CROSFALL

Confidential Reporting Of Structural Failures And Lessons Learnt

NEWSLETTER

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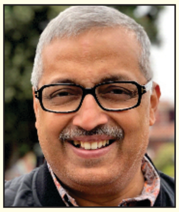
From the Desk of the President

I am happy to note that the editorial board of CROSFALL is coming out with the seventh edition. This unique newsletter aims to educate the readers about structural failures or near misses without revealing the identity of the person or the project. It has been well received by the readers and helped them to be cautious in their respective projects.

Every 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 a cement silo and its remedial actions, structural distress in the pier cap of a flyover and failure of an under-construction bridge due to foundation tilting.

It is noticed that gradually people are coming forward to send the reports. 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 7th issue of CROSFALL Newsletter, which is also the 1st newsletter in the current calendar year 2024. The three reports in this newsletter cover failure reports on cement silos, bridge foundations and bridge pier caps.

This newsletter is being prepared in the aftermath of the catastrophic failure of Fancis Skott Key Bridge at Baltimore, USA on 26th March 2024. The dramatic and spectacular progressive collapse of this continuous trussed bridge was captured in video and made viral on social media. Such failures once again remind all of us about the need to learn lessons from failures and thereby mitigate future risks. In case readers wish to know more about this bridge and about what lessons are to be taken by bridge owners and bridge engineers from this collapse, they may read the IAStructE newsletter of March 24 (free downloadable from IAStructE website), where an article is published on this topic.

While the Baltimore Bridge collapse will get all the attention of the global experts and I am sure proper investigation by NTSB will get to the root cause failure analysis and come out with lasting solution to the issue, there is a very pressing concern of Indian citizens on very frequent collapse of bridges in India, which are often not getting the attention it deserves. This is a very serious issue and drags the country down on the development front.

CROSFALL has attained much prominence and progress since our last newsletter, which was published in 1st week of January 2024. The newsletter is being discussed and lauded in many forums outside the IAStructE platforms. Behind the scene, the CROSFALL editorial board is working relentlessly to encourage practicing professionals to fearlessly contribute to CROSFALL by sharing their experiences with the fraternity. I take this opportunity to once again appeal readers to come forward and share their experience of failures.

Happy Reading !

— Alok Bhowmick

Contents

REPORT No. CF-22

Failure of a Cement Silo & Remedial Actions

This report is regarding the failure of a Cement Silo, which had taken place 4 decades ago. Failure of cement silos is not very common. A typical case of cement silo for a plant located in central India is described here. The plant was under construction in early eighties and construction of 4 cement silos adjoining each other was completed by end of 1984. These silos were meant for storing of cement. When the process of filling cement in the silos, was in progress, one of the silos gave way and got tilted. It rested against the adjoining silo failing which it would have collapsed on the packing plant. The silo failed and cement plant had to be stopped.

1. The Structure :

Group of four cement silos was constructed adjoining to the packing plant as shown (Fig. no. 1 & 2).

