IMPACT OF BRIDGE JACKING PROCEDURES ON PRECAST BEAMS DURING BEARING REPLACEMENT

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ABSTRACT

This paper presents a study of anchorage zone stresses in AASHTO type beams during bridge jacking operations commonly conducted to facilitate the replacement of elastomeric bridge bearings. The bridge jacking procedures considered involve the placement of jacks at various locations on the precast beams near the bearing seats. The goal of this study was to determine the impact of these different lifting techniques on the tensile stresses at the beam ends which have the potential to cause concrete cracking. A 3D nonlinear finite element analysis of beam end stresses was conducted to study the combined state of stress in the beam elements during the different bridge jacking procedures for in-service bridges. The results indicate that the different lifting configurations considered produce different stress patterns in the prestress anchorage zone which can result in tensile principle stresses which exceed the concrete tensile strength. The initiation of cracking in the beam anchorage zone reduces long-term durability and increases long-term maintenance demands. The results of this study can be used to inform bridge owners, contractors, and engineers regarding the appropriate lifting procedures for precast beam bearing replacement.

Keywords: Bearing Replacement, Bridge Jacking, Finite Element Analysis

INTRODUCTION

The periodic repair and maintenance of bridges is an essential step in extending the service life of existing bridges and maintaining existing investments in public infrastructure. One of the more common maintenance items for existing bridges is the replacement of elastomeric bearing pads which are the predominant type of bearing support used in prestressed concrete bridges. Bearing pads require replacement for a number of reasons including walk-out and general deterioration as shown in Figure 1 and Figure 2, respectively. A bearing replacement project requires lifting of the entire end span of a bridge superstructure to remove and replace the existing bearing pads. Many lifting techniques exist to achieve the required clearance for bearing pad replacement. Responsible agencies often have standard drawings for bridge lifting operations; however, contractors often have a strong preference based upon their previous experience and access conditions. This paper presents a study of three bridge lifting techniques observed in the Texas market in recent years to determine the impact of these lifting techniques on prestressed AASHTO type I-beams. A 3D nonlinear finite element analysis was conducted for each lifting technique to determine the likelihood of cracking in the beam ends (within the anchorage zone) due to the lifting operations.


Fig. 1 Elastomeric Bearing Walk-Out

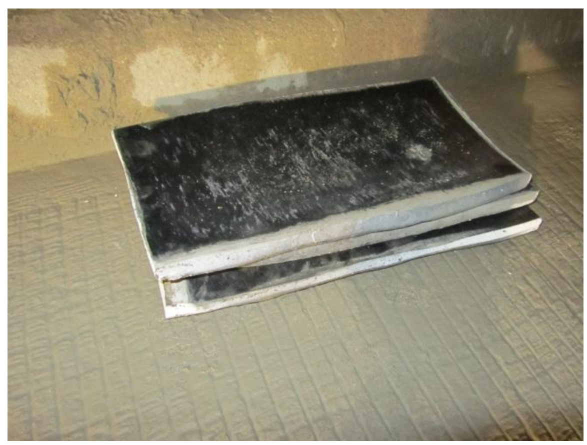


Fig. 2 Deteriorated Elastomeric Bearing Pads

BRIDGE LIFTING TECHNIQUES

Many combinations of lifting and support systems exist for the replacement of elastomeric bearing pads. These methods typically provide a base to support the reaction of the hydraulic jacks and a firm attachment to the bridge superstructure. The lifting reaction is most commonly supported either on-grade through the use of cribbing and support frames, or directly by the bridge bent or abutment. The most common support points for lifting a bridge superstructure are the I-beam top flange and the I-beam bottom flange.

Bottom Flange Lifting

Lifting from the bottom of the I-beam flange is considered desirable because it closely emulates the in-service support conditions for which the beams were originally designed. The main detraction for lifting from the bottom of the beam flange is the degree of effort required to achieve an adequate reactionary surface. At interior bents or on bridges with vertical abutment walls where an adequate jacking area is not available, lifting is typically performed with cribbing and support frames built below the superstructure as close as reasonably possible to the bent or abutment face as shown in Figure 3 and Figure 4.

