EFFECTS OF TEMPORARY PROPPING ON DESIGN OF PRESTRESSED CONCRETE BRIDGE GIRDERS

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ABSTRACT

During bridge construction phase, bridge girders in their simply supported state can be temporarily propped to gain benefits like obtaining shallower sections, more aesthetics, and greater span lengths. The temporary props will be removed once concrete slab has hardened (i.e., when girder and slab are in composite state).

The objective of this study is two-fold: (1) to estimate the maximum girder length when temporary propping is used and (2) to study the benefits of utilizing maximum allowable tensile stresses of $12\sqrt{f_c'}$ *as oppose to* $6\sqrt{f_c'}$ *during construction phase. The maximum propping forces are also derived so that stresses in critical locations of a propped girder are not greater than the specified maximum allowable stresses.*

Pacific Avenue Overcrossing in Everett, Washington is used as a proof of concept example to investigate the effects of temporary propping on precast girders. It is shown that for the same girder cross section and prestressed strands, temporary propping would allow an increase in the span length of up to 20%. Using the same cross section with more pre-tensioning, higher temporary allowable tensile stresses, and temporary propping would allow an increase in the span length of up to 55% in the girder. A parameterization of the procedure is also developed and presented.

Keywords: Prestressed Concrete, Temporary Propping, Construction Sequence, Allowable Stress, Temporary Stress, Final Stress.

INTRODUCTION

During bridge construction phase, bridge girders in their simply supported state can be temporarily propped to achieve benefits like obtaining shallower sections, more aesthetic appearance, and greater span lengths. In many cases, the cost saving associated with these benefits more than offsets the higher cost associated with utilizing temporary falseworks. Nikzad et al [1] have studied the performance of a propped spliced-girder vs. a propped non-spliced-girder. This study further investigates the effects of temporary propping on prestressed girders. Investigation of stresses in a prestressed concrete girder bridge using temporary propping construction method can be divided into four main stages i.e., (1) Transportation of bridge girders, (2) Erection of bridge girders and casting of wet concrete slab, (3) Removal of temporary props, and (4) Live loads and additional loads (i.e., wearing surface, sidewalk, curb, and barrier) on the composite section. In the first stage, a bridge girder is subjected to its self-weight and prestressed forces. The size and number of the prestressed strands need to satisfy the requirement that stress in concrete is not greater than the maximum allowable stresses. While tensile and compressive stresses need to be checked but more often tensile stress states provide more critical conditions since the tensile strength of concrete is approximately one tenth of its compressive stress. The sign convention used in this study is: tension positive and compression negative. Hence, the prestressed force is negative. The stress distribution at the mid-span of girder in its simply supported stage is shown in Fig. 1.

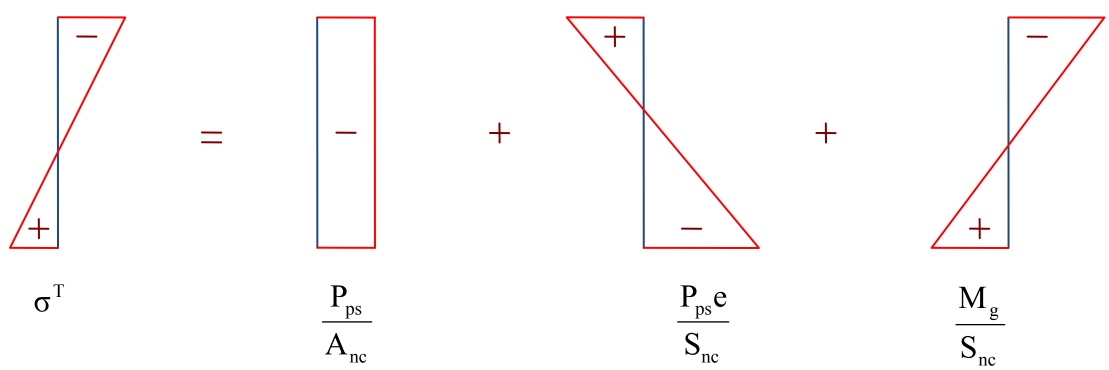


Fig. 1 Concrete Stress Distribution in Girder – During Transportation

Stresses at the top and bottom of the girder section during transportation are:

$$\sigma_{t,b}^{T} = \frac{P_{ps}}{A_{nc}} \mp \frac{P_{ps}e}{S_{nc}} \mp \frac{M_g}{S_{nc}} \tag{1}$$

where P_{ps} is the prestressed force, e is the eccentricity of the prestressed force, M_g is moment due to self-weight of girder and A_{nc} and S_{nc} are the area and elastic section modulus of non-composite section, respectively.

In the second stage, bridge girders are erected and possibly propped before casting of concrete slab. Bridge girders are designed to support the weight of wet concrete slab in addition to the forces during transportation. Since the weight of concrete slab is significant, it is necessary to increase the stiffness of bridge girders or to provide temporary propping during this stage. Temporary propping during construction is structurally efficient because for the same cross section it can significantly increase the girder length. Moreover, bridge girders can be pushed up by a propping force to provide even more reserve strength in the girder in the same manner as prestressing forces.

During erection, each girder acts like a two span continuous beam supported by permanent bents at two ends and temporary propping at mid-span. The maximum negative moment is therefore at the location of the propping force. Fig. 2 shows the stress distribution of the girder during erection at propping location.

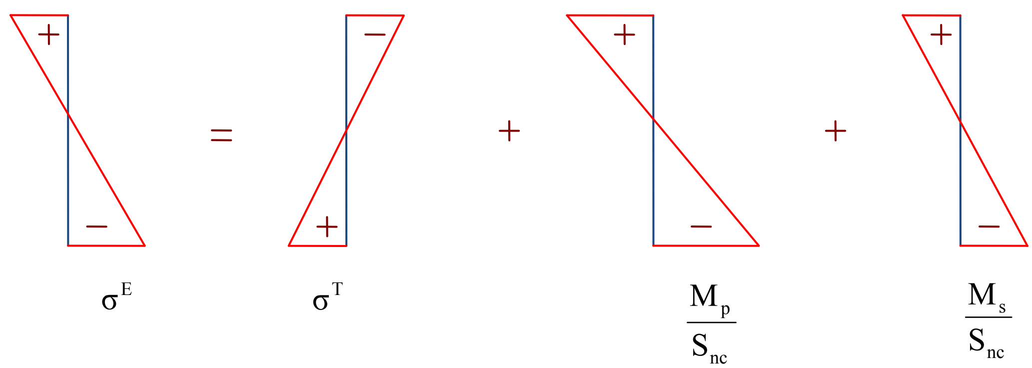


Fig. 2 Concrete Stress Distribution in Girder at Propping Location – During Erection

While a larger propping force provides more reserve capacity to be incorporated into the bridge girders, the stresses in girders shall always be kept below than the maximum allowable stresses. The moment due to propping force at mid-span of a simply supported beam is:

$$M_P = \frac{F_P L}{4} \tag{2}$$

where M_p and F_p are propping moment and force, respectively and L is the length of girder.

