Confidential Reporting Of Structural Failures And Lessons Learnt

NEWSLETTER

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From the Desk of the President

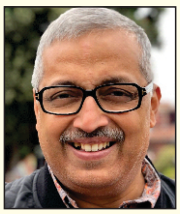
I am happy to note that the editorial board of CROSFALL is coming out with the eighth edition. The aim of this newsletter is to educate the readers about structural failures or near misses. Utmost care is taken not to reveal the identity of the project or the person reporting the article. The magazine 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 "CF25: Failure of modular expansion joints for a flyover", "CF26: Failure of pile foundation of an under-construction bridge in the coastal environment" and "CF27: failure of a bridge due to foundation settlements".

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



Welcome to 8th issue of CROSFALL Newsletter. We have witnessed a series of failures of bridges and airport terminal roof structures, in the past 2 weeks. 10 bridges have collapsed in Bihar and at 3 airport terminals, the roof structure collapsed. This is unprecedented and a matter of grave concern for all of us. Such failures not only dents image of Civil Engineers in the society, but it also drags the country down on the development front.

The three reports in this newsletter covers failure of 3 bridge structures, reflecting the poor quality of workmanship that unfortunately prevails in the industry. The first report pertains to failure of modular expansion joints in an urban elevated viaduct which was in service for just four years. Second report pertains to poor quality of workmanship in foundation of an under construction bridge in coastal environment, which came to light, quite accidentally, during construction of substructure and superstructure. The third report relates to rehabilitation of a long span bridge which settled by about a metre, during unprecedented floods of 1978. I am sure readers will find these failure reports along with the opinion of expert panels about ways and means to prevent such failures, very informative and educative.

I am happy to share with the readers that CROSFALL has attained much prominence and progress by now. The newsletter is being discussed and lauded in many forums outside the IAStructE platforms. I once again appeal practicing professionals to fearlessly contribute to CROSFALL by sharing their experiences with the fraternity.

Happy Reading !

— Alok Bhowmick

Contents

REPORT No. CF-25

Failure of Modular Expansion Joints of a long Flyover

1. Introduction:

In this report, the reporter describes the distress and damages observed in the modular expansion joints installed in a six-lane grade separator project, located in an urban setting, which was opened to traffic about four years ago. Several expansion joints in this grade separator had to be replaced in a short period, well before the intended design life of these joints. The reporter in this case had carried out investigation, analysed the possible causes of failure and suggested possible remedial measures

2. Role of Expansion Joints & Salient Features of Modular Type Expansion Joints :

The bridge expansion joints are primarily provided to accommodate the movements and rotations of the bridge superstructure and to permit vehicle traffic to travel smoothly across large expansion joint opening. Expansion joints should provide a smooth ride for traffic passing over the joint at the same time shall sustain all loads subjected to it from the passing traffic. Expansion joints shall also prevent ingress of water and debris through the expansion gap.

Modular expansion joints (MEJ) are usually provided where the movement demand is higher because of long spans. Modular expansion joints divide the total movement requirement of the superstructure among individual, smaller gaps. It consists of multiple steel beams (centre beams) arranged side by side to form a continuous system across the bridge deck. These beams are supported over cross beams, spaced at certain intervals, spanning between two decks. Some control mechanism is generally provided to ensure equal opening and closing of the gaps between the centre beams. The gaps are fitted with elastomeric sealing profiles, to prevent the ingress of water, chemicals, and debris.

3. Problem faced with the functioning of MEJ in this bridge:

According to the reporter, the modular Joints installed on the elevated structures had malfunctioned within a short period of time after installation. Problems encountered are as follows:

a) Heavy pounding in most of the joint locations with the passage of vehicles.

b) breaking of the several centre beams (Refer Fig. 1)

c) dislodgement of internal support bearings and compression springs

d) dislodgement of rubber seals

4. Observations:

a. Design Deficiencies

(i) *Improper Support Beam Design:* It appears that the standard detailing has not been followed for the supports. The gaps between the support (cross) beams appear to be large. Looking at the spacing between the support beams, the reporter is of the view that the dynamic behaviour of the centre beams has not been considered in design.

