# DESIGN, DETAILING, AND CONSTRUCTION OF WSDOT POST-TENSIONED SPLICED-GIRDER BRIDGES IN WASHINGTON STATE


**Richard Brice P.E. (presenter)**

**Bridge Software Engineer**

**and**

**Bijan Khaleghi**

**Concrete Specialist**

**Washington State Department of Transportation**

**Bridge and Structures Office**



## ABSTRACT

Precast spliced girder bridges have been gaining popularity in recent years. Precast spliced girders allow longer span lengths compared to that of conventional pretensioned girders and are capable of accommodating structures with plan curvature. In addition, precast spliced girder systems can provide economy by reducing construction time and impact to the traveling public. WSDOT has recently developed standard drawings, design charts and computer software to accommodate the use of spliced girders in bridge structures.

Spliced tub girders have successfully been used in the HOV Direct Access Bridge over Interstate 5 in Federal Way, Washington. This was an innovative and unique application of precast spliced girders for a Texas-T configuration with significant plan curvature. Bridges with significant plan curvature are traditionally built with cast-in-place concrete box girders or steel girders but this project demonstrated that precast spliced girders could successfully be used for bridges with plan curvature. Features and capabilities of WSDOT computer software for spliced girder design are also presented in this paper.



**Keywords:** Prestressed Girder, Long-Span, Spliced-Girders, Span Capability, Curvature

**Introduction**

A spliced precast girder bridge is defined as a type of superstructure in which precast concrete beam-type elements are joined longitudinally, typically using post-tensioning, to form the complete girder. The resulting superstructure cross-section is a conventional beam-and-slab system with a composite cast-in-place deck. Among the reasons to use spliced girders are reductions in the number of substructure units resulting from increased span lengths, reduction of girder units due to increased girder spacing, and functional and aesthetic improvements by reducing superstructure depth.

Spliced girder bridges have a proven track record, with more than 250 spliced girder bridges having been constructed in the United States, some of them dating back as early as 1952. In spite of their past and continued use, the application of this technique is not widespread. A significant reason for their limited use is the ambiguity in their design and analysis, rooted in the consideration of various issues with which the designer of conventional precast prestressed concrete girders is typically not familiar. In addition, the information available in the literature regarding the design, analysis and construction of spliced girder bridges is limited, as the experience, information, and methods used on these projects have tended to be job-specific, and the knowledge gained has not been made widely available for use on similar projects. This situation is gradually improving.

While the design requirements for spliced girder bridges are not significantly different from conventional prestressed concrete design, the analysis procedure must make additional considerations. Among the most relevant of these considerations are construction stages, multiple stressing stages, and combined effects of prestressing and post-tensioning. Thus, the design of spliced girder bridges involves greater complexity than is required for conventional precast/prestressed concrete girder designs. Designs are generally executed using a computer program or a series of spreadsheets.

Precast prestressed spliced trapezoidal girders have successfully been used in the S. 317$^{th}$ Street HOV Direct Access Bridge over Interstate 5 in Federal Way, Washington. This was an innovative and unique application of precast splice girders for a Texas-T bridge with significant plan curvature. Bridges with significant plan curvature are traditionally built with cast-in-place concrete box girders or steel girders. This project has demonstrated that precast spliced girders can successfully be used for bridges with plan curvature.

To facilitate the design of single span spliced girder bridges, WSDOT has developed standard drawings, design charts, and computer software. The design charts assist planners in selecting appropriate spliced girder configurations when comparing alternatives. The standard drawings greatly reduce the effort of plan preparation. The computer software automates the detailed calculations required for spliced girder design and analysis reducing the overall design effort.

**S. 317th Street HOV Direct Access Bridge**

The S. 317th Street HOV Direct Access Bridge over Interstate 5 in Federal Way, Washington is a single span Texas-T style spliced girder structure with significant plan curvature. Bridges of this type are traditionally built with cast-in-place concrete box girders or curved steel girders.

Figure 1 shows the subject structure crossing the southbound lanes of Interstate 5. In the final configuration there are four lanes and a gore area beneath the structure. The curvature of the structure can be seen in the right hand side of the image and the tight clearances are readily apparent.

**Figure 1 – Southbound I-5 at S. 317th Street, Looking North**

## *Project Overview*

The goal of this project was to create a “flyover stop” for regional mass-transit busses and other HOV traffic that provides access to surface streets and a large park and ride facility. Tight right of way constraints forced the access points into the median between northbound and southbound Interstate 5. The direct access structure spans four lanes of southbound Interstate 5.

