CROSFALL
Confidential Reporting Of Structural Failures And Lessons Learnt
NEWSLETTER
A PUBLICATION OF INDIAN ASSOCIATION OF STRUCTURAL ENGINEERS

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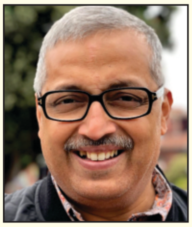
From the Desk of the President

I am extremely happy that after long deliberations & base work finally editorial board of CROSFALL is launching first issue. It is probably first newsletter of its kind which focusses on the structural failures purely from learning point of view. Interesting feature is that identity of the project and the people involved is not revealed and not asked for. This feature will encourage people to share their reports without fear. Editorial board & experts thoroughly review the reports & evaluate it for publishing. We are getting encouraging response after it was announced. We expect this newsletter will serve the civil & structural engineering fraternity in more than one way.

I would urge Civil & structural engineers to send reports freely without any fear and hesitation. Reports may be for any type of structure. It will be good for the society as well. Do send your feedback & suggestions for its improvement. My good wishes to the Chief editor & the members of the editorial board.

— Manoj Mittal

Message from Chief Editor



I am extremely pleased to write this column as Chief Editor of CROSFALL in this very first inaugural newsletter. CROSFALL newsletter is meant for confidential reporting on structural failures, with the objective to capture and share lessons learned from various structural safety issues which might not otherwise get public recognition. We have seen in the past that many a times, the technical details of structural failures are not shared with the engineering fraternity which prevents them from learning lessons. The intention is to have a global freely available database to be used by the construction industry anywhere to improve the safety of their buildings, structures, and national infrastructure.

I strongly believe that this CROSFALL newsletter will serve as a window through which we can share our experience without identifying ourselves and help to mitigate failure risks. At a time when the construction industry in India is under intense pressure, it is more important than ever that we learn from each other's experiences and CROSFALL provides a means whereby we can all contribute towards improving our safety standards.

