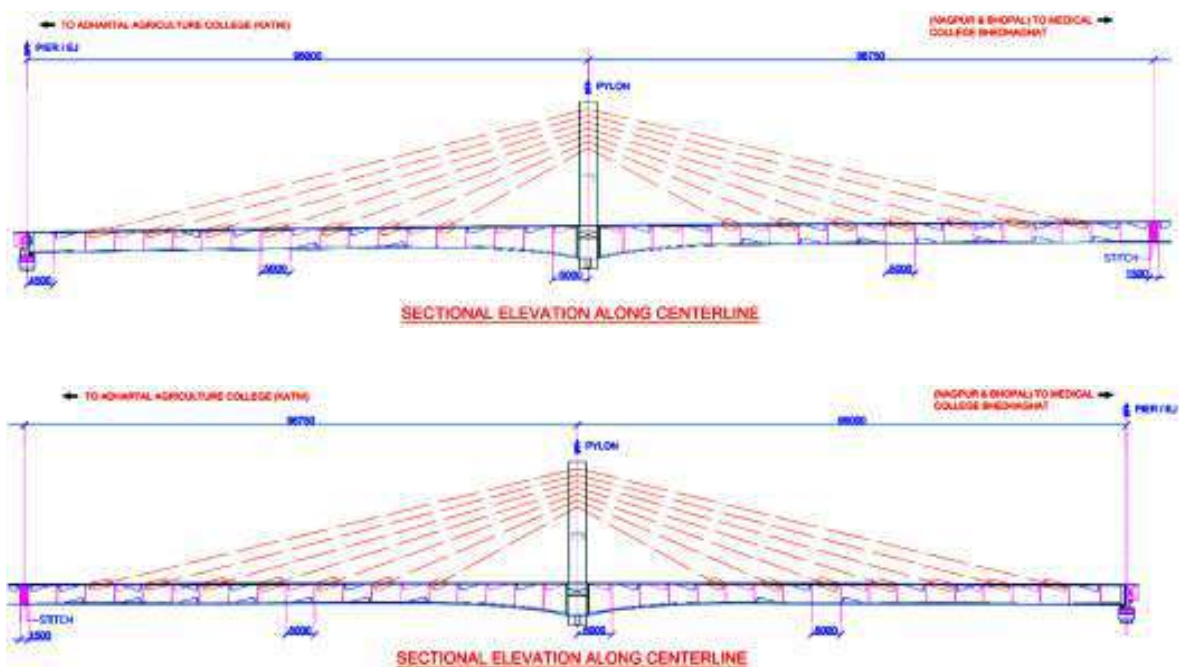


Fig : 1.1 Girder to Extradosed to Cable Stay

II. Bridge Conception - Jabalpur Extradosed Bridge

The Elevated Corridor in Jabalpur City comprises of approximately 5.905 km long 3-lane road consisting 385.5m long Extradosed Bridge. The Extradosed bridge consists of 193.5m main span and two 96m side span on each side. The cable stays provide intermediate supports for the girder in the three intermediate spans. They carry the load of the girder and transfer it to the pylons and to the back-stay cable anchorages. The cable stays, as a series of overlapping triangles, comprising the pylon and the girder, are placed rather far apart from each other. Thus, the relatively stiff extradosed girder has to span the large spacing between cables and in addition to resist the global forces.



[illegible][illegible]

through the webs. The stays cables transfer a part of load into the pylons. The 21mt high upper pylons are monolithically connected to the superstructure through the pier table above the lower pylons. Between the superstructure and

piers POT-PTFE bearings were installed to transmit loads to the substructure and to accommodate relative movements. The height of lower pylons is 10.253mt. Twin piers forming the lower pylon are monolithically casted with the pier table. Each lower pylon was founded on pile foundation.

After construction of foundations and all piers, a balanced cantilever segmental construction for the concrete box- Girder is adopted as the most efficient methods. This construction methodology is most advantageous as it will not disrupt the traffic and services below without expensive falsework. The cantilevers were constructed from 5.0 to 6.0m long segments.

III. Computation Model

A FEM model using Midas Software was developed for the analysis purpose. Concrete Grade of M55 is assigned to Girder and Upper pylon as Material Property and the lower Pylon is assigned M70 Grade. The Girder and pylons are simulated as member elements and Cables as truss elements. The Geometric property are assigned as given in section II. The construction stages are successively simulated for analysis purpose and to represent appropriate behavior of the girder during construction. The thickness of the webs and the bottom slab of cross-section track their real variation along the bridge.

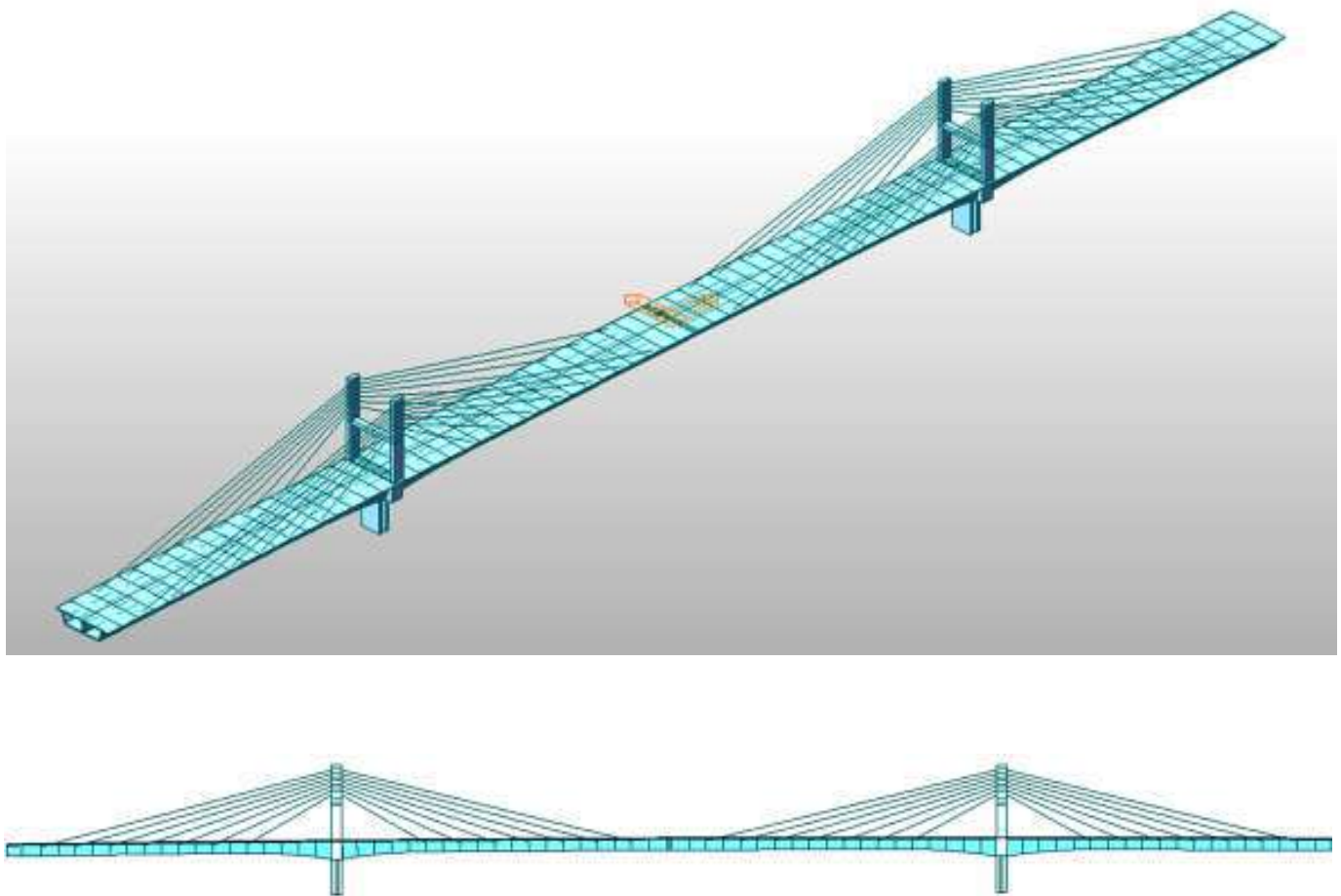


Fig:3.1 Finite element representation of Extradosed Bridge.

