Confidential Reporting Of Structural Failures And Lessons Learnt

NEWSLETTER

A PUBLICATION OF INDIAN ASSOCIATION OF STRUCTURAL ENGINEERS

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FROM THE DESK OF THE PRESIDENT

I am pleased to handover the responsibility of chairing the newly constituted editorial board of CROSFALL to Mr U K Rajeshirke and this 12th edition of CROSFALL is the first newsletter released with new editorial board formed under the chairmanship of Mr Rajeshirke. I take this opportunity to welcome the new team and wish them success. I am sure the newly formed board will take this newsletter to greater heights. I also encourage civil and structural engineers to contribute reports without fear or hesitation. The three reports published in this Newsletter point to the importance of communication in the design, construction, use, and modification of structures. Today's designers need to consider all possible situations, study past data and verify the same before using such data in design of structures. Also these failures clearly demonstrates that Designers need to be also involved in close interaction with the Contractors during construction process.

I encourage all Civil and Structural Engineers to read these reports, contribute by sharing their own experience confidentially without fear or hesitation.

Happy Reading!

— **Alok Bhowmick**

MESSAGE FROM CHIEF EDITOR

I am privileged to address you through my first note as Chief Editor of CROSFALL, having recently been entrusted with this responsibility by the Council of IAStructE for a two-year term. This publication has steadily evolved into an important platform for documenting lessons from structural failures and near misses, with the overarching aim of strengthening professional practice and advancing structural safety.

The current issue, Volume 4, Issue 2, presents three significant contributions. Report CF-37 examines the failure of Post-Tensioned I-Girders during prestressing and lifting, emphasizing the critical importance of staged stressing, rigorous proof checks, and strict quality control during construction. Report CF-38 analyses the impact of inadequate consideration of hydro-morphological effects in bridge planning, underscoring the necessity of comprehensive morphological studies at the DPR stage to avoid costly redesigns and vulnerabilities. The third article, Why are Bridges keeping on falling?, provides a broader perspective, drawing attention to systemic deficiencies in contracting practices, accountability mechanisms, and maintenance regimes, while also calling for long overdue reforms in professional regulation.

As I begin my tenure, I invite readers to engage with these reports and contribute actively to future issues. The continued success of CROSFALL depends on collective participation and commitment to learning.

— **Umesh K. Rajeshirke**
Chief Editor, CROSFALL

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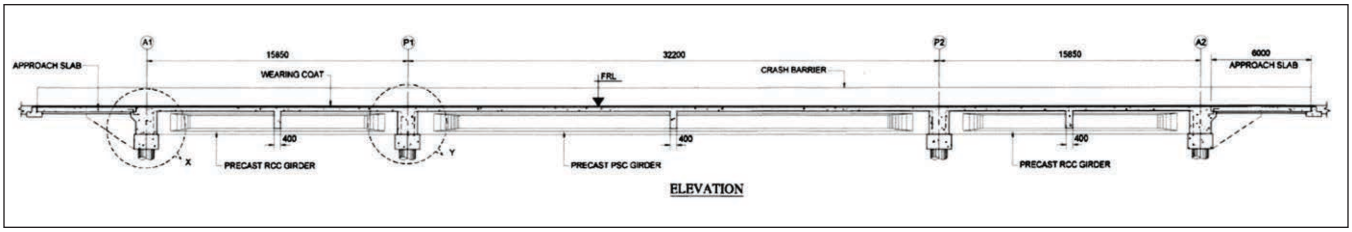
REPORT No. CF-37

Failure/Distress of Post Tensioned I Girder during Prestressing and Lifting Operation