— Alok Bhowmick

Contents

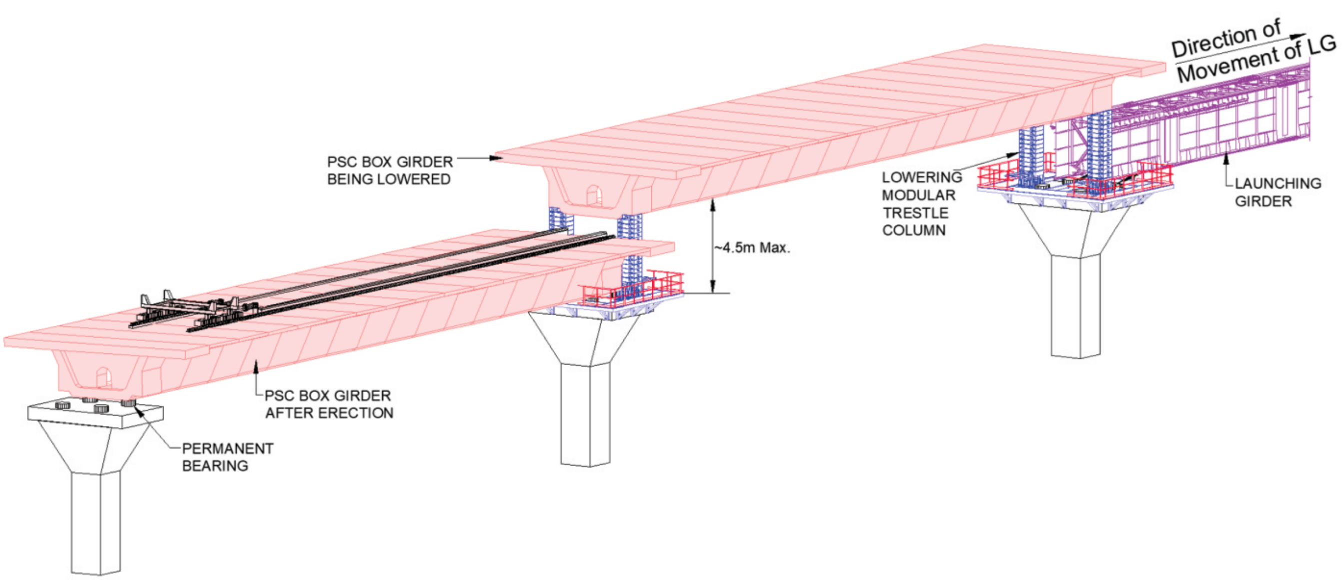
REPORT No. CF - 01

PSC Segmental Box Girder Failure during Erection Operation

This failure report is regarding a river bridge project where a 50m span PSC Box Girder fell into the river during erection and lowering operation. Fortunately, there was no casualty.

Details of the Bridge and Launching Scheme

The bridge was nearly a kilometer long. The span arrangement is comprised of a series of 50m simply supported spans. The superstructure was proposed as a precast PSC segmental box girder, which was launched using an underslung launching girder (ULG). Each span had 17 segments and the span was weighing around 900 tons. The design of the launching scheme, carried out by the temporary works consultant, envisaged assembling and erection of the underslung launcher over the abutment and pier cap in 1st two spans from the abutment end, followed by assembling of precast segments over the ULG. Segments were then glued and initial prestressing between segments was achieved. The four modular trestle supports were then installed at designated locations over the pier cap to support the span, transferring the load from ULG to Modular trestle columns. The modular trestles could be lowered or moved up by activating 4 hydraulic jacks under each trestle. After the permanent prestressing, the entire girder weight is transferred from ULG to the four modular trestle columns and the ULG is moved to the next span. Further to the movement of ULG, the segmental span was lowered in steps by operating 4 × 4 sets of hydraulic jacks till the span rests on permanent bearings. The sketch given below shows the arrangement of lowering the span :



TYPICAL SKETCH SHOWING LOWERING ARRANGEMENT OF PSC BOX GIRDER

Failure of Span during lowering

After the successful erection of a couple of spans in this bridge, failure occurred when one of the spans was being lowered. The incident occurred in the middle of the night when the lowering operation was being undertaken by the executing agency. It was reported that while lowering the span, one of the hydraulic jacks failed which triggered the failure of other adjacent jacks resulting in instability and fall.

Cause of Failure as per the Reporter

The reporter found that the launching/lowering operation adopted in this project is NOT commonly in practice for highway bridge construction. The lowering scheme was found to be highly vulnerable to any jerks or mechanical failure of hydraulic jacks. The modular trestle used for lowering the span was neither connected at the top nor at the base and was not braced in any direction. The reporter could not find the checks for the stability of the trestles for the safety aspect during lowering.

It was also not ensured by the concerned stakeholders to follow the precautions written in their own SOP related to the safety aspect during the lowering of the superstructure. Only authorized persons were allowed to operate the power pack and only trained persons were allowed to operate the jacks during lowering operation as per the SOP. This did not happen at the site and the lowering operation was taking place in the dead of the night with no engineering supervision and this crucial operation was left at the mercy of only untrained technicians.

Lessons Learnt

a) The scheme of lowering of PSC girder provided in this project was not a commonly used launching system. All stakeholders (i.e, the executing agency, the design consultant and the approving agency) should have exercised extra diligence in finalizing the scheme of erection. Stability checks for the temporary works during construction must be performed. The performance of any erection scheme and structural adequacy of the proposal should be ascertained prior to its finalization.

b) Technicians, Workmen, and Engineers involved in performing the launching operation must undergo formal training before they are allowed to perform such works.

c) Risk assessment of each and every launching/erection step shall be made by the A.E/I.E before accepting the same. Good coordination between A.E/I.E. and EPC Contractor / Concessionaire for project-related activities is key to mitigating risks of failure at the site.

d) In Projects of this nature where the risk levels are relatively high, the presence of Key Professionals of Authority Engineer / Independent Engineer at the site of works is crucial.