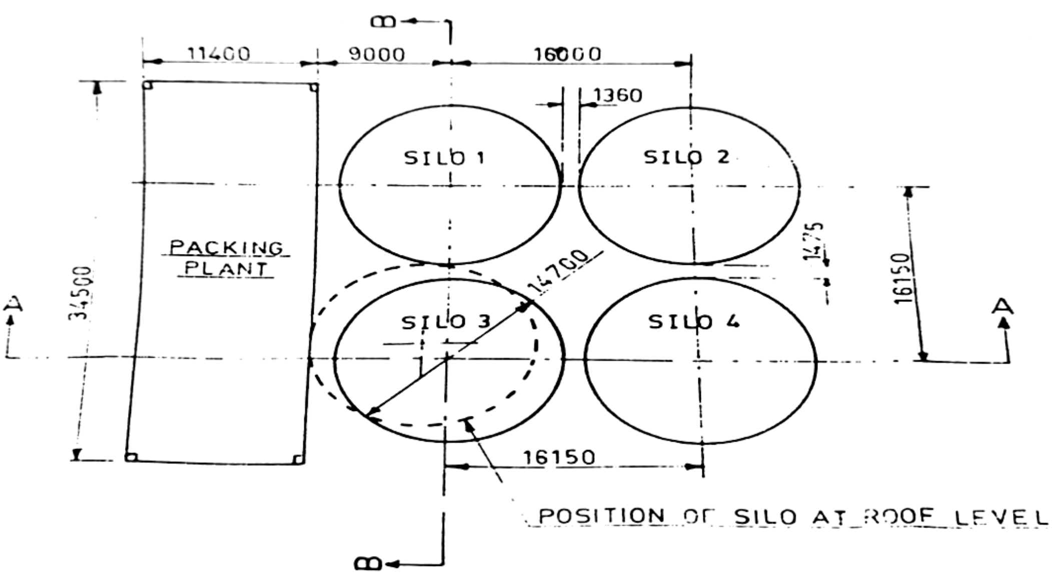


Fig 1 : Key Plan

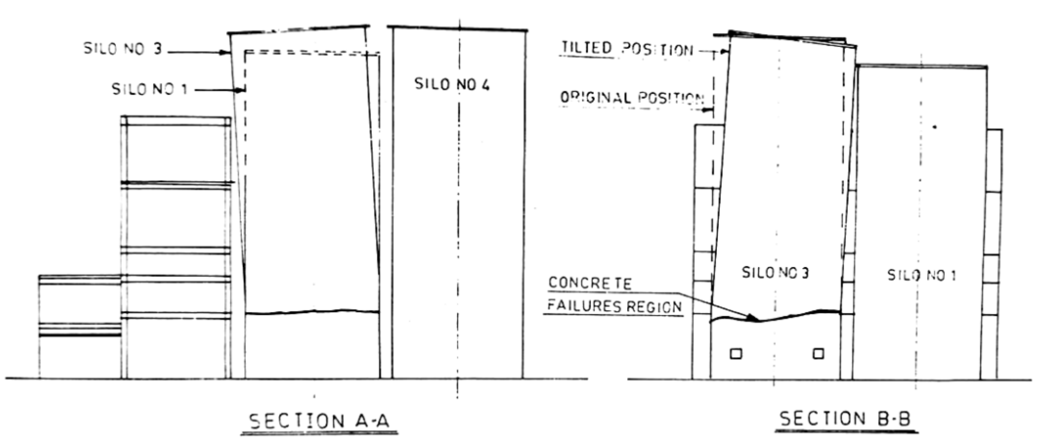


Fig 2 : Section

Capacity of the cement plant was 1.2 million tonnes. The silos were constructed in reinforced cement concrete and were founded on solid RCC footing resting on the hard rock. Each silo was 14-meter diameter internally and 37meter in height. All 4 silos were constructed by using slip form technique wherein screw jacks were used.

2. Nature of Failure:

Out of four silos, silo no.3 as shown in the above figures was in operation for about an year. This silo however was not used for full capacity. After a year in 1985, when the silo was being filled to almost full capacity, it got tilted by two meters and leaned upon adjoining silo which was full with cement at the time of the accident. But for the support from adjoining silo, the silo no. 3 would have collapsed resulting into a major accident. Fig No. 3 & 4 shows the tilted silo.

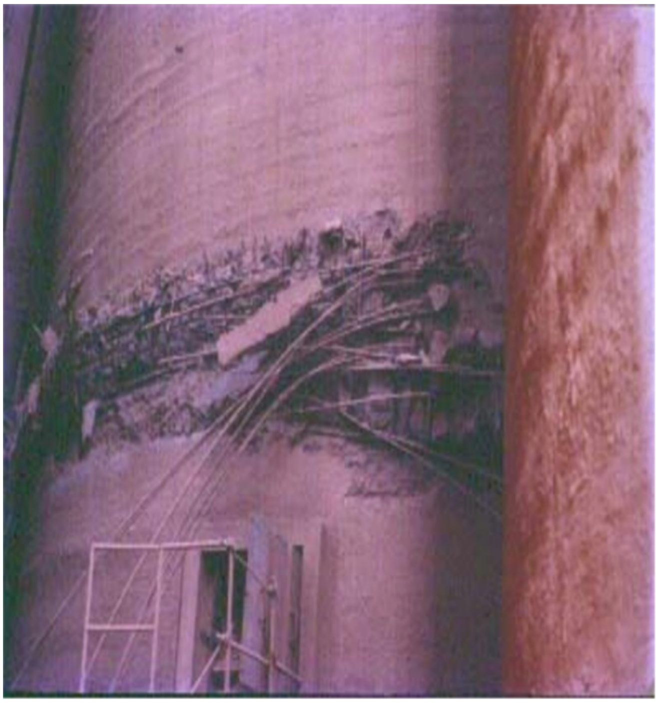


Fig 3 : Crushed Concrete

Fig 4 : Tilted Silo

There was crushing of concrete noticed at a height of about 7 meters. Tilting of silo occurred slowly in all taking about 25 minutes. The direction of the tilt kept on changing and the silo finally leaned along the line bisecting the packing plant and adjoining silo at right angle and got supported on the latter.