(ii) *Inadequate welding detail:* The reporter, on the basis of visual inspection of the welding detail, feels that the strength of connection between the centre beams and the support bars are questionable. Such "girder grid joints" are very sensitive regarding the welding details of the centre beam to support bar connection.

(iii) *Non-standard Material:* The material used for the compression bearings/springs appears to be of suboptimal quality.

Fig. 1 : Broken Centre Beams

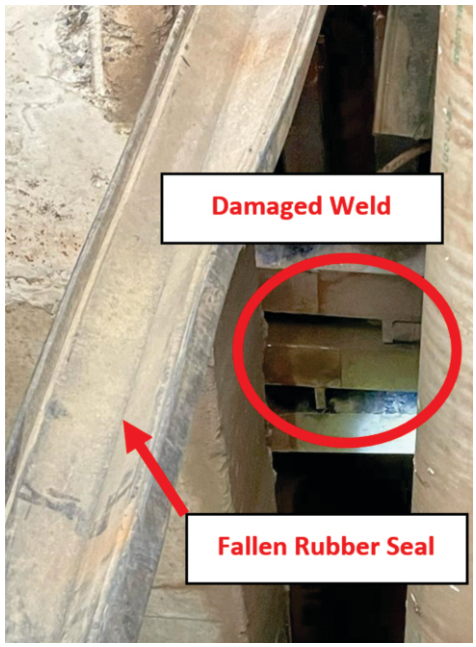


Fig. 2 : Damaged welds and Fallen Rubber Seal

b. *Poor manufacture and workmanship*

(i) *Improper Splice Detail and Welding:* The field splicing of the Expansion joints shows visibly poor connection details and poor workmanship of welding of the parts. From Fig. 3 below, it is evident that a proper groove angle is not formed for effective butt joints, which is required from consideration of high fatigue loads. Only the top part of the beams has been connected leaving gaps in the rest of the portion.

(ii) *Inadequate Corrosion Protection:* The joints removed from the bridge show signs of extensive corrosion indicating inadequate application of Corrosion Protection system (Refer Fig. 4).

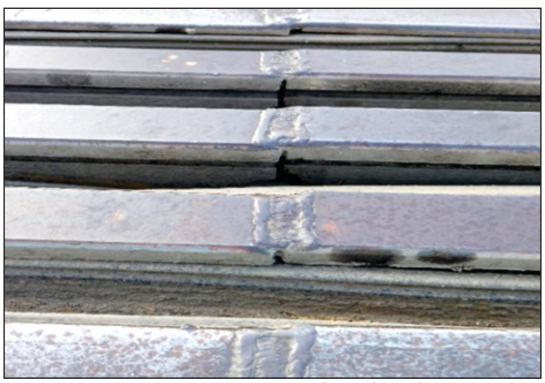


Fig. 3 : Improper splice details

Fig. 4 : Extensive Corrosion of the MEJ's taken out from the bridge deck

c. Installation issues

Based on scrutiny of the modular joint boxes, it was found that the concrete had penetrated and filled the modular joint boxes (Refer Fig. 5). This indicates that due care and attention were not given during the installation of the modular joints. However, a well detailed modular expansion joints should have a steel shuttering plate integrated with the joint, as otherwise it would be very difficult to achieve a perfect shuttering at site along the non-linear profile of any modular joint and it would always be prone to concrete intrusion.

Fig. 5 : Concrete intrusion on modular joint boxes, indicating poor installation

5. Conclusions:

Expansion joints are proprietary items and strictly following the basic principles of a proprietary design system is of utmost importance. The presence of numerous movable parts makes the Modular Joints particularly susceptible to fatigue and wear. If proper design taking effects of dynamic impacts and strict quality control in manufacture and installation are not followed, the joint will deteriorate very quickly, this case is proof of this fact.