Comments from the Expert Panel:

In most of the Erection and Launching schemes, it has been observed that the various components are not designed for lateral loads caused by wind and earthquakes. Lateral loads should not be ignored even though it is difficult to implement the safety measures, which require proper anchoring and /or bracings of the structure. The components forming part of the launching and erection scheme are required to be shifted after each operation to the next location. Anchoring and then de-anchoring is a time-consuming process and there is a tendency to ignore the safety measures. At the design stage itself, these should be designed and checked by the proof consultants and supervision authorities. The implementation of these measures has to be enforced during the construction stage by adhering to the SOP and Method Statements approved. Suggestions are given in para "Lessons learned" are very useful and should be implemented. Finally, the concept of Temporary works like Launching Girders and lowering of 900t full span superstructure by 5m over the pier cap requires much more engineering input than seems to have been applied. Also, overcrowding over the pier cap should have been avoided.

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REPORT No. CF - 02

Failure of a Trussed Bridge due to the Unregulated Passage of Over Weight Multi-axle Vehicle

This report is regarding the failure of a newly constructed 2 lane wide trussed bridge over a running canal, where the truss collapsed when a multi-axle tractor-trailer carrying an over-weight and over-dimensioned consignment tried to pass over the bridge in the middle of the night. Fig.1 and Fig. 2 show the collapsed bridge with OWC/ODC vehicle.

Fig. 1 : View of the Collapsed Bridge Over Canal

Fig. 2 : View of the OWC/ODC Vehicle on Collapsed Bridge

Salient features of the bridge:

The Bridge is 10.9 m wide comprising of 7.5 m carriage way with a 1.25 m raised footpath and 0.45 m crash barrier on either side. The superstructure is a 40.0 m span modified Pratt type through steel Truss with RCC deck slab and crash barrier. The transverse center to center of the truss is 11.4 m and the deck slab is spanning between cross girders. There are 8 bays of 5.0 m each in the truss and the distance between the bottom chord and top chord is 7.25m giving a vertical clearance of about 6.0m clear of knee bracing from FRL. The bridge is designed for critical of 2-Lanes of IRC class-A Loading with Impact spread over a length of 18.8m i.e.129.4t (2*55.4*1.168 IF) or one Lane of IRC class 70-R Loading with Impact spread over a length of 13.4m i.e.116.8t (100*1.168 IF).

Reason for failure:

Legally and as a general practice, the movement of the over - dimensioned consignments / over-weight consignments (ODC/OWC) are regulated by the authorities. Prior approval is needed by the transporter for moving such vehicles on a specific route and schedule. They are allowed to move on highway corridors only after ensuring that the bridges along that route are safe for the passage of such ODC/OWC vehicles. Such vehicles are required to be accompanied by a pilot vehicle and representative of road owning agency to ensure all the specified conditions are being followed. It is specified that at the time of a vehicle crossing a bridge, no other vehicle is allowed to ply on that bridge. Also, the maximum speed limit of vehicles should be 5 km/h and no breaks should be applied while vehicles move on the bridge.

In this case, the transporter tried to deviate from the allotted route as he could not pass the vehicle with 6.0 m height through a ROB with 5.5 m clearance and moved the vehicle carrying GVW of 305 MT over this affected bridge designed for IRC Class 70 R/ Class-A loadings. The bridge failed instantly with the vehicle on it and settled by more than about 2m at the 3/8th nodal point from one end of the bridge. Due to the shallow depth of the canal bed from the soffit of the bridge, the bridge did not collapse completely and stood in its position with the consignment trapped inside.

The failure has occurred apparently due to the buckling of compression members, which was caused due to the passage of the OWC vehicle carrying GVW of 305 MT having axle configuration shown in Fig 3 on the bridge designed for IRC Class A/70R.

