Confidential Reporting Of Structural Failures And Lessons Learnt

NEWSLETTER

A PUBLICATION OF INDIAN ASSOCIATION OF STRUCTURAL ENGINEERS

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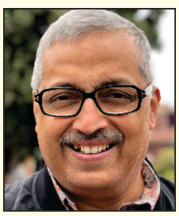
FROM THE DESK OF THE PRESIDENT

I am happy to note that the editorial board of CROSFALL is coming out with the ninth edition. The aim of this newsletter is to educate the readers about structural failures or near misses. Utmost care is taken not to reveal the identity of the project or the person reporting the article. The newsletter has been well-received by the fraternity.

Each edition of CROSFALL goes through a rigorous review process. Editorial board members & domain experts are doing fantastic work evaluating, editing & reviewing the reports. The current issue contains reports which raise serious concerns on various aspects, such as "CF28: Timely detection of distress in an under-construction dam led to avoidance of failure", "CF29: 54 year Old Bridge collapses while in service" and "CF30: Failure of Pile Foundation of a Bridge in Service".

I urge civil & structural engineers to send reports freely without fear or hesitation. Reports may be for any structural failure or structures with visible gross structural deficiencies and substantial risk of failure. Do send your feedback & suggestions.

— Prof. R. Pradeep Kumar



MESSAGE FROM CHIEF EDITOR

This is the 9th CROSFALL Newsletter since our inaugural edition in September 2022. With this publication, we have published 30 reports, covering a wide range of subjects in design and construction, primarily aiming to draw attention to safety issues in structural engineering, and to alert our reader to lessons that can be learned. We have seen in India series of bridge and building failures in last couple of years which are sobering reminders that we have a lot to contribute. We need to increase visibility and outreach of our newsletter, CROSFALL, so that more and more people read this newsletter and some of them get the inspiration to share their experience. CROSFALL plays a vital role in structural safety. By careful study of the report of failures and near misses, we can avoid disasters. When we fail to learn, and we repeat mistakes, disasters result.

This issue of the newsletter contains three reports, highlighting important lessons. Report CF-28 is titled "Timely detection of distress in an under-construction dam led to avoidance of failure". It reports a case of "Near-Misses". In this case the deficiency in quality of prestressing steel in the sluice gates could be noticed before water was stored to the full supply level. Had it not been so, there could have been serious disaster in collapse of gates and damages to trunion girders and piers of the spillway. Report No. CF-29 is the story of an old bridge which collapsed due to sheer negligence on the part of Owner Client to maintain the bridge. Repeated overlay on top of the bridge without having a check on increase of dead load, allowing the corrosion to grow unabated on the superstructure was the prime cause of mishap. Report No. CF-30 is about the failure of pile foundation of a bridge in coastal area, which got detected only after 8 to 9 years of operation. The extent of damage & distress noticed is a shocking revelation for Engineers.

I am sure readers will find the above reports interesting, insightful and educative. We welcome once again all our regular subscribers, readers and reporters for their support. We encourage readers to help us by passing this Newsletter on to all their contacts and to ask them to share their story with CROSFALL editorial board members. These reports are a readily available source of free information and may assist every reader in their future projects.

Happy Reading !

— Alok Bhowmick

Contents

REPORT No. CF-28

Timely detection of distress in an under-construction dam led to avoidance of failure

1. Introduction:

It is common practice to provide Hydraulic Gates in Spillway section of the dams for regulating water levels in the waterbody that forms behind the dam. In most of the dam projects, conventional type of structural steel gates are provided. Operation of these gates is somewhat clumsy and is also expensive. The use of prestressed radial gates is an alternative and such gates were used on one such Dam. Fig. 1 shows a view of the Dam in consideration. Normally high tensile wires or strands are used for anchoring these gates to the Spillway piers. However, in this dam, high tension alloy steel bars were used and failure of which threatened stability of the gates.

