



FROM THE DESK OF THE PRESIDENT

This issue of CROSFALL marks the 3.5 years of the founding of CROSFALL, which is a significant milestone considering the fact that there are a lot of reluctance amongst the engineers to report such failures, fearing backlash.

Originally created to offer professionals a confidential space to report safety concerns without fear of blame, it is, over the past three and a half years, gaining popularity. People in the industry are talking about it and some of the stakeholders are even fearing appearance of failure reports in CROSFALL, of their project. CROSFALL is getting recognised for helping to identify risks, share knowledge, drive cultural change, and enhance public safety.

While CROSFALL is making its impact slowly, the failures in India somehow are being witnessed more frequently than ever before. Some of the catastrophic, life-taking failures in India are sobering reminders that we are not learning lessons as we expect. Some of the major catastrophic failures in India which occurred in last 6 months are :

- Indrayani river bridge Collapse, near Pune in June 2025 (4 dead, several injured and swept away).
- Gambhira Bridge Collapse, Vadodara, Gujarat in July 2025 (22 deaths and several injuries).
- Failure of bridge in Araria district, over the Parman River in November 2025.
- Fire at a night club in Arpora, Goa on 6th Dec. 2025 (killed 25 people and injured 50).

Organisationally, CROSFALL has been shaped by a dedicated team of professionals who are in the editorial board. So far, CROSFALL has produced 42 reports of structural failures, near misses, ethical violations in last 13 issues. 30 out of these 42 reports published so far pertains to Bridges (This does not mean Bridges are failing more rapidly compared to Bldgs.). Breakup for Balance 10 cases are as follows: a) Buildings – 2, b) Ethical Violation – 3, c) Stadium – 1, d) Canopy – 1, e) Dams – 1, f) Embankment – 1 and g) Silo - 1.

All our editorial board members and expert panels are volunteers, and their service is deeply appreciated and deserves special recognition. It is their input that makes CROSFALL Newsletters an essential read for many stakeholders in the industry, academia, and government.

I wish to close my message by once again requesting all readers of this newsletter to spread this newsletter widely amongst your peers and encourage all for reporting structural safety concerns, even if they seem minor, to prevent future failures. Reports can be submitted confidentially, and the process focuses on learning, not blame. Information shared helps improve industry safety standards, making it crucial for professionals to contribute their experiences.

Happy Reading.

— Alok Bhowmick



MESSAGE FROM CHIEF EDITOR

This issue of CROSFALL continues our shared endeavour to promote learning from structural failures and near misses through a spirit of openness, professionalism, and confidentiality. Over the years, CROSFALL has emerged as a credible platform for engineers and stakeholders to exchange valuable lessons drawn from real-world experiences, with the sole objective of improving structural safety across the industry.

The case studies in this issue once again demonstrate that most structural distress situations arise from a combination of design, detailing, material, construction, and environmental factors. Such experiences underline the importance of holistic engineering judgement, careful review at every project stage, and continuous collaboration among all stakeholders.

CROSFALL's strength lies in the willingness of professionals to share their observations without fear or blame. I encourage all readers to actively contribute by reporting failures, near-misses, and safety concerns — even those that may appear minor — so that the profession as a whole can benefit from collective learning.

I sincerely acknowledge the dedicated efforts of our editorial board members and expert panel whose voluntary contributions ensure the technical quality and relevance of this publication.

Let us continue working together towards safer and more resilient infrastructure through shared knowledge and responsible engineering practice.

We hope this edition proves informative and thought-provoking.

— Umesh K. Rajeshirke
Chief Editor, CROSFALL

Editorial Board Members

Chief Editor

Mr. Umesh K. Rajeshirke, GC Member, IAStructE & MD, Spectrum Techno Consultants Pvt. Ltd.

Member

Mr. Alok Bhowmick, President, IAStructE & MD, B&S Engg. Consultants Pvt. Ltd.

Prof. R. Pradeep Kumar, Immediate Past President, IAStructE & Director, CSIR-CBRI, Roorkee

Mr. Manoj Mittal, Past President IAStructE & Civil / Structural Engineering Consultant, Shelter Consulting Engineers

Prof. Mahesh Tandon, Past President IAStructE & Chairman, Tandon Consultants Pvt. Ltd.

Mr. Rajiv Ahuja, GC Member, IAStructE & Independent Consultant (Highways & Bridges)

Mr. V. N. Heggade, Vice President (West), IAStructE & Design & Construction Consultant, DECon Complete Solutions

Dr. Harshavardhan Subbarao, GC Member, IAStructE, Chairman & MD, Construma Consultancy Pvt. Ltd.

Dr. Vandana Bhatt, Techno-Legal Consultant at Pro-Care Project Administrators & Management Advisors

Mr. Partha Pratim Banerjee, Honorary Treasurer, IAStructE & Technical Director, Ayesa India Pvt Ltd.

Mr. V. L. Deshpande, Fellow IIBE, Advisor, Metalmecanica Bridge group

Contents

Report No. CF-43 : Vulnerable bridges in Himalayas due to unstable geology and Landslides..... **02**

Report No. CF-44 : Code-based Minimum Reinforcement in Precast RCC Girders Leading to Early-age Surface Cracking **07**

Report No. CF-45 : Cracking of Precast Segments of A Segmental Bridge in Casting **10**

About CROSFALL Newsletter **19**

REPORT No. CF-43

Vulnerable bridges in Himalayas due to unstable geology and Landslides

1. Background

This report is on a case study of an elevated two-lane highway bridge in upper stretches of Himalaya. The existing two lanes are at-grade constructed some time back. The additional two lanes are elevated to avoid cutting the slopes and disturbing the set geology. This also helps in reducing the gradient, as at one end elevated bridge goes in to the tunnel (see photo 1). At this end the existing road is right below the elevated road on Portal piers and continues along the river. The existing road is taken beside the elevated carriageway at the other end. The elevated bridge was completed in the year 2022 and opened to traffic in the year 2023. It is an important bridge on a strategic connector on NH.

