PREDICTION OF PRETENSIONED AND POST-TENSIONED STRANDS LOSSES AND TOP & BOTTOM GIRDER STRESSES IN SPLICED GIRDER BRIDGE BY REFINED METHOD

A Project

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by

Laith Naji Zuhaira

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Department of Civil Engineering
Abstract

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PREDICTION OF PRETENSIONED AND POST-TENSIONED STRANDS LOSSES AND TOP & BOTTOM GIRDER STRESSES IN SPliced GIRDER BRIDGE BY REFINED METHOD

by

Laith Naji Zuhaira

The objective of this project is to predict change of stresses in prestressed and post-tensioned strands of spliced girder bridge at various time steps and loadings, and top and bottom fiber stresses of concrete girder.

For this project three different girder bridges were analyzed. First bridge was a simple span bridge 80 ft long with prestressed girder only, the purpose of this example is to show the procedure adopted by ASSHTO-LRFD 2012 to calculate immediate and long term losses in prestressed strands by refined method.

Second example is a simple span bridge with three spliced girders “45ft, 101ft, 45ft” and two temporary supports at girder splicing, these three prestressed segments connected by three post-tensioned tendons to work as a full simple span. In this example, equation of concrete creep and shrinkage of ASSHTO-LRFD are extended to accommodate presence of post-tensioned strands in addition to prestressed strands. Third example is two simple span of prestressed girders “105ft & 90ft” length connected by post-tensioned tendons to work as two continuous span,
To verify accuracy of the obtained results, Summary of analysis results were compared with software program “Leap-Consplice” results at the end of each bridge example.

Approved by:

__________________________________, Committee Chair
Benjamin Fell, Ph.D., P.E.

__________________________________
Date
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CHAPTER ONE
INTRODUCTION

1.1 Motivation

Prestressed concrete, an ideal combination of concrete and high strength steel, has emerged as an efficient material for modern construction. The construction of prestressed concrete bridges as a standard practice in the United States dates to 1949 when the Philadelphia Walnut Ave Bridge was constructed. The technical and economical benefits of prestressed concrete permit longer spans and increased girder spacing.

As designers attempt to use longer full-span beams, limitations in handling and transportation are encountered. Some of the limitations are imposed by the states regarding the size and weight of vehicles allowed on highways. Some states limit the maximum transportable length of beam. When any of these limitations preclude the use of full-span beams, shorter beam segments can be produced and shipped. These beam segments are then spliced together at or near the job site or in their final location. The splices are located in the spans, away from the piers. The beam segments are typically post-tensioned for the full length of the bridge unit, which can be either a simple span or a multiple span continuous unit.

While the introduction of splices and post-tensioning increases the complexity of the construction and adds cost, precast bridges of this type have been found to be very cost competitive with other systems and materials. The longest span in a modern spliced girder bridge in the United States is currently the 325-ft long river span in a four-span bridge over the Kentucky River near Gratz, Kentucky.

Common issues that may lead a designer to consider the use of precast prestressed concrete spliced girders for a project are as follows:
Increasing span lengths to reduce the number of substructure units and the total project cost;

Increasing the girder spacing to reduce the number of girder lines and the total project cost;

Increasing span lengths to improve safety by eliminating shoulder piers or interior supports;

Minimizing structure depth through the use of long, continuous members to obtain required vertical clearance for traffic, waterways, and so forth;

Avoiding the placement of piers in water to reduce environmental impact and total project cost;

Elimination of falsework that may restrict traffic beneath a structure or pose a safety hazard to traffic and construction workers.

Increased speed of construction, which reduces congestion and traffic delays.

Improving aesthetics through various design enhancements, such as more slender superstructures, longer spans, or hunched sections at piers;

Eliminating joints for improved structural performance, reduced long-term maintenance/increased service life, and improved rideability.

Efficient design of spliced prestress concrete bridges demands an accurate prediction of prestress and post-tensioned losses. The losses are defined as the loss of tensile stress in Strands which acts on the concrete component of the prestressed concrete section. Inaccurate prediction of losses results in excessive camber or deflection of prestressed concrete bridges. Excessive camber or deflection can, in turn, adversely affect the service conditions such as: cracking, overall
performance of the bridge. Excessive cracking can even reduce the bridge’s durability since cracking can be a route for water which deteriorate the concrete and its reinforcements.

This report is prepared to provide a detailed explanation of stress changing in prestressed/posttensioned Strands and variation of girder stresses at top & bottom fibers in the process of time and during different stages of loadings by adopting AASHTO LRFD 2012 refined method.

In prestressed concrete, the four major sources of prestress losses are Elastic Shortening, Creep, Shrinkage, and Steel Relaxation. Effect of deck shrinkage on prestressed Strands and stresses at extreme girder fibers are considered in this study as well.

In post-tensioned concrete, post-tensioned Strands subject to same prestressed Strands losses in addition to, Anchor set losses and friction losses along span length. Combined effect of prestressed and post-tensioned Strands losses on concrete stresses at top & Bottom fiber of girder are explained briefly at every stage of construction.

1.2 Objective and scope

The primary objective of this report is to calculate girder stresses and prestress / post-tension losses at different stages of loading and time steps by AASHTO LRFD 2012 refined method.

Design examples are important resources that enable a designer to approach a new type of design with increased confidence because they clearly present all of the required issues and procedures necessary to complete the design. Since design of spliced girder bridges, which is the major focus of this study, involves greater complexity in design that is required for conventional precast prestressed concrete bridge design, design examples were developed to facilitate the use of this
type of construction, which has great potential for extending the span ranges of precast prestressed concrete bridge.

Three design examples are presented in this study, first example representing conventional prestress girder which used to explain general concept and equations of losses by refined method, while the rest two examples representing configurations of spliced girder bridges. In all examples, an effort has been made to state all assumptions, so that the examples will be as clear and useful as possible.

In the last two examples, the prestress is applied in two stages: at release of the pretensioned strands, and at stressing of the post-tensioning tendons. A third stage could be possible if a second stage of post-tensioning were used. Concrete stresses must be computed and compared to limiting values at critical events that occur between the initial application of prestress at release of the pretensioned strands and the final conditions. Furthermore, the equations in the specifications must be modified to account for these issues. Finally analysis results were compared with outcomes of Leap Conspliced software program from Bentley.

1.3 Organization and outlines:

Chapter one of this report provides an explanation of the motivation for this study. The beginning of this chapter provides a general discussion of the problem being studied. It also contains the scope and organization of the report.

The Second chapter discusses prediction method of losses by AASHTO LRFD 2012 Specification procedure for instantaneous losses (Elastic Shortening, Anchor Set and friction losses) and long term prestress and post tension losses (Creep & Shrinkage of concrete and steel relaxation).
Chapter Three is a discussion of the permanent and transient loads adopted in this study and its relevant load distribution factors and impact load. This chapter also contains explanation of concrete compressive strength estimation in the process of time.

The results from this study are presented in Chapter Four. These results consist girder stresses and strands losses in different stages of construction, plots and tables of the obtained results compared with Leap Conspliced software programs.

A discussion of the analysis findings and an interpretation of the results are found in Chapter Five.
CHAPTER TWO
SHORT AND LONG TERM LOSSES

2.1 Overview

Efficient Design of prestress concrete bridges demands an accurate prediction of losses. The prestress losses are defined as the loss of tensile stress in the prestress which acts on the concrete component of the prestressed concrete section. In pretensioned concrete, the four major sources of prestress losses are elastic shortening ($\Delta f_{pES}$), concrete Creep ($\Delta f_{pCR}$), shrinkage ($\Delta f_{pSh}$) and steel relaxation ($\Delta f_{pR}$) as well as deck shrinkage.

Components of prestress losses are illustrated in Figure (2-1) and described below.

(a) Loss due to prestressing bed anchorage seating (A to B), relaxation between initial tensioning and transfer, and temperature change from that of the bare strand to temperature of the strand embedded in concrete (B to C).

(b) Instantaneous prestress loss at transfer due to prestressing force and self-weight (C to D).

(c) Prestress loss between transfer and deck placement due to shrinkage and creep of girder concrete and relaxation of prestressing strands (D to E).

(d) Instantaneous prestress gain due to deck weight on the non-composite section (E to F), and superimposed dead loads (SIDL) on the composite section (G to H).

(e) Long-term prestress losses after deck placement due to shrinkage and creep of girder concrete, relaxation of prestressing strands, and deck shrinkage (H to K).
2.2 Prestress Loss Prediction Methods:

Several loss prediction methods have been developed over the years, but simple practical solutions for accurate estimation of prestress loss have proved difficult. The accurate estimation of losses requires more precise knowledge of material properties as well as the interaction between creep, shrinkage of concrete and the relaxation of steel. In addition, prestress losses are influenced by composite action between the cast-in-place concrete deck and the precast concrete girders. Use of high-strength concrete in precast prestressed concrete allows for high levels of prestress and long span capacities. However, experience in estimating prestress loss for high-strength concrete is limited. The current methods for the prediction of losses can be classified according to their approach for the calculation of losses. They are listed according to their descending order of perceived accuracy:

a) Time – Step methods;

b) Refined methods;

c) Lump – sum methods.
a) Time – Step method:

These methods are based on a step-by-step numerical procedure implemented in specialized computer programs for the accurate estimation of long-term prestress losses. This approach is especially useful in multi-stage bridge construction such as spliced girder and segmental box girder bridges. As concrete creeps and shrinks, the prestressing strands shorten and decrease in tension. This, in turn, causes the strands to relax less than if they were stretched between two fixed points. As the prestressing strand tension is decreased, concrete creeps less, resulting in some recovery. To account for the continuous interactions between creep and shrinkage of concrete and the relaxation of strands with time, time will be divided into intervals; the duration of each time interval can be made progressively larger as the concrete age increases. The stress in the strands at the end of each interval equals the initial conditions at the beginning of that time interval minus the calculated prestress losses during the interval. The stresses and deformations at the beginning of an interval are the same as those at the end of the preceding interval. With this time-step method, the prestress level can be estimated at any critical time of the life of the structure.

b) Refined Method:

In this method each individual component of prestress losses (elastic shortening and time – dependent losses) is calculated separately. The individual losses are then summed up to obtain the total loss. The difficulty lies in the accurate computation of the interdependency of these individual components. The deck slab of composite sections creep less and shrink more than the precast girder. This can cause more prestress gain rather prestress loss.
c) Lump – Sum method:

Various parametric studies were conducted on the prestress losses of different kinds of prestressed beams under average conditions. The values and trends developed from these studies were utilized in the approximate Lump-Sum methods. Although these methods were useful in the preliminary design, they require reassessment in the final design. The current AASHTO-LRFD Approximate method was developed using this method.

2.3 Short Term Losses:

a) Instantaneous or Elastic Shortening ($\Delta f_{pES}$)

Loss due to Elastic Shortening is caused by the instantaneous compression of concrete when the prestress force is transferred to the hardened concrete member. As the concrete shortens it allows the prestressing steel to shorten with it. It is defined as the loss of tensile stress in prestressing steel due to the prestress combined with the stress gain due to the self-weight of the member. The Elastic Shortening depends on the modular ratio and the average stress in the concrete at the level of prestressing steel.

The loss due to elastic shortening in pretensioned member shall be taken as:

$$\Delta f_{pES} = \left( \frac{E_p}{E_{ci}} \right) (f_{cgp})$$

**AASHTO – LRFD (5.9.5.2.3a – 1)**

$$f_{cgp} = \frac{P_t}{A_g} - \left( \frac{P_t}{A_g} \right) \left( \frac{e^2}{I_g} \right) - \frac{M_g(e)}{I_g}$$

$$E_{ci} = 33000 w_c^{1.5} \sqrt{f'_c}$$

**AASHTO – LRFD (5.4.2.4 – 1)**

The loss due to elastic shortening in Post-Tensioned member shall be taken as:

$$\Delta f_{pES} = \frac{N - 1}{2N} \left( \frac{E_p}{E_{ci}} \right) (f_{cgp})$$

**AASHTO – LRFD (5.9.5.2.3a – 1)**
b) Seating or Anchor Set Losses ($\Delta f_{pAS}$):

Anchorage set loss is caused by the movement of the tendon prior to seating of the wedges or the anchorage gripping device. The magnitude of the minimum set depends on the prestressing system used. This loss occurs prior to transfer and causes most of the difference between jacking stress and stress at transfer. A common value for anchor set is $0.375\text{in}$.

Anchor set loss in post-tensioned member equal to:

$$\Delta f_{pAS} = 2(f_{pj})(R)(X)$$

$$X = \sqrt{\frac{(S)(E_p)}{(R)(f_{pj})}}$$

$$R = k + 2\frac{(e)(X)(\mu)}{(b^2)}$$

c) Friction Losses ($\Delta f_{pF}$):

For a posttensioned member, friction losses are caused by the tendon profile curvature effect and the local deviation in tendon profile wobble effects. AASHTO-LRFD 2012 specifies the following formula:

$$\Delta f_{pF} = f_{pj} \left(1 - e^{-(kx+\mu\alpha)}\right)$$

AASHTO - LRFD (5.9.5.2b - 1)

Table (2-1) indicates friction coefficients for Post-Tensioned Tendons

<table>
<thead>
<tr>
<th>Type of Steel</th>
<th>Type of Duct</th>
<th>$K$</th>
<th>$\mu$</th>
</tr>
</thead>
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<tr>
<td>Wire or strand</td>
<td>Rigid and semirigid galvanized metal sheathing</td>
<td>0.0002</td>
<td>0.15–0.25</td>
</tr>
<tr>
<td></td>
<td>Polyethylene</td>
<td>0.0002</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Rigid steel pipe deviators for external tendons</td>
<td>0.0002</td>
<td>0.25</td>
</tr>
<tr>
<td>High-strength bars</td>
<td>Galvanized metal sheathing</td>
<td>0.0002</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Table (2.1) Friction coefficients for post-tensioning tendons “AASHTO LRFD 2012”
2.4 Long Term Losses (Refined Method):

a) Creep of Girder Concrete ($\Delta f_{pCR}$)

The prolonged time-dependent deformation of the concrete under sustained compressive load or stress is called the creep. The rate of creep depends on various factors such as: age of concrete, magnitude of sustain stress, water-cement ratio, amount and type of cement, ambient temperature and relative humidity of the concrete, and aggregate properties. Engineer will need to calculate the coefficient for several different situations, at deck placement relative to transfer, at final relative to transfer, and final relative to deck placement.

Creep Coefficients as per AASHTO – LRFD 2012 are:

$$\Psi_{(t,ti)} = 1.9 (k_s)(k_f)(k_{hc})(k_{td})(t_i^{-0.118})$$  \hspace{1cm} \textit{AASHTO LRFD (5.4.2.3 – 2 – 1)}

$$k_s = 1.45 - 0.13 \left(\frac{V_s}{S}\right) \geq 1.0$$  \hspace{1cm} \textit{AASHTO LRFD (5.4.2.3 – 2 – 2)}

$$k_{hc} = 1.56 - 0.008H$$  \hspace{1cm} \textit{AASHTO LRFD (5.4.2.3 – 2 – 3)}

$$k_f = \frac{5}{1 + f'_{ci}}$$  \hspace{1cm} \textit{AASHTO LRFD (5.4.2.3 – 2 – 4)}

$$k_{td} = \frac{t}{61 + 0.4 \times f'_{ci} + t}$$  \hspace{1cm} \textit{AASHTO LRFD (5.4.2.3 – 2 – 5)}
Annual Average Ambient Relative Humidity in percent is illustrated in Fig. 2-2.

The prestress loss due to creep of girder concrete between time of transfer and deck placement, shall be determined as:

$$\Delta f_{CR} = \frac{E_p}{E_{ci}} f_{cgp} \left( \Psi_{(td,ti)} \right) (K_{id})$$ \hspace{1cm} AASHTO - LRFD (5.9.5.4.3a - 1)

$$K_{id} = \frac{1}{(1 + \left( \frac{E_p}{E_{ci}} \right) \left( \frac{A_{ps}}{A_g} \right) \left( 1 + \left( \frac{(A_g)(e_{pg})}{g} \right)^2 \right)) \left( 1 + 0.7(\Psi_{b(t,f,ti)}) \right)}$$ \hspace{1cm} AASHTO - LRFD (5.9.5.4.3a-2)

The change in prestress (loss is negative, gain is positive) due to creep of girder concrete between time of deck placement and final time, shall be determined as:

$$\Delta f_{PCD} = \frac{E_p}{E_{ci}} f_{cgp} \left[ \Psi_{b(t,f,ti)} - \Psi_{b(td,ti)} \right] (K_{df}) + \left( \frac{E_p}{E_{ci}} \right) (\Delta f_{ca}) \left( \Psi_{b(t,f,td)} \right) (K_{df})$$

$$\Psi_{(t,f,ti)} = 1.9 (k_s)(k_f)(k_{hc})(k_{tf,ti})(t_i^{-0.118})$$

$$\Psi_{(t,f,td)} = 1.9 (k_s)(k_f)(k_{hc})(k_{tf,td})(t_d^{-0.118})$$
\[ k_{df} = \frac{1}{(1 + \left( \frac{E_p}{E_{cl}} \right) \left( \frac{A_{ps}}{A_c} \right) \left[ 1 + \left( \frac{(A_c)(e_{pc})^2}{l_c} \right) \right]} \]  

\[ \text{AASHTO – LRFD (5.9.5.4a-2)} \]

\[ \Delta f_{PSH} = \varepsilon_{bid} \cdot (E_p) \cdot (K_{id}) \]  

\[ \text{AASHTO – LRFD (5.9.5.4.3a – 1)} \]

\[ \varepsilon_{bid} = (k_s) \cdot (k_f) \cdot (k_{hs}) \cdot (k_{(t_f,t_i)}) \cdot (0.48E - 03) \]  

\[ \text{AASHTO – LRFD (5.4.2.3.3 – 1)} \]

\[ K_{id} = \frac{1}{(1 + \left( \frac{E_p}{E_{cl}} \right) \left( \frac{A_{ps}}{A_g} \right) \left[ 1 + \left( \frac{(A_g)(e_{pg})^2}{l_g} \right) \right]} \]  

\[ \text{AASHTO – LRFD (5.9.5.4a-2)} \]

\[ \Delta f_{PSH} = \varepsilon_{bdf} \cdot (E_p) \cdot (K_{df}) \]  

\[ \text{AASHTO – LRFD (5.9.5.4a – 1)} \]

\[ \varepsilon_{bdf} = (k_s) \cdot (k_f) \cdot (k_{hs}) \cdot (k_{(t_f,t_d)}) \cdot (0.48E - 03) \]  

\[ \text{AASHTO – LRFD (5.4.2.3.3 – 1)} \]

**b) Shrinkage of Girder Concrete (Δf_{PSH})**

The change in volume of the concrete causes an overall shortening of the strand length and thus reduces the strand stress resulting in prestress losses. The rate of shrinkage is highly dependent on weather conditions, with very dry conditions accelerating shrinkage such that ultimate shrinkage is achieved in a few months, and with wet conditions stooping or reversing shrinkage happened altogether. Shrinkage is influenced by factors such as volume – to – surface ration, ambient relative humidity, and concrete age, type of curing and age of concrete under service.

Shrinkage Coefficients as per AASHTO – LRFD 2012 are:

\[ \varepsilon_{sh} = (k_s)(k_f)(k_{hs})(k_{(t_f,t_i)})(0.48E - 03) \]

\[ k_{hs} = 2.0 - 0.014 H \]

The prestress loss due to shrinkage of girder concrete between time of transfer and deck placement, shall be determined as:

\[ \Delta f_{PSH} = (\varepsilon_{bid})(E_p)(K_{id}) \]  

\[ \text{AASHTO – LRFD (5.9.5.4.3a – 1)} \]

\[ \varepsilon_{bid} = (k_s)(k_f)(k_{hs})(k_{(t_f,t_i)})(0.48E - 03) \]  

\[ \text{AASHTO – LRFD (5.4.2.3.3 – 1)} \]

The prestress loss due to shrinkage of girder concrete between deck placement and final time, shall be determined as:

\[ \Delta f_{PSH} = (\varepsilon_{bdf})(E_p)(K_{df}) \]  

\[ \text{AASHTO – LRFD (5.9.5.4a – 1)} \]

\[ \varepsilon_{bdf} = (k_s)(k_f)(k_{hs})(k_{(t_f,t_d)})(0.48E - 03) \]  

\[ \text{AASHTO – LRFD (5.4.2.3.3 – 1)} \]
\[ K_{df} = \frac{1}{(1 + \left( \frac{E_p}{E_{ci}} \right) \left( \frac{A_{ps}}{A_c} \right) \left( 1 + \frac{(A_c) (e_{pc})^2}{I_c} \right) \left[ 1 + 0.7 (\Psi_b(tf,ti)) \right]}
\]

c) Steel Relaxation (\( \Delta f_{PR} \))

Relaxation is the gradual reduction of stress over time subjected under sustained strain. It occurs without the changes in the length of the steel. Relaxation is a property of the prestressing steel and is independent of concrete properties. The prestress loss due to relaxation of prestress strands between time of transfer and deck placement, shall be determined as:

\[ \Delta f_R = -2.4 \left( \frac{t_{d(td,ti)}}{100 + t_{d(td,ti)}} \right) \]

d) Shrinkage of Deck Concrete (\( \Delta f_{PSS} \))

The prestress gain due to shrinkage of deck composite section, \( \Delta f_{PSS} \), shall be determined as:

\[ \Delta f_{PSS} = \left( \frac{E_p}{E_{ci}} \right) (\Delta f_{cdf}) \left( K_{df} \right) \left[ 1 + 0.7 \ Psi_b(tf,td) \right] \]

\[ \Delta f_{cdf} = \left( \frac{E_{ddf}}{E_{dd}} \right) (A_d) \left( \frac{1}{1 + 0.7 \ Psi_d(tf,td)} \right) \left( \frac{1 + (e_{pc})(e_{d})}{I_c} \right) \]

2.5 Approximate Estimate of Time – Dependent Losses:

For standard precast, pretensioned members subject to normal loading and environmental conditions the long-term prestress loss (\( \Delta f_{P,LT} \)) due to creep of concrete, shrinkage of concrete, and relaxation of steel shall be estimated using the following formula:

\[ \Delta f_{P,LT} = 10.0 \left( \frac{f_{pi} \cdot A_{ps}}{A_g} \right) (Y_h)(Y_{st}) + 12.0 (Y_h)(Y_{st}) + \Delta f_{PR} \]

\[ Y_h = 1.7 - 0.01 H \]

\[ Y_{st} = \frac{5}{1 + f'_{ci}} \]
CHAPTER THREE
LOAD DEFINITIONS

3.1 Permanent Loads:

Permanent loads are defined as loads and forces that are either constant or varying over a long time interval upon completion of construction. They include dead load of structural components and nonstructural attachments (DC), dead load of wearing surfaces and utilities (DW).

3.2 Transient Loads:

Transient loads are defined as loads and forces that are varying over a short time interval. A transient load is any load that will not remain on the bridge indefinitely. This includes vehicular live loads (LL) and their secondary effects including dynamic load allowance (IM).

a) HL-93 Design Load:

The AASHTO HL-93 (Highway Loading adopted in 1993) load includes variations and combinations of truck, tandem, and lane loading. The design truck is a 3-axle truck with variable rear axle spacing and a total weight of 72 kips (Figure 3-1). The design lane load is 640 plf. When loading the superstructure with HL-93 loads, only one vehicle per lane is allowed on the bridge at a time.

3.3 Live Load Distribution Factor

Live load distribution factors (LLDFs) are used to calculate the live load bending moment and shear force on Bridge girders caused by moving loads. LLDFs make not only live load analysis simpler but also keep designers away from having to develop complex 3-D models of simple Bridges. Table (3-1) indicate Live load moment distribution factor as per AASHTO-LRFD 2012
Table (3.1) Live loads distribution factors for moment in interior precast I girder.

<table>
<thead>
<tr>
<th>Type of Superstructure</th>
<th>Moment Distribution Factors</th>
<th>Range of Applicability</th>
</tr>
</thead>
</table>
| Concrete Deck, Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-Beams, T and Double T-Sections | One Design Lane Loaded: \[ 0.06 + \left( \frac{S}{14} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left( \frac{K_s}{12.0L_i^2} \right)^{0.1} \]  | \[ 3.5 \leq S \leq 16.0 \]  
\[ 4.5 \leq t_s \leq 12.0 \]  
\[ 20 \leq L \leq 240 \]  
\[ N_b \geq 4 \]  
\[ 10,000 \leq K_s \leq 7,000,000 \] |
|                                                                                      | Two or More Design Lanes Loaded: \[ 0.075 + \left( \frac{S}{9.5} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2} \left( \frac{K_t}{12.0L_i^3} \right)^{0.1} \] |                                                                                   |

Where,

\( S \) = spacing of beams or webs (ft.)

\( d \) = depth of beam or stringer (in).

\( L \) = span of beam (ft).

\( N_b \) = Number of beams, stringers or girders

Figure (3.1) HS-20 Design truck
3.4 Compressive Concrete Strength Prediction with Age:

The compressive strength of concrete is usually defined in terms of its specified strength at 28 days \((f'c)_{28}\). In this study the formula adopted by ACI-209 is used to calculate compressive strength of concrete at different ages, since there is no time-dependent behavior is given by AASHTO LRFD specification.

\[
(f'c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'c)_u
\]

\[
\beta = \frac{28}{A/B + 28}
\]

\[
a = \beta \cdot \left(\frac{A}{B}\right)
\]

\((f'c)_t\): Compressive strength at any time, ksi

\(A\) : rate of strength gain,

\(B\) : grade of concrete strength

\((f'c)_u\): ultimate compressive strength, ksi
CHAPTER FOUR

DESIGN EXAMPLES

This chapter includes three examples of prestressed and post-tensioned girders to briefly explain change of stresses in prestressed strands and girder extreme fibers at different stages of loading and time according to refined method adopted by AASHTO 2012. Example one consist of simple span of prestressed girder, example two is a simple span of prestressed girder, each girder consist of three prestressed segment spliced by three tendons to work as a full span. Example three is a continuous girder bridge with one segment at each span connected by post tensioned tendon to work as a two continuous span.

4.1 Simple Span Precast – Pretensioned BT-54 Girder Bridge
(no Post-tension)

This example illustrates the typical procedure in determining change of stresses in prestressed strands and girder extreme fibers at different stages of applied load and time steps, immediate and long term losses due to concrete elastic shortening, creep, shrinkage, deck shrinkage and steel relaxation are considered according to refined method of AASHTO-LRFD 2012 Bridge specifications.

Bridge Data:

The bridge has a span length of 80 ft (from centerline of support to centerline of support). Total deck width is 35 ft, including two 12 ft traffic lanes with two 1.5 ft concrete barriers. Bridge plan and transvers section views are shown in Fig. (4-1) and Fig. (4-2) respectively.
Figure (4.1) Bridge plan.

Figure (4.2) Bridge transvers section
Figure (4-3) Prestressed BT-54 girder cross section (a) girder gross section (b) composite section

<table>
<thead>
<tr>
<th>Girder Properties</th>
<th>Deck Properties</th>
<th>Strands Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_g$</td>
<td>659 m$^2$</td>
<td>S</td>
</tr>
<tr>
<td>$I_g$</td>
<td>268077 m$^4$</td>
<td>t</td>
</tr>
<tr>
<td>$D$</td>
<td>54 m$^2$</td>
<td>$f'_c$</td>
</tr>
<tr>
<td>$y_b$</td>
<td>27.63 m$^2$</td>
<td>A/B</td>
</tr>
<tr>
<td>$y_t$</td>
<td>26.37 m$^2$</td>
<td>Wearing surface</td>
</tr>
<tr>
<td>$w_c$</td>
<td>0.15 kcf</td>
<td>$w_s$</td>
</tr>
<tr>
<td>$v/s$</td>
<td>3.15 in</td>
<td>Barrier</td>
</tr>
<tr>
<td>$f'_c$</td>
<td>7 ksi</td>
<td>$w_b$</td>
</tr>
<tr>
<td>$A/B$</td>
<td>0.71</td>
<td></td>
</tr>
</tbody>
</table>

Table (4.1) Girder, deck and strands properties
Table (4.2) Stages of Construction

<table>
<thead>
<tr>
<th>Stages #</th>
<th>Description</th>
<th>Duration (days)</th>
<th>Total Duration (days)</th>
<th>Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cut Strands (beam age =1)</td>
<td>0</td>
<td>0</td>
<td>Girder Self-wt</td>
</tr>
<tr>
<td>2</td>
<td>Time Step through forming deck</td>
<td>30</td>
<td>30</td>
<td>n/a</td>
</tr>
<tr>
<td>3</td>
<td>Pour Deck</td>
<td>0</td>
<td>30</td>
<td>Slab self-wt</td>
</tr>
<tr>
<td>4</td>
<td>Time Step</td>
<td>4000</td>
<td>4030</td>
<td>n/a</td>
</tr>
<tr>
<td>5</td>
<td>Add Future Wearing Surface + LL</td>
<td>0</td>
<td>4030</td>
<td>( w_s + LL. )</td>
</tr>
</tbody>
</table>

**STAGE - 1**

At this stage, stress change in prestressed strands (loss) due to elastic shortening of concrete, loss of stress is calculated after transfer \( (t=1^{\text{day}}) \), compressive strength \( (f'c) \) and modulus of elasticity \( (E) \) of girder concrete are calculated at transfer.

\[
\Delta f_{\text{PE}} = \left( \frac{E_p}{E_{c,t=1}} \right) (f_{\text{gig}}) - 15.63^{\text{ksi}}
\]

\[
\sigma_{\text{top}} = \frac{P_i}{A_g} + \left( \frac{P_i (e_{Pig})(y_t)}{I_g} \right) + \left( \frac{M_g (y_t)}{I_g} \right) = 0.01^{\text{ksi}} (T)
\]

\[
\sigma_{\text{bot}} = \frac{P_i}{A_g} + \left( \frac{P_i (e_{Pig})(y_b)}{I_g} \right) + \left( \frac{M_g (y_b)}{I_g} \right) = -2.28^{\text{ksi}} (C)
\]

Table (4.3) Summary of stresses of PS strands and girder extreme fibers at stage 1.
STAGE - 2

At this stage, stress changes in prestressed strands (losses) calculated from transfer \((t = 1^{\text{day}})\) to deck placement \((t = 30^{\text{day}})\). These losses attribute to girder creep, shrinkage and steel relaxation. Compressive strength \((f'c)\) and modulus of elasticity \((E_c)\) of girder concrete are calculated at transfer.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>(f'c)</th>
<th>(E_c)</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>30^{\text{day}}</td>
<td>4.2^{\text{kis}}</td>
<td>3929^{\text{kis}}</td>
<td>(\Delta f_{p_{\text{CR}}}, \Delta f_{p_{\text{SH}}}, \Delta f_{p_{\text{R}}}}</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>(\Delta f_{p_{\text{CR}}} = \left( \frac{E_p}{E_{c_{t=1}}} \right) (f_{c_{g{g, t=1}}})(b_{b(t_d,t_i)})(K_{t_{d,t_i}}) )</td>
<td>-8.62^{\text{kis}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(\Delta f_{p_{\text{SH}}} = (E_{b{i,d}})(E_p)(K_{t_{d,t_i}}) )</td>
<td>-3.83^{\text{kis}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(\Delta f_{p_{(t_d,t_i)}} = - (2.4) \left( \frac{t_{d(t_d,t_i)}}{100 + t_{d(t_d,t_i)}} \right) )</td>
<td>-0.54^{\text{kis}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress Top &amp; Bottom Girder eq.</td>
<td>(\sigma_{\text{top}} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{ps})(y_t)}{I_g} )</td>
<td>-0.046^{\text{kis}} (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(\sigma_{\text{bot}} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{ps})(y_b)}{I_g} )</td>
<td>0.21^{\text{kis}} (T)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4.4) Summary of stresses of PS strands and girder extreme fibers at stage 2.
STAGE - 3

At this stage, stress change in prestressed strands (Gain) calculated after deck placement ($t = 30^{\text{day}}$). Compressive strength ($f'c$) and modulus of elasticity ($E_c$) of girder concrete are calculated at deck placement.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>$f'c$</th>
<th>$E_c$</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Placement</td>
<td>$30^{\text{day}}$</td>
<td>7.01ksi</td>
<td>5075.8ksi</td>
<td>$\Delta f_p_{ES}$</td>
</tr>
</tbody>
</table>

### PS Strands Losses eq.

$$\Delta f_p_{ES} = \left( \frac{E_p}{E_{c,t=30}} \right) (f_{cgp})$$

Value: 3.25ksi (gain)

### Stress Top & Bottom Girder eq.

Top:

$$\sigma_{\text{top}} = \frac{\Delta P_{t=30}}{A_g} + \frac{(\Delta R_{t=30})(e_{pg})(y_t)}{I_g} + \frac{(M_{\text{deck}})(y_t)}{I_g}$$

Value: -0.65ksi (C)

Bottom:

$$\sigma_{\text{bot}} = \frac{\Delta P_{t=30}}{A_g} + \frac{(\Delta R_{t=30})(e_{pg})(y_b)}{I_g} + \frac{(M_{\text{deck}})(y_b)}{I_g}$$

Value: 0.64ksi (T)

Table (4.5) Summary of stresses of PS strands and girder extreme fibers at stage 3.
STAGE - 4

At this stage, stress change in prestressed strands (loss) calculated from deck placement \( t = 30^{\text{day}} \) to final \( t = 4030^{\text{day}} \). These losses attribute to girder creep & shrinkage, deck shrinkage and steel relaxation. Compressive strength \( f'_c \) and modulus of elasticity \( E \) of girder concrete are calculated at deck placement.

Table (4.6) Summary of stresses of PS strands and girder extreme fibers at stage 4.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>( f'_c )</th>
<th>( E_c )</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>4030^{\text{day}}</td>
<td>7.01^{\text{ksi}}</td>
<td>5075.8^{\text{ksi}}</td>
<td>( \Delta f_{pCR}, \Delta f_{pSH}, \Delta f_{pR}, \Delta f_{pss} )</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta f_{pCR} )</td>
<td>( \frac{E_p}{E_c(t=30)} \left( f_{cgp} \left[ \Psi_{b(tf,ti)} - \Psi_{b(td,ti)} \right] K_{b(tf,td)} \right) + \left( \frac{E_p}{E_c(t=30)} \right) f_{cgp} (\Psi_{b(tf,td)}) (K_{b(tf,td)}) )</td>
<td>( -7.23^{\text{ksi}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta f_{pSH} )</td>
<td>( (E_{b(tf,td)}) (E_p) (K_{tf,td}) )</td>
<td>( -5.843^{\text{ksi}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta f_{R,4} )</td>
<td>( - (2.4^{\text{ksi}}) \times \frac{t_{d(tf,ti)}}{100 + t_{d(tf,ti)}} - \Delta f_{R,2} )</td>
<td>( -1.8^{\text{ksi}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta f_{pss} )</td>
<td>( \frac{E_p}{E_c} (\Delta f_{cdf})(K_{(tf,td)}) \left[ 1 + (0.7)(\Psi_{b(tf,td)}) \right] )</td>
<td>( 2.0^{\text{ksi}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress Top &amp; Bottom Girder due to CR,SH,R</td>
<td>Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta \sigma_{top} )</td>
<td>( \frac{\Delta p}{A_c} + \frac{(\Delta p) (e_{pc})(y_{tc})}{l_c} )</td>
<td>( -0.00368^{\text{ksi}} ) (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta \sigma_{bot} )</td>
<td>( \frac{\Delta p}{A_c} + \frac{(\Delta p) (e_{pc})(y_{bc})}{l_c} )</td>
<td>( 0.188^{\text{ksi}} ) (T)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[ \sigma_{\text{top}} = (f_{\text{dSH}}) \left( \frac{1}{A_c} - \frac{(e_d)(y_{tc})}{l_c} \right) \]
\[ \sigma_{\text{bot}} = (f_{\text{dSH}}) \left( \frac{1}{A_c} - \frac{(e_d)(y_{bc})}{l_c} \right) \]

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>(f'c)</th>
<th>(E_c)</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing Surface + LL</td>
<td>4030 \text{days}</td>
<td>7.18 ksi</td>
<td>5137 ksi</td>
<td>(\Delta f_{\text{PS}})</td>
</tr>
</tbody>
</table>

Table (4.7) Summary of stresses of PS strands and girder extreme fibers at stage 5.

STAGE – 5

At this stage, stress change in prestressed strands (gain) calculated due to applying external loads of wearing surface and live load. Compressive strength \((f'c)\) and modulus of elasticity \((E_c)\) of girder concrete are calculated at final “\(t = 4030 \text{day}\)”.

\[ \Delta f_{\text{PS}} = \left( \frac{E_p}{E_{ct=4030}} \right) (f_{\text{cgp}}) \]

\[ \sigma_{\text{top}} = \left( \frac{\Delta P}{A_c} + \frac{(\Delta P)(e_{pc})(y_{tc})}{I_c} \right) + \left( \frac{(M_{LL} + M_{ws})(y_{tc})}{I_c} \right) \]

\[ \sigma_{\text{bot}} = \left( \frac{\Delta P}{A_c} + \frac{(\Delta P)(e_{pc})(y_{bc})}{I_c} \right) + \left( \frac{(0.8 \times M_{LL} + M_{ws})(y_{bc})}{I_c} \right) \]
<table>
<thead>
<tr>
<th>Stage</th>
<th>Stress Change</th>
<th>$\Delta f_p$</th>
<th>$\Sigma f_p$</th>
<th>Accu. $\Sigma f_p$</th>
<th>Girder Stresses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\sigma_{top}$</td>
</tr>
<tr>
<td>1</td>
<td>$\Delta f_{PES}$</td>
<td>-15.63 ksi</td>
<td>-15.63 ksi</td>
<td>-15.63 ksi</td>
<td>+0.01 ksi</td>
</tr>
<tr>
<td>2</td>
<td>$\Delta f_{CR}$</td>
<td>-8.62 ksi</td>
<td>-12.97 ksi</td>
<td>-12.97 ksi</td>
<td>-0.046 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{SH}$</td>
<td>-3.83 ksi</td>
<td>-28.62 ksi</td>
<td>-28.62 ksi</td>
<td>-0.01 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{R}$</td>
<td>-0.54 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$\Delta f_{PES}$</td>
<td>+3.25 ksi</td>
<td>+3.25 ksi</td>
<td>-25.37 ksi</td>
<td>-0.65 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{CR}$</td>
<td>+7.23 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{SH}$</td>
<td>-5.84 ksi</td>
<td>-12.86 ksi</td>
<td>-12.86 ksi</td>
<td>0.003 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{R}$</td>
<td>-1.8 ksi</td>
<td>-38.23 ksi</td>
<td>-38.23 ksi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{PSS}$</td>
<td>+2.0 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$\Delta f_{PES}$</td>
<td>+1.3 ksi</td>
<td>+1.3 ksi</td>
<td>-36.9 ksi</td>
<td>-0.46 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{CR}$</td>
<td>-7.23 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{SH}$</td>
<td>-5.84 ksi</td>
<td>-12.86 ksi</td>
<td>-12.86 ksi</td>
<td>0.003 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{R}$</td>
<td>-1.8 ksi</td>
<td>-38.23 ksi</td>
<td>-38.23 ksi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{PSS}$</td>
<td>+2.0 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$\Delta f_{PES}$</td>
<td>+1.3 ksi</td>
<td>+1.3 ksi</td>
<td>-36.9 ksi</td>
<td>-0.46 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{CR}$</td>
<td>-7.23 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{SH}$</td>
<td>-5.84 ksi</td>
<td>-12.86 ksi</td>
<td>-12.86 ksi</td>
<td>0.003 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{R}$</td>
<td>-1.8 ksi</td>
<td>-38.23 ksi</td>
<td>-38.23 ksi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{PSS}$</td>
<td>+2.0 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4.8) Summary of stresses of prestressed strands and extreme fiber stresses of concrete girder.
Figure (4.4): Stress versus time in the strands in a pretensioned concrete girder
Figure (4-4) illustrates change of stresses in prestressed strands (loss & gain stresses) versus time as explained in the following stages:

a- **Stage 1**: Initially the strands stressed to “$0.75 \ f_{pu} = 202.5 \text{ ksi}$”. At transfer “cut strands” The prestressed girder subjects to elastic shortening causing a reduction in prestressed strands stress equal to $15.6 \text{ ksi}$, approximately 7.7% of initial strands stresses

b- **Stage 2**: for the period between transfer ($t = 1 \text{ day}$) and before deck placement ($t = 31 \text{ day}$), prestressed strands keep losing stresses gradually due to Creep, shrinkage of concrete, and strands relaxation, the amount of these losses are $13 \text{ ksi}$, which constitutes about 6.4% of initial stresses.

c- **Stage 3**: Prestressed strands gain an immediate stress after deck placement “$t=31 \text{ days}$”, the graph indicates that about $3.25 \text{ ksi}$ stress increment achieved in prestressed strands at this stage. This increment is about 1.6% of initial stress.

d- **Stage 4**: for the period between deck placement ($t = 31 \text{ day}$) and before applying wearing surface and Live load ($t = 4030 \text{ day}$), the graph shows a gradual stress reduction in prestressed strands in the process of time due to creep, shrinkage of concrete girder and steel relaxation, these accumulated losses equal to $14.87 \text{ ksi}$. It is noted that deck shrinkage contribute inversely by increasing stresses in prestressed strands (gain stresses) to about $2 \text{ ksi}$. The difference in slope between stage 2 and 4 attribute to deck shrinkage. The net prestress losses at this stage is $12.87 \text{ ksi}$ which constitute about 6.35% of total initial stresses.

e- **Stage 5**: Finally, the graph illustrates that the prestressed strands gain stresses due to external loads of wearing surface, the amount of stresses received is about $1.3 \text{ ksi}$ which equal to 0.64% of initial stresses.
Figure (4.5): Stress versus time in the top & bottom of pretensioned concrete girder
Figure (4-5) illustrates top & bottom girder stresses at mid span versus time as below,

a) **Stage 1**: At release (cut strands), bottom fiber subject to compression stress equal to $2.28\text{ksi}$, while top fiber subject to tension stress equal to $0.01\text{ksi}$. Both stresses are within the allowable service limit state of AASHTO 2012 Specification.

b) **Stage 2**: After cut strands ($t = 1\text{ day}$) and before deck placement ($t = 30\text{ days}$), compression stress at bottom surface gradually reduced to amount of $2.07\text{ksi}$ approximately $9\%$ reduction from initial stresses, while top surface stress changed from tension to compression stress “$0.036\text{ksi}”$. This change of stresses attribute to creep, shrinkage of concrete and steel relaxation.

c) **Stage 3**: at deck placement ($t = 30\text{days}$), the graph illustrates a sudden increment in compression stress at top girder fiber equal to $0.65\text{ksi}$, and an immediate tension stress at bottom fiber equal to “$0.64\text{ksi}$”. These changes in stresses lead to increase compression stress at top fiber of girder to $0.69\text{ksi}$ and reduces existing compression stress from $2.07\text{ksi}$ to $1.43\text{ksi}$ at bottom girder.

d) **Stage 4**: After deck placement the graph illustrate a gradual increase in compression stresses at top fiber from $0.69\text{ksi}$ to $1.27\text{ksi}$ (45% increment) and gradual decrease in compression stresses at bottom fiber from $1.43\text{ksi}$ to $1.04\text{ksi}$ (27% decrease) these changes contribute to creep, shrinkage of concrete and steel relaxation in addition to deck shrinkage which cause compression at top face and tension at bottom.

e) **Stage 5**: live load and wearing surface increase compression stresses at top surface from $1.27\text{ksi}$ to $1.74\text{ksi}$ with increment of $0.47\text{ksi}$ and changing compression stresses from $1.04\text{ksi}$ to tension stresses of $0.08\text{ksi}$ in bottom surface.
Pie chart shows that creep of concrete has a significant effect on prestressed strands losses, it participates about 41% of total prestress losses, while the remaining prestress losses distributed between concrete girder shrinkage 25%, concrete elastic shortening 28% and steel relaxation 6%.

Table (4-9) and figure (4-7) compare between software program “Leap-Consplice” and hand calculation results of prestressed strands losses, table (4-10) and figure (4-8) illustrate the difference of extreme fibers stresses of concrete girder obtained from the two methods of calculation.
### Prestressed Strands Losses, ksi

<table>
<thead>
<tr>
<th>Stage</th>
<th>Status</th>
<th>Time, day</th>
<th>Manual Calc, ksi</th>
<th>Leap-Consplice</th>
<th>% Diff., ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cut Strands</td>
<td>1</td>
<td>-15.63</td>
<td>-15.63</td>
<td>0.00%</td>
</tr>
<tr>
<td>2</td>
<td>Time Step</td>
<td>30</td>
<td>-28.62</td>
<td>-28.63</td>
<td>0.52%</td>
</tr>
<tr>
<td>3</td>
<td>Pour Deck</td>
<td>30</td>
<td>-25.37</td>
<td>-25.43</td>
<td>0.58%</td>
</tr>
<tr>
<td>4</td>
<td>Time Step</td>
<td>4030</td>
<td>-38.23</td>
<td>-37.62</td>
<td>2.13%</td>
</tr>
<tr>
<td>5</td>
<td>Wearing Surface</td>
<td>4030</td>
<td>-36.90</td>
<td>-36.31</td>
<td>1.35%</td>
</tr>
</tbody>
</table>

Table (4.9) Comparison of prestressed strands losses calculated manually versus Leap-Consplice software results.