The Boundary condition are considered as to represent fixed free behavior of the POT-PTFE bearing at the end supports. And at the pylon supports the Girder is rigidly connected to the pylon members.



Fig: 3.2 Jabalpur Extradosed Bridge- Construction stage.

IV. Some Other Extradosed Bridges by Assystem Stup

i. Cable Stayed ROB across Station Yard at Nagpur:

General Features:

Total Viaduct Length	:	455.2 m
Cable Stayed Span	:	111.8 m + 88.2 m
Approach Length	:	255.2 m
Carriageway Width	:	2 x 11.0 m - 2 x 3 lane
Pylon Height	:	45.3 m RCC
Foundation	:	Pile of 1200 diameter



Fig: 4.1 Nagpur Cable Stayed Bridge -Construction Stage



Fig: 4.2 Nagpur Cable Stayed Bridge

ii. Cable Stayed ROB over Bardhaman Station Yard:

General Features:

Total Length of the Bridge	:	188.431 m
CP1 to P1 (Steel composite deck)	:	124.163 m
P1 to CP2 (RCC Deck)	:	64.265 m
Number of Lanes in each Direction	:	2 (7.5 wide C/W)
Width of bridge deck for main span	:	27.7 m
Width of bridge deck for back span	:	28.2 m
Footpath	:	1.5 m on both sides
Deck slab for Main span	:	Pre-cast RCC Planks 130mm thick with 120mm cast-in-situ deck slab

Back span of RCC deck integral with pier CP2 and pylon P1.

Main span of steel composite Construction with bearing at pier location CP1.

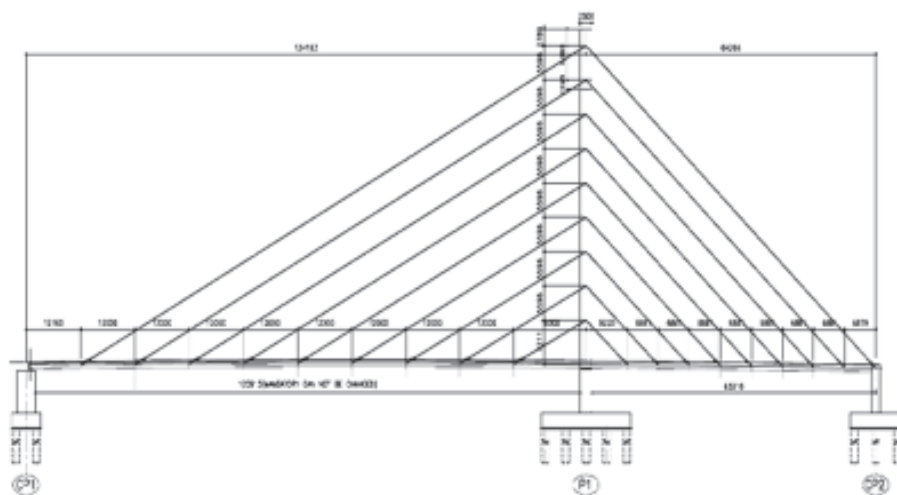


Fig: 4.3 General Arrangement



Fig: 4.4 Bardhaman Cable Stay Bridge - Construction Stage



Fig: 4.5 Bardhaman Cable Stay Bridge

iii. Extradosed Bridge across Durgam Cheruvu Lake, Hyderabad:

General Features:

Total Viaduct Length	:	517 m
Extradosed Span	:	97+234+96 m
Approach Viaduct	:	90 m
Total Width	:	25.96m including Footpath
Carriage Way	:	2x2 Lane
Upper Pylon Height	:	28 m RCC





Fig: 4.6 Durgam Cheruvu Extradosed Bridge -Construction Stage



Fig: 4.5 Durgam Cheruvu Extradosed Bridge

V. References:

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Innovative and Smart Infrastructure Techniques

for Bridge Maintenance and Monitoring



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Abstract

India's aging transport infrastructure needs effective and proactive bridge maintenance and monitoring to continue its safe operation during the entire life cycle. This article focuses on the innovation in bridge maintenance, inspection and monitoring of the bridges in the country.



how these improvements provide comprehensive insights into bridge integrity while streamlining the evaluation process. The technologies enable engineers to assess wear and tear more accurately, predict potential failures, and optimize maintenance schedules.

Innovative approaches for bridge maintenance and monitoring

Bridge maintenance requires both scheduled and unscheduled actions. For the unscheduled action, it is common to perform inventory and condition survey of existing structures by visual inspections. Since the year 1980, there have been several attempts made to automise the process by implementing Bridge Management Systems (BMS) and either by physical monitoring or Structural Health Monitoring (SHM).



Introduction

In view of the recent increase in the failures/ sudden collapses of bridges and other structures; maintenance and continuous monitoring is one of the most crucial factors for the safety and longevity as it enables early detection of damage particularly in India, where aging bridges present significant challenges. This article describes the cutting-edge techniques used for bridge evaluation and maintenance, with an emphasis on predictive maintenance strategies, allowing for accurate structural ratings. Based on practical experience with structural ratings, it demonstrates



Figure 1. Physical inspection by bridge division staff of M/s ICT Pvt. Ltd. using MBIU (Z-morh)

As part of a physical monitoring system, bridge condition surveys are often conducted by visual examination or by employing a Mobile Bridge Inspection Unit (MBIU). The MBIU technique enables the engineer to reach the bottom of the bridges (which is otherwise not accessible) to identify the damage/ deterioration even at the remote location of the bridges, such as bearings, underside of the bridge deck, substructure location and expansion joints as shown in Figure 1.

One typical example of Major Bridge @ Km. 26+100 (Kiratpur- Nerchowk project) where the inspection was carried out by the bridge division staff of M/s ICT Pvt. Ltd. using MBIU is shown in

Figure 2. During a detailed inspection, it was noticed that the end diaphragms of adjacent spans were touching each other leaving no space for expansion. This could lead to the development of extra stresses which were not accounted for in the design, further leading to the cracking of the structural components and hence crushing of the concrete. It was further noticed that in one of the spans, the metallic guided bearing was settled and there were visible cracks appearing on the pedestal. Further, efforts are underway to implement the innovative techniques to enable proactive maintenance and prolong the lifespan of structures by the use of drones for periodic inspections of bridges.



Figure 2. Detailed inspection of the remote locations of Major bridge @ Km. 26+100 (Kiratpur- Nerchowk project) using MBIU

SHM focuses on the assessment of deformations and displacements with the use of surface bonded or embedded sensors. At a global level, SHM enables damage detection by assessing the dynamic properties of the structure. The damage to the structure is indicated by the change in the vibration characteristics of the structure. This includes the vibration characteristics using smart material sensors (e.g. piezo-sensors, accelerometers, etc.).

Modern integrated SHM systems flourished in the mid-1990s in Asia for complex structural systems and long-span bridges (Balanced Cantilever, Extradosed Bridge and Cable stayed bridge). For such structures, environmental actions and the corresponding loads (wind, temperature, earthquake, etc.) together with the live loads (highway traffic/ Rail traffic), have a strong influence on their dynamic response, and can significantly influence the structural behavior and alter its geometry, thus limiting the serviceability performance even up to a partial closure. In India, there are some recent long-span highway bridges has been constructed which were equipped with SHM sensors and other instrumentation since the construction phase.