Fig. 1 : View of Dam

2. The Structure:

It is an arch-cum-gravity dam, which is curved in plan and rises 125 meter above the bed level, Fig.2 There are eight spillway gates in this dam, each of which is 10.2 meter long and 12.8 meter height. The gates rest on the crest of the spillway and are fixed to a beam called "Trunion Girder" which in turn is fixed to the concrete through bearings. Each gate is anchored with 96 Nos. of high tensile steel bars of 36mm and 21.5 meter long. Two bars of 11 meters were coupled for this purpose. Each gate is anchored with 9160 tonne prestressing force by using 48 prestressed bars on either side of the pier.

3. Nature of Failure:

After completion of the dam, during one of the routine inspections prior to commissioning, it was noticed that some prestressed bars were broken and a few bars had yielded. While going through stressing records, it was observed that 45 bars were broken during normal stressing. Some bars were restressed and, in this operation, another 54 bars were found broken. After a few months, a second inspection was carried out which revealed that another 31 bars were broken. Breaking of prestressed bars in course of time and at intervals indicated a substantial loss of prestress and gave alarming signal. The stability of the gates and related supporting structures of the dam was threatened.

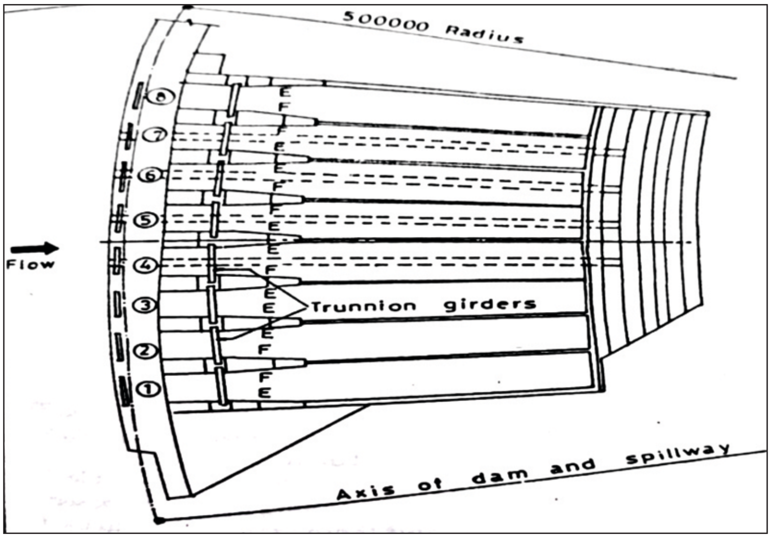


Fig. 2 : Details of Radial Gates

4. Possible Causes:

The high tensile bars used for prestressing appear to be not conforming to the specification and standards. A study of actual stressing results maintained by dam engineers indicated that the design elongations of 85mm was supposed to be obtained at a pressure of 997 kg/cm^2. However, it was achieved at a much lower pressure of about 725 kg/cm^2. Deviation observed is around 25 to 30% as against five percent normally permitted. Breaking strength of the prestressing steel was lower than specified. It was concluded that poor quality of prestressing bars and lack of quality control on prestressing steel has resulted in failure of anchoring arrangement of the radial gates.

5. Replacement of High Tensile Bars :

Proposal to replace existing bars by cable anchors without changing arrangement of the Trunion Girders, the Radial Gates and related components of the piers was found feasible and was accepted by the dam authorities. Criteria used for design of bars was on the basis of standard specifications and was not changed. (Fig. 3).

New cable anchor system was designed and developed to suit existing components of the radial gate support system. New anchor system envisaged use of six strand cable of 15.2 mm dia strand at each hole. New compact anchorage system of 6T15 was developed for this purpose.

