POTENTIAL IMPACT OF 0.7-INCH STRANDS ON PRECAST/ PRESTRESSED CONCRETE BRIDGE I-GIRDERS: SPACING OF LARGE DIAMETER STRANDS

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ABSTRACT

The main purpose of this analytical study was to verify that the 2 inch minimum spacing of ACI 318-05 and AASHTO (2004) can be used for 0.7 inch diameter strands by comparing various effects in girders using 0.7 and 0.6 inch diameter strands. Based on the parametric analysis it was concluded that by using 0.7 inch strands there was a considerable saving in the material ,for example a AASHTO BT-72 with 0.6 inch strand could be replaced with AASHTO BT-54 with 0.7 inch strand for the same span capacity. In order to fully realize the benefits and to verify the adequacy of 2 inch spacing a finite element analysis was carried out with two full-scale three dimensional AASHTO Type I girders with 0.6 inch and 0.7 inch diameter strands. Only the effects due to the prestressing force at transfer were studied in the two models. The maximum principal stress and the axial stress in the concrete along the direction of the strands were determined. Based on the analytical results from the FE model it was found that the girder with the 0.7 inch diameter strand was more vulnerable to cracking at the transition zone between the bottom flange and the web. This defect could be overcome by placing the required amount of confinement reinforcement at the end zone of the girder.

Keywords: Prestressed Concrete, Girders, FE Analysis.

INTRODUCTION

Pretensioned, prestressed members such as I-girders are widely used in the construction of bridges. The strand diameters in these members are predominantly 0.5 and 0.6 inches. In sections like I-girders, the area in the bottom flange to accommodate the strands is limited. Using the 0.7 inch diameter strands can decrease the required number of strands in a given section for an equivalent span capacity. Alternatively, an equal number of the larger 0.7 inch diameter strands can be used to accommodate longer spans for a given section. Further, an increased roadway clearance can possibly be achieved by using shallower members.

To investigate the maximum usable concrete strength in the application of bridge I-girders, Ma (2000)[1] performed an analytical study. In his study, the following assumptions were made:

- Design was based on a typical interior girder that was simply supported.
- Cross sectional shapes studied included AASHTO-PCI BTs and NUs.
- Girder spacings were 8 ft and 16 ft.
- Deck thickness was 7.5 in. for 8 ft girder spacing and 10 in. for 16 ft girder spacing.
- Concrete deck was cast-in-place and acted compositely with the girder.
- Concrete compressive strength of the deck was constant and equal to 4000 psi at 28 days.
- Live load consisted of HS-25 loading. Superimposed composite dead load was 40 psf.
- Prestress losses were constant and equal to 10% of initial prestress at release and 25% at service.
- The following prestressing strand diameters were used: 0.6-in. diameter Grade 270 ksi at 2-in. spacing and **0.7-in. diameter Grade 270 ksi at 2-in. spacing at midspan**.

Take the example of a simple span with NU1100 I-girders and a girder spacing of 8 ft. The concrete strength of the cast-in-place deck is $f'_{c,\ deck}$ = 4000 psi with a 7.5 in depth. Table 1 shows the impact of the 0.7-inch strand and girder concrete strength on the maximum span capacity of bridge I-girders. The maximum usable concrete strength level was in the range of 9000 to 12000 psi, 13000 to 16000 psi, 17000 to 20000 psi and 24000 to 29000 psi for 0.5 inch strand pattern, 0.6 inch strand pattern, 0.6 inch strand with bundling pattern and 0.7 inch strand with bundling pattern respectively. When 0.7-inch strands at 2-inch spacing are used, the span capacity can be increased by **178%**. For the NU section shape, the bottom flange can accommodate a total of 54 strands, comparing with 36 strands in the bottom flange of AASHTO-PCI BT shapes. When 0.7-inch strands are used, however, the disadvantage of accommodating less number of strands in BT shapes can be avoided thus longer spans can be produced since the maximum shipping length of I-girders has an upper limit.

Strands (No. – Type)	Girder Concrete Strength (ksi)	Maximum Span Capacity (ft)	Span/Depth
26 – 0.6” strands	6	85	20
36 – 0.6” strands	8	100	24
54 – 0.7” strands	16	150	36

Table 1 Impact of 0.7” strands and girder concrete strength

In order to fully realize the benefits shown in Table 1, it is important to study the feasibility of placing large 0.7 inch strands at 2 inch center-center spacing and to develop the quality control and design criteria, which is the objective of this research.

To achieve this objective, a FE analysis will be performed evaluating the potential impacts of 2 inch spacing for 0.7 inch strands and comparing it with 0.6 inch strands placed at 2 inch spacing and possibly other reinforcement details at the girder end regions. In the second phase of the project two AASHTO Type I girders with 0.7 inch strands with the selected spacing will be produced to evaluate the transfer and development lengths of the two AASHTO Type I girders.

PARAMETRIC STUDY

An example composite bridge with a single span was designed for this study using AASHTO Bulb Tee (BT- 54) beams topped with concrete deck. The following assumptions were made for this study: (1) The superstructure consists of six beams spaced at 8 feet centers. (2) The bridge was designed with an 8 inch cast-in-place concrete deck to resist all the superimposed dead loads, live loads, and impact. (3) A ½ inch wearing surface was considered as a part of the 8 inch deck. (4) An additional 2 inches of wearing surface was considered to be the future wearing surface. The design was accomplished in accordance with the AASHTO LRFD bridge design specification.

The concrete strength for the prestressed concrete girder was 8000 psi at transfer and 12000 psi at service. The concrete strength for the precast concrete deck was 4000 psi at service. The live load considered was HL-93 which consists of a load combination of design truck or design tandem with a dynamic allowance and a design lane load of 0.64 kip/ft without a dynamic allowance.

In this example the design was done for three different strand diameters (0.5 inch, 0.6 inch and 0.7 inch) with 2 inch spacing. The span capacity of the AASHTO Bulb Tee (BT- 54) girder, with the maximum 40 strands which could be accommodated in the bottom flange, increased 16.7 percent as the diameter of the strands was increased from 0.6 to 0.7 inches shown in the Table 2.