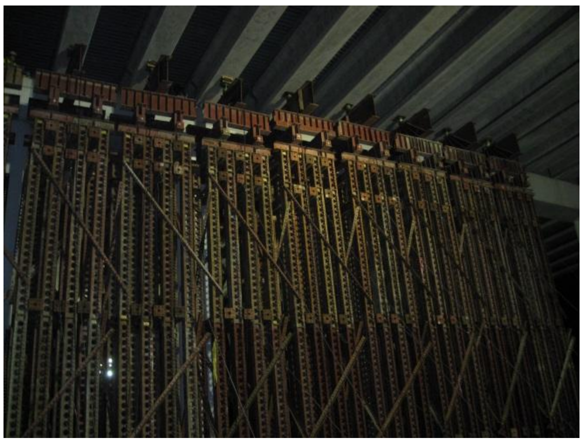


Fig. 3 Steel Frames Erected for Lifting


Fig. 4 Lifting from Bottom Flange

When lifting is to be done at a location where the ground below the span is not level such as at a sloped end wall abutment, the support conditions become more difficult. This difficulty can be overcome by designing a frame structure which is capable of lifting the bottom of the beams by distributing the load along the sloped end wall and abutment as shown in Figure 5 and Figure 6.

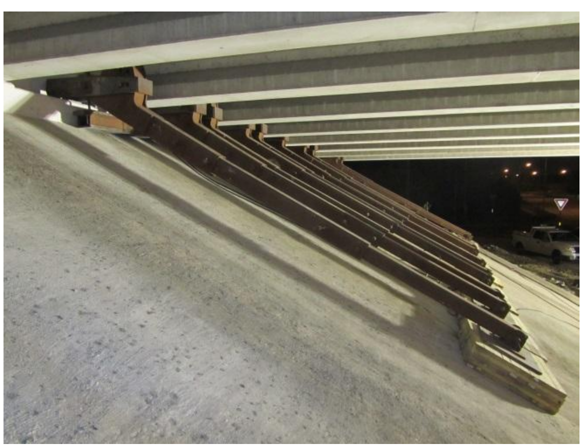


Fig. 5 Inclined Steel Frame for Lifting


Fig. 6 Lifting from Bottom Flange

Lifting with Timber

Lifting the bridge superstructure from the top beam flange requires some ingenuity to develop a stable support condition on the sloped flange. Perhaps the most common method for lifting the superstructure from the top flange is to use heavy timbers which are wedged in-between each beam line as shown in Figure 7 and Figure 8. The hydraulic jacks are then positioned below the timber span with the lifting load distributed between the two adjacent beam lines. This method requires large timbers which must be cut the exact beam spacing for the bridge being lifted.

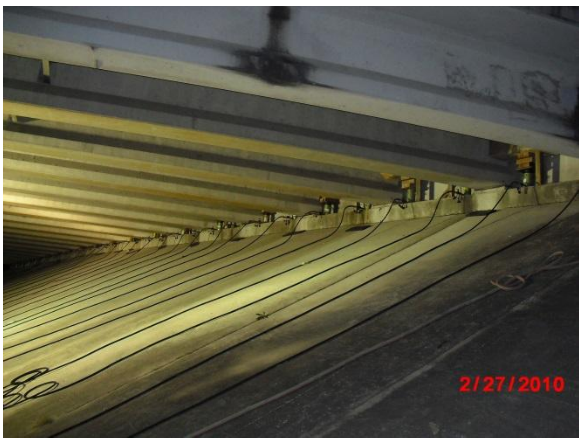


Fig. 7 Lifting from Beam Top Flange

Fig. 8 Lifting with Timbers

Lifting with Brackets

A second option available for bridge lifting from the top flange is the use of fitted brackets which are attached to the I-beam through the use of through bolts. This arrangement shown in Figure 9 requires a series of holes be drilled through the web of each beam. The principle of this arrangement is that the bolts through the web of the I-beam will be tensioned to provide a compressive force attaching the brackets firmly to the sides of the beam to prevent slippage of the brackets during lifting. The holes are typically specified to be oversized and the bolts are not intended to act in bearing during the lifting procedure. A benefit of this method is that the brackets will work for bridges with any beam spacing allowing for greater flexibility.