Stresses at the top and bottom of the cross section during erection are:

$$\sigma^E_{t,b} = \sigma^T_{t,b} \mp \frac{F_p L}{4S_{nc}} \mp \frac{M_s}{S_{nc}} \tag{3}$$

where M_s is moment due to wet slab at mid-span location of girder. For an optimal design, the tensile stress equals to the maximum allowable tensile stress. The only unknown in Equation (3) is the propping force. During erection stage, the top fiber of the girder's mid-span cross section is under tension. Letting the maximum allowable tensile stress be $12\sqrt{f'_c}$, the maximum propping force that can be applied to the girder is:

$$F_{max} = \frac{S_{nc}\left(\sigma^T_t - 12\sqrt{f'_c}\right) - M_s}{0.25L} \tag{4}$$

After concrete slab is hardened, slab and girder will act together as a composite section. Composite beam will start carrying loads once the props are removed. In this stage, the girder is subjected to the weight of the slab, the propping force acting downward, and any additional loads during erection phase. The weight of slab and propping force now acts on a continuous beam structures. The reaction at propping location of a continuous beam due to propping force and weight of slab is:

$$F_r = F_p + f(w_s, L, n) \quad (5)$$

where $f(w_s, L, n)$ is reaction due to weight of slab, which is a function of the weight of slab per unit length of girder (w_s), span length (L), and the number of spans (n). The force applied on the girder due to the removal of prop is the reaction at the prop location. However, in this stage, it is necessary to take into account of prestressed loss due to relaxation of prestressed strands. Fig. 3 shows the stress distribution in the girder during removal of props.

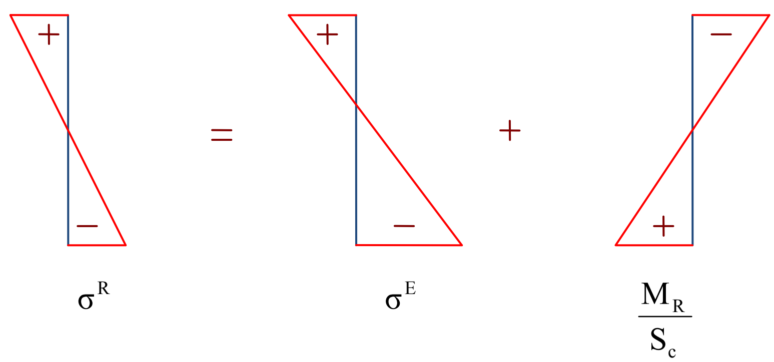


Fig. 3 Concrete Stress Distribution in Girder – Removal of Propping Stage

Stresses at the top and bottom of the cross section during removal of props are:

$$\sigma^R_{t,b} = \sigma^E_{t,b} \mp \frac{M_r}{S_c} \quad (6)$$

where M_r is moment at mid-span of girder due to removal of props (i.e., the moment at prop location due to F_r), and S_c is the elastic section modulus of the composite section.

In the final stage of construction, girders are post tensioned. Additional loads due to future wearing surface, barriers and vehicular live load (i.e., HL93) are carried by the composite section. Fig. 4 shows the stress distribution in the girder at final stage.

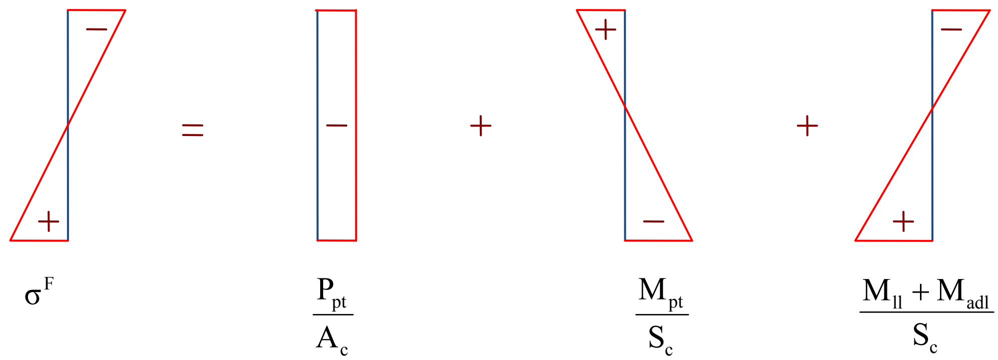


Fig. 4 Concrete Stress Distribution in Composite Section – Final

In this final state, three combinations of dead load and live load need to be considered in accordance to Table 5.9.4.2.1-1 of AASHTO [2]. Stresses at the top and bottom of the cross section at the final stage are:

$$\sigma^F_{t,b} = \sigma^R_{t,b} + \frac{P_{pt}}{A_c} \mp \frac{M_{pt}}{S_c} \mp \frac{M_{ll} + M_{adl}}{S_c} \qquad (7)$$

where A_c, S_c are the area and elastic section modulus of composite section, respectively, P_{pt} and M_{pt} are post-tension force and moment, respectively. M_{ll} and M_{adl} are moments at mid-span of girder due to live load (HL93) and the additional dead load such as weight of future wearing, sidewalk, curb, and barrier, respectively.

EXAMPLE - PACIFIC AVENUE OVERCROSSING

The Pacific Avenue Overcrossing in Everett, Washington is used as a proof of concept example to investigate the effects of temporary propping. The Bridge was constructed using temporary propping technique. However, no upward propping forces were introduced in the girders (i.e., snug-tight condition). A construction phase photo of Pacific Avenue Overcrossing is shown in Fig. 5. The construction sequence of the Bridge is shown in Fig. 6.