The structure is 128 feet in overall length. Four spliced trapezoidal tub girders, each consisting of two precast segments of 35 ft and 88 ft in length, make up the main superstructure. The segments were temporarily supported on a shoring tower until the composite deck was placed, the 5 ft wide splices where constructed and the four 22 strand tendons per girder were stressed. In this particular instance, an unusually wide splice was used to match the size of a transverse diaphragm that distributes the reactions from curved edge beams to the main girders.

The elevated T-intersection joins the main span to the interstate access ramps. Turning movements of mass transit vehicles are accommodated by 50 ft radius flairs at the intersections of the span and access ramps. Curved edge beams frame into the diaphragm at the splice location and are supported on an abutment wall at the Eastern pier. This configuration of straight precast girders with curved edge beams framing into the splice provide the same plan configuration as is traditionally achieved with cast-in-place box girders. The framing plan and typical section are shown in Appendix A.

The total bridge cost was $2,286,264. The precast girders cost $347,300 and the post-tensioning was $68,050.

## *Selection of Structure Type*

Precast prestressed concrete bridges have become the preferred type of bridge construction, primarily for reasons of economy, savings in life-cycle costs and their rapid construction. However, the use of precast/prestressed concrete bridges for longer spans has been limited primarily due to transportation constraints. In order to overcome these drawbacks and to have an alternative to compete with steel superstructures, methods to achieve greater span lengths with precast/prestressed girders have become of great interest.

Spliced precast segments were better suited for this structure than conventional single piece precast prestressed girders. An open trapezoidal tub section was chosen for aesthetic reasons. A single piece girder of this type would weight in excess of 200 kips. WSDOT design criteria states:

- All prestressed girders with shipping weights less than 155 kips are of a conventional pre-tension design.

- All prestressed girders with shipping weights between 155 and 200 kips are of a conventional pre-tensioned design with a post-tensioned spliced girder alternative.

- All prestressed girders with a shipping weight in excess of 200 kips are of a post-tensioned spliced girder design.

In this particular application, the girder splice provides a convenient location to attach the curve edge beams.

## *Design*

The design of spliced girder bridges depends on several parameters that significantly influence performance and cost. The most relevant are time dependent effects, splicing locations, construction sequences, girder segment geometries, number of beams, and the arrangement of prestress and post-tensioned reinforcement. Normally most design variables are determined based on the designer’s judgment and on a trial and error processes.

The design of precast segments, as well as precast post-tensioned members, must satisfy the requirements of both allowable stress design and ultimate strength using the current

AASHTO LRFD Specifications and the additional criteria detailed in the WSDOT Bridge Design Manual.

The critical construction stages for the S. 317th Street HOV Direct Access Bridge are generally the same as any other structure of similar construction. The first critical stage is when the prestressing strands are released. The actual concrete stresses are determined by summing the stresses due to the girder self-weight and those due to the release of the prestressing strands. Girder top and bottom stresses are checked with the allowable concrete stress limits. Critical stage two occurs when the deck and splice joint are cast. Stresses are determined by summing the stress due to girder self-weight, deck dead load, non-composite dead load, construction live load, and placement of the deck and splice concrete. Top and bottom stresses along the segment are checked with the allowable concrete stress limits. The third critical stage is when the post-tensioning tendons are stressed. Concrete stresses are determined by summing the stresses due to the girder self-weight, deck dead load, non-composite dead load, temporary pier removal, stress on prestressing strands due to post-tensioning, and stress on post-tensioned strands. Stresses must be checked in the girder segments and the splices. The fourth critical stage is unique to this structure. The edge beams for the curved flares are released from their falsework supports. Concrete stresses must be checked for the applicable loading and limits states. Stresses, moments, and shears due to all the previously applied permanent loading along with live load must be considered in the final configuration of the structure. All strength limit states must be satisfied in this stage.

## Construction Sequence

There are many aspects that can be altered in the design of spliced girder bridges. Of particular importance for this type of construction are the post-tensioning sequence and the sequence of construction stages. The relative sequence of post-tensioning and deck placement has a profound effect on the design of the structure. When post-tensioning occurs prior to deck placement, higher strength concrete is needed for the splice elements. Cast-in-place concrete strength is generally limited to 4 KSI in rural areas and can be as high as 6 KSI in urban areas. The strength of the splice concrete can limit the amount of post-tensioning and ultimately the span length.