### Top & Bottom Girder Stresses, ksi

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>-2.28</td>
<td>-2.28</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>-0.036</td>
<td>-0.03</td>
<td>0.00</td>
<td>-2.07</td>
<td>-2.07</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>-0.69</td>
<td>-0.68</td>
<td>0.00</td>
<td>-1.43</td>
<td>-1.43</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>-1.27</td>
<td>-1.33</td>
<td>0.06</td>
<td>-1.04</td>
<td>-1.04</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>-1.74</td>
<td>-1.89</td>
<td>0.15</td>
<td>0.16</td>
<td>-1.89</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table (4.10) Comparison of top and bottom girder stresses calculated manually versus Leap-Consplice software results.
Figure (4.7): Comparison of Leap Con splice & manual results of strands stress changes with time
Figure (4.8): Comparison of Leap Consplice & manual result at top & bottom of concrete girder
4.2 Simple Span of Spliced Pretensioned Girder Bridge W24PTMG:

Bridge Data (3 Segments PS & PT):

The bridge has a total span length of 194.5\(^{\circ}\). (From centerline of left support to centerline of right support), the span consist of three prestressed segments connected by three post-tensioned tendons. Total deck width is 45\(^{\circ}\), including two 12\(^{\circ}\) traffic lanes with two 1.5\(^{\circ}\) concrete barriers. Bridge elevation and cross section are shown in Fig 4-9.

This example illustrates the procedure in determining strands losses and girder top & Bottom stresses of spliced girder bridge at every stage of applied load and strain due to creep, shrinkage, and steel relaxation at mid span.

Figure (4.9) Bridge elevation and cross section.
Figure (4.10) Girder cross section
<table>
<thead>
<tr>
<th>Girder Properties</th>
<th>Strands Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_g$</td>
<td>1211 $\text{in}^2$</td>
</tr>
<tr>
<td>$I_g$</td>
<td>144719 $\text{in}^4$</td>
</tr>
<tr>
<td>D</td>
<td>94.49in</td>
</tr>
<tr>
<td>$y_b$</td>
<td>45.64 $\text{in}^2$</td>
</tr>
<tr>
<td>$y_t$</td>
<td>48.85 $\text{in}^2$</td>
</tr>
<tr>
<td>$w_c$</td>
<td>0.15 $\text{kcf}$</td>
</tr>
<tr>
<td>v/s</td>
<td>3.61 $\text{in}$</td>
</tr>
<tr>
<td>$f'_c$</td>
<td>9 $\text{ksi}$</td>
</tr>
<tr>
<td>A/B</td>
<td>0.71</td>
</tr>
<tr>
<td>Cement Type</td>
<td>I</td>
</tr>
<tr>
<td>Deck Properties</td>
<td># Strands/Tendons 19</td>
</tr>
<tr>
<td>S</td>
<td>6.89 $\text{ft}$</td>
</tr>
<tr>
<td>t</td>
<td>8 $\text{in}$</td>
</tr>
<tr>
<td>$f'_c$</td>
<td>4 $\text{ksi}$</td>
</tr>
<tr>
<td>A/B</td>
<td>4.71</td>
</tr>
<tr>
<td>Cement Type</td>
<td>III</td>
</tr>
</tbody>
</table>

| Type | Low Relax. | Dia. | 0.6 $\text{in}$ |
| A_b | 0.217 $\text{in}^2$ | 28500 $\text{ksi}$ |
| $f_{pu}$ | 270 $\text{ksi}$ |
| PS | # Strands 10 |
| As, total | 2.17 $\text{in}^2$ |
| Conc. Cover | 3 $\text{in}$ |
| PT | # Tendons 3 |
| Conc. Cover | 10.48 $\text{in}$ |

Table (4.11) Girder, deck and strands properties

Wearing surface ($w_s$) = 0.24 $\text{k/ft}$
Barrier weight = 0.12 $\text{k/ft}$
Humidity =80%
Live Load: Design Truck (HS20), Design Lane.
Segment 1 length: 45’- 1”
Segment 2 length: 101’ – 4”
Segment 3 length: 45’ – 1”
Table (4.12) Stages of construction.

**STAGE -1-**

At this stage, stress change in prestressed strands (losses) calculated after transfer ($t = 1^{\text{day}}$) due to Elastic Shortening. Compressive strength ($f'_c$) and modulus of elasticity ($E_c$) of girder concrete are calculated at transfer. Span length is 101.3 ft.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>$f'_c$</th>
<th>$E_c$</th>
<th>Change of stress</th>
<th>PS Strands Losses eq.</th>
<th>Top &amp; Bottom Girder Stress eq.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cut Strands</strong></td>
<td>1$^{\text{day}}$</td>
<td>5.4ksi</td>
<td>4455ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Change of stress</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\Delta f_{\text{PES}}$</td>
<td>$\sigma_{\text{top}}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\Delta f_{\text{PES}} = \left( \frac{E_p}{E_c t=1} \right) (f_{cgp})$</td>
<td>$\sigma_{\text{top}} = \frac{P_i}{A_g} + \frac{(P_i)(e_{pg})(y_t)}{I_g} + \frac{(M_g)(y_t)}{I_g}$</td>
</tr>
<tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\Delta f_{\text{PES}} = -2.143^{\text{ksi}}$</td>
<td>$\sigma_{\text{top}} = -0.39^{\text{ksi}} (C)$</td>
</tr>
<tr>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\sigma_{\text{bot}} = \frac{P_i}{A_g} + \frac{(P_i)(e_{pg})(y_b)}{I_g} + \frac{(M_g)(y_b)}{I_g}$</td>
<td>$\sigma_{\text{bot}} = -0.33^{\text{ksi}} (C)$</td>
</tr>
</tbody>
</table>

Table (4.13) Summary of stresses of PS strands and girder extreme fibers at stage 1.
**STAGE -2-**

At this stage, stress changes in prestressed strands (losses) calculated from transfer \((t = 1^{day})\) to deck placement \((t = 21^{day})\). These losses caused by girder creep “\(\Delta f_{PCR}\)”, shrinkage “\(\Delta f_{PSH}\)” and steel relaxation “\(\Delta f_{R}\)”. Span length is 101.3\(\text{ft}\).

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>(\gamma_c)</th>
<th>(E_c)</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>(21^{day})</td>
<td>5.4(\text{ksi})</td>
<td>4455(\text{ksi})</td>
<td>(\Delta f_{PCR}, \Delta f_{PSH}, \Delta f_{R})</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td></td>
<td></td>
<td></td>
<td>Value</td>
</tr>
<tr>
<td>(\Delta f_{PCR} = \left( \frac{E_p}{E_{c,t=1}} \right) f_{cgp,t=1} (\Psi_{b(td,ti)}(K_{td,ti})) )</td>
<td></td>
<td></td>
<td>-0.93(\text{ksi})</td>
<td></td>
</tr>
<tr>
<td>(\Delta f_{PSH} = (\epsilon_{bid})(E_p)(K_{td,ti}) )</td>
<td></td>
<td></td>
<td>-3.0(\text{ksi})</td>
<td></td>
</tr>
<tr>
<td>(\Delta f_{R(td,ti)} = - (2.4) \left( \frac{t_{d(td,ti)}}{100 + t_{d(td,ti)}} \right) )</td>
<td></td>
<td></td>
<td>-0.4(\text{ksi})</td>
<td></td>
</tr>
<tr>
<td>Stress Top &amp; Bottom Girder eq.</td>
<td></td>
<td></td>
<td></td>
<td>Value</td>
</tr>
<tr>
<td>(\sigma_{top} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{ps})(y_t)}{I_g} )</td>
<td></td>
<td></td>
<td>-0.006(\text{ksi}) (C)</td>
<td></td>
</tr>
<tr>
<td>(\sigma_{bot} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{ps})(y_b)}{I_g} )</td>
<td></td>
<td></td>
<td>0.020(\text{ksi}) (T)</td>
<td></td>
</tr>
</tbody>
</table>

Table (4.14) Summary of stresses of PS strands and girder extreme fibers at stage 2.
STAGE -3-

At this stage, stress change in prestressed strands (Gain) calculated after deck placement \( t = 21^{\text{days}} \). Compressive strength \( f_c' \) and modulus of elasticity \( E_c \) of girder concrete are calculated at deck placement. Span length is 101.3 ft.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>( f_c' )</th>
<th>( E_c )</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Placement</td>
<td>21(^{\text{day}})</td>
<td>8.93 ksi</td>
<td>5729 ksi</td>
<td>( \Delta f_{p_{ES}} )</td>
</tr>
</tbody>
</table>

\[
\Delta f_{p_{ES}} = \left( \frac{E_p}{E_{c,t=21}} \right) (f_{cgp}) = 1.537 \text{ ksi (gain)}
\]

<table>
<thead>
<tr>
<th>Top &amp; Bottom Girder eq.</th>
<th>Value</th>
<th>Bottom Girder eq.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{top}} = \frac{\Delta P_{t=21}}{A_g} + \left( \frac{\Delta P_{t=21}}{A_g} \right) (e_{pg})(y_t) + \left( \frac{M_{deck}}{I_g} \right) (y_c) )</td>
<td>-0.36 ksi (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sigma_{\text{bot}} = \frac{\Delta P_{t=21}}{A_g} + \left( \frac{\Delta P_{t=21}}{A_g} \right) (e_{pg})(y_b) + \left( \frac{M_{deck}}{I_g} \right) (y_b) )</td>
<td>0.327 ksi (T)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4.15) Summary of stresses of PS strands and girder extreme fibers at stage 3.
**STAGE -4-**

At this stage, stress change in prestressed strands (losses) calculated from deck placement \((t = 21^{\text{day}})\) to post-tensioning \((t = 35^{\text{day}})\). These losses attribute to girder creep “\(\Delta f_{\text{PCR}}\)” & shrinkage “\(\Delta f_{\text{PSH}}\)”, deck shrinkage “\(\Delta f_{\text{Pss}}\)” and steel relaxation “\(\Delta f_{\text{pR}}\)”. Compressive strength \((f'c)\) and modulus of elasticity \((E_c)\) of girder concrete are calculated at deck placement. Span length is \(101.3^{\text{ft}}\).

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>(f'c)</th>
<th>(E_c)</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>(35^{\text{day}})</td>
<td>(8.926^{\text{ksi}})</td>
<td>(5727.8^{\text{ksi}})</td>
<td>(\Delta f_{\text{PCR}}, \Delta f_{\text{PSH}}, \Delta f_{\text{Pss}}, \Delta f_{\text{pR}})</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\Delta f_{\text{PCR}})</td>
<td>(\left(\frac{E_p}{E_{c(t=21)}}\right)(f_{\text{cgp},t=1})<a href="K_%7Bb(tp,td)%7D">\Psi_{b(tp,ti)} - \Psi_{b(td,ti)}</a> + \left(\frac{E_p}{E_{c(t=21)}}\right)(f_{\text{cgp},t=21})(\Psi_{b(tp,td)})(K_{b(tp,td)}))</td>
<td>(0.093^{\text{ksi}})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\Delta f_{\text{PSH}})</td>
<td>(\left(\epsilon_{b(tp,td)}\right)(E_p)(K_{tp,td}))</td>
<td>(-1.1^{\text{ksi}})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\Delta f_{\text{pR}})</td>
<td>(-\left(2.4^{\text{ksi}}\right)\left(\frac{t_{d(tp,ti)}}{100 + t_{d(tp,ti)}}\right) - \Delta f_{R2})</td>
<td>(-0.21^{\text{ksi}})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4.16) Summary of stresses of PS strands and girder extreme fibers at stage 4.
\[
\Delta f_{\text{ps}}(t_{\text{f,curr}}) = \left( \frac{E_p}{E_c} \right) (\Delta f_c) (K_d) \left[ 1 + 0.7 (\Psi_{b(t_{\text{f,td}})}) (k_{(t_{\text{f,curr}})}) \right] = 0.197 \text{ksi}
\]

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder due to CR, SH, R</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{\text{top}} = \frac{\Delta P}{A_g} \frac{(\Delta P)(e_{PS})(y_t)}{l_g} )</td>
<td>-0.0016 \text{ksi (C)}</td>
</tr>
<tr>
<td>(\sigma_{\text{bot}} = \frac{\Delta P}{A_g} \frac{(\Delta P)(e_{PS})(y_b)}{l_g} )</td>
<td>0.0057 \text{ksi (T)}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder due to Deck Shrinkage</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{\text{top}}(t_f, t_{\text{d,cur}}) = f_{\text{d,SH}} \left( \frac{1}{A_c} - \frac{(y_c)(e_d)}{I_c} \right) (k_{(t_{\text{d,cur}})}) )</td>
<td>-0.055 \text{ksi}</td>
</tr>
<tr>
<td>(\sigma_{\text{bot}}(t_f, t_{\text{d,cur}}) = f_{\text{d,SH}} x \left( \frac{1}{A_c} - \frac{(y_{bc})(e_d)}{I_c} \right) (k_{(t_{\text{d,cur}}, tp)} )</td>
<td>0.0176 \text{ksi}</td>
</tr>
</tbody>
</table>

**STAGE -5-**

At this stage, stress change in prestressed strands “PS, PT” (losses) due to post tension stress and falsework removal at \((t = 35\text{days})\). Compressive strength \((f'_c)\) and modulus of elasticity \((E_c)\) of girder concrete are calculated at Post-tension stresses and falsework removal. Span length is \(195^g\)
<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>$f_c$</th>
<th>$E_c$</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT &amp; Falsework Removal</td>
<td>35$^{\text{day}}$</td>
<td>9.05$^{\text{ksi}}$</td>
<td>5765.7$^{\text{ksi}}$</td>
<td>$\Delta f_{\text{PS}}$</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td>-10.92$^{\text{ksi}}$</td>
</tr>
<tr>
<td>PT Strands Losses eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td>2.5$^{\text{ksi}}$</td>
</tr>
<tr>
<td>$\Delta f_{\text{PS}} = 2(\Delta f_{\text{pi}})(R)(X)$</td>
<td></td>
<td></td>
<td></td>
<td>6.134$^{\text{ksi}}$</td>
</tr>
<tr>
<td>$\Delta f_{\text{ES}} = \frac{(N - 1)}{2N} \left( \frac{E_p}{E_{ct=35}} \right)(f_{\text{cgp}})$</td>
<td>Value</td>
<td></td>
<td></td>
<td>3.65$^{\text{ksi}}$</td>
</tr>
<tr>
<td>Stress Top &amp; Bottom Girder eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td>$-0.92^{\text{ksi}}$ (C)</td>
</tr>
<tr>
<td>$\sigma_{\text{top}} = \frac{P_{\text{PT}}}{A_c} + \frac{P_{\text{PT}}(e_{\text{PT,c}})(y_{tc})}{I_c} + \frac{(M_{\text{fwr}})(y_{tc})}{I_c}$</td>
<td></td>
<td></td>
<td></td>
<td>$-2.25^{\text{ksi}}$ (T)</td>
</tr>
</tbody>
</table>

Table (4.17) Summary of stresses of PS strands and girder extreme fibers at stage 5.

**STAGE -6-

At this stage, stress change in prestressed and post-tensioned strands (losses) calculated from Post tensioning ($t = 35^{\text{day}}$) to final ($t = 4035^{\text{day}}$). These losses attribute to girder creep & shrinkage, deck shrinkage and steel relaxation. Compressive strength ($f_c$) and modulus of elasticity ($E_c$) of girder concrete are calculated at Post-tensioning. Span length is $195^{\text{ft}}$. 

Table (4.18) Summary of stresses of PS strands and girder extreme fibers at stage 6.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>f'c</th>
<th>E_c</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>4035&lt;sup&gt;day&lt;/sup&gt;</td>
<td>9.05&lt;sup&gt;k&lt;/sup&gt;i</td>
<td>5765.7&lt;sup&gt;k&lt;/sup&gt;i</td>
<td>Δf&lt;sub&gt;CR&lt;/sub&gt;, Δf&lt;sub&gt;SH&lt;/sub&gt;, Δf&lt;sub&gt;R&lt;/sub&gt;, Δf&lt;sub&gt;ss&lt;/sub&gt;</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δf&lt;sub&gt;CR&lt;/sub&gt;</td>
<td>(E&lt;sub&gt;p&lt;/sub&gt;)&lt;sub&gt;E&lt;sub&gt;ct=35&lt;/sub&gt;&lt;/sub&gt; (f&lt;sub&gt;cgp,t=1&lt;/sub&gt;) [ψ&lt;sub&gt;b(tf,ti)&lt;/sub&gt; - ψ&lt;sub&gt;b(tp,ti)&lt;/sub&gt;] (K&lt;sub&gt;b(tp,tp)&lt;/sub&gt;)</td>
<td>-9.45&lt;sup&gt;k&lt;/sup&gt;i</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ (E&lt;sub&gt;p&lt;/sub&gt;)&lt;sub&gt;E&lt;sub&gt;ct=35&lt;/sub&gt;&lt;/sub&gt; (f&lt;sub&gt;cgp,t=21&lt;/sub&gt;) [ψ&lt;sub&gt;b(tf,td)&lt;/sub&gt; - ψ&lt;sub&gt;b(tp,td)&lt;/sub&gt;] (K&lt;sub&gt;b(tp,tf)&lt;/sub&gt;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ (E&lt;sub&gt;p&lt;/sub&gt;)&lt;sub&gt;E&lt;sub&gt;ct=35&lt;/sub&gt;&lt;/sub&gt; (f&lt;sub&gt;cgp,t=35&lt;/sub&gt;) [ψ&lt;sub&gt;b(tf,tp)&lt;/sub&gt;] (K&lt;sub&gt;b(tp,tf)&lt;/sub&gt;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δf&lt;sub&gt;SH&lt;/sub&gt; = (ε&lt;sub&gt;bpf&lt;/sub&gt;) (E&lt;sub&gt;p&lt;/sub&gt;) (K&lt;sub&gt;pf&lt;/sub&gt;)</td>
<td>-4.79&lt;sup&gt;k&lt;/sup&gt;i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δf&lt;sub&gt;PS&lt;/sub&gt; = - 2.4 x (t&lt;sub&gt;d(tf,tp)&lt;/sub&gt; - t&lt;sub&gt;d(tf,td)&lt;/sub&gt;) - Δf&lt;sub&gt;R1&lt;/sub&gt; - Δf&lt;sub&gt;R2&lt;/sub&gt;</td>
<td>-1.73&lt;sup&gt;k&lt;/sup&gt;i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δf&lt;sub&gt;ss&lt;/sub&gt; = (E&lt;sub&gt;p&lt;/sub&gt;)&lt;sub&gt;E&lt;sub&gt;ct=28&lt;/sub&gt;&lt;/sub&gt; (Δf&lt;sub&gt;cdt&lt;/sub&gt;) (K&lt;sub&gt;(tf,td)&lt;/sub&gt;)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.3&lt;sup&gt;k&lt;/sup&gt;i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 0.7 x ψ&lt;sub&gt;b(tf,tdcur)&lt;/sub&gt; [K&lt;sub&gt;(tf,tdcur)&lt;/sub&gt; - K&lt;sub&gt;(tp,tdcur)&lt;/sub&gt;]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT Strands Losses eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δf&lt;sub&gt;CR&lt;/sub&gt; = (E&lt;sub&gt;p&lt;/sub&gt;)&lt;sub&gt;E&lt;sub&gt;ct=35&lt;/sub&gt;&lt;/sub&gt; (f&lt;sub&gt;cgp,t=35&lt;/sub&gt;) [ψ&lt;sub&gt;b(tf,tp)&lt;/sub&gt;] (K&lt;sub&gt;b(tp,tf)&lt;/sub&gt;)</td>
<td>-9.37&lt;sup&gt;k&lt;/sup&gt;i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δf&lt;sub&gt;SH&lt;/sub&gt; = (ε&lt;sub&gt;bpf&lt;/sub&gt;) (E&lt;sub&gt;p&lt;/sub&gt;) (K&lt;sub&gt;pf&lt;/sub&gt;)</td>
<td>-4.79&lt;sup&gt;k&lt;/sup&gt;i</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[
\Delta f_{RPT} = -2.4 \times \frac{t_d(t_f,t_p)}{100 + t_d(t_f,t_p)} \quad -2.34^{\text{ksi}}
\]

\[
\Delta f_{p_{SS}} = \left(\frac{E_p}{E_{ct=28}}\right) \left(\Delta f_{cdf}(K_{t(t_p)})\right) \left[1 + 0.7 x \Psi_{h(t_f,td,cur)} \left[k_{tt(t_f,td,cur)} - k_{tt(tp,td,cur)}\right]\right] \quad 1.3^{\text{ksi}}
\]

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder due to CR,SH,R</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta \sigma_{\text{top}}) = (\frac{\Delta P_S}{A_c} + \frac{(\Delta P_S)(e_{PS,c})(y_{tc})}{I_c}) (+\left(\frac{\Delta P_T}{A_c} + \frac{(\Delta P_T)(e_{PT,c})(y_{tc})}{I_c}\right))</td>
<td>-0.029^{\text{ksi}} (C)</td>
</tr>
<tr>
<td>(\Delta \sigma_{\text{bot}}) = (\frac{\Delta P_S}{A_c} + \frac{(\Delta P_S)(e_{PS,c})(y_{bc})}{I_c}) (+\left(\frac{\Delta P_T}{A_c} + \frac{(\Delta P_T)(e_{PT,c})(y_{bc})}{I_c}\right))</td>
<td>0.412^{\text{ksi}} (T)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder due to Deck Shrinkage</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{\text{top}}(t_f,td,cur) = (f_{dSH})\left(\frac{1}{A_c} - \frac{(y_{tc})(e_d)}{I_c}\right)\left(k_{d(t_f,td)}\right)) (-k_{(tp,td,cur)})</td>
<td>-0.364^{\text{ksi}}</td>
</tr>
<tr>
<td>(\sigma_{\text{bot}}(t_f,td,cur) = (f_{dSH})\left(\frac{1}{A_c} - \frac{(y_{bc})(e_d)}{I_c}\right)\left(k_{d(t_f,td)}\right)) (-k_{(tp,td,cur)})</td>
<td>0.117^{\text{ksi}}</td>
</tr>
</tbody>
</table>
STAGE 7

At this stage, stress change in prestressed and post-tensioned strands (gain) calculated due to applying external loads of wearing surface and live load. Compressive strength ($f'_c$) and modulus of elasticity ($E_c$) of girder concrete are calculated at “$t = 4035^{\text{day}}$”. Span length is 195 ft.

Table (4.19): Summary of stresses of PS strands and girder extreme fibers at stage 7.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>$f'_c$</th>
<th>$E_c$</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing Surface &amp; Live Load</td>
<td>4035^{day}</td>
<td>9.227 ksci</td>
<td>5823.3 ksci</td>
<td>$\Delta f_{\text{PS,PS}}, \Delta f_{\text{PS,PT}}$</td>
</tr>
<tr>
<td>$M_{\text{WC}}$</td>
<td>$M_{\text{LL(HS20)}}$</td>
<td>$M_{\text{Lane}}$</td>
<td>LLDF</td>
<td>$M_{\text{Total}}$</td>
</tr>
<tr>
<td>1702.36^{kft}</td>
<td>3221^{kft}</td>
<td>3026.42^{kft}</td>
<td>0.581</td>
<td>4247.3^{kft}</td>
</tr>
</tbody>
</table>

PS Strands Losses eq. Value

$$\Delta f_{\text{PS}} = \frac{E_p}{E_{c,t=4035}} (f_{\text{cgp}})$$

Value: 2.54 ksci

PT Strands Losses eq. Value

$$\Delta f_{\text{PT}} = \frac{2N}{N+1} \left( \frac{E_p}{E_{c,t=4035}} \right) (f_{\text{cgp}})$$

Value: 0.73 ksci

Stress Top & Bottom Girder eq. Value

$$\sigma_{\text{top}} = \left( \frac{(M_{\text{LL}})(y_{tc})}{I_c} + \frac{(M_{\text{ws}})(y_{tc})}{I_c} \right) + \left[ \frac{\Delta P_{\text{PS}}}{A_c} (\frac{f_{\text{PS,c}}(y_{tc})}{I_c}) \right] + \left[ \frac{\Delta P_{\text{PT}}}{A_c} (\frac{e_{\text{PT,c}}(y_{tc})}{I_c}) \right]$$

Value: -1.06 ksci (C)
\[ \sigma_{\text{bot}} = \left( \frac{(M_{LL})(y_{bc})}{I_c} + \frac{(M_{ws})(y_{bc})}{I_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{bc})}{I_c} \right] + \left[ \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{bc})}{I_c} \right] \]

\[ 1.60^{\text{ksi}} (T) \]

<table>
<thead>
<tr>
<th>Stage</th>
<th>Stress Change</th>
<th>( \Delta f_{p,PS} )</th>
<th>( \Sigma \Delta f_{PS} )</th>
<th>Accu. ( \Sigma \Delta f_{PS} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \Delta f_{p,ES} )</td>
<td>-2.143^{\text{ksi}}</td>
<td>-2.143^{\text{ksi}}</td>
<td>-2.143^{\text{ksi}}</td>
</tr>
<tr>
<td>2</td>
<td>( \Delta f_{p,CR} )</td>
<td>-0.93^{\text{ksi}}</td>
<td>-4.33^{\text{ksi}}</td>
<td>-6.473^{\text{ksi}}</td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,SH} )</td>
<td>-3.00^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,R} )</td>
<td>-0.40^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>( \Delta f_{p,ES} )</td>
<td>+1.537^{\text{ksi}}</td>
<td>+1.537^{\text{ksi}}</td>
<td>-4.936^{\text{ksi}}</td>
</tr>
<tr>
<td>4</td>
<td>( \Delta f_{p,CR} )</td>
<td>+0.093^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,SH} )</td>
<td>-1.10^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,R} )</td>
<td>-0.21^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,SS} )</td>
<td>+0.197^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>( \Delta f_{p,ES} )</td>
<td>-10.92^{\text{ksi}}</td>
<td>-10.92^{\text{ksi}}</td>
<td>-16.87^{\text{ksi}}</td>
</tr>
<tr>
<td>6</td>
<td>( \Delta f_{p,CR} )</td>
<td>-9.45^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,SH} )</td>
<td>-4.79^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,R} )</td>
<td>-1.73^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{p,SS} )</td>
<td>+1.30^{\text{ksi}}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>( \Delta f_{p,ES} )</td>
<td>+2.54^{\text{ksi}}</td>
<td>2.54^{\text{ksi}}</td>
<td>-29.00^{\text{ksi}}</td>
</tr>
</tbody>
</table>

Table (4.20) Summary of losses of prestressed strands
### Table (4.21) Summary of losses of post-tensioned strands

<table>
<thead>
<tr>
<th>Stage</th>
<th>Stress Change</th>
<th>Δf&lt;sub&gt;pES&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;pAS&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;pF&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;CR&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;SH&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;R&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;pss&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;pES&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;pAS&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;pF&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;CR&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;SH&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;R&lt;/sub&gt;</th>
<th>Δf&lt;sub&gt;pss&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Δf&lt;sub&gt;pES&lt;/sub&gt;</td>
<td>-3.65 ksi</td>
<td>-2.5 ksi</td>
<td>-6.134 ksi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+0.73 ksi</td>
<td>0.73 ksi</td>
<td>-26.75 ksi</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6</td>
<td>Δf&lt;sub&gt;pES&lt;/sub&gt;</td>
<td>16.5 ksi</td>
<td>-15.2 ksi</td>
<td>-27.48 ksi</td>
<td></td>
<td></td>
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</table>

### Table (4.22) Summary of top and bottom girder stresses

<table>
<thead>
<tr>
<th>Stage</th>
<th>Stress Change</th>
<th>σ&lt;sub&gt;top&lt;/sub&gt;</th>
<th>Σσ&lt;sub&gt;top&lt;/sub&gt;</th>
<th>σ&lt;sub&gt;bot&lt;/sub&gt;</th>
<th>Σσ&lt;sub&gt;bot&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Δf&lt;sub&gt;pES&lt;/sub&gt;</td>
<td>-0.39 ksi</td>
<td>-0.39 ksi</td>
<td>-0.33 ksi</td>
<td>-0.33 ksi</td>
</tr>
<tr>
<td>2</td>
<td>Δf&lt;sub&gt;pCR&lt;/sub&gt;</td>
<td>-0.006 ksi</td>
<td>-0.396 ksi</td>
<td>+0.020 ksi</td>
<td>-0.31 ksi</td>
</tr>
<tr>
<td></td>
<td>Δf&lt;sub&gt;pSH&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Δf&lt;sub&gt;pR&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Δf&lt;sub&gt;pES&lt;/sub&gt;</td>
<td>-0.36 ksi</td>
<td>-0.756 ksi</td>
<td>+0.327 ksi</td>
<td>+0.017 ksi</td>
</tr>
<tr>
<td>4</td>
<td>Δf&lt;sub&gt;pCR&lt;/sub&gt;</td>
<td>-0.0016 ksi</td>
<td>-0.806 ksi</td>
<td>+0.0057 ksi</td>
<td>+0.0233 ksi</td>
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<tr>
<td></td>
<td>Δf&lt;sub&gt;pSH&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Δf&lt;sub&gt;pR&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Δf&lt;sub&gt;pss&lt;/sub&gt;</td>
<td>-0.055 ksi</td>
<td>+0.0176 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Δf&lt;sub&gt;pES&lt;/sub&gt;</td>
<td>-0.92 ksi</td>
<td>-1.726 ksi</td>
<td>-2.25 ksi</td>
<td>-2.21 ksi</td>
</tr>
<tr>
<td>6</td>
<td>Δf&lt;sub&gt;pCR&lt;/sub&gt;</td>
<td>-0.0294 ksi</td>
<td>-2.123 ksi</td>
<td>+0.412 ksi</td>
<td>0.529 ksi</td>
</tr>
<tr>
<td></td>
<td>Δf&lt;sub&gt;pSH&lt;/sub&gt;</td>
<td>-0.393 ksi</td>
<td></td>
<td></td>
<td>-1.681 ksi</td>
</tr>
<tr>
<td></td>
<td>Δf&lt;sub&gt;pR&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Δf&lt;sub&gt;pss&lt;/sub&gt;</td>
<td>-0.364 ksi</td>
<td>+0.117 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Δf&lt;sub&gt;pES&lt;/sub&gt;</td>
<td>-1.06 ksi</td>
<td>-3.183 ksi</td>
<td>1.60 ksi</td>
<td>-0.081 ksi</td>
</tr>
</tbody>
</table>
Figure (4.11): Stress versus time in the strands in pretensioned and post-tensioned concrete girder.

- Pretension (PT) Stress
- Post-tension (PT) Stress

Key Points:
- PT Stress: 
  - **Stage 1**: (Time = 0) Initial Stress
  - **Stage 2**: (Time = 12 hrs) Relaxation
  - **Stage 3**: (Time = 3 days) Stress in the strands

- Pretension Stress: 
  - **Stage 1**: (Time = 0) Initial Stress
  - **Stage 2**: (Time = 12 hrs) Stress in the strands

- Notes:
  - PT Stress = 40 kN/mm²
  - Pretension Stress = 60 kN/mm²
Figure (4-11) illustrates stress changing in prestressed strands and post-tensioned tendon versus time:

a- **Stage 1**: after “1 day” of girder concrete pouring, The graph indicates an immediate stress reduction of prestressed strands equal to “2.14 ksi” approximately 1.1% of initial strands stresses due to elastic shorting of concrete girder at time of cut strands.

b- **Stage 2**: After cut strands (t =1 day) and before deck placement (t =21 day), prestressed strands keep losing stresses gradually due to Creep and shrinkage of concrete, in addition to strands relaxation, the amount of these losses are 4.33 ksi, which constitutes about 2.1% of initial stresses,

c- **Stage 3**: At deck placement (t =21 day), the graph illustrates a sudden gain of stress about 1.54 ksi in prestressed strands, this value represents the increment shown is about comparing to end of previous stage. The percentage of gain stress is about 0.8% of initial stress.

d- **Stage 4**: After deck placement (t =21 day) and before post-tensioning girders (t =35 day), the graph shows a gradual stress reduction in prestressed strands in the process of time due to creep, shrinkage of concrete girder and steel relaxation, these accumulated losses equal to 1.02 ksi *about 0.5% of initial stress*, it is noted that deck shrinkage and creep of concrete girder have inverse contribution by increasing stresses in prestressed strands (gain stresses) to about 0.29 ksi.

e- **Stage 5**: At time of post-tensioning (t =35 day) the three prestressed girders will be connected together and the temporary supports are released, the graph shows a sudden drop in the stress of prestressed strands due to compression stress at girder cross section
by posttensioned strands. The amount of prestressed strands losses is about $10.9^{\text{ksi}}$, which constitute about 5.4% of initial stress. Also, at this stage the post – tensioned tendons encounter reduction of stresses due to Anchor set, friction and concrete elastic shortening equal to $2.5^{\text{ksi}}$, $6.13^{\text{ksi}}$ and $3.65^{\text{ksi}}$ respectively.

f. **Stage 6:** for the period between Post-tensioning & removal of temporary supports ($t = 35^{\text{day}}$) and before final stage ($t = 4035^{\text{day}}$), creep, shrinkage of concrete and steel relaxation participate gradually in reduction of prestressed and post-tensioned strands stresses, it is noted that the Prestressed strands reduced almost $15.97^{\text{ksi}}$ and post-tension reduced about $16.5^{\text{ksi}}$. These losses constitute about 7.9% and 8.15% respectively of initial stresses. On contrary, deck shrinkage increase stresses in both prestressed and post-tensioned strands about 0.7% of initial stress.

g. **Stage 7:** At this stage live load and wearing surface are applied on the composite section of spliced girder ($t = 4035^{\text{day}}$), the graph shows an immediate gain of stress in prestressed and post-tensioned due to external loads.
Figure (4.12): Stress versus time in the top & bottom of Pretensioned concrete girder
Figure (4-12) illustrates top & bottom girder stresses at mid span versus time as below,

a) **Stage 1**: when prestressed strands released (cut strands), both bottom and top fibers are subjected to compression stresses equal to 0.36 ksi and 0.33 ksi respectively,

b) **Stage 2**: for the period between cut strands (t = 1 day) and before deck placement (t = 21 days), compression stresses at bottom surface gradually reduced to amount of 0.31 ksi, while compression stresses at top surface increases from 0.39 ksi to 0.396 ksi. This change in stresses attribute to creep, shrinkage of girder concrete and steel relaxation.

c) **Stage 3**: At deck placement (t = 21 days), the graph illustrates a sudden increment in compression stress at top girder fiber “0.36 ksi” and an immediate tension stress at bottom fiber “0.327 ksi”. These changes in stresses lead to increase compression stress at top fiber of girder to 0.76 ksi and change compression stress to tension stress 0.02 ksi at bottom fiber.

d) **Stage 4**: After deck placement (t = 21 days) and before post-tensioning girders (t = 35 days), gradual increase in compression stresses at top fiber from 0.76 ksi to 0.81 ksi is shown in graph, and gradual increase in tension stresses at bottom fiber from 0.02 ksi to 0.04 ksi. These changes owing to creep and shrinkage of concrete and steel relaxation in addition to deck shrinkage which cause compression at top face and tension at bottom fiber.

e) **Stage 5**: At this stage, compression stress at top fiber increased about “0.92 ksi” from “0.81 ksi” to 1.73 ksi and change stresses at bottom fiber of girder from tension stress 0.04 ksi to compression stresses of “2.21 ksi”.

f) **Stage 6**: After Post-tensioning & removal of temporary support (t = 35 days) and before final stage (t = 4035 days), compression stress at top fiber of girder increased from 1.73 ksi to 2.12 ksi, while compression stress at bottom fiber of concrete reduced from “2.21 ksi” to “1.68 ksi” due to gradual increase in tension stresses. These changes in stresses are attribute to creep, shrinkage of girder concrete, deck shrinkage and steel relaxation.
g) **Stage 7**: At this stage live load and wearing surface are applied on the composite section of spliced girder \((t = 4035^{\text{day}})\), the graph indicates that compression stress at top fiber of girder increased from \(2.21^{\text{ksi}}\) to \(3.19^{\text{ksi}}\) and reduced at bottom fiber from \(1.68^{\text{ksi}}\) to \(0.028^{\text{ksi}}\) due to tension stress \(1.65^{\text{ksi}}\) at this stage.

![Pie chart showing percentage of prestressed strands losses](image.png)

Figure (4.13) Percentage of prestressed strands losses

Pie chart shows that elastic shortening of concrete has a significant effect on prestressed Strands losses, it participates about 38% of total prestress losses, while the remaining prestress losses distributed between concrete girder creep 29%, concrete shrinkage 24% and steel relaxation 7% respectively.
Percentage of post-tensioned strands losses illustrate in the pie chart (4-12) which shows that creep of concrete has a significant effect on prestress losses, it participates about 33% of total post-tension losses, while the remaining prestress losses distributed between friction losses 23%, concrete girder shrinkage 17%, concrete elastic shortening 10%, anchor set losses 9%, and steel relaxation 8% respectively.

Table (4-23), table (4-23) and figure (4-15) compare between software program “Leap-Consplice” and hand calculation results of prestressed and post-tensioned strands losses, table (4-25) and figure (4-16) illustrate the difference in concrete girder extreme fibers stresses obtained from the two methods of calculation.
### Prestressed Strands Losses, ksi

<table>
<thead>
<tr>
<th>Stage</th>
<th>Status</th>
<th>Time, day</th>
<th>Manual Calc.</th>
<th>Leap – Consplice</th>
<th>% Diff., ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cut Strands</td>
<td>1</td>
<td>-2.13</td>
<td>-2.28</td>
<td>6.78%</td>
</tr>
<tr>
<td>2</td>
<td>Time Step</td>
<td>21</td>
<td>-6.46</td>
<td>-6.19</td>
<td>4.20%</td>
</tr>
<tr>
<td>3</td>
<td>Pour Deck</td>
<td>21</td>
<td>-4.94</td>
<td>-5.56</td>
<td>11.2%</td>
</tr>
<tr>
<td>4</td>
<td>Time Step</td>
<td>35</td>
<td>-6.01</td>
<td>-6.78</td>
<td>11.3%</td>
</tr>
<tr>
<td>5</td>
<td>Apply PT</td>
<td>35</td>
<td>-16.92</td>
<td>-17.97</td>
<td>5.84%</td>
</tr>
<tr>
<td>6</td>
<td>Time Step</td>
<td>4035</td>
<td>-31.56</td>
<td>-31.09</td>
<td>1.50%</td>
</tr>
<tr>
<td>7</td>
<td>WS</td>
<td>4035</td>
<td>-29.00</td>
<td>-28.78</td>
<td>0.76%</td>
</tr>
</tbody>
</table>

Table (4.23) Comparison of manual calculation of prestressed strands losses with Leap-Con splice software results.

### PT Strands Losses, ksi

<table>
<thead>
<tr>
<th>Stage</th>
<th>Status</th>
<th>Time, day</th>
<th>PS-Manual</th>
<th>Leap – Consplice</th>
<th>% Diff., ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Apply PT</td>
<td>35</td>
<td>-12.29</td>
<td>-10.54</td>
<td>1.76%</td>
</tr>
<tr>
<td>6</td>
<td>Time Step</td>
<td>4035</td>
<td>-27.42</td>
<td>-25.93</td>
<td>5.43%</td>
</tr>
<tr>
<td>7</td>
<td>WS</td>
<td>4035</td>
<td>-26.68</td>
<td>-24.02</td>
<td>9.97%</td>
</tr>
</tbody>
</table>

Table (4.24) Comparison of manual calculation of post-tensioned strands losses with Leap-Con splice software results.

### Calc. - Stress, ksi

<table>
<thead>
<tr>
<th>Stage</th>
<th>Status</th>
<th>Top</th>
<th>Bott.</th>
<th>Top</th>
<th>Bott.</th>
<th>Top</th>
<th>Bott</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cut Strands</td>
<td>-0.39</td>
<td>-0.33</td>
<td>-0.35</td>
<td>-0.36</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>2</td>
<td>Time Step</td>
<td>-0.39</td>
<td>-0.31</td>
<td>-0.43</td>
<td>-0.25</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>3</td>
<td>Pour Deck</td>
<td>-0.75</td>
<td>0.02</td>
<td>-0.70</td>
<td>-0.08</td>
<td>0.18</td>
<td>0.14</td>
</tr>
<tr>
<td>4</td>
<td>Time Step</td>
<td>-0.81</td>
<td>0.04</td>
<td>-0.75</td>
<td>-0.06</td>
<td>0.24</td>
<td>0.16</td>
</tr>
<tr>
<td>5</td>
<td>Apply PT</td>
<td>-1.73</td>
<td>2.21</td>
<td>-1.71</td>
<td>-2.30</td>
<td>0.02</td>
<td>0.17</td>
</tr>
<tr>
<td>6</td>
<td>Time Step</td>
<td>-2.12</td>
<td>-1.68</td>
<td>-2.08</td>
<td>-1.85</td>
<td>0.04</td>
<td>0.22</td>
</tr>
<tr>
<td>7</td>
<td>WS+LL</td>
<td>-3.19</td>
<td>-0.03</td>
<td>-3.36</td>
<td>-0.02</td>
<td>0.17</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Table (4.25) Comparison of manual calculation of top and bottom girder stresses with Leap-Con splice software results.
Figure (4.15): Comparison of Leap Consplace & manual results of strands stress changes with time
Figure (4.16): Comparison of Leap Consplice & manual results at top & bottom of concrete girder
4.3 Two Continuous Span of Precast Spliced Girder BT-1400mm:

Bridge Data:

The bridge has a span length of 105\(^{\circ}\) & 95\(^{\circ}\) (From centerline of support to centerline of support). Total deck width is 45\(^{\circ}\), including two 12\(^{\circ}\) traffic lanes with two 1.5\(^{\circ}\) concrete barriers. Bridge Plan and cross section are shown in Figure 4-13.

This example illustrate the procedure in determining strands losses and girder top & Bottom stresses at every stage of applied load and strain due to creep, shrinkage, and steel relaxation.

Figure (4.17) Bridge plan and cross section
Figure (4.18): Bridge elevation

<table>
<thead>
<tr>
<th>Girder Properties</th>
<th>Strands Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_g$</td>
<td>924.5 in²</td>
</tr>
<tr>
<td>$I_g$</td>
<td>373349 in⁴</td>
</tr>
<tr>
<td>$D$</td>
<td>55.12 in</td>
</tr>
<tr>
<td>$y_b$</td>
<td>28.38 in²</td>
</tr>
<tr>
<td>$y_t$</td>
<td>26.74 in²</td>
</tr>
<tr>
<td>$w_c$</td>
<td>0.15 kcf</td>
</tr>
<tr>
<td>$f_c'$</td>
<td>5 ksi</td>
</tr>
<tr>
<td>$A/B$</td>
<td>0.71</td>
</tr>
<tr>
<td>Cement Type</td>
<td>1</td>
</tr>
<tr>
<td># Tendons</td>
<td>1</td>
</tr>
<tr>
<td>Deck Properties</td>
<td></td>
</tr>
<tr>
<td>$S$</td>
<td>6.89 ft</td>
</tr>
<tr>
<td>$t$</td>
<td>8 in</td>
</tr>
<tr>
<td>$f_c'$</td>
<td>4 ksi</td>
</tr>
<tr>
<td>$A/B$</td>
<td>4.71</td>
</tr>
<tr>
<td>Cement Type</td>
<td>III</td>
</tr>
</tbody>
</table>

Table (4.26) Girder, Deck and Strands Properties.

Wearing surface ($w_s$) = 0.24 k/ft
Barrier weight = 0.12 k/ft
Humidity = 80%
<table>
<thead>
<tr>
<th>Stages #</th>
<th>Description</th>
<th>Duration (days)</th>
<th>Total Duration (days)</th>
<th>Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cut Strands (beam age =1)</td>
<td>0</td>
<td>0</td>
<td>Girder Self-wt</td>
</tr>
<tr>
<td>2</td>
<td>Time Step through forming deck</td>
<td>21</td>
<td>21</td>
<td>n/a</td>
</tr>
<tr>
<td>3</td>
<td>Pour Deck</td>
<td>0</td>
<td>21</td>
<td>Slab self-wt</td>
</tr>
<tr>
<td>4</td>
<td>Time Step</td>
<td>29</td>
<td>50</td>
<td>n/a</td>
</tr>
<tr>
<td>5</td>
<td>Stress PT</td>
<td>0</td>
<td>50</td>
<td>PT</td>
</tr>
<tr>
<td>6</td>
<td>Time Step</td>
<td>4000</td>
<td>4050</td>
<td>n/a</td>
</tr>
<tr>
<td>7</td>
<td>Add Future Wearing Surface + LL</td>
<td>0</td>
<td>4050</td>
<td>w,+LL.</td>
</tr>
</tbody>
</table>

Table (4.27) Stages of construction

**STAGE -1-**

At this stage, stress change in prestressed strands (losses) calculated after transfer ($t = t_{day}$) due to Elastic Shortening. Compressive strength ($f'_c$) and modulus of elasticity (E) of girder concrete are calculated at transfer.
<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>f’c</th>
<th>E_c</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut Strands</td>
<td>1&lt;sup&gt;day&lt;/sup&gt;</td>
<td>3.0 ksi</td>
<td>3320.56 ksi</td>
<td>Δf&lt;sub&gt;pES&lt;/sub&gt;</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td>-8.77 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top &amp; Bottom Girder Stress eq.</td>
<td>Value</td>
<td>-0.60 ksi (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>σ&lt;sub&gt;top&lt;/sub&gt; = ( \frac{P_i}{A_g} + \frac{(P_i)(e_{FG})(y_t)}{I_g} + \frac{(M_g)(y_t)}{I_g} )</td>
<td>-1.06 ksi (C)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4.28) Summary of stresses of PS strands and girder extreme fibers at stage 1.