Fig. 5 Construction of Pacific Avenue Overcrossing

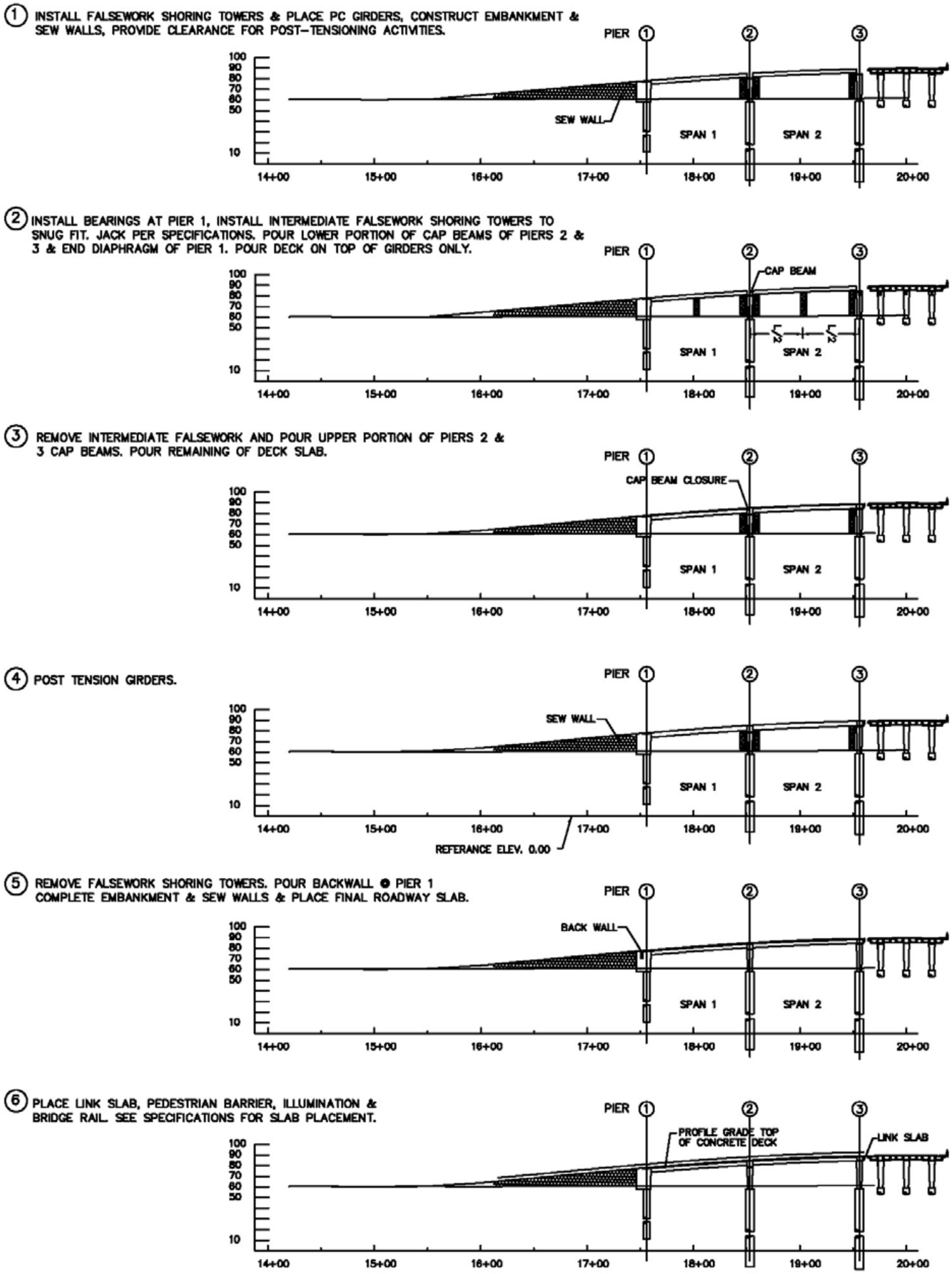


Fig. 6 Construction Sequence of the Pacific Avenue Overcrossing

The concrete strength of girders and slab are 10.0 and 5.0 ksi, respectively. The unit weight of concrete is 0.16 kips per cubic foot. Low relaxation prestressed strands of 0.5 inch diameter are used for girders. The prestressed strands have tensile strength of 270 ksi and yield strength coefficient of 0.91. The cross sectional properties of the non-composite and composite girder sections are shown in Table 1.

Table 1 Cross Sectional Properties of Non-Composite and Composite Sections

Section Properties	I (in^4)	A (in^2)	S_t (in^3)	S_b (in^3)	y_t (in)	y_b (in)
Non-Composite Section	285,120	1,456	9,580.9	17,555.6	29.7	16.2
Composite Section	924,235	2,389	55,508.8	31,560.2	24.2	29.3

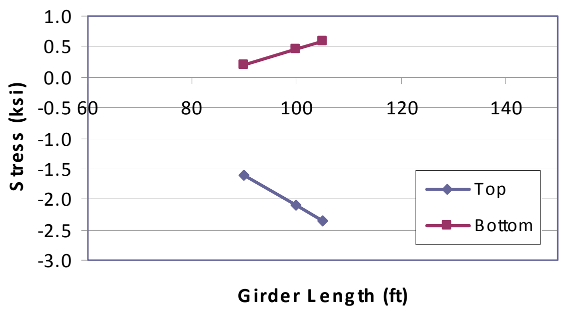
For these cross sectional properties, the number of prestressed strands and post-tensioned strands are determined for span lengths of 90, 100, 110, and 120 feet using temporary props in a snug-tight support conditions, respectively. Table 2 shows the number of strands used for different span lengths.

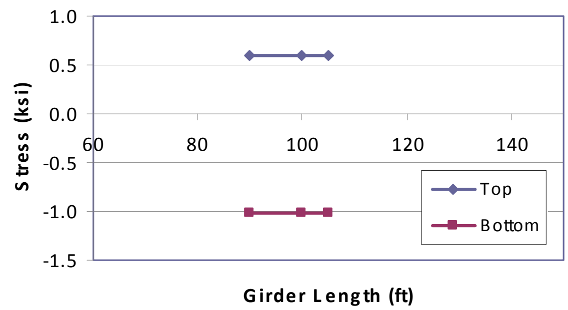
Table 2 Number of Pre-stressing Strands (PS) and Post-tensioning Strands (PT)

Span Length (ft)	90	100	110	120
Number of PS	24	32	50	62
Number of PT	36	48	48	58

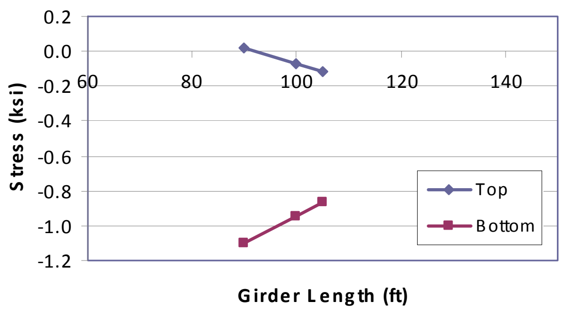
The girder is then propped as much as possible while satisfying maximum allowable tensile stress levels. By providing more propping force, the span length can be increased. The stresses at critical locations such as mid-span and supports of the girder during construction are checked to ensure the maximum allowable stresses are not exceeded. It is found that the stresses at supports are significantly less than the stresses at mid-span location, therefore only stresses at mid-span are presented here. Moreover, two levels of temporary allowable tensile stress are considered in this study. The first level, currently recommended by AASHTO, is one where maximum tensile stresses are kept below $6\sqrt{f_c^{'}}$ while the second level is one where the maximum allowable tensile stresses are kept below $12\sqrt{f_c^{'}}$. The final tensile stress is always kept below $6\sqrt{f_c^{'}}$. For compressive stress state, three combinations of live load and dead load are considered. The three load combinations are: (1) live load plus one-half of dead load, (2) dead load, and (3) live load plus dead load.