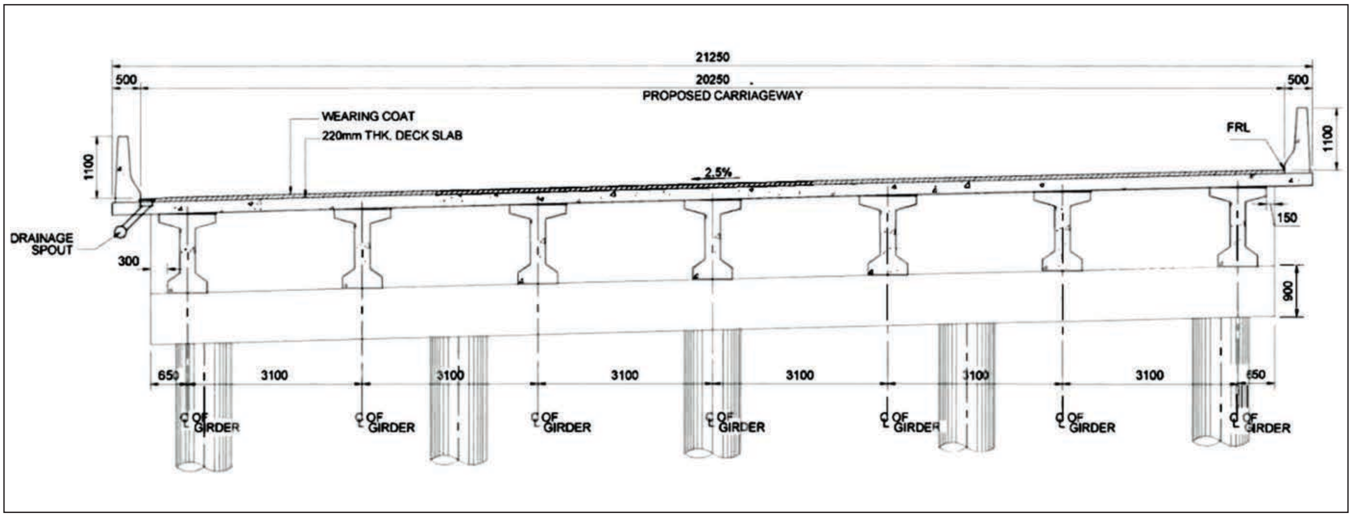
1. Introduction

This report examines the failure of Post-Tensioned Concrete (PSC) I-Girders, which are extensively used in infrastructure projects such as flyovers, underpasses, and viaducts. Typically, I-Girders are supported over bearings, with continuity between adjacent spans established using link slabs. In this specific case, the PSC girders are integrated with the pier-cap.

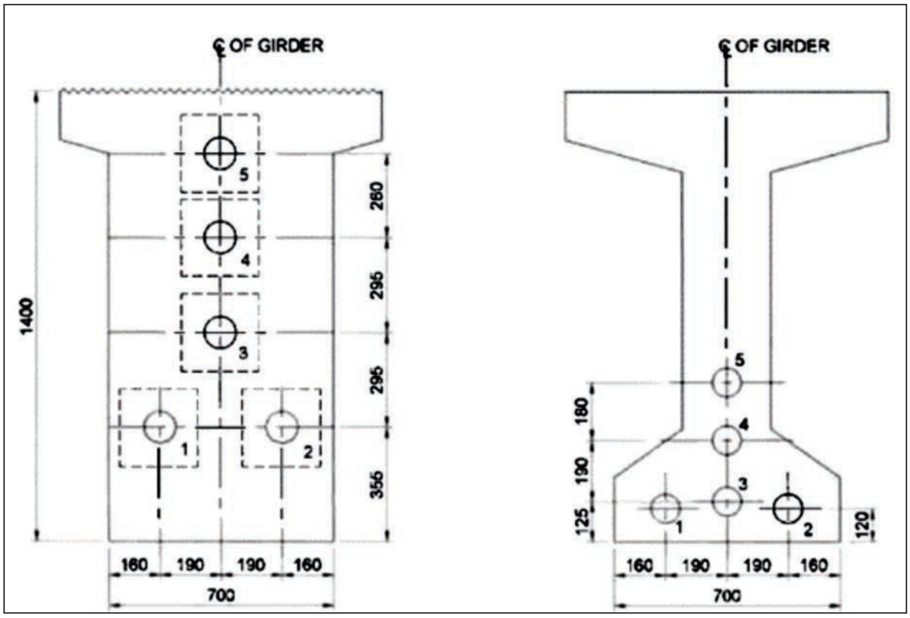
The bridge in question consists of three continuous spans (RCC-PSC-RCC) with a total length of 63.9 meters. The PSC girders are cast on the ground and prestressed in a single stage. Similarly, the RCC girders are cast on the ground and erected in place once the desired strength is achieved.