For example various kinds of SHM sensors were employed in the Paira bridge in Bangladesh and Phaphamau bridge in Allahabad for condition monitoring. The Phaphamau extradosed bridge was employed with various types of sensors and measuring units such as uniaxial and biaxial accelerometers, biaxial tilt meters, displacement sensors such as linear variable differential transformer (LVDT), strain gauges, weight in motion system were installed. Continuous monitoring is carried out using these sensors which are connected to the monitoring equipment using optical fibre network. A data acquisition system is used to store the raw data taken by all sensors of the monitoring system is stored on site. This data is accessed by engineers stationed at any other location for further analysis.

Conclusion

Considering the advantages of digitization and the technological capability that can increase efficiency at lower costs, it is imperative that maintenance procedures for the infrastructure



components be further optimized through the use of sensors and communication technologies, such as AI and machine learning (ML). Optimizing maintenance practices and identifying remodeling needs through sensors, communication technologies, etc. can be accomplished by

1. Supporting condition-based maintenance and smart infrastructures (use of sensing and inspection techniques in conjunction with models for structural integrity and degradation).
2. Use of cutting-edge technologies such as artificial intelligence (AI), radars, ultrasound, inspection robots, drones, satellite systems, etc. to carry out routine maintenance, inspection, and monitoring, improves infrastructure performance while simultaneously lowering risks and expenses.

However, with thousands of short- to medium-span bridges in India, condition monitoring of conventional bridges is a far more complicated task. Retrofitting these bridges in accordance with the new IRC regulations is a challenging task. The efficient application of technological advancements through a series of "policy," "management," and "technological" measures aids in periodic maintenance of these infrastructure components, which is essential for the safe and secure operation of road and rail structures as well as civil aviation structures.



Modular Expansion Joints With Seismic Fuse

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Abstract:

Expansion joints in bridges play a critical role in accommodating the expansion and contraction of bridge materials caused by temperature variation, creep, shrinkage and vehicular movement. Incorporating special modular expansion joints in seismic zones is crucial for ensuring the safety and longevity of

bridges. These joints not only accommodate temperature-induced expansion and contraction but also absorb and dissipate the forces generated during earthquakes, reducing damage and maintaining the bridge's structural integrity. When designing bridges in high seismic areas, it's essential to integrate advanced joint systems tailored to local seismic conditions.



Metco's specially designed FUSE-Box Systems are designed to protect modular expansion joints and their connecting structures from earthquake damage. Traditional expansion joints may fail during an earthquake if they close beyond their design limits, potentially causing significant damage to both the joint and the bridge structure. The FUSE-Element addresses this problem by acting as a predetermined breaking point that allows controlled failure, thus preventing severe damage. This system enables the joint to return to its original position with minimal effort after an earthquake, ensuring that emergency vehicles can still use the bridge. The FUSE-Box type modular expansion joint is particularly recommended for bridges in high seismic regions, offering the added benefit of design optimization, often reducing the number of required expansion gaps.

Metco has developed multiple types of fuse elements for modular expansion joints, some of which are described here.

Introduction:

Modern bridge design techniques, driven by millennial engineering advancements, have led to increasingly complex and demanding bridge structures. These advancements necessitate higher performance from expansion joints to meet growing challenges, such as:

- Greater seismic durability.
- The need for quick reparability and replaceability.
- Higher traffic loads.
- Increased movements and rotations in all directions.

As the demands on expansion joints grow, so too must the technology behind them. Continuous innovation in expansion joint technology is essential to meet these evolving needs, particularly as bridge owners/authority and maintainers aim to reduce life-cycle costs associated with maintenance and repairs. The ability to minimize traffic disruptions caused by repair or replacement work is also a priority for bridge maintainers.

Bridge designers, asset owners, and users must stay informed about these technological advancements to benefit from the improved functionality, reliability, and durability offered by newer expansion joint systems. It is crucial that designers and owners are aware of these developments, ensuring they select the right durability, testing standards, and repair

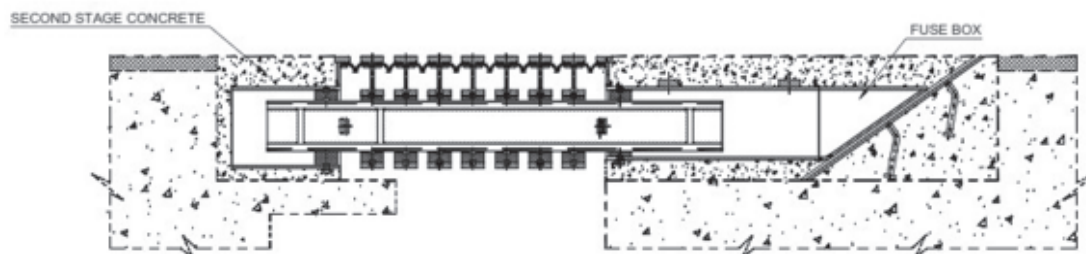
capabilities to maintain optimal expansion joint performance in the event of a seismic occurrence. This informed decision-making process will help to optimize the life-cycle performance of the joint, reducing maintenance efforts, costs, and environmental impact while ensuring that the structure remains functional for emergency and everyday traffic. One critical feature of the latest expansion joints is the ability to restore functionality quickly after a seismic event. Specifically, expansion joints that can be temporarily restored, allowing emergency vehicles to pass immediately after the event, are invaluable for post-earthquake operations. This is demonstrated in the modular expansion joint with the unique fuse-element, which has gained worldwide use for its ability to accommodate greater movements and rotations than other types of joints. This type of joint is widely regarded as one of the most versatile solutions for modern bridges. Two of the commonly used Fuse Elements developed by Metcoare described below. These fuse deployment systems have been developed by Metco over the years and have undergone extensive testing under simulated seismic loads and movements.

Longitudinal End-Type Fuse:

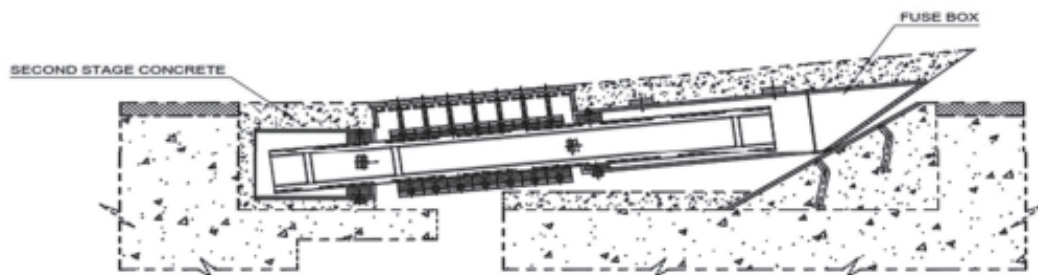
The Fuse Box mechanism is a core component of the modular expansion joint with fuse-element.

The system comprises a triangular steel element attached to one side of the expansion joint. This triangular element rests on a steel ramp that is permanently fixed to the main structure of the bridge. The interaction between the triangular element and the ramp is designed with a shear connection that has a predetermined capacity. In the event of an earthquake, if the movement capacity of the joint is exceeded, the connections between the triangular element and the ramp will fail. This failure occurs in a controlled manner, causing the triangular element and the joint to break free from the main structure. Metco's End-Type fuse box has multiple proprietary fuse elements integrated with the fuse box, which allows this controlled failure of the fuse. This controlled failure prevents severe damage to the joint and the bridge structure. After the earthquake, the joint remains in place across the bridge gap. Remarkably, the system allows the bridge to quickly return to functionality. With minimal effort, the expansion joint can be restored to a usable state, allowing emergency vehicles and evacuation traffic to pass safely across the bridge. Furthermore, the system is designed to be easily re-enabled, facilitating the resumption of normal traffic flow with minimal disruption.