The bridge consists of several spans of approximately 25m on pile foundations. Superstructure consists of 4 PSC post tensioned girders supported on RCC pier cap, single circular pier resting on piles through Pile cap. Superstructure is a 4-span deck continuous structure resting on elastomeric bearings. Alignment is curved, winding around the mountain. Close to the edge of the superstructure is a steep mountain on one side. River is at the base of the hill. Fig. 1 below shows the General Arrangement of the bridge. At one end existing two lane road is adjacent to elevated carriageway.



Photo 1 : Elevated bridge supported on portal pier above existing 2 lanes. Existing road winds along the river after elevated road enters tunnel.

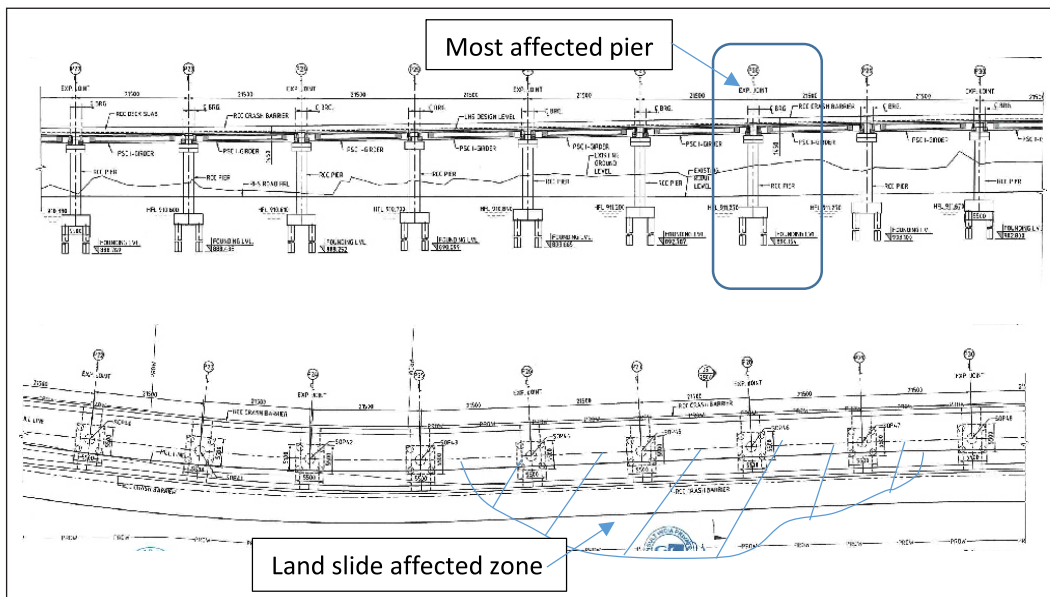


Fig. 1 : General Arrangement of the Bridge

2. The Problem

The Himalayan mountains have conglomerate formations, prone to landslides, as is well known. In mid-2024 a boulder got detached from the mountain and fell on the superstructure, damaging one of the span PSC girders and portion of deck slab. These were then repaired through external prestressing and reconstruction of damaged portion of deck slab. See photo 2 and Photo 3.



Photo 2 : Damage due to Boulder hitting the deck
 Note : Elevated bridge edge is very close to hill side.
 A big boulder crashed on to the parapet and rolled on to deck slab.

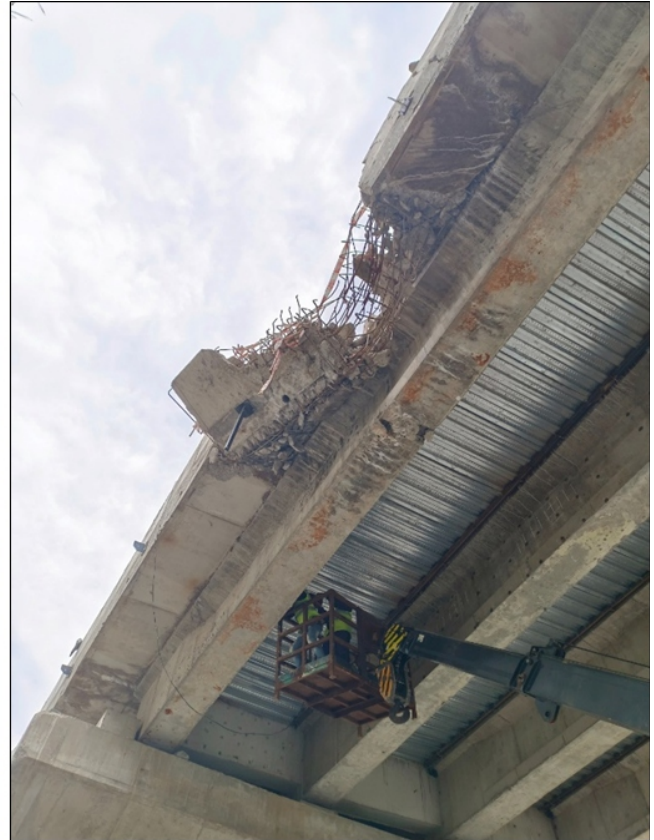


Photo 3 : Damaged PSC girder, deck slab & crash Barrier
 Note : This was repaired by crack sealing and external prestressing of PSC girder.
 Deck concrete was repaired with additional steel and non-shrink concrete.

The above incident was actually a nature's warning, which was considered as one off problem and only local distresses addressed, without addressing the concerns holistically for a long-term solution. Subsequently during recent monsoon in 2025, a major land slide occurred near pier P27. This affected piers and superstructure between P22-P28.

2.1 *Distresses noted/observed at site based on visual inspection*

- a. Lateral shift of piers towards river side
- b. Tilt of piers towards river
- c. Settlements of piers
- d. Shear dislocation in one of the piers

- e. Elastomeric bearings severely damaged
- f. Seismic arrestors damaged and crushed
- g. Superstructure was generally intact, visually but show minor damages.

Photos 4 to 6 shows the distress caused by landslide.



Enlarged view of pier completely broken in two pieces. Removal of debris could trigger further slide.

Photo 4 : Tilted & Cracked Pier with mangled reinforcement



Photo 5 : Superstructure intact but piers settled. A boulder is on the carriageway.



Photo 6 : Huge amount of debris on the pile caps. Two lane traffic on elevated road diverted to low level road.