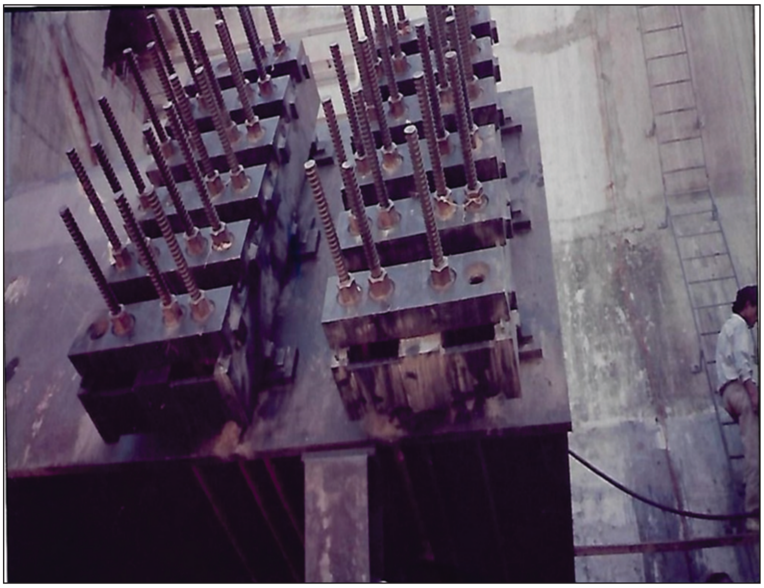


Fig. 3 : HT Steel Bar Anchors

The prestressing bars were destressed and removed carefully. Existing holes were used for housing the cable. No modification was required to be done except widening of anchorplates at the end of the cables to suit new anchor systems. Each strand was encased in HDPE sheath and filled with grease (Fig. 4)

The newly installed cables of 6T15 were stressed using special jacks developed for this purpose. Due to the higher ultimate capacity of the strand cables adopted, basic safety factors could be improved. Due to the new scheme, it was possible to monitor the prestressing force and augment it as necessary.

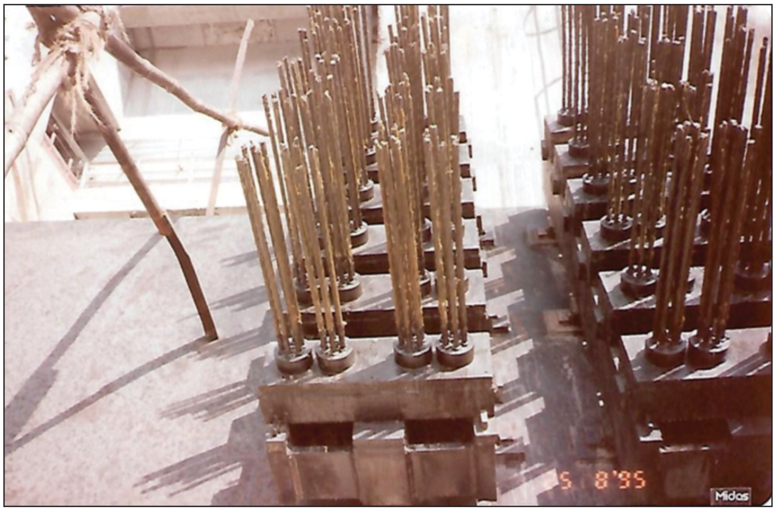


Fig. 4 : New Cable Anchors

6. Concluding Remarks :

The deficiency in quality of prestressing steel could be noticed before water was stored to the full supply level. Had it not been so, there could have been serious disaster in collapse of gates and damages to trunion girders and piers of the spillway. To avoid such perilous situations, it is highly desirable to test construction materials as per relevant standards and ensure that they fulfill technical requirements of the structure.

Opinion of Expert Panel

Poor quality of prestressing high tensile rebars used for the anchorage of radial gates of a dam led to their failure during initial prestressing itself. A large number of bars failed at a very early stage, just after the completion of the dam, and before commissioning. Even after a few months, it was found that further high tensile bars were broken. It was obvious that the quality of high tensile bars were questionable and did not meet the specifications and standards. The remedial measures were quickly conceived by way of the use of prestressed cables to replace the high tensile bars and a major disaster was thus avoided before water was stored to full supply level.

This report highlights the importance of strict quality control in material procurement and in the acceptance criteria for critical components in a system and the need for manufacturers to have a good factory production protocol including third party certification by a notified body. The importance of taking early remedial action to avoid disastrous consequences when signs of warning are manifest is also highlighted.