The principle of the Longitudinal End-Type FUSE-Box type Modular Expansion Joint are illustrated in the figure below:



Normal Condition

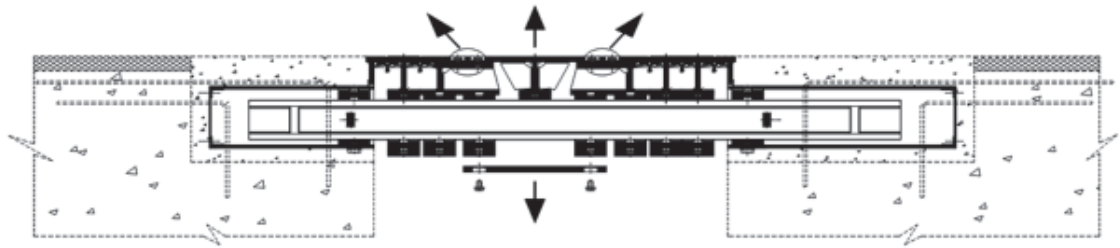


Max Closing Condition during Earthquake (Towards Joint)

Articulated Mid-Joint Fuse:

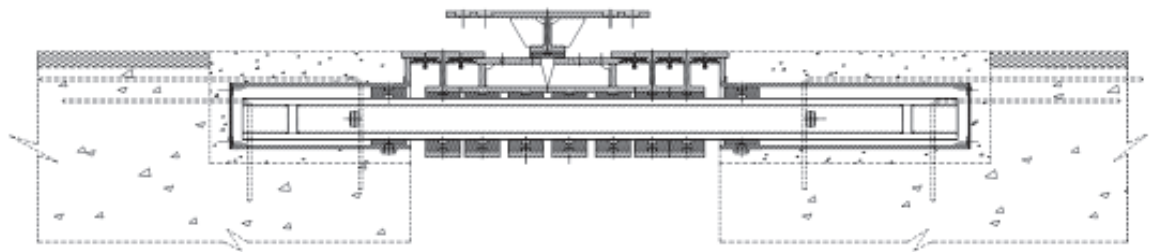
These joints are specifically designed to handle a wide range of multi axial movements and rotations. An Articulated Mid-Joint Fuse element is integrated between the center beams according to the specific movement requirements of the bridge. This element adds an additional layer of flexibility, enabling the system to accommodate a wider range of movements and forces. Metco's Articulated Mid-Joint fuse box has multiple proprietary fuse elements integrated with the articulated fuse box, which allows a controlled deployment of the fuse. This controlled deployment prevents severe damage to the joint and the bridge structure. After the earthquake, the fuse returns in place across the bridge gap.

The principle of the **Articulated Mid-Joint Fuse** Type Modular Expansion Joint is illustrated with the figure below:



Due to the internal stresses the center beams come to contract causing the articulated fuse element to activate and start rising above the DFL (Deck Finish Level) and the bottom plate to disconnect from the bolting arrangement of the joint

At the end of the seismic event the articulated fuse element is found to be completely elevated above the DFL and the bottom fuse element separated from the joint



Finally, the fuse element again returned to its position

Conclusion:

Metco's specially designed fuse elements are the result of years of intense theoretical research and prototype testing under simulated seismic events. The two types of fuse elements described here allow controlled deployment of the fuse during a seismic event, preventing significant damage to both the joint and the bridge structure. These joints are particularly recommended for bridges in high seismic regions, allowing quick return to functionality after seismic events and protecting the nation's assets.



Application of BSHMS for Maintenance of Bridges



Arko Dasgupta, MAGEBA

Bridges are vital components of transportation infrastructure. With aging structures, increasing traffic loads, and changing environmental conditions, the need for continuous and intelligent maintenance solutions has become critical. Traditional methods based on periodic visual inspections are often reactive and may miss early signs of structural degradation. Bridge Structural Health Monitoring Systems (BSHMS) offer a proactive solution by providing continuous data on structural behaviour, enabling early detection of potential issues and timely maintenance interventions.



What is BSHMS?

A BSHMS is a combination of sensors, data acquisition units, communication systems, and software platforms that monitor various physical parameters of a bridge. These parameters include strain, tilt, acceleration, temperature, displacement, and sometimes environmental data such as wind or humidity. The system collects and analyses this data in real-time or periodically, providing insights into the bridge's health and performance.



Typical BSHMS Flowchart

Role in Bridge Maintenance

BSHMS shifts the maintenance model from reactive to condition-based maintenance (CBM). Instead of waiting for visible signs of distress or following fixed maintenance schedules, engineers can make informed decisions based on real-time structural conditions. This reduces unnecessary interventions, minimizes downtime, and prevents sudden failures. In case of extreme events like earthquakes, floods, or collisions, the system helps assess structural integrity immediately.

Applications in the field

BSHMS has been widely applied in long-span bridges, urban flyovers, and railway bridges. It is especially beneficial for:

- Monitoring fatigue in steel bridges
- Detecting early-stage corrosion in cables or joints
- Tracking displacement in expansion joints and bearings
- Monitoring stress in pre-stressed concrete structures
- Post-disaster assessments and long-term performance tracking

These applications help bridge authorities move from reactive to predictive maintenance. By continuously tracking structural performance, BSHMS ensures safer, smarter, and more cost-effective infrastructure management.

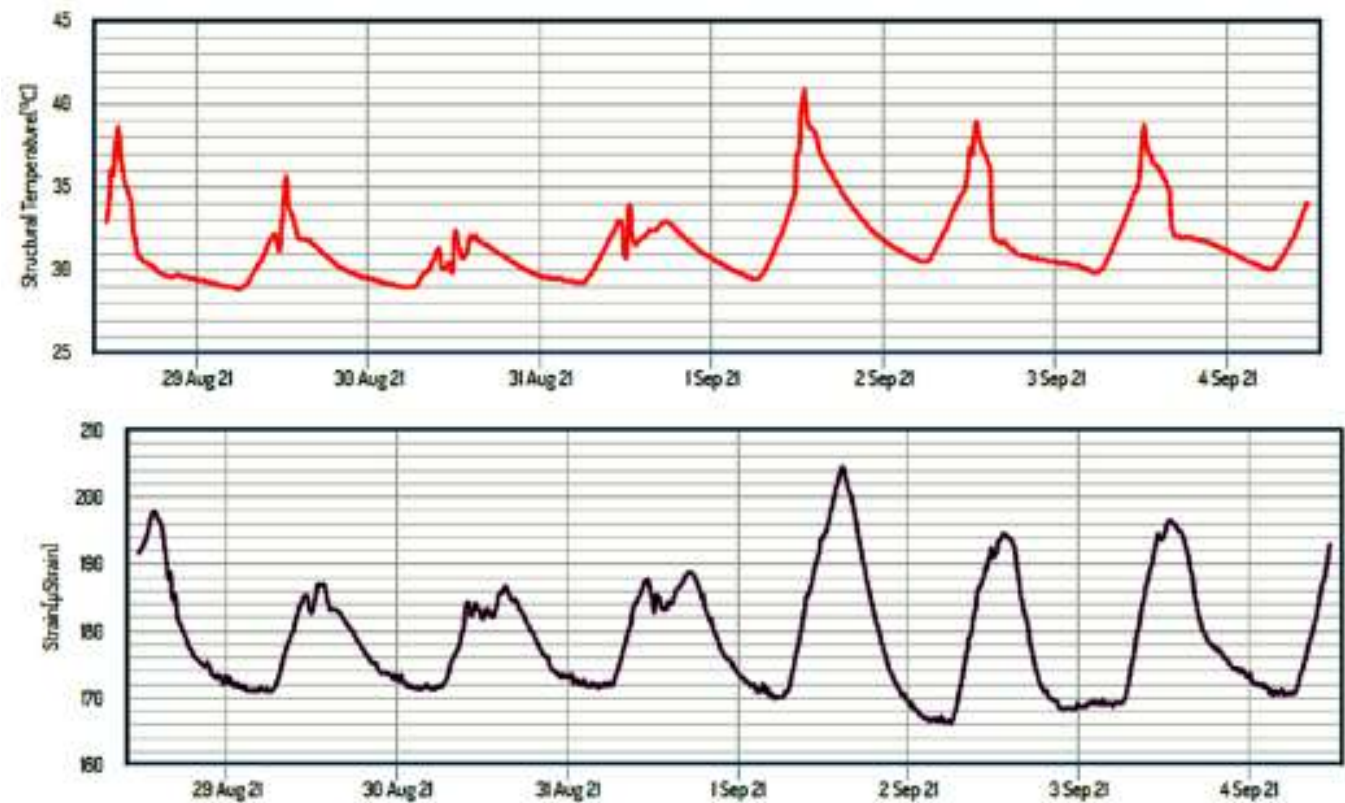


Effect of Cyclonic weather on a Cable Stayed Bridge

Deployment Strategies

BSHMS can be deployed in:

- New bridges during construction (embedded sensors)
- Existing bridges via retrofitting (surface-mounted sensors)
- Critical bridges with high traffic, long spans, or strategic value
- Temporary monitoring during repair, heavy load movements, or post-disaster evaluations



Structural Behaviour against Environmental Load

Advantages	Limitations
■ Enables early detection of faults ■ Enhances public safety and confidence ■ Supports optimized maintenance planning ■ Reduces lifecycle cost and asset downtime ■ Immediate post-event assessment	■ High installation and setup costs ■ Sensor aging and maintenance needs ■ Skilled interpretation required ■ Lack of standards for data use ■ Can generate data overload without filtering

Future Directions

- AI-driven maintenance scheduling based on predictive analytics
- Integration with BIM and digital twins for real-time structural simulation
- Autonomous inspection drones coupled with sensor data
- Smart SHM-as-a-Service platforms for small and medium bridges





Friction Pendulum Bearings for Extradosed Bridge over River Brahmaputra

Santanu Adhikary, MAGEBA

Introduction

The 1240m extradosed span of the 4km long bridge, incorporating flyovers, ramps, and viaducts over the Brahmaputra River connecting North Guwahati with Guwahati City, has been designed as a seismically isolated structure utilizing Friction Pendulum Bearings (FPBs) as its support system in the main span. The specially designed RESTON®PENDULUM Duplo FPB proved to be an optimal solution, meeting the required dynamic properties and supporting the substantial gravity load demand. This is the first time that Friction Pendulum Bearings have been used in an Indian bridge.



Artist's impression of the bridge

Project details and technical requirement

The extradosed span of the Bridge over River Brahmaputra, North Guwahati, Assam consists of a 1000 main span and two side spans of 120m each. The 1000m long main span is held by 6 pylons at 200m spacing. The span is supported on 24 nos. bearings, 4 nos. at each pylon location. The main span is designed as seismically isolated structure utilizing Friction Pendulum Bearings as the support system. In most of the other spans of this project (ramps and viaducts 2) large pot bearings (around 925T capacity) have been used. Major stakeholders of the project are:

Client: Government of Assam, PWRD
 Design consultant (extradosed bridge): Wiecon
 Bridge Design & Engineering Consultants
 Contractor: S P Singla Constructions Pvt. Ltd.

Structural and functional requirement

The project specified 24 numbers of Friction Pendulum Bearings, 4 at each pylon location. Each bearing was to carry a ultimate vertical load of about 79,000 kN. The seismic movement demand was $\pm 259\text{mm}$ and a maximum movement demand was $\pm 492\text{mm}$ (in extreme event).

The bearings system was to provide the following functional solutions:

- An effective stiffness of 13.5 kN/mm at a seismic movement of $\pm 259\text{mm}$
- A minimum damping of about 30% during seismic event
- Restoring the structure after an earthquake event.

RESTON®PENDULUM DuploFPBs as solution

RESTON®PENDULUM Duplo Friction Pendulum Bearings (PD78.8) of capacity 79,000 kN and movement capacity of $\pm 492\text{mm}$ were supplied.



RESTON®PENDULUM PD78.8 at workshop

Testing

Scaled down prototypes (scaled down to 50% of original bearing) were tested in Eucentre, Pavia, Italy and based on satisfactory test results, the main bearings were accepted.



Visiting team for witnessing and accepting the testing

Final inspection

All the 24 nos. full size RESTON®PENDULUM PD78.8 bearings were inspected for quality and dimensional correctness by the accepting authority and cleared for delivery at site.



**RESTON®PENDULUM
DUPLO FPBs being inspected at workshop**

Conclusion

Specially designed RESTON®PENDULUM Duplo Friction Pendulum Bearings used in this project are not only the larger of their kind but also uniquely designed to meet the unprecedented structural demands. The system provided the requisite isolation to the bridge structure reducing seismic lateral force to the desired level and dissipating seismic energy hence meeting all the complex demands of this special structure.





Achievement in Bridge Construction by Assam Public Works Road Department

Sri Chandan Sarma

Sp. Commissioner & Sp. Secretary to Govt. of Assam
Public Works (Health & Education) Department

Transportational challenges are a perennial problem in Assam. Rivers flowing through the state of Assam are one of the causes of such obstacles. Another factor in the problem is flood. These factors have always hampered the transportation of the people of Assam. However, as a result of the strong and inspiring leadership of the Hon'ble Chief Minister of Assam and his developmental vision, Assam has made commendable progress in the field of Transportation & Communication in the state of Assam, during the period of 2021 and 2024, this development has achieved a significant success.

Construction of bridges is a major and necessary step towards improving transportation. Needless to say, the builders face various problems in the construction of a bridge. The working season in Assam is only about 5 to 6 months. Therefore, there is very little time available for bridge construction in a year. Despite such problems, 1079 bridges have been constructed under the Assam Public Works Department in the last three years (April 2021 to March 2024). The following list shows the number of bridges constructed in each division of APWRD during April 2021 to March 2024.

List of Bridges constructed during Apr/21 to Mar/24

Sl. No.	Name of Division under APWRD	No. of Bridges completed
1	Baithalangso Division PWRD	10
2	Bajali Territorial Road Division	5
3	Bakulia Roads Division	7
4	Barchalla & Dhekiajuli T.R.Divn.	11
5	Barpathar Road Division	4
6	Barpeta, Mandia & Chenga T.R.Divn.	108
7	Bhawanipur, Sarbhog & Pakabetbari T.R.Divn.	21
8	Bilasipara Civil Sub-divn T.R.Divn.	17
9	Biswanath District T.R.Divn.	9
10	Bokakhat & Dergaon T.R.Divn.	8
11	Bongaigaon District T.R.Divn.	20
12	Barkhala & Katigora T.R.Divn.	15
13	Charaideo District T.R.Divn.	37
14	Chirang (R&B) Divn.	29
15	Dhakuakhana and Naoboicha T.R.Divn.	62
16	Dhemaji T.R.Divn.	51
17	Dhing & Rupahihat T.R.Divn.	3
18	Dholai & Sonai T.R.Divn.	4
19	Dhubri Civil Sub-division T.R.Divn.	13
20	Dibrugarh, Chabua, Lahowal, Khowang & Tingkhong T.R.Divn.	6
21	Digboi & Margherita T.R.Divn.	11
22	Diphu Road Divn.	4
23	Dispur and Dimoria T.R.Divn.	3
24	Dokmoka Road Divn.	7
25	Duliajan & Naharkatia T.R.Divn.	3