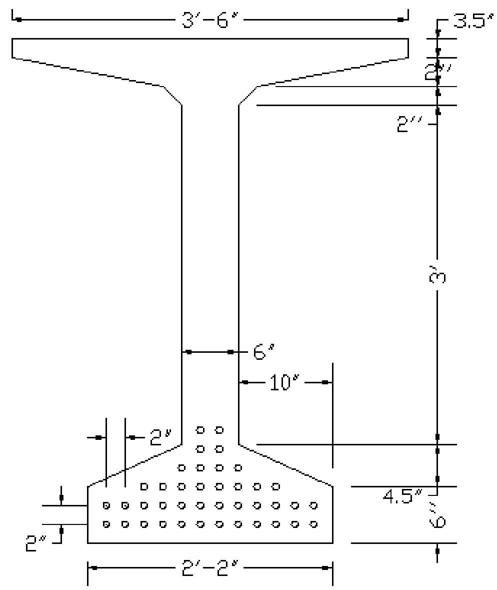

Fig. 1 AASHTO Bulb Tee 54 with 40 # of 0.7-inch strands at 2" spacing

Strands (No. – Type)	**Maximum Span Capacity (ft)**	**Girder Depth (in)**	**Span / Depth**	**Percent Increase in Span**
40 # - 0.5" Diameter	100	54	22.2	-
40 # - 0.6" Diameter	120	54	26.7	16.7
40 # - 0.7" Diameter	140	54	31.1	16.7
40 # - 0.6" Diameter	140	72	23.3	-

Table 2 Increase in the span capacity with the stand diameter

When an AASHTO Bulb Tee 72 with 0.6 inch strands was compared with an AASHTO Bulb Tee 54 with 0.7 inch strands it was found that both sections had essentially the same span capacity. These comparisons showed a considerable reduction in the section size when 0.7 inch strands are used, as shown in Figure 2.

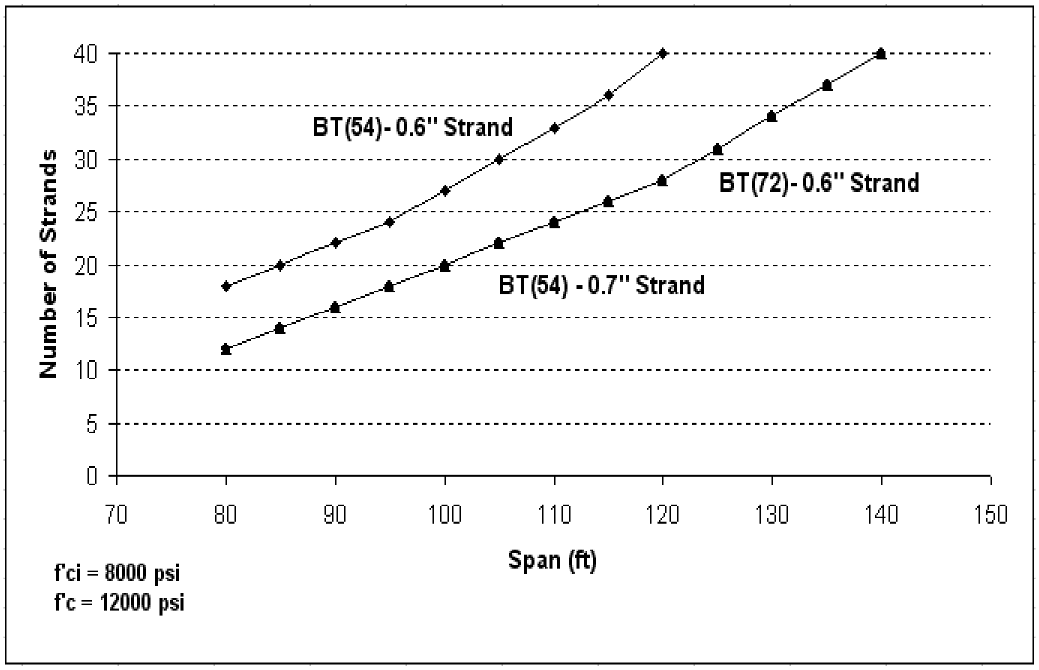

Fig. 2 Design chart showing the different span capacity for varying diameter of strand and section.

FINITE ELEMENT ANALYSIS

A finite element analysis was carried out in ABAQUS CAE to evaluate the effects of 0.7 inch strands at 2 inch spacing and compared it with 0.6 inch strands with the same 2 inch of spacing. The maximum principal stress in the concrete along the transfer length of the girder and the axial stress at selected sections of the girder end zone were obtained for the applied prestressing force only.

A 3D model of the AASHTO Type I beam was considered for the analysis, two girders were modeled, one with 0.7 inch and another with 0.6 inch strands. The prestressing force was the only force which was considered for the analysis, and was introduced by applying an initial compressive stress to the tendon elements.

MATERIAL PROPERTIES

A linear material model was assumed for both the tendon and the concrete. The Poisson's ratio of the tendon was 0.27 and the modulus of elasticity was 28500 ksi. The Poisson's ratio of the concrete was 0.18. At release the concrete strength was 8000 psi and the modulus of elasticity was calculated using the equation,

$$E_c = 33{,}000\, w_c^{1.5}\sqrt{f'_c}$$

Where w_c = unit weight of concrete (kcf)

LOADING

Prestressing force was applied as a stress using the technique called the "Initial Condition". Initial conditions are specified for particular nodes or elements, as appropriate. The initial conditions can be set in the keywords editor or in some cases using a subroutine. In this analysis the stresses are applied using the keywords editor. An effective stress of 182 ksi was applied as the initial stress to the truss elements (tendon).The effective stress was obtained after considering the initial loss due to the elastic shortening of the beam. The time dependent losses such as creep and shrinkage were not considered since the stress at transfer of the prestressing force was only considered. This initial stress was applied to the elements of the tendon within the transfer length of the girder. The value of the effective stress was varied linearly from 0 ksi at the end face of the girder to 182 ksi at the transfer point of the girder.

BOUNDARY CONDITION

The boundary condition was assumed as pinned at one end and rollers at the other end resembling a simply supported beam. The whole model was restrained along the lateral direction of the girder.

CONSTRAIN BETWEEN TENDON AND CONCRETE

The contact between the concrete and the tendons were applied using a technique called the "embedded element technique". The embedded element technique is used to specify an element or a group of elements that lie embedded in a group of host elements whose response will be used to constrain the translational degree of freedom of the embedded nodes (i.e., nodes of the embedded elements). All the host elements can have only translational degrees of freedom, and the number of translational degrees of freedom at a node on the embedded element must be identical to the number of translational degrees of freedom at a node on the host element. ABAQUS searches for the geometric relationship between nodes of the embedded elements (Tendons) and the host elements (Concrete). If a node of an embedded element lies within the host element, the translational degree of freedom at the node is eliminated and the nodes become an embedded node. This model used a set of truss elements (tendon) that were embedded in a set of solid elements (concrete) [ABAQUS/Standard User's manual (Version 6.7-5)].

MESHING

The girder concrete was meshed with 20-noded quadratic brick elements and the tendons were modeled with 3-node quadratic 3D truss elements as shown in Figure 3a and 3b.