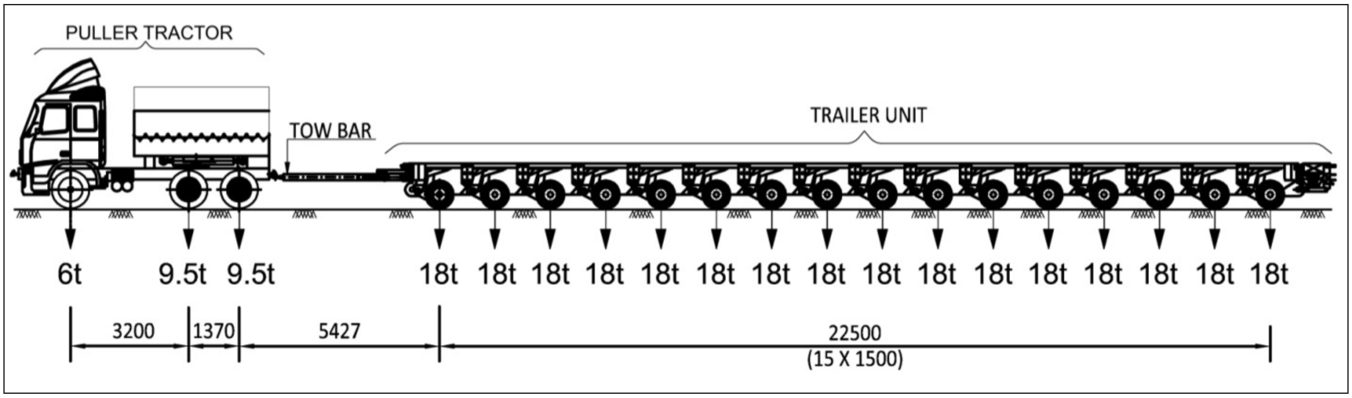

Fig. 3 : Axle Load Configuration of OWC/ODC Vehicle

Lesson Learnt and how to avoid such Mishaps:

1. The Road owning agency should ensure the following while giving permission for carrying OWC/ODC vehicles to avoid the occurrence of such mishaps in the future such as:

- The transporter should have real-time tracking of the OWC/ODC vehicle to ensure that the vehicle is moving on the permitted/allotted route.
- The OWC/ODC vehicle should be accompanied by a responsible and competent representative of the transporter who should ensure complete adherence to the stipulated conditions and directions of the Permission.
- The representatives of the road-owning agencies should also have a system in place to ensure that the transporter is strictly following the route as well as the instructions and conditions of movement of the OWC/ODC vehicle specified at the time of granting permission.

2. All the Bridges should have Bridge Information Display on both sides giving information about the bridge including permitted load and vertical clearance in case of through truss bridges, FOBs, underpasses, RUBs etc.
3. Heavy Duty height gauge should be installed, as per vertical and horizontal clearances on both sides before the entry to through type truss Bridges, FOBs, Underpasses, RUBs to prevent over-dimensioned vehicles to enter.

Comments from the Expert Panel:

The suggestions given in para "Lessons Learnt and How to avoid such Mishaps" are noteworthy and very useful in avoiding such mishaps. However, these are not easy to implement in our country due to laxity in enforcing the regulations, lack of awareness of the consequences of ignoring the regulations, and lack of alternative routes to the destination. There is always pressure on the transporter to carry OWC/ODC vehicle to the destination within a stipulated time which is difficult to achieve in view of several hurdles& constraints including the fact that not all bridges are capable to carry the loads exceeding permissible limits. Therefore, educating and creating awareness among all the stakeholders about the steps to be taken for avoiding such mishaps and enforcement of the regulations are of paramount importance. The road authority needs to invest in a GPS tracking system so that the movements of all vehicles of this category can be monitored. Transporters with large fleets of vehicles can similarly have their own system as a part of their asset management system.

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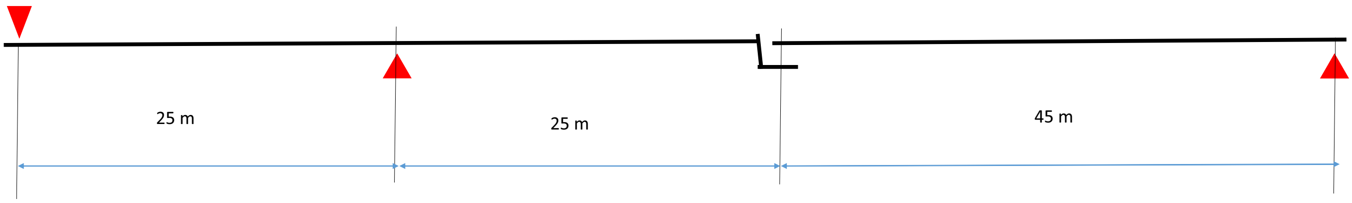
REPORT No. CF - 03