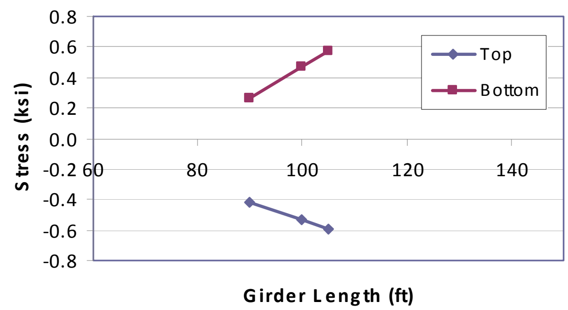
Fig. 7 to 10 show stresses at top and bottom fibers of girder when using the maximum allowable tensile stresses of $6\sqrt{f_c^{'}}$ for span lengths of 90, 100, 110, and 120 feet, respectively. It is observed that by using the maximum propping force, a span length of 90 feet can be extended to 105 feet; a span length of 100 feet can be extended to 115 feet; a span length of 110 feet can be extended to 125 feet; and a span length of 120 feet can be extended to 135 feet. Hence, the span length can be efficiently increased by approximately 15% if the maximum allowable tensile stress of $6\sqrt{f_c^{'}}$ is used.



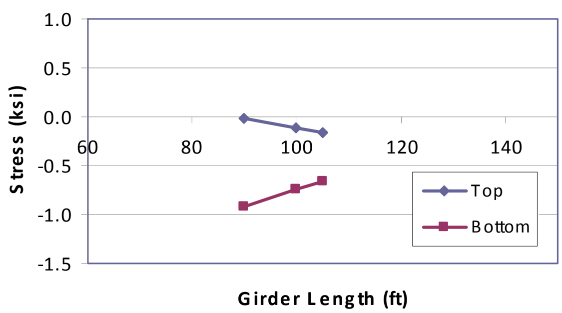


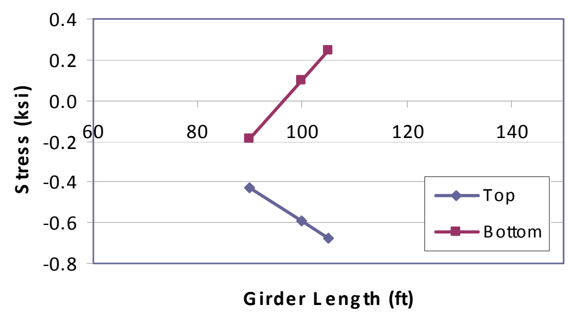
a) Transportation b) Erection





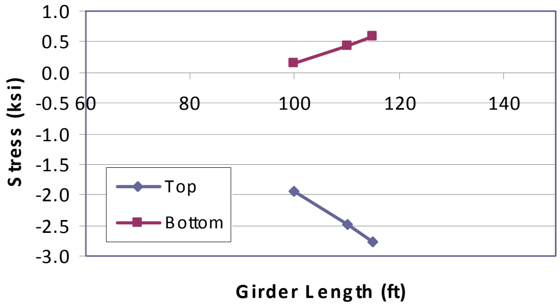
c) Removal of Props d) Live Load plus One-half Dead Load



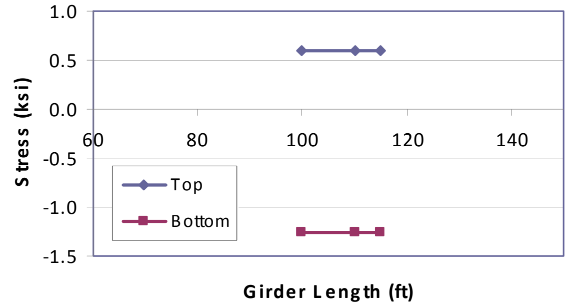


e) Dead Load f) Dead Load plus Live Load

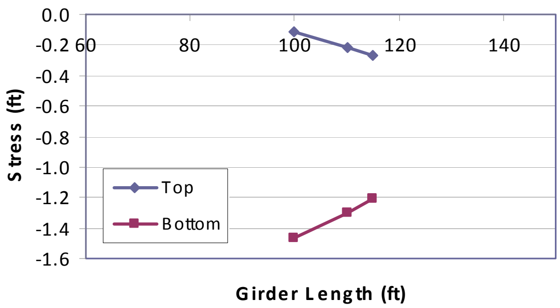
Fig. 7 Stresses at Mid-span Girder During Construction – Starting from Span Length of 90 feet and using the Maximum Allowable Tensile Stress of $6\sqrt{f_c^{'}}$



