RESEARCH REVIEW JOURNALS
Volume-04
Issue-06
June-2019

ISSN: 2455-3085 (Online)
RESEARCH REVIEW International Journal of Multidisciplinary
www.rrjournals.com[UGC Listed Journal]

Study on Repair of Prestressed Concrete Bridges

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ARTICLE DETAILS

Article History
Published Online: 12 June 2019

Keywords
Prestressed, Concrete Bridge, repair.

ABSTRACT

Today we are facing the problem of a growing number of existing prestressed concrete bridge structures that are in need of repair work. With prestressed concrete in particular, it is difficult to anticipate how the stress distribution in an existing structure will be affected by the removal or addition of concrete due to repair work. With the impending implementation of Eurocode in Europe, the development of suitable calculation methods on how to deal with this problem in accordance with the standard scripture, are compelling. This paper is part of a larger project, which will develop suitable methods for the evaluation of damages on bridges, and suitable repair work, in accordance with Indian code. This paper investigates the effect of repair work on a prestressed concrete bridge beam. The repair work constitutes the removal of old and/or damaged concrete and the addition of new concrete to repair the damage. The consequences of the repair work is investigated and presented by looking closely at the stress distribution in the cross section, and the losses in prestressing over a time-period of 100 years from construction. Concrete creep and shrinkage are taken into account, as well as prestressing steel relaxation. The results indicate that quite extensive repair procedures can be carried out without severe consequences to the structure. The time of the repair procedure is the most crucial to the structure, as large changes in stress are obtained when concrete is removed and replaced. The detrimental effects on the structure are more prominent the more extensive the repair procedure is.

1. Introduction

The building of prestressed concrete bridges in Scandinavia started in the 1950's. At present, many of these bridges, built in the 1950's and 1960's, are in need of repair work. A common form of damage is the deterioration of concrete, which would then need to be replaced. With prestressed concrete in particular, it is difficult to anticipate how the stress distribution in an existing prestressed concrete structure will be affected by the removal or addition of concrete due to repair work. Below, the effects on the prestressing losses and stress distribution of concrete removal from and addition to an existing prestressed concrete bridge structure are investigated. Both long-term and immediate effects are taken into consideration [1].

Problemand Limitations The problem constitutes determining the effects of repair work on a prestressed concrete bridge beam. The focal point of the study is to investigate how the long-term losses in tension in the prestressing tendons are influenced by the repair work. However, immediate effects will also be investigated. The following questions are to be answered [2]:

1. What changes in stress distribution, and thus also in long-term losses in tension, arise due to concrete removal and/or erosion?
2. To what extent does the altered stress distribution (1) inflict further long-term losses in the tendons?
3. What changes in stress distribution, and thus also in long-term losses in tension, arise due to the addition of new concrete?
4. How much concrete can be removed from the cross section?

Repair work is here limited to the removal of aged and/or damaged concrete, and the addition of new concrete to take its place. This repair work is carried out on a simply supported bridge structure, subjected to evenly distributed loads constituting the weight of the structure itself and the weight of a surfacing structure. Concrete is removed and added to the structure instantaneously. As new concrete is added, the bond between the new and old castings is assumed to be perfect. However, the new casting is not assumed to have any initial stiffness of its own. The concrete is here assumed to be a homogenous material behaving linearly as it is subjected to loading. The cross section of the bridge beam is T-shaped and made from concrete, equipped with prestressing steel, upper and lower reinforcement. The same calculations are carried out on three bridges, with varying span-lengths, amounts of reinforcement and prestressing steel and with varying cross-section heights and widths. Temperature differences between new and old concrete, arising from the hydration of the new concrete, are not considered [3].

2. Prestressed Concrete

Prestressed concrete is concrete cast around prestressing tendons that are either already tensioned or post-tensioned after concrete casting. Prestressing results in the bridge structure being curved slightly upwards before it is subject to any loading, thus minimizing the downward curvature once the loading is in place. The prestressing is utilized to compensate for the poor tensile strength of concrete. As a result of the prestressing, compressive stresses are introduced into the material, which will be gradually relieved as soon as the bridge structure is subjected to loading, and begins to curve downward. Thus, the tendons carry the tensile stresses rather than the concrete, thereby delaying the initiation of cracking in the material. By prestressing concrete, it can hence carry far more extensive loads than a non- pretensioned structure [4].