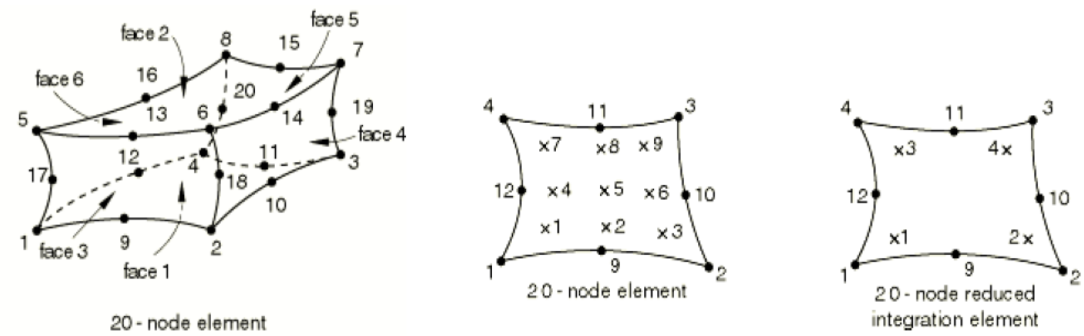

Fig. 3a 20-noded quadratic brick element with the integration points

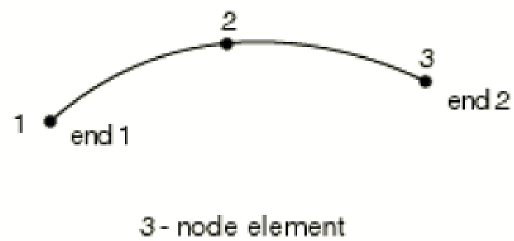

Fig. 3b 3-node quadratic 3D truss elements [ABAQUS/Standard User's manual (Version 6.7-5)]

RESULTS

Two AASHTO Type I girders were designed, one with 0.6 inch diameter strand and the other one with 0.7 inch diameter strand, with the same overall span capacity of 56 feet. The maximum principal and axial stresses in the concrete of the two 3D models are discussed in detail below.

The deflection due to prestressing force at transfer was calculated based on the modulus of elasticity of concrete and the moment of inertia of the non-composite precast beam. A deflection of 2.42" (↑) and 2.32" (↑) was calculated for the girder with the 0.7" diameter strands and 0.6" diameter strands respectively. The maximum deflection values obtained from the FE model were 2.091" (↑) and 2.103" (↑) for the girder with the 0.7" diameter strands and 0.6" diameter strands respectively. The deflection due to the self weight of the beam was 0.515" (↓). Thus the expected camber values are 1.905" (↑) and 1.805" (↑) for the girder with 0.7" diameter strands and 0.6" diameter strands respectively.

As shown in the Table 3, the girder with the 0.7 inch strand diameter reaches a maximum tensile stress of 1.74 ksi. Figure 4a shows the maximum tensile stress occurs in the number 2 strand at a distance of 2 inches from the end face of the girder. A tensile stress of 1.43 ksi is reached at the transition zone between the bottom flange and the web, which results in a high probability of cracking.

The girder with the 0.6 inch diameter strand reaches a maximum tensile stress of 1.54 ksi as shown in Table 3. Figure 4b shows the maximum tensile stress occurs in the number 7 strand at a distance of 2 inches from the end face of the girder. A tensile stress of 0.35 ksi is reached at the transition zone between the bottom flange and the web, which is less than the maximum tensile strength limit of concrete as specified in AASHTO LRFD (5.9.4.1.2), 0.68 ksi ($0.24\sqrt{f'_{ci}}$), which has the less probability of cracking.

The maximum principal stress contours at the end sections of the girder for 0.7 inch and 0.6 inch strands are shown in the Figure 5a and 5b respectively. The same stress contoured along the central vertical plane for 0.7 inch and 0.6 inch strands are shown in Figure 6a and 6b respectively. These figures show the cracking potential in the end zone of the girder.

	Maximum Principal Stress, ksi	
	0.7'' strands	**0.6'' strands**
Maximum Value at a section	1.74^T	1.53^T
Value at the transition zone (Bottom Flange and Web)	1.43^T	$0.35^T < 0.68^T$

T = Tensile Stress

Table 3 Values of maximum principal stress for the two diameters of strands

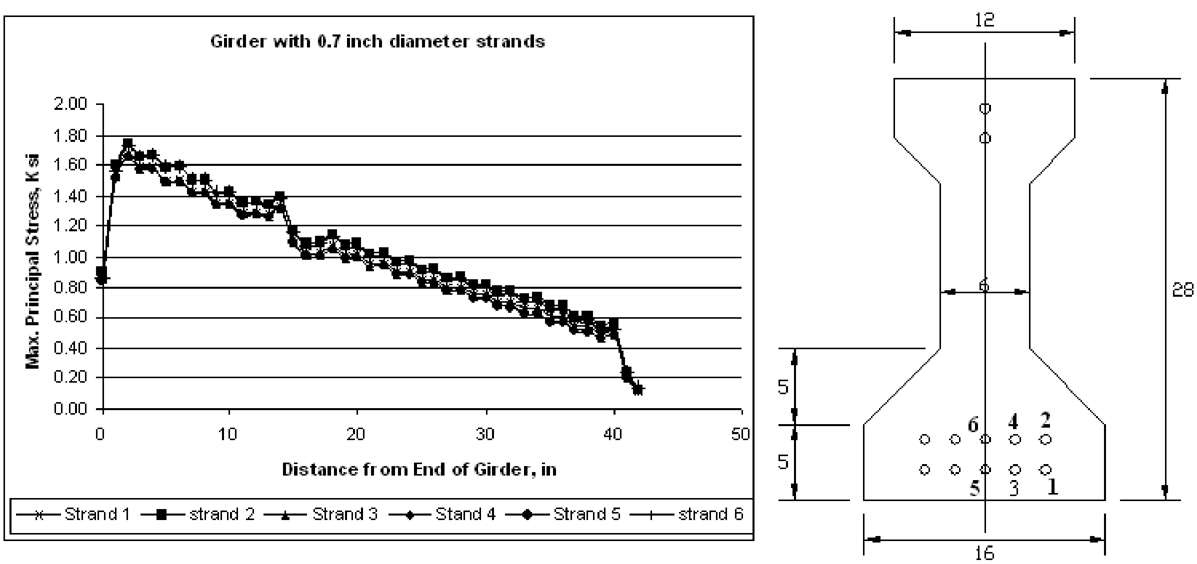

Fig. 4a Variation of maximum principal stress along the length of the girder from the end face at different locations of 0.7 inch diameter strand