**STAGE -2-**

At this stage, stress changes in prestressed strands (losses) calculated from transfer (\( t = 1<sup>day</sup> \)) to deck placement (\( t = 21<sup>day</sup> \)). These losses caused by girder creep, shrinkage and steel relaxation.

Table (4.29) Summary of stresses of PS strands and girder extreme fibers at stage 2.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>f’c</th>
<th>E_c</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>21&lt;sup&gt;day&lt;/sup&gt;</td>
<td>5.4 ksi</td>
<td>4455 ksi</td>
<td>Δf&lt;sub&gt;pCR&lt;/sub&gt;, Δf&lt;sub&gt;pSH&lt;/sub&gt;, Δf&lt;sub&gt;pR&lt;/sub&gt;</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td>Δf&lt;sub&gt;pCR&lt;/sub&gt; = ( \frac{E_p}{E_{ct=1}} (f_{cgp,t=1})(\Psi_{b(td.ti)})(K_{td.ti}) )</td>
<td>-4.56 ksi</td>
<td></td>
</tr>
<tr>
<td>Δf&lt;sub&gt;pSH&lt;/sub&gt; = ( (e_{bid})(E_p)(K_{td.ti}) ) = -3.83 ksi</td>
<td>-3.58 ksi</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[
\Delta f_R(t_d,t_i) = -(2.4) \left( \frac{t_{d(t_d,t_i)}}{100 + t_{d(t_d,t_i)}} \right)
\]

\[\text{Stress Top & Bottom Girder eq. Value}
\]

\[
\sigma_{\text{top}} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{PS})(y_t)}{I_g} \quad \text{Value}
\]

\[\sigma_{\text{bot}} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{PS})(y_b)}{I_g} \quad \text{Value}
\]

\[
\Delta f_p = \left( \frac{E_p}{E_{ct=21}} \right) (f_{cgp}) \quad \text{3.67 ksi (gain)}
\]

\[
\Delta f_p_{ES} = \left( \frac{E_p}{E_{ct=21}} \right) (f_{cgp}) \quad \text{Value}
\]

\[
\text{Stress Top & Bottom Girder eq. Value}
\]

\[
\sigma_{\text{top}} = \frac{\Delta P_{t=21}}{A_g} + \frac{(\Delta P_{t=21})(e_{pg})(y_t)}{I_g} + \frac{(M_{\text{deck}})(y_t)}{I_g} \quad \text{Value}
\]

\[
\sigma_{\text{bot}} = \frac{\Delta P_{t=21}}{A_g} + \frac{(\Delta P_{t=21})(e_{pg})(y_b)}{I_g} + \frac{(M_{\text{deck}})(y_b)}{I_g} \quad \text{Value}
\]

\text{Table (4.30): Summary of stresses of PS strands and girder extreme fibers at stage 3.}

**STAGE -3-**

At this stage, stress change in prestressed strands (Gain) calculated after deck placement \((t = 21^{\text{days}})\). Compressive strength \((f'c)\) and modulus of elasticity \((E)\) of girder concrete are calculated at deck placement.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>(f'c)</th>
<th>(E_c)</th>
<th>(\Delta f_p_{ES})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Placement</td>
<td>21\text{day}</td>
<td>4.96 ksi</td>
<td>4269.6 ksi</td>
<td>(\Delta f_p_{ES})</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td></td>
<td></td>
<td>3.67 ksi (gain)</td>
</tr>
<tr>
<td>(\Delta f_p_{ES} = \left( \frac{E_p}{E_{ct=21}} \right) (f_{cgp}))</td>
<td>Value</td>
<td></td>
<td></td>
<td>3.67 ksi (gain)</td>
</tr>
<tr>
<td>(\text{Stress Top &amp; Bottom Girder eq. Value})</td>
<td>Value</td>
<td></td>
<td></td>
<td>(-0.617\text{ksi (C)})</td>
</tr>
<tr>
<td>(\sigma_{\text{top}} = \frac{\Delta P_{t=21}}{A_g} + \frac{(\Delta P_{t=21})(e_{pg})(y_t)}{I_g} + \frac{(M_{\text{deck}})(y_t)}{I_g})</td>
<td>Value</td>
<td></td>
<td></td>
<td>(-0.617\text{ksi (C)})</td>
</tr>
<tr>
<td>(\sigma_{\text{bot}} = \frac{\Delta P_{t=21}}{A_g} + \frac{(\Delta P_{t=21})(e_{pg})(y_b)}{I_g} + \frac{(M_{\text{deck}})(y_b)}{I_g})</td>
<td>Value</td>
<td></td>
<td></td>
<td>(0.625\text{ksi (T)})</td>
</tr>
</tbody>
</table>
At this stage, stress change in prestressed strands (losses) calculated from deck placement ($t = 21^{\text{day}}$) to post-tensioning ($t = 50^{\text{day}}$). These losses attribute to girder creep & shrinkage, deck shrinkage and steel relaxation. Compressive strength ($f_c'$) and modulus of elasticity ($E$) of girder concrete are calculated at deck placement.

### Table (4.31) Summary of stresses of PS strands and girder extreme fibers at stage 4.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>$f_c'$</th>
<th>$E_c$</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>$50^{\text{day}}$</td>
<td>5.056ksi</td>
<td>4310.8ksi</td>
<td>$\Delta f_{CR}$, $\Delta f_{SH}$, $\Delta f_{R}$, $\Delta f_{SS}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PS Strands Losses eq.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta f_{CR} = \left( \frac{E_p}{E_{c(t=21)}} \right) \left( f_{cgp,t=1} \left[ \Psi_{b(tp,ti)} - \Psi_{b(td,ti)} \right] \right) \left( K_{b(tp,td)} \right)$</td>
<td>-1.07ksi</td>
</tr>
<tr>
<td>$\Delta f_{SH} = (E_{b(tp,td)})(E_p)(K_{tp,td})$</td>
<td>-2.69ksi</td>
</tr>
<tr>
<td>$\Delta f_{R} = - \left( 2.4^{\text{ksi}} \right) \left( \frac{t_{d(tp,ti)}}{100 + t_{d(tp,ti)}} \right) - \Delta f_{R2}$</td>
<td>-0.39ksi</td>
</tr>
<tr>
<td>$\Delta f_{SS(tf,curr)} = \left( \frac{E_p}{E_c} \right) \left( \Delta f_{cdt}(K_{df}) \right) \left[ 1 + (0.7)(\Psi_{b(tf,td)})(K_{(tp,curr)}) \right]$</td>
<td>0.575ksi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder due to CR, SH, R</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{top}} = \frac{\Delta P}{A_g} + \frac{(\Delta P)(e_{PS})(y_t)}{I_g}$</td>
<td>-0.0107ksi (C)</td>
</tr>
</tbody>
</table>
\[
\sigma_{\text{bot}} = \frac{\Delta P}{A_g} + \frac{(\Delta P)(e_{PS})(y_b)}{I_g} = 0.0475^{\text{ksi}} (T)
\]

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder due to Deck Shrinkage</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{\text{top(tf,tdcur)}} = (f_{dSH})(\frac{1}{A_c} - \frac{(y_{tc})(e_d)}{I_c})(k_{(tp,dcur)}))</td>
<td>-0.07^{\text{ksi}}</td>
</tr>
<tr>
<td>(\sigma_{\text{bot(tf,tdcur)}} = f_{dSH} \times (\frac{1}{A_c} - \frac{(y_{bc})(e_d)}{I_c})(k_{t(dcur,tp)}))</td>
<td>0.007^{\text{ksi}}</td>
</tr>
</tbody>
</table>

**STAGE -5-**

At this stage, stress change in prestressed strands “PS, PT” (losses) due to post tension stress at \(t = 50^{\text{days}}\). These losses attribute to concrete elastic shortening. Compressive strength \(f'c\) and modulus of elasticity \(E\) of girder concrete are calculated at post-tensioning.

![Diagram](image.png)

Table (4.32): Summary of stresses of PS strands and girder extreme fibers at stage 5.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>(f'c)</th>
<th>(E_c)</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>50^{\text{day}}</td>
<td>5.055^{\text{ksi}}</td>
<td>4310.3^{\text{ksi}}</td>
<td>(\Delta f_{PS})</td>
</tr>
<tr>
<td>PS Strands Losses eq.</td>
<td>Value</td>
<td>(\Delta f_{PS} = \left( \frac{E_p}{E_{c,t=35}} \right) (f_{cgp}))</td>
<td>8.0^{\text{ksi}}</td>
<td></td>
</tr>
<tr>
<td>PT Strands Losses eq.</td>
<td>Value</td>
<td>(\Delta f_{PS} = 2(\Delta f_p)(R)(X))</td>
<td>10.39^{\text{ksi}}</td>
<td></td>
</tr>
<tr>
<td>(\Delta f_p = (\Delta f_p - \Delta f_{PS}) (1 - e^{-(kx+\alpha\mu)}))</td>
<td>3.68^{\text{ksi}}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\Delta f_{PS} = \left( \frac{N - 1}{2N} \right) \left( \frac{E_p}{E_{c,t=35}} \right) (f_{cgp}))</td>
<td>7.91^{\text{ksi}}</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
At this stage, stress change in prestressed strands (losses) calculated from Post-tensioning ($t = 50^{th}$ day) to final ($t = 4050^{th}$ day). These losses attribute to girder creep & shrinkage, deck shrinkage and steel relaxation. Compressive strength ($f'c$) and modulus of elasticity (E) of girder concrete are calculated at post-tensioning.

### STAGE -6-

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder eq.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{top}} =$ &amp; $\sigma_{\text{bot}} =$</td>
<td></td>
</tr>
<tr>
<td>$\frac{P_{PT}}{A_c}$ &amp; $\frac{P_{PT}}{A_c}$</td>
<td></td>
</tr>
<tr>
<td>+ $\frac{P_{PT}(e_{PT,c})(y_{tc})}{I_c}$ &amp; + $\frac{P_{PT}(e_{PT,c})(y_{bc})}{I_c}$</td>
<td></td>
</tr>
<tr>
<td>+ $\left[ \Delta P_{PS} \right]<em>{\text{c}}$ &amp; + $\left[ \Delta P</em>{PS} \right]_{\text{c}}$</td>
<td></td>
</tr>
<tr>
<td>+ $\left[ \Delta P_{PT} \right]<em>{\text{c}}$ &amp; + $\left[ \Delta P</em>{PT} \right]_{\text{c}}$</td>
<td></td>
</tr>
<tr>
<td>$\left( \frac{1}{I_c} \right)$ &amp; $\left( \frac{1}{I_c} \right)$</td>
<td></td>
</tr>
<tr>
<td>-0.013 ksi (C) &amp; -1.313 ksi (T)</td>
<td></td>
</tr>
</tbody>
</table>

At this stage, stress change in prestressed strands (losses) calculated from Post-tensioning ($t = 50^{th}$ day) to final ($t = 4050^{th}$ day). These losses attribute to girder creep & shrinkage, deck shrinkage and steel relaxation. Compressive strength ($f'c$) and modulus of elasticity (E) of girder concrete are calculated at post-tensioning.
Table (4.33) Summary of stresses of PS strands and girder extreme fibers at stage 6.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>$f_c$</th>
<th>$E_c$</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>4050$^{\text{day}}$</td>
<td>5.055$^{\text{ksi}}$</td>
<td>4310.3$^{\text{ksi}}$</td>
<td>$\Delta f_{p_{\text{CR}}}$, $\Delta f_{p_{\text{SH}}}$, $\Delta f_{p_{\text{R}}}$, $\Delta f_{p_{\text{ss}}}$</td>
</tr>
</tbody>
</table>

### PS Strands Losses eq.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta f_{p_{\text{CR}}}$</td>
<td>$\left( \frac{E_p}{E_{c_{t=35}}} \right) (f_{c_{g_{p,t=1}}}) \left[ \psi_{b(t,t_{ti})} - \psi_{b(t,p,t_{p})} \right] (K_{b(t,p_{t})})$</td>
</tr>
<tr>
<td>$\Delta f_{p_{\text{SH}}}$</td>
<td>$= \left( \epsilon_{bp_{f}} \right) \left( E_{p} \right) \left( K_{pf} \right) \quad \text{Value} \quad -6.34^{\text{ksi}}$</td>
</tr>
<tr>
<td>$\Delta f_{R_{PS}}$</td>
<td>$= -2.4 \times \frac{t_{d(t_{fp})}}{100 + t_{d(t_{fp})}} - \Delta f_{R_{1}} - \Delta f_{R_{2}} \quad \text{Value} \quad -1.55^{\text{ksi}}$</td>
</tr>
<tr>
<td>$\Delta f_{p_{ss}}$</td>
<td>$= \left( \frac{E_p}{E_{c_{t=35}}} \right) (f_{c_{g_{p,t=35}}}) \left[ \psi_{b(t_{fp})} \right] (K_{b(t_{p})}) \quad \text{Value} \quad 1.25^{\text{ksi}}$</td>
</tr>
</tbody>
</table>

### PT Strands Losses eq.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta f_{p_{\text{CR}}}$</td>
<td>$\left( \frac{E_p}{E_{c_{t=35}}} \right) (f_{c_{g_{p,t=35}}}) \left[ \psi_{b(t_{fp})} \right] (K_{b(t_{p})}) \quad \text{Value} \quad -8.3^{\text{ksi}}$</td>
</tr>
<tr>
<td>$\Delta f_{p_{\text{SH}}}$</td>
<td>$= \left( \epsilon_{bp_{f}} \right) \left( E_{p} \right) \left( K_{pf} \right) \quad \text{Value} \quad -6.34^{\text{ksi}}$</td>
</tr>
<tr>
<td>$\Delta f_{R_{PT}}$</td>
<td>$= -2.4 \times \frac{t_{d(t_{fp})}}{100 + t_{d(t_{fp})}} \quad \text{Value} \quad -2.34^{\text{ksi}}$</td>
</tr>
<tr>
<td>$\Delta f_{p_{ss}}$</td>
<td>$= \left( \frac{E_p}{E_{c_{t=28}}} \right) (f_{c_{g_{p,t=28}}}) \left( \Delta f_{c_{df}} \right) \left( K_{(t_{fp},t_{td})} \right) \left[ 1 + 0.7 \times \psi_{b(t_{fp},t_{td})} \left[ K_{(t_{fp},t_{td})} - k_{t(t_{fp},t_{td})} \right] \right]$</td>
</tr>
</tbody>
</table>

### Stress Top & Bottom Girder due to CR,SH,R

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \sigma_{\text{top}}$</td>
<td>$= \frac{\Delta p_{ps}}{A_{c}} + \frac{(\Delta p_{ps}) (e_{PS_{c}}) (y_{tc})}{I_{c}} \quad \text{Value} \quad -0.01^{\text{ksi}} \quad (C)$</td>
</tr>
</tbody>
</table>

\(\Delta \sigma_{\text{bottom}}\) is calculated similarly.
\[ \Delta \sigma_{\text{bot}} = \left( \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{bc})}{I_c} \right) \\
\quad + \left( \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{bc})}{I_c} \right) \]

<table>
<thead>
<tr>
<th>Stress Top &amp; Bottom Girder due to Deck Shrinkage</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{top}}(t_f,t_{dcur}) = (f'c)(1 - \frac{(y_{tc})(e_d)}{I_c}) (k_{d(t_f,t_d)}) - k_{(t_p,d_{cur})} )</td>
<td>-0.16 ksi</td>
</tr>
<tr>
<td>( \sigma_{\text{bot}}(t_f,t_{dcur}) = (f'c)(1 - \frac{(y_{bc})(e_d)}{I_c}) (k_{d(t_f,t_d)}) - k_{(t_p,d_{cur})} )</td>
<td>0.015 ksi</td>
</tr>
</tbody>
</table>

**STAGE -7-**

At this stage, stress change in prestressed strands “PS, PT” (Gain) due to Wearing Surface & Live Load at \( t = 4050 \text{ days} \). Compressive strength \( (f'c) \) and modulus of elasticity \( (E) \) of girder concrete are calculated at final.
Table (4.34): Summary of stresses of PS strands and girder extreme fibers at stage 7.

<table>
<thead>
<tr>
<th>Status</th>
<th>Concrete Age</th>
<th>f'c</th>
<th>E_c</th>
<th>Change of stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing Surface &amp; Live Load</td>
<td>4050&lt;sub&gt;day&lt;/sub&gt;</td>
<td>5.126&lt;sup ksi&lt;/sup&gt;</td>
<td>4340.5&lt;sup ksi&lt;/sup&gt;</td>
<td>Δf&lt;sub&gt;pES,PS&lt;/sub&gt;, Δf&lt;sub&gt;pES,PT&lt;/sub&gt;</td>
</tr>
<tr>
<td>M&lt;sub&gt;W,C&lt;/sub&gt;</td>
<td>M&lt;sub&gt;LL,HS20&lt;/sub&gt;</td>
<td>M&lt;sub&gt;Lane&lt;/sub&gt;</td>
<td>LLDF</td>
<td>M&lt;sub&gt;Total&lt;/sub&gt;</td>
</tr>
<tr>
<td>317.52&lt;sup ksi&lt;/sup&gt;</td>
<td>1715.84&lt;sup ksi&lt;/sup&gt;</td>
<td>660.168&lt;sup ksi&lt;/sup&gt;</td>
<td>0.51</td>
<td>1221.76&lt;sup ksi&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**PS Strands Losses eq.**

\[
\Delta f_{pES} = \left( \frac{E_p}{E_{c,t=4035}} \right) (f_{cg}) = 0.49<sup ksi</sup>
\]

**PT Strands Losses eq.**

\[
\Delta f_{pES} = \left( \frac{E_p}{E_{c,t=4035}} \right) (f_{cg}) = 0.41<sup ksi</sup>
\]

**Stress Top & Bottom Girder eq.**

\[
\sigma_{top} = \left( \frac{(M_{LL})(y_{tc})}{l_c} + \frac{(M_{ws})(y_{tc})}{l_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS})(y_{tc})}{l_c} \right] + \left[ \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT})(y_{tc})}{l_c} \right]
\]

\[
\sigma_{bot} = \left( \frac{(M_{LL})(y_{bc})}{l_c} + \frac{(M_{ws})(y_{bc})}{l_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{bc})}{l_c} \right] + \left[ \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{bc})}{l_c} \right]
\]

\[
\sigma_{top} = -0.449<sup ksi</sup> (C)
\]

\[
\sigma_{bot} = 1.17<sup ksi</sup> (T)
\]
Change of stresses of prestressed and post-tensioned strands in different stages are summarized in table (4-35) and table (4-36) respectively, minus sign stands for stress losses, while positive sign stands for stress gain.

(4.35) Summary of losses of prestressed strands.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Stress Change</th>
<th>$\Delta f_{p,PS}$</th>
<th>$\Sigma \Delta f_{PS}$</th>
<th>Accu. $\Sigma \Delta f_{PS}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\Delta f_{pES}$</td>
<td>-8.77 ksi</td>
<td>-8.77 ksi</td>
<td>-8.77 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pCR}$</td>
<td>-4.56 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSH}$</td>
<td>-3.58 ksi</td>
<td>-8.54 ksi</td>
<td>-17.31 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pR}$</td>
<td>-0.40 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$\Delta f_{pES}$</td>
<td>+3.67 ksi</td>
<td>+3.67 ksi</td>
<td>-13.64 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pCR}$</td>
<td>-1.07 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSH}$</td>
<td>-2.69 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pR}$</td>
<td>-0.39 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSS}$</td>
<td>+0.575 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$\Delta f_{pES}$</td>
<td>-8.0 ksi</td>
<td>-8.0 ksi</td>
<td>-25.22 ksi</td>
</tr>
<tr>
<td>4</td>
<td>$\Delta f_{pCR}$</td>
<td>-12.63 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSH}$</td>
<td>-6.34 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pR}$</td>
<td>-1.55 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSS}$</td>
<td>+1.25 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$\Delta f_{pES}$</td>
<td>-10.39 ksi</td>
<td>-21.98 ksi</td>
<td>-21.98 ksi</td>
</tr>
<tr>
<td>6</td>
<td>$\Delta f_{pCR}$</td>
<td>-3.68 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pAS}$</td>
<td>-7.91 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pF}$</td>
<td>-10.39 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pR}$</td>
<td>-8.30 ksi</td>
<td>-15.738 ksi</td>
<td>-37.72 ksi</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSS}$</td>
<td>-6.34 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pAS}$</td>
<td>-3.68 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pF}$</td>
<td>-2.34 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSS}$</td>
<td>+1.25 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>$\Delta f_{pES}$</td>
<td>0.49 ksi</td>
<td>0.49 ksi</td>
<td>-37.31 ksi</td>
</tr>
</tbody>
</table>

(4.36) Summary of losses of post-tensioned strands.
Table (4.36) Summary of losses of post-tensioned strands.

Top and bottom girder concrete stresses are shown in table (4-37) at different stages of loadings and time stages.

Table (4.37) Summary of top and bottom girder stresses.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Stress Change</th>
<th>Girder Stresses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( \sigma_{\text{top}} )</td>
</tr>
<tr>
<td>1</td>
<td>( \Delta f_{\text{PES}} )</td>
<td>-0.6 ksi</td>
</tr>
<tr>
<td>2</td>
<td>( \Delta f_{\text{PES}} )</td>
<td>-0.022 ksi</td>
</tr>
<tr>
<td></td>
<td>( \Delta f_{\text{PES}} )</td>
<td>-0.617 ksi</td>
</tr>
<tr>
<td>4</td>
<td>( \Delta f_{\text{PES}} )</td>
<td>-0.0107 ksi</td>
</tr>
<tr>
<td>5</td>
<td>( \Delta f_{\text{PES}} )</td>
<td>-0.013 ksi</td>
</tr>
<tr>
<td>6</td>
<td>( \Delta f_{\text{PES}} )</td>
<td>-0.16 ksi</td>
</tr>
<tr>
<td>7</td>
<td>( \Delta f_{\text{PES}} )</td>
<td>-0.39 ksi</td>
</tr>
</tbody>
</table>
Figure (4.19): Stress versus time in the strands in pretensioned and post-tensioned concrete girder
Figure (4.20): Stress versus time in the top & bottom of PS & PT concrete girder
Figure (4.21): Percentage of prestressed strands losses

Figure (4.22): Percentage of post-tensioned strands losses
### Prestressed Strands Losses, ksi

<table>
<thead>
<tr>
<th>Stage</th>
<th>Status</th>
<th>Time, day</th>
<th>Manual Calc.</th>
<th>Leap - Consplice</th>
<th>Diff., ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cut Strands</td>
<td>1</td>
<td>-8.80</td>
<td>-8.86</td>
<td>0.70%</td>
</tr>
<tr>
<td>2</td>
<td>Time Step</td>
<td>21</td>
<td>-17.31</td>
<td>-17.24</td>
<td>0.41%</td>
</tr>
<tr>
<td>3</td>
<td>Pour Deck</td>
<td>21</td>
<td>-13.75</td>
<td>-13.71</td>
<td>0.29%</td>
</tr>
<tr>
<td>4</td>
<td>Time Step</td>
<td>50</td>
<td>-17.24</td>
<td>-18.04</td>
<td>4.43%</td>
</tr>
<tr>
<td>5</td>
<td>Apply PT</td>
<td>50</td>
<td>-25.35</td>
<td>-25.05</td>
<td>1.18%</td>
</tr>
<tr>
<td>6</td>
<td>Time Step</td>
<td>4050</td>
<td>-44.84</td>
<td>-41.74</td>
<td>6.91%</td>
</tr>
<tr>
<td>7</td>
<td>WS</td>
<td>4050</td>
<td>-38.87</td>
<td>-40.99</td>
<td>5.17%</td>
</tr>
</tbody>
</table>

Table (4.38): Comparison of manual calculation of Prestressed strands losses with Leap-Consplice software results

### PT Strands Losses, ksi

<table>
<thead>
<tr>
<th>Stage</th>
<th>Status</th>
<th>Time, day</th>
<th>PS-Manual</th>
<th>Leap – Consplice</th>
<th>Diff., ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Apply PT</td>
<td>50</td>
<td>-21.98</td>
<td>-20.54</td>
<td>7.0%</td>
</tr>
<tr>
<td>6</td>
<td>Time Step</td>
<td>4050</td>
<td>-37.72</td>
<td>-35.93</td>
<td>4.75%</td>
</tr>
<tr>
<td>7</td>
<td>WS</td>
<td>4050</td>
<td>-37.31</td>
<td>-35.02</td>
<td>6.14%</td>
</tr>
</tbody>
</table>

Table (4.39): Comparison of manual calculation of post-tensioned Strands losses with Leap-Consplice software results

### Calc. - Stress, ksi

<table>
<thead>
<tr>
<th>Stage</th>
<th>Status</th>
<th>Top</th>
<th>Bott</th>
<th>Top</th>
<th>Bott</th>
<th>Top</th>
<th>Bott</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cut Strands</td>
<td>-0.60</td>
<td>-1.06</td>
<td>-0.59</td>
<td>-1.06</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>Time Step</td>
<td>-0.622</td>
<td>-0.96</td>
<td>-0.61</td>
<td>-0.97</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>Pour Deck</td>
<td>-1.24</td>
<td>-0.34</td>
<td>-1.22</td>
<td>-0.35</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>4</td>
<td>Time Step</td>
<td>-1.325</td>
<td>-0.28</td>
<td>-1.29</td>
<td>-0.29</td>
<td>0.22</td>
<td>0.08</td>
</tr>
<tr>
<td>5</td>
<td>Apply PT</td>
<td>-1.338</td>
<td>-1.59</td>
<td>-1.32</td>
<td>-1.53</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>6</td>
<td>Time Step</td>
<td>-1.51</td>
<td>-1.25</td>
<td>-1.48</td>
<td>-1.22</td>
<td>0.41</td>
<td>0.01</td>
</tr>
<tr>
<td>7</td>
<td>WS+LL</td>
<td>-1.90</td>
<td>-0.45</td>
<td>-1.85</td>
<td>-0.33</td>
<td>0.37</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table (4.40): Comparison of manual calculation of top and bottom girder stresses with Leap-Consplice software results.
Figure (4.23): Comparison of Leap Consplice & manual results of strands stress changes with time with time.
Figure (4.24): Comparison of Leap Consplice & manual results at top & bottom of concrete girders.
CHAPTER FIVE
ANALYSIS OF RESULTS AND SUMMARY

The foremost objective of this project is to predict change of stresses in prestressed and post-tensioned spliced girder strands and girder top and bottom extreme fiber stresses at various time steps and loadings.

For this project three different girder bridges were analyzed. First bridge was a simple span bridge 80\textsuperscript{ft} long with prestressed girders only, the purpose of this example is to show the procedure adopted by ASSHTO-LRFD 2012 to calculate immediate and long term losses in prestressed strands by refined method.

Second example is a simple span bridge with three spliced girders “45\textsuperscript{ft}, 101\textsuperscript{ft}, 45\textsuperscript{ft}” and two temporary supports at girder splicing, these three prestressed segments connected by three post-tensioned tendons to work as a full simple span “196\textsuperscript{ft}” length. In this example, equations of concrete creep and shrinkage of ASSHTO-LRFD are extended to accommodate presence of post-tensioned strands in addition to prestressed strands. Step by step hand calculation used to calculate stresses of prestressed strands and girder extreme fibers stresses at various stages of construction.

Third example is two simple span of prestressed girders “105\textsuperscript{ft} & 95\textsuperscript{ft}” length connected by post-tensioned tendons to work as two continuous span.

Analysis results of these three example can be summarized as below:

1- Stress in prestressed strands is reduced immediately at release “cut strands” due to elastic shortening of concrete girder. Bottom surface of girder subject to compression stresses while top surface of girder subject to compression or tension stresses depending on the distance from the Neutral axes of girder.
2- Applying external loads “concrete deck, wearing surface and moving Live Loads” increase stresses of prestressed strands immediately “gain stress” and produce compression and tension stresses at top and bottom fibers of concrete girder respectively.

3- Creep & shrinkage of concrete and steel relaxation play a significant role in prestressed and post-tensioned strands losses, analysis results indicate a gradual and continues reduction in strands stresses in the process of time, analysis results show that more than “50%” of prestressed strands losses attribute to Creep & Shrinkage of concrete. These long term losses cause compression and tension stresses at top and bottom girder surfaces respectively. Prestressed strands gain a few amount of stresses due to concrete deck shrinkage, this gradual change of stress produce compression stresses at top fiber of girder and tension at bottom.

4- Compressive strength “f’c” and modulus of elasticity “E_c” of concrete girders have different values in the process of time, these variations have been considered during process of construction.

5- Analysis results of hand calculation according to AASHTO-LRFD 2012 have a good convergence to Leap-Consplice software program results.

Table (5-1) indicates summary of equations used to calculate stress change in prestressed strands at different stages of loading and time steps of simple span of precast prestressed girders.

Table (5-2) indicates summary of equations used to calculate change of stresses in prestressed strands at different stages of spliced and continuous girder bridge.

Table (5-3) indicates summary of equations used to calculate change of stresses in Post-tensioned strands in spliced and continuous girder bridge.
<table>
<thead>
<tr>
<th></th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Immediate Losses at release</strong></td>
<td><strong>Elastic Shortening</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pES} = \left( \frac{E_p}{E_{ci}} \right) (f_{cgp})$</td>
</tr>
<tr>
<td><strong>Long term losses between cut strands and deck placement</strong></td>
<td><strong>Creep</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pCR} = \left( \frac{E_p}{E_{cgp,t=1}} \right) (f_{cgp})(\Psi_b(t_{d,ti}) (K_{td,ti})$</td>
</tr>
<tr>
<td></td>
<td><strong>Shrinkage</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSH} = (\epsilon_{bid}) (E_p) (K_{td,ti})$</td>
</tr>
<tr>
<td></td>
<td><strong>Steel Relaxation</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{R(t_{d,ti})} = - (2.4) \left( \frac{t_d(t_{d,ti})}{100 + t_d(t_{d,ti})} \right)$</td>
</tr>
<tr>
<td></td>
<td><strong>Immediate Losses at deck Placement</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Elastic Shortening</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pES} = \left( \frac{E_p}{E_{c,t,deck}} \right) (f_{cgp})$</td>
</tr>
<tr>
<td><strong>Long term losses between deck placement and final</strong></td>
<td><strong>Creep of Girder</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pCR} = \left( \frac{E_p}{E_{c,t,deck}} \right) (f_{cgp}) \left[ \Psi_b(t_{f,ti}) - \Psi_b(t_{d,ti}) \right] K_b(t_{f,td})$ $+ \left( \frac{E_p}{E_{c,t,deck}} \right) (f_{cgp}) (\Psi_b(t_{f,td})) (K_b(t_{f,td}))$</td>
</tr>
<tr>
<td></td>
<td><strong>Shrinkage of Girder</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pSH} = (\epsilon_{b(t_{f,td})}) (E_p) (K_{tf,td})$</td>
</tr>
<tr>
<td></td>
<td><strong>Steel Relaxation</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{R,4} = - 2.4 x \frac{t_d(t_{f,ti})}{100 + t_d(t_{f,ti})} - \Delta f_{R,2}$</td>
</tr>
<tr>
<td></td>
<td><strong>Shrinkage of deck (gain)</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{ps} = \left( \frac{E_p}{E_c} \right) (\Delta f_{cdf}) (K_{(t_{f,td})}) \left[ 1 + 0.7 (\Psi_b(t_{f,td})) \right]$</td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{cdf} = \left( \frac{E_{ddf}}{E_c} \right) (A_d) (E_{c,deck}) \left[ 1 + 0.7 x \Psi_d(t_{f,td}) \right] x \left( \frac{1}{A_c} - \frac{(e_d)(E_{pc})}{I_c} \right)$</td>
</tr>
<tr>
<td><strong>Immediate Losses at LL &amp; Ws</strong></td>
<td><strong>Elastic Shortening</strong></td>
</tr>
<tr>
<td></td>
<td>$\Delta f_{pES} = \left( \frac{E_p}{E_{c,t,LL}} \right) (f_{cgp})$</td>
</tr>
</tbody>
</table>

Table (5.1): Summary of equations used to calculate change of stresses in strands of precast prestressed girder of simple span.
Table (5.2): Summary of equations used to calculate change of stresses in prestressed strands at different stages of spliced and continuous girder bridge at one stage of PT.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate Losses at release</td>
<td>$\Delta f_{p_{ES}} = \left( \frac{E_p}{E_{cl}} \right) (f_{cgp})$</td>
</tr>
<tr>
<td>Elastic Shortening</td>
<td></td>
</tr>
<tr>
<td>Long term losses between cut strands and deck placement</td>
<td>$\Delta f_{p_{CR}} = \left( \frac{E_p}{E_{cl}} \right) (f_{cgp,ti}) (\Psi_{b(t_d,ti)}(K_{td,ti}))$</td>
</tr>
<tr>
<td>Creep</td>
<td></td>
</tr>
<tr>
<td>Shrinkage</td>
<td>$\Delta f_{p_{SH}} = (E_{b,ia})(E_p)(K_{td,ti})$</td>
</tr>
<tr>
<td>Steel Relaxation</td>
<td></td>
</tr>
<tr>
<td>Immediate Losses at deck Placement</td>
<td>$\Delta f_{p_{ES}} = \left( \frac{E_p}{E_{c,t,deck}} \right) (f_{cgp})$</td>
</tr>
<tr>
<td>Elastic Shortening</td>
<td></td>
</tr>
<tr>
<td>Long term losses between deck placement and PT</td>
<td></td>
</tr>
<tr>
<td>Creep of Girder</td>
<td>$\Delta f_{p_{CR}} = \left( \frac{E_p}{E_{c,t,deck}} \right) (f_{cgp,ti}) \left[ \Psi_{b(t_p,ti)} - \Psi_{b(t_d,ti)} \right] (K_{b(tp,td)}) + \left( \frac{E_p}{E_{c,t,deck}} \right) (f_{cgp,t,deck})(\Psi_{b(tp,td)})(K_{b(tp,td)})$</td>
</tr>
<tr>
<td>Shrinkage of Girder</td>
<td>$\Delta f_{p_{SH}} = (E_{b(t_p,td)})(E_p)(K_{tp,td})$</td>
</tr>
<tr>
<td>Steel Relaxation</td>
<td>$\Delta f_R = -2.4 \times \frac{\tau_{d(t_p,td)}}{100 + \tau_{d(t_p,td)}} - \Delta f_{R1}$</td>
</tr>
<tr>
<td>Shrinkage of deck (gain)</td>
<td>$\Delta f_{pss} = \left( \frac{E_p}{E_{c}} \right) (\Delta f_{cdf})(K_{(t_f,td)})(1 + (0.7)(\Psi_{b(t_f,td)}))$</td>
</tr>
<tr>
<td>Immediate Losses at PT</td>
<td>$\Delta f_{p_{ES}} = \left( \frac{E_p}{E_{c,t,PT}} \right) (f_{cgp})$</td>
</tr>
<tr>
<td>Long term losses between deck placement and PT</td>
<td>Creep of Girder</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage of Girder</td>
<td>[ \Delta f_{pSH} = (E_{bpf}) (Ep) (K_{pf}) ]</td>
</tr>
<tr>
<td>Steel Relaxation</td>
<td>[ \Delta f_{RPS} = - 2.4 \times \frac{t_{d(tf,tp)}}{100 + t_{d(tf,tp)}} - \Delta f_{R1} - \Delta f_{R2} ]</td>
</tr>
<tr>
<td>Shrinkage of deck (gain)</td>
<td>[ \Delta f_{pSS} ]</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Immediate Losses at ( W_S )</td>
<td>Elastic Shortening</td>
</tr>
</tbody>
</table>
Table (5.3): Summary of equations used to calculate change of stresses in post-tensioned strands in spliced and continuous girder bridge.

<table>
<thead>
<tr>
<th>Immediate Losses</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Shortening</td>
<td>[ \Delta f_{PS} = \left( \frac{N - 1}{2N} \right) \left( \frac{E_p}{E_{c.t,PT}} \right) f_{cgp} ]</td>
</tr>
<tr>
<td>Anchor Set</td>
<td>[ \Delta f_{PSAS} = 2 \left( \Delta f_{p} \right) (R)(X) ]</td>
</tr>
<tr>
<td>Friction</td>
<td>[ \Delta f_{pt} = (\Delta f_{p} - \Delta f_{PSAS}) \left( 1 - e^{-(kx + a\mu)} \right) ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Long term losses between PT and Final</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creep of Girder</td>
<td>[ \Delta f_{PCR(PT)} = \left( \frac{E_p}{E_{c,PT}} \right) \left( f_{cgp,PT} \right) \left[ \Psi_{b(tf,tp)} \right] \left( K_{b(tp,tf)} \right) ]</td>
</tr>
<tr>
<td>Shrinkage of Girder</td>
<td>[ \Delta f_{PSH} = (E_{bpf}) (Ep) (K_{pf}) ]</td>
</tr>
<tr>
<td>Steel Relaxation</td>
<td>[ \Delta f_{RPT} = -2.4 \times \frac{t_{d(tf,tp)}}{100 + t_{d(tf,tp)}} ]</td>
</tr>
</tbody>
</table>

| Shrinkage of deck (gain) | \[ \Delta f_{PS} = \left( \frac{E_p}{E_{c,PT}} \right) \left( \Delta f_{cdr} \right) \left( K_{(tf,td)} \right) \left[ 1 + 0.7 \times \Psi_{b(tf,tdcur)} \right] \left[ k_{t(tf,tdcur)} - k_{t(tp,tdcur)} \right] \] |

<table>
<thead>
<tr>
<th>Immediate Losses due to wearing Surf.</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Shortening</td>
<td>[ \Delta f_{PS} = \left( \frac{N - 1}{2N} \right) \left( \frac{E_p}{E_{c.t=4035}} \right) f_{cgp} ]</td>
</tr>
</tbody>
</table>
Hand Calculation of Simple span precast – Pretensioned BT-54 Girder Bridge:

**Stage 1:**
At this stage, stress change in prestressed strands (losses) calculated after transfer ($t = 1 \text{ day}$)

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut Strands</td>
<td>1 day</td>
<td>$\Delta f_{pES}$</td>
</tr>
</tbody>
</table>

Compressive strength of concrete girder at transfer (after one day of concrete pouring)

$$ (f'_c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'_c)_u $$

$$ \beta = \frac{28}{\frac{A}{B} + 28} = \frac{28}{0.71 + 28} = 0.975 $$

$$ a = \beta \cdot \left(\frac{A}{B}\right) = (0.975)(0.71) = 0.692 $$

$$ (f'_c)_{t=1\text{day}} = \frac{(1)}{0.692 + (0.975)(1)}(7^{ksi}) = 4.2^{ksi} $$

Concrete Modulus after transfer ($t = 1 \text{ day}$)

$$ E_{c,t=1} = (33000)(w_c)^{1.5} \cdot \sqrt{(f'_c)_{t=1}} $$

$$ E_{c,t=1} = (33000)(0.15^{k/ft^3})^{1.5} \cdot \sqrt{4.2^{ksi}} = 3929^{ksi} $$
Initial prestress stress after transfer

\[ f_{pj} = 0.75 (f_{pu}) = 0.75 (270 \text{ksi}) = 202.5 \text{ksi} \]

Prestress force after transfer

\[ A_{ps} = (A_b)(\# \text{Strands}) = (0.217 \text{in}^2)(18) = 3.906 \text{in}^2 \]

\[ p_j = (f_{pj})(A_{ps}) = (202.5 \text{ksi})(3.906 \text{in}^2) = 790.97 \text{kip} \]

Girder self-weight per feet of length

\[ w^{klf} = (w^{kcf})(A_g) = (0.15 \text{k/ft}^3)(659 \text{in}^2 / 144 \text{in}^2/\text{ft}^2) = 0.69 \text{k/ft} \]

Girder self-weight bending moment at mid span

\[ M_g = (w^{klf}) \left( \frac{l^2}{8} \right) = (0.69 \text{k/ft}) \left( \frac{80 \text{ft}}{8} \right)^2 = 552 \text{k-ft} \]

Instantaneous loss – Elastic Shortening

\[ \Delta f_{pES} = \left( \frac{E_p}{E_{c,t=1}} \right) (f_{cgp}) \]

The prestressing stress at strands immediately after transfer

\[ f_{cgp} = \frac{p_j}{A_g} + \left( \frac{P_j(e_{pg})^2}{l_g} \right) + \left( \frac{M_g(e_{pg})}{l_g} \right) \]

\[ e_{pg} = y_b - \text{cover} = 27.63 \text{in} - 3 \text{in} = 24.63 \text{in} \]

\[ f_{cgp} = \frac{-790.97 \text{kip}}{659 \text{in}^2} + \frac{(-790.97 \text{kip})(24.63 \text{in})^2}{268077 \text{in}^4} + \frac{(552 \text{k-ft} \times 12 \text{in/ft})(24.63 \text{in})}{268077 \text{in}^4} \]

\[ f_{cgp} = -1.2 \text{ksi} - 1.79 \text{ksi} + 0.609 \text{ksi} = -2.381 \text{ksi} \]
\[ \Delta f_{PES} = \left( \frac{28500 \text{ ksi}}{3929 \text{ ksi}} \right) (-2.381 \text{ ksi}) = -17.27 \text{ ksi} \]

2nd Iteration

\[ f_{pi} = f_{pj} - \Delta f_{PES} = 202.5 \text{ ksi} - 17.27 \text{ ksi} = 185.23 \text{ ksi} \]

\[ p_i = (f_{pi})(A_{PS}) = (185.23 \text{ ksi})(3.906 \text{ in}^2) = 723.51 \text{ kips} \]

\[ f_{cgp} = \frac{-723.47 \text{ kips}}{659 \text{ in}^2} + \frac{(-723.47 \text{ kips})(24.63 \text{ in})^2}{268077 \text{ in}^4} + \frac{(552 \text{ kips} \times 12 \text{ in/ft})(24.63 \text{ in})}{268077 \text{ in}^4} \]

\[ f_{cgp} = -1.1 \text{ ksi} - 1.64 \text{ ksi} + 0.609 \text{ ksi} = -2.131 \text{ ksi} \]

\[ \Delta f_{PES} = \left( \frac{28500 \text{ ksi}}{3929 \text{ ksi}} \right) (-2.131 \text{ ksi}) = -15.46 \text{ ksi} \]

3rd Iteration

\[ f_{pi} = f_{pj} - \Delta f_{PES} = 202.5 \text{ ksi} - 15.46 \text{ ksi} = 187.04 \text{ ksi} \]

\[ p_i = (f_{pi})(A_{PS}) = (187.04 \text{ ksi})(3.906 \text{ in}^2) = 730.58 \text{ ksi} \]

\[ f_{cgp} = \frac{-730.58 \text{ kips}}{659 \text{ in}^2} + \frac{(-730.58 \text{ kips})(24.63 \text{ in})^2}{268077 \text{ in}^4} + \frac{(552 \text{ kips} \times 12 \text{ in/ft})(24.63 \text{ in})}{268077 \text{ in}^4} \]

\[ f_{cgp} = -1.11 \text{ ksi} - 1.653 \text{ ksi} + 0.609 \text{ ksi} = -2.154 \text{ ksi} \]

\[ \Delta f_{PES} = \left( \frac{28500 \text{ ksi}}{3929 \text{ ksi}} \right) (-2.154 \text{ ksi}) = -15.63 \text{ ksi} \]

Calculate Girder Top & Bottom stresses at transfer:

Initial prestress after transfer
\[ f_{pi} = f_{pj} - \Delta f_{pES} = 202.5^{ksi} - 15.63^{ksi} = 186.87^{ksi} \]

Prestress force after transfer

\[ p_i = (f_{pi})(A_{ps}) = (186.87^{ksi})(3.906^{in^2}) = 730^{kips} \]

\[ \sigma_{top} = \frac{p_i}{A_g} + \frac{(P_i)(e_{pg})(y_t)}{l_g} + \frac{(M_g)(y_t)}{l_g} \]

\[ \sigma_{top} = \frac{-730^{kips}}{659^{in^2}} + \frac{(-730^{kips})(24.63^{in})(-26.37^{in})}{268077^{in^4}} + \frac{(552^{k-ft} \times 12^{in/ft})(-26.37^{in})}{268077^{in^4}} \]

\[ \sigma_{top} = -1.11^{ksi} + 1.77^{ksi} - 0.65^{ksi} = 0.01^{ksi} \text{ (tension stress)} \]

\[ \sigma_{bot} = \frac{p_i}{A_g} + \frac{(P_i)(e_{pg})(y_b)}{l_g} + \frac{(M_g)(y_b)}{l_g} \]

\[ \sigma_{bot} = \frac{-730^{kips}}{659^{in^2}} + \frac{(-730^{kips})(24.63^{in})(27.63^{in})}{268077^{in^4}} + \frac{(552^{k-ft} \times 12^{in/ft})(27.63^{in})}{268077^{in^4}} \]

\[ \sigma_{bot} = -1.11^{ksi} - 1.85^{ksi} + 0.683^{ksi} = -2.28^{ksi} \text{ (compression stress)} \]

LRFD – AASHTO Concrete limit state after transfer:

\[ \sigma_{all,\text{comp.}} = 0.60 (f'_{ct=1}) = 0.60 (4.2^{ksi}) = -2.52^{ksi} > \sigma_{act.\text{comp.}} = -2.28 \text{ (Ok)} \]

\[ \sigma_{all,\text{ten.}} = 0.0948 \sqrt{f'_{ct=1}} = 0.0948 \sqrt{4.2^{ksi}} = 0.194^{ksi} > \sigma_{act.\text{ten.}} = 0.01 \text{ (Ok)} \]
**Stage 2:**