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REPORT No. CF-29

54 year Old Bridge Collapses while in service

This is the story of an old bridge, crossing over railway lines and a canal in an urban area, which collapsed suddenly without warning. The failure happened on the span across the canal at about 4 pm, ahead of the intense evening traffic of the city, and therefore caused only three deaths and damages to about a dozen vehicles plying on the collapsed span.

The bridge, opened to traffic in 1964, was one of the first prestressed concrete girder bridges in the city. It used multiple girders placed side by side, cross-stressed transversely through stiffeners at intervals, to ensure orthotropic plate behavior. While the six spans across railway tracks and vacant space were kept at 17.4 m, the span across the canal was made at 34.8m. The entire alignment was skewed at an angle of about 22 degrees to make the piers parallel to the railway tracks. Having a carriageway width of 12.8 m and pedestrian ways on either side of a width of 2.5m, the superstructure was formed with I girders laid parallel, top flanges touching with each other, all spans being of simply supported arrangement, and girders resting on plate bearings with lead sheets on expansion end. Fig.1 shows the cross-sectional arrangement of the bridge.

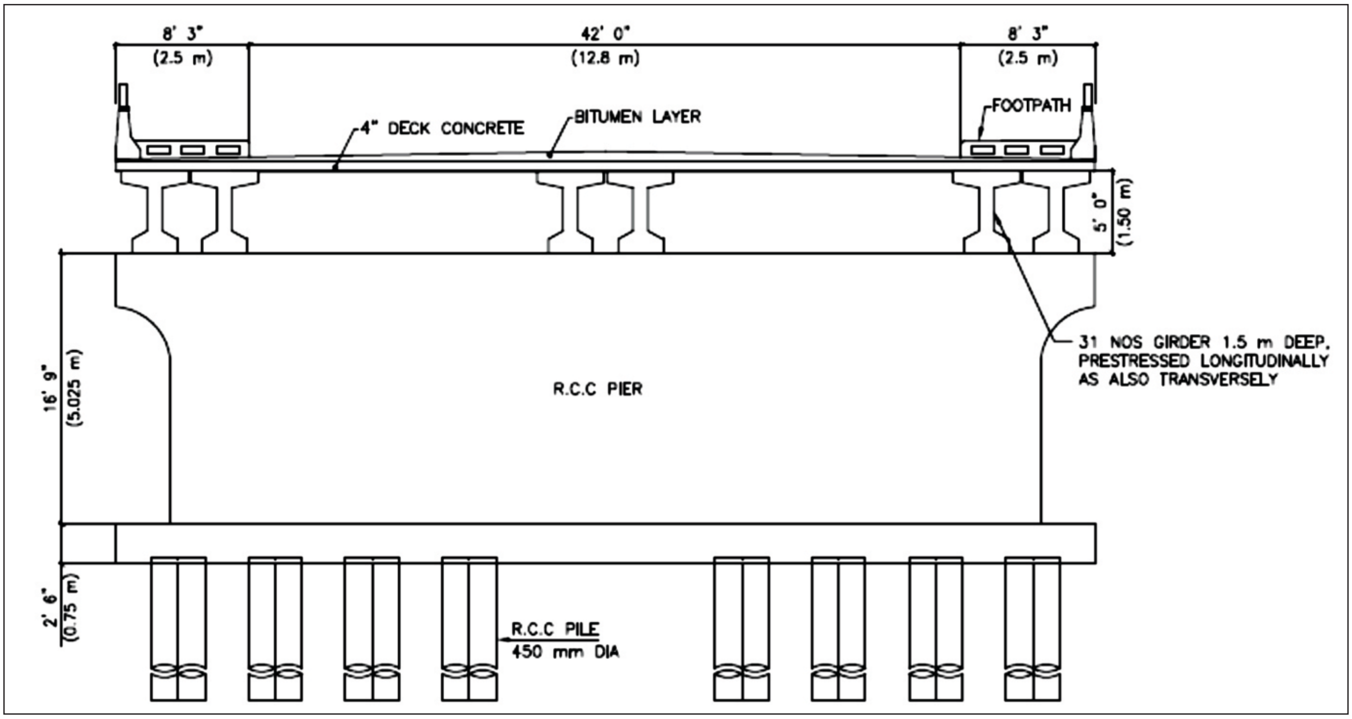

Fig. 1 : Sectional view showing the General Arrangement of the Canal Span Deck & Pier