To ensure the performance requirement of the joint components against fatigue and/or wear, Cl. 8 of IRC:SP:69-2011, stipulates furnishing sufficient evidence of the reliability of the proprietary products. Several type of tests, carried out by a recognized laboratory/ university/ institute on the joint components, as a part of product development tests have been recommended. The Client / Client's representative has the responsibility to check the reports thoroughly to ensure that the components used in actual products and those used in the fatigue/wear tests are the same.

It is also important for the accepting authority to check pre-approved WPS (Welding Procedure Specification) for specialized connections. The weld joint shall pass the Ultra-sonic test for welding. Fatigue test report from a recognized laboratory of butt welded splicing of Centre beams with 2 million load cycles shall be furnished by the manufacturer according to Cl. 8.2.5 of IRC:SP:69-2011. The actual splice welding should have been carried out adopting similar procedure, as adopted for testing.

An integrated shuttering plate should ideally be provided with modular expansion joints to properly seal the space between the underside of the joint and the vertical face of the recess. Without appropriate shuttering, there is a strong possibility of concrete intrusion within the moving parts of the joints thereby compromising the functionality of the joint.

Most importantly, during the selection of critical bridge components like bearings and expansion joints, it's important to consider the life-cycle costs associated with these products. In addition to the direct cost involved in the replacement work, the hardships to the bridge users during the replacement, which might need one or multiple lane closures, should also be considered. A little more upfront cost in selecting the right product and strict quality control in the design, manufacture, and installation of such products might go a long way in largely saving subsequent costs and hassles.

6. Opinion of Expert Panel :

Expansion Joints are an important element of any bridge and are subjected to fatigue and corrosion. Modular Expansion Joints are used when the expansion of the bridge deck is beyond the range of that which can be accommodated by strip seal joints (> 80 mm).

This report on the failure of modular expansion joints in a long flyover brings out the reasons as to why in some cases, early-age failures of modular expansion joints occur - either due to design deficiencies, manufacturing issues, poor workmanship or improper installation. IRC SP:69-2011 "Guidelines and Specifications for Expansion Joints" gives substantial guidance on the types of tests to be carried out and quality control to be exercised during manufacture and installation. Needless to add that early-age failures of expansion joints lead to direct costs as well as an indirect user delay costs, when viewed in the Life Cycle Cost framework. It is clear that it is very important to achieve high-quality control of expansion joints during manufacturing and installation at the site as per the manufacturer's specifications and method statements so that early age failures are avoided and life cycle costs are kept as low as possible.

The expansion joints are proprietary items. Selection of manufacturer for supply, with proven past records, adherence to the manufacturer's specifications and installation procedure, testing requirements and acceptance criteria and presence of manufacturer's representative at site during installation to guide the contractor, are key to ensuring expansion joints achieve their intended design life.

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REPORT No. CF-26

Failure of Pile Foundation of an Under-Construction Bridge in Coastal Environment

Introduction

This report is about the failure of pile foundations of an under-construction bridge, which accidentally came to the notice of authorities when local villagers took photographs of exposed part of pile foundations and published these photographs in local newspapers. It is reported that this bridge has 5 spans out of which 4 spans are of span length approximately 65m and one end span is of span length approximately 32m. One out of these 5 spans is a 'navigational span', the foundations and substructure on either side of which are designed to take barge collision impact forces. At the time of exposure of the poor workmanship issue, the piling work on all the foundations was completed. Pile caps and substructures of both the abutments, and two piers (i,e. Pier P1, and P4) are completed.

Observations :

The following observations were made by the reporter :

a. The concrete is mixed with bentonite in the top portion of the pile. It appears that the concreting of pile has not been carried out properly. The practice of continuing concreting even after the concrete reaches the top level of pile, so as to push the bentonite mixed concrete out of the pile shaft till good and sound concrete is available at the cut-off level, has not been followed at this case. The result can be seen in Fig.1 below, where it can be seen that the top portion of the pile has exposed reinforcement and very poor concrete.