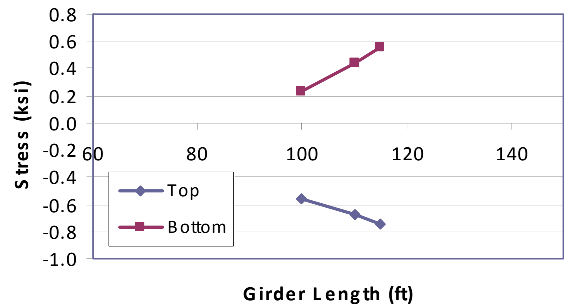
a) Transportation



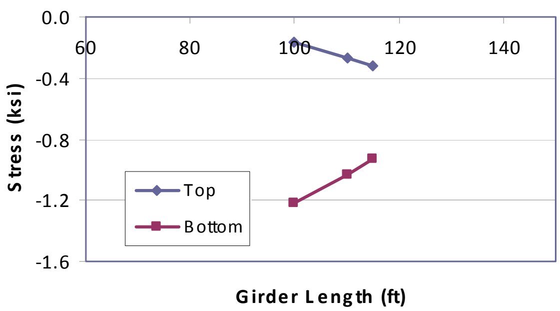
b) Erection



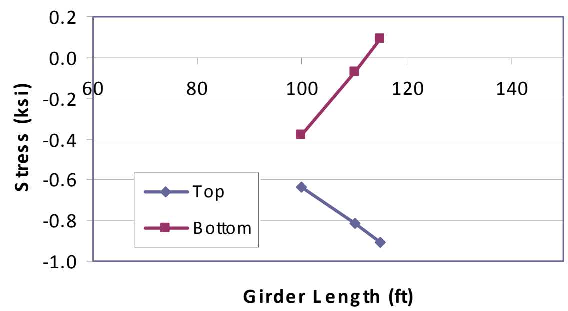
c) Removal of Props



d) Live Load plus One-half Dead Load

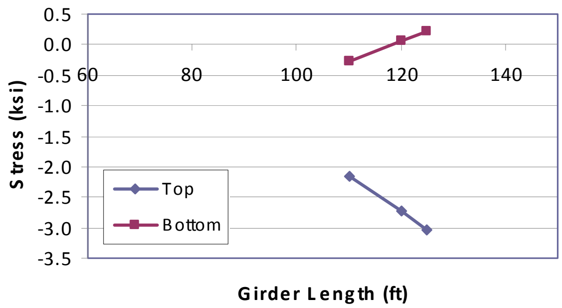


e) Dead Load

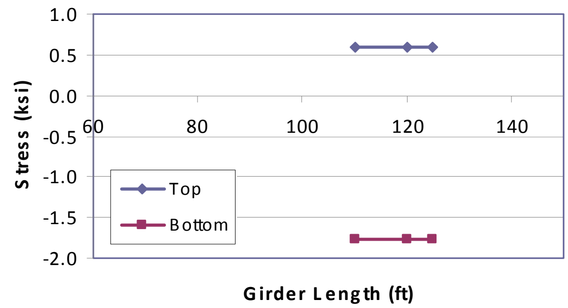


f) Dead Load plus Live Load

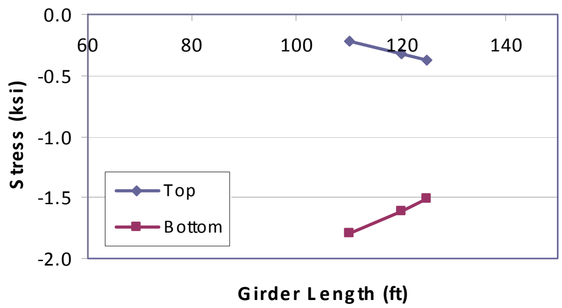
Fig. 8 Stresses at Mid-span Girder During Construction – Starting from Span Length of 100 feet and using the Maximum Allowable Tensile Stress of $6\sqrt{f_c'}$



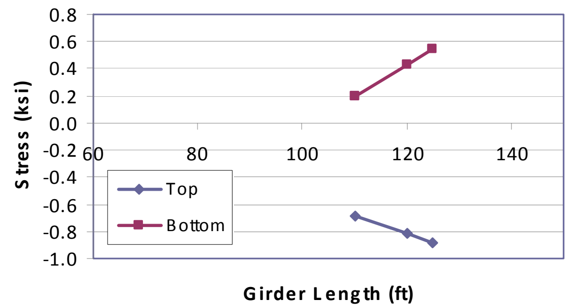
a) Transportation



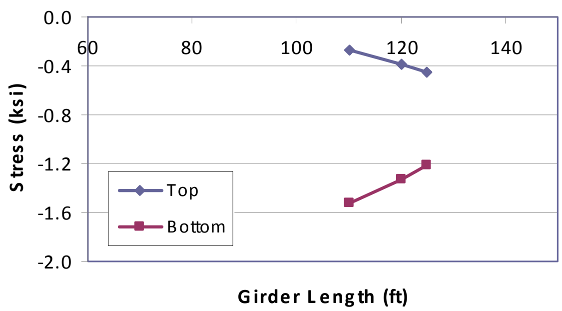
b) Erection



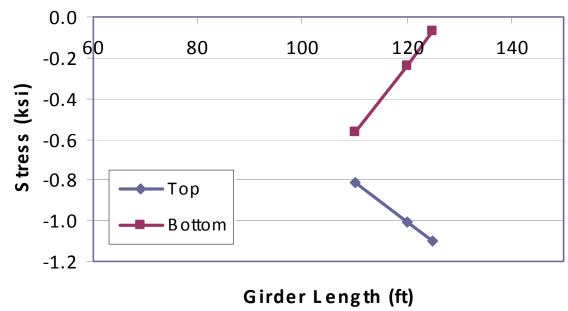
c) Removal of Props



d) Live Load plus One-half Dead Load

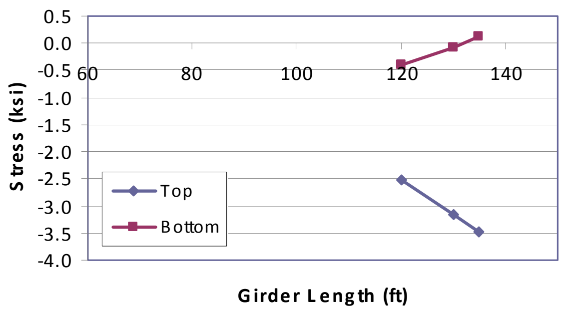


e) Dead Load

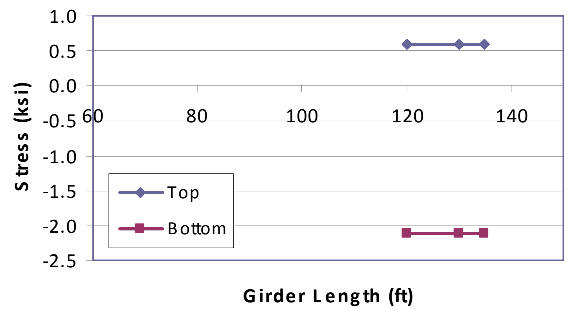


f) Dead Load plus Live Load

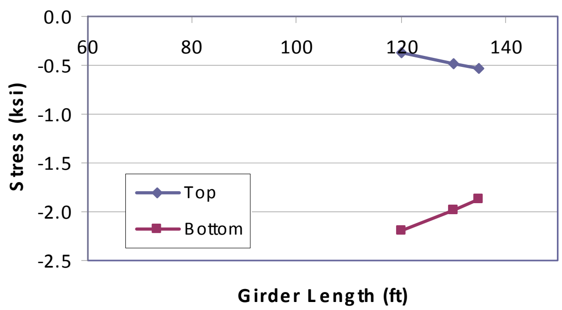
Fig. 9 Stresses at Mid-span Girder During Construction – Starting from Span Length of 110 feet and using the Maximum Allowable Tensile Stress of $6\sqrt{f_c^{'}}$