2.2 Distresses likely but not visible

- a. Shift of pier indicates shift of pile caps and piles. Shift of pile caps could not be observed / measured due to huge amount of debris on the caps.
- b. Piles could also have been damaged and/or tilted.
- c. PSC and deck slabs may have developed minor cracks, not very visible during inspection.

3. Observations

Constructing additional 2 lanes at the same level as existing two lanes would have required a lot of hill cutting, with steep slope of the hill and fragile Himalayan geology could have resulted in many landslides. It may have been considered undesirable. Providing elevated two additional lanes would help in:

- a. Eliminating cutting the hill slope as piles and pile caps were constructed at the existing road just adjacent to it.
- b. Reducing local steep gradients of the existing two lanes, by providing a flatter and uniform gradient.

However, chances of landslides in such situations cannot be ignored. With river at base, the hill slope was the natural drain. Movement of water on as well as below the surface (especially during monsoons) affects the hill stability. Small particles tend to move with water and create voids which accentuates the tendency to slide. The second hill slide occurred during the monsoon only. In case of a slide:

- a. The type and quantum of forces substructure is subjected to is unpredictable.
- b. Shifting of piers by as much as 50-120mm indicates either pile failure or shifting of entire block. This is possible if piles are inadequately anchored below the slip circle.
- c. It was difficult to establish that piles are intact. With piers tilting and shifting, jacketing of piers and anchoring the reinforcement in pier caps would have been very difficult.

4. Conclusions

Providing elevated bridge for additional two lanes instead of widening at grade is a good concept from the point of environmental damage. This should however be implemented with other measures which may be somewhat costly, if such recurring accidents are to be avoided. Such accidents lead to long traffic stoppages or diversions to a smaller road, ultimately reducing the benefits of 4 laning.

In such situations, a detailed geotechnical investigation including hill stability studies is a necessity. This should preferably be done at DBR stage so that mitigation measures can be worked out and methods/costs included in NIT. Mitigation measures can be soil nailing, gabions or any other slope protection treatment. A safety net to catch and prevent stray falling rocks from falling on to the deck with consequential damages need to be provided along such stretches. These need to be implemented during construction. Recurring accidental damages narrated above could be even more costly

A system of drains along the hill-on-hill slopes at one or more levels will reduce the problem induced due to water movement below the surface.

5. Recommendations

Following recommendations were made in this case:

- a. Affected spans P22 - P28 to be replaced completely, Superstructure, substructure and foundation etc. This may require changing the span arrangement. At most some PSC girders could be reused after thorough inspection and ND Testing.

- b. Detailed ND Testing of at least one 3 span unit on either side of affected zone.
- c. Revisit geotechnical studies on slope protection made earlier and if not, conduct the studies now on the entire stretch and implement the recommendations.
- d. Provide catch water drains above the slip circle line longitudinally and transfer the water to river below with underground pipes.
- e. Provide safety nets to catch the stray falling rocks as per geotechnical studies.

Opinion of Expert Panel

Despite the wealth of documented case studies all over the world, systematic approaches to finalise the conceptual design of bridges in hilly terrain, by correlating landslide hazard characteristics, are rare to find. The correlation is challenging due to the complexity of landslides, which can vary in movement types, volume, velocities, materials, and orientations.

From the case study presented in this article, it is clear that landslide risk studies were not carried out by the authorities during finalisation of the bridge alignment. Such studies should have been a part of the concept design and the risk analyst should have come out with various possible mitigation options, before deciding the bridge alignment and the structural scheme, including span arrangement for the bridge.

Preventing boulder falls and rockfalls on bridges in hilly terrain requires a combination of active slope stabilization (preventing detachment) and passive protection (intercepting fallen material). Key techniques include :

- a) rock netting,
- b) anchoring,
- c) catch fences, and
- d) proper drainage management.

There are a number of levels of effectiveness and levels of acceptability that may be applied in the use of these mitigation measures. While some landslide prone locations may require an immediate and absolute long-term correction, another location may only require minimal control for a short period. The measure to be chosen at any given site will depend upon the work of geotechnical engineer and engineering geologist, who have to combine their talents and energies to solve the problem. The continual collaboration and sharing of experience by engineers and geologists will no doubt move the field as a whole closer toward the science end of the art-science spectrum than it is at present.

REPORT No. CF-44

Code-based Minimum Reinforcement in Precast RCC Girders Leading to Early-age Surface Cracking

Introduction

The reporter in this case documents the occurrence of early-age surface cracks observed in precast reinforced concrete (RCC) girders, despite the provision of minimum surface reinforcement in accordance with applicable design codes. The girders form part of a building located in a highly humid tropical environment.

The structural system comprises precast T- and L-shaped girders interconnected by stitch concrete to form the floor system, thereby eliminating the need for conventional shuttering and extensive in-situ concreting. Similar precast structural systems have been successfully implemented in other regions of the country under different environmental conditions without such cracking issues.

Observations

During the site inspection, the following observations were recorded:

1. The cracks have been observed vertically in the web portion for entire length of the girders as clearly indicated in Photo 1.
2. Crack widths varied irregularly between 0.1 mm and 0.3 mm, with no consistent pattern observed.
3. Cracks generally appeared within 5 to 14 days after casting precast girders at the yard.



Photo 1: Elevation of Girder showing cracks



Photo 2: Closed View of Crack

4. Approximately 80% of the cracks were vertical (Photo 2), while a few inclined cracks were also observed (Photo 3). The inclined cracks typically had widths less than 0.1 mm.
5. The cracks were monitored for a period of at least two months from the time of first observation. No increase in crack length or width was recorded during this monitoring period.
6. It was noted that the number and distribution of cracks varied among girders having identical reinforcement detailing and concrete grades, as illustrated in the crack mapping shown in Photos 4 and 5.