26	Gohpur Civil Sub-division T.R.Divn.	15
27	Goalpara East & Jaleswar T.R.Divn.	22
28	Goalpara West & Dudhnoi T.R.Divn.	14
29	Golaghat & Khumtai T.R.Divn.	15
30	Halflong Road Divn.	6
31	Hailakandi District T.R.Divn.	1
32	Hajo Sualkuchi T.R.Divn.	7
33	Hamren Road Divn.	4
34	Hojai District T.R.Divn.	6
35	Jonai T.R.Divn.	49
36	Jorhat and Titabor T.R.Divn.	8
37	Kaliabor and Samuguri T.R.Divn.	5
38	Karimganj North and Karimganj South T.R.Divn.	24
39	Kohora Road Divn.	3
40	Kokrajhar Road Divn.	11
41	Lakhimpur, Ranganadi and Bihpuria T.R.Divn.	7
42	Lakhipur Civil Sub-division T.R.Divn.	7
43	Mahur Road Divn.	4
44	Maibong Road Divn.	4
45	Majuli District T.R.Divn.	23
46	Mangaldoi, Dalgaoon and Sipajhar T.R.Divn.	50
47	Morigaon District T.R.Divn.	20
48	Mushalpur R&B Divn.	48
49	Nagaon, Batadroba, Raha and Barhampur T.R.Divn.	21
50	Nalbari District T.R.Divn.	14
51	Nazira T.R.Divn.	17
52	New Guwahati T.R.Divn.	2
53	North Kamrup T.R.Divn.	8
54	Patharkandi and RK Nagar T.R.Divn.	24
55	Silchar & Udharbond T.R.Divn.	7
56	Sivsagar and Demow T.R.Divn.	7
57	South Kamrup T.R.Divn.	27
58	South Salmara District T.R.Divn.	14
59	Teok & Mariani T.R.Divn.	3
60	Tezpur, Naduar and Rangapara T.R.Divn.	7
61	Tinsukia, Doomdooma, Makum & Sadiya T.R.Divn.	6
62	Udalguri Road Divn.	86
63	Umpanai Road Divn.	1
64	Umrangso NEC Divn.	4
65	Fly over / ROB	10
	Total	1079

As such, the Assam government has made history by building one bridge every day on average. This is a milestone in the development of the new Assam. The strong leadership of the Chief Minister is the main inspiration for the revolutionary change in road connectivity by constructing one bridge every day. Now, villagers in the state can also travel easily from one part of the state to another at all times of the year. Today, every village in Assam is connected to state or national roads. This work has been made possible with funds from various categories like Pradhan Mantri Gram Sadak Yojana (PMGSY), Rural



Infrastructure Development Fund (RIDF), State Fund etc. The Government of Assam is committed to shape Assam into one of the most developed states in India. The present Assam government is also determined to make Assam the gateway to South-East Asia. It is expected that this development will further accelerate in the coming days.

Apart from that, two new 6-Lane Extra-dosed PSC Bridges over River Brahmaputra are being constructed, one connecting Guwahati and North Guwahati having project cost Rs.2608.68 Cr (Main Bridge Length = 1.24 Km) and another connecting Palashbari to Sualkuchi having project cost Rs. 3197.20 Cr (Main Bridge Length = 3.6 Km).

There is another project named "Assam Resilient Rural Bridges Program" funded by World Bank is also being implemented in Assam. The main objectives of this project are to provide and preserve safe, resilient, and cost-effective bridge on rural roads to support sustainable seamless connectivity and strengthen institutional management of bridges in the state. The project contains maintenance/rehabilitation, capacity expansion, or replacement of existing RCC bridges; conversion of existing Timber bridges to RCC Bridges; construction of



new RCC bridges across existing gaps and capacity enhancing measures including measures for planning, implementation, and management of rural bridges. Construction of 1184 no. of Bridges having 45162 m length will be implemented in this project with a total Project Cost of Rs.4700.00 Cr.

As huge number of rivers and tributaries are flowing across every district of Assam including mighty Brahmaputra flowing east to west of Assam, there is a need for a large number of bridge construction for an uninterrupted road communication throughout the state. The construction of bridges requires a lot of money, time and technology. So, Public Works Roads Department, Assam took every effort for construction of Bridges as per requirement and as a result, the PWRD Assam has completed the construction of 1079 numbers of RCC bridges in 1085 days with the bold support of Hon'ble Chief Minister of Assam, Dr. Himanta Biswa Sarma. It is seen from the data that approximately one bridge is constructed daily on average. It is a matter of great achievement for PWRD Assam as well as for the Govt. of Assam. It is a revolutionary figure in the record of bridge construction that will certainly boost in the development of Assam and benefit the people of the state. The Engineers of APWRD and construction teams associated with this deserves appreciation for such a great achievement.



Enhancing Transport Infrastructure with Penetron Crystalline Technology

A Performance-Based Approach to Durability and Sustainability

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Abstract

In the context of transport infrastructure, particularly roads and bridges, ensuring long-term durability and chemical resistance is crucial for maintaining structural integrity. The use of Crystalline Durability Admixture (CDA) offers a highly effective solution to enhance the impermeability and other characteristics of concrete. By integrating CDA into the concrete mix, a catalytic chemical reaction takes place within the concrete matrix that forms insoluble, needle-like crystals within the concrete matrix. These crystals effectively seal the concrete's pores and

micro-cracks, preventing water or moisture ingress and mitigating the risks associated with it, which can otherwise compromise the structure over time. CDA not only makes concrete impermeable but also plays a significant role in addressing common challenges faced by transport infrastructure, such as shrinkage, corrosion, sulphate attacks, and alkali- aggregate reactions. These issues often lead to cracking and water or moisture seepage, weakening the overall durability of roads and bridges. The incorporation of CDA helps combat these problems, ensuring that the concrete remains resistant to the adverse effects of environmental stresses. By utilizing

CDA in the construction of roads and bridges, infrastructure projects can benefit from improved long-term performance. The increased impermeability reduces the likelihood of water-related damage and minimizes the impact of external forces on the structure. As a result, transport infrastructure can be more resilient, requiring less maintenance over its lifespan and ensuring enhanced safety and reliability. Ultimately, the adoption of CDA offers a sustainable solution for enhancing the durability of critical transportation infrastructure, thereby contributing to the longevity and effectiveness of roads and bridges.

1. Introduction

The transport industry is continuously evolving, with concrete structures now being subjected to increasingly harsh and hostile environmental conditions. As these structures face constant stress from thermal fluctuations, shrinkage, and potential chemical degradation, ensuring their long-term durability has become more crucial than ever. The structural integrity, longevity, and functionality of concrete infrastructure, especially roads and bridges, can be significantly compromised if not properly protected. Ensuring optimal durability is essential not only to minimize maintenance costs but also to extend the service life of these critical assets and ensure their continued performance over time.

One of the most pressing challenges in concrete infrastructure is cracking, which can lead to severe issues. In structures such as roads, bridges, and tunnels, cracks can result in water or moisture infiltration, leading to deterioration, corrosion of reinforcement, and potential failure of the structure. Traditional methods for repairing these cracks, often involving costly maintenance and short-term fixes, can be economically burdensome and may not offer lasting solutions.

To address these challenges, crystalline technology has emerged as an innovative and highly effective solution for enhancing the durability of concrete in transport infrastructure. A key component of this technology is Crystalline Durability Admixture (CDA), such as Penetron Admix®. When mixed into the concrete, this admixture reacts with the water and byproducts of cement hydration to form insoluble, needle-

like crystals. These crystals grow within the concrete matrix, sealing pores, micro-cracks, and capillaries, thereby preventing water infiltration and enhancing the material's resistance to chemical attacks. The self-healing process effectively mitigates crack propagation, reduces permeability, and reinforces the concrete against harsh environmental factors like chlorides, sulphates, alkali-aggregate reactions, and freeze-thaw cycles.

This paper aims to explore the use of Penetron Admix and similar crystalline technologies in improving the durability of concrete structures, with a focus on their ability to self-heal cracks, enhance impermeability, and protect against environmental and chemical damage. The integration of CDA into concrete offers a sustainable, cost-effective approach to ensuring the longevity and resilience of vital transport infrastructure, ultimately contributing to safer, more reliable roads and bridges capable of withstanding the challenges of increasingly demanding environments.