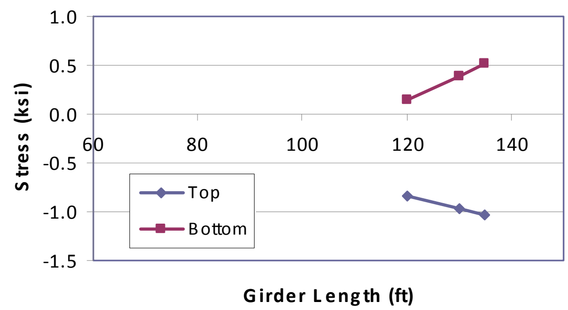
a) Transportation



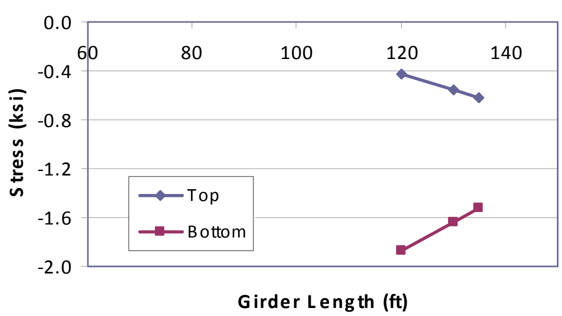
b) Erection



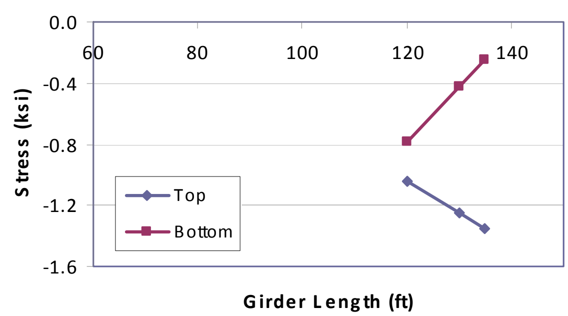
c) Removal of Props



d) Live Load plus One-Half Dead Load



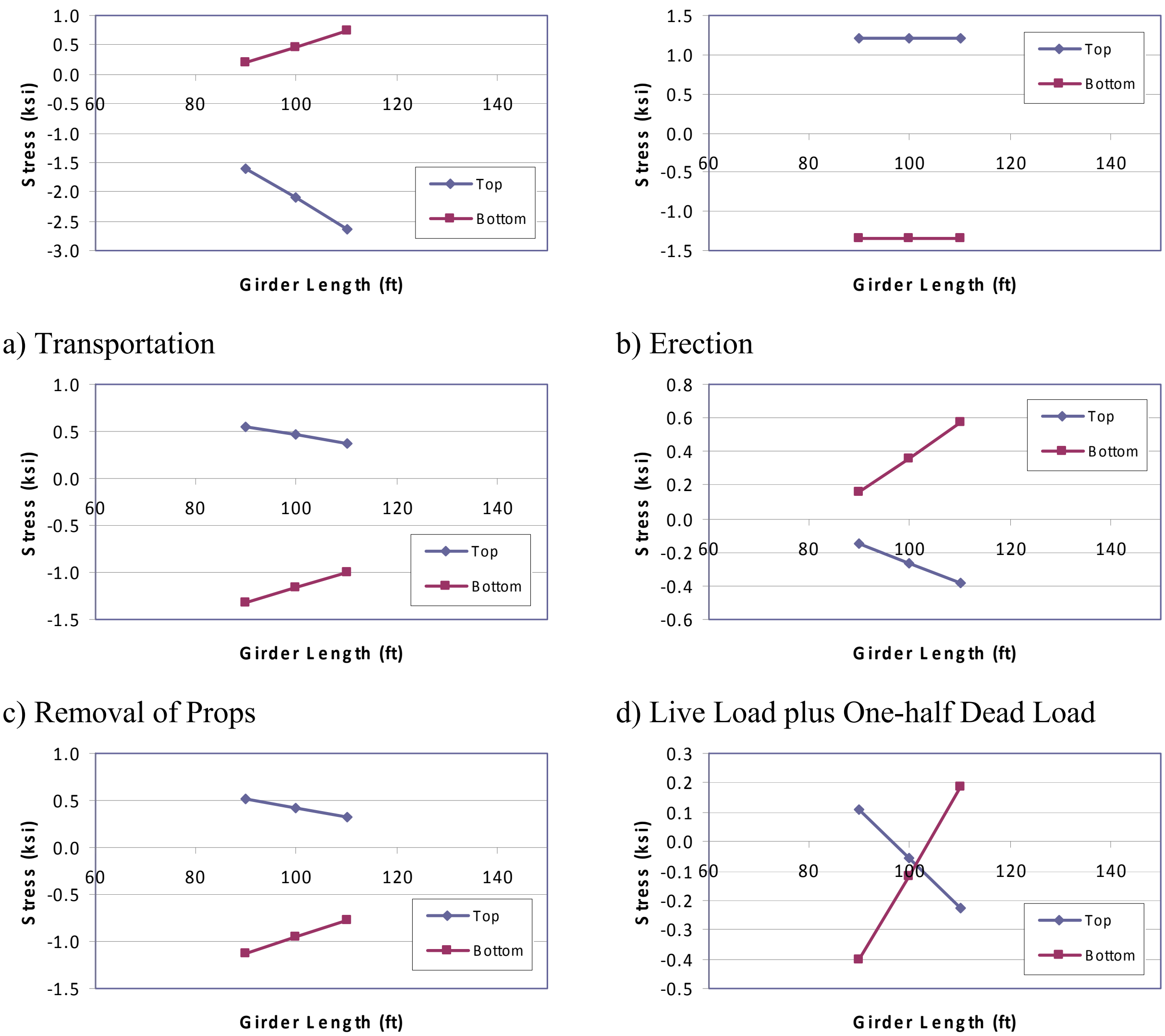
e) Dead Load



f) Dead Load plus Live Load

Fig. 10 Stresses at Mid-span Girder During Construction – Starting from Span Length of 120 feet and using the Maximum Allowable Tensile Stress of $6\sqrt{f_c^{'}}$

Fig. 11 to 14 show stresses at top and bottom fibers of girder when using the maximum allowable tensile stresses of $12\sqrt{f_c^{'}}$ for span lengths of 90, 100, 110, and 120 feet, respectively. It is observed that by using maximum propping force, a span length of 90 feet can be extended to 110 feet; a span length of 100 feet can be extended to 120 feet; a span length of 110 feet can be extended to 120 feet; and a span length of 120 feet can be extended to 140 feet. Hence, the span length can be efficiently increased by approximately 20% if the maximum allowable tensile stress of $12\sqrt{f_c^{'}}$ is used.

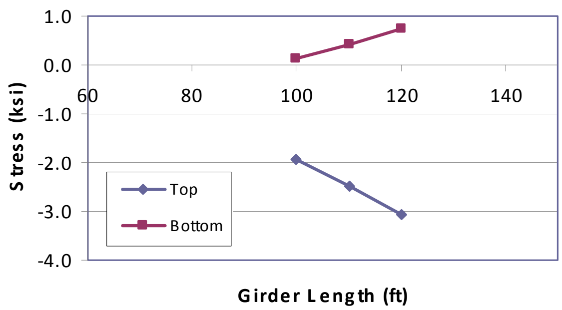


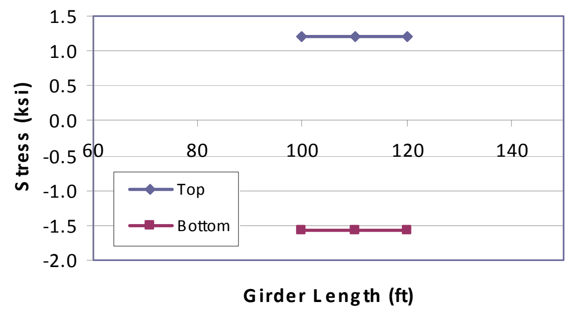
a) Transportation b) Erection

c) Removal of Props d) Live Load plus One-half Dead Load

e) Dead Load f) Dead Load plus Live Load

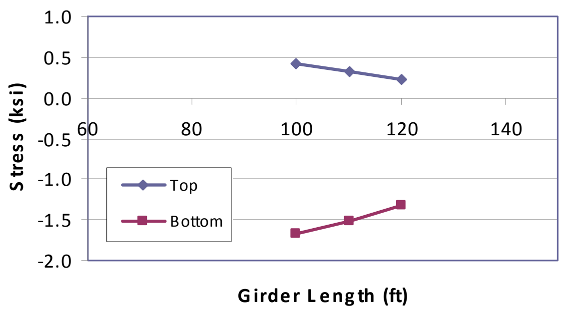
Fig. 11 Stresses at Mid-span Girder During Construction – Starting from Span Length of 90 feet and using the Maximum Allowable Tensile Stress of $12\sqrt{f_c^{'}}$