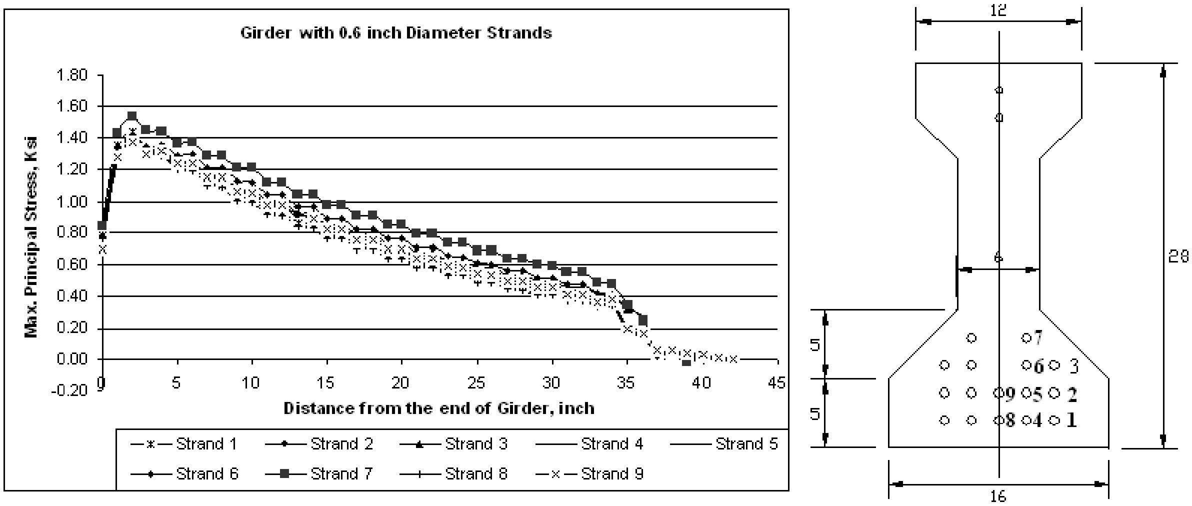

Fig. 4b Variation of maximum principal stress along the length of the girder from the end face at different locations of 0.6 inch diameter strand

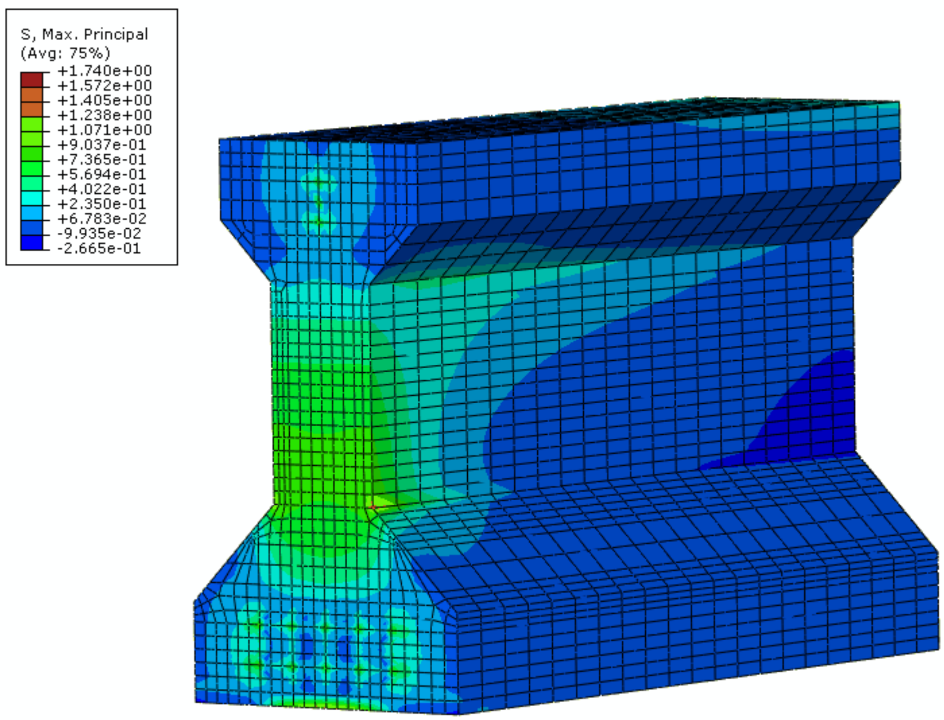

Fig. 5a Stress contour for the maximum principal stress for the end zone of a girder with 0.7 inch diameter strands

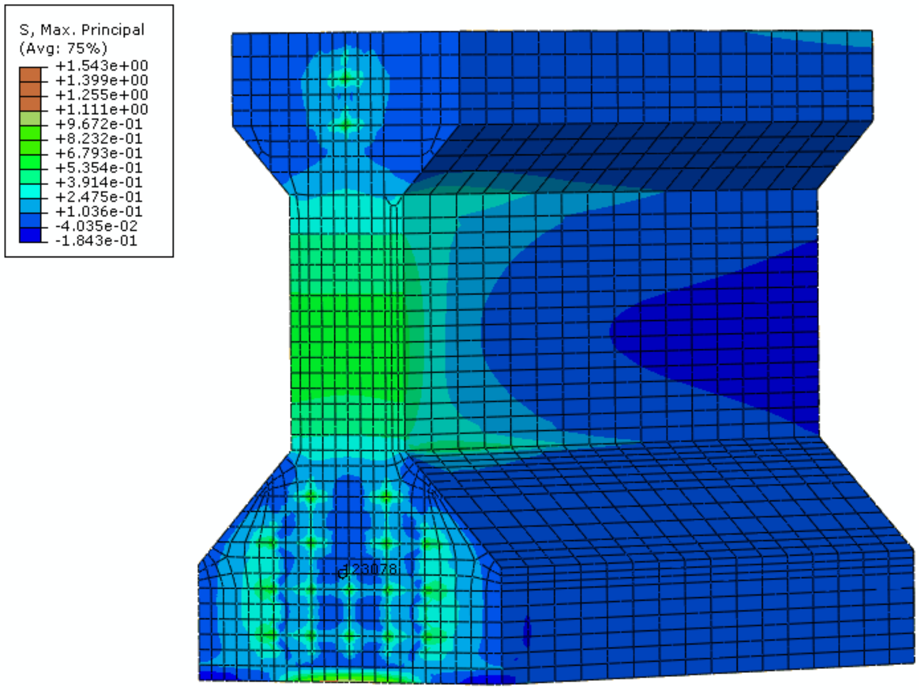

Fig. 5b Stress contour for the maximum principal stress for the end zone of a girder with 0.6 inch diameter strands