Photo 3: Closed View of Crack

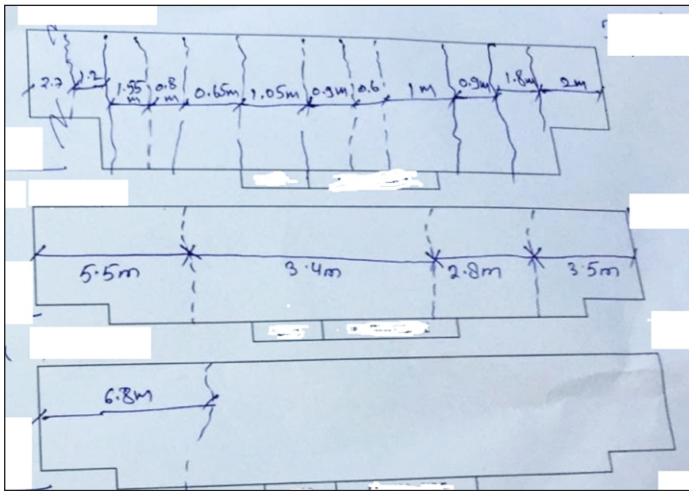


Photo 4: Crack Mapping

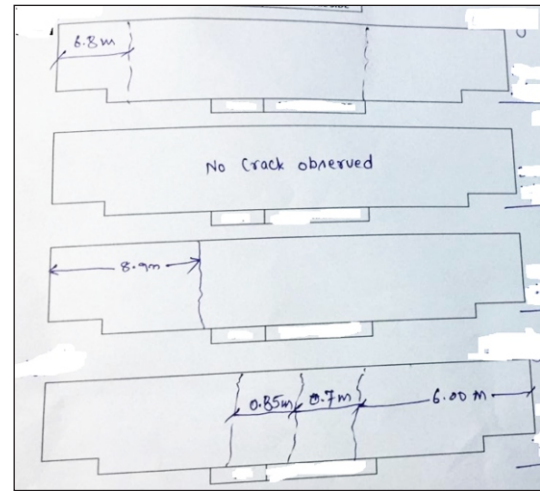


Photo 5: Crack Mapping

Possible Reasons

Based on the observed characteristics and subsequent investigations, the following possible causes were identified:

1. The abrupt nature and irregular pattern of cracks indicate that shrinkage cracking, potentially aggravated by inadequate side-face reinforcement, is the most probable cause. Thermal cracking has been ruled out due to the relatively thin web thickness.
2. Reinforcement detailing was verified against relevant Indian codes (IS, IRC, and IRS), and it was confirmed that the minimum required reinforcement had been adequately provided.
3. To further investigate the issue, the authority decided to cast two additional girders, one with increased surface reinforcement and another with mesh reinforcement. Cracks were observed in both these additional girders, like earlier girders.
4. The contractor reported that no cracking was observed in precast rectangular RCC girders of similar depth, reinforcement, and concrete mix.
5. Based on the above findings, the reporter concluded that the following factors may have influenced crack formation:
 - a. Environmental conditions at the project site, as similar girders performed satisfactorily in other regions.

- b. Higher shrinkage potential of the concrete used, possibly due to material properties. This may be due to use of crushed stone fine aggregates instead of natural sand.
- c. Additional restraint effects on the web caused by the flanges of T- and L-shaped girders.

Conclusions:

1. Most codal provisions for minimum surface reinforcement are primarily intended for in-situ concrete construction. In precast girders, additional secondary stresses arise during handling, transportation, and erection, which should be explicitly considered during design.
2. Concrete-related parameters such as shrinkage, creep, and thermal properties should be evaluated based on the actual material characteristics, particularly the type and quality of aggregates used.
3. Design codes specify only minimum requirements; therefore, the assessment of surface reinforcement should be carried out judiciously on a case-by-case basis, considering site conditions, girder configuration, concrete mix design, and construction methodology.
4. Given India's diverse climatic conditions, region-specific provisions addressing environmental and material variability should be incorporated into design codes. With the increasing prevalence of EPC contracts, reliance solely on minimum code requirements to optimize cost may compromise durability, highlighting the need for improved code guidance.

Opinion of The Experts Panel

Reinforced concrete elements are often exposed to rain and radiation from the sun, in addition to normal loads, and hence have to be provided with at least the minimum shrinkage and temperature reinforcement. Shrinkage and temperature reinforcement has traditionally been specified as a certain percentage of the cross-sectional area (about 0.12%-0.18%), which is often empirical. These percentage reinforcements have since been found to be inadequate by many practicing engineers. Some researchers have found that the reinforcement prescribed in codes has to be increased considerably to avoid cracks due to shrinkage and temperature effects.

The expert panel came to the conclusion that there can be number of reasons which can cause such cracks, such as:

- a) workmanship during concreting,
- b) plastic settlement of concrete,
- c) long term shrinkage of concrete,
- d) early age temperature drops, etcetera.

The appearance of distress in the form of cracking in any concrete structure is a matter of common concern and consternation to all stakeholders involved in any project. It may be noted that cracks are not totally avoidable in RCC structures, since local concrete shrinkage is not always controllable. Certain cracks may not be structurally serious, while others are. It is, therefore, important for the structural engineer to determine the structural significance of a crack and its effect on the serviceability of the structure and accordingly find an acceptable solution to the problem.

REPORT No. CF-45

Cracking of Precast Segments of A Segmental Bridge in Casting Yard

1. Introduction

The reporter in this case was one of the member of expert group who investigated forensically the distress in a number of precast segments and who were involved in formulating the remedial measures for the problem which was encountered at site. The issue is regarding cracks, which were observed in precast segments for a long span bridge over a mighty river in the northern part of India. These cracked segments were lying in the casting yard for a long period. The project (and the segments which were lying in the casting yard) has a long history. The project was initiated in 2010, but due to some reasons the contract was terminated in the year 2020. The project revived in the year 2023. Upon restart of the project, while taking stock of the old precast segments lying in the casting yard for a long period (casted between 2015 to 2020), it was found that several segments (i.e. 113 out of 188 segments) are having laminar cracks on the match cast face. The crack width, crack length and crack depth varies widely.