Report on Collapse of Bridge during Service due to Mismatch in Design & Drawing

A crucial concrete bridge, 95m long, linking two major towns collapsed one fine day after serving for only 12 years. Six people got injured in the tragedy. Fortunately, there was no casualty. The structural scheme and the span arrangement for this bridge were unique. It was a 2-span bridge having span lengths of 25m and 70m. The structural scheme comprised of a simply supported PSC box girder span of length 45m, which was supported on an Abutment at one side and was made to rest on overhanging cantilever span from the other side. The 25m end span on the other side is made continuous over the intermediate pier and is made to overhang by 25m to support this 45m simply supported span. Expansion joints are provided at the two abutments and the articulation point. The sketch below explains the details. The photograph shows the bridge immediately after failure.



It is obvious by looking at the structural scheme that the abutment at the end supporting the 25m end span is subjected to an upward reaction from the anchor span, unlike a conventional deck which gives a downward reaction. It is understood that the deck was anchored to the abutment by using prestressing cables, which were provided between the abutment and deck, to carry this upward reaction force.

Reasons for Failure:

The reporter informed CROSFALL that scrutiny of the GFC drawings post-failure revealed that there was a mismatch between the design requirement as given in the design calculation and the GFC drawing regarding details of prestressed anchor cables which is the root cause of the failure of this bridge. As per the design requirement, 6 Nos U-shaped 6T13 cables were needed. However, the draughtsman noted the requirement as 6 Nos 6T13 cables and showed only 3 U-shaped cables of 6T13 in the drawing interpreting one U-shaped cable as two cables. It is clear that the actual stress in the prestressing cables was double the design value. Probably there was enough margin in the stress due to which the bridge survived for 12 years. However, with time, due to stress corrosion, coupled with high relaxation losses in prestressing steel and lack of maintenance, this sudden failure occurred, in which the whole bridge was lost.

Lessons Learnt:

- The conceptual design of this bridge was quite innovative, but in such an out-of-box solution it is important to have "robustness" in the structural system to avoid disproportionate collapse (a collapse, after an event, which is greater than expected, given the magnitude of the initiating event).
- The drawings were not checked by the designer in the design office. It has to be ensured in the design office that the design intentions are communicated in the drawings very clearly and drawings have to undergo multiple levels of checking.
- If there is any confusion in the interpretation of the drawings at the site, the same has to be communicated to the design office for seeking clarification.
- Also structural conceptualisation where the stability is entirely dependent upon the uplift anchors, which are permanently subjected to tension, should be avoided in the first place to the extent possible. In a box girder, there is scope to add counter dead weight inside the box, which could be used to nullify the tensile reaction.

Comments of Expert Panel

In the first place, such risky structural arrangements involving articulated joints and uplifts should be avoided. Proper detailing of reinforcement, cables, anchorages and embedment etc. is very important and lack of proper detailing is one of the major reasons for failures. In our country, more often than not, the system of review of structural design and drawings by senior structural engineers is missing. Even proof consultants and supervision consultants do not take pains to check the design & drawings thoroughly. It is preferable to study literature, and consult senior colleagues and engineers, who are more experienced, on the projects involving risky schemes to avoid such failures. An experienced proof checker would have first carried out back of the envelope calculations of such a scheme where the stability itself is suspect to arrive at the size of the anchors to counteract uplift and made sure that even if there was a design office blunder, it would not go far. Articulations in the middle of the span are never a good idea and the engineer should have applied his mind to come up with a better concept design.

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REPORT No. CF - 04

Failure of PSC Segmental Box Girder during Prestressing

Salient Features of the Project and the failure incident :

This case pertains to the failure of a prestressed concrete segmental box girder span during the prestressing operation. The span hogged up during the last stages of prestressing, as can be seen from the photograph given in Fig. 1 below:

Fig. 1 : Photograph of the affected span

The simply supported precast PSC segmental superstructure was a part of a long river bridge. The span under consideration is a 60m span (E/J to E/J) between piers. There are two independent superstructures carrying a 2-lane carriageway each but supported on a single pier. The two box girders are separated with a gap of 4.5m in the median. The substructure and foundation are however common for the entire 4-lane carriageway carrying two independent box girders. Each box girder is having an overall width of 12.5 m.