3. Possible Causes of Failure:

Detailed investigation revealed that during construction of this silo, when the height of 7 meter had been reached, the shutters got stuck up. There was interruption of more than a month in concreting operations at that stage. It appears, that sufficient precautions were not taken to ensure proper continuity of wall. The concrete at that level remained weak. Joints are source of weakness and need to be treated properly to achieve same quality of the concrete. Though the silo was in operation for a year or so, it was never filled full. The failure occurred only when it happened to be full.

4. Concluding Remarks:

Rehabilitation of the silo was carried out in mid-eighties when facilities for investigation were very limited. Reasons for failure of the silo were analysed by the engineers and designers of the cement plant. It is gathered from them that the quality of concrete in particular zone of the silo might have led to this mishap. In conclusion it may therefore be said that quality of concrete should essentially be maintained in all parts of the structure during the construction.

5. Opinion of Expert Panel

The failure of the Silo no. 3 when it was in use, filled with cement, due to the local crushing of concrete at an improperly treated construction joint puts a sharp focus on the needs for proper treatment of construction joints before proceeding with further construction. Slip form technique was abruptly halted at 7m when the shutters got jammed and insufficient/incorrect treatment of this construction joints before resuming further construction leading to the crushing failure of the concrete at this location at a later time.

Also, the report serves to caution against choosing executing agency and personnel's who do not have the appropriate qualification, skill and experience to carry out construction. Client must examine the competency of the contractor and consultants before awarding such works.

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REPORT No. CF-23

Structural Distress in Pier Cap of a Flyover

1. Introduction

Flyovers are a common sight in the urban environment. The purpose of the flyover is generally to crossover a large arterial road perpendicular to its proposed alignment. The span at the crossing is often of the order 40-45m and this is termed as the "obligatory" span. The clear height of the flyovers is generally kept at 5.5m (minimum) below the soffit of the superstructure of the obligatory span. The remaining spans are of smaller lengths which would yield an overall economy of the whole scheme. Cast in situ construction of the superstructures in the urban environment are preferably avoided; Precast prestressed girders (Pretensioned or Posttensioned) being the norm. The width of the flyover depends on the traffic intensity and normally caters to 4 to 8 lanes. The total width of the deck can vary from 10 to 30m. When precast girder-slab concept is adopted the spacing of girders are kept at about 3.0m and edge cantilevers limited to 1.5m.

2. The Structure and Erection Sequence

The flyover, FIG-1, is a fairly long one with an obligatory precast span P4-P5 of 40m of box girder section. The remaining spans constituting the approaches have a length of 20-30m each depending on the location of underground utilities. Two cranes were required to erect the precast Box girder, FIG2, while a single crane was adequate for erecting the I- girders of the approach spans.

