Investigation of the Damage of Horizontally Curved Precast Prestressed Segmental Bridge

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Abstract: A horizontally curved precast segmental bridge collapsed during the prestrssing of stitching segment and the two segments around it from each side. The collapse was investigated and the main causes of damage are addressed in details.

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Key wards: precast segments- prestressed bridges-horizontally curved bridges- failure of bridges**.**

Introduction

Bridge B is one bridge among a series of bridges included in a highway project no. RA-186 in Kuwait. It is a horizontally curved; precast segmental bridge. A damage occurred during the prestressing of the stitching segment and the surrounding two segments from each side. The results of bridge inspection are illustrated. The possible causes of the damages are mentioned and a 3D computer model has been developed to correlate the site observations with the actual stress values. Finally, the main causes of the damage have been addressed.

Structural system of the bridge deck

The bridge deck consists of 4 spans from axis 01 to 05. Figure 1 illustrates the construction method of the bridge. Span 01-02 is cast in situe with a cantilever extending after axis 02 to 02A. Span 05-04 is cast in situe with a cantilever extending after axis 04 to 04A. The remaining part from 02A to 04A is segmental precast units. The deck is supported by Pot bearings with different restraints from axis 01 to axis 05.

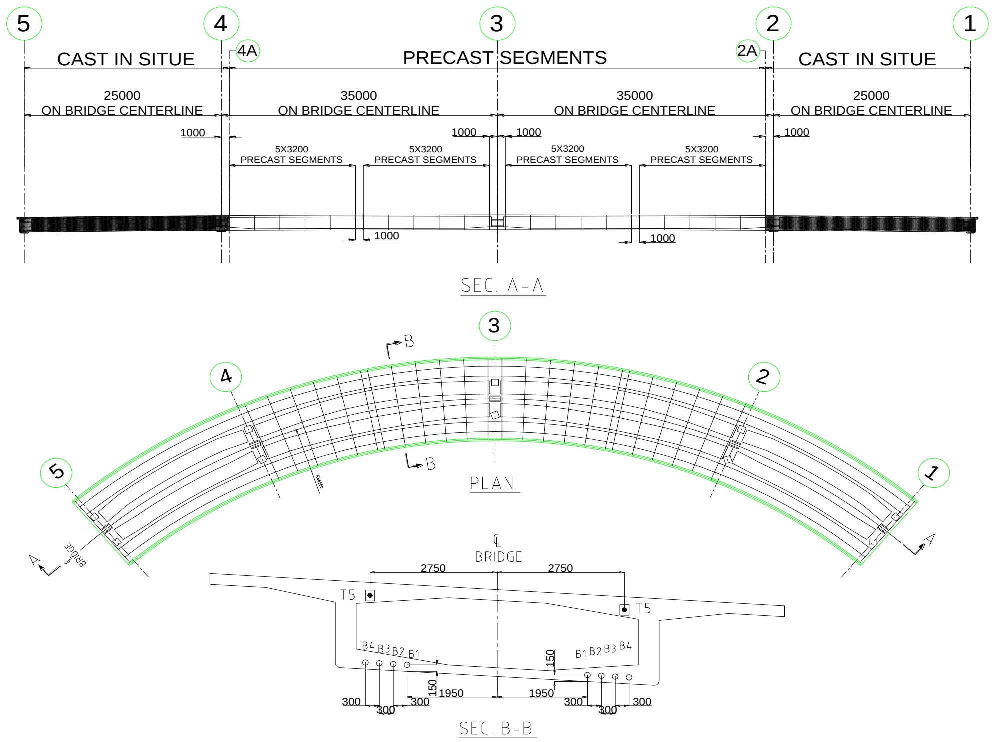


Figure 1: Details of Bridge Deck and Sequence of construction

Methodology of the investigation

The following procedure was followed in order to reach a sound conclusion about the causes of this damage:

Pictures 1 to 3: Casting Yard

a- The casting yard of the precast units has been visited. Pictures 1 to 3 show some views inside the casting yard.
b- The bridge was inspected, and the observations of this visit were coordinated with the pictures received from different sources.
c- The calculations and the design drawings prepared by the designer were checked
d- The shop drawings prepared by prestressing supplier, were reiewed
e- The details shown in the different drawings were compared to the requirements of AASHTO LRFD,[1], the specifications of the project.
f- Detailed computer analysis was prepared considering the three construction stages shown in the design drawings. The tendons were allocated considering the deviations explained to us during our visit and submitted in sketches. Figure 2 shows one of these sketches.
g- A 3-D stress analysis was conducted by the author to investigate the local stresses at the damaged area using ANSYS software, [2]. Solid element was used, [3].

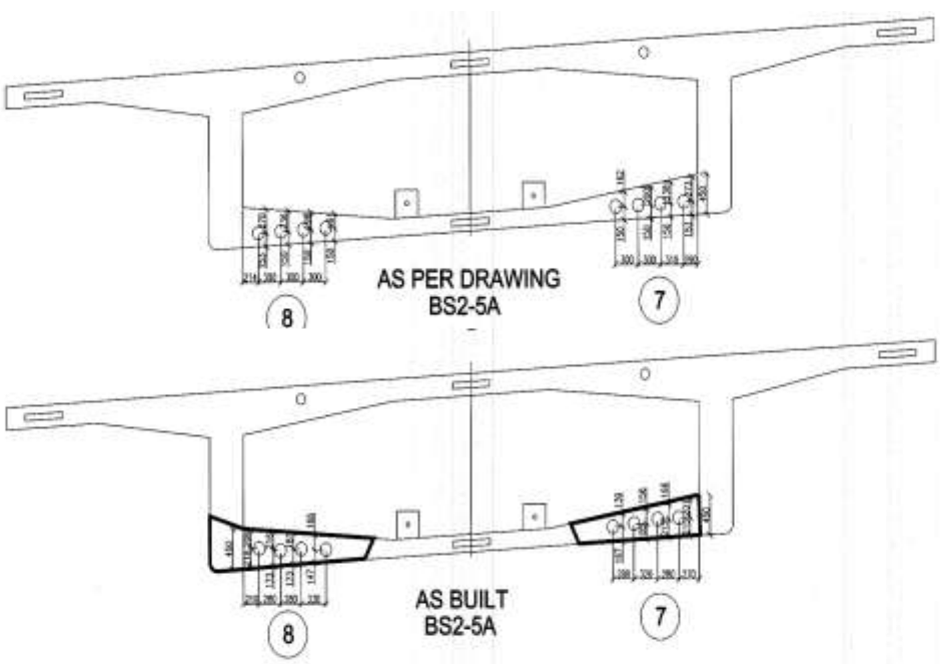
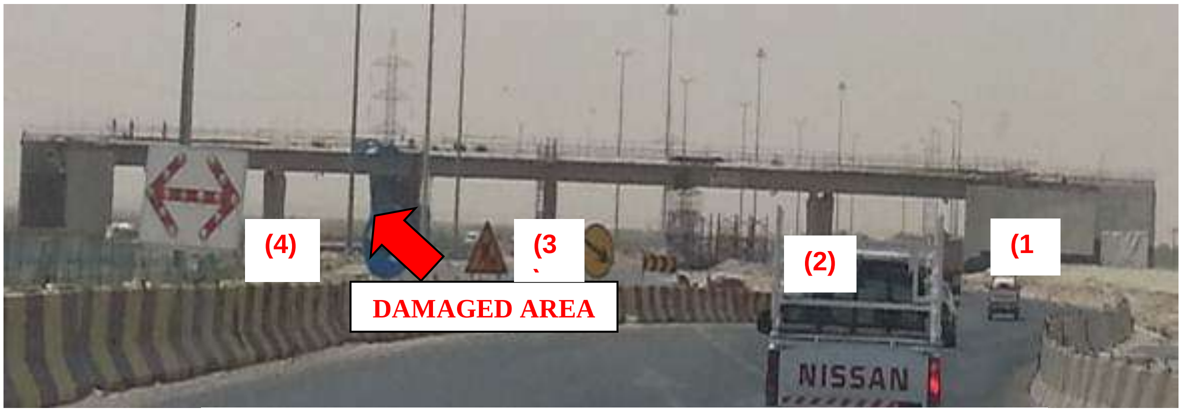