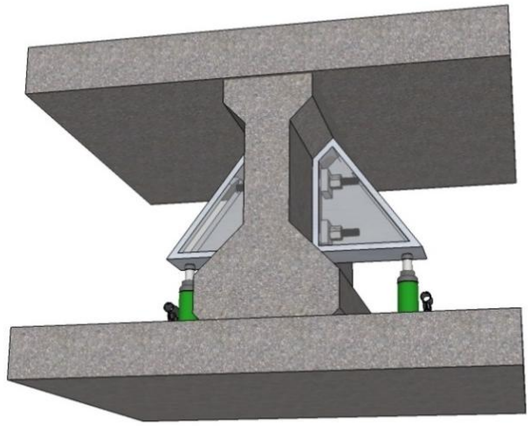


Fig. 9 Lifting with Steel Brackets

An additional concern that arises with the bracket lifting method is the necessity of drilling holes through the web of each beam in the span. These holes generally occur within the last foot of the beam so that the brackets will be positioned over the bent or abutment. Therefore, these holes are placed within the anchorage zone where the prestressing strands are often harped up into the web and where shear stresses are highest. As a result it is very likely that these holes will damage either shear reinforcement or prestressing strands. Following the bearing pad replacement it is also necessary to patch these holes to prevent moisture infiltration and externally supplement reinforcement damaged during coring the holes. Even with the use of non-shrink grouts, the potential for separation or cracking of the grout patches exists and this can create a path for moisture infiltration at the beam ends. From a durability standpoint, this bracket location corresponds to the most critical section of the beam near deck expansion joints which are likely to leak overtime and expose the beams to surface water.

DURABILITY ISSUES

The anchorage zones of prestressed beams are the most susceptible portion of the beam when it comes to long-term durability issues. Several key factors contribute to this including the placement of the anchorage zones near deck expansion joints, the high level of reinforcement to manage shear and bursting stresses, and the anchorage stresses induced by the prestressing strands. Even with a portion of the strands debonded, anchorage zone cracking can occur in prestressed beam ends and often takes one or more of the forms shown in Figure 10 and Figure 11. This cracking can be a result of low release strengths, improper detensioning sequence, improper detensioning techniques, or other design or construction issues[1]. Although additional reinforcement is provided in this region for crack control, beam end cracking still occurs and must be managed as a durability issue over time.

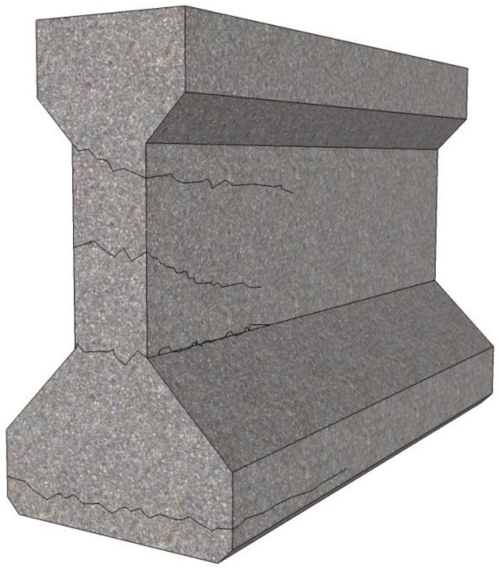


Fig 10. Typical Anchorage Zone Cracking

Fig. 11 Typical Anchorage Zone Cracking

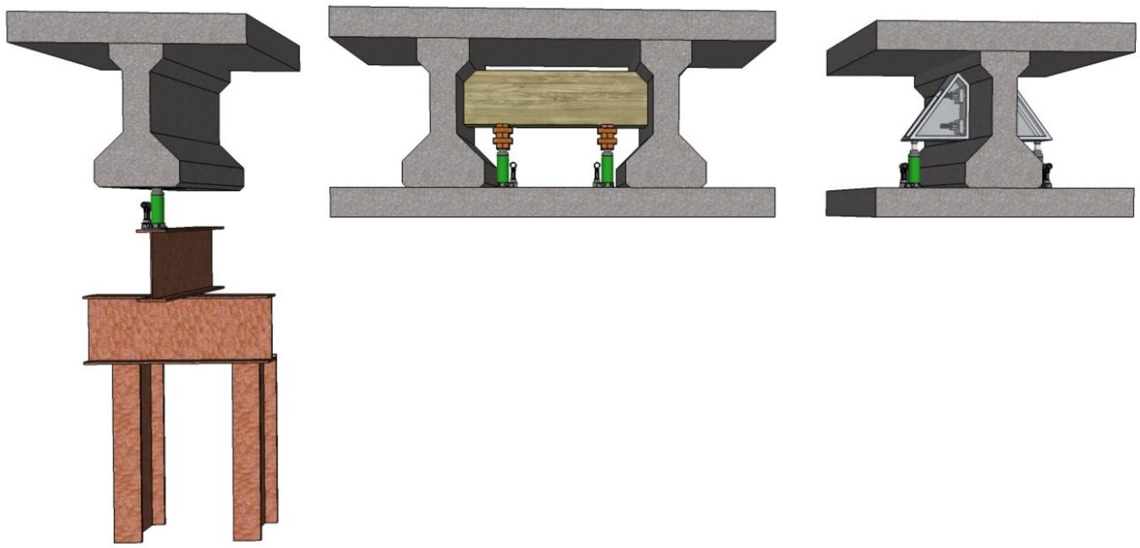
Bridge lifting operations have the potential to cause additional cracking within this region or to cause the spread or widening of pre-existing cracks depending on the techniques used in the lifting operations. Once these cracks develop in the presence of moisture, concrete deterioration mechanisms can be accelerated.