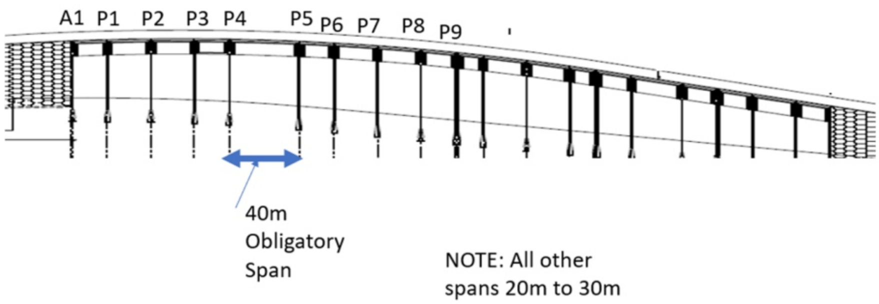

Fig 1 : Flyover Elevation

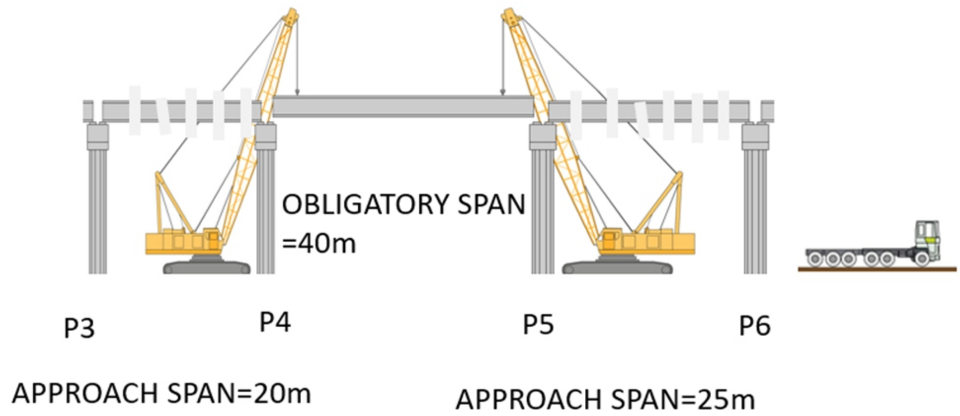

Fig 2 : Erection of Obligatory Span

The sequence of erection selected was to lift into position all the approach spans using the two cranes available at site except the spans P3-P4 and P5-P6, located on either side of the obligatory span the space being necessary for erecting the box girder as shown in FIG-2. The box girder was lifted on to the piers P4 and P5. The idea was to lift the girders of the spans P3-P4 and P5-P6 in the last stage.

3. Cracks in Pier Caps at P4 and P5.

The pier caps P4 and P5 showed cracks upto 0.4mm , FIG-3, before the last operation of erecting spans P3-P4 and P5-P6 could be started.

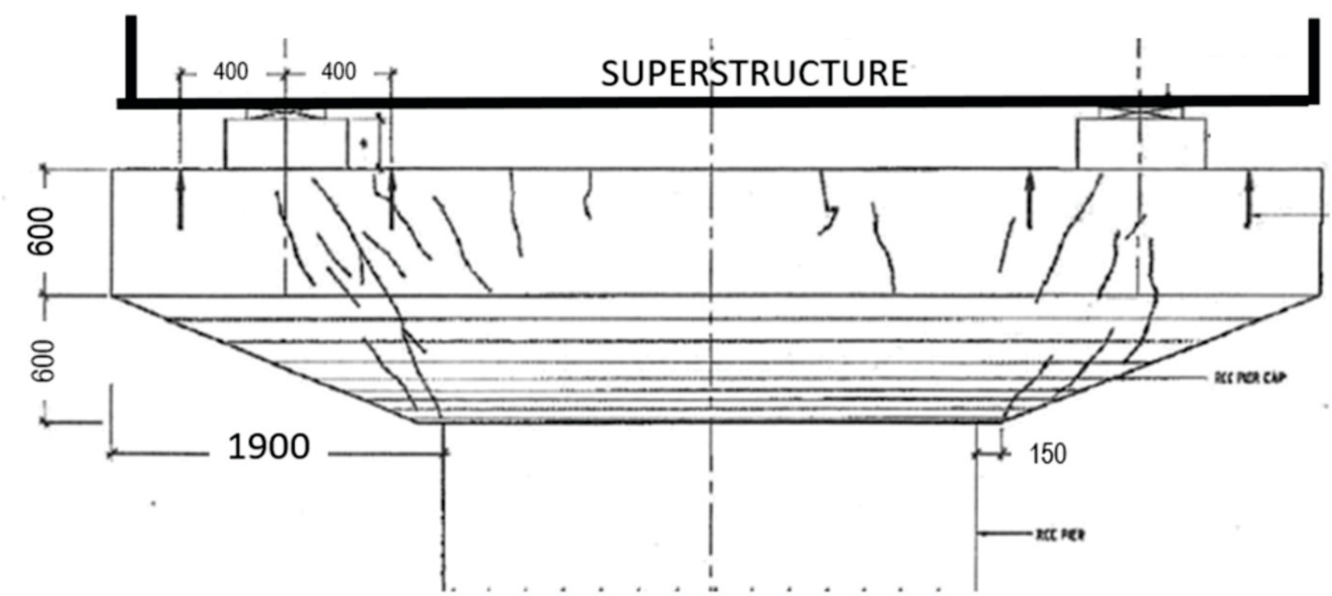

Fig 3 : Cracks in Pier Cap at P4 as Seen from Obligatory Span Side After its Erection.

4. Investigation

The design of pier caps was checked, and it was concluded that during service condition the design was meeting the provisions of the code IRC 112. The design of pier, piles and pile cap were checked and found to be in order for the service stage as well as this particular construction phase, FIG2. However the design check of pier cap for this construction phase was missing in the designs and was taken up for further study.