Figure 2: Deviation of tendons

Description of the damage

Picture 4 shows a general view of the bridge with the damage located between axis 3 and 4.



Picture 4: General view of Bridge B, showing the location of the damage

Pictures 5 to 9 show damage of the bottom slab of the closing segment and the first precast segment attached to it towards axis 4. These damages may be categorized by crushing of concrete, delamination and splitting stresses in the bottom slab.

Picture 5: Splitting of Concrete

Picture 6: Delamination of concrete

Picture 7: Splitting of concrete

Picture 8: Delamination and crushing of

Picture 9: Splitting and out of plane overstresses in the bottom slab

Main causes of the damages

The following possible causes of damages have been considered based on the given documents, site inspection, prestressing records, and computer analysis: concrete strength; design; detailing; profile of tendons and prestressing records. All of the above possible causes of damage were thoroughly investigated and a major observation was that the local effect of horizontal curvature of the tendons was not considered in the design. In addition, the size of the bottom ducts is bigger than commonly used in slabs.

Local effect of horizontally curved tendons

Horizontally curved tendons induce radial forces in the plane of tendon curvature. In addition, these curved tendons induce also out of plane forces perpendicular to the plane of tendon curvature caused by spreading of the strands within the duct, [1, 4, 5]. Generally speaking, curved tendons, exerts a pressure on the concrete causing splitting forces that must be considered in the design by adding special reinforcement. Moreover, the risk increases when curved tendons run parallel to each other in the plane of curvature, which is our case. The parallel curved tendons cause bursting force into the adjacent duct. Figures 3 and 4 illustrate the in plane and out of plane forces.

Without adequate reinforcement, the tendon radial forces may rip through the concrete cover or unbalanced compressive forces may push off the concrete on the outside of the curve, [6].

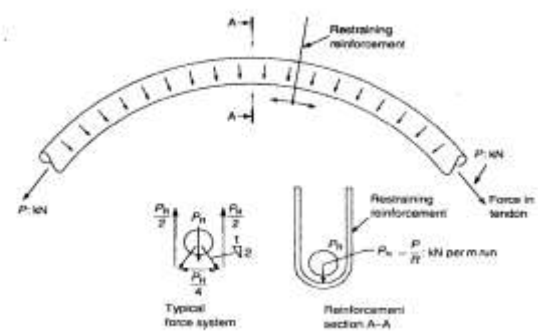


Figure 3: In Plan Radial Force (F/R)

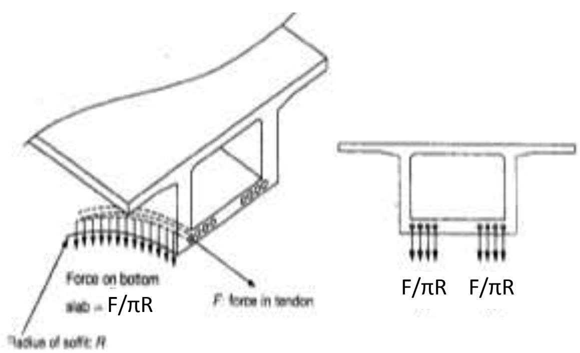


Figure 4: Out of Plan forces (F/πR)

In our case, we have a number of curved ducts in one plane, a lack of vertical hair pin around the tendon and along the whole length of tendon resulted in delamination of the concrete of the bottom slabs as shown in pictures 5 to 9. Moreover, the required reinforcement to hold the tendons in place during pouring the concrete has not been considered in the drawings. This was also observed in both the cast in place closing segment and the precast segment as shown in pictures 10 to 12. As a result, these tendons will move from their position due to the concrete pressure resulting in different stresses than shown by calculations.