At this stage, stress changes in prestressed strands (losses) calculated from transfer ($t = t_{day}$) to deck placement ($t = 30_{day}$). These losses caused by girder creep, shrinkage and steel relaxation.

\[
k_s = 1.45 - 0.13 \left( \frac{V}{S} \right) = 1.45 - (0.13)(3.15) = 1.04 > 1.0 \quad \text{ok}
\]

\[
k_f = \frac{5}{(1 + f'_c)} = \frac{5}{(1 + 4.2)} = 0.96
\]

\[
k_{hc} = 1.56 - 0.008H = 1.56 - (0.008)(80) = 0.92
\]

\[
k_{hs} = 2.0 - 0.014H = 2.0 - (0.014)(80) = 0.88
\]

*Stress Change due to Concrete Creep ($\Delta f_{PCR}$):*

\[
\Delta f_{PCR} = \left( \frac{E_p}{E_{ct,1}} \right) (f_{cgp,t=1})(\Psi_{b(td,tl)})(K_{td,tl})
\]

Time development factor ($k$) between transfer and deck placement.
\[ k_{(td,ti)} = k_{(30,1)} = \frac{(t_{td-ti})}{61 - (4 \times f'_{c,t=1}) + (t_{td-ti})} = \frac{(30 - 1)}{61 - (4 \times 4.2) + (30 - 1)} = 0.4 \]

Girder Creep coefficient (\( \Psi \)) at time of deck placement due to loading introduced at transfer.

\[ \Psi_{b(td,ti)} = (1.9)(k_s)(k_f)(k_{hc})(k_{t(td,ti)})(t_i)^{-0.118} \]
\[ \Psi_{b(td,ti)} = \Psi_{b(30,t1)} = (1.9)(1.04)(0.96)(0.92)(0.4)(1)^{-0.118} = 0.69 \]

Time development factor (\( k \)) between transfer and final.

\[ k_t(tf,ti) = k_t(4030,1) = \frac{t_{tf-ti}}{61 - 4 \times (f'_{c,t=1}) + t_{tf-ti}} = \frac{4029}{61 - (4)(4.2) + 4029} = 0.989 \]

Girder Creep coefficient (\( \Psi \)) at final due to loading introduced at transfer.

\[ \Psi_{b(tf,ti)} = (1.9)(k_s)(k_f)(k_{hc})(k_{t(tf,ti)})(t_i)^{-0.118} \]
\[ \Psi_{b(tf,ti)} = (1.9)(1.04)(0.96)(0.92)(0.989)(1)^{-0.118} = 1.73 \]

Transformed Section Coefficient (\( K \)) for time period between transfer and deck placement.

\[ K_{td,ti} = K_{(30,1)} = \frac{1}{1 + \left( \frac{E_p}{E_{ci}} \right) \left( \frac{A_{ps}^2}{A_g} \right) \left( 1 + \frac{(A_g)(e_{pg})^2}{l_g} \right) \left[ 1 + (\Psi_{(tf,ti)}) \right]} \]
\[ K_{td,ti} = \frac{1}{1 + \left( \frac{28500^{ksi}}{3929^{ksi}} \right) \left( \frac{3.906^{in^2}}{569^{in^2}} \right) \left( 1 + \frac{(569^{in^2})(24.63^{in^2})}{268077^{in^4}} \right) \left[ 1 + (0.7)(1.73) \right]} = 0.8 \]

Prestress loss due to creep of girder concrete between transfer and time of deck placement

\[ \Delta f_{p CR} = \left( \frac{28500^{ksi}}{3929^{ksi}} \right) (-2.154^{ksi})(0.69)(0.8) = -8.62^{ksi} \]

- **Stress Change due to Concrete Shrinkage** (\( \Delta f_{psH} \)): 
Concrete Shrinkage strain ($\varepsilon_b$) of girder between the time of transfer and deck placement

$$\varepsilon_b(t_{d,t_i}) = (k_s)(k_f)(k_{hs})(k_{(td,ti)})(0.48) \times (10)^{-0.3}$$

Prestress loss due to shrinkage of girder concrete between transfer and time of deck placement

$$\Delta f_{p_{SH}} = -(1.68E - 04)(28500)(0.8) = -3.83^{k}\text{si}$$

Stress Change due to Steel Relaxation ($\Delta f_{pR}$):

Relaxation of prestressing steel from transfer to deck placement

$$\Delta f_{R(t_{d,t_i})} = -(2.4)\left(\frac{t_{d(t_{d,t_i})}}{100 + t_{d(t_{d,t_i})}}\right)$$

$$\Delta f_{R(30,1)} = -(2.4)\left(\frac{29}{100 + 29}\right) = -0.54^{k}\text{si}$$

Prestressed Strands losses due to Creep & Shrinkage of concrete, and steel relaxation, from transfer to deck placement $\Delta f_{p_{LT(t_{d,t_i})}}$:

$$\Delta f_{p_{LT(t_{d,t_i})}} = \Delta f_{p_{CR}} + \Delta f_{p_{SH}} + \Delta f_{pR} = (-8.62^{k}\text{si}) + (-3.83^{k}\text{si}) + (-0.54^{k}\text{si}) = -12.99^{k}\text{si}$$

Total Prestressed Strands losses ($\Sigma \Delta f_{p_{(td,t_i)}}$) from transfer to deck placement.

$$\Sigma \Delta f_{p_{(td,t_i)}} = \Delta f_{p_{LT(t_{d,t_i})}} + \Delta f_{p_{ES}} = (-12.99^{k}\text{si}) + (-15.63^{k}\text{si}) = -28.62^{k}\text{si}$$

Calculate Girder Top & Bottom stresses before deck Placement:

Change of stresses at extreme girder fibers due to Creep, Shrinkage and Strands Relaxation
\[ \Delta p = (\Delta f_{pLT(t,t,d)})(A_{ps}) = (12.99^{ksi})(3.906^{in^2}) = 50.74^{ksi} \]

\[
\sigma_{top} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{ps})(y_t)}{I_g} 
\]

\[
\sigma_{top} = \frac{(50.74^{kips})}{659^{in^2}} + \frac{(50.74^{kips})(24.63^{in})(-26.37^{in})}{268077^{in^4}} = -0.046^{ksi} \text{(compression)} 
\]

\[
\sigma_{bot} = \frac{\Delta p}{A_g} + \frac{(\Delta p)(e_{ps})(y_b)}{I_g} 
\]

\[
\sigma_{bot} = \frac{(50.74^{kips})}{659^{in^2}} + \frac{(50.74^{kips})(24.63^{in})(27.63)}{268077^{in^4}} = 0.21^{kis} \text{(tension)} 
\]

Girder Top and bottom fiber stresses at end of stage 2 (before deck placement):

<table>
<thead>
<tr>
<th>Stress</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stages 1+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{top} )</td>
<td>0.01^{ksi}</td>
<td>-0.046^{ksi}</td>
<td>-0.036^{ksi}</td>
</tr>
<tr>
<td>( \sigma_{bot} )</td>
<td>-2.28^{ksi}</td>
<td>0.21^{ksi}</td>
<td>-2.07^{ksi}</td>
</tr>
</tbody>
</table>

**Stage 3:**

At this stage, stress change in prestressed strands (Gain) calculated after deck placement (\( t = 30 \) days)

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Stress gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Placement</td>
<td>30 day</td>
<td>( \Delta f_{pES} )</td>
</tr>
</tbody>
</table>
Bending Moment at mid-span due to deck placement

\[ M_{deck} = (w_c)(s)(t) \left(\frac{l^2}{8}\right) = \left(0.15 \frac{k}{ft^3}\right) (7 ft) \left(\frac{8\,\text{in}}{12\,\text{ft}}\right) \left(\frac{(80\,\text{ft})^2}{8}\right) = 560\,k\,ft \]

Compressive strength of concrete girder at deck placement \((t = 30\,\text{days})\)

\[ (f^'c)_t = \frac{t}{a + \beta \cdot t} \cdot (f^'c)_u \]

\[ (f^'c)_{t=30} = \frac{30}{0.692 + (0.975)(30)} (7\,\text{ksi}) = 7.01\,\text{ksi} \]

Concrete Modulus at deck placement \((t = 30\,\text{day})\)

\[ E_{c,t=30} = (33000) \left(w_c\right)^{1.5} \times \sqrt{(f^'c)_{t=30}} \]

\[ E_{c,t=30} = (33000)(0.15 \frac{k}{ft^3})^{1.5} \times \sqrt{7.01\,\text{ksi}} = 5075.8\,\text{ksi} \]

Change in prestressing stress immediately after deck placement

\[ f_{cgp} = \frac{(M_{deck})(e_{pg})}{I_g} \]
\[ f_{cgp} = \frac{(560^{k-ft})(12^{in/ft})(24.63^{in})}{268077^{in^4}} = 0.62^{ksi} \]

Instantaneous gain due to Elastic Shortening after deck placement

\[ \Delta f_{ES} = \left( \frac{E_p}{E_{c,t=30}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5075.8^{ksi}} \right) (0.62^{ksi}) = 3.48^{ksi} \]

2\textsuperscript{nd} Iteration

\[ f_{cgp} = \left( \frac{M_{deck}}{l_g} \right) (e_{pg}) + \left( \frac{\Delta f_{PS}}{A_g} \right) (f_{cgp}) + \left( \frac{\Delta f_{ES}}{A_g} (A_{PS})(e_{pg}) \right) \]

\[ f_{cgp} = 0.62^{ksi} + \frac{-3.48^{ksi}(3.906^{in^2})}{659^{in^2}} + \frac{-3.48^{ksi}(3.906^{in^2})(24.63^{in})}{268077^{in^4}} = 0.6^{ksi} \]

\[ \Delta f_{ES} = \left( \frac{E_p}{E_{c,t=30}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5075.8^{ksi}} \right) (0.6^{ksi}) = 3.37^{ksi} \]

3\textsuperscript{rd} Iteration

\[ f_{cgp} = 0.62^{ksi} + \frac{\Delta f_{PS}}{A_g} (A_{PS}) + \frac{\Delta f_{ES}}{A_g} (A_{PS})(e_{pg}) \]

\[ f_{cgp} = 0.62^{ksi} + \frac{-3.37^{ksi}(3.906^{in^2})}{659^{in^2}} + \frac{-3.37^{ksi}(3.906^{in^2})(24.63^{in})}{268077^{in^4}} = 0.578^{ksi} \]

Instantaneous prestress gain at time of deck placement:

\[ \Delta f_{ES} = \left( \frac{E_p}{E_{c,t=30}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5075.8^{ksi}} \right) (0.578^{ksi}) = 3.25^{ksi} \ (Gain \ stress) \]

Total Prestressed Strands losses (\( \Sigma \Delta f_{P(td,ti)} \)) from transfer to deck placement (end of stage 3).

\[ \Sigma \Delta f_{P(td,ti)} = \Delta f_{P_{LT}(ti,td)} + \Delta f_{P_{ES}} = (-28.62^{ksi}) + (3.25^{ksi}) = -25.37^{ksi} \]
Calculate Girder Top & Bottom stresses at deck placement:

\[ \Delta P_{t=30} = (\Delta f_{pES})(A_p) = (3.25^{k_{si}})(3.906^{in^2}) = 12.69^{k_{ips}} \]

\[ \sigma_{top} = \frac{\Delta P_{t=30}}{A_g} + \frac{(\Delta P_{t=30i})(e_{pg})(y_t)}{l_g} + \frac{(M_{deck})(y_t)}{l_g} \]

\[ \sigma_{top} = \frac{-12.69^{k_{ips}}}{659^{in^2}} + \frac{(-12.69^{k_{ips}})(24.63^{in})(-26.37^{in})}{268077^{in^4}} + \frac{(560^{in} x 12^{in/ft})(-26.37^{in})}{268077^{in^4}} \]

\[ \sigma_{top} = -0.02 + 0.031 - 0.66 = -0.65^{ksi} \]

\[ \sigma_{bot} = \frac{\Delta P_{t=30}}{A_g} + \frac{(\Delta P_{t=30i})(e_{pg})(y_b)}{l_g} + \frac{(M_{deck})(y_b)}{l_g} \]

\[ \sigma_{bot} = \frac{-12.69^{k_{ips}}}{659^{in^2}} + \frac{(-12.69^{k_{ips}})(24.63^{in})(27.63^{in})}{268077^{in^4}} + \frac{(560^{k_{-ft}} x 12^{in/ft}) x (27.63^{in})}{268077^{in^4}} \]

\[ \sigma_{bot} = -0.02^{ksi} - 0.03^{ksi} + 0.69^{ksi} = 0.64^{ksi} \]

Girder Top and bottom stresses after deck placement \((t = 30^{days})\)

<table>
<thead>
<tr>
<th>Stress</th>
<th>Stage 1+2</th>
<th>Stage 3</th>
<th>Stages 1-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{top})</td>
<td>-0.036^{ksi}</td>
<td>-0.65^{ksi}</td>
<td>-0.69^{ksi}</td>
</tr>
<tr>
<td>(\sigma_{bot})</td>
<td>-2.07^{ksi}</td>
<td>0.64^{ksi}</td>
<td>-1.43^{ksi}</td>
</tr>
</tbody>
</table>

**Stage 4:**

At this stage, stress change in prestressed strands (losses) calculated from deck placement \((t = 30^{days})\) to final \((t = 4030^{days})\). These losses caused by girder creep & shrinkage, deck shrinkage and steel relaxation.

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time step</td>
<td>4030 days</td>
<td>(\Delta f_{pCR}, \Delta f_{pSH}, \Delta f_{pR}, \Delta f_{pSS})</td>
</tr>
</tbody>
</table>
Modulus Concrete of Deck

\[ E_{c,\text{deck}} = (33000)(w_c)^{1.5} \sqrt{(f'c)} \]

\[ E_{c,\text{deck}} = (33000)(0.15)^{1.5} \sqrt{(4^{ksi})} = 3834.25^{ksi} \]

Compressive strength of concrete girder at deck placement.

\[ (f'c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'c)_u \]

\[ (f'c)_{t=30\ days} = \frac{(30)}{0.692 + (0.975)(30)}(7^{ksi}) = 7.01^{ksi} \]

Concrete Modulus at deck placement (t = 30 day)

\[ E_{c,t=30} = (33000)(w_c)^{1.5} \cdot \sqrt{(f'c)_{t=1}} \]

\[ E_{c,t=30} = (33000)(0.15^{k/ft^3})^{1.5} \cdot \sqrt{7.01^{ksi}} = 5075.86^{ksi} \]

Effective width of deck \((b_{eff})\):

\[ n = \frac{(E_{girder})}{(E_{deck})} = \frac{5075.8^{ksi}}{3834.25^{ksi}} = 1.325 \]
\[ b_{eff} = (w)(1/n) = (7\text{ft})(1/1.325) = 5.285\text{ft} \]

Effective area of deck:

\[ (A_{deck})_{eff} = (5.285\text{ft} \times 12\text{in/ft}) \times 8\text{in} = 507.4\text{in}^2 \]

Area of Composite section \( A_c \)

\[ A_c = A_g + (A_{deck})_{eff}. \]

\[ A_c = 659\text{in}^2 + 507.4\text{in}^2 = 1166.4\text{in}^2 \]

Location of Neutral Axes of composite section

\[ y'_c = \frac{(A_g)(y_b) + (A_{deck})(y_{deck})}{A_c} = \frac{(659\text{in}^2)(27.63\text{in}) + (507.4\text{in}^2)(54\text{in} + 4\text{in})}{(659\text{in}^2 + 507.4\text{in}^2)} = 40.84\text{in} \]

Moment of Inertia of composite section \( I_c \)

\[ I_c = [I_g + (A_g)(y'_c - y_b)^2] + [I_{deck} + (A_{deck})(y_{deck} - y'_c)^2] \]

\[ I_c = [268077\text{in}^4 + (659\text{in}^2)(40.84\text{in} - 27.63\text{in})^2] + \frac{(5.285\text{ft} \times 12\text{in/ft}) (8\text{in})^3}{12} \]

\[ + (507.4\text{in}^2)(54\text{in} + 4\text{in} - 40.84\text{in})^2 = 535193\text{in}^4 \]

\[ \Delta f_p_{CR} = \left( \frac{E_p}{E_{c(t=30)}} \right) (f_{cgp}) \left[ \Psi_{b(t_f,t_i)} - \Psi_{b(t_d,t_i)} \right] K_{b(t_f,t_d)} \]

\[ + \left( \frac{E_p}{E_{c(t=30)}} \right) (f_{cgp})(\Psi_{b(t_f,t_d)})(K_{b(t_f,t_d)}) \]

\[ \Psi_{b(t_d,t_i)} = 0.69 \]
\[
\Psi_{b(t_f,t_i)} = 1.73
\]

\[
K_{(t_f,t_d)} = \frac{1}{1 + \left( \frac{E_p}{E_{cl}} \right) \left( \frac{A_{ps}}{A_c} \right) \left( 1 + \frac{(A_c) \left( e_{pc}\right)}{l_c} \right) \left[ 1 + 0.7 \times \Psi_{(t_f,t_i)} \right]}
\]

\[
e_{pc} = y'_{c} - \text{cover} = 40.84^{in} - 3^{in} = 37.84^{in}
\]

\[
K_{b(t_f,t_d)} = \frac{1}{1 + \left( \frac{28500^{ksi}}{3929^{ksi}} \right) \left( \frac{3.906^{in^2}}{1166.4^{in^2}} \right) \left( 1 + \frac{(1166.4^{in^2}) \left( 37.84^{in^2}\right)^2}{535193.2^{in^4}} \right) \left( 1 + 0.7 \times 1.73 \right)}
\]

\[
= 0.82
\]

Time development factor \((k)\) between deck placement and final

\[
k_t(t_f,t_d) = k_t(4030,30) = \frac{t_d}{(61 - 4 \times f'_{ci} + t_d)} = \frac{4000}{(61 - 4 \times 4.2 + 4000)} = 0.99
\]

Girder creep coefficient \((\Psi)\) at final time due to loading introduced at deck placement.

\[
\Psi_{b(t_f,t_d)} = (1.9)(k_z)(k_f)(k_{hc})(k_{t(t_d,t_i)})(t_i^{-0.118})
\]

\[
\Psi_{b(t_f,t_d)} = (1.9)(1.04)(0.96)(0.92)(0.99)(30)^{-0.118} = 1.16
\]

Prestress loss due to creep of girder concrete between deck placement and final

\[
\Delta f_{pCR} = \left( \frac{28500^{ksi}}{5075.86^{ksi}} \right) \left( -2.154^{ksi} \right) \left[ 1.73 - 0.69 \right] \left( 0.82 \right)
\]

\[
+ \left( \frac{28500^{ksi}}{5075.86^{ksi}} \right) \left( 0.578^{ksi} \right) \left( 1.16 \right) \left( 0.82 \right) = -7.23^{ksi}
\]

\* Stress Change due to Concrete Shrinkage \((\Delta f_{pSH})\):

\[
\Delta f_{pSH} = (\varepsilon_{b(t_f,t_d)}) \left( E_p \right) (K_{t_f,t_d})
\]
Concrete Shrinkage strain ($\varepsilon_b$) of girder between deck placement and Final.

$$
\varepsilon_{b(tf,td)} = (k_s)(k_f)(k_{hs})(k_{(tf,ti)} - k_{(td,ti)})(0.48) \times (10)^{-03}
$$

Prestress loss due to Shrinkage of girder concrete between deck placement and final

$$
\Delta f_{p_{SH}} = -(2.5E - 04)(28500^{ksi})(0.82) = -5.843^{ksi}
$$

- **Stress Change due to Steel Relaxation ($\Delta f_{PR}$):**

$$
\Delta f_{R,4} = -2.4 \times \frac{t_{d(tf,ti)}}{100 + t_{d(tf,ti)}} - \Delta f_{R,2}
$$

$$
\Delta f_{R,4} = -2.4 \times \frac{4029}{100 + 4029} - 0.54 = -2.34^{ksi} + 0.54^{ksi} = -1.8^{ksi}
$$

- **Stress Change due to Deck Shrinkage: ($\Delta f_{ps}$)**

$$
\Delta f_{ps} = \left(\frac{E_p}{E_c}\right)(\Delta f_{cdf})(K_{(tf,td)})\left[1 + (0.7)(\Psi_{b(tf,td)})\right]
$$

$$
k_f = \frac{5}{1 + f'_{ci}} = \frac{5}{1 + 0.8 \times 4^{ksi}} = 1.19
$$

Assume 7 days deck currying, $t_{currying} = 30^{days} + 7^{days} = 37^{days}$

$$
\Delta t_{currying} = 3040^{days} - 37^{days} = 3993^{days}
$$

Time development factor ($k$) between deck currying and final.

$$
k_{t(tf,tcurre)} = \frac{t_{(tcurre,tf)}}{61 - 4 \times f'_c + t_{(tcurre,tf)}} = \frac{3993}{61 - 4 \times (0.8 \times 4) + 3993} = 0.988
$$

$$
\varepsilon_{d(tf,tdcur)} = (k_s)(k_f)(k_{hs})(k_{t(tf,tdcur)})(0.48 \times 10)^{-03}
$$
\[ k_s = 1.45 - 0.13 \left( \frac{\nu}{s} \right) = 1.45 - (0.13)(0.67) = 1.36 > 1.0 \quad \text{ok} \]

\[ \epsilon_{d(tf,tdcur)} = (1.36)(1.19)(0.88)(0.988)(0.48) \times 10^{-03} = 6.75E - 04 \]

Deck Creep coefficient \((\Psi)\) at time of End deck currying to final.

\[ \Psi_{d(tf,tdcur)} = (1.9) (k_s) (k_f) (k_{hc}) (k_{t(td,tf)}) (t_i)^{-0.118} \]

\[ \Psi_{d(tf,tdcur)} = (1.9) (1.36) (1.19) (0.92)(0.988) x (7)^{-0.118} = 2.222 \]

Eccentricity of deck with respect to the gross composite section \(e_d\).

\[ e_d = D - y'_{c} + \frac{t_{deck}}{2} = 54^{in} - 40.84^{in} + \frac{8^{in}}{2} = 17.16^{in} \]

Change in concrete stress \(\Delta f_{cdf}\) at centroid of prestressing strands due to long-term losses between deck placement and final.

\[ \Delta f_{cdf} = \frac{(E_{ddf})(A_d)(E_{cdeck})}{[1 + 0.7 x \Psi_{d(tf,tdcur)}]} \times \left( \frac{1}{A_c} - \frac{(e_d)(e_{pc})}{I_c} \right) \]

\[ \Delta f_{cdf} = \frac{(6.75E - 04)(672^{in^2})(3834.3^{ksti})}{[1 + (0.7)(2.222)]} \left( \frac{1}{1166.4^{in^2}} - \frac{17.16^{in}(37.84^{in})}{535193^{in^4}} \right) = 0.24^{ksi} \]

The prestress gain due to shrinkage of deck concrete section, \(\Delta f_{pss}\), shall be determined as:

\[ \Delta f_{pss} = \left( \frac{E_p}{E_{c,t=37}} \right) (\Delta f_{cdf})(K_{(tf,tcurl)})(1 + 0.7 \Psi_b (t_f, t_d)) \]

Compressive strength of concrete at end of deck currying \((t=37^{days})\).

\[ (f' c)_t = \frac{t}{a + \beta \cdot t} \cdot (f' c)_u \]

\[ (f' c)_{t=37} = \frac{37}{0.692 + (0.975)(37)} (7^{ksi}) = 7.04^{ksti} \]
Concrete Modulus at deck placement (t = 37\text{\text{day}})

\[ E_{c,t=37} = (33000)(w_c)^{1.5} \times \sqrt{(f'_c)_{t=37}} \]

\[ E_{c,t=37} = (33000)(0.15k^3)^{1.5} \times \sqrt{7.04^k} = 5086.7^{ksi} \]

\[ \Delta f_{pss} = \left( \frac{28500^{ksi}}{5086.7^{ksi}} \right) (0.24)(0.82)[1 + (0.7)(1.16)] = 2.0^{ksi} \]

Change in prestress stresses due to girder Creep & Shrinkage, Steel relaxation, and deck shrinkage from deck placement to final:

\[ \Delta f_{pLT(tf,td)} = \Delta f_{pCR} + \Delta f_{pSH} + \Delta f_{pR} + \Delta f_{pss} \]

\[ = (-7.23^{ksi}) + (-5.843^{ksi}) + (-1.8^{ksi}) + (2.0^{ksi}) = -12.87^{ksi} \]

Total Prestressed Strands losses (\( \Sigma \Delta f_{p(tf,ti)} \)) from transfer to the end of stage 4.

\[ \Sigma \Delta f_{p(tf,ti)} = \Sigma \Delta f_{p stage3} + \Delta f_{pLT(tf,td)} = (-25.25^{ksi}) + (-12.87^{ksi}) = -38.12^{ksi} \]

Calculate concrete stresses at Top & Bottom of girder at end of stage 4:

Stress Change in prestressed Strands due to Creep & Shrinkage of concrete and steel relaxation.

\[ \Delta p = (\Delta f_{pLT(tf,td)})(A_Ps) = (12.87^{ksi})(3.906^{in^2}) = 50.27^{kip} \]

\[ \Delta \sigma_{top} = \frac{\Delta p}{A_c} + \frac{(\Delta p)(e_{pc})(y_{tc})}{I_c} \]

\[ y_{tc} = D - y' = 54^{in} - 40.84^{in} = 13.16^{in} \]

\[ \Delta \sigma_{top} = \frac{50.27^{kip}}{1166.4^{in^2}} + \frac{(50.27^{kip})(37.84^{in})(-13.16^{in})}{535193^{in^4}} = -0.00368^{ksi} \]
\[ \Delta \sigma_{\text{bot}} = \frac{\Delta p}{A_c} + \frac{(\Delta P)(e_{pc})(y_{bc})}{I_c} \]

\[ y_{bc} = y' = 40.84^{\text{in}} \]

\[ \Delta \sigma_{\text{bot}} = \frac{50.27^{\text{kips}}}{1166.4^{\text{in}^2}} + \frac{(50.27^{\text{kips}})(37.8^{\text{in}})(40.84^{\text{in}})}{535193^{\text{in}^4}} = 0.188^{\text{ksi}} \]

Stress Change in prestressed Strands due to Deck Shrinkage

\[ f_{dSH} = \frac{(e_{ddf} - e_{bdf})(A_d)(E_{cd})}{[1 + 0.7 \times \Psi_{d(tf,tdcur)}]} \]

\[ e_{bdf} = (k_s)(k_f)(k_{hs})[k_{(tdcur,tf)} - k_{(tdcur,ti)}] \times 0.48 \times 10^{-03} \]

\[ k_{(tdcur,ti)} = \frac{t_{(tdcur,ti)}}{61 - 4xf'c + t_{(tdcur,ti)}} = \frac{36}{61 - (4)(4.2) + 36} = 0.45 \]

\[ e_{bdf} = (1.04)(0.96)(0.88)[0.989 - 0.45] \times 0.48 \times 10^{-03} = 2.27E - 04 \]

\[ f_{dSH} = \frac{[(6.75E - 04) - (2.27E - 04)](672^{\text{in}^2})(3834.4^{\text{ksi}})}{[1 + 0.7 \times 2.22]} = -452^{\text{ksi}} \]

\[ \sigma_{\text{top}} = (f_{dSH}) \left( \frac{1}{A_c} - \frac{(e_d)(y_{tc})}{I_c} \right) \]

\[ \sigma_{\text{top}} = -452^{\text{ksi}} \times \left( \frac{1}{1166.4^{\text{in}^2}} - \frac{(17.16^{\text{in}})(-13.16^{\text{in}})}{535193^{\text{in}^4}} \right) = -0.58^{\text{ksi}} \]

\[ \sigma_{\text{bot.}} = (f_{dSH}) \left( \frac{1}{A_c} - \frac{(e_d)(y_{bc})}{I_c} \right) \]

\[ \sigma_{\text{bot}} = \left( -452^{\text{ksi}} \right) \left( \frac{1}{1166.4^{\text{in}^2}} - \frac{(17.16^{\text{in}})(40.84^{\text{in}})}{535193^{\text{in}^4}} \right) = 0.20^{\text{ksi}} \]
Total change of stresses in prestressed strands

$$\Sigma \Delta \sigma_{\text{top}} = (-0.58^{\text{kpsi}}) + (-0.0036^{\text{kpsi}}) = -0.584^{\text{kpsi}}$$

$$\Sigma \Delta \sigma_{\text{bot}} = (0.20^{\text{kpsi}}) + (0.188^{\text{kpsi}}) = 0.388^{\text{kpsi}}$$

Girder Top and bottom fiber stresses at end of stage 4

<table>
<thead>
<tr>
<th>Stress</th>
<th>Stage 1+3</th>
<th>Stage 4</th>
<th>Stages 1-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{top}}$</td>
<td>$-0.69^{\text{kpsi}}$</td>
<td>$-0.584^{\text{kpsi}}$</td>
<td>$-1.274^{\text{kpsi}}$</td>
</tr>
<tr>
<td>$\sigma_{\text{bott.}}$</td>
<td>$-1.43^{\text{kpsi}}$</td>
<td>0.388$^{\text{kpsi}}$</td>
<td>$-1.042^{\text{kpsi}}$</td>
</tr>
</tbody>
</table>

**Stage 5:**

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing Surface + LL</td>
<td>4030 days</td>
<td>$\Delta f_{\text{PES}}$</td>
</tr>
</tbody>
</table>

$$M_{(ws+barr)} = (w_s + w_{\text{bar}}) \left(\frac{l^2}{8}\right)$$

$$M_{(ws+barr)} = (0.245^{k/ft} + 0.12^{k/ft}) \left(\frac{(80ft)^2}{8}\right) = 292^{k-ft}$$

$$M_{LL(HS20)} = (32^{kips}) \left(\frac{l}{4}\right) + (32^{kips}) \left(\frac{\frac{l}{2} - 14ft}{l}\right) \left(\frac{l}{2}\right) + \frac{(8^{kips}) \left(\frac{l}{2} - 14ft\right)}{l} \left(\frac{l}{2}\right)$$
\[ M_{LL(HS20)} = (32^{kip})(\frac{80^ft}{4}) + (32^{kip})(\frac{80^ft}{2} - 14^ft)(\frac{80^ft}{2}) + \frac{(8^{kip})(\frac{80^ft}{2} - 14^ft)}{80^ft}(\frac{80^ft}{2}) = 1160^{k-ft} \]

\[ M_{LL(HS20)} \times D.I. = (1160^{k-ft})(1.33) = 1542.8^{k-ft} \]

\[ M_{(Lane \ Load)} = \left(0.64^{k/ft}\right)\left(\frac{(80^ft)^2}{8}\right) = 512^{k-ft} \]

\[ LL_{DF.(1 \ lane)} = 0.06 + \left(\frac{S}{14}\right)^{0.4} \left(\frac{S}{L}\right)^{0.3} \left[\frac{k_g}{(12)(L)(t)}\right]^{10.1} \]

\[ k_g = n \left[ l_g + (A_g)(e_g)^2 \right] \]

\[ e_g: \text{distance between center of gravity of girder and deck (in)} \]

\[ e_g = D - y_b - \frac{t_f}{2} = 54^{in} - 27.63^{in} + \frac{8^{in}}{2} = 30.37^{in} \]

\[ k_g = 1.325 \left(268077^{in^4} + (659^{in^2})(30.37^{in})^2 \right) = 1160563.5^{in^4} \]

\[ LL_{DF.(1 \ lane)} = 0.06 + \left(\frac{7}{14}\right)^{0.4} \left(\frac{7}{80}\right)^{0.3} \left[\frac{1160563.5^{in^4}}{(12)(80^ft)(8^{in})^3}\right]^{10.1} = 0.46 \]

\[ LL_{DF.(2 \ lane)} = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left[\frac{k_g}{(12)(L)(t)}\right]^{10.1} \]

\[ LL_{DF.(2 \ lane)} = 0.075 + \left(\frac{7}{9.5}\right)^{0.6} \left(\frac{7}{80}\right)^{0.2} \left[\frac{1160563.5^{in^4}}{(12)(80^ft)(8^{in})^3}\right]^{10.1} = 0.63 \]

\[ M_{LL(Total)} = \left[ M_{(Lane \ Load)} + M_{LL(HS20) \times D.I.}\right] \times LL_{DF}. \]

\[ M_{LL(Total)} = \left[ 512^{k-ft} + 1542.8^{k-ft}\right] (0.63) = 1294.5^{k-ft} \]

\[ f_{cgp} = \frac{(M_{LL})(e_{pc})}{l_c} + \frac{(M_{ws})(e_{pc})}{l_c} \]
\[ f_{cgp} = \frac{(1294.5^{k-ft})(12^{in})(37.84^{in})}{535193^{in^4}} + \frac{(292^{k-ft})(12^{in})(37.84^{in})}{535193^{in^4}} = 1.10^{ksi} + 0.25^{ksi} = 1.35^{ksi} \]

\[(f'_c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'_c)_u \]

\[(f'_c)_{t=30} = \frac{4030}{0.692 + (0.975)(4030)} (7^{ksi}) = 7.18^{ksi} \]

Concrete Modulus at deck placement (t = 4030 day)

\[ E_{c,t=4030} = (33000) (w_c)^{1.5} \times \sqrt{(f'_c)_{t=4030}} \]

\[ E_{c,t=4030} = (33000)(0.15^{k/ft^2})^{1.5} \times \sqrt{7.18^{ksi}} = 5137^{ksi} \]

\[ \Delta f_{PES} = \left( \frac{E_p}{E_{c,t=4030}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5137^{ksi}} \right) (0.25^{ksi}) = 1.387^{ksi} \]

2\(^{nd}\) Iteration:

\[ f_{cgp} = \frac{(M_{ws})(e_p c)}{I_c} + \frac{(\Delta f_{PES})(A_p s)}{A_c} + \frac{(\Delta f_{PES})(A_p s)(e_p c)^2}{I_c} \]

\[ f_{cgp} = \frac{(292^{k-ft})(12^{in})(37.84^{in})}{535193.2^{in^4}} + \frac{(-7.5^{ksi})(3.906^{in^2})}{1166.4^{in^2}} + \frac{(-7.5^{ksi})(3.906^{in^2})(37.84^{in})^2}{535193.2^{in^4}} \]

\[ f_{cgp} = 0.248^{ksi} - 0.025^{ksi} - 0.078^{ksi} = 0.145^{ksi} \]

\[ \Delta f_{PES} = \left( \frac{E_p}{E_c} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5137^{ksi}} \right) (0.145^{ksi}) = 0.804^{ksi} \]

3\(^{rd}\) Iteration:

\[ f_{cgp} = \frac{(292^{k-ft})(12^{in})(37.84^{in})}{535193.2^{in^4}} + \frac{(-0.804^{ksi})(3.906^{in^2})}{1166.4^{in^2}} + \frac{(-0.804^{ksi})(3.906^{in^2})(37.84^{in})^2}{535193.2^{in^4}} \]
\[ f_{cgp} = 0.248^{ksi} - 0.003^{ksi} - 0.0002 = 0.24^{ksi} \]

\[ \Delta f_{ES} = \left( \frac{E_p}{E_c} \right) (f_{cgp}) = \left( \frac{28500}{5137} \right) (0.24) = 1.3 \text{ ksi} \]

Total prestressed Strands losses (\( \Sigma \Delta f_{p(t_f,t_l)} \)) from transfer to the end of stage 5.

\[ \Sigma \Delta f_{p(t_f,t_l)} = \Sigma \Delta f_{p_{stage4} + \Delta f_{ES,stage5}} = (-38.11^{ksi}) + (1.3^{ksi}) = -36.81^{ksi} \]

**Calculate Girder Top & Bottom stresses at end of stage 5:**

Change of stresses at Top & Bottom of concrete girder

\[ f_{cgp} = \frac{(M_{LL})(e_{pc})}{I_c} + \frac{(M_{ws})(e_{pc})}{I_c} \]

\[ f_{cgp} = \frac{(1294.5^{k-ft})(12^{ft})(37.84^{in})}{535193^{in^4}} + \frac{(292^{k-ft})(12^{ft})(37.84^{in})}{535193^{in^4}} = 1.10^{ksi} + 0.25^{ksi} \]

\[ = 1.35^{ksi} \]

\[ \Delta f_{PES} = \left( \frac{E_p}{E_{c,t=4030}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5137^{ksi}} \right) (1.35^{ksi}) = 7.49^{ksi} \]

2\(^{nd}\) Iteration:

\[ f_{cgp} = \frac{(M_{LL} + M_{ws})(e_{pc})}{I_c} + \frac{(\Delta f_{pES})(A_{pc})}{A_c} + \frac{(\Delta f_{pES})(A_{pc})(e_{pc})^2}{l_c} \]

\[ f_{cgp} = \frac{(1294.5^{k-ft} + 292^{k-ft})(12^{ft})(37.84^{in})}{535193.2^{in^4}} + \frac{(-7.5^{ksi})(3.906^{in^2})}{1166.4^{in^2}} \]

\[ + \frac{(-7.5^{ksi})(3.906^{in^2})(37.84^{in})^2}{535193.2^{in^4}} \]

\[ f_{cgp} = 1.346^{ksi} - 0.025^{ksi} - 0.002^{ksi} = 1.32^{ksi} \]

\[ \Delta f_{pES} = \left( \frac{E_p}{E_c} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5137^{ksi}} \right) (1.32^{ksi}) = 7.3^{ksi} \]

3\(^{rd}\) Iteration:
\[ f_{cgp} = \frac{(1294.5^\text{k-ft} + 292^\text{k-ft})(12^\text{in}) (37.84^\text{in})}{535193.2^\text{in}^4} + \frac{(-7.3^\text{ksi})(3.906^\text{in}^2)}{1166.4^\text{in}^2} \]
\[ + \frac{(-7.3^\text{ksi})(3.906^\text{in}^2)(37.84^\text{in})^2}{535193.2^\text{in}^4} \]

\[ f_{cgp} = 1.346^\text{ksi} - 0.024^\text{ksi} - 0.002 = 1.32^\text{ksi} \]

\[ \Delta f_{pES} = \left( \frac{E_p}{E_c} \right) f_{cgp} = \left( \frac{28500}{5137} \right) (1.32) = 7.2 \text{ ksi} \]

\[ \Delta P_i = (\Delta f_{pES})(A_p) = (7.2^\text{ksi})(3.906^\text{in}^2) = 28.1^\text{ksi} \]

\[ \sigma_{top} = \left( \frac{\Delta P_i}{A_c} + \frac{(\Delta P_i)(e_{pc})(y_{tc})}{I_c} \right) + \frac{(M_{LL} + M_{WS})(y_{tc})}{I_c} \]

\[ \sigma_{top} = \left( \frac{-28.1^\text{ksi}}{1166.4^\text{in}^2} + \frac{(-28.1^\text{ksi})(37.8^\text{in})(-13.23^\text{in})}{535193.2^\text{in}^4} \right) \]
\[ + \left( \frac{1294.5^\text{k-ft} + 292^\text{k-ft})(12^\text{in}) (-13.23^\text{in})}{535193.2^\text{in}^4} \right) \]

\[ \sigma_{top} = (-0.024^\text{ksi} + 0.026^\text{ksi}) + (-0.47^\text{ksi}) = -0.468^\text{ksi} \]

\[ \sigma_{bot} = \left( \frac{\Delta P_i}{A_c} + \frac{(\Delta P_i)(e_{pc})(y_{bc})}{I_c} \right) + \frac{(0.8 \times M_{LL} + M_{WS})(y_{bc})}{I_c} \]

\[ \sigma_{bot} = \left( \frac{-28.1^\text{ksi}}{1166.4^\text{in}^2} + \frac{(-28.1^\text{ksi})(37.8^\text{in})(40.77^\text{in})}{535193.2^\text{in}^4} \right) \]
\[ + \left( \frac{0.8 \times 1294.5^\text{k-ft} + 292^\text{k-ft})(12^\text{in}) (40.77^\text{in})}{535193.2^\text{in}^4} \right) \]

\[ \sigma_{bot} = (-0.024^\text{ksi} - 0.081^\text{ksi}) + (1.21^\text{ksi}) = 1.12^\text{ksi} \]

Girder Top and bottom fiber stresses at end of stage 5

<table>
<thead>
<tr>
<th>Stress</th>
<th>Stage 1-4</th>
<th>Stage 5</th>
<th>Stages 1-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{top} )</td>
<td>-1.274ksi</td>
<td>-0.468ksi</td>
<td>-1.74ksi</td>
</tr>
<tr>
<td>( \sigma_{bot} )</td>
<td>-1.042ksi</td>
<td>1.12ksi</td>
<td>0.08ksi</td>
</tr>
</tbody>
</table>
4.2 Simple span precast – Pretensioned W24PTMG Girder Bridge:

Stage 1:

At this stage, stress change in prestressed strands (losses) calculated after transfer 

\((t = 1 \text{ day})\) due to Elastic Shortening.

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut Strands</td>
<td>1 day</td>
<td>(\Delta f_{pES})</td>
</tr>
</tbody>
</table>
Compressive strength of concrete at transfer (after one day of concrete pouring)

\[(f'c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'c)_u\]

\[\beta = \frac{28}{\frac{A}{B} + 28} = \frac{28}{0.71 + 28} = 0.975\]

\[a = \beta \cdot \left(\frac{A}{B}\right) = (0.975) \cdot (0.71) = 0.692\]

\[(f'c)_{t=1 \text{ day}} = \frac{1}{0.692 + (0.975) \cdot 1} \quad (9) = 5.4 \text{ ksi}\]

Concrete Modulus after transfer (t = 1 day)

\[E_{c,t=1} = (33000)(w_c)^{1.5} \cdot \sqrt{(f'_c)_{t=1}}\]

\[E_{c,t=1} = (33000)(0.15)^{1.5} \cdot \sqrt{5.4} = 4455 \text{ ksi}\]

Initial prestress after transfer

\[f_{pj} = 0.75 (f_{pu}) = 0.75 (270 \text{ ksi}) = 202.5 \text{ ksi}\]

Prestress force after transfer

\[p_j = (f_{pj})(A_{ps}) = (202.5 \text{ ksi})(2.17 \text{ in}^2) = 439.43 \text{ kips}\]
Girder self-weight per feet of length

\[ w_{krf} = (w^{kcf})(A_g) = (0.15^{k/ft^3})(1211^{in^2}/144^{in^2}/ft^2) = 1.26^{k/ft} \]

Girder self-weight bending moment at mid span

\[ M_g = (w^{krf})(\frac{l^2}{8}) = (1.26^{k/ft}).\frac{(101.3^{ft})^2}{8} = 1616^{k-ft} \]

Instantaneous loss – Elastic Shortening

\[ \Delta f_{pES} = \left( \frac{E_p}{E_{ct=1}} \right) (f_{cgp}) \]

The prestressing stress immediately after transfer

\[ f_{cgp} = \frac{p_j}{A_g} + \frac{(p_j)(e_{pg})^2}{l_g} + \frac{(M_g)(e_{pg})}{l_g} \]

\[ e_{pg} = y_b - cover = 45.64^{in} - 3^{in} = 42.64^{in} \]

\[ f_{cgp} = \frac{-439.43^{kips}}{1211^{in^2}} + \frac{(-439.43^{kips})(42.64^{in})}{1447119^{in^4}} + \frac{(1616.2^{k-ft} x 12^{in/ft})(42.64^{in})}{1447119^{in^4}} \]

\[ f_{cgp} = -0.363^{ksi} - 0.552^{ksi} + 0.571^{ksi} = -0.344^{ksi} \]

\[ \Delta f_{pES} = \left( \frac{28500^{ksi}}{4455^{ksi}} \right) (-0.344^{ksi}) = -2.20^{ksi} \]

2\textsuperscript{nd} Iteration:

\[ f_{pi} = f_{pj} - \Delta f_{pES} = 202.5^{ksi} - 2.20^{ksi} = 200.3^{ksi} \]

\[ p_i = (f_{pi}) (A_{ps}) = (200.3^{ksi})(2.17^{in^2}) = 434.65^{kips} \]
\[
f_{cgp} = \frac{-434.65^{kips}}{1211^{in^2}} + \frac{(-434.65^{kips})(42.64^{in})^2}{1447119^{in^4}} + \frac{(1616.2^{k-ft} \times 12^{in/ft})(42.64^{in})}{1447119^{in^4}}
\]

\[
f_{cgp} = -0.36^{ksi} - 0.546^{ksi} + 0.57^{ksi} = -0.336^{ksi}
\]

\[
\Delta f_{pES} = \left(\frac{28500^{ksi}}{4455^{ksi}}\right)(-0.336^{ksi}) = -2.15^{ksi}
\]

3rd Iteration:

\[
f_{pi} = f_{pj} - \Delta f_{pES} = 202.5^{ksi} - 2.15^{ksi} = 200.35^{ksi}
\]

\[
p_i = (f_{pi}) (A_{ps}) = (200.35^{ksi})(2.17^{in^2}) = 434.76^{ksi}
\]

\[
f_{cgp} = \frac{-434.76^{kips}}{1211^{in^2}} + \frac{(-434.76^{kips})(42.64^{in})^2}{1447119^{in^4}} + \frac{(1616.2^{k-ft} \times 12^{in/ft})(42.64^{in})}{1447119^{in^4}}
\]

\[
f_{cgp} = -0.359^{ksi} - 0.546^{ksi} + 0.57^{ksi} = -0.335^{ksi}
\]

\[
\Delta f_{pES} = \left(\frac{28500^{ksi}}{4455^{ksi}}\right)(-0.335^{ksi}) = -2.143^{ksi}
\]

Calculate Girder Top & Bottom stresses at transfer:

Initial prestress after transfer

\[
f_{pi} = f_{pj} - \Delta f_{pES} = 202.5^{ksi} - 2.143^{ksi} = 200.36^{ksi}
\]

Prestress force after transfer

\[
p_i = (f_{pi}) (A_{ps}) = (200.36^{ksi}) \cdot (2.17^{in^2}) = 434.78^{kips}
\]
Stage 2:

At this stage, stress change in prestressed strands (losses) calculated from transfer 
(t = 1 day) to deck placement (t = 21 days). These losses caused by girder creep, shrinkage 
and steel relaxation.