While the shorter spans were made up of 41 girders, the longer canal span that collapsed had 30 girders almost abutting each other. This unusual girder arrangement was followed to ensure depths as shallow as possible, with strict obligatory requirements for ensuring adequate clearance on railway track and the lowest possible formation level of the road surface to restrict the lengths of approach embankments at both ends and thus ensure compliance with the geometrics of merging roads at both ends. While the 17.4m spans used girders with a depth of 0.6m (L/28.5), the longer 34.8m span used a 1.5m depth (L/23), clearance requirement across the canal being lower. The girders were supported on RCC plate type piers and abutments supported on in-situ piles of diameters 40 cm and 45 cm.

Considering the state-of-the-art knowledge available in India at that time, the design adopted was forward-looking and addressed all the concerns of planners very well.

The girders were topped by an in situ 100 mm thick RCC slab and bituminous wearing course of an average thickness of 125 mm.

The girders, for the failed span, were prestressed with 60 nos. 7 mm HT wires with a prestressing force of 3.57 T on each wire, using the Gifford Udall system. The transverse prestressing along the cross-stiffener was done using 3 Nos. of 8/7 mm wires, to ensure compliance with the design assumption of orthotropic behavior.

The bridge, designed for loading standards applicable for National Highways at that time, had served well the ever-increasing traffic loads for the past 54 years (till the bridge collapsed). With the wearing course getting frequently damaged by heavy goods vehicles and intense city traffic spread over day and night, the wearing coats were renewed often, without, perhaps, keeping track of the total thickness initially specified and designed for. Investigations after the collapse have revealed a much larger thickness of Bituminous wearing coat than the original specified 125mm, causing net tensions on the bottom flanges of the girders, which was originally kept at 2.8 kg/cm^2 compressive stress. This led to cracks in concrete, and progressive corrosion due to the humid atmosphere above the canal area. Frequent travelers across the bridge had complained that of late, the span used to accumulate rainwater at the center, perhaps due to sagging, and the same was rectified by adding more bituminous mix !

The other reason for failure perhaps was the corrosion of the transverse prestressing wires which had been stressed in situ, (after the erection of the girders), from a cantilever staging hung from the girders themselves. The anchorages and the ducts encasing the wires were grouted with cement mortars, which shrunk and got loose and fell off with time, making water ingress easier. Loss of prestressing could have adversely affected the orthotropic behavior and imbalance in the sharing of load carried by individual girders.

Maintenance of the bridge had been affected, with the inaccessibility of the underside of girders due to high voltage lines of electrified rail tracks and the absence of maintenance work manuals. While the bridge belonged to the Public Works Department, the land underneath was under the control of Railways for the track portion and of the Port authorities for the canal area, being responsible for the same. Such multiple control of an infrastructure causes a lack of accountability unless a protocol is established.

This collapse, once again, highlights the importance of systematic, controlled maintenance of critically important and capital-intensive infrastructure objects, built more than 50 years ago and already subject to the ever-increasing traffic intensity and rising axle loads. It also prompts the need for condition assessment at regular intervals and rehabilitation of such structures before the accidents happen, causing the loss of human life and tormenting disruption of urban life over long periods of reconstruction.

Opinion of Expert Panel

A significant stock of Bridges exists in India which are subject to increasing axle loads and intensity of traffic for years for which they were never designed. In this particular case, a combination of causes led to the probable collapse of the span including traffic load, for which the bridge was never designed, and which had drastically increased over time, and the increased dead load due to bituminous overlays led to tension at the bottom of the girders. The additional probable causes of failure are failure of the transverse prestressing system due to corrosion and consequent loss of prestress, insufficient maintenance, as access to the soffit of the girders was dangerous, due to presence of high voltage electric lines, the possible lack of co-ordination between three authorities responsible for the asset without any clear division of their responsibilities and accountability. In this case, the collapse of the bridge and loss of lives could have been avoided with proper follow-up of a maintenance regime based upon a maintenance manual, which was non-existent.