The effect of torsion moment caused by the radial horizontal force due to curved tendons on slabs reinforcement has not been considered. Moreover, the combined effect of regional bending and local bending moments due to radial horizontal forces was not considered in the design.

The effects of the above mentioned combined actions require reinforcement around the ducts and along the slab of the box section.


Pictures 10 and 11: Lack of steel holders in the casting yard

Picture 12: Lack of steel holders in the site

Computer verification:

A 3D model was prepared using ANSYS software [2]. The bridge deck was modeled according to the sequence of construction and prestressing. The objective of this computer model is to study the stresses resulting in the local zone of damage The bridge was modeled using solid elements as shown in figure 5, [3].

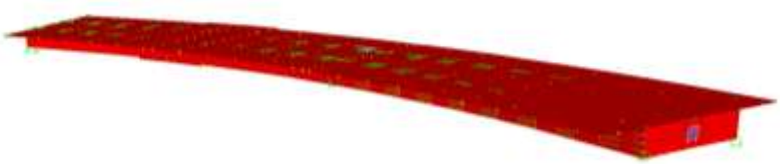



Figure 5: 3-D Model using solid elements

The stresses at this area are obtained due to prestressing of 7 tendons in the bottom flange, prestressing all the top tendons and the own weight of the deck.. The results are shown in figures 6 to 8, and may be briefed as follows:

- Figure 6 illustrates the radial normal stress along Y axis at the bottom flange of the enclosing segment. There is local tensile stress at the damaged area ranges between 160 to 240 Kg/cm^2. This stress is higher than the capacity of concrete especially with lack of enough reinforcement to withstand this stress.

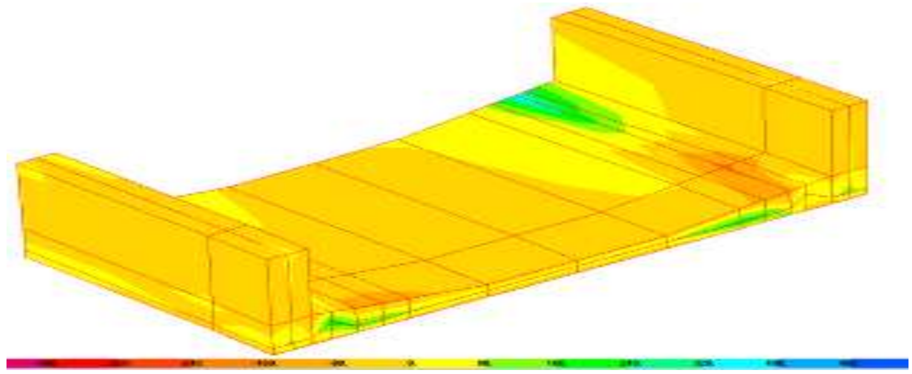


Figure 6: Radial Stress at Middle of Enclosing Segment (normal stress, Y axis)

- Figure 7 illustrates the distribution of normal stress in x direction. As show in the figure, there is stress concentration at the local area, between the ducts, ranges between 400 to 500 Kg/cm^2. This value was calculated assuming evenly distributed through the complete box section and the result was 100 Kg/cm^2. The effect of stress concentration in this narrow zone is much higher than would be expected. This explains the crushing of concrete around the ducts shown in the pictures above, pictures 5 to 9. This stress concentration may be attributed to the big duct diameter to accommodate the remarkable big number of strands at each duct, 31 strands. The effect of stress concentration could have been avoided by using less number of strands, e.g.19, with smaller ducts diameter.
- Figure 8 illustrates the distribution of the horizontal shear stress through X-Y plan. The maximum values ranges between 350 and 400 Kg/cm^2. This value is about 10 times the shear strength of concrete, which justifies the delamination shown in the pictures.