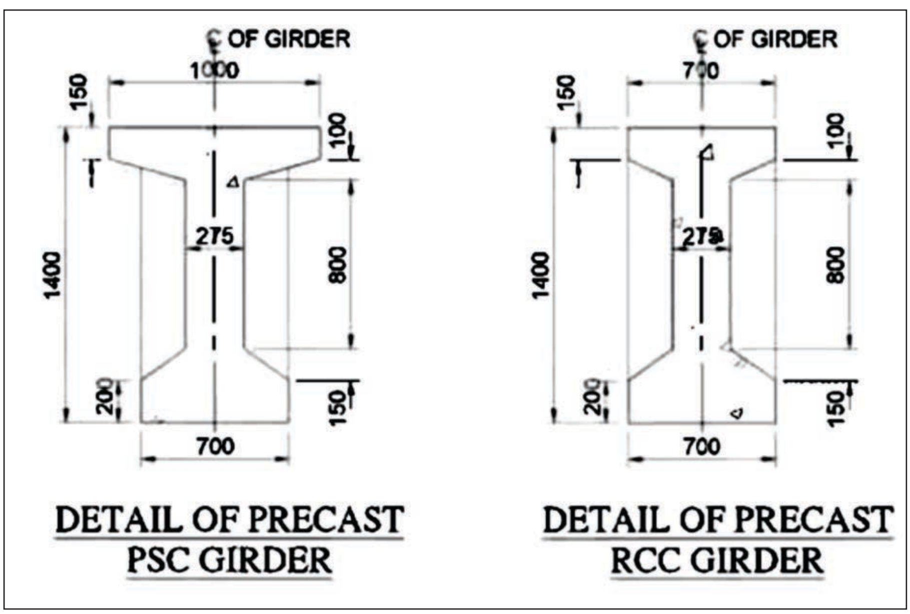
Span Arrangement



Typical Cross Section at Integral Pier



Pt Arrangement at Midspan



Dimensional Details

Stressing Details

Cable No.	Extension (mm)	Jacking Force (KN)	No. of Strands	Anchorage Type	Length of Cable (mm)
1	222.9	1726.08	12	12K13	32419.9
2	222.9	1726.08	12	12K13	32419.9
3	224.6	2589.12	18	19K13	32430.5
4	224.5	1726.08	12	12K13	32435.0
5	223.7	1006.88	7	12K13	32436.7

2. Failure during stressing

The RCC girders were erected in position and did not show any distress. During stressing of the PSC-I Girders, it was noticed that the girders hogged more than 250mm at the mid span. Post-stressing the girders failed due to concrete crushing.

3. Probable Causes of Failure

Drawings suggest that all cables shall be stressed when beam concrete is 28 days old with minimum concrete strength of 45MPa. The design calculations indicate that the girders were actually designed for a concrete grade of M50. At the time of stressing, the actual concrete grade, as per core test was found to be less than 30MPa

Compressive Stress:

As per the design calculations, The maximum compressive stress at the bottom of the girder during lifting is 22.23MPa.

Permissible limit of compressive stress during construction is 0.48FCk = 0.48x30MPa = 14.4MPa.

Span/Depth Ratio:

The girder's length was 31.4m with a depth of 1.4m, resulting in a span/depth ratio of approximately 22.5. This ratio is high for simply supported girders, making them vulnerable during construction stages.

4. Lessons Learnt

Design Insufficiency: The incident highlights a clear fault in design. Proper design checks and quality assurance should be performed before releasing designs and drawings.

Peer Review: There was a lack of serious peer review or proof checking by experienced engineers. It is imperative that thorough design reviews and peer checks are performed to identify potential issues before construction

Construction Stages: Attention should be paid to construction stages, especially when implementing integral type arrangements of precast PSC-I girders. Stressing all cables in a single stage can make the girders vulnerable. Consider staged stressing of the tendons to reduce the risk of excessive deflections and concrete crushing.

L/D Ratio: Ensure sufficient depth during construction and stressing when the composite section is not active.

Monitoring and Testing: Regularly monitoring and testing the of concrete strength and girder performance during construction is important to detect and address any issues promptly.

5. Opinion of Expert Panel

The report demonstrates fundamental lapses in design as well as Quality Control of post tensioned Concrete (PSC) 'I' Girders used for a bridge. The structural arrangement of (RCC-PSC-RCC) spans should have been made continuous for Live Load by the use of link slabs instead of using full deck continuity, i.e., diaphragm continuity, which is not recommended for such an arrangement. In fact, the ideal arrangement should have been to do all three spans pre-stressed with use of continuity cables passing through the diaphragms in the hogging region. Even in the current arrangement, post-tensioned girder cannot be restressed again or cables replaced for any future requirement, nor can the anchorage area of the tendons be inspected as they will be inaccessible due to the casting of diaphragm.

The span to depth ratios are closer to the requirements of AASHTO Code, but far from the requirements of the IRC Codes which give span to depth ratios of around 13.93 for a 31.4m span. There can be small variations in their span to depth ratio. The stressing was to be done when the concrete had achieved a strength of 45 MPa. It was done when it was less than 30 MPa strength! The design does not take into consideration the requirements to cater for the permissible limit of compressive stress during stressing of 0.48 fcj = 14.4 MPa (for 30 Mpa strength), as per design it was 22.23 MPa (for 45 Mpa strength) !

It is pertinent to note that from the photographs, the girder was cast on the ground with multiple support points along its length. There should have been removed prior to prestressing so as to mobilise the dead weight of the girder cast against excessive hogging deformation during prestressing. The stressing operation appears to have been done without the benefit of this Dead Load to counter the second order moment due to hogging deflection.