Post-Tensioning

Post-tensioning implies casting the concrete before the tensioning steel is tensioned. In bridge construction, several tensioning cords are put into post-tensioning ducts that serve as protection against corrosion, for example. Once the cables have been tensioned the tubes are injected with concrete, in order to establish full interaction between the concrete and the tendons. By achieving full interaction the structural materials can be regarded as concurrent, rather than just individual structural elements. After the tendons have been tensioned and the tubes have been injected, the prestressing steel is thus activated. The cables are normally placed along the moment diagram of the structure, in a parabola shaped curve. The curvature of the cables, however, initiates friction between pre-tensioning steel and the post-tensioning tube, as the cables are being tensioned. This results in a loss in the prestressing force applied to the tendons [5].

Immediate Losses of Prestress

The immediate losses of prestress during post-tensioning include, firstly, loss due to friction. If the tendons are curved inside the concrete structure, friction will occur at the bends of the strands, which results in a loss of tension. Secondly, wedge draw-in of the anchorage devices anchoring the tendons at the ends of the beam, results in a loss of tensioning. Finally, losses are induced due to the instantaneous deformation of the concrete as the tendons are stressed. The effect of the latter depends on the order in which the strands are tensioned [6].

Time-Dependent Losses of Prestress

The prestressing strands do not only suffer immediate losses, but tension is also lost gradually over time. Engström (1) maintain that when the prestressing cable of a simply supported beam structure is tensioned, the structure will respond with an elastic strain: where P is the tensile force in the prestressing cable. This initial deflection will increase with time, due to creep. The strain related to creep is:

where φ is the creep coefficient. Furthermore, the concrete will shrink, which will result in decreased tension in the prestressed tendon, and thus a strain εcs. The creep and the shrinkage will both result in a loss in prestressing tension. This loss can be calculated by summing up the strains, s cr ε ε ε + = Δ , and multiplying them with the modulus of elasticity of the prestressing tendons.

Creep and shrinkage are both time-dependent properties of concrete. Thus, the loss in prestressing and the stress distribution in a prestressed concrete bridge structure are also timedependent variables. According to Engström (1), creep and shrinkage reach final values in a long-term perspective, leaving the effective prestressing force amounting to about 75-80% of its initial value. Time-dependent losses should thus be calculated for a structure, taking the reduction in strain due to concrete deformation by creep and shrinkage under permanent loads, and reduction in stress due to steel relaxation under tension into account [7].

3. Repair of pre-stressed concrete structures

Publications concerning the reparation of concrete structures are plentiful. However, literature related to the repair of prestressed concrete bridges in particular, is scarce. This is due to the fact that the technology for building prestressed concrete bridges was not fully developed until the beginning of the 1950's. Many of the bridges built in the 1950's and 1960's are still in good working condition, and thus few cases of repair work on prestressed concrete bridges have been encountered in the Nordic countries before recent years [8].

Defects and Damage

Damages to prestressed concrete structures can occur as damage to the prestressing tendons, deterioration of the concrete or member displacement. Damage to the tendons can be articulated as exposed, damaged or severed strands. Member displacement implies, for example, the rotation of the deck due to heavy vehicle impact. Damage to prestressing tendons and member displacement will not be further discussed in this paper. The severity of damage depends on its location. The most severe damage case is when the concrete protecting the prestressing strands is deteriorated, leaving the tendons partially visible through the remaining structural concrete. Concrete can deteriorate by scaling, cracking or spalling. Scaling is a progressive disintegration process which dissolves the cement paste, starting from the surface and moving downward. This occurs due to repeated freeze-thaw cycles, poor drainage or deicing chemicals, for example. Cracking can occur in multiple locations on the structure, and have a variety of directions, but is essentially initiated due to excessive tensile stresses. The most prominent in bridges are longitudinal cracks, which often appear between prestressed concrete box beams, and random cracks, which occur due to, for example, poor curing methods or load deflection. Finally, spalling is a breaking out process of the concrete, which is initiated at the top reinforcing steel. Spalling appears as a result of corrosion of the rebars and is accelerated with the presence of chlorides.