2. Durable Concrete Infrastructure

The American Concrete Institute (ACI) defines durability as "the ability of concrete to resist weathering action, chemical attack, and abrasion while retaining its desired engineering properties" (ACI 201.2R-16).

Concrete durability is a key factor in ensuring that structures remain functional and safe throughout their intended lifespan, especially when exposed to challenging environmental conditions. Traditionally, concrete mix designs focused heavily on achieving high strength, with less emphasis on properties related to long-term performance, such as water permeability, shrinkage, thermal differential, corrosion, sulphate attack, alkali-aggregate reactions, etc. However, recent advancements in concrete technology have shifted the focus towards performance-based design, particularly for large, critical infrastructure projects. This shift is driven by two main considerations: the ease with which high-strength concrete can be produced today and the growing understanding that durability plays a more significant role in the long-term success and sustainability of a structure than merely increasing its strength.

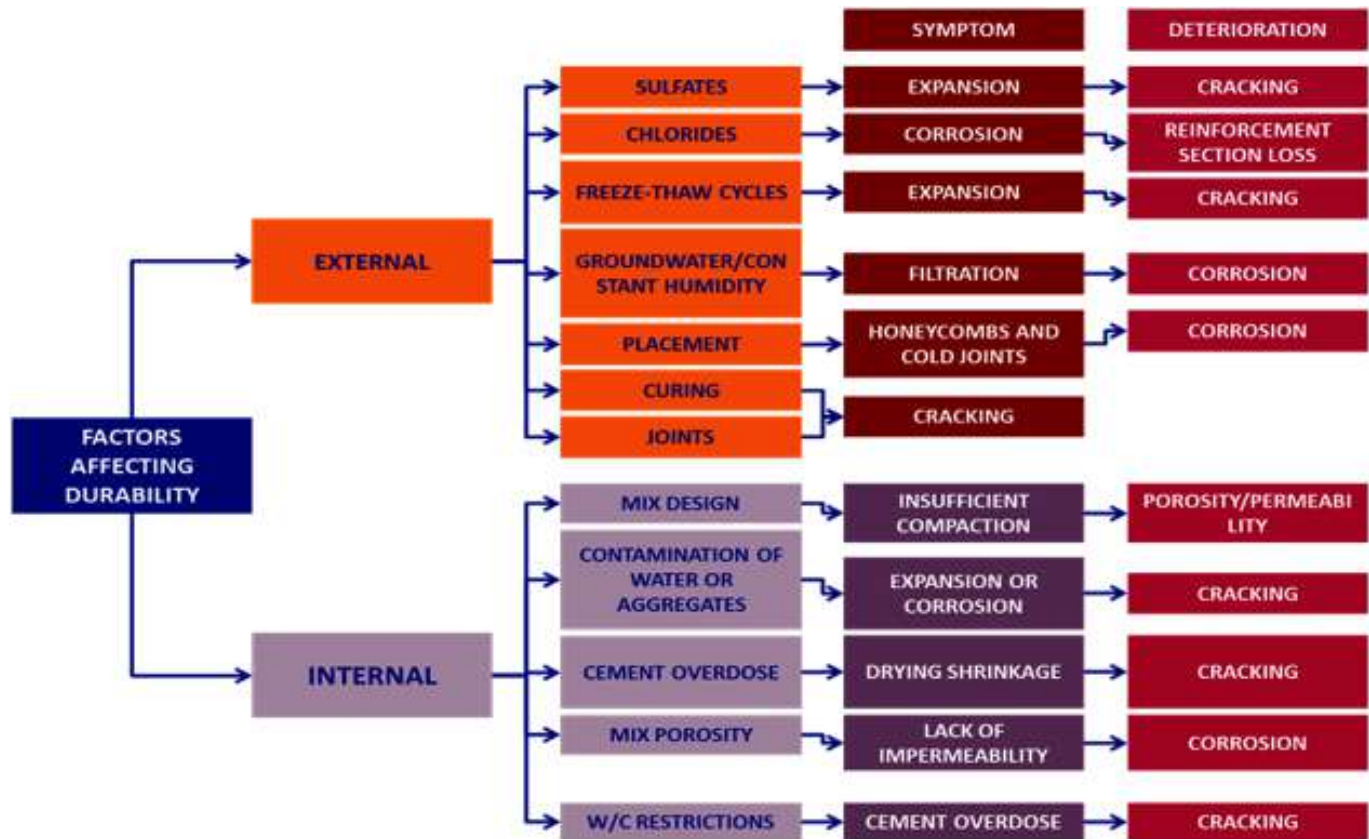


Figure 1: Factors Affecting Concrete Durability (Internal vs. External)

Durability is influenced by both the characteristics of the concrete itself (internal), such as the water-cement ratio, aggregates, the type of binder used, etc., as well as the external conditions the concrete structure is likely to face. Factors like thermal fluctuations and exposure to aggressive chemical environments can accelerate the deterioration of concrete, making it more susceptible to issues like cracking and spalling.

For large-scale projects, like roads, bridges, tunnels, dams, hydropower projects, etc., where long-term durability is essential, focusing on durability rather than just strength ensures that these structures remain safe and efficient throughout their operational life.

3. Challenges in Roads and Bridges

Concrete structures face several challenges that can lead to deterioration:

Thermal Expansion and Contraction : Temperature fluctuations induce stress, leading to cracks.

Shrinkage : Concrete shrinks as it cures, causing cracks that can lead to water ingress.

Corrosion of Reinforcement : Water and chemical exposure accelerate reinforcement corrosion.

Alkali-Aggregate Reactions (AAR) : Reactive aggregates cause expansion, leading to cracking.

Carbonation : Carbon dioxide reduces concrete pH, making it more vulnerable to corrosion.

Freeze-Thaw Cycles : In cold climates, freezing water causes cracks, leading to strength loss.

4. Technology Overview (Penetron Crystalline Technology)

Crystalline durability and waterproofing products enhance concrete durability by sealing pores and micro-cracks through chemical reactions. This significantly reduces maintenance costs and extends service life without affecting concrete strength.

Key Benefits of Penetron Crystalline Technology:

- Provides a "self-healing" concrete (Self-heals cracks up to 0.5mm).
- Resistance to high hydrostatic pressure (20 bar).
- Increases compressive strength.
- Resists chemical attack (pH 3-11).
- Reduces chloride penetration and carbonation.
- Prevents Alkali-Silica-Reaction (ASR).
- Prevents reinforcement steel from corrosion.
- Non-toxic & Green Product (Contains Zero VOC).
- Protection remains intact when the surface is damaged.

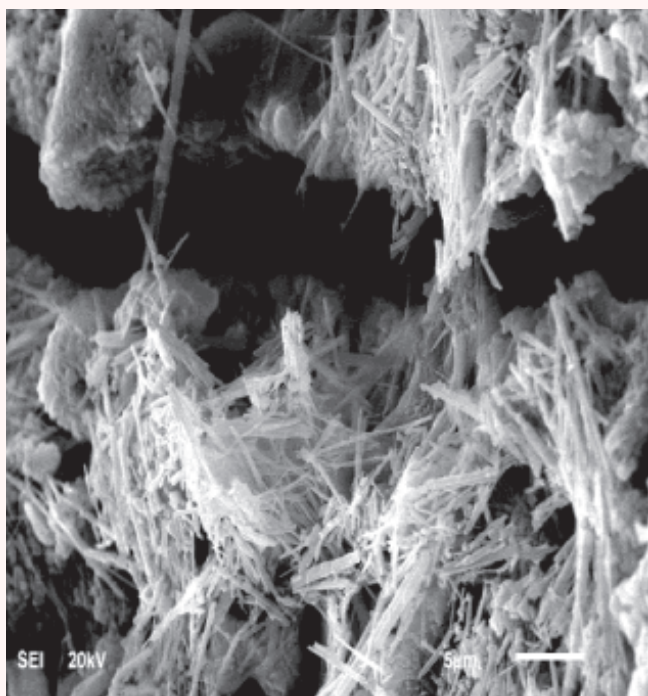


Figure 2: Crystal Formation (SEM Analysis)

Some of the key advantages of introducing Penetron products into concrete are:

Service Life extension: Our crystalline technology enhances the service life of concrete structures by creating a self-healing mechanism that seals cracks and prevents water or moisture infiltration, thereby reducing corrosion and deterioration.