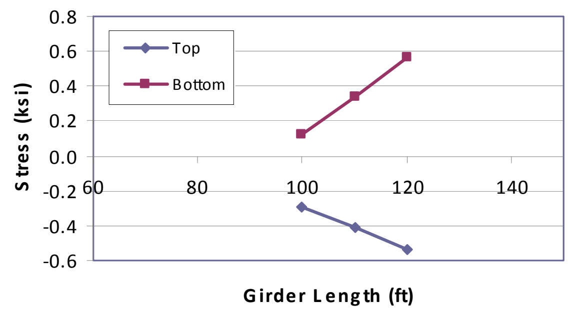




a) Transportation

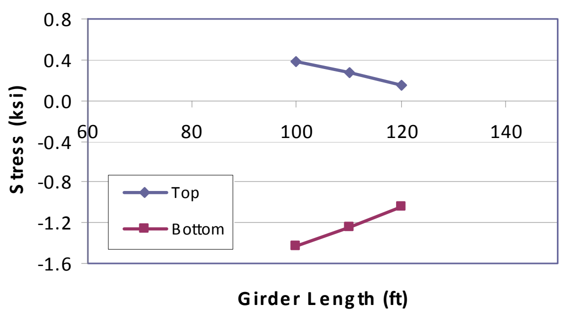
b) Erection

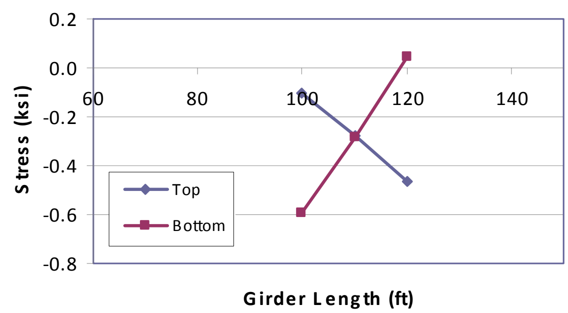




c) Removal of Props

d) Live Load plus One-half Dead Load

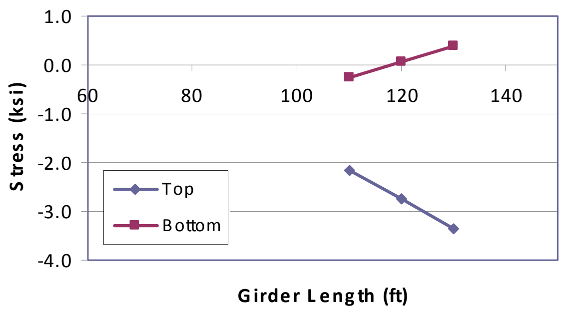




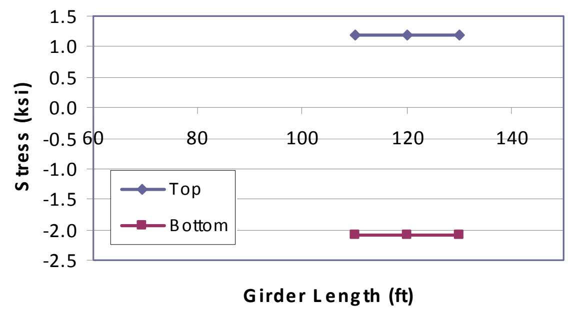
e) Dead Load

f) Dead Load plus Live Load

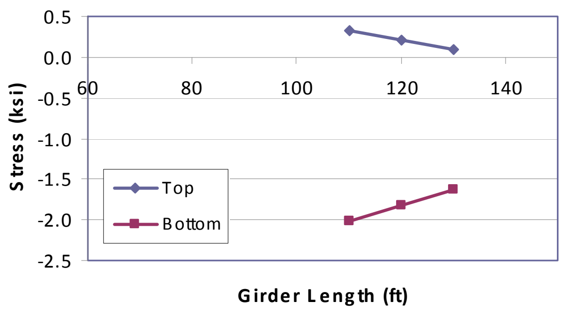
Fig. 12 Stresses at Mid-span Girder During Construction – Starting from Span Length of 100 feet and using the Maximum Allowable Tensile Stress of $12\sqrt{f_c^{'}}$