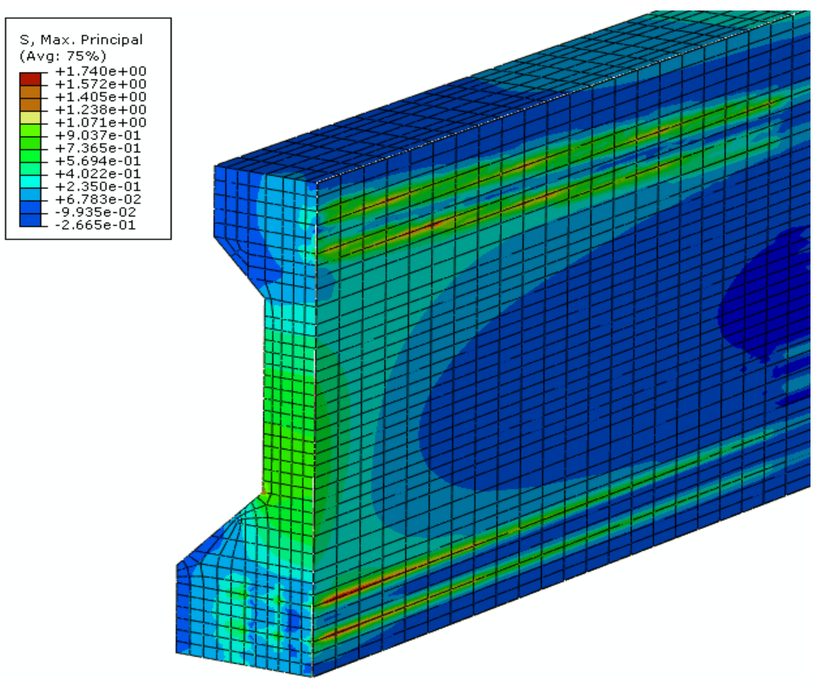

Fig. 6a Maximum principal stress distribution near the end zone of the girder with 0.7 inch diameter strands

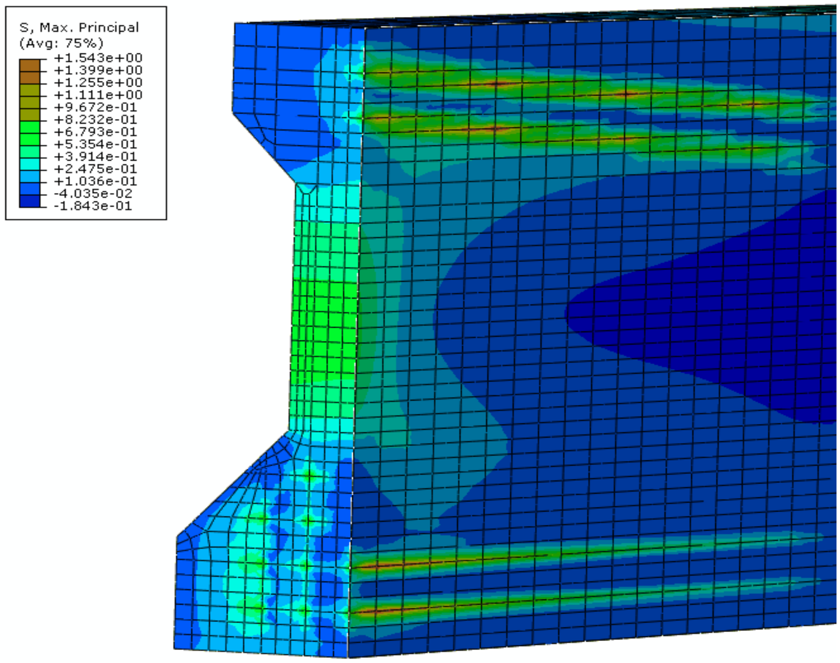

Fig. 6b Maximum principal stress distribution near the end zone of the girder with 0.6- inch diameter strands

The axial stress variation along the depth of the girder at the selected sections shown in Figure 7 for 0.7 and 0.6 inch strands are shown in Figures 8a and 8b respectively. The prestress force is transferred to the concrete and the axial stress variation becomes linear from the end face of the girder to the transfer point, which are 32 inches for 0.6 inch strands and 42 inches for 0.7 inch strands. The transfer point is calculated based on the equation in AASHTO LRFD-2004.

As shown in the Table 4, an axial stress of 1.09 ksi (Tension) is reached in the girder with 0.7 inch diameter strands were a stress of 0.43 Ksi (Tension) is reached in the girder with 0.6 inch diameter strands. Thus the girder with 0.7 inch strand exceeds the maximum concrete tensile strength of 0.68 ksi.

At the transfer length, the girder with 0.7 inch diameter strands reached a compressive stress of 3.90 ksi at the bottom fiber and a tensile stress of 0.24 ksi at the top fiber which is below the maximum tensile strength limit of concrete. The girder with 0.6 inch diameter strand reached a compressive stress of 3.60 ksi at the bottom fiber and a tensile stress of 0.17 ksi at the top fiber which is also within the maximum tensile strength limit of concrete.

The axial stress contoured along the central vertical plane for 0.7 inch and 0.6 inch strands are shown in Figure 9a and 9b respectively. It can be seen how the effective stress is reached from the end face to the transfer point of the girder.

Distance from the End Face of Girder, inch	**Maximum Axial Stress, Ksi**	
	0.7'' strands (Top Fiber /Bottom fiber)	**0.6'' strands** (Top Fiber /Bottom fiber)
X= 0	$0.07^{T}/\mathbf{1.09}^{T}$	$0.027^{T}/0.43^{T}$
Transfer Length (X=42'' for 0.7'' strands) (X=32'' for 0.6'' strands)	$0.24^{T}/3.40^{C}$	$0.17^{T}/3.61^{C}$

T = Tensile Stress
C= Compressive Stress

Table 4 Values maximum axial stress for the two diameters of strands at different sections of the girder at the end zone