Repair Procedure Briefing

Wear and tear to concrete bridge decks occur continuously due to, for example, repeated freezethaw cycles and heavy traffic loads. In the Northern countries, additional deterioration of bridge decks is invoked by use of deicing salts on roads and studded tires on vehicles. If damage to the concrete deck is too extensive for mere patching with a sealer, the dilapidation of the concrete bridge deck requires damaged concrete to be removed, and to be replaced by new concrete. The removal of the concrete can be done in multiple ways, for example, by different kinds of blasting, scrabbling, milling or waterjetting.

Bond

When damaged concrete is removed from an existing bridge deck, the method of removal is of uttermost importance to how the structure will perform once new concrete has been cast to replace the deteriorated concrete. Full interaction between overlay and base structure is desirable, but can normally only be achieved if the base surface, after the removal of deteriorated concrete, is rough to the surface, clean and free from microcracking. Selective removal of damaged concrete, leaving a surface with the properties described above, can only be achieved by waterjetting. An alternative method to improve interaction between the new and old concretes is to attach the overlay to the base with a mechanical device, such as reinforcement. To attain full interaction, the damaged concrete should first be removed by waterjetting and, when the new concrete is cast, the repairing concrete should be sufficiently attached to the existing structure with reinforcement [9].

Interaction between Repair Concrete and Base Structure

Full interaction between the existing concrete structure and the newer repair concrete is desirable when repairing a bridge structure. Full interaction between the newer and the older concretes will allow the repaired bridge deck to work as a homogenous structural element. when repairing the compression zone of a beam, additional concrete is cast, which results in a differential shrinkage between the different concretes. This differential shrinkage will, however, mainly affect the stiffness of the repaired structure, rather than remarkably affecting its strength. Cracks may develop as a result of change in forces that arise due to the differential shrinkage between the new and the old concrete castings. Furthermore, cracks may develop due to differences in temperature between the old and new structures, as the new concrete hydrates. The difference in temperature can be minimized by cooling the new concrete casting during hydration and/or by pre-heating the old structure. The more repair concrete is cast, the more extensive the heating due to hydration. The interaction between the old structure and the new casting is also affected by vibrations from traffic during the hardening of the new concrete. The strength of the new casting may reduce, and the bond between the old and the new concrete may weaken, due to vibrations. Hence, it is of importance to minimize vibrations during the hardening of the new concrete, possibly by temporary speed limits. The extent of the transference of the shrinkage and creep strains from the repair concrete to the old structure is determined by the elastic moduli (E) of the two materials, or, rather their relative stiffness [10]:

If the repair material is stiffer than the existing structure, strains can be transferred from the repair concrete to the old concrete. If the relation is the opposite, the two castings display no or negligible structural interaction, which implies that either tensile stress or no stress at all will be present in the repair concrete. The shrinkage of the repair concrete is the most extensive during a few weeks just after the casting. During this time, shrinkage is either transferred or restrained, depending on the modulus of elasticity of the old structure. Since the original structure is, at least initially, stiffer than the repair concrete, the restrained shrinkage of the repair patch will induce tensile forces in the repair concrete. If this tensile stress exceeds the tensile strain of the new concrete, cracking will occur.

Effect of Prestressing

In the case where only the concrete is damaged, and not the prestressing tendons, the stress distribution in the prestressed structural element will be affected by the repair work. For example, if the bottom part of a beam has suffered extensive losses in concrete, but the prestressing cables are still intact, the prestressing applied initially will still be present, whereas the concrete area will be reduced. In a single-span bridge, dead load alone will result in the maximum compressive stress, because of the initial prestressing. This problem can be solved by preloading the structure while it is repaired. The preloading is accomplished by adding tensile forces to make up for the extra compression. Calculations should be carried out, on the reduced cross section, in order to determine whether the stresses are at an acceptable level, before the bridge deck is repaired.

4. Bridge modelling

Models for calculating the effects of repair work on a bridge structure were made, studying an existing bridge structure in Haidarabad, India. The original bridge and the geometrical models used in calculations are presented below.