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>21 day</td>
<td>ΔfPCR, ΔfPSH, ΔfPCR</td>
</tr>
</tbody>
</table>
\[ k_s = 1.45 - 0.13 \left( \frac{V}{S} \right) = 1.45 - (0.13)(3.61) = 0.98 < 1.0 \quad k_s = 1.0 \]

\[ k_f = \frac{5}{1 + f'_{ct}} = \frac{5}{1 + 5.4} = 0.782 \]

\[ k_{hc} = 1.56 - 0.008H = 1.56 - (0.008)(80) = 0.92 \]

\[ k_{hs} = 2.0 - 0.014H = 2.0 - (0.014)(80) = 0.88 \]

\[ \text{Stress Change due to Concrete Creep (}\Delta f_{pc}\text{):} \]

\[ \Delta f_{pc} = \left( \frac{E_p}{E_{c,t=1}} \right) (f_{cgp,t=1})(\Psi_{b(td,ti)})(K_{(td,ti)}) \]

Time development factor \((k)\) between transfer and deck placement.

\[ k_{(td,ti)} = k_{(21,1)} = \frac{t_{td-ti}}{(61 - 4 \times f'_{ct=1} + t_{td-ti})} = \frac{20}{(61 - 4 \times 5.4 + 20)} = 0.34 \]

Girder Creep coefficient \((\Psi)\) at time of deck placement due to loading introduced at transfer

\[ \Psi_{b(td,ti)} = (1.9)(k_s)(k_f)(k_{hc})(k_{(td,ti)})(t_i)^{-0.118} \]

\[ \Psi_{b(td,ti)} = (1.9)(1.0)(0.782)(0.92)(0.34)(1)^{-0.118} = 0.46 \]
Time development factor \((k)\) between transfer and final.

\[
k_{t(t_f,t_i)} = k_{t(4035,1)} = \frac{t_{t_f-t_i}}{(61 - 4 f'_c + t_{t_f-t_i})} = \frac{4034}{(61 - (4 \times 5.4) + 4035)} = 0.99
\]

Girder Creep coefficient \((\Psi)\) at final due to loading introduced at transfer

\[
\Psi_{b(t_f,t_i)} = (1.9)(k_s)(k_f)(k_{h.c})(k_{t(t_f,t_i)})(t_i)^{-0.118}
\]

\[
\Psi_{b(t_f,t_i)} = (1.9)(1.0)(0.782)(0.92)(0.99)(1)^{-0.118} = 1.35
\]

Transformed Section Coefficient \((K)\) for time period between transfer and deck placement.

\[
K_{(t_d,t_i)} = \frac{1}{1 + \left(\frac{E_p}{E_{ci}}\right)\left(\frac{A_{ps}}{A_g}\right)\left(1 + \frac{A_g x e_{pg}}{I_g}\right)[1 + (0.7) \Psi_{(t_f,t_i)}]}
\]

\[
K_{(t_d,t_i)} = \frac{1}{1 + \left(\frac{28500k_{si}}{4455k_{si}}\right)\left(\frac{2.17in^2}{1211in^2}\right)\left(1 + \frac{1211in^2 x (42.64in)^2}{1447119in^4}\right)[1 + (0.7)(1.35)]}
\]

\[
= 0.947
\]

Prestress loss due to creep of girder concrete between transfer and deck placement.

\[
\Delta f_{p_{cr}} = \left(\frac{28500k_{si}}{4455k_{si}}\right)(-0.335k_{si})(0.46)(0.947) = -0.93k_{si}
\]

- Stress Change due to Concrete Shrinkage \((\Delta f_{p_sh})\):

\[
\Delta f_{p_{sh}} = (\epsilon_{bid})(E_p)(K_{td,t_i})
\]

Concrete Shrinkage strain \((\epsilon_b)\) of girder between the time of transfer and deck placement

\[
\epsilon_{b(td,t_i)} = (k_s)(k_f)(k_{h.c})(k_{t(td,t_i)})(0.48)(10)^{-0.13}
\]
\[ \varepsilon_{b(td,ti)} = (1.0)(0.782)(0.88)(0.34)(0.48)x(10)^{-03} = 1.12E - 04 \]

Prestress loss due to shrinkage of girder concrete between transfer and deck placement.

\[ \Delta f_{p,SH} = -(1.12E - 04)(28500^{ksi})(0.947) = -3.0^{ksi} \]

Stress Change due to Steel Relaxation (\( \Delta f_{pR} \)):

\[ \Delta f_R = -(2.4) \cdot \frac{t_{d(td,ti)}}{100 + t_{d(td,ti)}} \]

\[ \Delta f_R = -(2.4) \left( \frac{20}{100 + 20} \right) = -0.4^{ksi} \]

Prestress losses due to Creep and Shrinkage of concrete, and steel relaxation, from transfer to deck placement:

\[ \Delta f_{p,LT(ti,td)} = \Delta f_{p,CR} + \Delta f_{p,SH} + \Delta f_{p,R} = (-0.93^{ksi}) + (-3.0^{ksi}) + (-0.4^{ksi}) = -4.33^{ksi} \]

Total losses (\( \Sigma \Delta f_p \)) from transfer to deck placement.

\[ \Sigma \Delta f_{p,STG2} = \Delta f_{p,LT(td,ti),STG2} + \Delta f_{p,ES,STG1} = (-4.33^{ksi}) + (-2.143^{ksi}) = -6.473^{ksi} \]

Calculate Girder Top & Bottom stresses before deck Placement:

Stress change at extreme fiber of girder due to creep, shrinkage and strands relaxation

\[ \Delta p_t = \Delta f_{p,LT(ti,td)} \times A_{p_s} = 4.33^{ksi} \times 2.17^{in^2} = 9.396^{ksi} \]

\[ \sigma_{top} = \frac{\Delta p_t}{A_g} + \frac{(\Delta p_t)(e_{PS})(y_t)}{l_g} \]
\[
\sigma_{\text{top}} = \frac{9.396 \text{ ksi}}{1211 \text{ in}^2} + \frac{(9.396 \text{ ksi}) (42.64 \text{ in}) (-48.85 \text{ in})}{1447119 \text{ in}^4} = -0.006 \text{ ksi}
\]

\[
\sigma_{\text{bot}} = \frac{\Delta P_i}{A_g} + \frac{(\Delta P_i) (e_{PS}) (y_b)}{l_g}
\]

\[
\sigma_{\text{bot}} = \frac{9.396 \text{ ksi}}{1211 \text{ in}^2} + \frac{9.396 \text{ ksi} \times 42.64 \text{ in} \times (45.64 \text{ in})}{1447119 \text{ in}^4} = 0.020 \text{ ksi}
\]

Girder Top and bottom stresses at end of stage 2 (before deck placement):

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stages 1+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{\text{top}})</td>
<td>-0.39 ksi</td>
<td>-0.006 ksi</td>
<td>-0.396 ksi</td>
</tr>
<tr>
<td>(\sigma_{\text{bot}})</td>
<td>-0.33 ksi</td>
<td>0.020 ksi</td>
<td>-0.31 ksi</td>
</tr>
</tbody>
</table>

**Stage 3:**

At this stage, stress change in prestressed strands (Gain) calculated after deck placement 

\((t = 21 \text{ days})\).

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Stress gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Placement</td>
<td>21 day</td>
<td>(\Delta f_{PS})</td>
</tr>
</tbody>
</table>

Moment at mid-span due to deck placement
\[ M_{\text{deck}} = (w_c)(s)(t) \frac{l^2}{8} = (0.15^{k/ft^3})(6.89^{ft}) \left( \frac{8^{in}}{12^{in/ft}} \right) x \frac{(101.3^{ft})^2}{8} = 883.8^{k-ft} \]

Compressive strength of concrete girder at deck placement (\(t = 21 \text{ days}\))

\[ (f'c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'c)_u \]

\[ (f'c)_{21} = \frac{21}{0.692 + (0.975)(21)} (9^{ksi}) = 8.93^{ksi} \]

Concrete Modulus at deck placement (\(t = 21 \text{ day}\))

\[ E_{c.t=21} = (33000) \cdot (w_c)^{1.5} \cdot x \sqrt{(f'c)_{t=21}} \]

\[ E_{c.t=21} = (33000)(0.15^{k/ft^3})^{1.5} \cdot x \sqrt{8.93^{ksi}} = 5729^{ksi} \]

Change in prestressing stress immediately after deck placement

\[ f_{cgP} = \frac{(M_{\text{deck}})(e_{pg})}{I_g} \]

\[ f_{cgP} = \frac{(883.8^{k-ft})(12^{in/ft})(42.64^{in})}{1447119^{in^4}} = 0.312^{ksi} \]

\[ \Delta f_pES = \left( \frac{E_p}{E_{c.t=21}} \right)(f_{cgP}) = \left( \frac{28500^{ksi}}{5729^{ksi}} \right)(0.312^{ksi}) = 1.55^{ksi} \]

2\(^{rd}\) Iteration

\[ f_{cgP} = \frac{(M_{\text{deck}})(e_{pg}) - (\Delta f_pES)(A_{PS}) - (\Delta f_pES)(A_{PS})(e_{pg})}{I_g} \]
\[ f_{cgp} = \left( \frac{883.8^{k-ft}(12^{in/ft})(42.64^{in})}{1447119^{in^4}} \right) - \left( \frac{(1.55^{ksi})(2.17^{in^2})}{1211^{in^2}} \right) - \left( \frac{(1.55^{ksi})(2.17^{in^2})(42.64^{in})}{1447119^{in^4}} \right) \]

\[ = 0.312^{ksi} - 0.00278^{ksi} - 0.0001^{ksi} = 0.309^{ksi} \]

\[ \Delta f_{ES} = \frac{E_p}{E_c} \times f_{cgp} = \left( \frac{28500^{ksi}}{5729^{ksi}} \right) \times 0.309^{ksi} = 1.537^{ksi} \]

**3rd Iteration**

\[ f_{cgp} = \left( \frac{M_{deck}}{l_g} \right) - \left( \frac{\Delta f_{ES}(A_p)}{A_g} \right) - \left( \frac{\Delta f_{ES}(A_p) e_{pg}}{l_g} \right) \]

\[ = \frac{883.8^{k-ft}(12^{in/ft})(42.64^{in})}{1447119^{in^4}} - \frac{(1.537^{ksi})(2.17^{in^2})}{1211^{in^2}} - \frac{(1.537^{ksi})(2.17^{in^2})(42.64^{in})}{1447119^{in^4}} \]

\[ = 0.312^{ksi} - 0.00275^{ksi} - 0.0001^{ksi} = 0.309^{ksi} \]

Prestress change (gain) at deck placement.

\[ \Delta f_{ES} = \left( \frac{E_p}{E_{ct=21day}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5729^{ksi}} \right) (0.309^{ksi}) = 1.537^{ksi} \]

Total stress (\( \Sigma \Delta f_p \)) from transfer to deck placement (end of stage 3).

\[ \Sigma \Delta f_{P_{stg3}} = \Sigma \Delta f_{P_{stg(1-2)}} + \Delta f_{P_{ES,stg3}} = (-6.473^{ksi}) + (1.537^{ksi}) = -4.936^{ksi} \]

Calculate Girder Top & Bottom stresses at deck placement:

\[ \Sigma P = (\Delta f_{PES,stg3})(A_{ps}) = (1.537^{ksi})(2.17^{in^2}) = 3.335^{kips} \]

\[ \sigma_{top} = \frac{\Delta P_t}{A_g} + \left( \frac{\Delta P_t}{l_g} \right) (e_{pg})(y_t) + \left( \frac{M_{deck}}{l_g} \right) (y_t) \]

\[ = \frac{-3.335^{kips}}{1211^{in^2}} + \frac{(-3.335^{kips})(42.64^{in})(-48.85^{in})}{1447119^{in^4}} + \frac{(883.8^{k-ft})(12^{in/ft})(-48.85^{in})}{1447119^{in^4}} \]
\[ \sigma_{\text{top}} = -0.0028^{ \text{ksi}} + 0.005^{ \text{ksi}} - 0.36^{ \text{ksi}} = -0.36^{ \text{ksi}} \]

\[ \sigma_{\text{bot}} = \frac{\Delta P_i}{A_g} + \frac{(P_i)(e_{pg})(y_b)}{I_g} + \frac{(M_{\text{deck}})(y_b)}{I_g} \]

\[ \sigma_{\text{bot}} = \frac{-3.335^{ \text{kip}}}{1211^{ \text{in}^2}} + \frac{(-3.335^{ \text{kip}})(42.64^{ \text{in}})(45.64^{ \text{in}})}{1447119^{ \text{in}^4}} + \frac{(883.8^{ \text{k}}-ft \times 12^{ \text{in}/ft})(45.64^{ \text{in}})}{1447119^{ \text{in}^4}} \]

\[ \sigma_{\text{bot}} = -0.0028^{ \text{ksi}} - 0.0045^{ \text{ksi}} + 0.334^{ \text{ksi}} = 0.327^{ \text{ksi}} \]

Girder Top and bottom stresses at end of stage 3 (t =21 days):

<table>
<thead>
<tr>
<th>Status</th>
<th>Stage 1+2</th>
<th>Stage 3</th>
<th>Stages 1-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{top}} )</td>
<td>-0.396^{ \text{ksi}}</td>
<td>-0.36^{ \text{ksi}}</td>
<td>-0.756^{ \text{ksi}}</td>
</tr>
<tr>
<td>( \sigma_{\text{bot}} )</td>
<td>-0.31^{ \text{ksi}}</td>
<td>0.327^{ \text{ksi}}</td>
<td>0.017^{ \text{ksi}}</td>
</tr>
</tbody>
</table>

**Stage 4:**

At this stage, stress change in prestressed strands (losses) calculated from deck placement (\( t =21 \text{ days} \)) to post tension (\( t = 35 \text{ days} \)). These losses caused by girder creep & shrinkage, deck shrinkage and steel relaxation.

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time step</td>
<td>35 days</td>
<td>( \Delta f_{p_{CR}}, \Delta f_{p_{SH}}, \Delta f_{p_{R}}, \Delta f_{p_{SS}} )</td>
</tr>
</tbody>
</table>
Modulus Deck concrete.

\[ E_{c,\text{deck}} = (33000)(w_c)^{1.5} \times \sqrt{(f'c)} \]

\[ E_{c,\text{deck}} = (33000)(0.15)^{1.5} \times \sqrt{4k\text{si}} = 3834.25\text{ksi} \]

Compressive strength of concrete girder at \((t = 35 \text{ days})\)

\[ (f'c)_t = \frac{t}{\alpha + \beta \cdot t} \cdot (f'c)_u \]

\[ (f'c)_{35} = \frac{35}{0.692 + (0.975)(35)} \cdot (9\text{ksi}) = 9.047\text{ksi} \]

Concrete Modulus at deck placement \((t = 35 \text{ day})\)

\[ E_{c,t=35} = (33000) \cdot (w_c)^{1.5} \times \sqrt{(f'c)_{t=35}} \]

\[ E_{c,t=35} = (33000)(0.15^{k/ft^3})^{1.5} \times \sqrt{9.047\text{ksi}} = 5766.38\text{ksi} \]

Effective width of deck \((b_e)\)

\[ n = \frac{(E_{\text{girder}}-t=35\text{day})}{(E_{\text{deck}}-t=35\text{day})} = \frac{5766.38\text{ksi}}{3834.25\text{ksi}} = 1.504 \]

\[ b_e = (w) \cdot \frac{1}{n} = (6.89^{ft})(1/1.504) = 4.582^{ft} \]
\[(A_{\text{deck}})_{\text{eff.}} = (4.582 \text{ ft} \times 12 \text{ in/ft}) \times 8 \text{ in} = 439.86 \text{ in}^2\]

Area of composite section \(A_c\).

\[A_c = A_g + (A_{\text{deck}})_{\text{eff.}}\]

\[A_c = 1211 \text{ in}^2 + 439.86 \text{ in}^2 = 1650.86 \text{ in}^2\]

Location of Neutral Axes \(y'\_c\).

\[y'\_c = \frac{(A_g)(y_b) + (A_{\text{deck}})(y_{\text{deck}})}{A_c} = \frac{(1211 \text{ in}^2)(45.64 \text{ in}) + (439.86 \text{ in}^2)(94.49 \text{ in} + 4 \text{ in})}{(1650.86 \text{ in}^2)} = 59.72 \text{ in}\]

Moment of Inertia of composite section \(I_c\).

\[I_c = [I_g + (A_g)(d_g)^2] + [I_{\text{deck}} + (A_{\text{deck}})(d_{\text{deck}})^2]\]

\[I_c = [1447119 \text{ in}^4 + 1211 \text{ in}^2(59.72 \text{ in} - 45.64 \text{ in})^2] + \left[\frac{(4.582 \text{ ft} \times 12 \text{ in})}{12}\right]\left(\frac{8 \text{ in}}{3}\right) + (439.86 \text{ in}^2)(94.49 \text{ in} + 4 \text{ in} - 59.72 \text{ in})^2 = 2350700 \text{ in}^4\]

• Stress Change due to Concrete Creep \((\Delta f_{p\text{CR}})\):

\[\Delta f_{p\text{CR}} = \left(\frac{E_p}{E_{c(t=21)}}\right)(f_{\text{cgp},t=1})(\Psi_{b(tp,t_i)} - \Psi_{b(td,t_i)}) (K_{b(tp,td)}) + \left(\frac{E_p}{E_{c,t=21}}\right)(f_{\text{cgp},t=21})(\Psi_{b(tp,td)})(K_{b(tp,td)})\]

\[\Psi_{b(td,t_i)} = 0.46\]

\[\Psi_{b(tf,t_i)} = 1.35\]
Time development factor \((k)\) between transfer and PT.

\[
k_{t(tp,ti)} = k_{t(35,1)} = \frac{t_d}{(61 - 4 \times f'_{ci} + t_d)} = \frac{34}{(61 - 4 \times 5.4 + 34)} = 0.46
\]

Girder creep coefficient \((\Psi)\) at time of post tension due to loading introduced at transfer

\[
\Psi_{b(tp,ti)} = (1.9)(k_s)(k_f)(k_{hc})(k_{t(tp,ti)})(t_i^{-0.118})
\]

\[
\Psi_{b(tp,ti)} = (1.9)(1.0)(0.782)(0.92)(0.46)(1^{-0.118}) = 0.63
\]

Time development factor \((k)\) between deck placement and PT.

\[
k_{t(tp,td)} = k_{t(35,21)} = \frac{t_d}{(61 - 4 \times f'_{ci} + t_d)} = \frac{(35 - 21)}{(61 - 4 \times 5.4 + (35 - 14))} = 0.26
\]

Girder Creep coefficient \((\Psi)\) at time of post tension due to loading introduced at deck placement

\[
\Psi_{b(tp,td)} = (1.9) (k_s) (k_f) (k_{hc}) (k_{t(tp,td)}) (t_i^{-0.118})
\]

\[
\Psi_{b(tp,td)} = (1.9) (1.0) (0.782) (0.92) (0.26) (21^{-0.118}) = 0.248
\]

Transformed Section Coefficient \((K)\) for time period between deck placement and final.

\[
K_{b(tf,td)} = \frac{1}{1 + \left( \frac{E_p}{E_{c,t=21}} \right) \left( \frac{A_{ps}}{A_c} \right) \left( 1 + \frac{(A_c)(e_{pc})^2}{I_c} \right) \left[ 1 + 0.7 x \Psi_{(tf,ti)} \right]}
\]

\[
e_{pc} = y'_{c} - cover = 59.72^{in} - 3^{in} = 56.72^{in}
\]

\[
K_{b(tf,td)} = \frac{1}{1 + \left( \frac{28500^{ksi}}{5729^{ksi}} \right) \left( \frac{2.17^{in^2}}{1650.86^{in^2}} \right) \left( 1 + \frac{1650.86^{in^2} x (56.72^{in})^2}{2350700^{in^4}} \right) x (1 + 0.7 x 1.35)}
\]

\[
= 0.96
\]
\[
\Delta f_{pCR} = \left( \frac{28500^{ksi}}{5729^{ksi}} \right) \left( -0.335^{ksi} \right) \left[ 0.63 - 0.46 \right] (0.96)
+ \left( \frac{28500^{ksi}}{5729^{ksi}} \right) \left( 0.309 \right) \left( 0.248^{ksi} \right) \left( 0.96 \right) = +0.093^{ksi}
\]

- Stress Change due to Concrete Shrinkage (\(\Delta f_{pSH}\)):

\[
\Delta f_{pSH} = (\varepsilon_b(t_p, t_d))(E_p)(K_{t_p,t_d})
\]

Concrete Shrinkage strain (\(\varepsilon_b\)) of girder between deck placement and PT.

\[
\varepsilon_b(t_p, t_d) = (k_s)(k_f)(k_{r,p}) \left( k_{t_p,t_i} - k_{t_d,t_i} \right)(0.48) \times (10)^{-03}
\]

\[
\varepsilon_b(t_p, t_d) = (1.0) \times (0.782)(0.88) \times (0.46 - 0.34)(0.48) \times (10)^{-03} = 39.6E - 06
\]

Prestress loss due to shrinkage of girder concrete between deck placement and PT.

\[
\Delta f_{pSH} = -(39.6E - 06)(28500^{ksi})(0.96) = -1.1^{ksi}
\]

- Stress Change due to Steel Relaxation (\(\Delta f_{pR}\)):

\[
\Delta f_{R} = -2.4 \times \frac{t_d(t_p, t_i)}{100 + t_d(t_p, t_i)} - \Delta f_{R1}
\]

\[
\Delta f_{R} = -2.4 \times \frac{34}{100 + 34} - 0.4 = -0.61^{ksi} + 0.4^{ksi} = -0.21^{ksi}
\]

- Stress Change due to Deck Shrinkage: (\(\Delta f_{pss}\))

\[
\Delta f_{pss} = \left( \frac{E_p}{E_c} \right) \left( \Delta f_{Cf} \right)(K_{df}) \left[ 1 + (0.7)(\psi_{b(t_f,t_d)}) \right]
\]

\[
k_f = \frac{5}{1 + f'_c} = \frac{5}{1 + 0.8 \times 4^{ksi}} = 1.19
\]
Assume 7 days deck currying, \( t_{\text{currying}} = 21^{\text{days}} + 7^{\text{days}} = 28^{\text{days}} \)

\[ t_f - t_{\text{currying}} = 4035^{\text{days}} - 28^{\text{days}} = 4007^{\text{days}} \]

Time development factor \((k)\) between deck currying and final.

\[ k_{t(t_f,t_{\text{curr}})} = \frac{t_{(t_{\text{cur}},t_f)}}{61 - 4 x f'_c + t_{(t_{\text{cur}},t_f)}} = \frac{4007}{61 - 4 x (0.8 x 4) + 4007} = 0.988 \]

Shrinkage Strain of deck concrete between deck placement and final time.

\[ \varepsilon_{d(t_f,t_{\text{dcur}})} = (k_s)(k_f)(k_{hs})(k_{td})(0.48 x 10)^{-03} \]

\[ \varepsilon_{d(t_f,t_{\text{dcur}})} = (1.0)(1.19)(0.88)(0.988)(0.48)(x)(10)^{-03} = 4.97E - 04 \]

Deck Creep coefficient \((\Psi)\) at time of End deck currying to final.

\[ \Psi_{d(t_f,t_{\text{dcur}})} = (1.9)(k_s)(k_f)(k_{hc})(k_{t(t_f,t_{\text{dcur}})})(t_i)^{-0.118} \]

\[ \Psi_{d(t_f,t_{\text{dcur}})} = (1.9)(1.0)(1.19)(0.92)(0.988)(7)^{-0.118} = 1.634 \]

Eccentricity of deck with respect to the gross composite section \(e_d\).

\[ e_d = D - y'_c + \frac{t_{\text{deck}}}{2} = 94.49^{\text{in}} - 59.72^{\text{in}} + \frac{8^{\text{in}}}{2} = 38.77^{\text{in}} \]

Change in concrete stress at centroid of prestressing strands \(\Delta f_{c(dcur,t_f)}\) due to long-term losses between end of deck currying and final.

\[ \Delta f_{c(dcur,t_f)} = \frac{(\varepsilon_{ddf})(A_d)(E_{cdeck})}{[1 + 0.7 x \Psi_{d(t_f,t_{\text{dcur}}})]} x \left( \frac{1}{A_c} - \frac{(e_d)(e_{pc})}{I_c} \right) \]
\[
\Delta f_{c\{d\text{cur}, tf\}} = -\frac{(4.97E - 04) \left(661.44^\text{in}^2\right) (3834.3^\text{ksi})}{[1 + (0.7) (1.634)]} \times \left(\frac{1}{1650.86^\text{in}^2} - \frac{(56.72^\text{in}) \times (38.77^\text{in})}{2350700^\text{in}^4}\right) \\
= 0.194^\text{ksi}
\]

Girder Creep coefficient (\(\Psi_{b\{t_f,t_{d\text{curr}}\}}\)) at time of end deck currying (t=28 day)

\[
\Psi_{b\{t_f,t_{d\text{curr}}\}} = (1.9)(k_s)(k_f)(k_{hc})(k_{t\{t_f,t_{d\text{curr}}\}})(t_{d\text{curr}})^{-0.118}
\]

\[
\Psi_{b\{t_f,t_{d\text{curr}}\}} = (1.9) (1.0) (0.782) (0.92) (0.988) (28)^{-0.118} = 0.913
\]

The prestress gain due to shrinkage of deck composite section \(\Delta f_{pss}\). From end of deck currying to final time.

\[
\Delta f_{pss} = \left(\frac{E_p}{E_{c,t=28}}\right) \left(\Delta f_{c\text{df}}\right)(K_{\{t_f,t_d\}})\left[1 + (0.7) \cdot \Psi_{b\{t_f,t_{d\text{curr}}\}}\right]
\]

\[
\Delta f_{pss} = \left(\frac{28500^\text{ksi}}{5751.4^\text{ksi}}\right) (0.194)(0.96)[1 + (0.7)(0.913)] = 1.513^\text{ksi}
\]

Time development factor (\(k\)) between end of deck currying and PT.

\[
k_{t\{t_{\text{cur}}, tp\}} = \frac{t_{\{t_p,t_{\text{cur}}\}}}{61 - 4 \times f'_{c} + t_{\{t_p,t_{\text{cur}}\}}} = \frac{7}{61 - 4 \times (0.8 \times 4) + 7} = 0.13
\]

The prestress gain due to shrinkage of deck composite section \(\Delta f_{pss}\). From end of deck currying to PT.

\[
\Delta f_{pss} = \Delta f_{pss\{t_f,t_{\text{cur}}\}} \times k_{\{t_p,t_{\text{cur}}\}}
\]

\[
\Delta f_{pss} = \Delta f_{pss\{t_{\text{cur}},t_f\}} \times k_{\{t_{\text{cur}},tp\}} = (1.513^\text{ksi}) (0.13) = 0.197^\text{ksi}
\]
Change in prestress stresses due to girder Creep & Shrinkage, steel relaxation, and deck shrinkage from deck placement to PT:

\[
\Delta f_{pLT(tp,td)} = \Delta f_{pCR} + \Delta f_{pSH} + \Delta f_{pR} + \Delta f_{pss}
\]

\[
= (+0.093^{k_{psi}}) + (-1.1^{k_{psi}}) + (-0.21^{k_{psi}}) + (+0.197^{k_{psi}}) = -1.02^{k_{psi}}
\]

Total prestressed Strands losses (ΣΔfp) from transfer to the end of stage 4.

\[
\Sigma \Delta f_{p_{stg4}} = \Sigma \Delta f_{p_{stage3}} + \Delta f_{p_{LT(tp,td),stg4}} = (-4.936^{k_{psi}}) + (-1.02^{k_{psi}}) = -5.96^{k_{psi}}
\]

Calculate concrete stresses at Top & Bottom of girder at end of stage 4:

Stresses due to Creep, Shrinkage of concrete and steel Relaxation:

\[
\Sigma \Delta f_{p} = \Delta f_{pCR} + \Delta f_{pSH} + \Delta f_{pR} = (0.093^{k_{psi}}) + (-1.1^{k_{psi}}) + (-0.21^{k_{psi}}) = -1.21^{k_{psi}}
\]

\[
\Delta p = \Sigma \Delta f_{p} \times A_{ps} = (-1.21^{k_{psi}}) \times (2.17^{in^2}) = 2.64^{kip_s}
\]

\[
\sigma_{top} = \frac{\Delta P}{A_g} + \frac{(\Delta P) (e_{ps})(y_t)}{l_g}
\]

\[
\sigma_{top} = \frac{2.64^{kip_s}}{1211^{in^2}} + \frac{(2.64^{kip_s})(42.64^{in})(-48.85^{in})}{1447119^{in^4}} = -0.0016^{k_{psi}}
\]

\[
\sigma_{bot} = \frac{\Delta P}{A_g} + \frac{(\Delta P) (e_{ps})(y_b)}{l_g}
\]

\[
\sigma_{bot} = \frac{2.64^{kip_s}}{1211^{in^2}} + \frac{(2.64^{kip_s})(42.64^{in})(45.64^{in})}{1447119^{in^4}} = 0.0057^{k_{psi}}
\]

Stresses due to Deck Shrinkage:

Compression force at center of deck due to deck shrinkage \( f_{ash} \)
\[ f_{dSH} = \frac{(E_{df} - E_{bf})(A_d)(E_{cd})}{[1 + 0.7 \times \psi_{d(t_f,tdcur)}]} \]

\[ \epsilon_b(t_{f,tcurr}) = (k_s)(k_s)(k_{hs}) [k_{(t_f,ti)} - k_{(tdcur,ti)}] \times 0.48 \times 10^{-03} \]

\[ k_{(tcurr,ti)} = \frac{t_{(tcurr,ti)}}{61 - 4xf'c + t_{(tcurr,ti)}} = \frac{(28 - 1)}{61 - 4x5.4 + 27} = 0.407 \]

\[ k_{(tf,ti)} = 0.99 \]

\[ \epsilon_b(t_{f,tcurr}) = (1.0)(0.782)(0.88) [0.99 - 0.407] \times 0.48 \times (10)^{-03} = 1.93E - 04 \]

\[ f_{dSH} = - \frac{[(4.97E - 04) - (1.93E - 04)](661.44)(3834.4)}{[1 + 0.7 \times 1.634]} = -359.65 \text{ kips} \]

\[ \sigma_{top} = f_{dSH} \times \left( \frac{1}{A_c} - \frac{(y_{tc})(e_d)}{I_c} \right) \]

\[ y_{tc} = 94.49^\text{in} - 59.72^\text{in} = 34.77^\text{in} \]

\[ \sigma_{top(t_f,tdcur)} = -359.65 \text{ kips} \times \left( \frac{1}{1650.86^\text{in}^2} - 34.77^\text{in} \right)(38.77^\text{in})2350700^\text{in}^4 = -0.424 \text{ ksi} \]

\[ \sigma_{top(tp,tdcur)} = \sigma_{top(t_f,tdcur)} \times k_{(tp,tdcur)} = (-0.424^\text{ksi})(0.13) = -0.055^\text{ksi} \]

\[ \sigma_{bot} = f_{dSH} \times \left( \frac{1}{A_c} - \frac{(y_{bc})(e_d)}{I_c} \right) \]

\[ \sigma_{bot(t_f,tdcur)} = -359.65 \times \left( \frac{1}{1650.86^\text{in}^2} - \frac{(59.72^\text{in})(38.77^\text{in})}{2350700^\text{in}^4} \right) = 0.136^\text{ksi} \]

\[ \sigma_{bot(tp,tdcur)} = \sigma_{bot(t_f,tdcur)} \times k_{(tdcur,tp)} = 0.136 \times 0.13 = 0.0176^\text{ksi} \]
Change of Girder Top & Bottom Stresses at stage 4 due to deck Shrinkage ($\Delta f_{dSH}$) and Girder Creep, Shrinkage and steel relaxation ($\Delta f_{CR+SH+R}$).

$$\Sigma \sigma_{top,stage4} = \sigma_{top} \cdot \Delta f_{dSH} + \sigma_{top} \cdot \Delta f_{CR+SH+R} = (-0.055^{ksi}) + (-0.0016^{ksi}) = -0.0566^{ksi}$$

$$\Sigma \sigma_{bot,stage4} = \sigma_{bot} \cdot \Delta f_{dSH} + \sigma_{bot} \cdot \Delta f_{CR+SH+R} = (0.01762^{ksi}) + (0.0057^{ksi}) = 0.0233^{ksi}$$

Girder Top and bottom stresses at end of stage 4 ($t = 35$ days):

<table>
<thead>
<tr>
<th></th>
<th>Stage 1+2+3</th>
<th>Stage 4</th>
<th>Stages 1-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{top}$</td>
<td>-0.75^{ksi}</td>
<td>-0.0566^{ksi}</td>
<td>-0.806^{ksi}</td>
</tr>
<tr>
<td>$\sigma_{bot}$</td>
<td>0.017^{ksi}</td>
<td>0.0233^{ksi}</td>
<td>0.040^{ksi}</td>
</tr>
</tbody>
</table>

**Stage 5:**

At this stage, stress change in prestressed strands “PS, PT” (losses) due to post tension stress and falsework removal at ($t = 35^{days}$).

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT+ Falsework removing</td>
<td>35 days</td>
<td>$\Delta f_{PES,PS},\Delta f_{PES,PT}$</td>
</tr>
</tbody>
</table>

$$f_{pj} = 0.75 (f_{pu}) = 0.75 (270^{ksi}) = 202.5^{ksi}$$

Prestress force after transfer
\[ p_j = (f_p)(A_{pt}) = (202.5^{ksi})(12.37^{in^2}) = 2504.925^{kips} \]

Anchor set loss:

\[ \Delta f_{pas} = 2 (\Delta f_{pi})(R)(X) \]

\[ e = y_b - P_{cover} = 45.64^{in} - 10.84^{in} = 34.8^{in} \]

\[ R = K + \frac{(2\ e\ \mu)}{b^2} = 0.0002^{1/ft} + \frac{2\ (34.8^{in}/12^{ft})\ (0.2)}{(97.75^{ft})^2} = 0.00032^{1/ft} \]

Length influenced by the Anchor set x:

\[ X = \sqrt{\frac{(S)(E_p)}{(R)(f_{pj})}} = \sqrt{\frac{(0.375^{in}/12^{in/ft})(285000^{ksi})}{(0.00032^{1/ft})(202.5^{ksi})}} = 117.2^{ft} \]

Prestress losses at edge of girder due to anchor set

\[ \Delta f_{pas} = 2 (\Delta f_{pi})(R)(X) = 2 \left( 202.5^{ksi} \right) \left( 0.00032^{1/ft} \right) \left( 117.2^{ft} \right) = 15.2^{ksi} \]
Prestress losses at \( x = 117 \) ft of girder due to anchor set.

\[
\Delta f_{pAS,x=117ft} = \left( \Delta f_{pAS}/2 \right) = \left( 15.2 \text{ksi} / 2 \right) = 7.6 \text{ksi}
\]

Prestress losses at mid span “\( x = 97.75 \) ft” of girder due to anchor set.

\[
\Delta f_{pAS,x=97.75ft} = 2 \left( \frac{\Delta f_{pAS}/2}{117ft} \right) (117ft - 97.75ft) = 2 \left[ \frac{15.2}{2} \right] (117ft - 97.75ft)
\]

\[
= 2.5 \text{ksi}
\]

Prestress losses at mid span “\( x = 97.75 \) ft” of girder due to friction.

\[
\Delta f_{pf,x=97.75ft} = (\Delta f_{p} - \Delta f_{pAS}) \left( 1 - e^{-(kx+αμ)} \right)
\]

\[
= (202.5 \text{ksi} - 2.5 \text{ksi})(1 - e^{0.0002^{\frac{1}{2}} x 97.75ft + 0.058 x 0.2}) = 6.134 \text{ksi}
\]

Instantaneous losses of PT due to Anchor set and friction.

\[
\Delta f_{pAS} + \Delta f_{pf} = 2.5 \text{ksi} + 6.134 \text{ksi} = 8.634 \text{ksi}
\]

Downward force at each spliced point due to temporary support removal.

\[
R_{\text{supp.}} = (w_g + w_{\text{deck}}) \left( 0.5 x \left( \frac{l_{\text{tot}} - l_{\text{mid}}}{2} \right) + \left( \frac{l_{\text{mid}}}{2} \right) \right)
\]

\[
R_{\text{supp.}} = (1.26^{k/ft} + 0.689^{k/ft}) \left[ 0.5 x \left( \frac{194.5^{ft} - 101.3^{ft}}{2} \right) + \left( \frac{101.3^{ft}}{2} \right) \right] = 144.13^{kips}
\]

Moment at midspan \( M_{fwr} \). Due to temporary support removal.

\[
M_{fwr} = R_{\text{supp.}} \left( \frac{l_{\text{tot}} - l_{\text{mid}}}{2} \right) = 144.13^{kips} \left( \frac{194.5^{ft} - 101.3^{ft}}{2} \right) = 6716.46^{k-ft}
\]

Prestress stress at time of PT and temporary support removal
\[
f_{cgp,PT} = \left( \frac{-PT}{A_c} + \frac{(PT)(e_{PT,c})^2}{I_c} \right) + \frac{(M_{fwr})(e_{PT,c})}{I_c}
\]

\[
p_i = [202.5 - (\Delta f_{pAS} + \Delta f_{pf})] (A_{PT}) = (202.5^\text{kpsi} - 8.634^\text{kpsi})(12.37^\text{in}^2) = 2398^\text{kips}
\]

\[
y_{bc} - PT\text{ cover} = 59.72^\text{in} - 10.84^\text{in} = 48.88^\text{kips}
\]

\[
f_{cgp,PT} = \left( \frac{-2398^\text{ksi}}{1650.86^\text{in}^2} + \frac{(-2398^\text{ksi})(48.88^\text{in})^2}{2350700^\text{in}^4} \right) + \frac{\left(6716.46^\text{k-ft} \times 12^\text{ft} \right)^\left(48.88^\text{in}\right)}{2350700^\text{in}^4}
\]

\[
= -3.889^\text{kpsi} + 1.676^\text{kpsi} = -2.213^\text{kpsi}
\]

Post Tension losses “\(\Delta f_{p,ES}\)" due to Elastic Shortening at midspan

\[
\Delta f_{pES, x=97.75^\text{ft}} = \left( \frac{N - 1}{2N} \right) \left( \frac{E_p}{E_{c,t=35}} \right) (f_{cgp})
\]

\[
\Delta f_{pES, x=97.75^\text{ft}} = \left( \frac{3 - 1}{2(3)} \right) \left( \frac{28500}{5765.7^\text{kpsi}} \right) (-2.213^\text{kpsi}) = -3.646^\text{kpsi}
\]

Total PT instantaneous losses

\[
\Delta f_{pAS, PT, ES, x=97.75^\text{ft}} = 2.5^\text{kpsi} + 6.134^\text{kpsi} + 3.646^\text{kpsi} = 12.28^\text{kpsi}
\]

\[
PT = [202.5 - (\Delta f_{pAS, PT, ES})] (A_{PT}) = (202.5^\text{kpsi} - 12.28^\text{kpsi})(12.37^\text{in}^2)
\]

\[
= 2353^\text{kpsi}
\]

\[
f_{cgp,PS} = \left( \frac{-PT}{A_c} + \frac{(-PT)(e_{PT,c})(e_{PS,c})}{I_c} \right) + \frac{(M_{fwr})(e_{PS,c})}{I_c}
\]
\[ f_{cgp,ps} = \left( \frac{-2353}{1650.86} \right) \left( \frac{ksi}{in^2} \right) + \left( \frac{-2353}{2350700} \right) \left( 48.88 \right) \left( \frac{in}{ksi} \right) \left( \frac{56.72}{in} \right) \]

\[ + \left( \frac{6716.46}{2350700} \right) \left( \frac{k}{ft} \times \frac{in}{12} \right) \left( \frac{ksi}{in} \right) \]

\[ = -4.2 + 1.945 = -2.256 ksi \]

\[ \Delta f_{pES,PS} = \left( \frac{E_p}{E_{c,t=35}} \right) \left( f_{cgp} = \left( \frac{28500}{5765.7} \right) \left( -2.256 \right) = -11.15 ksi \right) \]

**2nd Iteration**

\[ \Delta_{ps} = (\Delta f_{pES})(A_{PS}) = (11.15 ksi)(2.17 in^2) = 24.12 kips \]

\[ \Delta_{PT} = (\Delta f_{pES})(A_{PT}) = (3.646 ksi)(12.37 in^2) = 45.1 kips \]

\[ N = \frac{\# Tandons - 1}{2 \times \# Tandons} = \frac{3 - 1}{2 \times 3} = \frac{2}{6} = 0.333 \]

\[ f_{cgp,ps} = \left( \frac{-PT}{A_c} \right) + \left( \frac{(-PT)(e_{PT,c})(e_{PS,c})}{I_c} \right) + \left( \frac{(M_{fwr})(e_{PS,c})}{I_c} \right) + \left[ \frac{\Delta PT}{A_c} + \frac{(\Delta PT)(e_{PT,c})(e_{PS,c})}{I_c} \right] \]

\[ + \left( \frac{\Delta PS}{A_c} \right) + \left[ \frac{(\Delta PS)(e_{PS,c})^2}{I_c} \right] \]
\[
f_{cgp,PS} = \left( \frac{-2398^{kips}}{1650.86^{in^2}} + \frac{(-2398^{kips})(48.88^{in})(56.72^{in})}{2350700^{in^4}} \right)
\]
\[
+ \left( \frac{6716.46^{kips} \times 12^{ft} \times 56.72^{in}}{2350700^{in^4}} \right)
\]
\[
+ \left[ \frac{45.1^{kips}}{1650.86^{in^2}} + \frac{(45.1^{kips})(48.88^{in})(56.72^{in})}{2350700^{in^4}} \right]
\]
\[
+ \left( \frac{24.12^{kips}}{1650.86^{in^2}} + \frac{(24.12^{kips})(56.72^{in})^2}{2350700^{in^4}} \right)
\]
\[
= (-2.336^{ksi}) + (+0.081^{ksi}) + (+0.0476^{ksi}) = -2.21^{ksi}
\]

\[
\Delta f_{ES,PS} = \left( \frac{E_p}{E_{c,t=35}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5765.7^{ksi}} \right) (-2.21^{ksi}) = -10.92^{ksi}
\]

Total prestressed Strands losses (\(\Sigma \Delta f_{PS}\)) from transfer to the end of stage 5.

\[
\Sigma \Delta f_{PS,stag 5} = \Sigma \Delta f_{stag4} + \Delta f_{ES,stag5} = -5.96^{ksi} + (-10.92^{ksi}) = -16.88^{ksi}
\]

Stresses at Prestressed PT.

\[
f_{cgp,PT} = \left( \frac{-PT}{A_c} + \frac{(-PT)(e_{PT,c})^2}{l_c} + \frac{(M_{fwr})(e_{PT,c})}{l_c} \right) + \left[ \frac{\Delta PT}{A_c} + \frac{(\Delta PT)(e_{PT,c})^2}{l_c} \right]
\]
\[
+ \left( \frac{\Delta PS}{A_c} + \frac{(\Delta PS)(e_{PS,c})(e_{PT,c})}{l_c} \right)
\]
\[
f_{cgp,PT} = \left( \frac{-2398^{kips}}{1650.86^{in^2}} + \frac{\left( -2398^{kips} \right) (48.88^{in})^2}{2350700^{in^4}} + \frac{\left( 6716.46^{kips} \times 12^{ft} \right) (48.88^{in})}{2350700^{in^4}} \right)
+ \left[ \frac{45.1^{kips}}{1650.86^{in^2}} + \frac{(45.1^{kips}) (48.88^{in})^2}{2350700^{in^4}} \right]
+ \left( \frac{24.12^{kips}}{1650.86^{in^2}} + \frac{(24.12^{kips}) (56.72^{in}) (48.88^{in})}{2350700^{in^4}} \right)
= (-2.336^{ksi}) + (+0.073^{ksi}) + (+0.0431^{ksi}) = -2.22^{ksi}
\]

Post-tensioned Strands losses due to Elastic shortening:

\[
\Delta f_{ES,PT_{x=97.75^{ft}}} = \left( \frac{3 - 1}{2(3)} \right) \left( \frac{28500}{5765.7^{ksi}} \right) (-2.22^{ksi}) = -3.65^{ksi}
\]

Post-tensioned Strands losses at end of stage 5 \((t=35^{days})\)

\[
\Delta f_{PTAS} + \Delta f_{PTf} + \Delta f_{ES,PT_{x=97.75^{ft}}} = 2.5^{ksi} + 6.134^{ksi} + 3.65^{ksi} = 12.28^{ksi}
\]