Design Consultant must exercise all due care during design and take into consideration the effect of the impact of construction stages on design, and in this case, may be, to have done the prestressing in two stages. There is a clear need for Proof Consultants to exercise diligence in their work and check vigorously, the designs and drawings. The Contractor and Quality Control Project Management Consultant also need to have exercised Quality Control and ensured attaining the correct concrete strength prior to pre-stressing as required by the design.

Lapses in design, proof checking and QC at site have combined to ensure the failure of the girder in the casting bed even before its erection onto the pier caps.

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REPORT No. CF-38

Impact of Ignoring Hydro-morphological Effects of Mighty Rivers in Planning of a Bridge – A Case Study

1. Background

a) This is the report of a bridge over a mighty river, which has undergone a series of substantive changes in the span arrangement, bridge length as well as bridge location with respect to river, all during the construction stage. The changes were necessitated primarily due to the incorrect assessment of river morphology. Since the construction was being carried out in EPC mode, change of span arrangement, bridge length as well as bridge location is considered as a contractual variation an this led to huge time and cost overrun in the project.

b) ***Year 2015-16 :*** As per the original Contract Agreement, the bridge proposed as per the DPR was with a span arrangement of 5x30.0m + 15 x 50.0m forming a total length of 900m. The bridge start point on the right bank was at chainage 158+050, which was about 200m behind the existing guide bund. Reason for extending the bridge length beyond the right guide bund was essentially to fly over a cross road close by.

c) ***Year 2017 :*** When the construction started on ground, it was realized by all stakeholders that the bridge position do not cater to the requirement of the stream, which was already flowing more towards the left bank of the river. While guide bund was provided in the right bank, the left bank was left unprotected. After much discussion between all stakeholders, it was decided to shift the bridge by 300m towards the left bank, provide a separate flyover for the cross road and provide an LVUP over the bund road. The bridge length was reduced from 900m to 850m with span arrangement of 17 x 50m. Reduction in bridge length is apparently to adjust for the cost variation and avoid contractual variation in price.

d) ***Year 2022 :*** Mid-way into the construction, unexpected changes were noticed in the nature and direction of the river flow. The mainstream of the river was shifting towards the left bank at a rapid pace. This compelled the authorities to extend the bridge length by another 500m. 10 spans of 50m each was added. The revised bridge length was 1350m with span arrangement of 27 spans of 50m each, as against 900m envisaged in the original contract.

e) ***Year 2024 :*** The bridge construction was completed and opened to traffic. Meanwhile the river further shifted towards left bank, cutting the banks close to the bridge. The river was flowing primarily towards the left bank.

f) Fig. 1 below shows the development of the project from 2015 till 2022. Fig.2 shows the plan view with shifting records of the stream during the period 2017 to 2024

g) Lack of river protection in the left bank of the river threatens erosion of bank, including the approach embankment of the bridge. There is fear that the approach embankments of the bridge may get washed away unless some protection measures are taken on priority to protect the left banks, on both upstream and downstream of the bridge. The authorities were alarmed by this strong possibility and sought opinion from a team of experts to mitigate the problem.