2. The problem observed at Site

Based on available information regarding morphological characteristics of the cracks, following are the brief summary :

- a) A total of 113 segments out of 188 segments in the casting yard reportedly have cracks. There are 75 segments which are free of cracks
- b) Most of the cracks reported occurred at the faces of match cast joints, which are likely to be covered and not visible once the segment is joined.
- c) Number, Width, Length and Depth of cracks varies widely. From consideration of 'width of crack', there are 19 segments having crack width less than 0.2mm, 64 segments having crack width between 0.2mm and 1mm, 24 segments having crack width between 1mm and 2mm, 4 segments with crack width between 2mm and 3mm and 2 segments where crack width exceeds 3mm. Pi-Chart of the breakup is given in Fig.1 for ready reference
- d) From consideration of 'Depth of crack', there are 15 segments having depth of crack less than 50mm, 41 segments having crack depth between 50mm and 100mm, 47 segments having crack depth between 100mm and 200mm, 6 segments with crack depth between 200mm and 300mm and 4 segments where crack depth exceeds 300mm. Pi-Chart of the breakup is given in Fig. 2 for ready reference

3. Procedure adopted for Pre-casting of box girder segments

Long Line match casting method is used for the casting of segments. The entire span is made up of pier segments and cantilever segments on either side of pier segments. Pier segments consist of 2 nos. of diaphragm segments and a centrally sandwiched segment. The cantilever segments consist of typical

segments, expansion joint segments, expansion diaphragm segment and abutment segments. Fig. 3 shows typical segments which were lying in the casting yard at the time of inspection by the reporter. The encircled zone in the photograph shows the 3-point supporting mechanism adopted at site.

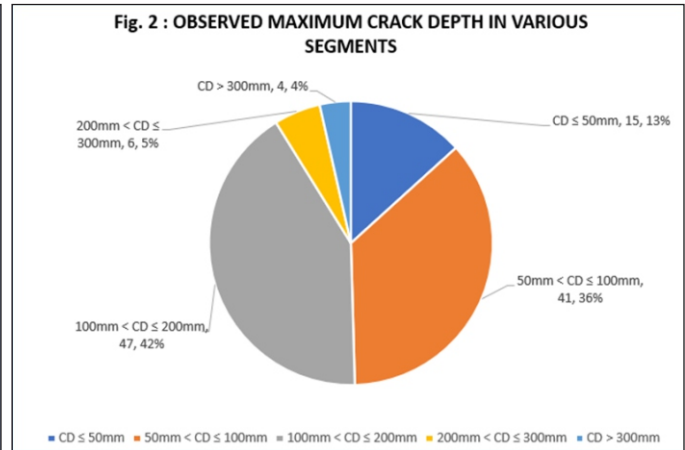
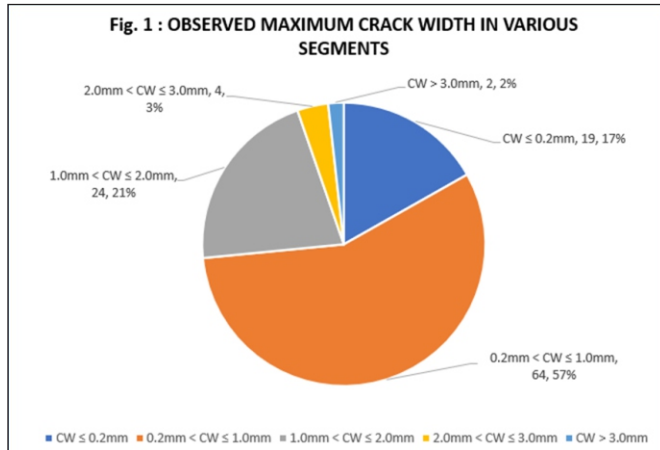


Fig. 3 : Left : Typical Pier Segments and cantilever segments, Right : 3 point support for segments at stacking yard

The 2 nos. of pier diaphragm segments (PDS) are cast in a separate casting bed with the bulk heads on either side. Then the PDS are shifted to long line match casting bed and the cantilever segments are cast adopting longline match casting method. Then the pier central segment (PCS) is match cast separately between the 2 PDS.

The struts and the rebar cage are fabricated in a separate casting bed and jig respectively before being lowered in to casting mould. The transverse prestressing is done in 2 stages in longline casting bed itself after attaining required strength of concrete as specified in the drawings.

The perusal of construction documents in the form of method statements and the photographic evidence provided reveal that the pre-casting of the segments meets the requirement of all the standard engineering practices.

Generally, the cracks observed during the site inspection are at the centre of the flanges, bottom slab and webs. In flanges and bottom slab particular, the cracks are along the centreline of sheathing ducts. At the

first glance, the cracks appeared to have occurred during the demoulding of the match cast segments. These sorts of cracks can happen, if the match cast segments are not separated out horizontally and tilted wrongly while demoulding. The procedure adopted for demoulding of the segments were discussed during the site inspection and was found to be satisfactory. Also, it is reported that the cracks were not observed after the demoulding of the segments but were observed in the stacking yard over the period.

Another reason for the potential cracks in the stacking yard is because of the improper stacking boundary conditions. The precast segments have to be stacked on 3 point supports to ensure that the all-support points are active. It has been generally observed at the site that the precast segments are meticulously stacked on 3-point support as such the cracking due to stacking arrangement is ruled out. Also, these cracks would have been flexural or shear cracks on the webs in diagonal pattern, if it were to be because of stacking conditions and handling of segments.

Generally, the quality of the concreting and the workmanship can be inferred by the damages and the honeycombing in shear keys. It is observed that the damages as well as honeycombing in shear keys are not even 5% implying good quality of workmanship and quality control measures. Fig. 4 shows some of the laminar cracks in the match-casting face of the segments that are under scrutiny



Fig. 4 : Left : Central horizontal cracks in top flange; Right : Central vertical crack in the web

The perusal of the concrete mix design reveals that M50 grade of concrete has 477 kg of cement with water cement ratio of 0.31, bereft of any mineral admixtures. The absence of mineral admixtures with very high OPC content makes the concrete early thermal crack prone. However, it was revealed during site inspection that the cracks observed in the stacking yard were over the period cracks and are not early thermal cracks. Also, the slump of the concrete 180mm is easily pumpable with the ability to reach the nooks and corners during the concreting.

From the above records and information provided during the interaction at the site with various stake holders, it can be inferred that the cracks observed could be long term shrinkage cracks. If the exposed surfaces are not provided with sufficient reinforcement to cater to long term shrinkage effect, these horizontal cracks on the surfaces can happen. The inference can be validated by the fact that the cracks are not through and through but only on the surfaces up to the maximum depth of around 200mm. Those precast segments which were already erected will not have these cracks as they were not exposed to environment for a long time for the long term shrinkage cracks to happen.