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REPORT No. CF-30

Failure of Pile Foundation of a Bridge-in-Service

1. Background :

This failure report pertains to two bridges in coastal area, supported on bored-cast-in-site pile foundation, where the foundation showed signs of severe distress / damage. The bridge was constructed and opened to traffic in 2015, but it showed signs of distress within 2-3 years of its service. The owner client had hired a structural auditing agency of repute in the year 2018 to assess the health of the bridge. Though the auditing agency did not carry out any inspection / investigation of the foundation, the agency carried out NDT and detailed inspection of substructure and superstructure of this bridge and pointed out many serious lapses in the workmanship. Also, it pointed out lapses relating to maintenance and operations. The safety auditing agency concluded way back in 2018 that the extent of distress and premature aging of structural components supported with the poor results of NDT indicated serious lapses on the part of Contractor and the Supervision Consultant for execution & lapses on the part of Owner for maintenance.

Distress in foundation came to light after 9 years of its operation, only recently (2024). The Client once again involved an expert bridge engineer to look into the matter. After detailed inspection of these two bridges, the expert concluded that the bridges require immediate attention and repair to prevent any untoward incident and any catastrophe. He recommended short term as well as long term measures, which are to be implemented in this case.

2. Observations at Site by the Expert Bridge Engineer:

a) The pile foundations in water spans in the two bridges under discussion were found to be critical as steel lining in top portion of free-standing piles was found to be fully corroded and concrete in within almost full diameter and length varying from 2.5m to 0.6m of pile between bed and soffit of pile cap was missing due to its erosion as can be seen in the picture below (Fig. 1).

Fig. 1 : Pile Liner fully corroded and concrete in pile top portion missing or eroded

b) With the help of a diver, it was possible to pluck/pinch concrete using bare hands, as can be seen in below pictures (Fig. 2). The concrete grade for the pile as per GFC drawing is M40.

Fig. 2 : Pile Concrete could be Plucked / Pinched using bare hands

c) The condition of pile foundation is found to be extremely critical due to absence of concrete in 3 out of 6 pile-group, in case of two pier foundations, 4 out of 6 pile-group in one pier foundation. There are two other foundation pile groups where the condition was found to be bad though not as critical as stated above.

3. Underwater Inspection of the Bridge Foundation:

Inspection was carried out by a specialist team, under-water but above the river bed level, in areas where the foundations was visually accessible. Hammering, rod piercing was carried out. Fig. 3 & Fig. 4 shows the cavity mapping carried out based on under-water inspection of the piles for two typical Pile Groups (Say Group A and Group B).