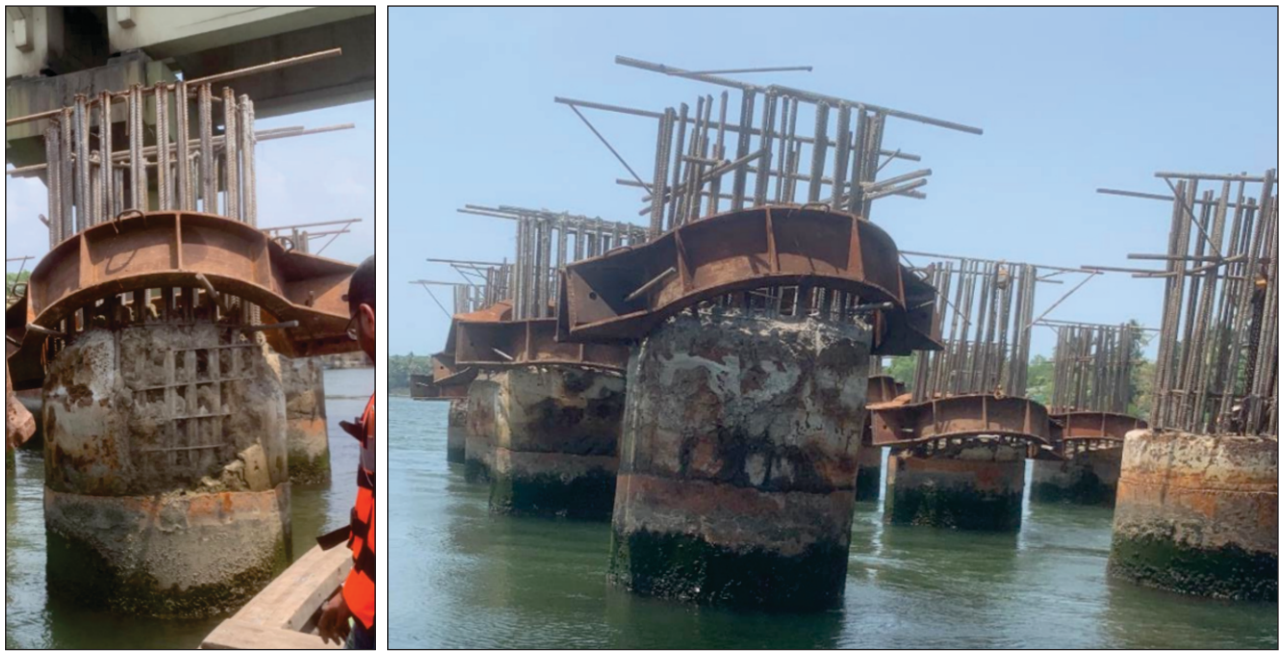

Fig. 1 : Exposed reinforcement and bentonite mixed concrete in top portion of the pile below the cut-off level

b. The reporter noted that the reinforcement cage inside the pile bore is totally out of alignment resulting in the concrete cover at one side of the pile of 250 mm and nil on the opposite side as seen in Fig. 2 below. These two values also indicate that in addition to variable cover the circularity of the reinforcement cage was also not maintained and the cage is elliptical.

c. The stainless-steel reinforcement bars are supposed to have been used in this project for protection against corrosion. However, the dowels from piles as well as the exposed reinforcement in piles without adequate cover are seen as rusted/decoloured, as shown in Fig. 3. This raises doubt about the material quality used.