5. Pier Cap Check for the Particular Construction Phase

The pier cap during the construction phase shown in FIG2 is subjected to shear, flexure as well as torsion. It was concluded that the missing torsion check and required detailing of reinforcement for the same was the reason for the appearance of the cracks. It was decided to check the provisions in IRC Codes for construction stage which is discussed in the next section.

6. Codal Provisions

a) In accordance with IRC112 Appendix A-6, "Design Considerations for Construction Stages" Clause A6-1 (2) mentions that SLS as well as ULS should be verified during various stages of construction.

Further, in the same code, clause 12.1 (1), the SLS check involves stress level, crack width and deflection. However, in Table 12.1 crack width in reinforced concrete members are to be checked for Quasi permanent loads only; there being no mention of limiting crack width in Construction Stage.

b) In IRC6 Table B-3 Amendment published in Indian Highways Condition Dec22, in Construction Condition, 5.2, checks in Quasi permanent condition are not necessary.

7. Conclusions

a) The check for torsion in pier caps in service as well as construction stage is essential, and so also the detailing of the reinforcement.

b) Crack width check needs to be introduced as part of the SLS check during construction stage along with recommendations of the limiting crack width in IRC112.

c) In IRC6, changes in Table B-3 should be made to be in sync with (b) above.

8. Opinion of Expert Panel

Expert Panel is of the view that while the conclusions a) above is acceptable and very well appreciated, the conclusions drawn by the reporter in b) and c) above are debatable and the panel is not aligned with the reporter's views on these issues.

As per the Expert Panel, crack width checks for the construction stage can be relaxed since it is a short-term situation. Also, the panel does not find ambiguity or conflict between two IRC codes (Namely IRC 112 and IRC 6) as pointed out by the reporter. Quasi-permanent load combination is applicable for those loads that are present on the structure for a substantial period of design life. Hence, the construction stage should not be treated as a quasi-permanent situation. As per IRC112, Appendix A-6 (3.3) point (2), only a rare condition check is to be performed during the construction stage. Cracks during the construction stage are not of major concern in case stresses (both in concrete & reinforcement) are kept within the permissible limits. Cracks are a matter of concern during the service stage for which one has to satisfy the requirement of crack width during service stage design. As per the latest amendment of IRC 6 for construction stage analysis, provisions are in line with the same philosophy as stated above. Also, according to Eurocode [EC2 Clause 113.3.2 (101)], serviceability criteria for the completed structure need not be applied to intermediate execution stages, provided that durability and final appearance of the completed structure are not affected (e.g deformations).

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REPORT No. CF-24

Failure of an Under Construction Bridge due to Foundation Tilting

1. Introduction

a) This report is about a river bridge, 2 lane wide, 335m long, which is under construction since more than 10 years and has faced rough weathers due to various technical reasons. The original contract was awarded in the year 2012. The original contractor however left the contract in 2016, after completing a part of the work, when a number of well foundation for the bridge got tilted beyond restoration.

b) In the original scheme, the bridge had 9 spans of 37.2m (c/c of expansion gap). The foundation proposed was the Well/Caisson foundation (resting on rocky strata) for piers and open foundation for Abutments. The superstructure comprised of PSC T Girder (3 girders per span) with in-situ deck slab over precast girders.

c) MOST Standard drawings were adopted for the Superstructure. RCC circular pier with Pier Cap was proposed for the substructure. Fig.1 attached shows the span arrangement

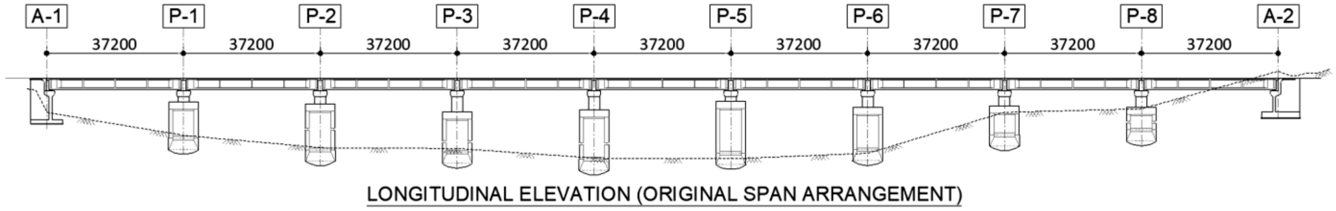

Fig. 1 : Span Arrangement for the Bridge as per Original Design

d) Out of 8 pier wells, 3 wells reportedly got tilted and shifted beyond restoration (which is at pier number P2, P3 & P4. At the time of termination of the original contract, the status of construction completed is as follows :