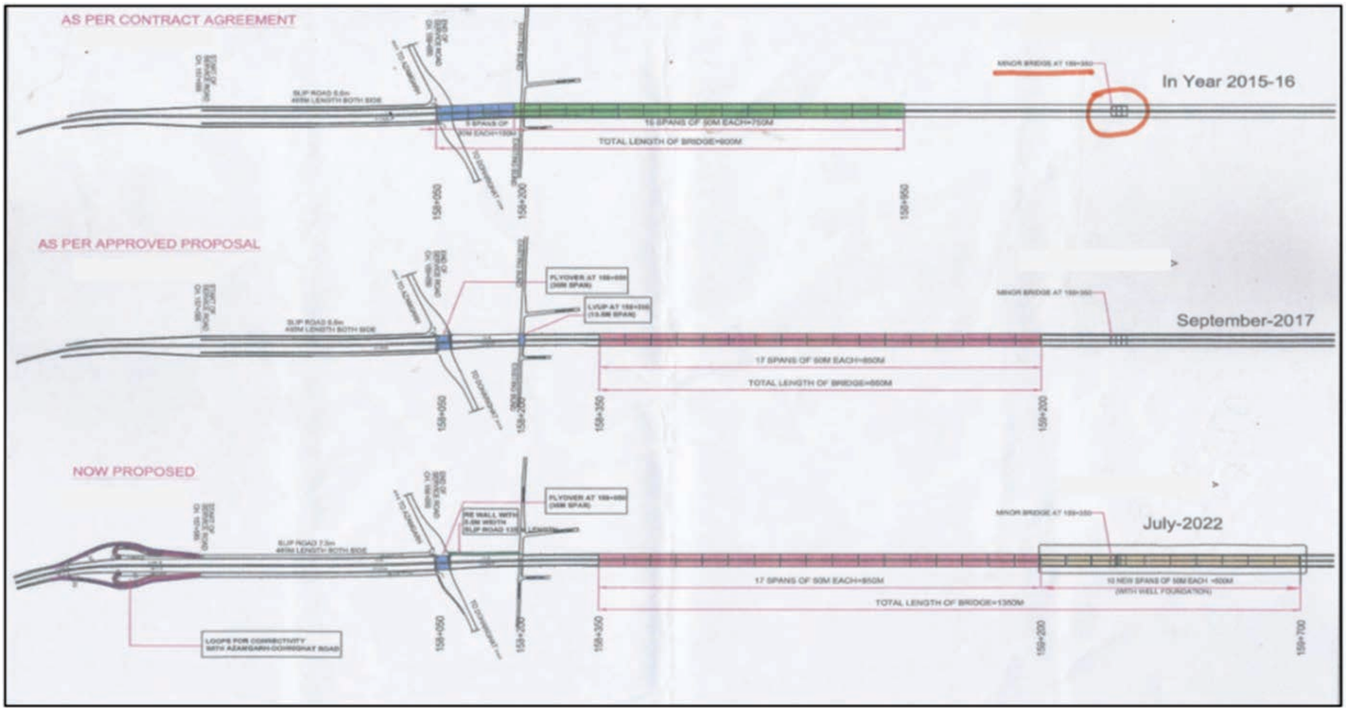

Fig. 1 : Showing the changes in bridge location, and length with passage of time

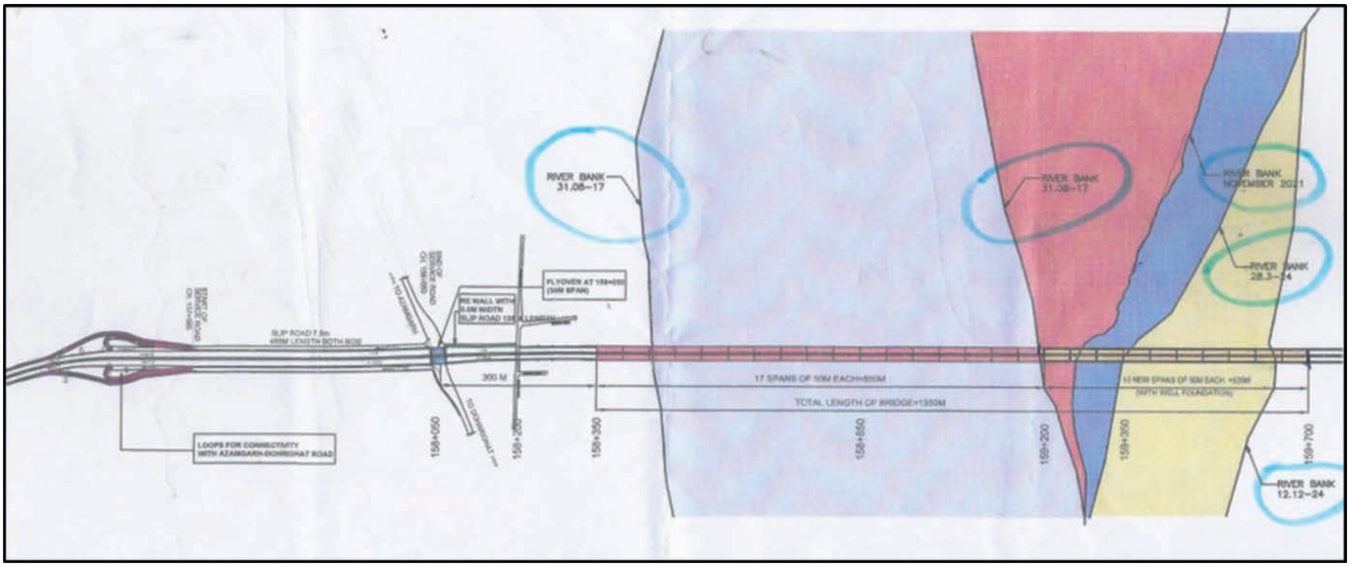

Fig. 2 : Showing Shifting tendency of river towards Left Bank side during previous years

2. Findings of the Expert team appointed by Authorities

a) The expert team noted that on the upstream side of abutment (A2), the river has shifted beyond the abutment location by more than 50m in a period of less than one year, creating an island between the active channel and present bank of the river. Plate-5 shows some of the photographs of u/s side of riverbank. Fig. 3 shows some of the photographs taken from left bank abutment showing cutting of embankment towards the left bank (both U/S as well as D/S side), endangering the bridge approaches.