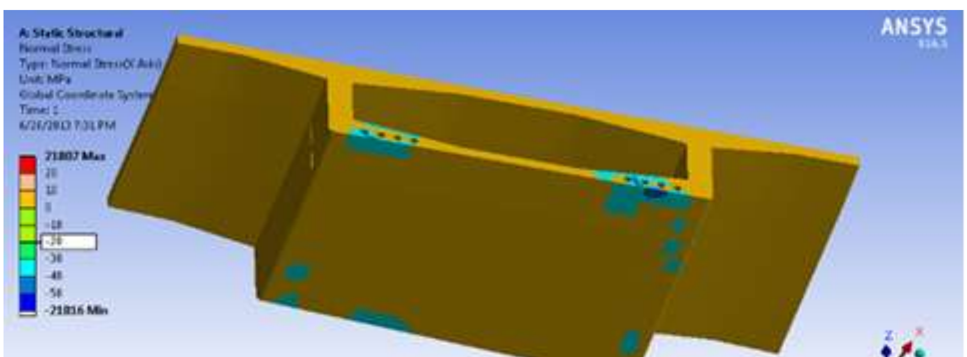


Figure 7: Normal stress (X axis)

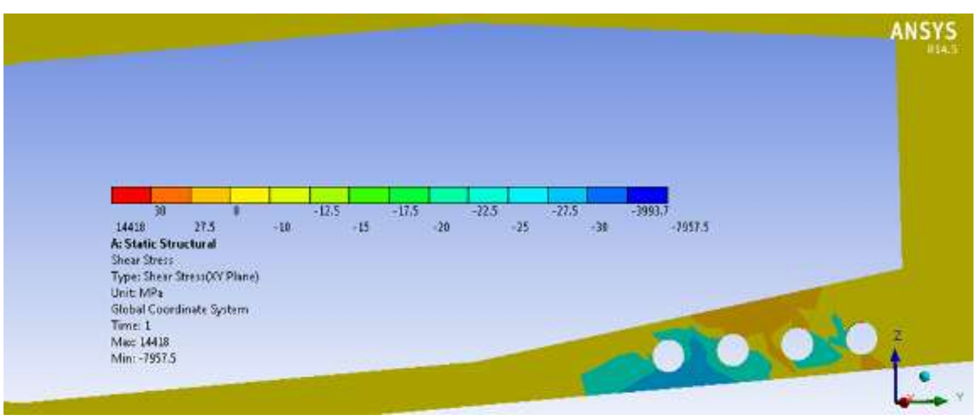


Figure 8: Horizontal shear stress along (X-Y Plan)

Conclusions

From the above investigation, the following points are concluded to be the main reasons for the damage observed in the deck:

- The effects of horizontally curved tendons are not considered in the design. These effects resulted in radial in plane forces and out of plane forces that are higher than the strength of the concrete. The necessary reinforcement to withstand these forces was not shown in the design calculations, design drawings and shop drawings.
- The number of strands in each tendon in the bottom slab, (31), is relatively higher than commonly used in slabs and it is concentrated in small portion of this bottom slab. A more efficient distribution with more tendons and less strands in each tendons would have reduced the stress concentration resulting in the shown damage of this bottom flange of the box section.
- The area of the ducts are big relative to the thickness of the bottom slab resulting in stress concentration more than the capacity of the concrete.
- Lack of vertical reinforcement to withstand shear and lateral forces.
- Lack of holders to keep the ducts in their right location during pouring the concrete.
- The combined effect of regional bending and local bending moments due to radial horizontal forces was not considered in the design.

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