Calculate concrete stresses at Top & Bottom of girder at end of stage 5:

\[
P_{PT} = 2398^{kips}
\]

\[
\Delta p_s = (\Delta f_{PS})(A_p) = \left( 10.92^{ksi} \right) \left( 2.17^{ksi} \right) = 23.7^{ksi}
\]

\[
\Delta p_{PT} = (\Delta f_{PT})(A_p) = \left( 3.65^{in^2} \right) \left( 12.37^{ksi} \right) = 45.2^{ksi}
\]

\[
e_{PS} = y_{bc} - \text{cover} = 59.72^{in} - 3^{in} = 56.72^{in}
\]

\[
\sigma_{top} = \left[ \frac{P_{PT}}{A_c} + \frac{P_{PT} (e_{PT,c})(y_{tc})}{I_c} \right] + \left( \frac{M_{fwr}}{I_c} (y_{tc}) \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{tc})}{I_c} \right] + \left[ \frac{\Delta P_{PT}}{A_c} \right]
+ \left( \frac{(\Delta P_{PT})(e_{PT,c})(y_{tc})}{I_c} \right)
\]
\[ \sigma_{\text{top}} = \left[ \frac{-2398 \text{kips}}{1650.86 \text{in}^2} + \frac{(-2398 \text{kips})(48.88 \text{in})(-34.77 \text{in})}{2350700 \text{in}^2} \right] \\
+ \left[ \frac{(6716.46 \text{kip-ft} \times 12 \text{ft})}{2350700 \text{in}^2} \right] (-34.69 \text{in}) \\
+ \left[ \frac{23.7}{1650.86 \text{in}^2} + \frac{(23.7)(56.72 \text{ksi})(-34.77 \text{in})}{2350700 \text{in}^2} \right] \\
+ \left[ \frac{45.2kips}{1650.86 \text{in}^2} + \frac{(45.2kips)(48.88 \text{in})(-34.77 \text{in})}{2350700 \text{in}^2} \right] \\
= (0.281 \text{ksi}) + (-1.19 \text{ksi}) + (-0.0055 \text{ksi}) + (-0.005 \text{ksi}) = -0.92 \text{ksi} \]

\[ \sigma_{\text{bot}} = \left[ \frac{P_{\text{PT}}}{A_c} + \frac{P_{\text{PT}} (e_{\text{PT,c}})(y_{bc})}{I_c} \right] + \left[ \frac{(M_{\text{fwr}}) (y_{bc})}{I_c} + \frac{\Delta P_{\text{PS}}(e_{\text{PS,c}})(y_{bc})}{I_c} \right] \\
+ \left[ \frac{\Delta P_{\text{PT}}}{A_c} + \frac{(\Delta P_{\text{PT}})(e_{\text{PT,c}})(y_{bc})}{I_c} \right] \]

\[ \sigma_{\text{bot}} = \left[ \frac{-2398 \text{kips}}{1650.86 \text{in}^2} + \frac{(-2398 \text{kips})(48.88 \text{in})(59.72 \text{in})}{2350700 \text{in}^2} \right] + \frac{(6716.46 \text{kip-ft} \times 12 \text{ft})}{2350700 \text{in}^2} \frac{59.72 \text{in}}{ \text{in}^2} \\
+ \left[ \frac{23.7}{1650.86 \text{in}^2} + \frac{(23.7)(56.72 \text{ksi})(59.72 \text{in})}{2350700 \text{in}^2} \right] \\
+ \left[ \frac{45.2kips}{1650.86 \text{in}^2} + \frac{(45.2kips)(48.88 \text{in})(59.72 \text{in})}{2350700 \text{in}^2} \right] \\
= (-4.43 \text{ksi}) + (2.048 \text{ksi}) + (0.0485 \text{ksi}) + (0.0835 \text{ksi}) = -2.25 \text{ksi} \]

Girder Top and bottom stresses at end of stage 5 (t =35\text{days}): 

<table>
<thead>
<tr>
<th></th>
<th>Stage 1-4</th>
<th>Stage 5</th>
<th>Stages 1-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{top}} )</td>
<td>-0.806 \text{ksi}</td>
<td>-0.92 \text{ksi}</td>
<td>-1.726 \text{ksi}</td>
</tr>
<tr>
<td>( \sigma_{\text{bot}} )</td>
<td>0.040 \text{ksi}</td>
<td>-2.25 \text{ksi}</td>
<td>-2.21 \text{ksi}</td>
</tr>
</tbody>
</table>
Stage 6:

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>4035 days</td>
<td>( \Delta f_{p_{CR}}, \Delta f_{p_{SH}}, \Delta f_{p_{R}}, \Delta f_{p_{SS}} )</td>
</tr>
</tbody>
</table>

\( t_i = 35 \text{ day}, \ t_d = 4035 - 35 = 4000 \text{ day} \)

\[ \Delta f_{p_{CR(PS)}} = \left( \frac{E_p}{E_{c,t=35}} \right) (f_{cgp,t=1}) [\Psi_{b(t_f,t_i)} - \Psi_{b(tp,t_i)}] \left( K_{b(t_f,tp)} \right) \]

\[ + \left( \frac{E_p}{E_{c,t=35}} \right) (f_{cgp,t=21}) [\Psi_{b(t_f,t_d)} - \Psi_{b(tp,t_d)}] \left( K_{b(tp,t_f)} \right) \]

\[ + \left( \frac{E_p}{E_{c,t=35}} \right) (f_{cgp,t=35}) [\Psi_{b(t_f,tp)}] \left( K_{b(tp,t_f)} \right) \]

\( \Psi_{b(t_d,t_i)} = 0.46 \)

\( \Psi_{b(tp,t_i)} = 0.63 \)

\( \Psi_{b(tp,t_d)} = 0.248 \)

\( \Psi_{b(t_f,t_i)} = 1.35 \)

Time development factor \((k)\) between deck placement and final.

\[ k_{t(t_f,t_d)} = k_{t(4035,21)} = \frac{t_{f-t_d}}{(61 - 4 \ f'_{ci} + t_{f-t_i})} = \frac{(4035 - 21)}{(61 - (4 \times 5.4) + (4035 - 21)} = 0.989 \]

Girder Creep coefficient \((\Psi)\) at final due to loading introduced at deck placement.

\[ \Psi_{b(t_f,t_d)} = (1.9)(k_s)(k_f)(k_{he})(k_{t(t_f,t_d)})(t_i)^{-0.118} \]

\[ \Psi_{b(t_f,t_d)} = (1.9)(1.0)(0.782)(0.92)(0.989)(21)^{-0.118} = 0.944 \]
Time development factor \((k)\) between PT and final.

\[
k_{(t_{f,tp})} = k_{(4035,35)} = \frac{t_{f-td}}{(61 - 4 f'_{ci} + t_{f-td})} = \frac{(4035 - 21)}{(61 - (4 x 5.4) + (4035 - 21))} = 0.989
\]

Girder Creep coefficient \((\Psi)\) at final due to loading introduced at PT

\[
\Psi_{b(t_{f,fp})} = (1.9)(k_s)(k_f)(k_{he})(k_{(t_{f,td})})(t_i)^{-0.118}
\]

\[
\Psi_{b(t_{f,fp})} = (1.9)(1.0)(0.782)(0.92)(0.989)(35)^{-0.118} = 0.889
\]

\[
K_{b(t_{f,fp})} = \frac{1}{1 + \left(\frac{E_p}{E_{c,t=35}}\right)\left(\frac{A_{ps}}{A_c}\right)\left(1 + \left(\frac{A_c}{e_{ps,c}}\right)^2\right)}[1 + 0.7 x \Psi_{(t_{f,ti})}] \times (1 + 0.7 x 1.35)
\]

\[
K_{b(t_{f,fp})} = \frac{1}{1 + \left(\frac{28500^{k_{si}}}{5765.7^{k_{si}}}\right)\left(\frac{2.17 \text{ in}^2}{1650.86 \text{ in}^2}\right)\left(1 + \frac{1650.86 \text{ in}^2 x (56.72 \text{ in}^2)^2}{2350700 \text{ in}^4}\right)} \times (1 + 0.7 x 1.35)
\]

\[
= 0.96
\]

\[
\Delta f_{CR(PS)} = \left(\frac{28500^{k_{si}}}{5765.7^{k_{si}}}\right)(-0.335^{k_{si}}) [1.35 - 0.63] (0.96)
\]

\[
+ \left(\frac{28500^{k_{si}}}{5765.7^{k_{si}}}\right)(0.309^{k_{si}}) [0.944 - 0.248] (0.96)
\]

\[
+ \left(\frac{28500^{k_{si}}}{5765.7^{k_{si}}}\right)(-2.21^{k_{si}}) [0.889] (0.96) = -9.45^{k_{si}}
\]

\[
\Delta f_{CR(PT)} = \left(\frac{E_p}{E_{c,t=35}}\right)\left(f_{cgp,t=35}\right) [\Psi_{b(t_{f,fp})}](K_{b(t_{f,fp})})
\]

\[
\Delta f_{CR(PT)} = \left(\frac{28500^{k_{si}}}{5765.7^{k_{si}}}\right)(-2.22^{k_{si}}) [0.889] (0.96) = -9.37^{k_{si}}
\]
Stress Change due to Concrete Shrinkage ($\Delta f_{PSH}$):

$$\Delta f_{PSH} = (\epsilon_{bpf})(E_p)(K_p)$$

$$\epsilon_{bpf} = (k_s)(k_f)(k_{hs}) \left[ k_{(t_f,ti)} - k_{(t_p,ti)} \right] (0.48) \times 10^{-03}$$

$$\epsilon_{bpf} = (1.0)(0.782)(0.88) [0.99 - 0.46] (0.48) \times 10^{-03} = 1.75 E - 04$$

$$\Delta f_{PSH} = (1.75 E - 04)(28500^{k_{si}})(0.96) = -4.79^{k_{si}}$$

Stress Change due to Steel Relaxation ($\Delta f_{PR}$):

$$\Delta f_{RPS} = -2.4 \times \frac{t_{d(t_f, t_p)}}{100 + t_d(t_f, t_p)} - \Delta f_{R1} - \Delta f_{R2}$$

$$\Delta f_{RPS} = -2.4 \times \frac{4034}{100 + 4034} - 0.4 - 0.21 = -1.73^{k_{si}}$$

$$\Delta f_{RPT} = -2.4 \times \frac{t_{d(t_f, t_p)}}{100 + t_d(t_f, t_p)}$$

$$\Delta f_{RPT} = -2.4 \times \frac{4035 - 35}{100 + 4000} = -2.34^{k_{si}}$$

Stress Change due to Deck Shrinkage: ($\Delta f_{PS}$)

$$\Delta f_{PS} = \left( \frac{E_p}{E_{c,t=28}} \right) (\Delta f_{cdf}) (K_{(t_f, t_d)}) \left[ 1 + 0.7 x \Psi_{b(t_f, t_dcur)} \right] \left[ k_{t(t_f, t_dcur)} - k_{t(t_p, t_dcur)} \right]$$

$$\Delta f_{PS} = \left( \frac{28500^{k_{si}}}{5751.4^{k_{si}}} \right) (0.194^{k_{si}})(0.96)[1 + 0.7 x 0.913][0.988 - 0.13] = 1.3^{k_{si}}$$

$$\Sigma \Delta f_{PS} = \Delta f_{CR} + \Delta f_{PSH} + \Delta f_{R} + \Delta f_{PS} = (-9.45^{k_{si}}) + (-4.79^{k_{si}}) + (-1.73^{k_{si}}) + (1.3^{k_{si}}) = -14.67^{k_{si}}$$
\[ \Sigma \Delta f_{PT} = \Delta f_{PC} + \Delta f_{SH} + \Delta f_{R} + \Delta f_{SS} = (-9.37^{ksi}) + (-4.79^{ksi}) + (-2.34^{ksi}) + (1.3^{ksi}) = -15.2^{ksi} \]

Calculate concrete stresses at Top \& Bottom of girder

\[ \Delta p_{PS} = (\Sigma \Delta f_{PS})(A_{PS}) = (14.67^{ksi})(2.17^{in^2}) = 31.83^{kips} \]

\[ \Delta p_{PT} = (\Sigma \Delta f_{PT})(A_{PT}) = (15.2^{ksi})(12.37^{in^2}) = 188.0^{kips} \]

\[ \Delta \sigma_{top} = (\sigma_{top. \Delta fdSH})(k_{d(f,t,d)} - (k_{d(f_p,t_c,cur)}) + \left(\frac{\Delta p_{PS}}{A_c} + \frac{\Delta p_{PS} (e_{PS,c}) (y_{tc})}{I_c}\right) 
+ \left(\frac{\Delta p_{PT}}{A_c} + \frac{\Delta p_{PT} (e_{PT,c}) (y_{bc})}{I_c}\right) \]

\[ \Delta \sigma_{top} = (-0.424^{ksi})(0.988 - 0.13) + \left(\frac{31.83^{kips}}{1650.86^{in^2}} + \frac{(31.83^{kips})(56.72^{in})(-34.77^{in})}{2350700^{in^4}}\right) 
+ \left(\frac{188^{kips}}{1650.86^{in^2}} + \frac{(188^{kips})(48.88^{in})(-34.77^{in})}{2350700^{in^4}}\right) \]

\[ \Delta \sigma_{top} = -0.364^{ksi} - 0.0074^{ksi} - 0.022^{ksi} = -0.393^{ksi} \]

\[ \Delta \sigma_{bot} = (\sigma_{bot. \Delta fdSH})(k_{d(f,t,d)} - (k_{d(f_p,t_c,cur)}) + \left(\frac{\Delta p_{PS}}{A_c} + \frac{\Delta p_{PS} (e_{PS,c}) (y_{bc})}{I_c}\right) 
+ \left(\frac{\Delta p_{PT}}{A_c} + \frac{\Delta p_{PT} (e_{PT,c}) (y_{bc})}{I_c}\right) \]

\[ \Delta \sigma_{bot} = (0.136^{ksi})(0.988 - 0.13) + \left(\frac{31.83^{kips}}{1650.86^{in^2}} + \frac{(31.83^{kips})(56.72^{in})(59.72^{in})}{2350700^{in^4}}\right) 
+ \left(\frac{188^{kips}}{1650.86^{in^2}} + \frac{(188^{kips})(48.88^{in})(59.72^{in})}{2350700^{in^4}}\right) \]

\[ \Delta \sigma_{bot} = 0.117^{ksi} + 0.065^{ksi} + 0.347^{ksi} = 0.529^{ksi} \]
Girder Top and bottom stresses at end of stage 6 (t = 4035 days):

<table>
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<tr>
<th></th>
<th>Stage 1-5</th>
<th>Stage 6</th>
<th>Stages 1-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{top}}$</td>
<td>-1.726 ksi</td>
<td>-0.393 ksi</td>
<td>-2.12 ksi</td>
</tr>
<tr>
<td>$\sigma_{\text{bott.}}$</td>
<td>-2.21 ksi</td>
<td>0.529 ksi</td>
<td>-1.681 ksi</td>
</tr>
</tbody>
</table>

Stage 7:

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ws + LL</td>
<td>4035 days</td>
<td>$\Delta f_{PE,PS}, \Delta f_{PE,PT}$</td>
</tr>
</tbody>
</table>

$$M_{(ws)} = (w_s) \left( \frac{l^2}{8} \right)$$

$$M_{(ws+\text{barrier})} = \left( 0.24 + 0.12 \frac{k}{ft} \right) \left( \frac{194.5 ft}{8} \right)^2 = 1702.36^{k-ft}$$

$$M_{LL(HS20)} = 32^{kip} \left( \frac{l}{4} \right) + 32^{kip} \left( \frac{l}{2} - 14 \right) \left( \frac{l}{2} \right) + 8^{kip} \left( \frac{l}{2} - 14 \right) \left( \frac{l}{2} \right)$$

$$M_{LL(HS20)} = 32^{kip} x \frac{194.5 ft}{4} + 32^{kip} x \frac{194.5 ft}{2} - 14 \left( \frac{194.5 ft}{2} \right) x \frac{194.5 ft}{2}$$

$$+ 8^{kip} x \left( \frac{194.5 ft}{2} - 14 \right) \left( \frac{194.5 ft}{2} \right) = 3221^{k-ft}$$

$$M_{LL(HS20)} \ (D.I.) = 3221^{k-ft} \times 1.33 = 4283.93^{k-ft}$$

$$M_{(Lane \ Load)} = (0.64^{k/ft}) (194.5^{ft})^2/8 = 3026.42^{k-ft}$$

$$LL \cdot DF \ (1 \ lane) = 0.06 + \left( \frac{S}{14} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left[ \frac{k_g}{12(L)(t)^3} \right]^{0.1}$$

$$k_g = n \left( l_g + (A_g)(e_g)^2 \right)$$
\( e_g \): distance between center of gravity of girder and deck (in).

\[
e_g = D - y_b - \frac{t_f}{2} = 94.49\text{in} - 45.64\text{in} + \frac{8\text{in}}{2} = 52.85\text{in}
\]

\( k_g = 1.504 \left( 1447119^{\text{in}^4} + (1211^{\text{in}^2})(52.85^{\text{in}})^2 \right) = 7263703.88^{\text{in}^4} \)

\[
LL_{DF(1\ \text{lane})} = 0.06 + \left( \frac{S}{14} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \times \left[ \frac{k_g}{12(L)(S)^{3}} \right]^{0.1}
\]

\[
LL_{DF(1\ \text{lane})} = 0.06 + \left( \frac{6.89^{ft}}{14} \right)^{0.4} \left( \frac{6.89^{ft}}{194.5} \right)^{0.3} \times \left[ \frac{7263703.88^{\text{in}^4}}{12(194.5^{ft})(8^{\text{in}^3})^{3}} \right]^{0.1} = 0.391
\]

\[
LL_{DF(2\ \text{lane})} = 0.075 + \left( \frac{S}{9.5} \right)^{0.6} \times \left( \frac{S}{L} \right)^{0.2} \times \left[ \frac{k_g}{12(L)(t)^{3}} \right]^{0.1}
\]

\[
LL_{DF(2\ \text{lane})} = 0.075 + \left( \frac{6.89^{ft}}{9.5} \right)^{0.6} \left( \frac{6.89^{ft}}{194.5} \right)^{0.2} \times \left[ \frac{7263703.88^{\text{in}^4}}{12x(194.5^{ft})(8^{\text{in}^3})^{3}} \right]^{0.1} = 0.581
\]

\[
M_{LL(\text{Total})} = [M_{(\text{lane Load})} + M_{LL(HS20) \times D.I}] \ \text{LL}_{DF}
\]

\[
M_{LL(\text{Total})} = [3026.42^{k-ft} + 4283.93^{k-ft}] \ (0.581) = 4247.3^{k-ft}
\]

Immediate losses of Prestressed Strands (PS):

\[
f_{cgp,PS} = \frac{(M_{ws})\ (e_{PS,c})}{I_c}
\]

\[
f_{cgp,PS} = \frac{(1702.36^{k-ft}\times12) \times (56.72^{\text{in}})}{2350700^{\text{in}^4}} = 0.493^{\text{ksi}}
\]

\[
\Delta f_{PS,PS} = \left( \frac{E_p}{E_{c,t=4035}} \right) (f_{cgp}) = \left( \frac{28500^{\text{ksi}}}{5823.3^{\text{ksi}}} \right) (0.493^{\text{ksi}}) = 2.4^{\text{ksi}}
\]

Immediate losses of Post-tensioned Strands:
\[ f_{cgp,PT} = \frac{(M_{ws})(e_{PT,c})}{l_c} \]

\[ f_{cgp,PT} = \frac{(1702.36^{k-f\times 12} \times 48.88^{in})}{2350700^{in^4}} = 0.425^{ksi} \]

\[ \Delta f_{ES,PT} = \left( \frac{N-1}{2N} \right) \left( \frac{E_p}{E_{c,t=4035}} \right) (f_{cgp}) = \left( \frac{3-1}{2 \times 3} \right) \left( \frac{28500^{ksi}}{5823.3^{ksi}} \right) (0.425^{ksi}) = 0.69^{ksi} \]

2\text{nd} \text{ Iteration}

\[ \Delta p_s = (\Sigma \Delta f_{PS})(A_p) = (2.4^{ksi})(2.17^{in^2}) = 5.21^{kips} \]

\[ \Delta p_t = (\Sigma \Delta f_{PT})(A_p) = (0.69^{ksi})(12.37^{in^2}) = 8.54^{kips} \]

Immediate losses of Prestressed Strands (PS):

\[ f_{cgp,PS} = \left( \frac{(M_{ws})(e_{PS,c})}{l_c} \right) + \left( \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})^2}{l_c} \right) - \left( \frac{\Delta P_{PT}}{A_c} - \frac{(\Delta P_{PT})(e_{PS,c})(e_{PT,c})}{l_c} \right) \]

\[ f_{cgp,PS} = (0.493^{ksi}) + \left( \frac{5.21^{ksi}}{1650.86^{in^2}} + \frac{5.21^{ksi}}{2350700^{in^4}} \right) \]

\[ + \left( \frac{8.54^{ksi}}{1650.86^{in^2}} + \frac{8.54^{ksi}}{2350700^{in^4}} \right) (56.72^{in}) (48.88^{in}) \]

\[ f_{cgp,PS} = (0.493^{ksi}) + (0.010^{ksi}) + (0.015^{ksi}) = 0.518^{ksi} \]

\[ \Delta f_{PS,PS} = \left( \frac{E_p}{E_c} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5823.3^{ksi}} \right) (0.518^{ksi}) = 2.54^{ksi} \]

Immediate losses of Post-tensioned Strands (PT):

\[ f_{cgp,PT} = \left( \frac{(M_{ws})(e_{PT,c})}{l_c} \right) + \left( \frac{\Delta P_{PS}}{A_c} + \frac{\Delta P_{PS}(e_{PS,c})(e_{PT,c})}{l_c} \right) - \left( \frac{\Delta P_{PT}}{A_c} - \frac{(\Delta P_{PT})(e_{PT,c})^2}{l_c} \right) \]
\[ f_{cgp, PT} = (0.425\, \text{ksi}) + \left( \frac{(5.21\, \text{ksi})}{1650.86\, \text{in}^2} + \frac{(5.21\, \text{ksi})(56.72\, \text{in})(48.88\, \text{in})}{2350700\, \text{in}^4} \right) \\
+ \left( \frac{8.54\, \text{ksi}}{1650.86\, \text{in}^2} + \frac{(8.54\, \text{ksi})(48.88\, \text{in})^2}{2350700\, \text{in}^4} \right) \]

\[ f_{cgp, PT} = (0.425\, \text{ksi}) + (0.0093\, \text{ksi}) + (0.014\, \text{ksi}) = 0.448\, \text{ksi} \]

\[ \Delta f_{PES, PT} = (\frac{N - 1}{2N}) \left( \frac{E_p}{E_c} \right) (f_{cgp}) = \left( \frac{3 - 1}{2\times3} \right) \left( \frac{28500\, \text{ksi}}{5823.3\, \text{ksi}} \right) (0.448\, \text{ksi}) = 0.731\, \text{ksi} \]

Calculate Girder Top & Bottom stresses

Immediate losses of Prestressed Strands (PS):

\[ f_{cgp, PS} = \frac{(M_{LL})(e_{PS,c})}{I_c} + \frac{(M_{WS})(e_{PS,c})}{I_c} \]

\[ f_{cgp, PS} = \frac{(4247.3\, \text{k}-\text{ft} \times 12)(56.72\, \text{in})}{2350700\, \text{in}^4} + \frac{(1702.36\, \text{k}-\text{ft} \times 12) \times (56.72\, \text{in})}{2350700\, \text{in}^4} = 1.23\, \text{ksi} + 0.493\, \text{ksi} \\
= 1.72\, \text{ksi} \]

\[ \Delta f_{PES,PS} = \left( \frac{E_p}{E_{c,t=4035}} \right) (f_{cgp}) = \left( \frac{28500\, \text{ksi}}{5823.3\, \text{ksi}} \right) (1.72\, \text{ksi}) = 8.43\, \text{ksi} \]

Immediate losses of Post-tensioned Strands:

\[ f_{cgp, PT} = \frac{(M_{LL})(e_{PT,c})}{I_c} + \frac{(M_{WS})(e_{PT,c})}{I_c} \]

\[ f_{cgp, PT} = \frac{(4247.3\, \text{k}-\text{ft} \times 12)(48.88\, \text{in})}{2350700\, \text{in}^4} + \frac{(1702.36\, \text{k}-\text{ft} \times 12) \times (48.88\, \text{in})}{2350700\, \text{in}^4} \\
= 1.059\, \text{ksi} + 0.425\, \text{ksi} = 1.485\, \text{ksi} \]
$$\Delta p_{ES,PT} = \left( \frac{N - 1}{2N} \right) \left( \frac{E_p}{E_{c,t=4035}} \right) (f_{cgp}) = \left( \frac{3 - 1}{2 \times 3} \right) \left( \frac{28500^{ksi}}{5823.3^{ksi}} \right) (1.485^{ksi}) = 2.42^{ksi}$$

2nd Iteration

$$\Delta p_S = (\Sigma \Delta f_p S)(A_{ps}) = (8.43^{ksi})(2.17^{in^2}) = 18.293^{kips}$$

$$\Delta p_T = (\Sigma \Delta f_p T)(A_{ps}) = (2.42^{ksi})(12.37^{in^2}) = 29.935^{kips}$$

Immediate losses of Prestressed Strands (PS):

$$f_{cgp,PS} = \left( \frac{(M_{LL})(e_{PS,c}) + (M_{WS})(e_{PS,c})}{I_c} \right) + \left( \frac{\Delta P_S}{A_c} + \frac{(\Delta P_S)(e_{PS,c})^2}{I_c} \right) - \left( \frac{\Delta P_T}{A_c} - \frac{(\Delta P_T)(e_{PS,c})(e_{PT,c})}{I_c} \right)$$

$$f_{cgp,PS} = (1.23^{ksi} + 0.493^{ksi}) + \left( \frac{(18.293^{ksi})}{1650.86^{in^2}} + \frac{(18.293^{ksi})(56.72^{in})(2^{in})}{2350700^{in^4}} \right) + \left( \frac{29.935^{ksi}}{1650.86^{in^2}} + \frac{(29.935^{ksi})(56.72^{in})(48.88^{in})}{2350700^{in^4}} \right)$$

$$f_{cgp,PS} = (1.723^{ksi}) + (0.0361^{ksi}) + (0.0534^{ksi}) = 1.8125^{ksi}$$

$$\Delta f_{ES,PS} = \left( \frac{E_p}{E_c} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{5823.3^{ksi}} \right) (1.8125^{ksi}) = 8.87^{ksi}$$

Immediate losses of Post-tensioned Strands (PT):

$$f_{cgp,PT} = \left( \frac{(M_{LL})(e_{PT,c}) + (M_{WS})(e_{PT,c})}{I_c} \right) + \left( \frac{\Delta P_S}{A_c} + \frac{\Delta P_S(e_{PS,c})(e_{PT,c})}{I_c} \right) - \left( \frac{(\Delta P_T)}{A_c} - \frac{(\Delta P_T)(e_{PT,c})^2}{I_c} \right)$$
\[ f_{cgp, PT} = (1.0598^{ksi} + 0.425^{ksi}) + \left(\frac{18.293^{ksi}}{1650.86^{in^2}} + \frac{(18.293^{ksi})(56.72^{in})(48.88^{in})}{2350700^{in^4}}\right) \]
\[ + \left(\frac{29.935^{ksi}}{1650.86^{in^2}} + \frac{(29.935^{ksi})(48.88^{in})^2}{2350700^{in^4}}\right) \]

\[ f_{cgp, PT} = (1.485^{ksi}) + (0.0327^{ksi}) + (0.0486^{ksi}) = 1.57^{ksi} \]

\[ \Delta f_{PES, PT} = \left(\frac{N - 1}{2N}\right)\left(\frac{E_p}{E_c}\right) (f_{cgp}) = \left(\frac{3 - 1}{2\times3}\right)\left(\frac{28500^{ksi}}{5823.3^{ksi}}\right)(1.57^{ksi}) = 2.56^{ksi} \]

\[ P_{PT} = 2398^{kips} \]

\[ \Delta P_{PS} = (\Delta f_{PS})(A_{PS}) = (8.87^{ksi})(2.17^{in^2}) = 19.25^{kips} \]

\[ \Delta P_{PT} = (\Delta f_{PT})(A_{PT}) = (2.56^{ksi})(12.37^{in^2}) = 31.67^{kips} \]

\[ e_{PS} = y_{bc} - cover = 59.72^{in} - 3^{in} = 56.72^{in} \]

\[ \sigma_{top} = \left(\frac{(M_{LL})(y_{tc})}{I_c} + \frac{(M_{ws})(y_{tc})}{I_c}\right) + \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS})(y_{tc})}{I_c} + \frac{\Delta P_{PT}}{A_c} \]
\[ + \frac{(\Delta P_{PT})(e_{PT})(y_{tc})}{I_c} \]

\[ \sigma_{top} = \left(\frac{(4247.3^{ksi} \times 12^{in/ft})(-34.77^{in})}{2350700^{in^4}} + \frac{(1702.36^{ksi} \times 12^{in/ft})(-34.77^{in})}{2350700^{in^4}}\right) \]
\[ + \frac{19.25^{kips}}{1650.86^{in^2}} + \frac{(19.25^{kips})(56.72^{in})(-34.77^{in})}{2350700^{in^4}} \]
\[ + \frac{31.67^{kips}}{1650.86^{in^2}} + \frac{(31.67^{kips})(48.88^{in})(-34.77^{in})}{2350700^{in^4}} \]

\[ = (-0.754^{ksi}) + (-0.302^{ksi}) + (-0.0045^{ksi}) + (-0.0037^{ksi}) = -1.064^{ksi} \]
\[
\sigma_{\text{bot}} = \left( \frac{(M_{LL})(y_{bc})}{I_c} + \frac{(M_{ws})(y_{bc})}{I_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{bc})}{I_c} \right] + \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{bc})}{I_c}
\]

\[
\sigma_{\text{bot}} = \left( \frac{0.8 \times (4247.3^{k-ft} \times 12^{in/ft})(59.72^{in})}{2350700^{in^4}} + \frac{(1702.36^{k-ft} \times 12^{in/ft})(59.72^{in})}{2350700^{in^4}} \right)
\]

\[
+ \left[ \frac{19.25^{kips}}{1650.86^{in^2}} + \frac{(19.25^{kips})(56.72^{in})(59.72^{in})}{2350700^{in^4}} \right]
\]

\[
+ \left[ \frac{31.67^{kips}}{1650.86^{in^2}} + \frac{(31.67^{kips})(48.88^{in})(59.72^{in})}{2350700^{in^4}} \right]
\]

\[
= (1.036^{ksi}) + (+0.519^{ksi}) + (0.039^{ksi}) + (0.059^{ksi}) = 1.6^{ksi}
\]

Girder top & bottom fibers stresses.

<table>
<thead>
<tr>
<th></th>
<th>Stage 1-6</th>
<th>Stage 7</th>
<th>Stages 1-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{\text{top}})</td>
<td>-2.12^{ksi}</td>
<td>-1.064^{ksi}</td>
<td>-3.184^{ksi}</td>
</tr>
<tr>
<td>(\sigma_{\text{bott.}})</td>
<td>-1.681^{ksi}</td>
<td>1.6^{ksi}</td>
<td>-0.081^{ksi}</td>
</tr>
</tbody>
</table>
APPENDIX -3-

Hand Calculation of Two Continuous Span of Precast Girder BT-1400mm:

Stage 1:

At this stage, stress change in prestressed strands (losses) calculated after transfer \((t = 1 \text{ day})\)

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut Strands</td>
<td>1 day</td>
<td>(Δf_{PES} )</td>
</tr>
</tbody>
</table>

Compressive strength of concrete at transfer (after one day of concrete pouring)

\[
(f'c)_{t} = \frac{t}{a + \beta \cdot t} \cdot (f'c)_{u}
\]

\[
\beta = \frac{28}{\frac{A}{B} + 28} = \frac{28}{0.71 + 28} = 0.975
\]

\[
a = \beta \cdot \left(\frac{A}{B}\right) = (0.975)(0.71) = 0.692
\]

\[
(f'c)_{t=1 \text{day}} = \frac{(1)}{0.692 + (0.975)(1)} \cdot (5^{ksi}) = 3.0^{ksi}
\]

Concrete Modulus after transfer \((t = 1 \text{ day})\)
\[ E_{c,t=1} = (33000)(w_c)^{1.5} \cdot \sqrt{(f'_{c})_{t=1}} \]

\[ E_{c,t=1} = (33000)(0.15^{k/ft^3})^{1.5} \cdot 3.0^{kksi} = 3320.56^{kksi} \]

Initial prestress after transfer

\[ f_{pj} = 0.75 \left( f_{pu} \right) = 0.75 \left( 270^{kisi} \right) = 202.5^{kisi} \]

Prestress force after transfer

\[ p_j = (f_{pj})(A_{PS}) = (202.5^{kisi})(3.906^{in^2}) = 790.97^{kips} \]

Girder self-weight per feet of length

\[ w^{kif} = (w^{kcf})(A_g) = (0.15^{k/ft^3})(924.5^{in^2}/144^{in^2/ft^2}) = 0.963^{k/ft} \]

Girder self-weight bending moment at 0.4L

\[ R_{left} = (w^{k/ft})(L^{ft})/2 = \left( 0.963^{ft} \right)(105^{ft})/2 = 50.558^{kips} \]

\[ M_g = (R_{left})(0.4L) - \left( \frac{w^{k}}{ft} \right) \left( \frac{0.4L}{2} \right) \]

\[ M_g = (50.558^{kips})(0.4 \times 105^{ft}) - \left( 0.963^{k} \right) \left( \frac{(0.4 \times 105^{ft})}{2} \right) = 1274.1^{k-ft} \]

Instantaneous loss - Elastic Shortening

\[ \Delta f_{pES} = \left( \frac{E_p}{E_{c,t=1}} \right) (f_{cgp}) \]

The prestressing stress immediately after transfer
\[ f_{cgp} = \frac{P_j}{A_g} + \frac{(p_j)(e_{PS})^2}{I_g} + \frac{(M_g)(e_{PS})}{I_g} \]

\[ e_{PS} = y_b - \text{cover} = 28.38^{\text{in}} - 4^{\text{in}} = 24.38^{\text{in}} \]

\[ f_{cgp} = \frac{-790.97^{\text{kips}}}{924.5^{\text{in}^2}} + \frac{(-790.97^{\text{kips}})(24.38^{\text{in}})^2}{373349^{\text{in}^4}} + \frac{(1274.1^{\text{kips/f}} x 12^{\text{in/f}})(24.38^{\text{in}})}{373349^{\text{in}^4}} \]

\[ f_{cgp} = -0.86^{\text{ksi}} - 1.26^{\text{ksi}} + 0.998^{\text{ksi}} = -1.122^{\text{ksi}} \]

\[ \Delta f_{PES} = \left( \frac{28500^{\text{ksi}}}{3320.56^{\text{ksi}}} \right) (-1.122^{\text{ksi}}) = -9.63^{\text{ksi}} \]

2nd Iteration:

\[ f_{pi} = f_{pj} - \Delta f_{PES} = 202.5^{\text{ksi}} - 9.63^{\text{ksi}} = 192.87^{\text{ksi}} \]

\[ P_i = (f_{pi})(A_{PS}) = (192.87^{\text{ksi}})(3.906^{\text{in}^2}) = 753.35^{\text{kips}} \]

\[ f_{cgp} = \frac{-753.35^{\text{kips}}}{924.5^{\text{in}^2}} + \frac{(-753.35^{\text{kips}})(24.38^{\text{in}})^2}{373349^{\text{in}^4}} + \frac{(1274.1^{\text{kips/f}} x 12^{\text{in/f}})(24.38^{\text{in}})}{373349^{\text{in}^4}} \]

\[ f_{cgp} = -0.815^{\text{ksi}} - 1.2^{\text{ksi}} + 0.998^{\text{ksi}} = -1.017^{\text{ksi}} \]

\[ \Delta f_{PES} = \left( \frac{28500^{\text{ksi}}}{3320.56^{\text{ksi}}} \right) (-1.017^{\text{ksi}}) = -8.73^{\text{ksi}} \]

3rd Iteration:

\[ f_{pi} = f_{pj} - \Delta f_{PES} = 202.5^{\text{ksi}} - 8.73^{\text{ksi}} = 193.77^{\text{ksi}} \]

\[ P_i = (f_{pi})(A_{PS}) = (193.77^{\text{ksi}})(3.906^{\text{in}^2}) = 756.865^{\text{kips}} \]

\[ f_{cgp} = \frac{-756.865^{\text{kips}}}{924.5^{\text{in}^2}} + \frac{(-756.865^{\text{kips}})(24.38^{\text{in}})^2}{373349^{\text{in}^4}} + \frac{(1274.1^{\text{kips/f}} x 12^{\text{in/f}})(24.38^{\text{in}})}{373349^{\text{in}^4}} \]
\[ f_{cgp} = -0.82^{\text{ksi}} - 1.2^{\text{ksi}} + 0.998^{\text{ksi}} = -1.022^{\text{ksi}} \]

\[ \Delta f_{pES} = \left( \frac{28500^{\text{ksi}}}{3320.56^{\text{ksi}}} \right) (-1.022^{\text{ksi}}) = -8.77^{\text{ksi}} \]

**Calculate Girder Top & Bottom stresses at transfer:**

**Initial prestress after transfer**

\[ f_{pi} = f_{pj} - \Delta f_{pES} = 202.5^{\text{ksi}} - 8.77^{\text{ksi}} = 193.73^{\text{ksi}} \]

**Prestress force after transfer**

\[ P_i = (f_{pi})(A_{ps}) = (193.73^{\text{ksi}})(3.906^{\text{in}^2}) = 756.71^{\text{kip}} \]

\[ \sigma_{top} = \frac{P_i}{A_g} + \frac{(P)(e_{ps})(y_t)}{I_g} + \frac{(M_g)(y_t)}{I_g} \]

\[ \sigma_{top} = \frac{-756.71^{\text{kip}}}{924.5^{\text{in}^2}} + \left( \frac{-756.71^{\text{kip}}(24.38^{\text{in}})(-26.74^{\text{in}})}{373349^{\text{in}^4}} \right) \]

\[ + \left( \frac{(1274.1^{k-ft} x 12^{\text{in}/ft})(-26.74^{\text{in}})}{373349^{\text{in}^4}} \right) \]

\[ \sigma_{top} = (-0.82^{\text{ksi}} + 1.32^{\text{ksi}}) - 1.1^{\text{ksi}} = -0.60^{\text{ksi}} \]

\[ \sigma_{bot} = \frac{P_i}{A_g} + \frac{(P)(e_{ps})(y_b)}{I_g} + \frac{(M_g)(y_b)}{I_g} \]

\[ \sigma_{bot} = \frac{-756.71^{\text{kip}}}{924.5^{\text{in}^2}} + \left( \frac{-756.71^{\text{kip}}(24.38^{\text{in}})(28.38^{\text{in}})}{373349^{\text{in}^4}} \right) \]

\[ + \left( \frac{(1274.1^{k-ft} x 12^{\text{in}/ft})(28.38^{\text{in}})}{373349^{\text{in}^4}} \right) \]

\[ \sigma_{bot} = (-0.82^{\text{ksi}} - 1.40^{\text{ksi}}) + 1.16^{\text{ksi}} = -1.06^{\text{ksi}} \]
**Stage 2:**

At this stage, stress change in prestressed strands (losses) calculated from transfer \((t = 1 \text{ day})\) to deck placement \((t = 21 \text{ days})\). These losses caused by girder creep, shrinkage and steel relaxation.

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>21 day</td>
<td>(\Delta f_{p_{CR}}, \Delta f_{p_{SH}}, \Delta f_{p_{CR}})</td>
</tr>
</tbody>
</table>

\[
k_s = 1.45 - 0.13 \left(\frac{v}{s}\right) = 1.45 - (0.13) (3.88) = 0.946 < 1.0 \quad k_s = 1.0
\]

\[
k_f = \frac{5}{(1 + f'_{ci})} = \frac{5}{(1 + 3.0)} = 1.251
\]

\[
k_{hc} = 1.56 - 0.008H = 1.56 - (0.008)(80) = 0.92
\]

\[
k_{hs} = 2.0 - 0.014H = 2.0 - (0.014)(80) = 0.88
\]

- **Stress Change due to Concrete Creep** \((\Delta f_{p_{CR}}):\)

\[
\Delta f_{p_{CR}} = \left(\frac{E_p}{E_{c,t=1}}\right) (f_{cg,t=1}) (\psi_{b(t_d,t_i)}) (K_{t_d,t_i})
\]

Time development factor \((k)\) between transfer and deck placement.
\[ k_{(td,ti)} = k_{(21,1)} = \frac{t_{td-ti}}{(61 - 4 \times f'_{c,t=1} + t_{td-ti})} = \frac{20}{(61 - 4 \times 3 + 20)} = 0.29 \]

Girder Creep coefficient (\( \psi \)) at time of deck placement due to loading introduced at transfer

\[ \psi_{b(td,ti)} = (1.9)(k_s)(k_f)(k_{hc})(k_{t(td,ti)})(t_i)^{-0.118} \]

\[ \psi_{b(t21,t1)} = (1.9)(1.0)(1.251)(0.92)(0.29)(1)^{-0.118} = 0.634 \]

Time development factor (\( k \)) between transfer and final.

\[ k_{t(tf,ti)} = k_{t(4034,1)} = \frac{t_{t-f-ti}}{(61 - 4 \times f'_{ci} + t_{t-f-ti})} = \frac{4034}{(61 - 4(3.0) + 4034)} = 0.99 \]

Girder Creep coefficient (\( \psi \)) at final due to loading introduced at transfer

\[ \psi_{b(tf,ti)} = (1.9)(k_s)(k_f)(k_{hc})(k_{t(tf,ti)})(t_i)^{-0.118} \]

\[ \psi_{b(tf,ti)} = (1.9)(1.0)(1.251)(0.92)(0.99)(1)^{-0.118} = 2.165 \]

Transformed Section Coefficient (\( K \)) for time period between transfer and deck placement.

\[ K_{(td,ti)} = \frac{1}{1 + \left( \frac{E_p}{E_{ci}} \right) \left( \frac{A_{ps}}{A_g} \right) \left( 1 + \left( \frac{A_g}{A_{ps}} \right) (\varepsilon_{ps})^2 \right) \left[ 1 + (0.7) \psi_{(t,ti)} \right]} \]

\[ K_{td,ti} = \frac{1}{1 + \left( \frac{28500^{ksi}}{3320.56^{ksi}} \right) \left( \frac{3.906^{in^2}}{924.5^{in^2}} \right) \left( 1 + \left( \frac{924.5^{in^2}}{373349^{in^2}} \right) \left( 24.38^{in} \right)^2 \right) \left[ 1 + (0.7)(2.165) \right]} = 0.82 \]

Prestress loss due to creep of girder concrete between transfer and deck placement.

\[ \Delta f_{pCR} = \left( \frac{28500^{ksi}}{3320.56^{ksi}} \right) (-1.022^{ksi})(0.634)(0.82) = -4.56^{ksi} \]

- Stress Change due to Concrete Shrinkage (\( \Delta f_{pSH} \)): 

\[ \Delta f_{pSH} = \left( \frac{28500^{ksi}}{3320.56^{ksi}} \right) (0.82) \]

\[ \Delta f_{pSH} = -3.74^{ksi} \]
\[ \Delta f_p_{SH} = (\varepsilon_{bid})(E_p)(K_{td,ti}) \]

Concrete Shrinkage strain (\(\varepsilon_b\)) of girder between the time of transfer and deck placement

\[ \varepsilon_{b(td,ti)} = (k_s)(k_f)(k_{hs})(k_{(td,ti)})(0.48)(10)^{-0.3} \]

\[ \varepsilon_{b(td,ti)} = (1.0)(1.251)(0.88)(0.29)(0.48)x(10)^{-0.3} = 1.53E - 04 \]

Prestress loss due to shrinkage of girder concrete between transfer and deck placement.

\[ \Delta f_p_{SH} = -(1.53E - 04)(28500^{kst})(0.82) = -3.58^{kst} \]

\[ \Delta f_p = \Delta f_p_{LT} \]

Stress Change due to Steel Relaxation (\(\Delta f_p\)):

\[ \Delta f_R = -(2.4 \frac{t_{d(td,ti)}}{100 + t_{d(td,ti)}}) \]

\[ \Delta f_R = -(2.4 \left( \frac{20}{100 + 20} \right)) = -0.4^{ksi} \]

Prestress losses due to Creep and Shrinkage of concrete, and steel relaxation, from transfer to deck placement:

\[ \Delta f_p_{LT(ti,td)} = \Delta f_p_{CR} + \Delta f_p_{SH} + \Delta f_p_R = (-4.56^{ksi}) + (-3.58^{ksi}) + (-0.4^{ksi}) = -8.54^{ksi} \]

Total losses (\(\Sigma \Delta f_p\)) from transfer to deck placement.

\[ \Sigma \Delta f_p = \Delta f_p_{LT(ti,td)} + \Delta f_p_{ES} = (-8.54^{ksi}) + (-8.77^{ksi}) = -17.31^{ksi} \]

**Calculate Girder Top & Bottom stresses before deck Placement:**

Stress change at extreme fiber of girder due to creep, shrinkage and strands relaxation

\[ \Delta P_t = \Delta f_p_{LT(ti,td)} x A_p_s = (8.54^{ksi})(3.906^{ln^2}) = 33.357^{kips} \]
\[
\sigma_{\text{top}} = \frac{\Delta p_i}{A_g} + \frac{(\Delta p_i)(e_{PS})(y_t)}{I_g}
\]

\[
\sigma_{\text{top}} = \frac{33.357 \text{ kips}}{924.5 \text{ in}^2} + \frac{(33.357 \text{ ksi})(24.38 \text{ in})(-26.74 \text{ in})}{373349 \text{ in}^4} = -0.022 \text{ ksi}
\]

\[
\sigma_{\text{bot}} = \frac{\Delta p_i}{A_g} + \frac{(\Delta p_i)(e_{PS})(y_b)}{I_g}
\]

\[
\sigma_{\text{bot}} = \frac{33.357 \text{ kips}}{924.5 \text{ in}^2} + \frac{(33.357 \text{ ksi})(24.38 \text{ in})(28.38 \text{ in})}{373349 \text{ in}^4} = 0.098 \text{ ksi}
\]

Girder Top and bottom stresses at end of stage 2 (before deck placement):

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stages 1+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{\text{top}})</td>
<td>-0.6 ksi</td>
<td>-0.022 ksi</td>
<td>-0.622 ksi</td>
</tr>
<tr>
<td>(\sigma_{\text{bot}})</td>
<td>-1.06 ksi</td>
<td>0.098 ksi</td>
<td>-0.962 ksi</td>
</tr>
</tbody>
</table>
**Stage 3:**

At this stage, stress change in prestressed strands (Gain) calculated after deck placement

\( t = 21 \text{ days} \).