Fig. 3 : Showing Shifting tendency of river towards Left Bank side during previous years (Alarming situation w.r.to shifting during March.2024 to Dec.2024)

b) On downstream side of left abutment A2 the river is moving curvilinearly creating back flow towards abutment and finally inclined towards center of river at a very large distance. Plate 6 shows some of the photographs of d/s side of riverbank.

c) With the shifting of river towards A2 side, no major adverse effect of scour (based on the scour measured by the contractor) was noticed on adjoining piers.

d) The slope pitching & Launching Apron on the A2 side was only partially completed and the team observed that this pitching work was of sub-standard quality not done as per standard specifications (Plate-1 (a & b) above).

e) Based on local inquiry, it was confirmed that the river is extensively meandering in nature, and it was flowing 200m away from the present location of A2 in the year 1975 which is further confirmed through review of old satellite imagery as shown in Fig. 4.

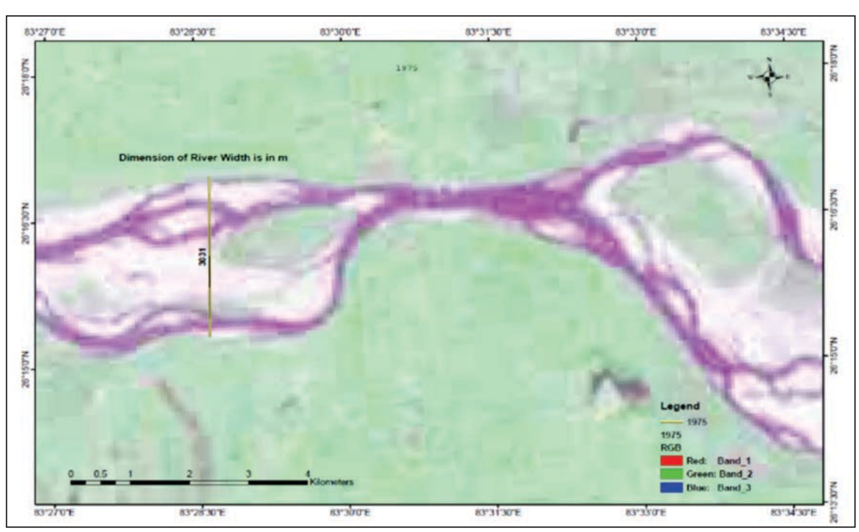

Fig. 4 : Showing Shifting tendency of river towards Left Bank side during previous years (Alarming situation w.r.to shifting during March.2024 to Dec.2024)

3. Proposed Solution by Expert Team

a) The mighty river over which the bridge is constructed, is a perennial transboundary river, which originates in the Tibetan Plateau near lake Mansarovar and cuts through the Himalayas in Nepal. This Himalayan River carries sand, silt and boulders when it flows downstream. Past studies in this river have shown that the dominance of sand and silt in the flow are prone to lateral erosion and further Sinuosity in the river occurs due to high discharge and sudden reduction in gradients as well as flow velocity. Past studies have also indicated that the river is susceptible to future migration. Due to irregular meandering, lateral shifting, and the high sinuosity, which is very sensitive to lateral erosion, the only way to protect any bridge structure crossing this river is only after protecting both of its banks suitably. This aspect should have been taken note of during the DPR stage itself, before floating of tenders.

b) Based on Google Imagery of the stream at bridge site, one taken from the year 1975, with bridge location marked in this image, it can be seen that while the bridge length is kept as 1350m, which may look sufficient from current google imagery, however, the 50 year old imagery (1975) indicates that the bridge length should have been at least 3031m, to clear the spread of the waterway, in case there is no bank protection.

c) Considering the present situation, where the river is eroding the unprotected left banks close to Abutment A2, the following short term (Immediate) mitigation measures to be taken on priority to protect the immediate approach embankments of the bridge so that the corridor remains functional post this years monsoon.

   i. To complete the balance construction activities of launching apron, slope protection works of the Abutment (A2) i/c slope of approaches, on priority as per the available Good for Construction Drawing (GFC).

   ii. To remove / clean the construction debris from the riverbed which was lying around the piers which block some portion of the river flow.

   iii. To monitor during monsoon, the depth of actual scour at all piers in order to ascertain that the scour levels are still above the design scour levels of piers. Based on ground level / riverbed level profile @50m interval in upstream / downstream from the abutment (A2) indicates that the depth of erosion is around 7m to 8m at the time of inspection of the bridge. From the shifting pattern of the river, it appears that it may hit upon the approach to abutment (A2) in future if adequate river training works are not carried out timely.