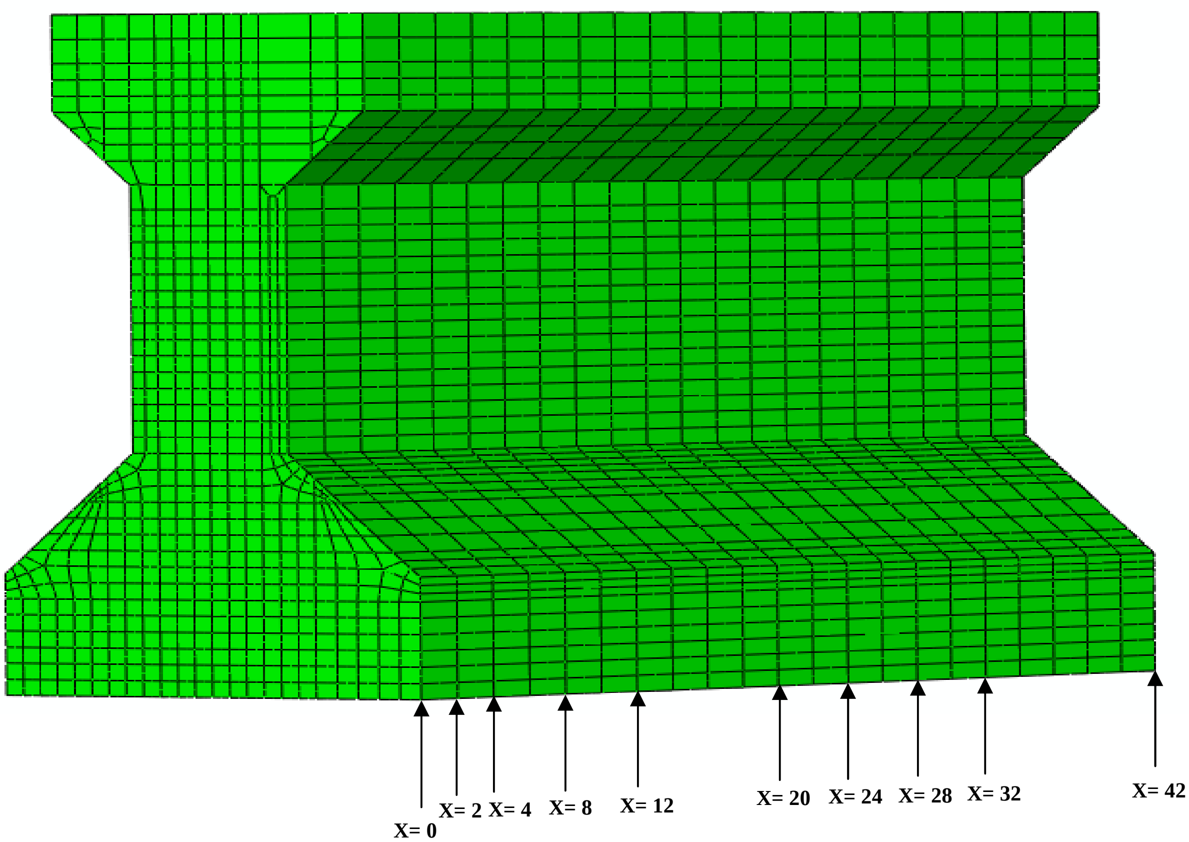

Fig. 7 Finite element model of a prestressed concrete I-girder

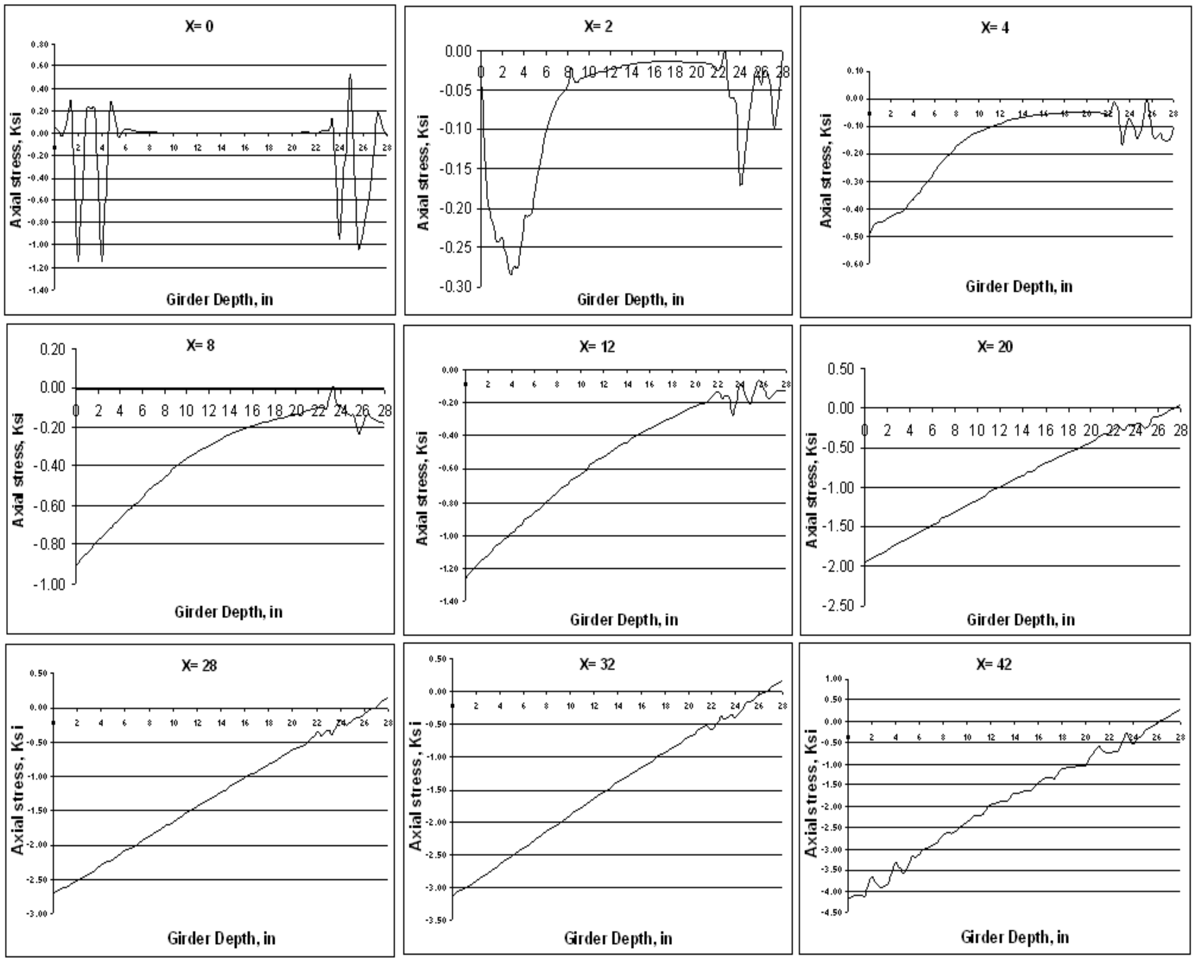

Fig. 8a Axial stress distribution at different sections near the end of the girder with 0.7 inch diameter strands