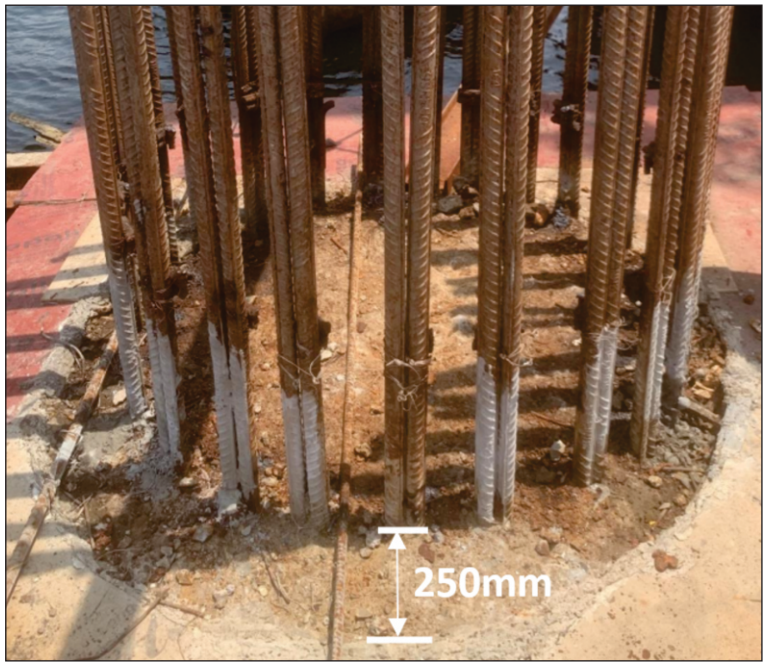

Fig. 2 : Reinforced cage placed with 250mm cover on one side and NIL gap at the other end. Circularity of cage is also not maintained

Fig. 3 : Reinforcement Bars having signs of corrosion

Conclusions:

a) Substandard quality and workmanship in the construction of pile foundations is visible in this case.

b) In almost all the piles, which are exposed by removing the liner or at locations where pile caps are not cast, there are clear indications of heavy bentonite contamination of concrete in the exposed portions of the piles. It seems standard piling methodology and precautions of boring, cleaning, washing, lowering of cage, and concreting have not been adopted/used.

c) The production, quality, and workability (slump) of the concrete appear to be below acceptable standards which has led to honeycombing, segregations, and voids in the piles.

d) The used steel reinforcement, which is either exposed on the pile surface due to cage movement/inadequate cover or left for doweling into the pile cap is showing rusting and decolouring. This can be due to the non-conformance of the procured steel for specified specifications.

e) The reporter was surprised to find that all the procedures for execution and testing as per specifications and contractual requirements are in place, as per records, but the finished product at the site is grossly substandard.

f) As per GFC drawings, it was required to conduct an integrity test on each pile to confirm the quality of the concrete and the presence of any voids, honeycombing, necking, area reductions, contaminations, etc. On record, these tests were reportedly performed on piles, and results were recorded conforming to the required quality and specifications but, at the site, the exposed portions of piles were found to be non-conforming and sub-standard as per visual inspection.

Recommendations :

Following steps are recommended by the reporter to the Client / Executing agency :

a) Expose all the piles by cutting the liner from the cut-off level downwards till good concrete is seen

b) Remove the unsound or bentonite contaminated concrete up to the level where visually good and sound concrete is seen.

c) Confirm the cover to the reinforcement at the level of good/sound concrete. If a deficient cover is found, then continue removing the concrete up to the bed or where the required cover is encountered whichever is earlier. If required, temporary coffer dam or suitable arrangement shall be adopted for dry area for inspection and rectification.

d) Perform a pile integrity test from the location of sound and good concrete to confirm the quality of concrete in the balance portion of the pile below.

e) A few samples of stainless steel should be taken from the dowels left for pile caps. These samples should be sent to accredited laboratories

f) NDT tests including taking micro concrete cores should be done in the elements already constructed to confirm their acceptability as per drawings and specifications.

g) The above works should be done under the strict supervision of competent representatives from authority. All the crucial stages of above investigations should be video-graphed.