The erection of the precast concrete segments was carried out using trestle supported arrangement. After the segments were joined through epoxy gluing between adjacent segments, the prestressing cables were stressed from both ends, in the sequence given in the "Good For Construction" drawings. During the stressing of the last two cables, cracks developed on one blister of a segment. In addition, hogging and crushing of concrete were observed at the interface of certain segments close to midspan.

Diagnosis & Prognosis:

The superstructure was subsequently de-stressed by releasing stress from the cables by using single pull jacks in the same fashion as stressing was made. All the segments taken out from the span were kept in the casting yard for inspection and further necessary testing/investigation. It was then decided to investigate the cause of cracking and crushing by a third party who will investigate the reasons for failure and also the structural soundness & quality of the remaining segments yet to be erected. Broadly, the following issues were investigated:

- Review and Checking of the design and drawings of the superstructure for its safety.
- Investigate patterns and causes of cracking in the segments including crack & cover mapping.
- Conducting Quality & Strength checks including NDT tests.
- Investigate the cause of the bursting of blister blocks and check the design of blister blocks.
- Investigate the cause of concrete crushing at the junction of segments during stressing operation.
- Feasibility of repair of segments affected by cracks and checking the adequacy of segments not affected by cracks.

Results of Investigations:

Based upon the extensive investigations, it was found that the quality and workmanship of concrete were the main reasons for failure. The results of the investigations are summarised below:

a) ***Deficiencies in Design:***

Design and drawings of the superstructure were found to be adequate in general except that Construction stage analysis was not done for checking stresses due to lifting and stacking of the segments. In addition, the blister block design had the following deficiencies:

i) The isolated intermediate soffit blisters are anchored in the middle of the soffit and not at the junction of web and soffit which is not a desirable practice, particularly when the force per cable is high.

ii) The reinforcement provided in the blister block is not detailed adequately and has not been provided throughout the length of blister blocks. The provided reinforcement is confined within 1.5m from the face of blisters and thus, the critical end zone of blister is left un-reinforced, which is unsafe.

iii) Drawing shows the provision of additional reinforcement in the soffit slab as tie-back reinforcement, for the tensile load transferred from the blister, however, it is not feasible to provide such reinforcement in precast segmental construction.

b) ***Concrete Quality and Strength:***

i) Concrete cube test results were found to be "acceptable" as per codal specifications. However, NDT tests such as Core Testing and Schmidt hammer tests established that actual concrete strength was far below the design concrete strength.

ii) Failure of anchorage cone in intermediate blisters occurred due to inadequate reinforcement and poor compaction of concrete at the most critical points in the structure. The anchorage cone at the blister had an edge distance less than the prescribed value as per the manufacturer's catalogue.

iii) From Visual inspection, longitudinal, transverse, star-shaped, and scatter cracks were observed at several locations. The cracks measured by a specialized agency are reported of widths varying from 0.1mm to 0.3mm and depths varying from 30mm to 100mm. Honeycombing was also found in almost all the segments. Edges were also found damaged in the anchorage zone, cantilever slabs, bottom slabs, and deck slabs at several locations. Crushing was observed on top of deck slabs at a few locations and reinforcement was found exposed at a few locations. Shear keys of the segments were found damaged at several locations.

iv) From the results of the cover assessment, it can be inferred that existing concrete cover in various segments has been carbonated up to 70 percent of design cover in a very short period of about two years. This shows that concrete is porous and honeycombed. Due to this, the probability of corrosion in the steel reinforcement is likely to increase in the near future which will induce spalling, cracks, etc. in the concrete and thus, decrease the moment resistance capacity of the section.

v) Water absorption results, which indicate porosity in the concrete, reveal that it is in the range of 2.53% to 5.15 % which is beyond the maximum limit of 3.0 percent, as per IS: 516 (Part-4)-2018. Thus, water absorption results reveal poor quality concrete.

c) ***Workmanship:***

i) Application of epoxy in the joints of the segments was not carried out properly and the epoxy resin as applied was set even before the jointing of segments and the two match cast surfaces have not joined even after application of prestress. The hardened epoxy is likely to prevent 100% contact between the match cast segments, thereby increasing the stresses at locations where there is contact established.

ii) Clear cover to reinforcement for the deck slab and webs was found to be more than the design cover. However, the designs of webs and deck slab (at either face of the web) was found adequate in structural strength even with an increased cover.

iii) Variation in web thickness is up to -10 mm (i.e. lesser than required) to 30 mm (i.e. more than required) which results in mismatching of adjacent segments.