4. Analysis on Observed Cracks

General

Visible cracking in concrete during construction and during service stage is not an uncommon sight. It is not easy to totally avoid cracks in PSC structures, since not all portions of the structure are pre-compressed in 3 directions and local concrete shrinkage and/or plastic settlement or thermal induced stresses is not always controllable. The presence of cracking in a structure however does not necessarily indicate deficiency in strength or serviceability and durability of concrete structures. Some cracks may not be structurally serious while others are. It is therefore important to look at the nature of cracks, determine the structural significance of the observed crack and its effect on the durability of the structure.

In general, in today's technology it is very rare that the triggering mechanism can be traced to a single source. Each of the sources cited above, when taken individually, may produce stresses which may not be sufficient for the crack to occur. But when two or more source combine, their effect may cause stresses, that exceeds the tensile strength of concrete causing cracks. The determination of a single or a combination of probable causative factors for cracks is therefore best carried out by process of elimination.

Cause of Cracking in Precast Box Girder Segments

Cracking in post-tensioned concrete box girders generally occur due to various reasons. The reasons for development of cracks also depend upon the time when such crack appears. There can be following three distinct stages in which cracks can appear :

- a) Stage 1 : Cracking during concrete hardening
- b) Stage 2 : Cracking during construction and erection stage
- c) Stage 3 : Cracking during service / operational stage

Since the cracks observed in this project are in segments which are mainly located at the casting yard, the cause of cracks obviously falls under Stage -1 stated above (i.e. cracks during hardening process). In this stage of hardening process, there is high sensitivity to develop tensile stresses in concrete, caused by number of factors such as :

- a) early-age temperature drops, thermal gradients caused during cooling of deck surfaces due to poor thermal conductivity of concrete,
- b) autogenous plastic shrinkage,
- c) Misalignment of Tendons in slab coupled with plastic settlement ...etc..

Differential temperature within concrete, caused by heat of hydration can be a primary source of crack development in the early stage when tensile strength of concrete is still developing. When these stresses exceed the early-stage tensile strength of concrete, cracks appear in concrete. Fig. 5 shows the various number of parameters to which the thermal gradient can be influenced, such as solar radiation, ambient temperature, wind speed fluctuations, material properties, surface characteristics and sectional shape.

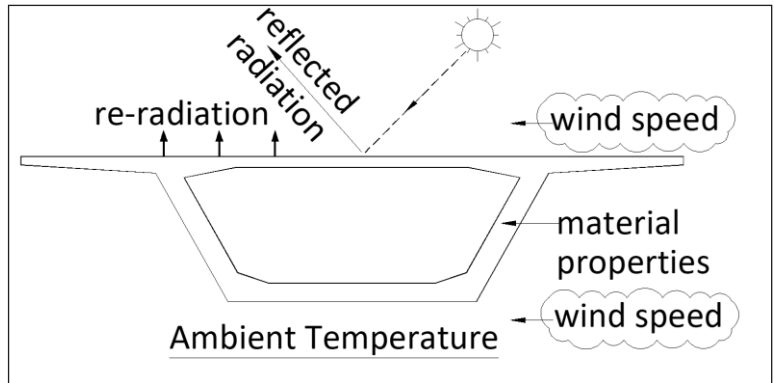


Fig. 5 : Thermal Response Parameters

Shrinkage cracks can occur on the concrete when it dries up and shrinks at the surface level of concrete, when the concrete is still in plastic state. There are number of reasons for development of plastic shrinkage cracks, such as excess of water content in the mix, delayed finishing of surface, reduced proportion of paste in the mix (binder+water), reduced binder fineness or due to reduced content of SCM. Plastic Shrinkage cracks however appear only perpendicular to the surface, as shown in Fig. 6 below.

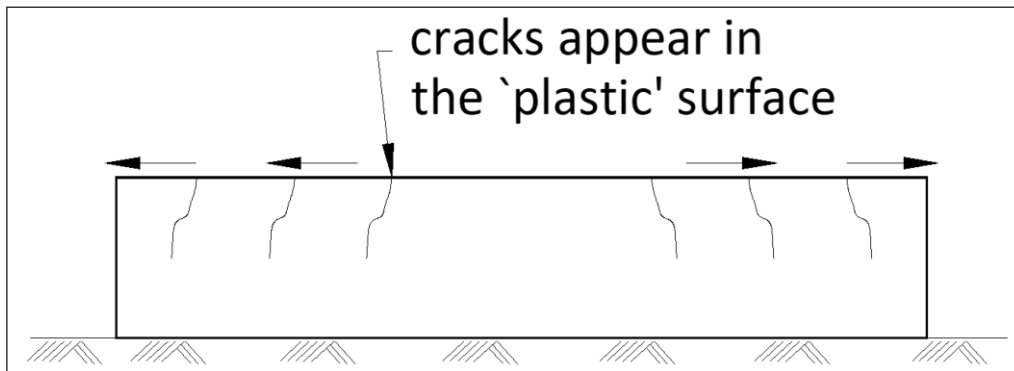


Fig. 6 : Plastic Shrinkage Crack patterns

Laminar cracking may also develop in the top of the flange midway between the segment joints, caused due to tendon misalignment, as shown in Fig. 7. Longitudinal ducts at the segment joints are usually placed at their proper position, being held in position by the bulkhead form or by the position of ducts in the segment cast against. However in case there are insufficient number of supporting chairs to these empty ducts, or in case they are deflected downward by the weight of wet concrete being placed, or by workman working in the fresh concrete, the duct profile will have an angle break or cusp at each joint, which adds to the risk of local spalling and bursting.