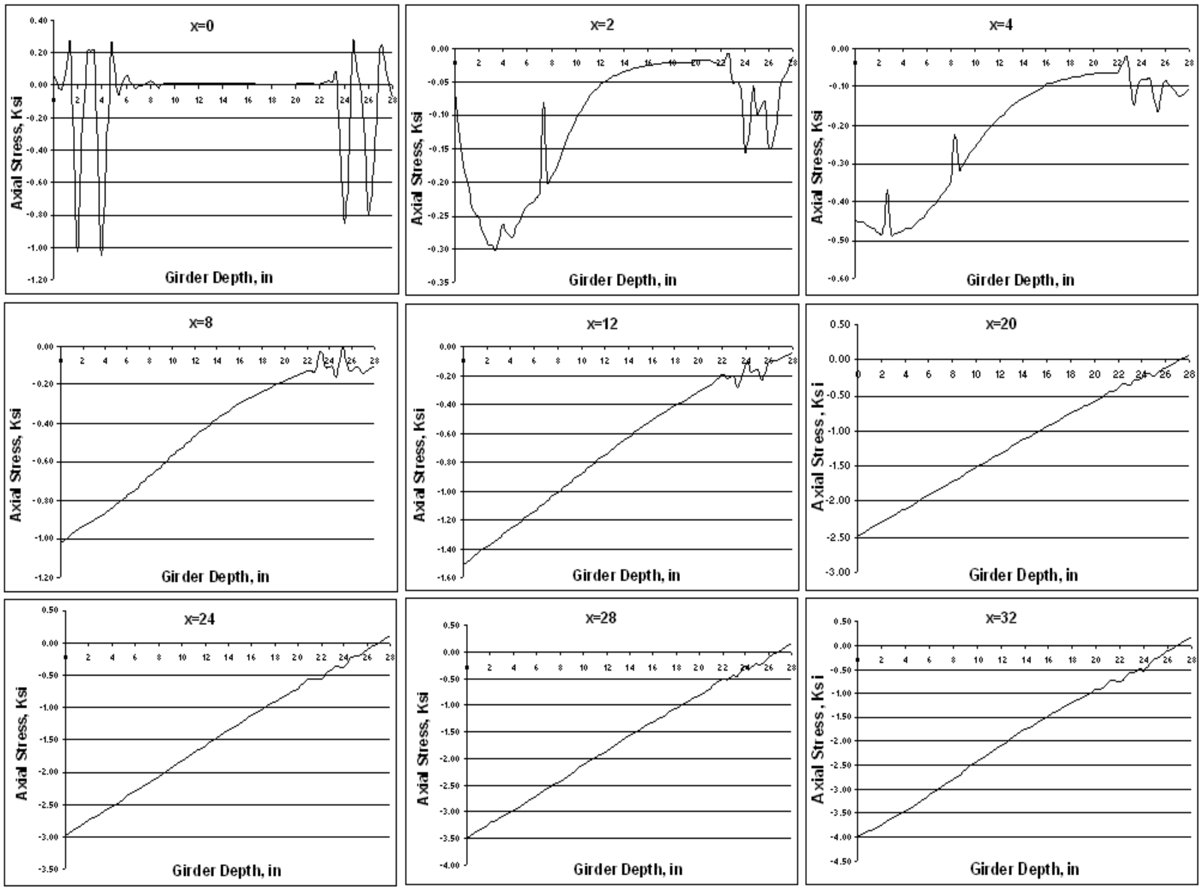

Fig. 8b Axial stress distribution at different sections near the end of the girder with 0.6 inch diameter strands

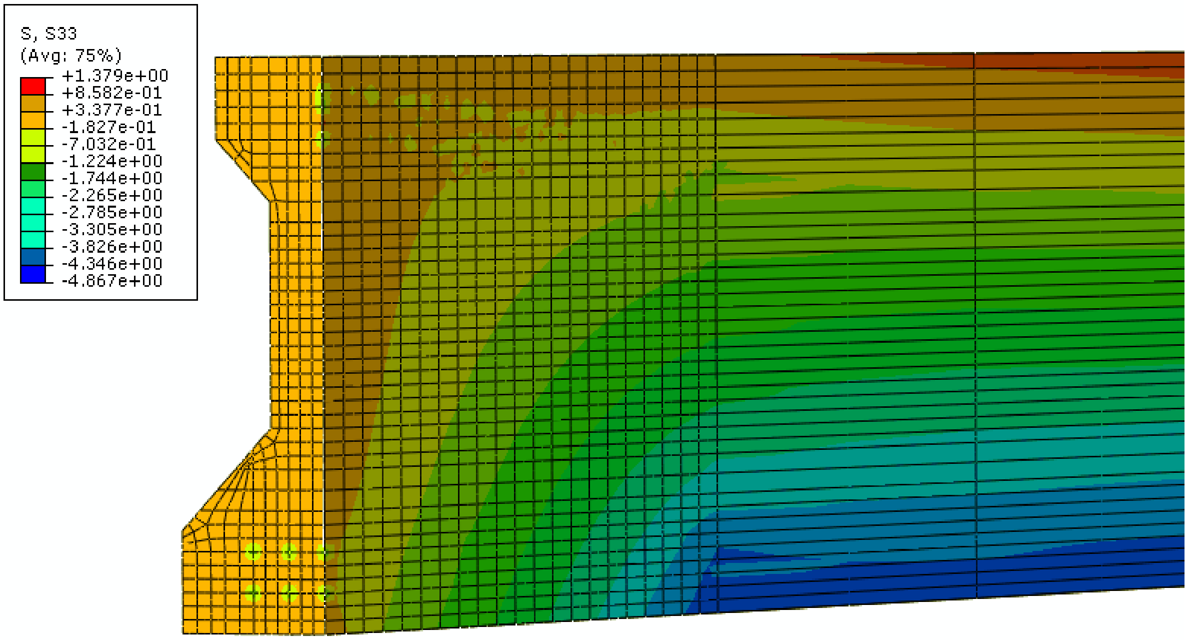

Fig. 9a Axial stress distribution in the direction parallel the direction of the tendons in the girder with 0.7-inch diameter strands.