When post-tensioned after deck placement, splice concrete stress requirements are reduced and compression is imparted into the deck. The demand on the prestressing strands is increased because the noncomposite girder segments must carry the weight of the deck concrete before it cures. Though the performance and durability of the deck is improved by the compressive stresses due to post-tensioning, future deck replacement scenarios must be carefully studied.

The post-tensioning was applied after deck placement for this particular structure. The primary reason for choosing this construction sequence was the limitations on the splice concrete strength. The required splice concrete strength was 6 KSI.

## Prestress Losses

There are several methods available for estimating time dependent prestress losses. Some of these methods are cumbersome and require in-depth time-dependent analysis to account for construction stages and materials properties. Estimating time-dependent prestress losses for simple span post-tensioned spliced girders are greatly simplified by virtue of the fact that effects of continuity are not present.

Regardless of the method of predicting time dependent losses, the sequence of application of prestress forces into the girder must be accounted for. The accuracy of prestress losses for spliced-girders required detailed analysis of the time-dependent effects of creep, shrinkage and relaxation, as well as anchor set, wobble and curvature losses in the post-tensioning tendons. Additional elastic shortening loss in the prestressing strands occurs as the post-tensioning tendons are stressed. Creep losses are affected for both stages of prestress because additional stresses are present to cause creep at the centroid of the prestressing strands or tendons.

The refined method of predicting losses presented in the AASHTO LRFD specifications can be extended to single span spliced-girder bridges where the post-tensioning is done in a single stage. The loss prediction formulas are summarized in Appendix B.

## Detailing

The precast segments are minimally prestressed. The prestressing counteracts the dead load stresses from self-weight and stresses during handling and shipping. If the deck is placed before post-tensioning, the prestressing must counteract this dead load as well. Prestressing strands are straight without any draping since they will interfere with the post-tensioning ducts. Strands may be debonded to control concrete stresses. Strands are placed in the top and bottom flanges of girder sections and are fully stressed to $0.75f_{pu}$. Top strands are generally temporary and serve only to control stresses and improve stability during handling and shipping. The number of required prestressing strands is selected to provide enough prestress in the precast beam not to have concrete stresses exceed allowable limits at release and upon placing the concrete deck.

A parabolic post-tensioning strand layout counteracts the bending moment demands for the simply supported beam. The number of post-tensioning tendons is selected to provide enough pre-compression to resist live and dead loads when they are transferred from the individual girder segments to the full simple span. Multiple strand tendons are assumed and the distance between each duct varies along the girder length. Post-tensioning design requirements are evaluated at the middle of each segment and at the center of the splice joint.

The webs of the segments are thickened to accommodate the post-tensioning anchorage hardware as well as the bursting stresses and shear forces at the ends of the girder.

Splices are typically two feet wide and are typically located at approximately the ¼ and ¾ points (when three segments are used), but can be shifted to accommodate traffic opening, stream crossing, or other such requirements. For this structure, a single splice at the one-third point was used to accommodate traffic requirements. The size of the splice minimizes the amount of cast-in-place concrete while allowing ample room to splice the ducts and adjust for minor variations in tendon profile without introducing angle points which will result in increased friction loss.

Experience has show that matching the one inch cover of the precast segments in the cast-in-place splices is problematic. Precasters make use of external form vibrators to achieve good consolidation of the concrete. The splices are generally formed with plywood and rely on manually operated stingers to vibrate the concrete. With one inch cover, it is difficult to get the vibrator between the form and reinforcement and the result is often poorly consolidated concrete. To alleviate this problem, two inches of cover is provided at splice locations.

A set of standard spliced girder drawings for a WSDOT trapezoidal spliced tub is presented in Appendix C.

## *Design Tools*

Precast concrete bridge systems are the preferred type of structure in Washington State. WSDOT has developed a turnkey system to make the design and analysis of precast and spliced girder bridge systems fast and efficient. In addition to the standard details and drawings described above, WSDOT has developed span capability charts and computer software.

### Span Capability Charts

When determining the initial size and type of a structure, the combinations are vast. Span capability charts assist in preliminary design by listing maximum span lengths, concrete strength requirements, and prestress and post-tensioning requirements for various girder types and spacing configurations. The span capability chart for WSDOT trapezoidal tub girders is showing in Appendix D.

### Computer Software

The spliced-girder analysis and design may be done using any program with time-dependent analysis capabilities. The program must be capable of analyzing a structure that is constructed in many stages. In addition to the section properties and applied loads, the program should allow time dependent material properties, prestressing tendons, and multiple erection phases at different times.