   iv. There are existing flood embankment guide bund (top width about 5m to 6m with slope pitching) and impervious spurs (top width about 3m/4m, length about 150m, spacing about 200m with slope pitching) on right bank, near abutment (A1). In absence of any detailed studies, similar arrangement (with different length and spacing of the impervious spurs (repelling / deflecting / Sadimenting) may be provided on left. The tentative length of protection suggested (based on site visit) is :

   - For a length of 1040m on the U/S side of Abutment A2
   - For a length of 250m in downstream side of Abutment A2

   This measure can be planned and implemented at the earliest. All relevant river training activities as remedial measures shall be carried out in the light of IRC:89-2019 "Guidelines for Design and Construction of River Training and Control works for Road Bridges" & Section 2500 of MoRTH Specification for Road and Bridge Works (Fifth Revision)

d) In addition to above suggestive measures, the expert team was of the opinion that as a long term measure, a detailed morphological study using Geo-Spatial Technique in River Shifting Analysis of the River may be carried out to come out with a long term bank protection solution to guide the river flow.

Expert Comments:

This paper highlights the critical importance of conducting a detailed morphological assessment during the DPR (Detailed Project Report) stage for determining the correct alignment, span arrangement, and bridge location. In the present case, inadequate evaluation of river morphology led to major design modifications during execution like changes in span configuration, bridge length, which resulted in significant time and cost overruns. Additionally, river protection measures were found to be inadequately designed and implemented. Historical satellite imagery from 1975 reveals that the river's active width was substantially greater than considered, indicating that even the revised bridge length of 1350 meters may be insufficient without comprehensive and continuous bank protection.

It is imperative that the Client and its representatives ensure the selection of technically competent DPR consultants and ensure that all essential studies, including morphological, hydraulic etc. are thoroughly conducted before approval of bridge location and span arrangement.

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REPORT No. CF-39

Why are Bridges Keeping on Falling?

(This article has been published by the same author in slightly modified form in the Morning Standard, New Delhi on 30 July, Wednesday)

– Amitabha Ghoshal
Advisory Consultant & Past President, CEAI

Bridges are the most important element in a surface transport network. Once built they are extremely difficult to replace and it becomes challenging even to close them for a few days or hours for essential repair work. A sudden failure puts back normal life indefinitely, affects development works and causes economic losses for the country. It is important for public at large to be aware of the reasons that cause such failures and raise voices to prevent occurrence for their own safety and the financial well-being of the country.

Bridges fail across the world, and this is happening since eternity. In developed countries these failures are analysed, findings shared and discussed, and the lessons learned recorded for prevention of future recurrences. In India the trend has been to form enquiry committees, and hush up the matter. There are thus no gains for the bridge engineering profession.

The classical failure of the Tacoma Narrows bridge in USA in 1940 was instantly shared across the world, the reasons analysed and debated, and the video of the failure became standard teaching material for engineering students across the world. The result, - there has been no such failure ever since and every engineer knows that a light weight long span bridge needs to be checked for Aerodynamic stability and model tests have to be done in a laboratory. The deplorable failure of the West Gate bridge in Australia in 1970 was similarly explored, enquiry commission installed, research initiated, and they came out with a comprehensive analytical report that became Bible for the makers of design codes across the world. People came to know of the problems with thin walled box girders made with steel plates, that had become the favourite of engineers trying to cut down on steel consumption, and the failures of Box Girders just never recurred.

In our country the much publicised and deplored failure of the Morbi Bridge, an unstiffened suspension bridge that tended to wobble with people walking on the deck. The Media attention particularly alerted the authorities. Despite the large casualties we have not learned the lesson- none of the multiple unstiffened suspension bridges in lower Himalayas have yet been intensively inspected or rehabilitation process started, as far as public knowledge indicates! The spectacular failure of the Majherhat bridge in Kolkata (Year 2018), that caused endless misery to the residents of the city, has been all but forgotten. No analytical studies were done or research initiated, and no mandatory notification has been issued to authorities across the country to ensure that the wearing coat on the bridge deck should not be allowed to go beyond design thickness- a common folly of bridge maintenance teams and widely believed to be the root cause of the failure!! We shall surely witness more such failures.

Technical knowledge on Bridges is globally shared and countries follow identical design norms, openly shared and updated, learning from each other.

Humanity learnt bridging techniques from nature, looking at fallen tree trunks across the streams and the forward growing creepers entangling each other to provide uninterrupted crossing facility!

The bridges of early era used to be in the form of beams, or trusses (which are geometrically arranged structural sections), supported on bearings put on piers. Urge for making longer spans to achieve economy in cost led to use of Arch and Bow-string girders (e.g, Sydney Harbour Bridge).