Description

The reference bridge in Haidarabad, India is a single-span bridge made from prestressed concrete (post-tensioning), built in 2009. The span-length of the bridge is 28.5 meters, and the bridge beam height is 1.35 meters. Haidarabad Bridge drawings and pictures can be found in A [11].

Geometrical Modelling

The original bridge in Haidarabad above has been used to create three simple bridge models, with different span lengths of 20, 28 and 36 meters. All three models are equipped with prestressing tendons and both upper and lower reinforcement. In order to simplify the calculations, the cross section was simplified to a T-beam cross section with perpendicular corners. The thickness of the concrete in the model is the average width of the non-plane members of the original structure. The cross section height and width was somewhat altered for the bridges of span-lengths 20 and 36 meters, whereas the bridge with span-length 28 meters is a simplified copy of the original bridge in Haidarabad. A preliminary dimensioning was made in a simple computer program, namely Tassu, which utilizes the rules and regulations of the Finnish National Standards. The tensioning of the tendons is done in a way which provides all the strands in the same cross section with the same initial prestressing force. The prestressing force is assumed to remain the same in all tendons after the effects from initial losses have been assessed. The initial prestressing force, however, differs between the different bridges. The posttensioning is done from one end of the bridge only. Wedge draw-in for the specific wedges used in Haidarabad has been defined as 10 mm [12].

20-Meter Span-Length

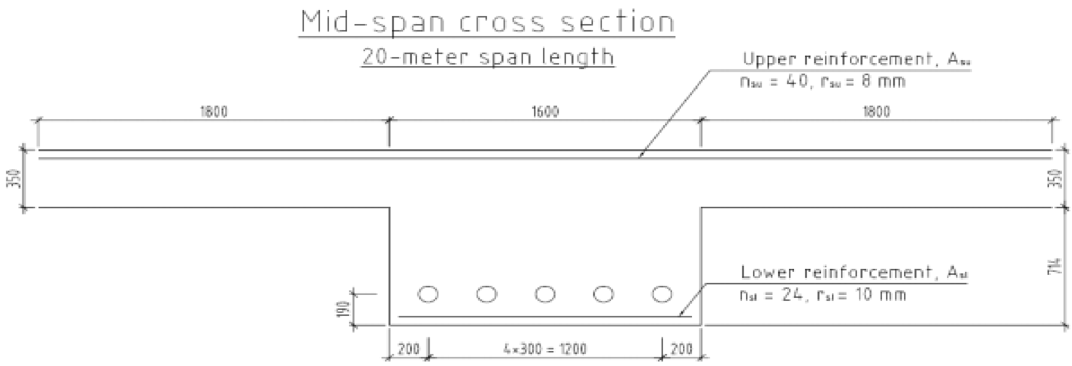

Figure 1: Mid-span cross section of bridge model with span-length 20 meters.

The 20-meter beam T-section has a smaller width than the haidarabad Bridge and the other two cross sections (1.6 meters), a total cross section height of 1.064 meters and 5 ducts for prestressing cables (Figure 1), in two layers near the ends of the beam (Figure 2). Each duct containing prestressing cables has 14 individual cables inside. The curvature of the prestressing is depicted in below [13].

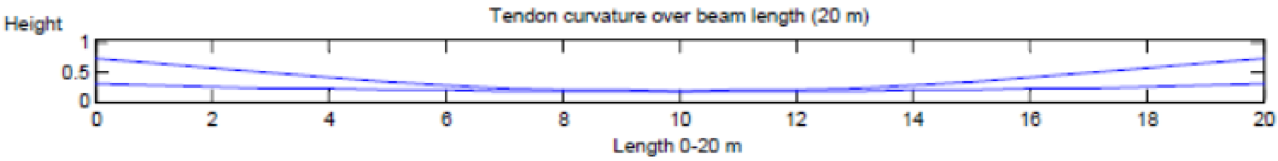

Figure 2: Tendon curvature for bridge model with span-length 20 metrrs.