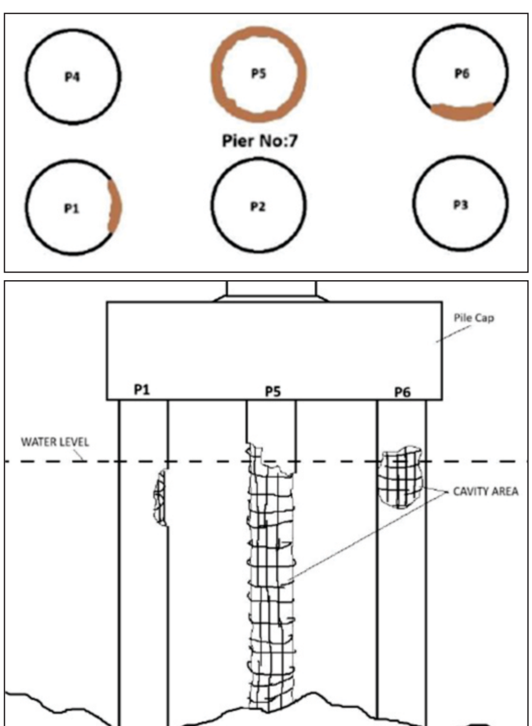

Fig. 3 : Cavity Mapping for Piles under Pier-A

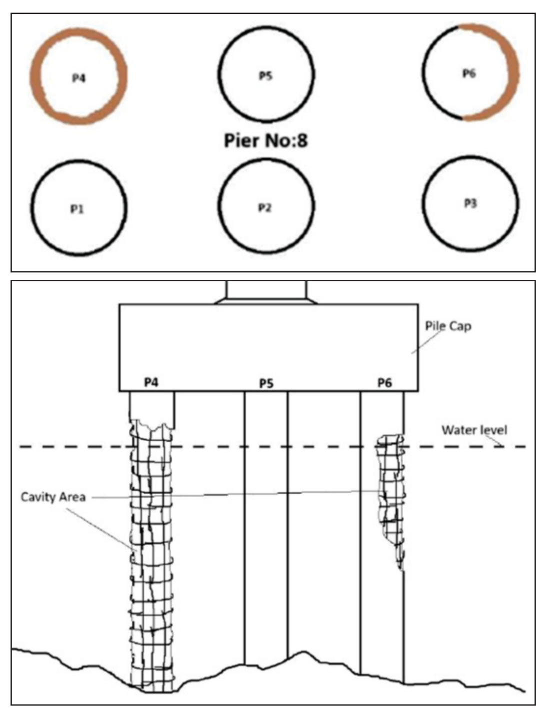

Fig. 4 : Cavity Mapping for Piles under Pier-B

Fig. 5 shows some of the photographs taken under-water.

Fig. 5 : Photographs under water showing distress in Pile Foundation

4. Recommendations by the Bridge Expert:

a) Few pier foundations in both the bridges were found to be in extreme critical condition. Pile liners fully corroded in these foundations and pile concrete in the top zone fully eroded. The reinforcement bars are exposed and unsupported for substantial length in many cases.

b) The fact that the concrete around reinforcement which are still sticking, are in loose state, which is coming out simply by hand plucking, indicates that the strength of concrete is also far too low.

c) The pile erosion seen above bed level due to substandard concrete may exist below bed also, which can only be ascertained by conducting pile integrity tests. Therefore, it is important to check the quality of concrete in all the piles for establishing safety of the structure.

d) As a short-term solution, to prevent any mishap, it is proposed to repair the affected piles by anti-wash out non-shrink, high-strength cementitious micro-concrete for underwater repairs. The concrete shall be of strength M50.

e) As an immediate task, It is essential to check the quality and consistency of pile foundation for all the piles, for their full length. This can be done by using pile integrity test or by other similar available methods.

f) Depending on the results of tests on pile foundation, a long-term solution will have to be adopted for the safety of the bridge. The permanent solution, if necessary, will be either constructing new group of piles around existing piles and integrating them with existing pile caps.

Opinion of Expert Panel

It is a clear case of sub-standard work execution & supervision, without adhering to the construction specifications. For any pile foundation construction, sub-surface exposure environment has to be assessed and the cover has to be provided accordingly. If the sub-surface water is contaminated and aggressive, cover needs to be increased and anti-corrosive treatment to the reinforcement has to be provided. Anti-corrosive paint has to be provided on steel liners. The concrete mix too had to be designed for aggressive sub-surface environment for which guidelines are available in Indian codes. Corrosion may also occur if the water mixed in concrete does not meet the quality requirements. It seems in this case, water mixed and quality of sub-surface water have not been tested during construction. The quality of concrete seems to be poor and it appears no pile integrity tests were conducted after pile casting. The quality standards and specifications have been mentioned in IS:2911, IRC:112 and MoRT&H Specifications, but it is obvious that these have not been followed by the contractor nor enforced by the supervision authority. In the opinion of Expert Panel, all the piles should be rejected and alternative foundation should be introduced. Needless to mention that quality control measures as specified in the codes and IRC MoRT&H Specifications must be strictly followed.

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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.

To submit the report :

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

E-mail : crosfall.iastructe@gmail.com