S. No.	Component	Status of Construction when original contract was terminated
1	Foundation	• Abutment foundation completed • Pier Well Foundation at P1, P5, P6, P7 & P8 Completed • Pier Well at P2, P3 & P4 tilted beyond restoration
2	Substructure	• Abutments completed • Pier & Pier Cap at P1, P5, P6, P7, P8 completed
3.	Superstructure & Bearings	• Span A1-P1, P5-P6, P6-P7, P7-P8 & P8-A2 completed. Elastomeric Bearings installed in these spans • Balance spans remaining

e) Construction contract for the balance work of this bridge was to another executing agency in December 2021. The new contractor proposed the following revision in the span arrangement in this project, in view of the abandonment of 3 well foundations :

i. Abandoned original location of foundation at P2, P3 & P4 and introduced new foundation P1A (in between P1 & P2), P2A (in between P2 & P3), P3A (in between P3 & P4), and P4A (in between P4 & P5).

ii. Pile foundation proposed for the new foundations at P1A, P2A, P33A and P4A, instead of Well foundation. 1.2m diameter pile, 4 numbers per pier is provided. These pile foundations are reportedly well-socketed into rock.

iii. Well Foundations at P1, P5, P6, P7 & P8 were strengthened using 750mm diameter bored cast-in-situ piles installed surrounding the existing well. These ring piles were proposed to be connected by a ring beam at top and also proposed to be connected to the well cap at the pile locations.

iv. For Span P1-P1A and P4A-P5, the span length has become 18.6m as against 37.2m. Precast RCC T Girder with in-situ deck slab proposed for these spans. For spans, P1A-P2A, P2A-P3A, and P3A-P4A, the original span configuration with PSC T girder is proposed.

f) The status of construction work carried out by the second contractor at the time of tilting of well is as follows :

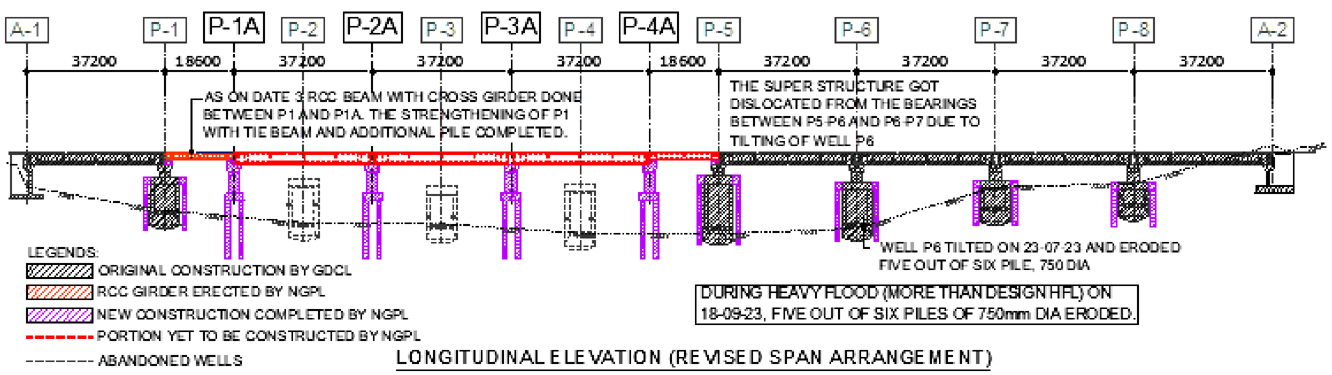

Fig. 2 : Span Arrangement of the Bridge as per Revised Design

S. No.	Component	Additional Work carried out by the Present Contractor
1	Foundation	• Pier Well Foundation at P1A, P2A, P3A, and P4A Completed • Pile foundations (750mm diameter bored cast-in-situ piles, 6 numbers per well) for strengthening of well foundation P1, P5, P6, P7 & P8 completed • Ring Beam connecting the 750mm dia Piles and also connecting with Well Foundation completed in case of P1
2	Substructure	Pier & Pier Cap at P1A, P2A, P3A and P4A completed
3.	Superstructure & Bearings	Precast RCC Girders for Span P1-P1A erected.

g) During the monsoon season in 2023, Well P6 tilted significantly towards upstream. The tilt is visibly about 20 degrees. The spans resting on this foundation shifted, tilted, and also got dislodged from bearings. Though these spans did not get completely dislodged from the top, but were hanging in a precarious position at the time the reporter visited the project site. The water level at the time of this incident was reportedly much below the design HFL. The 750mm diameter piles surrounding the well P6 were reportedly not visible after this tilting of the well. These piles either broke due to the tilting of the well foundation or got uprooted from the base itself. The exact position of these piles was unknown. It was reported that the ring piles constructed surrounding other wells were intact and no damage was visible. It was also reported that the flood level in this monsoon exceeded the design HFL by about 600mm to 700mm. The water marks in pier cap indicated that the it has touched the top of sloping portion of pier cap.