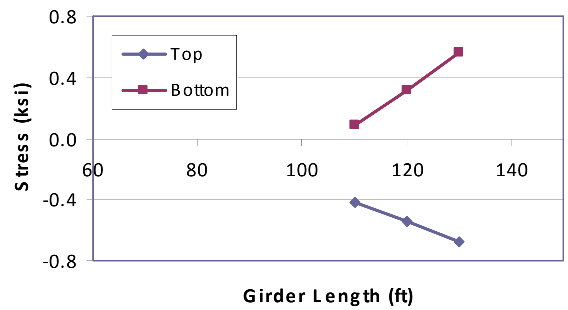
a) Transportation



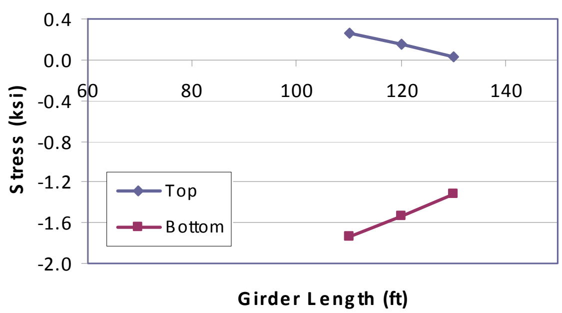
b) Erection



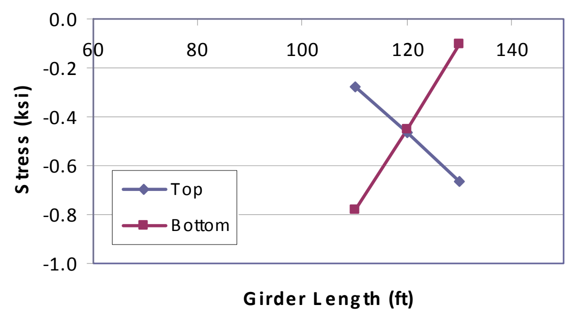
c) Removal of Props



d) Live Load plus One-half Dead Load

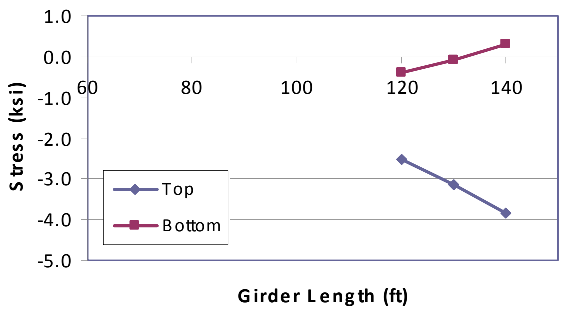


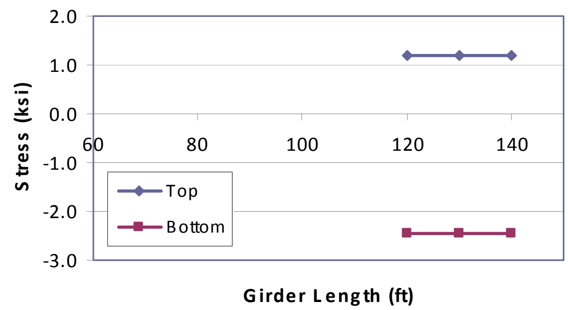
e) Dead Load



f) Dead Load plus Live Load

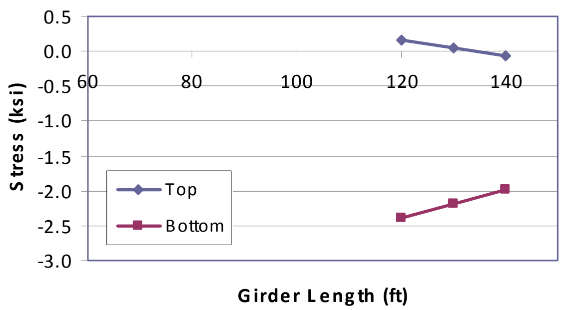
Fig. 13 Stresses at Mid-span Girder During Construction – Starting from Span Length of 110 feet and using the Maximum Allowable Tensile Stress of $12\sqrt{f_c^{'}}$

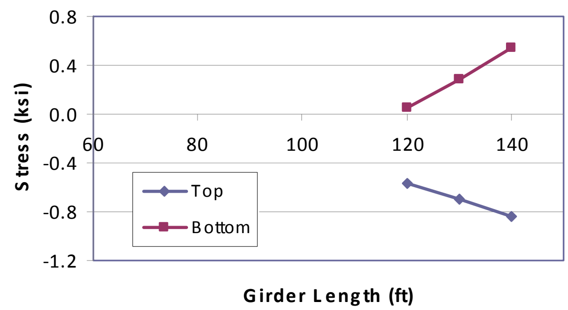




a) Transportation

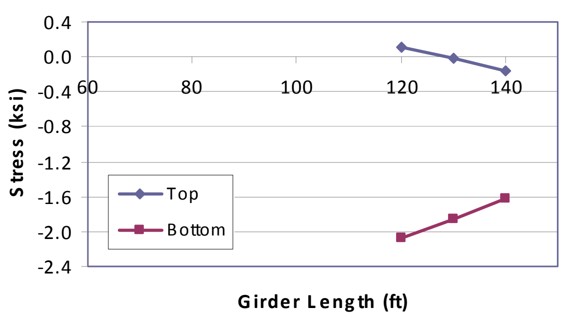
b) Erection

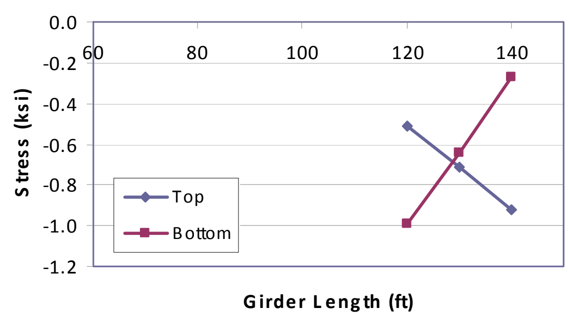




c) Removal of Props

d) Live Load plus One-half Dead Load





e) Dead Load

f) Dead Load plus Live Load

Fig. 14 Stresses at Mid-span Girder During Construction – Starting from Span Length of 120 feet and using the Maximum Allowable Tensile Stress of $12\sqrt{f_c^{'}}$

Thus, by increasing the maximum allowable tensile stress from $6\sqrt{f_c^{'}}$ to $12\sqrt{f_c^{'}}$, the span length can be increased by approximately 5%. By using the same cross section and increasing the number of prestressed and post-tensioned strands as shown in Table 2, span lengths can be increased by 50% and 55% for allowable tensile stress levels of $6\sqrt{f_c^{'}}$ and $12\sqrt{f_c^{'}}$, respectively. The effects of propping and the increasing the maximum allowable tensile stress on span length are illustrated in Fig. 15.

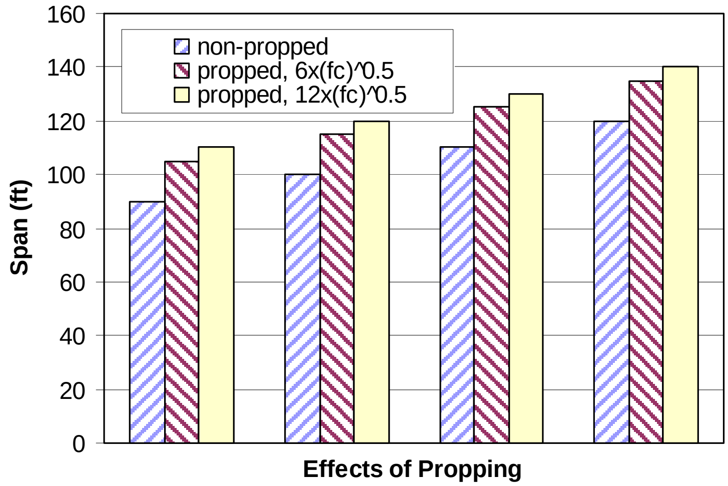


Fig. 15 Effects of Propping and Increasing Maximum Allowable Tensile Stress on Span Length

CONCLUSIONS

It is shown that during bridge construction, bridge girders can be temporarily propped to achieve benefits like obtaining shallower sections, more aesthetics, and greater span lengths. The temporary props will be removed once concrete slab is hardened (i.e., girder and slab are acting as a composite section). Pacific Avenue Overcrossing in Everett, Washington is used as a proof-of-concept example in this study. Stresses at the mid-span and support locations of the girder have been computed. It is observed that stresses at support locations do not govern. For compressive stress, three combinations of the dead load and live load have been considered. The combination of live load plus one-half dead load is the most critical. It is shown that for the same girder cross section and prestressed strands, temporary propping can increase a span length by 15% and 20% for allowable tensile stress levels of $6\sqrt{f_c^{'}}$ and $12\sqrt{f_c^{'}}$, respectively. Moreover, by utilizing more prestressed strands, span length can be increased by 50% and 55% for allowable tensile stress levels of $6\sqrt{f_c^{'}}$ and $12\sqrt{f_c^{'}}$, respectively.

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