28-Meter Span-Length

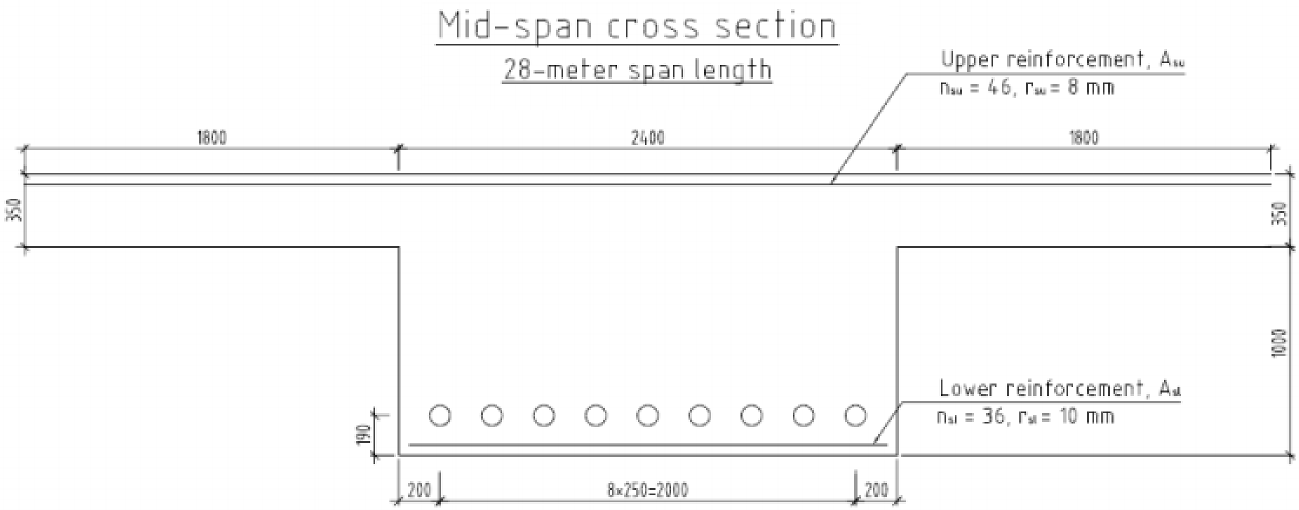

Figure 3: Mid-span cross section of bridge model with span-length 28 meters.

The cross section of the 28-meter bridge model is a simplified version of the cross section of the actual haidarabad Bridge, with a total height of 1.35 meters, a width of 2.4 meters and 9 ducts for prestressing cables (Figure 3), in two layers near the ends of the beam (Figure 4). Each duct containing prestressing cables has 14 individual cables inside. The curvature of the tendons, over the length of the beam, is depicted below [14].

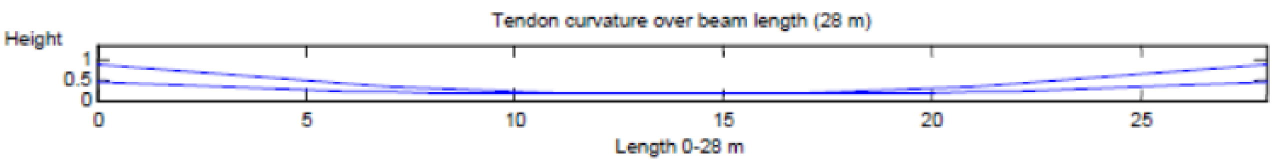

Figure 4: Tendon curvature for bridge model with span-length 28 meters.

5. Conclusions

The most severe effects due to the reparation of a prestressed concrete beam are not obtained permanently in the structure, but rather as an elastic effect at the time of repair. The stresses increase and/or decrease very quickly as concrete is removed and replaced. From a long-term perspective there are no considerable changes in the prestressing losses, neither when the entire upper flanges are removed, nor removed and replaced.

Removal of Concrete

The more concrete is removed, the lower the level of compression at the level of the upper reinforcement. However, no tensile stresses are obtained. The compression at the level of the lower reinforcement increases due to the removal of concrete but it never reaches the limit for non-linear creep. The changes in stress distribution from a long-term perspective are small when very little concrete is removed. The compression at the level of the upper reinforcement reaches a permanently lower level after the removal of concrete. At the level of the lower reinforcement the compression is permanently elevated after the removal of concrete. The effect on the loss in prestressing is negligible. Thus, the entire upper flange can be removed from the cross section as long as the tensile stresses are monitored and kept below the tensile strength of the concrete.

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