2. Likely Cause of Tilting of Well Foundation at P6 :

The reporter states that the likely cause of tilting of well P6 after more than 7 years of its construction appears to be any one or a combination of the following reasons. Reporter is also of the view that detailed forensic investigation, structural audit, review of designs and drawings and desk studies will be required to further zero down on the exact reason for failure.

a. **Wrong Choice of Foundation by the 1st Contractor:** Well Foundation as the foundation type for this bridge appears to be a wrong choice in the first place. While well foundations are quite appropriate foundations for alluvial soil, there are many projects where serious problems have been encountered when well foundation is made to rest on bouldery or rocky strata. The rock levels are never even at the founding level and the dipping profile of the rock bed often poses a huge challenge in placing the cutting edge at the founding level. This problem should have been anticipated based on past experience of several projects in India. There are several case studies available in INDIAN HIGHWAYS publications demonstrating difficulties faced in the completion of such bridge projects. Some of these projects took decades to complete and some of these projects are still under construction, even after decades. Few example projects where well foundation resting on rocky strata encountered problems leading to time and cost overrun are as follows :

i) Parallel Railway Bridge near Rail-Cum-Road Bridge near Salimgarh fort, Delhi (Bridge construction started in 2003. Still under construction)

ii) Signature Bridge, Delhi - Well P23 on sloping rock

iii) Passighat Bridge, Arunachal Pradesh (Bridge took more than 20 years to complete due to choice of well foundation on bouldery strata)

iv) Tapi Bridge, Maharashtra (Bridge completed after 14 years)

b. **Improper seating of Well Foundation:** Well foundation resting on rock shall be taken to adequate depth and seated evenly all around the periphery on sound rock and provided adequate embedment. It is very likely that the well foundation is not seated properly in the rocky strata. The cutting edge may be seated in hard strata for some portion and soft strata for some portion.

c. **Lack of expertise in design/construction of well foundation founded in rocky strata:** After having chosen "Well" as the type of foundation for this bridge, the design, detailing and construction should have matched the challenges that were expected and should have taken into consideration measures to mitigate the risk of uneven seating of well, which is likely to be the root cause of tilting of all the wells in this bridge. The sloping rock strata affect both the sinking of the well and its proper seating on the bedrock. Designers and Contractors involved in the project should have incorporated all possible measures in anticipation of this challenge (i.e. provision for controlled blasting, provision for pneumatic sinking, provision in steining for introducing micro piles …etc.). It is not out of place to mention that the design and detailing, construction of such wells requires not only a high level of skill for the designer (who is expected to anticipate such problems during the design stage and keep adequate provisions to deal with such eventualities), but it also requires the contractor to engage site engineers and workmen having past experience of the sinking of well foundation in similar strata.

d. **Constriction of the linear waterway, causing an increase of the velocity of flow in the river:** During construction in the 2nd phase with a new contractor (for the balance work), it is possible that the waterway was constricted by blocking a part of the stream for ease of construction. This localized increase in flow velocity could have eroded the finer particles from below the founding level of the well causing instability.

e. **Lack of Supervision during construction:** It is possible that supervision was lacking during seating of the well foundation in rock, with a minimum depth of embedment.

3. Likely Cause of Uprooting of 750mm Piles used for Strengthening of Well Foundation at P5 & P6

All the piles surrounding well P6, and 5 out of 6 piles surrounding well P5 were not visible when the REPORTR made a visit to the project site. These piles are broken from somewhere in the middle or likely to be uprooted from the base. The first impression about the likely cause of uprooted/broken piles appears to be any one or a combination of the following :

a. **Improper seating of pile foundation in the underlying strata:** It is possible that the piles are not properly socketed in the underlying rocky strata. At the time of the failure of these piles, they were not tied to each other and therefore vulnerable for toppling, in case they are not socketed firmly into rock.

b. **Deficient Design:** It is possible that these 750mm diameter piles were not designed for construction stage, when these piles are not tied with the well/ring beam.