Opinion of Expert Panel:

The failure as reported in this paper, is completely due to gross negligence of the executing agency and failure of proper supervision by the supervising team from client/client's representative. The team did not follow the standard procedure and methodology of construction technique and the minimum quality checks which are laid down in the contracts/codes/guidelines. Even, test results (like integrity testing) did not reflect the true condition observed at site, which raises doubt about the reliability of conducted test. Poor execution and installation followed by fake Pile Integrity Tests all collude to ensure the failure of the pile foundations in this case. Recommendations to redeem the situation are highlighted. Clients should exercise caution and choose an experienced piling contractor/sub-contractor. Strict action against the representative of Authority, agency who represented as Authority's Engineer/Independent Engineer and the executing agency should be taken to prevent recurrence of such malpractice in the country. An independent third-party check is recommended who will critically check and certify the quality of the repair works in this situation. However, expert panel is of the view, looking at the nature of distress, that it may have been prudent to reject such defective piles and instead construct new set of piles.

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REPORT No. CF-27

Failure of a Bridge due to Foundation Settlements

1. General

This 2 lane bridge, 478.8m long was constructed in 1970s. The substructure of this bridge comprised of twin hollow reinforced concrete cellular piers which are supported on 6.1-meter diameter single circular masonry well-foundation. Superstructure is made of two cell reinforced concrete box girders of balanced cantilever type with main span of 48.8 meter and 12.2 meter long cantilevers on either side. The suspended spans of 24.4-meter length are supported on cantilever tips. Fig. 1 below shows the span arrangement schematically. Steel rocker bearings at one end and segmental roller bearings at the other end have been provided for the main spans as well as suspended spans.

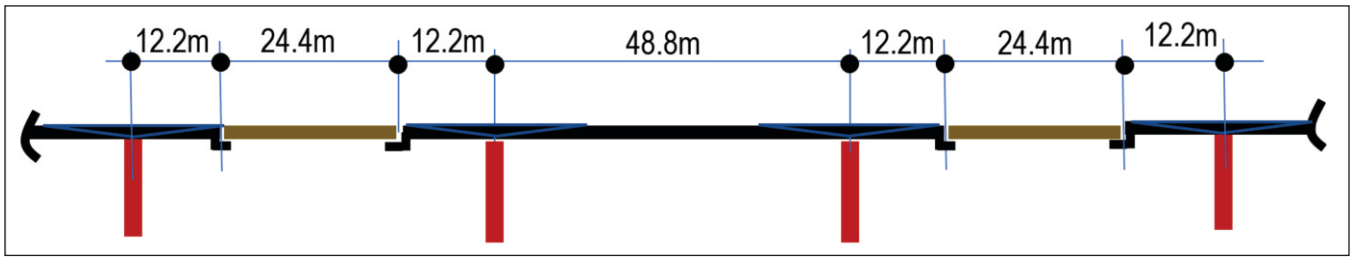

Fig. 1 : Typical Span Arrangement for the Bridge (Schematic)

2. Nature of Failure:

During the unprecedented floods of 1978, one of the pier underwent heavy scouring and eventually tilted longitudinally in the grade of one in 42 and settled by 86 centimeters. There was some additional relative settlement between the upstream and downstream faces of the pier by about 3 centimeters. Consequently, the top of the pier supported on the affected well moved longitudinally by 86 centimeters. Single segmental roller bearings provided on the Pier toppled and box girder fell on collapsed bearing with an impact. Total settlement of box girder over pier was 1.34 meters. Fig. 2 and Fig. 3 show the photo of the bridge after experiencing large settlement on one pier.