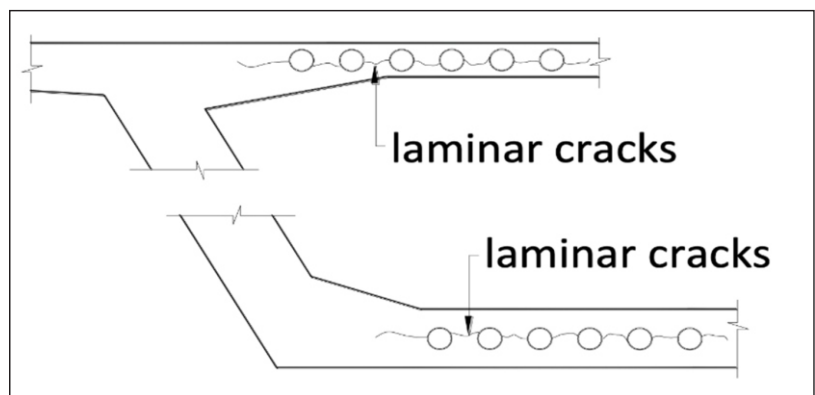


Fig. 7 : Laminar Cracks due to Effects of Plastic Settlement

Cracking may also appear in the top of the flange midway between the segment joints. When there are series of longitudinal tendons placed one after the other, the pushing of the series of ducts downward by the workers during deck concreting, if not done carefully, can create a weak plane. The area of concrete between the tendons to resist tension developed due to settlement is low and therefore there is every likelihood of such laminar cracks in such a situation.

The transverse tendons of deck slab also can further accentuate the problem during service stage as the curvature of the cable in the span produces an upward pressure on the top part of deck slab which may try to widen the cracks in the weak plane. Fig. 8 shows the cable layout of transverse cable in deck slab, which is self-explanatory. However, in this case as the transverse prestressing is already done at casting yard itself, the laminar cracks should had occurred immediately after transverse prestressing.

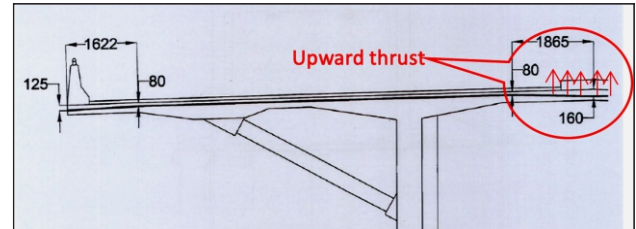


Fig. 8 : Transverse prestressing cable layout providing upward thrust in deck slab at location of laminar cracks

5. Root Cause of Cracks in this project and its impact

It is concluded by the experts after detailed diagnosis and prognosis that the most probable cause of laminar cracks in all 113 segments lying at the casting yard, is workmanship during concreting and plastic settlement. Other possible reasons, i.e. early age temperature drops, autogenous plastic shrinkage and stacking boundary conditions cannot be of-course ruled out.

Perusal of the bar bending schedule clearly shows that there were no reinforcements provided at the match cast surfaces. Thus, the cracked match cast surfaces are not detailed to cater for shrinkage induced stresses. Hence by elimination process, one can easily infer that the cracks are caused by a possible combination of the reasons stated above (i.e. poor workmanship, plastic settlement, lack of surface reinforcement at the match cast surface).

6. Remediation

The match cast surface laminar cracks, similar to laminar cracks caused due to plastic settlement and bad workmanship in the middle of a match cast vertical surface of thin slab and parallel to the surface remains as an internal crack, if it is not treated with epoxy injection. Such internal cracks can prove to be harmful than surface cracks which are in the exposed surfaces of concrete and perpendicular to the surfaces.

The homogeneity of concrete thickness is of fundamental importance to deformation characteristics of cracked concrete structures. Although these internal cracks are invisible while inside the member, they change the strain distribution in the concrete. The concrete section do not behave as one unit and under live loads, 'secondary cracks' will start developing inside. Fig. 9 shows symbolically a

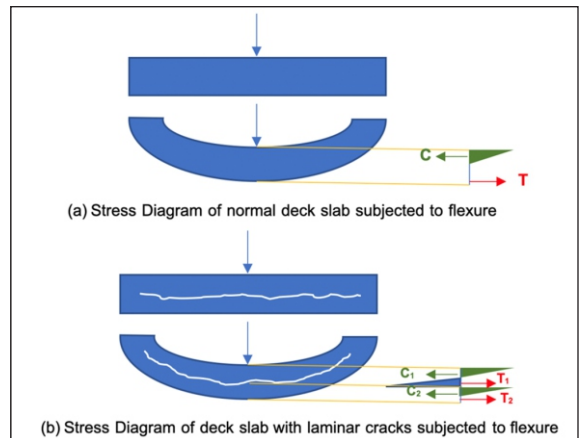


Fig. 9 : Typical Stress Diagram of thin deck slab 'without' and 'with' internal laminar cracks

typical stress diagram of a thin deck slab subjected to flexure, 'with' and 'without' internal cracks. Thus, it is essential to treat the cracks so that the concrete becomes homogenous.

Laminar cracking has the potential to propagate in to a spalling failure during further tensioning of the longitudinal tendons, which will produce a deformation in the reinforcement and displacement of the tendon. There are recorded history of such laminar cracks which led to spalling during stressing or grouting operation. Fig. 10 shows the delamination and spalling of concrete caused due to presence of laminar cracks. It can be seen that delamination can cause significant increase in the compressive stress at the extreme fibres due to loss of some portion of concrete, which can lead to crushing of concrete and consequent failure. It can be safely deduced by elimination process of various causes of cracking that the match cast surface cracks are long term shrinkage laminar cracks, propagating to the maximum depth of around 300 to 400mm at the centre of precast segment slabs and webs. These cracks can lead to delamination and spalling of concrete during prestressing operation.