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Stress gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Placement</td>
<td>21 days</td>
<td>( \Delta f_{PES} )</td>
</tr>
</tbody>
</table>

Moment at 0.4L due to deck placement

\[
\begin{align*}
    w_{\text{deck}} &= (w_c \frac{k}{ft^3})(S^{ft})(t^{in})/(12^{ft}) = \left( \frac{0.1575}{ft} \right) (5.5^{ft})(8^{in})/(12^{ft}) = 0.55^{k/ft} \\
    R_{\text{left}} &= (w_{\text{deck}}^{k/ft})(L^{ft})/2 = (0.55^{k/ft})(105^{ft})/2 = 28.88 \text{ kips} \\
    M_{\text{deck}} &= (R_{\text{left}})(0.4L) - \left( \frac{k}{W^{ft}} \right) \left( \frac{(0.4L)^2}{2} \right) \\
    M_{\text{deck}} &= (28.88^{kips})(0.4 \times 105^{ft}) - (0.55^{k/ft}) \left( \frac{(0.4 \times 105^{ft})^2}{2} \right) = 727.86^{k-ft}
\end{align*}
\]

Compressive strength of concrete girder at deck placement \( t = 21 \text{ days} \)
\[(f'c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'c)_u\]

\[(f'c)_{21} = \frac{21}{0.692 + (0.975) \cdot (21)} \cdot (5\text{ksi}) = 4.96\text{ ksi}\]

Concrete Modulus at deck placement (t = 21 day)

\[E_{c,t=21} = (33000)(w_c)^{1.5} x \sqrt{(f'c)_t=21}\]

\[E_{c,t=21} = (33000)(0.15\text{ ksi}/ft^3)^{1.5} x \sqrt{4.96\text{ ksi}} = 4269.64\text{ ksi}\]

Change in prestressing stress immediately after deck placement

\[f_{cgp} = \frac{(M_{deck})(e_{pg})}{I_g}\]

\[f_{cgp} = \frac{(727.86\text{ ksi}/ft)(12\text{ in}/ft)(24.38\text{ in})}{373349\text{ in}^4} = 0.57\text{ ksi}\]

\[\Delta f_{pES} = \frac{E_p}{E_{c,t=21}} \cdot (f_{cgp}) = \left(\frac{28500\text{ ksi}}{4269.64\text{ ksi}}\right)(0.57\text{ ksi}) = 3.8\text{ ksi}\]

2nd Iteration

\[f_{cgp} = \frac{(M_{deck})(e_{ps})}{I_g} - \frac{(\Delta f_{pES})(A_{ps})}{A_g} - \frac{(\Delta f_{pES})(A_{ps})(e_{ps})}{I_g}\]

\[f_{cgp} = \frac{(727.86\text{ ksi}/ft)(12\text{ in}/ft)(24.38\text{ in})}{373349\text{ in}^4} - \frac{(3.8\text{ ksi})(3.906\text{ in}^2)}{924.5\text{ in}^2}
- \frac{(3.8\text{ ksi})(3.906\text{ in}^2)(24.38\text{ in})}{373349\text{ in}^4} = 0.55\text{ ksi}\]

\[\Delta f_{pES} = \frac{E_p}{E_c} \cdot f_{cgp} = \left(\frac{28500\text{ ksi}}{4269.64\text{ ksi}}\right)(0.55\text{ ksi}) = 3.67\text{ ksi}\]
3rd Iteration

\[
f_{cgp} = \frac{(M_{deck})(e_{PS})}{I_g} - \frac{(\Delta f_{pES})(A_{PS})}{A_g} - \frac{(\Delta f_{pES})(A_{PS})(e_{PS})}{I_g}
\]

\[
f_{cgp} = \left( \frac{727.86^{k-ft}}{373349^{in^4}} \right)(12^{in/ft})(24.38^{in}) \left( \frac{3.67^{ksi}}{924.5^{in^2}} \right)(3.906^{in^2}) - \left( \frac{3.67^{ksi}}{373349^{in^4}} \right)(24.38^{in}) = 0.55^{ksi}
\]

Prestress change (gain) at deck placement.

\[
\Delta f_{pES} = \left( \frac{E_p}{E_{c,t=21day}} \right) f_{cgp} = \left( \frac{28500^{ksi}}{4269.64^{ksi}} \right)(0.55^{ksi}) = 3.67^{ksi}
\]

Total stress (\(\Sigma \Delta f_p\)) from transfer to deck placement (end of stage 3).

\[
\Sigma \Delta f_p = \Sigma \Delta f_{p(1+2)} + \Delta f_{pES} = (-17.31^{ksi}) + (3.67^{ksi}) = -13.64^{ksi}
\]

Calculate Girder Top & Bottom stresses at deck placement:

\[
\Delta P = (\Delta f_{pES})(A_{PS}) = (3.67^{ksi})(3.906^{in^2}) = 14.335^{kips}
\]

\[
\sigma_{top} = \frac{\Delta P}{A_g} + \frac{(\Delta P)(e_{PS})(y_t)}{I_g} + \frac{(M_{deck})(y_t)}{I_g}
\]

\[
\sigma_{top} = \frac{-13.335^{kips}}{924.5^{in^2}} + \frac{(-13.335^{kips})(24.38^{in})(-26.74^{in})}{373349^{in^4}}
\]

\[
\sigma_{top} = \frac{14.335^{kips} x 12^{in/ft}(-26.74^{in})}{373349^{in^4}}
\]

\[
\sigma_{top} = -0.0144^{ksi} + 0.023^{ksi} - 0.626^{ksi} = -0.617
\]

\[
\sigma_{bot} = \frac{\Delta P}{A_g} + \frac{(\Delta P)(e_{pg})(y_b)}{I_g} + \frac{(M_{deck})(y_b)}{I_g}
\]
\[
\sigma_{bot} = \frac{-13.335^{kip}}{924.5in^2} + \frac{(-13.335^{kip})(24.38^{in})(28.38^{in})}{373349^{in^4}}
\]
\[
+ \frac{(727.86^{k-ft} \times 12^{in/ft})(28.38^{in})}{373349^{in^4}}
\]

\[
\sigma_{bot} = -0.0144^{ksi} - 0.0247^{ksi} + 0.664^{ksi} = 0.625^{ksi}
\]

Girder Top and bottom stresses at end of stage 3 (t =21 days):

<table>
<thead>
<tr>
<th>Status</th>
<th>Stage 1+2</th>
<th>Stage 3</th>
<th>Stages 1-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{top})</td>
<td>-0.622^{ksi}</td>
<td>-0.617^{ksi}</td>
<td>-1.24^{ksi}</td>
</tr>
<tr>
<td>(\sigma_{bott.})</td>
<td>-0.962^{ksi}</td>
<td>0.625^{ksi}</td>
<td>-0.337^{ksi}</td>
</tr>
</tbody>
</table>

**Stage 4:**

At this stage, stress change in prestressed strands (losses) calculated from deck placement (\(t =21^{days}\)) to post tension (\(t = 50^{days}\)). These losses caused by girder creep & shrinkage, deck shrinkage and steel relaxation.

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time step</td>
<td>50 days</td>
<td>(\Delta f_{pCR}, \Delta f_{pSH}, \Delta f_{pR}, \Delta f_{pSS})</td>
</tr>
</tbody>
</table>

Modulus Deck concrete.

\[
E_{C_{deck}} = (33000)(w_c)^{1.5} \cdot \sqrt{(f'c)}
\]

\[
E_{C_{deck}} = (33000)(0.15)^{1.5} \cdot \sqrt{(4^{ksi})} = 3834.25^{ksi}
\]

Compressive strength of concrete girder at (\(t = 50^{days}\))

\[
(f'c)_t = \frac{t}{a + \beta \cdot t} \cdot (f'c)_u
\]
\[ (f'c)_{50} = \frac{50}{0.692 + (0.975)(50)} \times (5^{\text{ksi}}) = 5.056^{\text{ksi}} \]

Concrete Modulus at deck placement (t = 50 day)

\[ E_{c,t=50} = (33000)(w_c)^{1.5} \times \sqrt{(f'c)_{t=35}} \]

\[ E_{c,t=50} = (33000)(0.15^{k/ft^3})^{1.5} \times \sqrt{5.056^{\text{ksi}}} = 4310.8^{\text{ksi}} \]

Effective width of deck (b_e)

\[ b_e = (w)\left(\frac{1}{n}\right) = (5.5^{ft}) \left(\frac{1}{1.124}\right) = 4.893^{ft} \]

\[ (A_{\text{deck}})_{\text{eff.}} = (4.893^{ft} \times 12^{in/ft}) \times 8^{in} = 469.7^{in^2} \]

Area of composite section \(A_c\)

\[ A_c = A_g + (A_{\text{deck}})_{\text{eff.}}. \]

\[ A_c = 924.5^{in^2} + 469.7^{in^2} = 1394^{in^2} \]

Location of Neutral Axes \(y'_c\)

\[ y'_c = \frac{(A_g)(y_b) + (A_{\text{deck}})(y_{\text{deck}})}{A_c} = \frac{(924.5^{in^2})(28.38^{in}) + (469.7^{in^2})(55.12^{in} + 4^{in})}{1394^{in^2}} \]

\[ = 38.74^{in} \]

Moment of Inertia of composite section \(I_c\)

\[ I_c = [I_g + (A_g)(d_g)^2] + [I_{\text{deck}} + (A_{\text{deck}})(d_{\text{deck}})^2] \]
\[ I_c = \left[ 373349in^4 + 924.5in^2x(38.74in - 28.38in)^2 \right] + \left( \frac{4.893ft x 12in/ft}{12} \right) (8in)^3 \]
\[ + (469.7in^2)(55.12in - 38.74in + 4in)^2 = 670167.7in^4 \]

- **Stress Change due to Concrete Creep** \( \Delta f_{PC} \):

\[ \Delta f_{CR} = \left( \frac{E_p}{E_{c(t=21)}} \right)(f_{cgp})[\Psi_{b(tp,ti)} - \Psi_{b(td,ti)}](K_{b(tp,td)}) \]
\[ + \left( \frac{E_p}{E_{c,t=21day}} \right)(f_{cgp@sta3})(\Psi_{b(tp,td)})(K_{b(tp,td)}) \]

\[ \Psi_{b(td,ti)} = 0.634 \]

\[ \Psi_{b(tf,ti)} = 2.165 \]

Time development factor \((k)\) between transfer and PT.

\[ k_{t(tp,ti)} = k_{t(34,1)} = \frac{t_{(tp,ti)}}{61 - 4 \times f'_{ci} + t_{(tp,ti)}} = \frac{(50 - 1)}{61 - 4 \times 3.0 + 49} = 0.5 \]

Girder creep coefficient \((\Psi)\) at time of post tension due to loading introduced at transfer

\[ \Psi_{b(tp,ti)} = (1.9)(k_s)(k_f)(k_{hc})(k_{t(tp,ti)})(t_i^{-0.118}) \]

\[ \Psi_{b(tp,ti)} = (1.9)(1.0)(1.251)(0.92)(0.5)(1^{-0.118}) = 1.093 \]

Time development factor \((k)\) between deck placement and PT.

\[ k_{t(tp,td)} = k_{t(50,21)} = \frac{t_{(tp,td)}}{61 - 4 \times f'_{ci} + t_{(tp,td)}} = \frac{(50 - 21)}{61 - 4 \times 3 + (50 - 21)} = 0.37 \]

Girder Creep coefficient \((\Psi)\) at time of post tension due to loading introduced at deck placement

\[ \Psi_{b(tp,td)} = (1.9) (k_s) (k_f) (k_{hc}) (k_{t(tp,td)})(t_i^{-0.118}) \]
$\Psi_{b(tp,td)} = (1.9)(1.0)(1.251)(0.92)(0.37)(21^{-0.118}) = 0.565$

Transformed Section Coefficient ($K$) for time period between deck placement and final.

$$K_{b(d,f)} = \frac{1}{1 + \left(\frac{E_p}{E_{ci}}\right)\left(\frac{A_{ps}}{A_c}\right)\left(1 + \frac{(A_c)(e_{ps,c})^2}{I_c}\right)[1 + 0.7 \times \Psi_{(t_f,ti)}]}$$

$$e_{pc} = y'_{c} - \text{cover} = 38.74 \text{in} - 4 \text{in} = 34.74 \text{in}$$

$$K_{b(tf,td)} = \frac{1}{1 + \left(\frac{28500 \text{ksi}}{4269.64 \text{ksi}}\right)\left(3.906 \text{in}^2\right)\left(\frac{1 + \frac{1394 \text{in}^2 \times (34.74 \text{in})^2}{670041.5 \text{in}^4}}{1}\right) x (1 + 0.7 \times 2.165)} = 0.858$$

$$\Delta f_{p,CR} = \left(\frac{28500 \text{ksi}}{4269.64 \text{ksi}}\right)(-1.022 \text{ksi})[1.093 - 0.634] (0.858)$$

$$+ \left(\frac{28500 \text{ksi}}{4269.64 \text{ksi}}\right)(0.55 \text{ksi})(0.565)(0.858) = -1.07 \text{ksi}$$

**Stress Change due to Concrete Shrinkage ($\Delta f_{p,SH}$):**

$$\Delta f_{p,SH} = (\epsilon_{b(tf,tp)})(E_p)(K_{tp,td})$$

Concrete Shrinkage strain ($\epsilon_b$) of girder between deck placement and PT.

$$\epsilon_{b(tf,tp)} = (k_s)(k_f)(k_{hs})(k_{tp,ti} - k_{(td,ti)}) \times (10)^{-03}$$

$$\epsilon_{b(tf,tp)} = (1.0)(1.251)(0.88)(0.5 - 0.29)(0.48)(10)^{-03} = 1.11 E - 04$$

Prestress loss due to shrinkage of girder concrete between deck placement and PT.

$$\Delta f_{p,SH} = -(1.11 E - 04)(28500 \text{ksi})(0.858) = -2.69 \text{ksi}$$
Stress Change due to Steel Relaxation ($\Delta f_R$):

$$\Delta f_R = -2.4 \times \frac{t_d(tp,ti)}{100 + t_d(tp,ti)} - \Delta f_{R1}$$

$$\Delta f_R = -2.4 \times \frac{49}{100 + 49} - (-0.4) = -0.61^{kst} + 0.4^{kst} = -0.39^{kst}$$

Stress Change due to Deck Shrinkage: ($\Delta f_{ps}$)

$$\Delta f_{ps} = \left(\frac{E_p}{E_c}\right)(\Delta f_{df})(K_{df})[1 + (0.7) \cdot (\Psi_{b(t_f,t_d)})]$$

$$k_f = \frac{5}{1 + f_{ci}'} = \frac{5}{1 + 0.8 \times 4^{kst}} = 1.19$$

Assume 7 days deck currying, $t_{currying} = 21^{days} + 7^{days} = 28^{days}$

$t_f - t_{currying} = 4050^{days} - 28^{days} = 4022^{days}$

Time development factor ($k$) between deck currying and final.

$$k_{t(t_{cur},t_f)} = \frac{t_{(t_{cur},t_f)}}{61 - 4 \times f_{ci}^' + t_{(t_{cur},t_f)}} = \frac{4022}{61 - 4 \times (0.8 \times 4) + 4022} = 0.988$$

Shrinkage Strain of deck concrete between deck placement and final time.

$$\varepsilon_{d(t_f,t_{cur})} = (k_z)(k_f)(k_{hc})(k_{td})(0.48 \times 10)^{-03}$$

$$\varepsilon_{d(t_f,t_{cur})} = (1.0)(1.19)(0.88)(0.988)(0.48) \times (10)^{-03} = 4.97E^{-04}$$

Deck Creep coefficient ($\Psi$) at time of End deck currying to final.

$$\Psi_{d(t_f,t_{cur})} = (1.9)(k_z)(k_f)(k_{hc})(k_{t(t_{cur},ti)})(t_i)^{-0.118}$$
\[ \Psi_{d(t_f, t_{dcurr})} = (1.9) \times (1.0) \times (1.19) \times (0.92) \times (0.988) \times (7)^{-0.118} = 1.634 \]

Eccentricity of deck with respect to the gross composite section \( e_d \).

\[ e_d = D - y'_c + \frac{t_{deck}}{2} = 55.12^{\prime\prime} - 38.74^{\prime\prime} + \frac{8^{in}}{2} = 20.38^{in} \]

Change in concrete stress at centroid of prestressing strands \( \Delta f_{c(dcurr, sf)} \) due to long-term losses between end of deck currying and final.

\[ \Delta f_{c(dcurr, tf)} = \left( \frac{E_{pdf}}{[1 + 0.7 \cdot \Psi_{d(t_f, t_{dcurr})}]} \right) \times \left( \frac{1}{A_c} - \frac{(e_d)(e_{PS,c})}{I_c} \right) \]

\[ \Delta f_{pss} = - \left( \frac{4.97E_{psi}}{[1 + (0.7)(1.634)]} \left( \frac{1}{1394^{in^2}} - \frac{(20.38^{in})(34.74^{in})}{670167.7^{in^4}} \right) \right) \]

Girder Creep coefficient (\( \Psi_{b(t_f, t_{dcurr})} \)) at time of end deck currying (\( t=28 \) day)

\[ \Psi_{b(t_f, t_{dcurr})} = (1.9) \times (k_s)(k_f)(k_{hc})(k_{t(t_f, t_{dcurr})})(t_{dcurr})^{-0.118} \]

\[ \Psi_{b(t_f, t_{dcurr})} = (1.9) \times (1.0) \times (1.251) \times (0.92) \times (0.988) \times (28)^{-0.118} = 1.46 \]

The prestress gain due to shrinkage of deck composite section \( \Delta f_{pss} \). From end of deck currying to final time.

\[ \Delta f_{pss} = \left( \frac{E_{p}}{E_{c,t=28}} \right) \times \left( \Delta f_{cdf}(K_{df}) \times \left[ 1 + (0.7) \cdot \Psi_{b(t_f, t_{dcurr})} \right] \right) \]

\[ \Delta f_{pss} = \left( \frac{28500^{kpsi}}{4286.8^{kpsi}} \right) \times (0.159)(0.86)[1 + (0.7)(1.46)] = 1.838^{kpsi} \]

Time development factor (\( k \)) between end of deck currying and PT.
\[ k_{t(tcur, tp)} = \frac{t_{t(cur, tp)}}{61 - 4 x f'_c + t_d} = \frac{(50 - 28)}{61 - 4 \times (0.8 \times 4) + (50 - 28)} = 0.313 \]

The prestress gain due to shrinkage of deck composite section \( \Delta f_{pss} \). From end of deck currying to PT.

\[ \Delta f_{pss} = \Delta f_{pss(tcur, tf)} \times k_{(tcur, tp)} \]

\[ \Delta f_{pss} = \Delta f_{pss(tcur, tf)} \times k_{(tcur, tp)} = (1.838^{ksi})(0.313) = 0.575^{ksi} \]

Change in prestress stresses due to girder Creep & Shrinkage, steel relaxation, and deck shrinkage from deck placement to PT:

\[ \Delta f_{pLT(tf, tp)} = \Delta f_{pCR} + \Delta f_{pSH} + \Delta f_{pR} + \Delta f_{pss} \]

\[ = (-1.07^{ksi}) + (-2.69^{ksi}) + (-0.39^{ksi}) + (+0.575^{ksi}) = -3.58^{ksi} \]

Total losses (\( \Sigma \Delta f_p \)) from transfer to the end of stage 4.

\[ \Sigma \Delta f_p = \Sigma \Delta f_{p_stage1+2+3} + \Delta f_{pLT(tf, PT)} = (-13.64^{ksi}) + (-3.58^{ksi}) = -17.22^{ksi} \]

Calculate concrete stresses at Top & Bottom of girder at end of stage 4:

- Stresses due to Creep, Shrinkage of concrete and steel Relaxation:

\[ \Sigma \Delta f_p = \Sigma \Delta f_{pCR} + \Delta f_{pSH} + \Delta f_{pR} = (-1.07^{ksi}) + (-2.69^{ksi}) + (-0.39^{ksi}) = -4.15^{ksi} \]

\[ \Delta p_t = \Sigma \Delta f_p \times A_p = (4.15^{ksi})(3.906^{in^2}) = 16.21^{kips} \]

\[ \sigma_{top} = \frac{\Delta P_t}{A_g} + \frac{(\Delta P)(e_{psc})(y_t)}{I_g} \]

\[ \sigma_{top} = \frac{16.21^{kips}}{924.5^{in^2}} + \frac{(16.21^{kips})(24.3^{in})(-26.74^{in})}{373349^{in^4}} = -0.0107 \, ksi \]
\[ \sigma_{\text{bot}} = \frac{\Delta P}{A_g} + \frac{(\Delta P)(e_{PS,c})(y_h)}{I_g} \]

\[ \sigma_{\text{bot}} = \frac{16.21\text{kip}}{924.5\text{in}^2} + \frac{(16.21\text{kip})(24.3\text{in})(28.38\text{in})}{373349\text{in}^4} = 0.0475\text{ksi} \]

- Stresses due to Deck Shrinkage:

Compression force at center of deck due to deck shrinkage \( f_{\text{dSH}} \)

\[ f_{\text{dSH}} = \frac{(E_{d\text{df}} - E_{bdf})(A_d)(E_{cd})}{[1 + 0.7 \times \psi_{d(tf,tcu)}]} \]

\[ E_{bdf} = (k_s)(k_f)(k_{ns}) \left[ k_{(ti,tf)} - k_{(tcu,ti)} \right] 0.48 \times 10^{-03} \]

\[ k_{(ti,tcu)} = \frac{t_{(ti,tcu)}}{61 - 4x f'c + t_{(ti,tcu)}} = \frac{(28 - 1)}{61 - (4x3) + 27} = 0.355 \]

\[ k_{(ti,tf)} = \frac{t_{(ti,tf)}}{61 - 4x f'c + t_{(ti,tf)}} = \frac{(4050 - 1)}{61 - 4x3 + (4050 - 1)} = 0.988 \]

\[ E_{bdp} = (1.0)(1.251)(0.88)[0.988 - 0.355](0.48)(10)^{-03} = 3.34E-04 \]

\[ f_{\text{dSH}} = \frac{[(4.97E - 04) - (3.34E - 04)](529\text{in}^2)(3834.4\text{ksi})}{[1 + 0.7 \times 1.634]} = -153.93\text{kip} \]

\[ \sigma_{\text{top}} = f_{\text{dSH}} \times \left( \frac{1}{A_c} - \frac{(e_d)(y_c)}{I_c} \right) \]

\[ \sigma_{\text{top}(t\text{cu},t_f)} = (-153.93\text{kip})\left( \frac{1}{1394\text{in}^2} - \frac{(20.38\text{in})(-26.74\text{in})}{670167.7\text{in}^4} \right) = -0.236\text{ksi} \]

\[ \sigma_{\text{top}(t\text{cu},t_p)} = \sigma_{\text{top}(t\text{cu},t_f)} \times k_{t(dcu,tp)} = (-0.236\text{ksi})(0.313) = -0.074\text{ksi} \]
\[ \sigma_{\text{bot}} = f_{\text{dSH}} x \left( \frac{1}{A_c} - \frac{(e_d)(y_b)}{I_c} \right) \]

\[ \sigma_{\text{bot}(t_{\text{dcur},tf})} = (-153.93^{\text{ksi}}) x \left( \frac{1}{1394^{\text{in}^2}} - \frac{(20.38^{\text{in}})(28.38^{\text{in}})}{670167.7^{\text{in}^4}} \right) = 0.0224^{\text{ksi}} \]

\[ \sigma_{\text{bot}(t_{\text{dcur},tp})} = \sigma_{\text{bot}(t_{\text{dcur},tp})} x k_{t(t_{\text{dcur},tp})} = (0.0224^{\text{ksi}})(0.313) = 0.007^{\text{ksi}} \]

Change of Girder Top & Bottom Stresses at stage 4 due to deck Shrinkage \((\Delta f_{\text{dSH}})\) and Girder Creep, Shrinkage and steel relaxation \((\Delta f_{\text{CR+SH+R}})\).

\[ \Sigma \sigma_{\text{top,stage 4}} = \sigma_{\text{top}} \cdot \Delta f_{\text{dSH}} + \sigma_{\text{top}} \cdot \Delta f_{\text{CR+SH+R}} = (-0.074^{\text{ksi}}) + (-0.010^{\text{ksi}}) = -0.085^{\text{ksi}} \]

\[ \Sigma \sigma_{\text{bot,stage 4}} = \sigma_{\text{bot}} \cdot \Delta f_{\text{dSH}} + \sigma_{\text{bot}} \cdot \Delta f_{\text{CR+SH+R}} = 0.007^{\text{ksi}} + (0.0475^{\text{ksi}}) = 0.0545^{\text{ksi}} \]

Girder Top and bottom stresses at end of stage 4 \((t = 50 \text{ days})\):

<table>
<thead>
<tr>
<th></th>
<th>Stage 1+2+3</th>
<th>Stage 4</th>
<th>Stages 1-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{top}} )</td>
<td>-1.24^{\text{ksi}}</td>
<td>-0.085^{\text{ksi}}</td>
<td>-1.325^{\text{ksi}}</td>
</tr>
<tr>
<td>( \sigma_{\text{bott}} )</td>
<td>-0.337^{\text{ksi}}</td>
<td>0.0545^{\text{ksi}}</td>
<td>-0.283^{\text{ksi}}</td>
</tr>
</tbody>
</table>

**Stage 5:**

At this stage, stress change in prestressed strands “PS, PT” (losses) due to post tension stress at \((t = 50 \text{ days})\).

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>50 days</td>
<td>( \Delta f_{\text{pES,PS},t}, \Delta f_{\text{pES,PT}} )</td>
</tr>
</tbody>
</table>

\[ f_{p_j} = 0.75 \left( f_{p_u} \right) = 0.75 \left( 270^{\text{ksi}} \right) = 202.5^{\text{ksi}} \]

Prestress force after transfer

\[ p_j = (f_{p_j})(A_{PS}) = (202.5^{\text{ksi}})(3.255^{\text{in}^2}) = 659.14^{\text{kip}} \]
Anchor set loss:

\[ \Delta f_{PAS} = 2 \left( \Delta f_{pi} \right) \left( R \right) \left( X \right) \]

\[ e = y_b - PT_{cover} = 28.38^{\text{in}} - 10^{\text{in}} = 18.38^{\text{in}} \]

\[ R = K + \frac{(2 e \mu)}{b^2} = 0.0002^{\text{ft}} + \frac{2 (18.38^{\text{in}}/12^{\text{in/ft}}) (0.15)}{42^2} = 0.00046^{\text{1/ft}} \]

Length influenced by the Anchor set x:

\[ X = \sqrt{\frac{(S)(E_p)}{(R)(f_p)}} = \sqrt{\frac{(0.375^{\text{in/12^{in/ft}}})(28500^{\text{ksi}})}{(0.00046^{\text{ft}})(202.5^{\text{ksi}})}} = 97.78^{\text{ft}} \]

Prestress losses at edge of girder due to anchor set

\[ \Delta f_{PAS} = 2 \left( \Delta f_{pi} \right) \left( R \right) \left( X \right) = 2 \left( 202.5^{\text{ksi}} \right) \left( 0.00046^{\text{1/ft}} \right) \left( 97.78^{\text{ft}} \right) = 18.22^{\text{ksi}} \]

Prestress losses at \( x = 97.78^{\text{ft}} \) of girder due to anchor set.

\[ \Delta f_{PAS,x=0^{\text{ft}}} = \left( \Delta f_{PAS}/2 \right) = \left( 18.22^{\text{ksi}} / 2 \right) = 9.11^{\text{ksi}} \]
Prestress losses at 0.4L "x = 42 ft" of girder due to anchor set.

\[
\Delta f_{PA, x=42/ft} = 2 \left[ \frac{(\Delta f_{PA}/2)}{x/ft} \right] (x/ft - 0.4/ft) = 2 \left[ \frac{(9.11^{ksi})}{97.78^{ft}/0.4} \right] (97.78^{ft} - 42^{ft}) = 10.39^{ksi}
\]

Prestress losses at 0.4L "x = 40 ft" of girder due to friction.

\[
\Delta f_{PF, x=42/ft} = (\Delta f_p - \Delta f_{PA}) \left( 1 - e^{-(kx+\alpha\mu)} \right)
\]

\[
= (202.5^{ksi} - 10.39^{ksi})(1 - e^{-\left(\frac{0.0002^{ft} \times 42^{ft} + 0.073 \times 0.15}{1} \right)}) = 3.68^{ksi}
\]

Instantaneous losses of PT due to Anchor set and friction.

\[
\Delta f_{PA, p} + \Delta f_{PF} = 10.39^{ksi} + 3.68^{ksi} = 14.07^{ksi}
\]

\[
P_T = [202.5 - (\Delta f_{PA, p} + \Delta f_{PF})] (A_{PS}) = [202.5^{ksi} - 14.07^{ksi}] (3.255) = 613.34^{ksi}
\]

\[
f_{cgp, PT} = \frac{-P_T}{A_c} + \left( \frac{P_T}{(\epsilon_{PT,c})^2} \right)
\]

\[
\epsilon_{PT} = y_b - \text{cover} = 38.74^{in} - 10^{in} = 28.74^{in}
\]

\[
f_{cgp, PT} = \frac{-613.34^{ksi}}{1394^{in^2}} + \left( \frac{-613.34^{ksi}(28.74^{in})^2}{670167.7^{in^4}} \right) = -1.196^{ksi}
\]

Post Tension losses "\(\Delta f_{PT, ES}\)" due to Elastic Shortening at 0.4L

\[
\Delta f_{PES, x=42ft} = \left( \frac{E_p}{E_{ci}} \right) (f_{cgp})
\]

\[
\Delta f_{PT, ES, x=42ft} = \left( \frac{28500}{4310.3^{ksi}} \right) (-1.196^{ksi}) = -7.91^{ksi}
\]

Total PT instantaneous losses

\[
\Delta f_{PA} + \Delta f_{PF} + \Delta f_{PT, ES, x=97.75/ft} = (-10.39^{ksi}) + (-3.68^{ksi}) + (-7.91^{ksi}) = -21.98^{ksi}
\]
\[ PT = [202.5 - (\Delta f_{P,AS} + \Delta f_{pf} + \Delta f_{P,ES})] \] 
\[ (A_{PT}) = (202.5^{ksi} - 21.98^{ksi})(3.255^{in^2}) \]
\[ = 587.59^{ksi} \]

\[ f_{cgp,PS} = \frac{-PT}{A_c} + \frac{(PT)(e_{PT,c})(e_{PS,c})}{I_c} \]

\[ f_{cgp,PS} = \frac{-587.59^{ksi}}{1394^{in^2}} + \frac{(-587.59^{ksi})(28.74^{in})(34.74^{in})}{670167.7^{in^4}} = -1.3 \]

\[ \Delta f_{PES,PS} = \left( \frac{E_p}{E_{c,t=50}} \right) (f_{cgp}) = \left( \frac{28500}{4310.3^{ksi}} \right) (-1.3) = -8.596^{ksi} \]

2\text{nd Iteration}

\[ \Delta PS = (\Delta f_{PES})(A_{PS}) = (-8.596^{ksi})(3.906^{in^2}) = -33.576^{kips} \]

\[ \Delta PT = (\Delta f_{PES})(A_{PT}) = (-7.91^{ksi})(3.255^{in^2}) = -25.75^{kips} \]

Instantaneous Prestressed Strands Losses

\[ f_{cgp,PS} = \left[ \frac{-PT}{A_c} + \frac{(PT)(e_{PT,c})(e_{PS,c})}{I_c} \right] + \left( \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})^2}{I_c} \right) \]
\[ + \left( \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(e_{PS,c})}{I_c} \right) \]

\[ f_{cgp,PS} = \frac{-613.34^{k}}{1394^{in^2}} + \frac{(-613.34^{k})(28.74^{in})(34.74^{in})}{670167.7^{in^4}} \]
\[ + \frac{(33.576^{kips})}{1394^{in^2}} + \frac{(33.567^{kips})(34.74^{in})^2}{670167.7^{in^4}} \]
\[ + \frac{(25.75^{kips})}{1394^{in^2}} + \frac{25.75^{k}(28.74^{in})(34.74^{in})}{670167.7^{in^4}} \]

\[ f_{cgp,PS} = -1.35^{ksi} + 0.085^{ksi} + 0.057^{ksi} = -1.21^{ksi} \]
\[ \Delta f_{ES,PS} = \left( \frac{E_p}{E_{c,t=50}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{4310.3^{ksi}} \right) (-1.21^{ksi}) = -8.0^{ksi} \]

Instantaneous Post-Tensioned Strands Losses

\[ f_{cgp,PT} = \left[ \frac{-P_{PT}}{A_c} + \left( -\frac{P_{PT}(e_{PT,c})}{I_c} \right)^2 \right] + \left( \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(e_{PT,c})}{I_c} \right) + \left( \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})^2}{I_c} \right) \]

\[ f_{cgp,PT} = \left[ \frac{-613.34^k}{1394^in^2} + \frac{(-613.34^k)(28.84^in)^2}{670167.7^in^4} \right] + \left( \frac{33.576^k}{1394^in^2} + \frac{33.576^k(34.74^in)(28.74^in)}{670167.7^in^4} \right) \]

\[ + \left( \frac{25.75^{kips}}{1394^in^2} + \frac{25.75^{kips}(28.74^in)^2}{670167.7^in^4} \right) \]

\[ f_{cgp,PT} = -1.20^{ksi} + 0.074^{ksi} + 0.050^{ksi} = -1.076^{ksi} \]

\[ \Delta f_{ES,PT} = \left( \frac{E_p}{E_{c,t=50}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{4310.3^{ksi}} \right) (-1.076^{ksi}) = -7.1^{ksi} \]

Calculate concrete stresses at Top & Bottom of girder at end of stage 5:

\[ \Delta P_{PS} = (\Delta f_{ES,PS})(A_{PS}) = (8.0^{ksi})(3.906^in^2) = 31.25^{kips} \]

\[ \Delta P_{PT} = (\Delta f_{ES,PT})(A_{PT}) = (7.1^{ksi})(3.255^in^2) = 23.11^{kips} \]

\[ \sigma_{top} = \left( \frac{P_{PT}}{A_c} + \left( \frac{P_{PT}(e_{PT,c})(y_{tc})}{I_c} \right) \right) + \left( \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{tc})}{I_c} \right) + \left( \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{tc})}{I_c} \right) \]
\[ \sigma_{\text{top}} = \left( \frac{-613.34^k}{1394^{in^2}} + \frac{(-613.34^k)(28.74^{in})(-16.38^{in})}{670167.7^{in^4}} \right) \]
\[ + \left( \frac{31.25^{kips}}{1394^{in^2}} + \frac{(31.25^{kips})(34.74^{in})(-16.38^{in})}{670167.7^{in^4}} \right) \]
\[ + \left( \frac{23.11^{kips}}{1394^{in^2}} + \frac{(23.11^{kips})(28.74^{in})(-16.38^{in})}{670167.7^{in^4}} \right) \]
\[ = -0.0091^{ksi} + (-0.0041^{ksi}) + 0.00034 = -0.013^{ksi} \]

\[ \sigma_{\text{bot}} = \left( \frac{P_{PT}}{A_c} + \frac{(P_{PT})(e_{PT,c})(y_{bc})}{I_c} \right) + \left( \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{bc})}{I_c} \right) \]
\[ + \left( \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{bc})}{I_c} \right) \]

\[ \sigma_{\text{bot}} = \left( \frac{-613.34^k}{1394^{in^2}} + \frac{(-613.34^k)(28.74^{in})(38.74^{in})}{670167.7^{in^4}} \right) \]
\[ + \left( \frac{31.25^{kips}}{1394^{in^2}} + \frac{(31.25^{kips})(34.74^{in})(38.74^{in})}{670167.7^{in^4}} \right) \]
\[ + \left( \frac{23.11^{kips}}{1394^{in^2}} + \frac{(23.11^{kips})(28.74^{in})(38.74^{in})}{670167.7^{in^4}} \right) \]
\[ = -1.458^{ksi} + 0.085^{ksi} + 0.06^{ksi} = -1.313^{ksi} \]

Girder Top and bottom stresses at end of stage 5 (t=50 days):

<table>
<thead>
<tr>
<th></th>
<th>Stage 1-4</th>
<th>Stage 5</th>
<th>Stages 1-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{top}} )</td>
<td>-1.325^{ksi}</td>
<td>-0.013^{ksi}</td>
<td>-1.33^{ksi}</td>
</tr>
<tr>
<td>( \sigma_{\text{bot}} )</td>
<td>-0.283^{ksi}</td>
<td>-1.313^{ksi}</td>
<td>-1.59^{ksi}</td>
</tr>
</tbody>
</table>
Stage 6:

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Step</td>
<td>4050 days</td>
<td>$\Delta P_{CR}, \Delta P_{SH}, \Delta P_{R}, \Delta P_{SS}$</td>
</tr>
</tbody>
</table>

$t_i = 50^{day}$, $t_d = 4050^{day} - 50^{day} = 4000^{day}$

- Stress Change due to Concrete Creep ($\Delta P_{CR}$):

$$\Delta P_{CR(PS)} = \left( \frac{E_p}{E_{ct=50}} \right) (f_{cgp,t=1}) [\Psi_{b(tf,ti)} - \Psi_{b(tp,ti)}] (K_{b(tf,tp)})$$

$$+ \left( \frac{E_p}{E_{ct=50}} \right) (f_{cgp,t=21}) [\Psi_{b(tf,td)} - \Psi_{b(tp,td)}] (K_{b(tp,tf)})$$

$$+ \left( \frac{E_p}{E_{ct=50}} \right) (f_{cgp,t=50}) [\Psi_{b(tf,tp)}](K_{b(tp,tf)})$$

$\Psi_{b(td,ti)} = 0.634$

$\Psi_{b(tp,ti)} = 1.093$

$\Psi_{b(tp,td)} = 0.565$

$\Psi_{b(tf,ti)} = 2.165$

$t_f - t_d = 4050^{days} - 21^{days} = 4029^{days}$

Time development factor ($k_t$) between deck placement and final.

$$k_{t(tf,td)} = \frac{t_{(td,tf)}}{61 - 4 x f'_{c} + t_{(tcu,tf)}} = \frac{4029}{61 - 4 x 3.5 + 4029} = 0.988$$

Girder Creep coefficient ($\Psi$) at final due to loading introduced at deck placement.

$$\Psi_{b(tf,td)} = (1.9) (k_s) (k_f) (k_{hc}) (k_{t(tf,td)}) (t_i^{-0.118})$$
\[ \Psi_b(t_f, t_d) = (1.9)(1.0)(1.251)(0.92)(0.988)(21)^{-0.118} = 1.51 \]

Time development factor \((k)\) between PT and final.

\[ t_r - t_p = 4050^{\text{days}} - 50^{\text{days}} = 4000^{\text{days}} \]

\[ k_{t(t_f, t_d)} = \frac{t_{(t_f, t_d)}}{61 - 4 x f'_c + t_{(t_{cur}, t_f)}} = \frac{4000}{61 - 4 x 3.5 + 4000} = 0.988 \]

Girder Creep coefficient \((\Psi)\) at final due to loading introduced at PT

\[ \Psi_b(t_f, t_p) = (1.9) (k_s) (k_f) (k_{hc}) (k_{t(t_f, t_p)})(t_i^{-0.118}) \]

\[ \Psi_b(t_f, t_p) = (1.9)(1.0)(1.251)(0.92)(0.988)(50)^{-0.118} = 1.36 \]

\[ K_{b(d,f)} = \frac{1}{1 + \left( \frac{E_p}{E_{cl}} \right) \left( \frac{A_{ps}}{A_c} \right) \left( 1 + \frac{(A_c) (e_{ps,c})^2}{I_c} \right) \left[ 1 + 0.7 x \Psi_{(t_f, t_i)} \right]} \]

\[ K_{b(t_f, t_d)} = \frac{1}{1 + \left( \frac{28500^{ksi}}{4269.64^{ksi}} \right) \left( \frac{3.906^{in^2}}{1394^{in^2}} \right) \left( 1 + \frac{1394^{in^2} x (34.76^{in})^2}{670167.7^{in^4}} \right) x (1 + 0.7 x 2.165)} \]

\[ = 0.858 \]

\[ \Delta \bar{P}_{CR(PS)} = \left( \frac{28500^{ksi}}{4310.3^{ksi}} \right) (-1.022^{ksi}) [2.165 - 0.93] (0.86) \]

\[ + \left( \frac{28500^{ksi}}{4310.3^{ksi}} \right) (0.55^{ksi}) [1.51 - 0.565] (0.86) \]

\[ + \left( \frac{28500^{ksi}}{4310.3^{ksi}} \right) (-1.21^{ksi}) [1.36] (0.86) = -12.63^{ksi} \]

\[ \Delta \bar{P}_{CR(PT)} = \left( \frac{E_p}{E_{ct=35}} \right) (f_{cgp,t=50}) [\Psi_b(t_f, t_p)] (K_{b(t_p,t_f)}) \]
\[ \Delta f_{CR(PT)} = \left( \frac{28500^{ksi}}{4310.3^{ksi}} \right) \left( -1.076^{ksi} \right) \left[ 1.36 \right] \left( 0.86 \right) = -8.3^{ksi} \]

- **Stress Change due to Concrete Shrinkage** \((\Delta f_{SH})\):

\[ \Delta f_{SH} = (\epsilon_{bpf})(E_P)(K_{pf}) \]

\[ \epsilon_{bpf} = (k_s)(k_f)(k_{hs}) \left[ k_{(tf,ti)} - k_{(tp,ti)} \right] \left( 0.48 \right) \times 10^{-03} \]

\[ \epsilon_{bpf} = (1.0)(1.251)(0.88) \left[ 0.99 - 0.50 \right] \left( 0.48 \right) \times 10^{-03} = 2.59 E - 04 \]

\[ \Delta f_{SH} = \left( 2.59 E - 04 \right) \left( 28500^{ksi} \right) \left( 0.86 \right) = -6.34^{ksi} \]

- **Stress Change due to Steel Relaxation** \((\Delta f_{R})\):

\[ \Delta f_{R,PS} = -2.4 \times \frac{t_d(tf,ti)}{100 + t_d(tf,ti)} - \Delta f_{R1} - \Delta f_{R2} \]

\[ \Delta f_{R,PS} = -2.4 \times \frac{4049}{100 + 4049} - (-0.4) - (-0.39) = -1.55^{ksi} \]

\[ \Delta f_{R,PT} = -2.4 \times \frac{t_d(tf,tp)}{100 + t_d(tf,ti)} \]

\[ \Delta f_{R,PT} = -2.4 \times \frac{4000}{100 + 4000} = -2.34^{ksi} \]

- **Stress Change due to Deck Shrinkage** \((\Delta f_{ss})\):

\[ \Delta f_{ss} = \left( \frac{E_p}{E_c} \right) (\Delta f_{cdf})(K_{(dcur,f)}) \left[ 1 + 0.7 x \Psi_{b(tf,tdcur)} \right] \left[ k_{t(dcur,tf)} - k_{t(dcur,tp)} \right] \]

\[ \Delta f_{ss} = \left( \frac{28500^{ksi}}{4310.3^{ksi}} \right) \left( 0.159^{ksi} \right) \left( 0.86 \right) \left[ 1 + 0.7 \times 1.46 \right] \left[ 0.988 - 0.31 \right] = 1.25^{ksi} \]
\[ \Sigma \Delta f_{PS} = \Delta f_{CR} + \Delta f_{SH} + \Delta f_{R} + \Delta f_{SS} = (-12.63^{ksi}) + (-6.34^{ksi}) + (-1.55^{ksi}) + (1.25^{ksi}) = -19.27^{ksi} \]

\[ \Sigma \Delta f_{PT} = \Delta f_{CR} + \Delta f_{SH} + \Delta f_{R} + \Delta f_{SS} = (-8.3^{ksi}) + (-6.34^{ksi}) + (-1.55^{ksi}) + (1.25^{ksi}) = -14.94^{ksi} \]