4. Possible Remedial Solution:

Reporter, on the basis of above diagnosis worked out various possible options, out of which Client / Contractor has to choose one, based on further studies. These possible options, alongwith their merits and demerits are as given below :

Option 1 : To Carryout thorough structural audit and propose remedial measure based on audit

Proposal : After detailed investigations, if it is found that all other major structural items (except well at P6) are in sound condition, the same bridge foundation substructure and superstructure can be utilised after the restoration of superstructure of P5-P6 & P6-P7 span to its intended position. Well foundation at P6 can be abandoned and substituted by a group of pile foundation with a portal frame and a new substructure can be provided at the same location.

In case foundations other than P6 are found to have problems of seating / socketing, appropriate remedial measures to be taken depending upon the problem assessment.

Merits : This is most sustainable solution as most of the structural items constructed so far will be utilised, if found suitable.

Demerits : A thorough investigation is required for all structural items. Specialist agencies need to be involved for the investigation of the condition of foundations. In spite of best efforts, the results may not be 100% assured since the foundation is buried and not inspectable.

Time required : Proper investigation of foundation will be time consuming. After completion of site investigation, its interpretation and taking a decision on further course of action will also consume reasonable time. Once decided, construction of the remaining items can be finished quickly. But stabilisation of superstructure and replacement of foundation and substructure for P6 pier will not only be a slow but also a time taking process.

Option 2 : Change Span arrangement by abandoning all Well Foundation and installing Pile Foundation in between the Well Foundations

Proposal : After detailed investigations, if all well foundations are reported as doubtful, all wells and their substructure can be abandoned and intermediate pile foundations (similar to P1A, P2A, P3A…) may be installed in between well foundation and both end spans can be made 18.6m long. All other spans will remain 37.2m long.

Merits : Moderately sustainable solution as only newly constructed pile foundation and abutments can be utilised. From already constructed superstructure, deck slab can be dismantled and PSC girders can be stored at stacking yard built at ground level (with the help of crawler mounted high capacity cranes). Same girders can be used later.

Demerits : Before taking a decision for adoption of this option, a thorough investigation is required for all foundations and substructure proposed to be used. Specialist agency need to be involved for investigation of condition of pile foundation.

Time Required : For proper forensic investigation of every element, lot of time will be required. After completion of site investigation, its interpretation and taking decision on further course of action will also consume reasonable time. Once decided, the construction of remaining items can be finished quickly. But stabilisation of the superstructure and replacement of foundation and substructure for P6 pier will be a slow and time taking process.

Option 3 : Change all foundations

Proposal : After detailed investigations, if integrity of all items is reported as doubtful, all substructure and foundations have to be demolished and new bridge can be constructed at same alignment. Well and piles upto lowest water level also need to be dismantled so that obstruction of waterway is minimised. New bridge on pile foundation may be installed at some intermediate locations of foundations (in between already done well & pile foundations).

Merits : Decision can be quickly taken to demolish the bridge.

Demerits : Lot of debris will be generated in dismantling all items of the bridge. Cost of construction of new bridge will be high.

Time Required : Once decided to go for this option, lot of time will be spent to dismantle the bridge components and clear debris from site. Once this is done, construction of new bridge with pile foundation will take least time.

Option 4 : New Bridge at different alignment

Proposal : After detailed investigations, if integrity of all items is reported as doubtful, after abandonment of all substructure and foundations new bridge can be constructed at an alignment just upstream or downstream (min. 20m away) of the existing alignment. Wells for P1 to P6 (lying in course of active channel) upto lowest water level need to be dismantled so that additional obstruction of waterway is minimised. New bridge on pile foundation may be installed with piers in line with original location of foundations.

Merits : Decision can be quickly taken to abandon the constructed bridge. Construction of new bridge can be commenced immediately. Waterway will increase because of pile foundation instead of wells.

Demerits : Lot of debris will be generated in dismantling all items of the bridge. Cost of construction of new bridge will be high. Additionally, due to realignment of the bridge, approaches also need some modification. Additional land acquisition may be required.

Time Required : Once decided to go for this option, construction of new bridge with pile foundation will take least time. Dismantling of existing bridge can be done, parallelly.

5. Opinion of Expert Panel

Improper proposal of foundation may lead to delay and distress in any of structures. Every foundation proposal shall be delivered based on geotechnical parameters and available skills. Experience engineers should be engaged both in design and construction to avoid any distress in structures during service life. Before construction by second contractor, structural audit should have been conducted to identify the distress in the structures and embedment of foundation in rock to opt for suitable solution for the bridge.

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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

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