Increased Durability : Our crystalline technology strengthens concrete, reducing the risk of cracks and boosting long-term durability.

Enhanced Chemical Resistance : Concrete treated with Penetron® technology resists corrosion from harsh chemicals, improving its lifespan and performance.

Reduced Maintenance Costs : Our products minimize the need for repairs, offering substantial savings on long-term maintenance.

Improved Sustainability : The extended life cycle and reduced maintenance requirements of structures contribute to environmentally responsible construction.

5. Crystalline Products for Transport Infrastructure Projects

Crystalline products, including Penetron Admix and Penetron Crystalline Coating treatments, react with water and hydration byproducts of cement to form insoluble crystals, sealing pores and preventing concrete deterioration.

5.2 Topical vs. Integral Application

Crystalline products can be applied topically or integrally, with the choice depending on project needs and site conditions.

5.2.1 Topical Crystalline Products (Penetron Coating, Penecrete Mortar)

Existing Structures : Creates a protective barrier against various chemical attacks.

Cost-Efficient : More economical than conventional repair methods.

Quick Application : Suitable for projects with tight timelines.

5.2.2 Integral Crystalline Products (Penetron Admix)

New Construction : Ensures long-term protection.

Durability : Becomes an intrinsic part of concrete for lasting protection.

Harsh Conditions : Withstands extreme environments better than conventional topical applications.

6. Future of Crystalline Admixtures in Roads & Bridges



The integration of crystalline technology enhances concrete durability and reduces maintenance costs in concrete structures. By utilizing CDA, CS, and advanced grouting crystalline products, infrastructure projects can extend lifespan and improve operational efficiency. Crystalline technology remains vital for protecting critical structures from water ingress, chemical exposure, and physical wear.

6.1 Sustainability and Long-Term Benefits: Towards Zero Carbon Concrete

Crystalline Admixtures supports sustainability by minimizing repair needs, reducing material consumption, and lowering the carbon footprint of maintenance activities. By enhancing service life and resilience, it ensures infrastructure projects remain cost-effective and environmentally friendly in the long term. The Crystalline Admixtures can significantly reduce the overall carbon footprint of the concrete structures.

7. Conclusion

Ensuring concrete durability is a fundamental aspect of infrastructure design and maintenance. Crystalline technology improves resistance to permeability, chemical attacks, freeze-thaw cycles,

and erosion, ultimately enhancing structural longevity. With proven applications in major infrastructure projects worldwide, including roads, bridges, railways, metros, tunnels, hydropower projects, dams, etc., Penetron continues to be a reliable choice for ensuring the long-term success of these critical assets.

8. Penetron Crystalline Product Range

CDA: Crystalline Durability Admixture (Penetron Admix)

CS: Crystalline slurry coating (Penetron)

Crystalline Mortar: Crystalline repair mortar (Penecrete Mortar)

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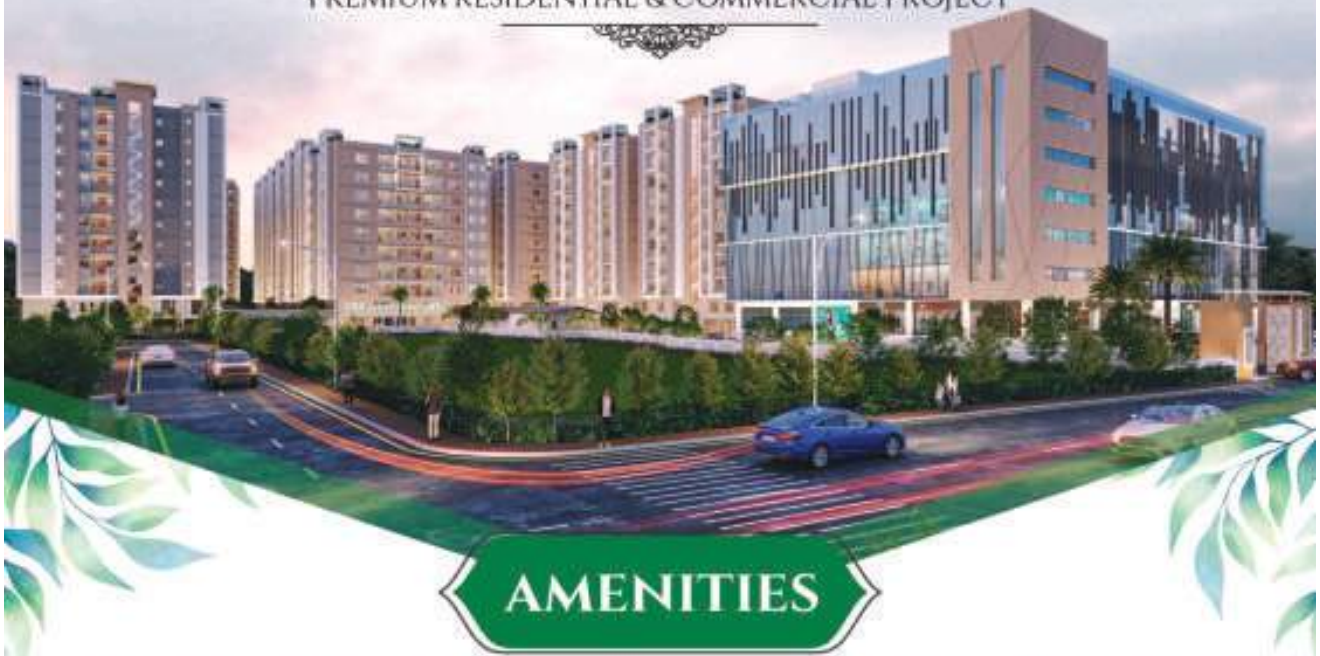
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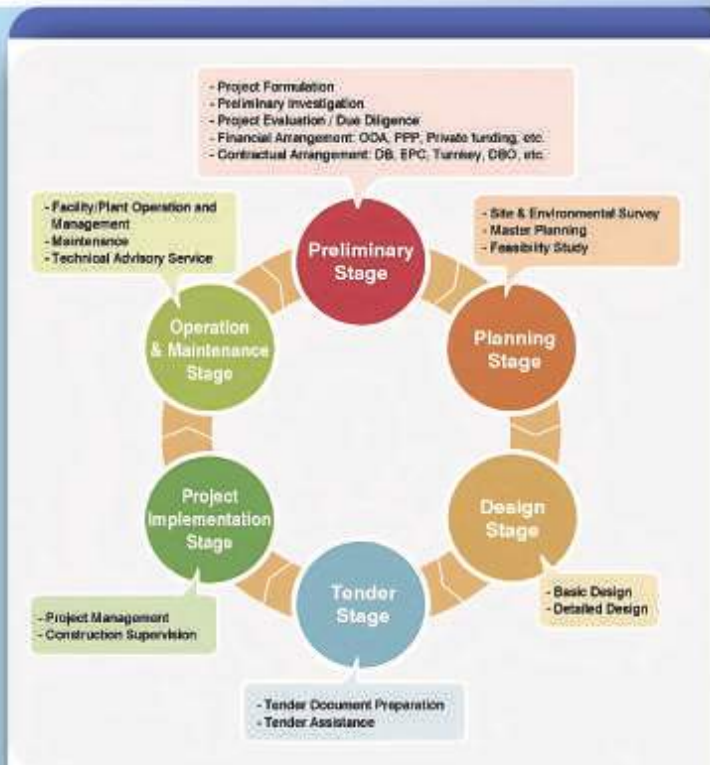
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