In view of the above, it was concluded that the PSC box girder failed due to a variety of reasons such as poor-quality control, bad workmanship, and improper reinforcement detailing in the blister block. The quality of coarse aggregates and fine aggregates was not up to the required specifications. All the remaining precast segments yet to be erected were rejected. Later, the source of the aggregates was changed, and quality & workmanship standards were improved for the new segments which were erected without any problem during the prestressing operation.

Lessons Learnt :

i) Adequacy and acceptance of cube test results alone do not ensure good quality concrete and design strength. Apart from strength, it is important to ensure the quality of concrete in terms of durability criteria. Quality of concrete should be ensured for the structural components being cast by following an approved design mix, ensuring the quality of raw ingredients and water as per specifications, and ensuring proper cover, reinforcement placement, and thicknesses of various components. Curing is a major factor in achieving the desired concrete strength which should be ensured.

ii) Quality control at the site should be exercised by a competent and knowledgeable Quality Control Engineer. Regular supervision should be done by the Head Office of the Contractor and a proper record should be maintained of all the quality control checks. Authority and Authority's Engineer/Independent Engineer should enforce quality control diligently at all stages of construction.

iii) The designer should develop detailed drawings properly, especially where there is reinforcement congestion, and increase concrete dimensions suitably to ensure proper space for concrete to go in. Thicknesses specified in design codes are minimum and the designer should increase these at points of reinforcement / cable congestion.

iv) Self-compacting concrete or high-performance concrete should be preferred in highly reinforced sections.

v) Overstressing of prestressing cables and extra elongation, more than the values specified in the drawing should be avoided. Prestress force more than the design value is detrimental to the structure.

vi) Workmanship should be improved by imparting training to the skilled manpower who work at the site.

Comments of Expert Panel

Several similar failures have occurred in recent times which is alarming. The main reasons for such failures are poor quality of concreting, honeycombing, lack of proper curing, damaged shear keys, congestion of reinforcement and prestressing cable, and improper gluing & matching of segments. Quality of concreting suffers also due to heavy congestion of reinforcement and prestressing cables. It is becoming a common practice to support large spans with wide decks on a single superstructure comprising two webs. This causes the concentration of design forces and requires heavy reinforcement & cables resulting in heavy congestion. Our design codes & specifications should be reviewed for the required minimum thicknesses of webs, deck slabs, and soffit slabs so as to avoid congestion. Designers too should increase the concrete dimensions at locations of reinforcement congestion rather than provide minimum thicknesses prescribed in the codes. The codes too should address this problem and cautions designers to be careful about congestion of reinforcement. Shop drawings should be prepared to highlight the vulnerable locations prone to failure. High performance and self-compacting concrete should be made mandatory for such superstructures. Far too many mistakes occurred during the design and construction stage of this project. For areas of congested reinforcement, it is better to make 3D drawings of reinforcement as is being insisted by some owners. The designer can then review whether any change in detailing or revision of thickness of concrete elements is necessary. Each concrete segment must be critically examined for defects when it is in the stacking yard before delivery to the site. The erection stage must also have detailed method statements for each activity. Only a team of experienced engineers should be entrusted with the job of precast segmental construction as it has far too many complex operations and pitfalls.

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About the CROSFALL Newsletter

CROSFALL is a unique 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 to be reported by professionals, without exposing their identity and without creating concerns in areas like co-worker relations, client loyalty, or insurance. Any identifiable details, such as a project, product, individual or organization, will 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 if necessary, but this will also remain strictly confidential.

The newsletter will report only 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 see around or what they experience on any real-life projects. Anyone involved in the civil engineering 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