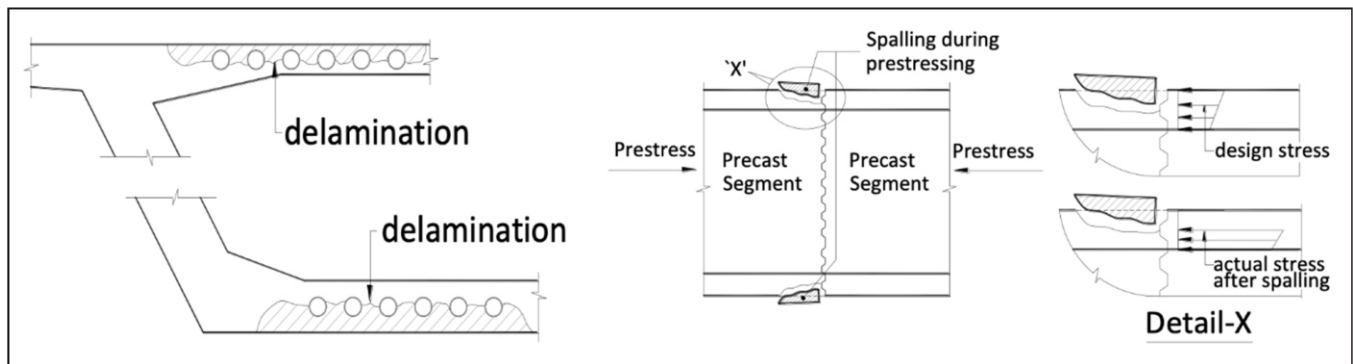


Fig. 10 : Possible failure mode due to delamination in Precast Segments during prestressing

Therefore the remediation is to re-establish the homogeneity of concrete thickness by adopting the appropriate repair methodology.

7. The Way Forward suggested by Expert Group

On the basis of the study of the various documents submitted to the conciliators and the testing of various hypothesis for cracks, the recommendations of the conciliators are as below.

1. The cracks having the width less than 0.2mm may not require any treatment as the same are likely to be closed during epoxy application.
2. The rest of the cracks shall be completely repaired with epoxy grouting or any other suitable method to re-establish the homogeneity of the concrete as per the recommendations of the specialised agency.
3. The crack repair procedure shall be executed by the competent third party as the service life requirements of these segments depend upon the efficiency of the executing agency.
4. After repairing the segments, the homogeneity of the concrete shall be confirmed by NDT tests.
5. After the repairs / crack closures, it shall be ensured that, the cracks spreading across the ducts, especially near the joints are not causing any migration of grouts from one duct to another.

6. To ensure the match cast surfaces fitting during the erection, wherever the cracks are sealed with epoxy, small concave groove should be made along the line of the cracks. These grooves will be filled up during epoxy application.
7. As a measure of abundant precaution, in-situ sample test to simulate compression force (due to prestressing) effect on segment face shall be carried out for the worst effected 5 segments. Among these 5 segments, the 3 segments with more than 3 mm crack width and 400mm depth gets included. While simulating the prestressing effects in the test, the live load and superimposed dead load effects on the deck may also be simulated.
8. There are 3 segments with 3mm crack width. If all the 3 tests meet performance requirement, there is no need to carry out anymore simulated tests for other segments less than 3mm crack width. If the tests of segments with more than 3mm crack width fail, these precast segments may be rejected. The use of segments with further alternative repairs may be discussed with the engineer in charge.
9. During the erection process, every segment joint shall be monitored for spalling at every stage of activities, including the segment transportation on top. If any signs of spalling or cracking at the joints are observed, this shall be reported to the engineer in charge immediately.
10. The repaired segments shall be provided with additional redundancy during erection stage by retaining the crane support until the epoxy glue is hardened after the temporary / permanent prestressing is applied as appropriate from Contractor's temporary works design. This will ensure that, there is an additional safety measure in place, incase if there are any reduction in the expected interface shear performance on the cracked web shear keys before the joint become monolithic with a set epoxy glue.
11. The genesis of the cracks is improper reinforcement detailing of the precast segments. The match cast surfaces are not detailed for long term shrinkage effects. For the future pre-casting of the segments, the precast segment reinforcement detailing at the match cast surfaces has to be changed.
12. As the precast segments including the repaired segments are likely to be there in casting yard for some more time, the segments have to be monitored for likely development of long-term shrinkage cracks at match cast surfaces.

Opinion of The Experts Panel

This is one of the rare cases where elements precast are being used after a substantial lapse of 5-10 years. Using these elements back, with cracks on match cast segments, in structure extreme care needs to be taken.

Structure is longitudinally and transversely prestressed and segments are match cast, so in the, structural cracking is not expected current state in stacking yard. The cracks have appeared on match cast surface, these are wider up to 0.3mm and fairly deep up to 500mm, which is a cause for worry. The cause of the cracks has not been identified. Mix design for M50 grade is reported as, cement 477kg/m³ with OPC. It is not clear whether it is a equivalent cement content or all OPC. W/c ratio is 0.31, with no admixture but a slump of 180 mm as per the report. Obtaining such a slump without admixtures is doubtful. If correct,

- (a) it is likely to be prone to internal honeycombing, as shutter vibrators can give a smooth outer finish. It means similar cracks may be present inside the concrete mass too,

- (b) High cement content could also lead to internal cracking due to heat of hydration if it was not cured well.

If segments are intended to be reused it is necessary to ensure:

1. Crack mapping and ND testing including USPV is required to be done. Edge spalling specially at match cast surfaces could lead to problems later when longitudinal prestressing is done.
2. It is necessary to ensure that there is no internal cracking. USPV tests in good numbers in each segment will help.
3. Edge spalling if seen, should be treated well. It can lead to overstressing and consequent crushing when longitudinal prestress is applied. This generally happens when prestressed span is lowered on to the pier cap.
4. Treating cracks deeper than 50-100mm is very difficult, here many cracks are even deeper. Crack filling material does not penetrate so deep and when longitudinal prestress is applied, delamination could occur which will get accentuated due to internal cracking.
5. Even when crack are finished smooth, perfect matching as in a match cast segment is required to be achieved, otherwise shear key crushing and subsequent problems may arise. Reusing such segments should be done only with extreme care.

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

Disclaimer :

The objective of this newsletter is to help professionals to make structures safer. This is achieved by publishing information about failures and about unethical practices, based on the confidential reports received by IAStructE and information available in the public domain. IAStructE can not be held liable for the veracity of the information given by the reporter. As this document is based on the Confidential reporting system, the reporter's name and identity as well as the project name, location and identity will not be divulged under any circumstances. Expert Panel opinions given in this document are those of the group of individual experts in the field and not that of the association. IAStructE cannot be held liable for the opinions expressed herein. This newsletter is intended for those who will evaluate the significance and limitations of its contents and take responsibility for its use and application. No liability (including negligence) for any loss resulting from opinions/informations given in this newsletter is accepted.