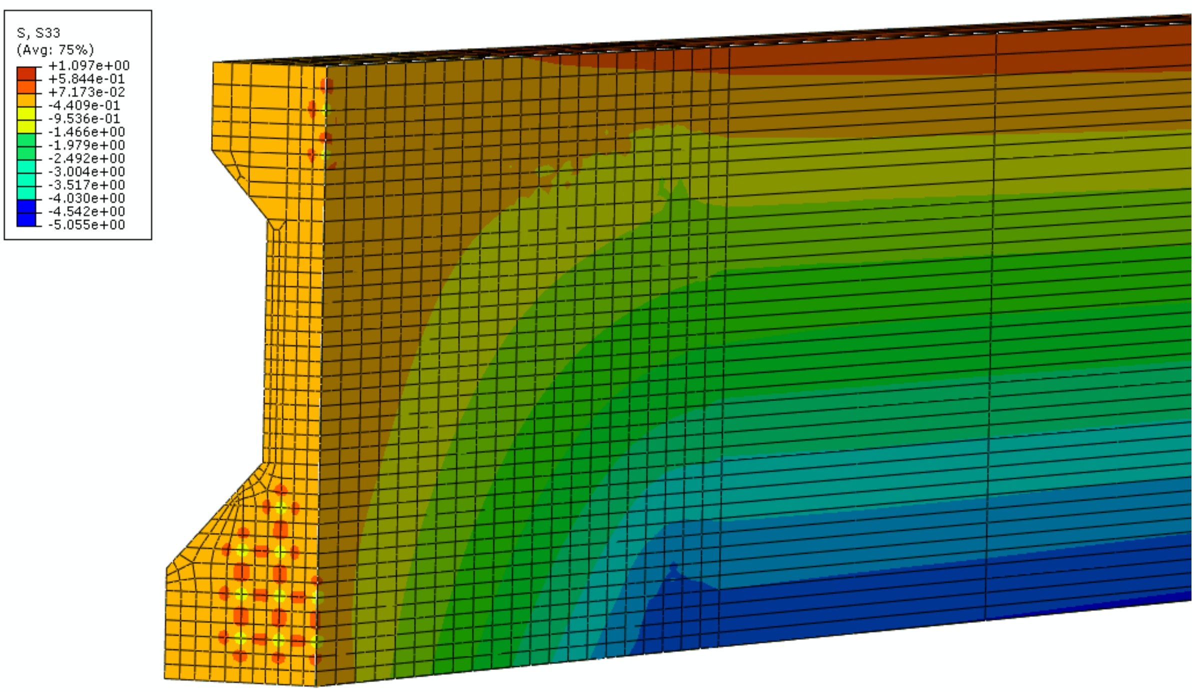

Fig. 9b Axial stress distribution in the direction parallel the direction of the tendons in the girder with 0.6-inch diameter strands.

EXPERIMENTAL INVESTIGATION

Two AASHTO Type I beams were designed with the following assumptions: (1) A bridge of six beams spaced at 8 feet centers. (2) The bridge was designed with cast-in-place concrete deck with a 8 inch actual thickness and 7.5 inch of structural thickness included in the 8 inch. (3) A haunch thickness of 0.5 inch was considered. (4) An additional 2 inches of wearing surface was considered to be the future wearing surface. (5) Prestress losses involved an initial loss of 10% at transfer and a total of 25% at service. (6) Span of each girder designed was 56 feet. The design was accomplished in accordance with the AASHTO LRFD bridge design specification.

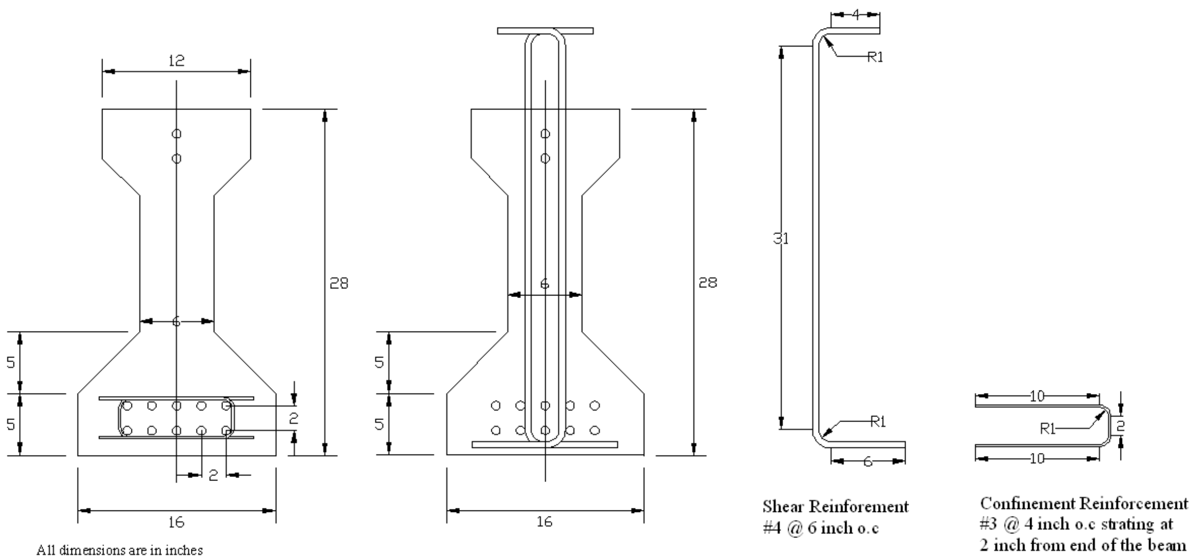

Fig. 10 AASHTO Type I girder with 0.7 inch strand arrangement and shear reinforcement details

MATERIAL ORDERING

The two girders are planned to be cast at the Ross Prestressed concrete, inc. at their plant at Bristol. The 0.7 inch strands are donated by MMI Strand Co. About 5000 feet of 0.7 inch is manufactured by them at their plant at Newnan, Georgia and shipped to the Ross Prestressed concrete, Inc at Bristol. About 24 Nos. of stressing devices such as jaws and chucks are provided by Coreslab Structures (Omaha) Inc.

TESTING

The transfer and the development length for the two girders are to be determined by measuring the concrete surface strain from the time of release of the strands.

CONCLUSIONS

The analytical investigation presented in this paper considered only the effects due to the prestressing force at transfer. Based on the analytical investigation, the following conclusions were obtained.

- Using 0.7 inch diameter strands have potential advantages, such as higher span capacity, reduction in the section size and material saving and an increased roadway clearance can be achieved by using shallower members.
- The precast/prestressed I-girders are usually cracked at the end sections during the release of the prestressing force, the analytical study shows that there is a high probability of cracking at the transition zone between the bottom flange and the web for the 0.7 inch diameter strands when compared with the 0.6 inch diameter strands.
- This cracking at the end section can be minimized with the use of confinement steel at the girder ends.
- Further analytical study should be performed in order to determine the effects of the confinement steel for both 0.7 inch diameter strands and 0.6 inch diameter strands.

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