FINITE ELEMENT ANALYSIS

A nonlinear 3D finite element analysis was undertaken to assess the impact that the different lifting procedures have on the total state of stress at the end of a typical AASHTO type I-beam. This analysis considered the full state of stress including the impacts of the bridge self-weight, prestressing force, and the bridge lifting operations. This analysis was conducted using ANSYS Mechanical Version 13.0 utilizing both the Workbench and APDL user interface modules[2].

Lifting Techniques Modeled

Three different common lifting conditions were analyzed as discussed in the preceding sections. These lifting load cases included: (a) lifting from the bottom flange, (b) lifting from the top flange (timber method), and (c) lifting from the top flange (bracket method). These three methods are show schematically in Figure 12. The lifting techniques analyzed for lifting from the top flange are similar in nature with the main difference being the addition of the holes required for the bracket method.



(a) (b) (c)

Fig. 12 Schematic of Lifting Conditions Modeled

Modeling Parameters

The models were based upon a typical Texas Type-C Prestressed I-Beam configuration with a simply supported span of 75 feet and 36 prestressing strands. An effective prestressing force of 27 kips was applied for each prestressing strand. The prestressing forces were distributed throughout the beam section with the majority of the prestressing force applied to the bottom flange to produce an eccentric prestressing force with some prestressing carried up into the web of the beams for a harped-strand configuration. The beam self-weight, tributary deck weight, and a portion of the parapet weight were also applied to the model. Live loads were not considered as bridges are typically closed during bearing replacement operations. Based on the configuration of the lifting technique being considered, applicable support conditions were applied to either the top or bottom flange of the beam. In the case of the top flange lift, a bearing plate parallel to the top flange with a length of 8 inches placed at the end of the span was used for the support conditions on each side of the flange. In the case of the bottom flange lift, a bearing plate 18 inches square was assumed to be centered 2 feet from the end of the span.

Modeling of Concrete Behavior

Modeling the behavior of reinforced concrete is complicated by its fundamentally nonlinear behavior caused by the interaction of steel reinforcement after concrete cracking. The Solid65 nonlinear element within ANSYS was employed for this analysis to consider the behavior of the beams after initial cracking[2]. This element allows for the specification of cracking and crushing strengths for the concrete material which were selected based upon 6,000 psi concrete for this beam span configuration. This element also allows for the specification of reinforcement in up-to three orthogonal directions which is engaged only after cracking is initiated. This reinforcement is evenly smeared throughout each element and therefore does not occur in discrete bars within the element. A reinforcement ratio of 2% of the cross sectional area was applied to both the longitudinal and transverse directions at the beam ends.

As the nonlinear model is analyzed, the program determines the cracking and crushing status of each element in the finite element mesh, updates the element stiffness, and iterates to an equilibrium solution. During post-processing, element cracking is displayed by circles oriented in the direction of cracking. In the event that cracking occurs in more than one direction, the first crack in the element is shown in red, the second in green and the third in blue as shown in Figure 13 (no third axis/blue cracking shown). These elements similarly represent crushing in up to three directions through the use of tricolored octagonal symbols. Based on the configuration of the models produced in this study, no crushing was induced in any of the models.