*Calculate concrete stresses at Top & Bottom of girder*

\[ \Delta P_{PS} = (\Sigma \Delta f_{PS})(A_{PS}) = (19.27^{ksi})(3.906^{in^2}) = 75.27^{kips} \]

\[ \Delta P_{PT} = (\Sigma \Delta f_{PT})(A_{PT}) = (14.94^{ksi})(3.26^{in^2}) = 48.7^{kips} \]

\[ \sigma_{top(tf,tdcur)} = -0.236^{ksi} \]

\[ \sigma_{bot(tf,tdcur)} = 0.0224^{ksi} \]

\[ \Delta \sigma_{top} = \sigma_{top(tdcur,tf)}x(k_{(tf,tcur)} - k_{(tp,tcurl)}) + \left( \frac{\Delta P_{PS}}{A_c} + \frac{\Delta P_{PS} (e_{PS,c})(y_c)}{I_c} \right) \]

\[ + \left( \frac{\Delta P_{PT}}{A_c} + \frac{\Delta P_{PT} (e_{PT,c})(y_c)}{I_c} \right) \]

\[ \Delta \sigma_{top} = (-0.236^{ksi})(0.988 - 0.31) + \left( \frac{75.27^{kips}}{1394^{in^2}} + \frac{75.27^{kips}(34.74^{in})(-16.38^{in})}{670167.7^{in^4}} \right) \]

\[ + \left( \frac{48.7^{kips}}{1394^{in^2}} + \frac{(48.7^{kips})(28.74^{in})(-16.38^{in})}{670167.7^{in^4}} \right) \]

\[ = -0.16^{ksi} + (-0.01^{ksi}) + 0.0007^{ksi} = -0.169^{ksi} \]

\[ \Delta \sigma_{bot} = \sigma_{bot(tdcur,tf)}x(k_{(tf,tcurl)} - k_{(tp,tcurl)}) \]

\[ + \left( \frac{\Delta P_{PS}}{A_c} + \frac{\Delta P_{PS} (e_{PS,c})(y_{bc})}{I_c} \right) \left( \frac{\Delta P_{PT}}{A_c} + \frac{\Delta P_{PT} (e_{PT,c})(y_{bc})}{I_c} \right) \]
\[ \Delta \sigma_{bot} = 0.0224^{ksi} \times (0.988 - 0.31) + \left( \frac{75.27^{kips}}{1394^{in^2}} + \frac{75.27^{kips}(34.74^{in})(38.74^{in})}{670167.7^{in^4}} \right) \\
\quad + \left( \frac{48.7^{kips}}{1394^{in^2}} + \frac{48.7^{kips}(28.74^{in})(38.74^{in})}{670167.7^{in^4}} \right) \\
= 0.015^{ksi} + 0.205^{ksi} + 0.116^{ksi} = 0.336^{ksi} \]

Girder Top and bottom stresses at end of stage 6 (t = 4050 days):

<table>
<thead>
<tr>
<th></th>
<th>Stage 1-5</th>
<th>Stage 6</th>
<th>Stages 1-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{top} )</td>
<td>-1.33^{ksi}</td>
<td>-0.169^{ksi}</td>
<td>-1.50^{ksi}</td>
</tr>
<tr>
<td>( \sigma_{bott} )</td>
<td>-1.59^{ksi}</td>
<td>0.336^{ksi}</td>
<td>-1.254^{ksi}</td>
</tr>
</tbody>
</table>

**Stage 7:**

<table>
<thead>
<tr>
<th>Status</th>
<th>Age of Concrete</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ws + LL</td>
<td>4050 days</td>
<td>( \Delta f_{PE,PS,PE,PT} )</td>
</tr>
</tbody>
</table>

\( ws^{k/ft} = 0.24^{k/ft} \)

\( w_{barrier} = 0.12^{k/ft} \)

\( M_{(ws+barrier)} = 106.7^{k-ft} \)

\( M_{LL(HS20)} = 1290.104^{k-ft} \)

\( M_{LL(HS20)} (D.I.) = 1290.104^{k-ft} \times 1.33 = 1715.84^{k-ft} \)

\( M_{(Lane \ Load)} = 660.168^{k-ft} \)

\( LL_{DF (1lane)} = 0.06 + \left( \frac{S}{14} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left[ \frac{k_g}{12(L)(t)^3} \right]^{0.1} \)

\( k_g = n (l_g + (A_g)(e_g)^2) \)
\(e_g\): distance between center of gravity of girder and deck (in)

\[
e_g = D - y_b - \frac{t_f}{2} = 55.12\text{in} - 28.38\text{in} + \frac{8\text{in}}{2} = 30.74\text{in}
\]

\(k_g = 1.124 \left(373349\text{in}^4 + (924.5\text{in}^2)(30.74\text{in})^2\right) = 1401575.24\text{in}^4\)

\[\text{LL}_{DF. (1 \text{ lane})} = 0.06 + \left(\frac{5.5\text{ft}}{14}\right)^{0.4} \left(\frac{5.5\text{ft}}{105\text{ft}}\right)^{0.3} \times \left[\frac{1401575.24\text{in}^4}{12(105\text{ft})(8\text{in})^3}\right]^{0.1} = 0.37\]

\[\text{LL}_{DF. (2 \text{ lane})} = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \times \left(\frac{S}{L}\right)^{0.2} \times \left[\frac{k_g}{12(L)(t)^3}\right]^{0.1}\]

\[\text{LL}_{DF. (2 \text{ lane})} = 0.075 + \left(\frac{5.5\text{ft}}{9.5}\right)^{0.6} \left(\frac{5.5\text{ft}}{105\text{ft}}\right)^{0.2} \left[\frac{1401575.24\text{in}^4}{12(105\text{ft})(8\text{in})^3}\right]^{0.1} = 0.51\]

\[M_{LL(\text{Total})} = [M_{\text{lane Load}} + M_{LL(HS20)} \times D.I)] \text{ LL}_{DF.}\]

\[M_{LL(\text{Total})} = [1715.84\text{k-ft} + 660.168\text{k-ft}] (0.51) = 1211.76\text{k-ft}\]

Immediate losses of Prestressed Strands (PS):

\[
f_{cgp,PS} = \frac{(M_{ws})(e_{PS,c})}{I_c}
\]

\[f_{cgp,PS} = \left(\frac{106.7\text{k-ft} \times 12\text{ft}^{in}}{670167.7\text{in}^4}\right) (34.74\text{in}) = 0.066\text{ksi}\]

\[\Delta f_{PS} = \left(\frac{E_p}{E_{c,t=4050}}\right) (f_{cgp}) = \left(\frac{28500\text{ksi}}{4340.5\text{ksi}}\right) (0.066\text{ksi}) = 0.433\text{ksi}\]

Immediate losses of Post-tensioned Strands:

\[
f_{cgp,PT} = \frac{(M_{ws})(e_{PT,c})}{I_c}
\]
\[ f_{cgp, PT} = \left( \frac{106.7 \times 12\, \text{ft}}{670167.7\, \text{in}^4} \right) \left( 28.74\, \text{in} \right) = 0.055\, \text{ksi} \]

\[ \Delta f_{PE, PT} = \left( \frac{E_p}{E_{c,t=4050}} \right) \left( f_{cgp} \right) = \left( \frac{28500\, \text{ksi}}{4340.5\, \text{ksi}} \right) \left( 0.055\, \text{ksi} \right) = 0.36\, \text{ksi} \]

2nd Iteration

\[ \Delta P_{PS} = (\Delta f_{PS})(A_{PS}) = (0.433\, \text{ksi})(3.906\, \text{in}^2) = 1.69\, \text{kips} \]

\[ \Delta P_{PT} = (\Delta f_{PT})(A_{PT}) = (0.36\, \text{ksi})(3.26\, \text{in}^2) = 1.17\, \text{kips} \]

Immediate losses of Prestressed Strands (PS):

\[ f_{cgp} = \left( \frac{(M_{ws})(e_{PS,c})}{I_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})^2}{I_c} \right] + \left[ \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(e_{PS,c})}{I_c} \right] \]

\[ f_{cgp, PS} = (0.066\, \text{ksi}) + \left( \frac{1.69\, \text{kips}}{1394\, \text{in}^2} + \frac{(1.69\, \text{kips})(34.74\, \text{in})^2}{670167.7\, \text{in}^4} \right) \]

\[ + \left( \frac{1.17\, \text{kips}}{1394\, \text{in}^2} + \frac{(1.17\, \text{kips})(28.74\, \text{in})(34.74\, \text{in})}{670167.7\, \text{in}^4} \right) \]

\[ f_{cgp, PS} = (0.066\, \text{ksi}) + (0.0013\, \text{ksi}) + (0.0026\, \text{ksi}) = 0.07\, \text{ksi} \]

\[ \Delta f_{ES, PS} = \left( \frac{E_p}{E_c} \right) \left( f_{cgp} \right) = \left( \frac{28500\, \text{ksi}}{4340.5\, \text{ksi}} \right) \left( 0.07\, \text{ksi} \right) = 0.46\, \text{ksi} \]

Immediate losses of Post-tensioned Strands (PT):

\[ f_{cgp, PT} = \left( \frac{(M_{ws})(e_{PT,c})}{I_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(e_{PT,c})}{I_c} \right] + \left[ \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})^2}{I_c} \right] \]
\[ f_{cgp,PT} = (0.055^{ksi}) + \left( \frac{1.69^{kips}}{1394^{in^2}} + \frac{(1.69^{kips})(34.74^{in})(28.74)}{670167.7^{in^4}} \right) \\
+ \left( \frac{1.17^{kips}}{1394^{in^2}} + \frac{(1.17^{kips})(28.74^{in})^2}{670167.7^{in^4}} \right) \\
= (0.055^{ksi}) + (0.0037^{ksi}) + (0.0023^{ksi}) = 0.061^{ksi} \]

\[ \Delta f_{ES, PT} = \left( \frac{E_p}{E_{c,t=4050}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{4340.5^{ksi}} \right) (0.061^{ksi}) = 0.40^{ksi} \]

Calculate Girder Top & Bottom stresses

Immediate losses of Prestressed Strands (PS):

\[ f_{cgp,PS} = \frac{(M_{Lb})(e_{PS,c})}{I_c} + \frac{(M_{ws})(e_{PS,c})}{I_c} \]

\[ f_{cgp,PS} = \frac{(1211.76^{k-ft \times 12^{ft}})(34.74^{in})}{670167.7^{in^4}} + \frac{(106.7^{k-ft \times 12^{ft}})(34.74^{in})}{670167.7^{in^4}} \]

\[ f_{cgp,PS} = 0.753^{ksi} + 0.0664^{ksi} = 0.82^{ksi} \]

\[ \Delta f_{ES} = \left( \frac{E_p}{E_{c,t=4050}} \right) (f_{cgp}) = \left( \frac{28500^{ksi}}{4340.5^{ksi}} \right) (0.82^{ksi}) = 5.38^{ksi} \]

Immediate losses of Post-tensioned Strands:

\[ f_{cgp,PT} = \frac{(M_{Lb})(e_{PT,c})}{I_c} + \frac{(M_{ws})(e_{PT,c})}{I_c} \]

\[ f_{cgp,PT} = \frac{(1211.76^{k-ft \times 12^{ft}})(28.74^{in})}{670167.7^{in^4}} + \frac{(106.7^{k-ft \times 12^{ft}})(28.74^{in})}{670167.7^{in^4}} \]

\[ f_{cgp,PT} = 0.62^{ksi} + 0.055^{ksi} = 0.675^{ksi} \]
\[ \Delta f_{ES,PT} = \left( \frac{E_p}{E_{c,t=4050}} \right) (f_{c,GP}) = \left( \frac{28500^{ksi}}{4340.5^{ksi}} \right) (0.675^{ksi}) = 4.43^{ksi} \]

2nd Iteration

\[ \Delta P_{PS} = (\Delta f_{ES,PS})(A_{PS}) = (5.39^{ksi})(3.906^{in^2}) = 21.01^{kips} \]

\[ \Delta P_{PT} = (\Delta f_{ES,PT})(A_{PT}) = (4.43^{ksi})(3.26^{in^2}) = 14.44^{kips} \]

Immediate losses of Prestressed Strands (PS):

\[ f_{c,GP} = \left( \frac{(M_{LL})(e_{PS,c})}{I_c} + \frac{(M_{WS})(e_{PS,c})}{I_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})}{I_c} \right]^2 \]

\[ f_{c,GP,PS} = (0.753^{ksi} + 0.064^{ksi}) + \left( \frac{21.01^{kips}}{1394^{in^2}} + \frac{(21.01^{kips})(34.74^{in})^2}{670167.7^{in^4}} \right) \]

\[ f_{c,GP,PS} = \left( \frac{14.44^{kips}}{1394^{in^2}} + \frac{(14.44^{kips})(28.74^{in})(34.74^{in})}{670167.7^{in^4}} \right) \]

\[ f_{c,GP,PS} = (0.82^{ksi}) + (0.053^{ksi}) + (0.032^{ksi}) = 0.905^{ksi} \]

\[ \Delta f_{PS,ES} = \left( \frac{E_p}{E_c} \right) (f_{c,GP}) = \left( \frac{28500^{ksi}}{4340.5^{ksi}} \right) (0.905^{ksi}) = 5.94^{ksi} \]

Immediate losses of Post-tensioned Strands (PT):

\[ f_{c,GP,PT} = \left( \frac{(M_{LL})(e_{PT,c})}{I_c} + \frac{(M_{WS})(e_{PT,c})}{I_c} \right) \]

\[ + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(e_{PT,c})}{I_c} \right] + \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})^2}{I_c} \]
\[ f_{cgp, PT} = (0.62^{k_{si}} + 0.055^{k_{si}}) + \left( \frac{21.01^{kip}_{s}}{1394^{in^2}} + \frac{(21.01^{kip}_{s})(34.74^{in})(28.74)}{670167.7^{in^4}} \right) \\
\quad + \left( \frac{14.44^{kip}_{s}}{1394^{in^2}} + \frac{(14.44^{kip}_{s})(28.74^{in})^2}{670167.7^{in^4}} \right) \\
= (0.675^{k_{si}}) + (0.031^{k_{si}}) + (0.03^{k_{si}}) = 0.736^{k_{si}} \\
\]

\[ \Delta p_{ES, PT} = \left( \frac{E_p}{E_{c,t=4050}} \right) (f_{cgp}) = \left( \frac{28500^{k_{si}}}{4340.5^{k_{si}}} \right) (0.736^{k_{si}}) = 4.83^{k_{si}} \]

\[ \sigma_{top} = \left( \frac{(M_{LL})(y_{tc})}{I_c} + \frac{(M_{ws})(y_{tc})}{I_c} \right) + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{tc})}{I_c} \right] \\
\quad + \left[ \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{tc})}{I_c} \right] \\
\sigma_{top} = \left( \frac{(1211.76^{k_{s}} \times 12^{ft})(-16.38^{in})}{670167.7^{in^4}} + \frac{(106.7^{k_{s}} \times 12^{ft})(-16.38^{in})}{670167.7^{in^4}} \right) \\
\quad + \left( \frac{21.01^{kip}_{s}}{1394^{in^2}} + \frac{(21.01^{kip}_{s})(34.74^{in})(-16.38^{in})}{670167.7^{in^4}} \right) \\
\quad + \left( \frac{14.44^{kip}_{s}}{1394^{in^2}} + \frac{(14.44^{kip}_{s})(28.74^{in})(-16.38^{in})}{670167.7^{in^4}} \right) \\
\sigma_{top} = (-0.355^{k_{si}} - 0.0313^{k_{si}}) + (-0.003^{k_{si}}) + (0.0002^{k_{si}}) = -0.39^{k_{si}} \]

\[ \sigma_{bot} = \left( \frac{0.8x(M_{LL})(y_{bc})}{I_c} + \frac{(M_{ws})(y_{bc})}{I_c} \right) \\
\quad + \left[ \frac{\Delta P_{PS}}{A_c} + \frac{(\Delta P_{PS})(e_{PS,c})(y_{bc})}{I_c} \right] + \left[ \frac{\Delta P_{PT}}{A_c} + \frac{(\Delta P_{PT})(e_{PT,c})(y_{bc})}{I_c} \right] \]
\[ \sigma_{\text{bot}} = \left( \frac{0.8 \times (1211.76 \text{ ksi} \times 12 \text{ in})}{670167.7 \text{ in}^4} \times \frac{\text{in}}{\text{in}^4} \right) + \left( \frac{106.7 \text{ ksi} \times 12 \text{ in}}{670167.7 \text{ in}^4} \right) (38.74 \text{ in}) \]

\[ + \left[ \frac{21.01 \text{ kips}}{1394 \text{ in}^2} + \frac{21.01 \text{ kips} \times (34.74 \text{ in})(38.74 \text{ in})}{670167.7 \text{ in}^4} \right] \]

\[ + \left( \frac{14.44 \text{ kips}}{1394 \text{ in}^2} + \frac{(14.44 \text{ kips})(28.74 \text{ in})(38.74 \text{ in})}{670167.7 \text{ in}^4} \right) \]

\[ \sigma_{\text{bot}} = (0.67 \text{ ksi} + 0.074 \text{ ksi}) + (0.0573 \text{ ksi}) + (0.034 \text{ ksi}) = 0.8 \text{ ksi} \]

Girder top & bottom fibers stresses.

<table>
<thead>
<tr>
<th></th>
<th>Stage 1-6</th>
<th>Stage 7</th>
<th>Stages 1-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{top}} )</td>
<td>-1.50ksi</td>
<td>-0.39ksi</td>
<td>-1.89ksi</td>
</tr>
<tr>
<td>( \sigma_{\text{bot.}} )</td>
<td>-1.25ksi</td>
<td>0.8ksi</td>
<td>-0.45ksi</td>
</tr>
</tbody>
</table>
REFERENCES


3- Prestress Losses and the Estimation of long-term deflections and camber for prestressed concrete bridges, Hema Jayseelan.

4- PCI Bridge Design Manual, November 2011.
# LIST OF SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_p$</td>
<td>Modulus of elasticity of prestressing steel, (ksi)</td>
</tr>
<tr>
<td>$E_{ci}$</td>
<td>Modulus of elasticity of concrete at transfer or time of load application, (ksi).</td>
</tr>
<tr>
<td>$W_c$</td>
<td>Unit weight of concrete (kcf).</td>
</tr>
<tr>
<td>$f'c$</td>
<td>Specified compressive strength (ksi).</td>
</tr>
<tr>
<td>$f_{csp}$</td>
<td>Sum of concrete stresses at the center of gravity of prestressing tendons due to the prestressing force at transfer and the self-weight of the member at the sections of maximum moment, (ksi).</td>
</tr>
<tr>
<td>$P_i$</td>
<td>Total prestressing force immediately after transfer</td>
</tr>
<tr>
<td>$e$</td>
<td>Eccentricity of the centroid of the prestressing strands with respect to the centroid of the girder.</td>
</tr>
<tr>
<td>$A_g$</td>
<td>Area of the gross cross-section of the girder.</td>
</tr>
<tr>
<td>$I_g$</td>
<td>Moment of inertia of the gross cross-section of the girder</td>
</tr>
<tr>
<td>$M_g$</td>
<td>Moment due to girder self-weight.</td>
</tr>
<tr>
<td>$S$</td>
<td>Anchor set length (in).</td>
</tr>
<tr>
<td>$X$</td>
<td>Length of tendon from the jacking point to the point being considered (ft).</td>
</tr>
<tr>
<td>$k$</td>
<td>Wobble friction coefficient (per ft. of tendon).</td>
</tr>
</tbody>
</table>
\( f_{pi} \) Initial jacking stress in the tendon (ksi).

\( M \) Curvature friction Coefficient.

\( A \) Sum of the absolute values of angular change of prestressing steel path from jacking end, or from the nearest jacking end if tensioning is done equally at both ends, to the point under investigation (rad.).

\( H \) Relative humidity (%). In the absence of better information, \( H \) may be taken from Figure 5.4.2.3.3-1.

\( K_v \) factor for the effect of the volume-to-surface ratio of the component

\( k_f \) factor for the effect of concrete strength

\( k_{hc} \) humidity factor for creep

\( k_{td} \) time development factor

\( t \) Maturity of concrete (day), defined as age of concrete between time of loading for creep calculations, or end of curing for shrinkage calculations, and time being considered for analysis of creep or shrinkage effects

\( ti \) Age of concrete at time of load application (day).

\( V/S \) Volume-to-surface ratio (in.).

\( f'ci \) Specified compressive strength of concrete at time of prestressing for pretensioned members and at time of initial loading for non-prestressed members.
If concrete age at time of initial loading is unknown at design time, \( f'_{ci} \) may be taken as 0.80 \( f'_c \) (ksi).

\[ \Psi_{b(ad, n)} \] girder creep coefficient at time of deck placement due to loading introduced at transfer per Eq. 5.4.2.3.2-1

\( t_d \) Age at deck placement (days).

\( \Delta f_{cdf} \) Change in concrete stress at centroid of prestressing strands due to long-term losses between deck placement and final, combined with deck weight and superimposed loads (ksi).

\[ \Psi_{b(tf, td)} \] girder creep coefficient at final time due to loading at deck placement per Eq. 5.4.2.3.2-1

\( \varepsilon_{bid} \) concrete shrinkage strain of girder between the time of transfer and deck placement per Eq. 5.4.2.3.3-1

\( K_{id} \) Transformed section coefficient that accounts for time-dependent interaction between concrete and bonded steel in the section being considered for time period between transfer and deck placement.

\( e_{pg} \) Eccentricity of prestressing force with respect to centroid of girder (in.); positive in common construction where it is below girder centroid.

\[ \Psi_b (tf, ti) \] girder creep coefficient at final time due to loading introduced at transfer per Eq. 5.4.2.3.2-1


<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_f$</td>
<td>Final age (days).</td>
</tr>
<tr>
<td>$T_i$</td>
<td>Age at transfer (days).</td>
</tr>
<tr>
<td>$H$</td>
<td>Humidity factor for Shrinkage.</td>
</tr>
<tr>
<td>$C_{bdf}$</td>
<td>Shrinkage strain of girder between time of deck placement and final time per Eq.5.4.2.3.3-1</td>
</tr>
<tr>
<td>$K_{df}$</td>
<td>Transformed section coefficient that accounts for time-dependent interaction between concrete and bonded steel in the section being considered for time period between deck placement and final time</td>
</tr>
<tr>
<td>$e_{pc}$</td>
<td>Eccentricity of prestressing force with respect to centroid of composite section (in.), positive in typical construction where prestressing force is below centroid of section</td>
</tr>
<tr>
<td>$A_c$</td>
<td>Area of section calculated using the gross composite concrete section properties of the girder and the deck and the deck-to-girder modular ratio (in²)</td>
</tr>
<tr>
<td>$I_c$</td>
<td>Moment of inertia of section calculated using the gross composite concrete section properties of the girder and the deck and the deck-to-girder modular ratio at service (in⁴).</td>
</tr>
<tr>
<td>$A_d$</td>
<td>Area of deck concrete (in²)</td>
</tr>
<tr>
<td>$E_{cd}$</td>
<td>Modulus of elasticity of deck concrete at final time due to loading introduced shortly after deck placement (i.e. overlays, barriers, etc.) per Eq.5.4.2.3.2-1.</td>
</tr>
</tbody>
</table>
$C_{diff}$  Shrinkage strain of deck concrete between placement and final time per Eq.5.4.2.3.3-1.

$E_d$  eccentricity of deck with respect to the gross composite section, positive in typical construction where deck is above girder (in)

Ψ$_{b(tf, td)}$  girder creep coefficient at final time due to loading at deck placement per Eq.5.4.2.3.2-1

$N$  Number of identical prestressing tendons

$f_{pi}$  Prestressing steel stress immediately prior to transfer (ksi).

$H$  The average annual ambient relative humidity (%).

$γ_h$  Correction factor for relative humidity of the ambient air.

$γ_{st}$  correction factor for specified concrete strength at time of prestress transfer to the concrete member.

$Δf_{pr}$  An estimate of relaxation loss taken as 2.4ksi for low relaxation strand.

$Δfps$  The prestress gain due to shrinkage of deck.

$M_{LL(HS20)}$  Live Load Moment due to design Truck.

$M_{(ws+barrier)}$  Moment Due to wearing surface and barriers.

$LLDF_{(1Lane)}$  Live Load distribution factor per one lane
$LLDF_{(2\text{Lane})}$ Live Load distribution factor per two lane
### Prestress Losses & Extrem Fiber stresses of Simply Supported Girder BT-54 (EX-01)

<table>
<thead>
<tr>
<th>Girder</th>
<th>&quot;BT-54&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_g$ (in$^2$)</td>
<td>659.00</td>
</tr>
<tr>
<td>$I_g$ (in$^4$)</td>
<td>268077.00</td>
</tr>
<tr>
<td>$D$ (in)</td>
<td>54.00</td>
</tr>
<tr>
<td>$Y_b$ (in)</td>
<td>27.63</td>
</tr>
<tr>
<td>$Y_t$ (in)</td>
<td>-26.37</td>
</tr>
<tr>
<td>$w_c$ (ksi)</td>
<td>0.15</td>
</tr>
<tr>
<td>$w$ (k/ft)</td>
<td>0.69</td>
</tr>
<tr>
<td>$M_g$ (k')</td>
<td>549.17</td>
</tr>
<tr>
<td>$V/S$ (in)</td>
<td>3.15</td>
</tr>
<tr>
<td>$L_{mid}$ (ft)</td>
<td>80.00</td>
</tr>
</tbody>
</table>

#### Girder
- $A/B = a/B = 0.71$
- $\beta = 4.7$
- $a = 0.692$
- $A/B = a/B = 4.024$

#### Deck
- $A/B = a/B = 0.856$
- $a = 0.692$

| $\phi$ (in) | 0.6 |
| $A_{ps}$ (in$^2$) | 21609 |
| $A_{ps}$ (in$^2$) | 506.45 |
| $Ep$ (ksi) | 28500 |
| $\sigma_{pu}$ (ksi) | 270 |
| $\sigma_{pj}$ (ksi) | -790.965 |
| $\sigma_{g}$ (ksi) | 0.67 |
| $\sigma_{c}$ (ksi) | 0.15 |
| $\sigma_{c}$ (ksi) | 0.69 |

#### Comp.

| $A_c$ (in$^2$) | 1165.45 |
| $I_c$ (in$^4$) | 534909.4 |
| $D$ (in) | 62.00 |
| $Y_b$ (in) | 40.83 |
| $Y_t$ (in) | -13.17 |
| $w_c$ (ksi) | 37.8 |
| $w$ (k/ft) | 17.17 |

#### Deck Placement
- $\beta = 4.7$
- $A/B = a/B = 4.024$

#### Stage 1

| $M,K''$ | $P,kips$ | $f_{gp},ksi$ | $\Delta|ES,ksi$ |
|----------|----------|---------------|----------------|
| PS       | -19481.5 | -790.97       | -2.990         |
| Self-wt  | 6590.0   | 0.00          | 0.605          |
| PS iterate | 1503.6 | 61.0          | 0.231          |
| PS       | -2.154   | -15.63        | 15.63          |

#### Girder Stress,ksi

| $f_p,ksi$ | $P,kips$ | $\Delta f_p |ES| (ksi)$ |
|-----------|----------|----------------|
| 186.87    | 730      | -15.63         |

| $\Delta f_p |ES| (ksi)$ | $f_p,ksi$ | $P,kips$ |
|-------------|----------|----------|----------|
| 0.06        | 0.25     | 1503.6   | 61.0      |

- $\Delta f_p |ES| (ksi)$: 0.06
- $f_p,ksi$: 0.25
### Stage 2

<table>
<thead>
<tr>
<th>$k_{(td,ti)}$</th>
<th>$\Psi_{b_{(td,ti)}}$</th>
<th>$\epsilon_{b_{(td,ti)}}$</th>
<th>$k_{(t,t)}$</th>
<th>$\Psi_{b_{(t,t)}}$</th>
<th>$K_{(td,ti)}$</th>
<th>$\Delta f_{CR}$</th>
<th>$\Delta f_{SH}$</th>
<th>$\Delta f_{R}$</th>
<th>$\Delta f_{pLT_{(td,ti)}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>0.69</td>
<td>1.67E-04</td>
<td>0.989</td>
<td>1.73</td>
<td>0.808</td>
<td>-8.75</td>
<td>-3.86</td>
<td>-0.54</td>
<td>-13.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_{k''}$</th>
<th>$P_{,kips}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.570</td>
<td>3.201</td>
</tr>
</tbody>
</table>

**PS Losses**

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>1265.1</td>
<td>51.4</td>
</tr>
</tbody>
</table>

### Stage 3

<table>
<thead>
<tr>
<th>$M_{,k''}$</th>
<th>$P_{,kips}$</th>
<th>$f_{cgp}$</th>
<th>$\Delta f_{pES}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck</td>
<td>6720.0</td>
<td>0.0</td>
<td>0.617</td>
</tr>
<tr>
<td>$PS_{iter}$</td>
<td>-307.952</td>
<td>-12.503</td>
<td>-0.047</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$f_{P_{,ksi}}$</th>
<th>$P_{,kips}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>176.9</td>
<td>691.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta f_{pES_{,td}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.201</td>
</tr>
</tbody>
</table>

**Girder Stress, ksi**

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>-28.779</td>
<td>-0.034</td>
</tr>
</tbody>
</table>

### Stage 4

<table>
<thead>
<tr>
<th>$k_{b_{(t,td)}}$</th>
<th>$\Psi_{b_{(t,td)}}$</th>
<th>$\epsilon_{b_{(t,td)}}$</th>
<th>$kd_{(t,tcu)}$</th>
<th>$f_{d_{(t,tcu)}}$</th>
<th>$\Psi_{d_{(t,tcu)}}$</th>
<th>$\Delta f_{CR}$</th>
<th>$\Delta f_{SH}$</th>
<th>$\Delta f_{R}$</th>
<th>$\Delta f_{pss_{(t,tcu)}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.82</td>
<td>1.16</td>
<td>2.51E-04</td>
<td>0.988</td>
<td>6.77E-04</td>
<td>2.228</td>
<td>-7.23</td>
<td>-5.85</td>
<td>-1.80</td>
<td>-14.88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta f_{pss_{(t,tcu)}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
</tr>
</tbody>
</table>

**Girder Stress, ksi**

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>-25.578</td>
<td>-0.684</td>
</tr>
</tbody>
</table>

### Stage 5

<table>
<thead>
<tr>
<th>$M_{(ws+b),k-ft}$</th>
<th>$M_{,HS20,K-ft}$</th>
<th>$LL$, factor</th>
<th>$M_{,LL,K-ft}$</th>
<th>$M_{,Lane,K-ft}$</th>
<th>$M_{,Kg}$</th>
<th>$D_{,F,1-lane}$</th>
<th>$D_{,F,2-lane}$</th>
<th>$M_{,(K-ft)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>292.00</td>
<td>1160</td>
<td>1.33</td>
<td>1542.8</td>
<td>512</td>
<td>1162204</td>
<td>0.46</td>
<td>0.632</td>
<td>1299.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_{,k''}$</th>
<th>$P_{,kips}$</th>
<th>$f_{cgp}$</th>
<th>$\Delta f_{pES}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS</td>
<td>3504.0</td>
<td>0.0</td>
<td>0.248</td>
</tr>
<tr>
<td>LL</td>
<td>15594.5</td>
<td>0.0</td>
<td>1.103</td>
</tr>
<tr>
<td>PS iter</td>
<td>-188.7</td>
<td>-5.0</td>
<td>-0.018</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta f_{pES}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta f_{pES}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>-37.17</td>
<td>-1.736</td>
</tr>
</tbody>
</table>

### Stage 6

<table>
<thead>
<tr>
<th>$\Delta f_{pES}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.076</td>
</tr>
</tbody>
</table>
## Prestress Losses & Extrem Fiber stresses of Simply Supported Girder W24PTMG (EX-02)

<table>
<thead>
<tr>
<th>Girder:</th>
<th>&quot;W24PTMG&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_g, \text{(in}^2\text{)}$</td>
<td>1211</td>
</tr>
<tr>
<td>$I_g, \text{(in}^4\text{)}$</td>
<td>1447119</td>
</tr>
<tr>
<td>$D, \text{(in)}$</td>
<td>94.49</td>
</tr>
<tr>
<td>$Y_{b, \text{(in)}}$</td>
<td>45.64</td>
</tr>
<tr>
<td>$Y_{t, \text{(in)}}$</td>
<td>0.15</td>
</tr>
<tr>
<td>$w_{c, \text{(Kcf)}}$</td>
<td>1.26</td>
</tr>
<tr>
<td>$w, \text{(k/ft)}$</td>
<td>1618.1</td>
</tr>
<tr>
<td>$V/S, \text{(in)}$</td>
<td>3.61</td>
</tr>
<tr>
<td>$L, \text{mid, (ft)}$</td>
<td>101.3</td>
</tr>
<tr>
<td>$L, \text{tot, (ft)}$</td>
<td>194.5</td>
</tr>
</tbody>
</table>

### Girder

- $A/B=\alpha= 0.71$
- $\beta=28/(A/B+28)= 0.975$
- $a=\beta*(A/B)= 0.692$

### Deck

- $A/B=\alpha= 4.7$
- $\beta=28/(A/B+28)= 0.856$
- $a=\beta*(A/B)= 4.024$

### Girder

<table>
<thead>
<tr>
<th>$f'c_i$</th>
<th>$f'c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00</td>
<td>9.00</td>
</tr>
</tbody>
</table>

### Deck Placement

- $t, \text{day}$
- $f'c_{i, \text{day}}$
- $E_{ci, \text{ksi}}$

- 1 5.397 4453.6 Strands Cut
- 21 8.926 5727.8 Deck Placement
- 28 9.000 5751.4 End Deck Curing
- 35 9.045 5765.7 PT+FW Removal
- 4035 9.227 5823.3 WS+LL

### Prestress Losses & Extrem Fiber stresses of Simply Suppoored Girder W24PTMG (EX-02)

<table>
<thead>
<tr>
<th>$\phi_i, \text{(in)}$</th>
<th>$A_{b_i} \text{(in}^2\text{)}$</th>
<th>#</th>
<th>$A_{ps_i} \text{(in}^2\text{)}$</th>
<th>$E_p, \text{(ksi)}$</th>
<th>$f_{pu, \text{(ksi)}}$</th>
<th>$f_{ps, \text{(ksi)}}$</th>
<th>$p_i, \text{(ksi)}$</th>
<th>Cover, \text{(in)}</th>
<th>$e_{ps_i}, \text{(in)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.217</td>
<td>10</td>
<td>2.17</td>
<td>28500</td>
<td>270</td>
<td>202.5</td>
<td>439.425</td>
<td>3</td>
<td>42.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$S, \text{(ft)}$</th>
<th>$t, \text{(in)}$</th>
<th>$A_d, \text{(in}^2\text{)}$</th>
<th>$Y_{b, \text{(in)}}$</th>
<th>$w_{c, \text{(Kcf)}}$</th>
<th>$w, \text{(k/ft)}$</th>
<th>$M_d, \text{(k-ft)}$</th>
<th>$f', \text{c,ksi)}$</th>
<th>$E_c, \text{(ksi)}$</th>
<th>$n$</th>
<th>$b \text{eff, (ft)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.89</td>
<td>8</td>
<td>661.4</td>
<td>98.49</td>
<td>0.15</td>
<td>0.689</td>
<td>883.8</td>
<td>4</td>
<td>3834.3</td>
<td>1.504</td>
<td>4.582</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$A_{eff, \text{(in}^2\text{)}}$</th>
<th>$l, \text{(in}^4\text{)}$</th>
<th>$k_s$</th>
<th>$k_f$</th>
<th>$k_h$</th>
<th>$k_h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>439.87</td>
<td>18768</td>
<td>1</td>
<td>1.19</td>
<td>0.88</td>
<td>0.92</td>
</tr>
</tbody>
</table>

### PT

<table>
<thead>
<tr>
<th>$A_{b, \text{(in}^2\text{)}}$</th>
<th>$P, #$</th>
<th>$A_{PT, \text{(in}^2\text{)}}$</th>
<th>Tendon</th>
<th>$A_{PT, \text{tot, (in}^2\text{)}}$</th>
<th>$e_{fr}$</th>
<th>$b_{fr}$</th>
<th>$\alpha$</th>
<th>$\mu$</th>
<th>$k (1/ft)$</th>
<th>Anch-S, \text{in}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.217</td>
<td>19.00</td>
<td>4.1230</td>
<td>3.00</td>
<td>12.37</td>
<td>34.80</td>
<td>97.75</td>
<td>0.05934</td>
<td>0.2</td>
<td>0.0002</td>
<td>0.375</td>
</tr>
</tbody>
</table>

### Comb.

<table>
<thead>
<tr>
<th>$A_{c, \text{(in}^2\text{)}}$</th>
<th>$l, \text{(in}^4\text{)}$</th>
<th>$D, \text{(in)}$</th>
<th>$Y_{b, \text{(in)}}$</th>
<th>$Y_{t, \text{(in)}}$</th>
<th>$e_{pc, \text{(in)}}$</th>
<th>$e_{ed, \text{(in)}}$</th>
<th>$e_{ov, e_{PT, \text{(in)}}}$</th>
<th>$e_{ov, e_{PT, \text{(in)}}}$</th>
<th>$e_{ov, e_{PT, \text{(in)}}}$</th>
<th>$e_{ov, e_{PT, \text{(in)}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1650.87</td>
<td>2350713</td>
<td>102.49</td>
<td>59.72</td>
<td>34.77</td>
<td>56.7</td>
<td>38.8</td>
<td>10.84</td>
<td>48.9</td>
<td>45.28</td>
<td>14.4</td>
</tr>
</tbody>
</table>

### girder

<table>
<thead>
<tr>
<th>to</th>
<th>ti</th>
<th>td</th>
<th>td-curing</th>
<th>tp</th>
<th>tf</th>
<th>to - ti</th>
<th>ti - td</th>
<th>td - tp</th>
<th>tp - tf</th>
<th>ti - tp</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>21</td>
<td>28</td>
<td>35</td>
<td>4035</td>
<td>1</td>
<td>20</td>
<td>14</td>
<td>4000</td>
<td>34</td>
</tr>
</tbody>
</table>

### deck

<table>
<thead>
<tr>
<th>ti-tf</th>
<th>td-tf</th>
<th>td-cur-tf</th>
<th>ti</th>
<th>t-cur</th>
<th>tp</th>
<th>tp-ti</th>
<th>tp-t_cur</th>
<th>tf-tp</th>
</tr>
</thead>
<tbody>
<tr>
<td>4034</td>
<td>4014</td>
<td>4007</td>
<td>1</td>
<td>7</td>
<td>14</td>
<td>13</td>
<td>7</td>
<td>4000</td>
</tr>
</tbody>
</table>

### W_s, ksf | W_s, k/ft | W_bar, k/ft
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.035</td>
<td>0.24</td>
<td>0.12</td>
</tr>
</tbody>
</table>
### Stage 1

<table>
<thead>
<tr>
<th>PS</th>
<th>Top</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>M, k''</td>
<td>0.270</td>
<td>-0.954</td>
</tr>
<tr>
<td>P, kips</td>
<td>-0.655</td>
<td>0.612</td>
</tr>
<tr>
<td>f cgp Δƒ ES</td>
<td>-0.003</td>
<td>0.010</td>
</tr>
<tr>
<td>Self wt</td>
<td>19417.0</td>
<td>0.00</td>
</tr>
<tr>
<td>PS iter.</td>
<td>197.3</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>-0.333</td>
<td>-2.132</td>
</tr>
<tr>
<td></td>
<td>2.132</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200.4</td>
<td>434.8</td>
</tr>
<tr>
<td></td>
<td>-2.13</td>
<td>-0.39</td>
</tr>
<tr>
<td></td>
<td>-0.33</td>
<td></td>
</tr>
</tbody>
</table>

### Stage 2

<table>
<thead>
<tr>
<th>M, k''</th>
<th>P, kips</th>
<th>Δƒ pES(ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.34</td>
<td>0.460</td>
<td>-0.003</td>
</tr>
<tr>
<td>1.11E-04</td>
<td>0.990</td>
<td>0.010</td>
</tr>
<tr>
<td>1.35</td>
<td>0.947</td>
<td>-0.006</td>
</tr>
<tr>
<td></td>
<td>400.4</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
<td>-0.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.007</td>
</tr>
</tbody>
</table>

### Stage 3

<table>
<thead>
<tr>
<th>Deck</th>
<th>M, k''</th>
<th>P, kips</th>
<th>f cgp Δƒ pES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10605.5</td>
<td>0.0</td>
<td>0.312</td>
</tr>
<tr>
<td></td>
<td>-140.644</td>
<td>-3.298</td>
<td>-0.007</td>
</tr>
<tr>
<td></td>
<td>0.306</td>
<td>1.52</td>
<td>-1.52</td>
</tr>
<tr>
<td></td>
<td>-0.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Stage 4

<table>
<thead>
<tr>
<th>K b(tf,td)</th>
<th>k (tp,ti)</th>
<th>k b(tp,td)</th>
<th>k b(tp,td)</th>
<th>Δƒ pSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.96</td>
<td>0.46</td>
<td>0.63</td>
<td>0.26</td>
<td>4.18E-05</td>
</tr>
<tr>
<td>0.09</td>
<td>-1.14</td>
<td>-0.21</td>
<td>-1.26</td>
<td></td>
</tr>
<tr>
<td>0.194</td>
<td>0.913</td>
<td>0.988</td>
<td>0.13</td>
<td>0.019</td>
</tr>
</tbody>
</table>

### Girder Stress, ksi

- Top: 0.270
- Bottom: -0.954
- Δƒ pES: -0.003
- 0.010
- PS iter.: 400.4
- 9.4
- Δƒ pSS: 0.194
- 0.913
- 0.988
- 0.13
- 0.990
- 4.07E-01
- 1.93E-04
- 4.97E-04
- 1.634
- 0.19

### Deck-SH

<table>
<thead>
<tr>
<th>Deck-SH</th>
<th>M, k''</th>
<th>P, kips</th>
<th>Δƒ SH (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-359.7</td>
<td>-0.424</td>
<td>0.136</td>
<td></td>
</tr>
<tr>
<td>0.0424</td>
<td>0.136</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.002</td>
<td>0.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.055</td>
<td>0.023</td>
<td></td>
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<tr>
<td>0.017</td>
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**Girder Stress, ksi**

- Top: 0.002
- Bottom: -0.007
### Stage 5

<table>
<thead>
<tr>
<th>( f_pj, \text{ ksi} )</th>
<th>( N, \text{ factor} )</th>
<th>( R, (1/\text{ft}) )</th>
<th>( x, \text{ ft} )</th>
<th>( R, \text{ Kips} )</th>
<th>( M, \text{ K-ft} )</th>
<th>( \Delta f_{AS, \text{ ksi}} )</th>
<th>( \Delta f_{PF, \text{ ksi}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>202.5</td>
<td>0.33</td>
<td>0.000321</td>
<td>116.98</td>
<td>144.24</td>
<td>6721.42</td>
<td>15.23</td>
<td>-2.50</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Girder Stress, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{AS, \text{ ksi}} )</td>
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</tbody>
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### Stage 6

<table>
<thead>
<tr>
<th>( k, (\text{ft}^{1/2}) )</th>
<th>( \Psi ), ( M_k^* )</th>
<th>( P, \text{ Kips} )</th>
<th>( f_{CP, \text{PS}} )</th>
<th>( \Delta f_{ES, \text{PS}} )</th>
<th>( f_{CP, \text{PT}} )</th>
<th>( \Delta f_{ES, \text{PT}} )</th>
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</thead>
<tbody>
<tr>
<td>PT</td>
<td>(-117088.1)</td>
<td>(-2395.3)</td>
<td>(-4.276)</td>
<td>(-3.886)</td>
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<tr>
<td>F.Wall</td>
<td>80657.0</td>
<td>0.0</td>
<td>1.946</td>
<td>1.677</td>
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</tr>
<tr>
<td>PS iter</td>
<td>1342.9</td>
<td>23.7</td>
<td>0.047</td>
<td>0.042</td>
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<tr>
<td>PT iter</td>
<td>2089.0</td>
<td>42.7</td>
<td>0.076</td>
<td>0.069</td>
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</tr>
<tr>
<td></td>
<td>(-2.207)</td>
<td>(-10.91)</td>
<td>10.91</td>
<td>(-2.097)</td>
<td>(-3.455)</td>
<td>3.455</td>
</tr>
<tr>
<td>Top</td>
<td>Bottom</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta f_{ES, \text{PT}} )</td>
<td>( \Delta f_{ES, \text{PS}} )</td>
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<td></td>
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</tr>
<tr>
<td>(-3.46)</td>
<td>(-10.91)</td>
<td>(-0.923)</td>
<td>(-2.249)</td>
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</table>

### Stage 7

<table>
<thead>
<tr>
<th>( M, \text{ K-ft} )</th>
<th>( \Delta f_{ES, \text{PS}} )</th>
<th>( \Delta f_{ES, \text{PT}} )</th>
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</thead>
<tbody>
<tr>
<td>WS</td>
<td>20493.6</td>
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<tr>
<td>LL</td>
<td>51006.4</td>
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<tr>
<td>PS iter</td>
<td>314.2</td>
<td>5.5</td>
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<tr>
<td>PT iter</td>
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<td>9.1</td>
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<td>0.522</td>
<td>2.553</td>
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</table>

<table>
<thead>
<tr>
<th>Girder Stress, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{AS, \text{ ksi}} )</td>
</tr>
</tbody>
</table>

### Stage 8

...