Post Second World War, with the thrust on Sustainability, the choice has moved to bridges supported by cables, and across the world Cable Stayed bridges (Signature Bridge in Delhi) and Extradosed Bridges (Nivedita Setu in Kolkata) have become popular. With these changes in technology, engineering knowledge needs upgrading. There have been widely circulated reports of distress observed on cables across the world, and the bridge in Genoa named after its fabled Italian designer Morandi had a spectacular failure due to corrosion of cables, leaving behind many dead and with multiple vehicles collapsing underneath.

For understanding the reasons for failure of bridges, one has to recognise the various types of failures that take place. There are failures that happen years after the operation of the bridges, sometimes due to inadequate or lack of maintenance practice. Same can also be a result of adoption of a design technology, without proper appreciation of long term deterioration issues in design. Cable supported bridges come under this category as there is inadequate understanding of the deterioration of cables that are subjected to constant exposure to rain, sun, and frost- the protective layer on cables by epoxy based chemicals and UV protected sheathings are yet to reach perfection.

In our country, of late, failures during construction, and immediately after the construction, are becoming commonplace. Though official investigation results are not made public, the evident reasons are that construction agencies do not always have the requisite experience, and more often the responsibility for construction are transferred to subcontractors with little or no experience, after the job has been secured based on the past capabilities of the original selected contractor! Motivation obviously is the poor rates secured in the first place.

If one wants to list the apparent fault-lines in our society that has made the country a claimant for maximum failures of Bridges, the list will be long, but let us highlight the important ones:

a. The practice of choosing the L1 bidder, despite official claim of disregarding the same, leads to award of the contract at unworkable price, and that is the motivation for compromising on quality of materials supplied, deployment of unskilled work team and adoption of unsafe practices. Adoption of Quality Based Selection (QBS) for specialised jobs should be the norm.

b. In EPC contracts, the authorities must check the credential of the deployed agencies like Design Consultants and Sub-contractors of the successful bidders as deficiency of capability can lead to failures.

c. The agencies actually deployed, including the Academic bodies entrusted with Proof Checking of design, must be made accountable, when a failure occurs. This requires a systemic change whereby these agencies are kept in the loop through the construction of the bridge, otherwise the liabilities will have to remain limited.

d. Every important Bridge must have a Maintenance manual created with help of the designers and the implementation of the same must be made mandatory, with provision for penalties in case of noncompliance.

e. There has to be a budget allotted for maintenance and staff identified for carrying out systematic maintenance. Updating of skills of staff, deployed for bridge work on regular basis, by agencies like IEI, CEAI, ACCE, IAStructE etc. is essential. Engineers whether in private organisations like consultants and contractors or with the authorities like PWD, SEB, Irrigation, Municipal Corporations, all require upgrading of skill on continued basis throughout their career by selected agencies so that they can implement safe practices and guarantee the optimum use of resources of our poor country.

It is unfortunate that in our country Engineering is not yet regulated as a profession and any graduate from an engineering college is entitled to issue construction documents and approve construction work from day one, unlike other professionals like Lawyers, Accountants, Doctors etc. Enacting an Engineers Bill, has been in process for more than fifty years and yet to become a reality.

Hopefully these changes will stem the failures of bridges in our country!!

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About the CROSFALL Newsletter

CROSFALL is a newsletter created by Indian Association of Structural Engineers (IAStructE). Its purpose is to share lessons learnt from structural failures, near-misses and safety concerns. CROSFALL is greatly encouraged and inspired by CROSS (Confidential Reporting on Structural Safety), UK, which is a collaborative effort of three institutions (IStructE, ICE and HSE). There is however no connection between CROSFALL-IAStructE and CROSS-UK.

CROSFALL has a confidential reporting system, which allow safety issues and failures to be reported by professionals, without exposing their identity. Any identifiable details, such as a project, product, individual or organisation, remain completely confidential to CROSFALL editorial team. Reporters' personal information will be collected to only verify the contents of the report, and to communicate with the reporter as and when necessary. The newsletter will report only failures and safety related issues with the objective to learn lessons from such failures and to help prevent future structural failures, by providing insight into root causes of such failures and spurring the development of safety improvement measures. CROSFALL team will depend on professionals to submit reports, whenever they can share their concerns about what they witness around or what they experience on any real-life projects. Anyone involved in the construction industry is welcome to submit a report. The more reports submitted, the better CROSFALL can identify and quantify safety issues across the industry. This will help the entire industry to learn lesson from CROSFALL publications

What can be reported?

- Structural failures,
- Poor Design and Detailing, Lack of Seismic Safety in planning
- Safety concerns about high risk erection schemes at Site
- Safety concerns on Temporary Works
- Near misses or observations relating to procedures followed at site, which may lead to failures or collapses.
- Unethical practices in the profession.

To submit the report :

Visit : www.iastructe.co.in/crosfall.php

E-mail : crosfall.iastructe@gmail.com