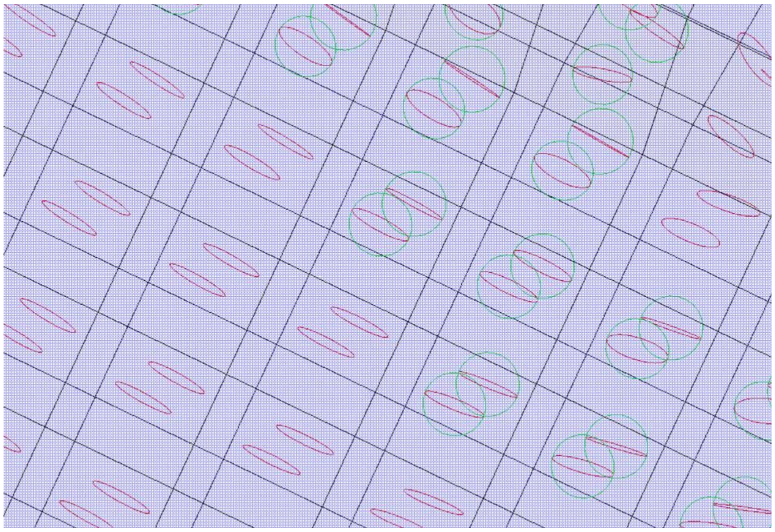


Fig. 13 Sample ANSYS Solid65 Element Cracking Results

ANALYSIS RESULTS

The results of the analysis showed a region of cracking at the end of the beams in all three beam lifting models primarily associated with the prestressing forces applied at the beam ends. This cracking is shown to occur within the entire depth of the beam section but is most pronounced near the bottom flange where the eccentric prestressing is applied. These results conform well to the industry knowledge of prestressing stress distributions in AASHTO beams[3]. The degree of cracking did vary based on the lifting technique employed as shown below.

Timber and Bracket Lifting

The results of the analysis of the timber lifting technique at the top flange are shown in Figure 14 and Figure 15 and the results of the bracket lifting technique at the top flange are shown in Figure 16 and Figure 17. Review of the results shows general agreement between the two modeling load cases. The principle stress contour plots shown in Figure 15 and Figure 17 are in units of psi with a sign convention of negative for compression and positive for tension. Lifting the superstructure from the underside of the top flange causes a region of tensile stresses within the top flange and web at the end of the beam. The magnitude of the final tensile stresses in the concrete are reduced by the nonlinear nature of the model which allows for reduction of element stiffness after cracking occurs. The bracket technique adds a series of holes in the beam web; however, these holes occur in a region already cracked in the similar timber lifting technique, therefore the overall impact of the holes on the state of stress during lifting appears to be minimal. Note that no bolt bearing was assumed in this analysis.

Bottom Flange Lifting

The results of the bottom flange lifting techinque are more favorable as shown in Figure 18 and Figure 19. Cracking in the top flange is reduced although the potential for a larger area of cracking in the bottom flange is indicated. This lifting technique closely resembles the design support conditions and in-service state of stress for the beam.

Review of the principle stress contour plots for each of the three lifting techniques mirrors the results discussed for the cracking plots. Lifting from the top flange induces tensile forces at the junction of the web and the top flange while lifting from the bottom of the I-beam section does not induce tension in this region.

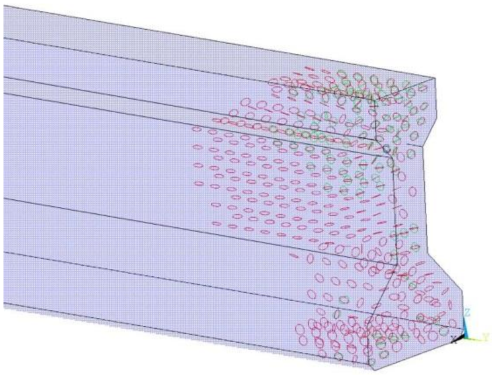


Fig. 14 Cracking Plot for Timber Lift

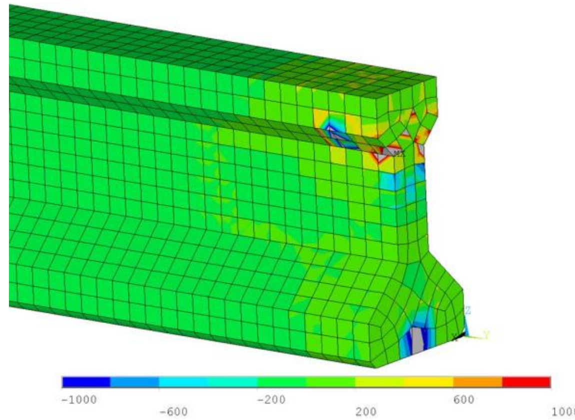


Fig. 15 Principle Stress Contour Plot for Timber Lift (psi)