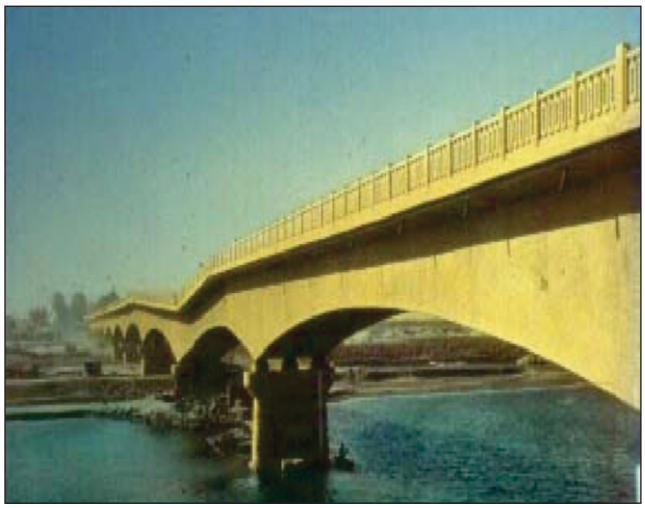

Fig. 2 : Settlement of Pier

Fig. 3 : Misaligned Decking

The suspended spans supported on cantilever tips at either end of the box girder also got tilted, one in downward and the other one in upward direction. Rocker bearings provided at the other adjacent pier (PN+1) were not damaged or dislocated due to span rotation. Some cracks developed in the webs of the box girder as well as pier cap at the location of the impact.

Traffic had to be suspended on this bridge due to settlement of the pier pending investigation about the failure of the structure and possible rehabilitation.

3. Causes of Failure:

The main reason for settlement of the Pier appears to be extraordinarily heavy floods which occurred first time after the opening of the bridge. As a result, there was excessive scour around the well foundation at the pier which has undergone large settlement, adversely affecting its stability. The well settlement was non-uniform thereby alignment of many bridge components like pier, well cap, cut roller main bearings and suspended span bearings and the suspended span itself was affected severely disabling the bridge to carry the traffic.

In addition to the causes mentioned above, some of the related aspects inviting attention of bridge engineers are basic calculation of the flood volume, arriving at the HFL, and computation of scour depth which is done as per codal provisions based on empirical formula of Lacey and calculation of waterway. While executing the work of rehabilitation of this bridge by the reporter, it also came to the reporters notice that the alignment of the bridge itself was faulty. It is well known that the bridge should be located on straight reach on upstream and downstream side for a certain minimum length. However, unfortunately this was not adhered to in this case. In fact, the river was taking a sharp turn while approaching the bridge. Apparently the administrative and political considerations might have prevailed for fixing the final alignment. The river meandered at the location and there was abnormal concentration of flow at the specific Pier causing the mishap.

4. Restoration of the Bridge :

The bridge was restored by taking measures to tackle the distresses in different components of the bridge as described briefly as under:

(a) ***Foundation :*** In order to prevent deeper scour and thereby ensure required grip around the wells, a flexible garland consisting of cement concrete blocks and boulders in wire crates was provided below normal scour level for the wells. This protection was found very effective and worked well subsequently for more than three decades.

Fig. 4 : Span lowered on new bearings

(b) ***Well Cap :*** Well cap of Pier No.3 has gone down below LWL due to settlement of the foundation. A new well cap over old well cap was constructed to accommodate thickening of the pier, placement of steel trestles for lifting of the superstructures and also to take care of tilting of the foundation etc.

(C) ***Pier and the Cap :*** The integrity of the damaged pier and its cracked pier cap was restored by epoxy injection treatment and it was further strengthened by jacketing. New pier and pier cap was designed such that the bearings on the new pier cap could be placed at the position of top bearing plates attached to the superstructure.

(d) ***Lifting of the superstructure :*** The superstructure was lifted progressively by about 1350 mm in stages to bring it to original line and level by using hydraulic jacks.

(e) ***Installation of new bearings and lowering of the span :*** The span was lifted higher than required to facilitate installation of the new bearings. Finally the span was lowered on these bearings by using the jacks.

Opinion of Expert Panels

The failure and restoration report are very informative and educative for the practicing engineers. This is a classic example of under estimation of hydraulic parameters like discharge, HFL and scour level. The empirical formula for estimation of hydraulic parameters should be used with caution which are not applicable to all the conditions. Hence, hydraulic parameters shall be estimated on case to case basis with due considerations given to local effects and by using other suitable methods. Proper geotechnical investigation is must since soil strata may vary from pier to pier and silt factors may vary. Over estimation of silt factor will lead to underestimation of scour depth. Planning for selection of bridge site should be done by experienced and qualified designers and location of bridge at sharp radius should be avoided. If unavoidable, scour evaluation should factor for the extra scour caused by flow in sharp bend. Counter scour measures should be adopted in such situations.

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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 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