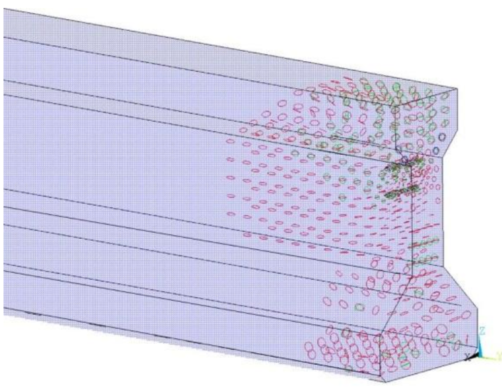


Fig 16. Cracking Plot for Bracket Lift

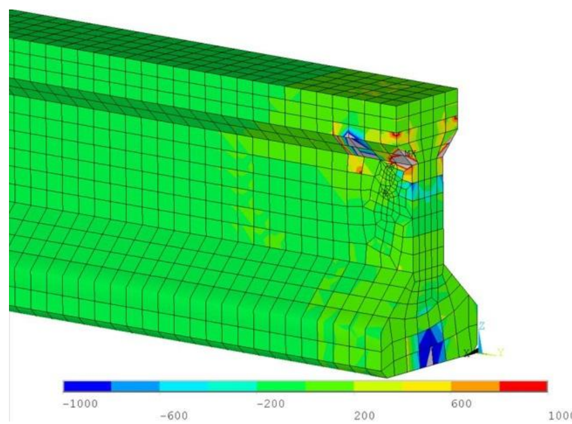


Fig 17. Principle Stress Contour Plot for Bracket Lift (psi)

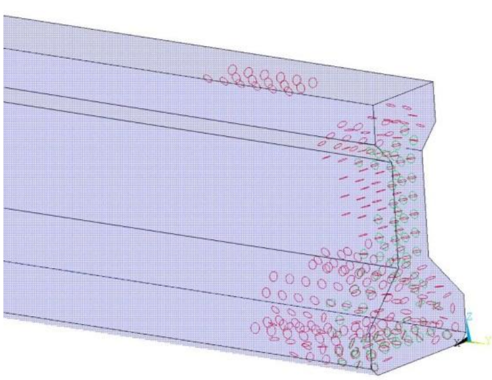


Fig.18 Cracking Plot for Bottom Flange Lift

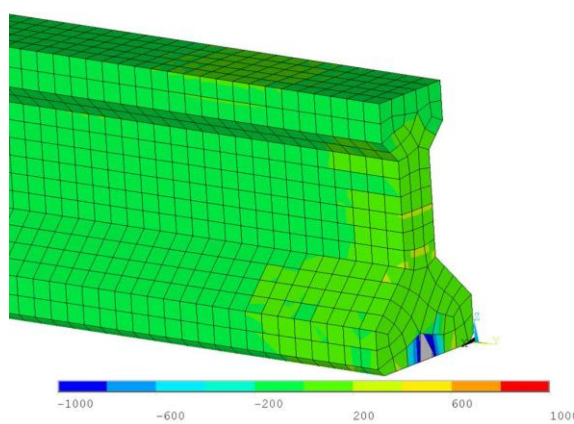


Fig. 19 Principle Stress Contour Plot for Bottom Flange Lift (psi)

CONCLUSIONS

This paper provides an overview of typical methods used for the lifting of bridge superstructures to replace elastomeric bearing pads as well as the potential locations for cracking induced by each method. This paper also provides a means by which to compare the impact of different lifting techniques to weigh the pros and cons of each method. The modeling predicts cracking in the anchorage zone under the combined state of stress produced by the prestressing forces and the support conditions. The analysis shows that lifting from the bottom flange of the section produces the least potential for additional cracking during lifting operations while both methods reviewed for lifting from the top flange produce similar levels of cracking potential. Lifting from the beam bottom flange is recommended whenever site conditions allow to minimize the potential for lift induced cracking. Minimization of cracking in the anchorage zones of prestressed beams is important for long-term durability. The presence of cracking allows avenues for moisture infiltration into the beam section promoting the corrosion of prestress and mild steel reinforcement when exposed to environmental factors. Responsible agencies, consulting engineers, and contractors should consider the implication that lifting operations may have on the long-term durability of I-beam sections.

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