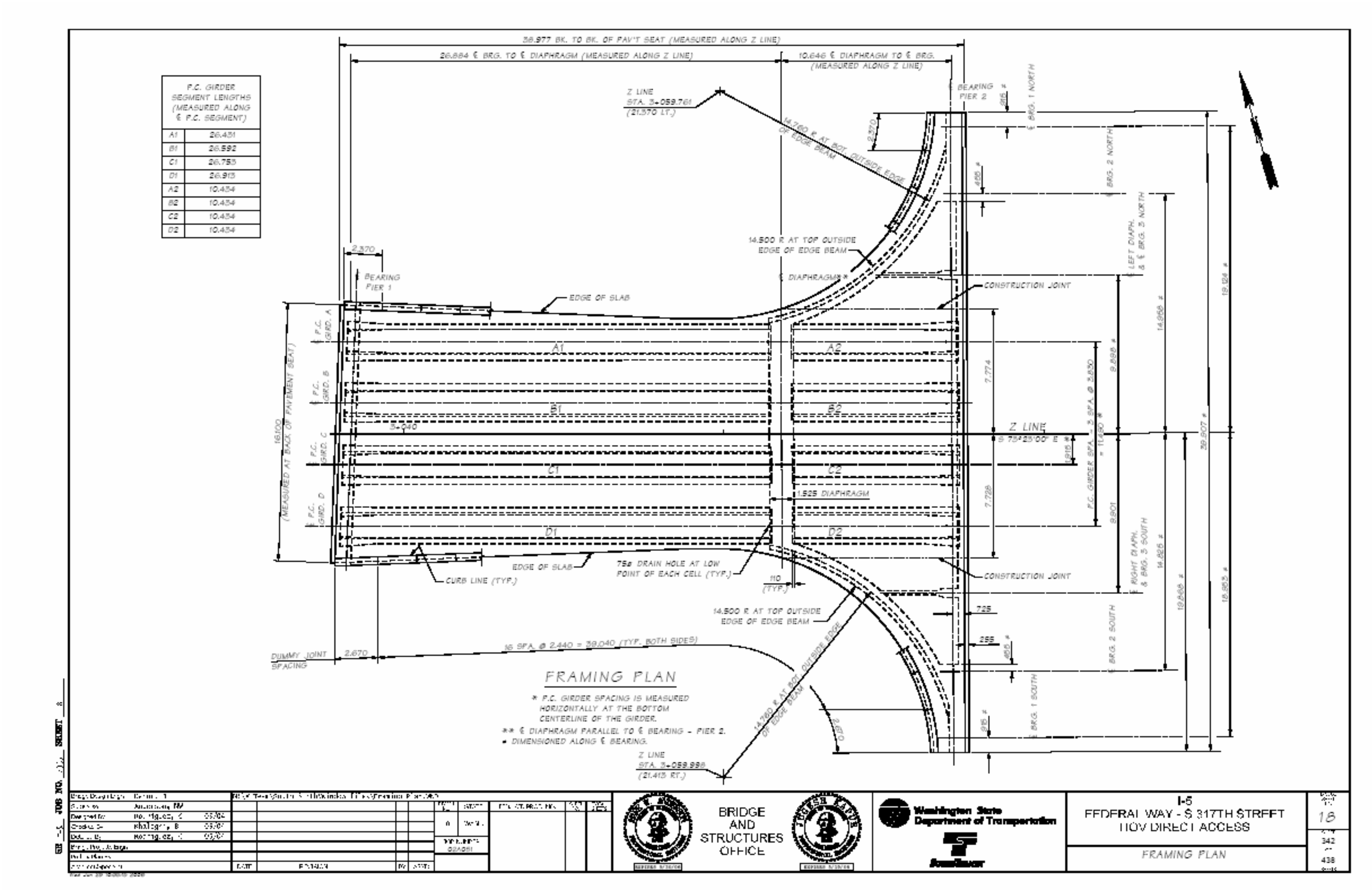
To facilitate the design of prestressed and spliced-girder bridges WSDOT has developed the PGSuper and PGSplice computer programs. PGSuper for the design of simple span pretensioned girder bridges. PGSplice is for the design of simple span post-tensioned spliced girder bridges.  Both programs feature support for the AASHTO LRFD Bridge Design Specifications and WSDOT BDM.  PGSplice analyzes simple span spliced girders for strength and service limit states for flexure and shear. It provides camber and deflection analysis as well as girder segment stability analysis for lifting and shipping. Detailed reports supporting every calculation are generated. The software has a fully customizable library for any I- or U-shaped beams and allows customization of design criteria.

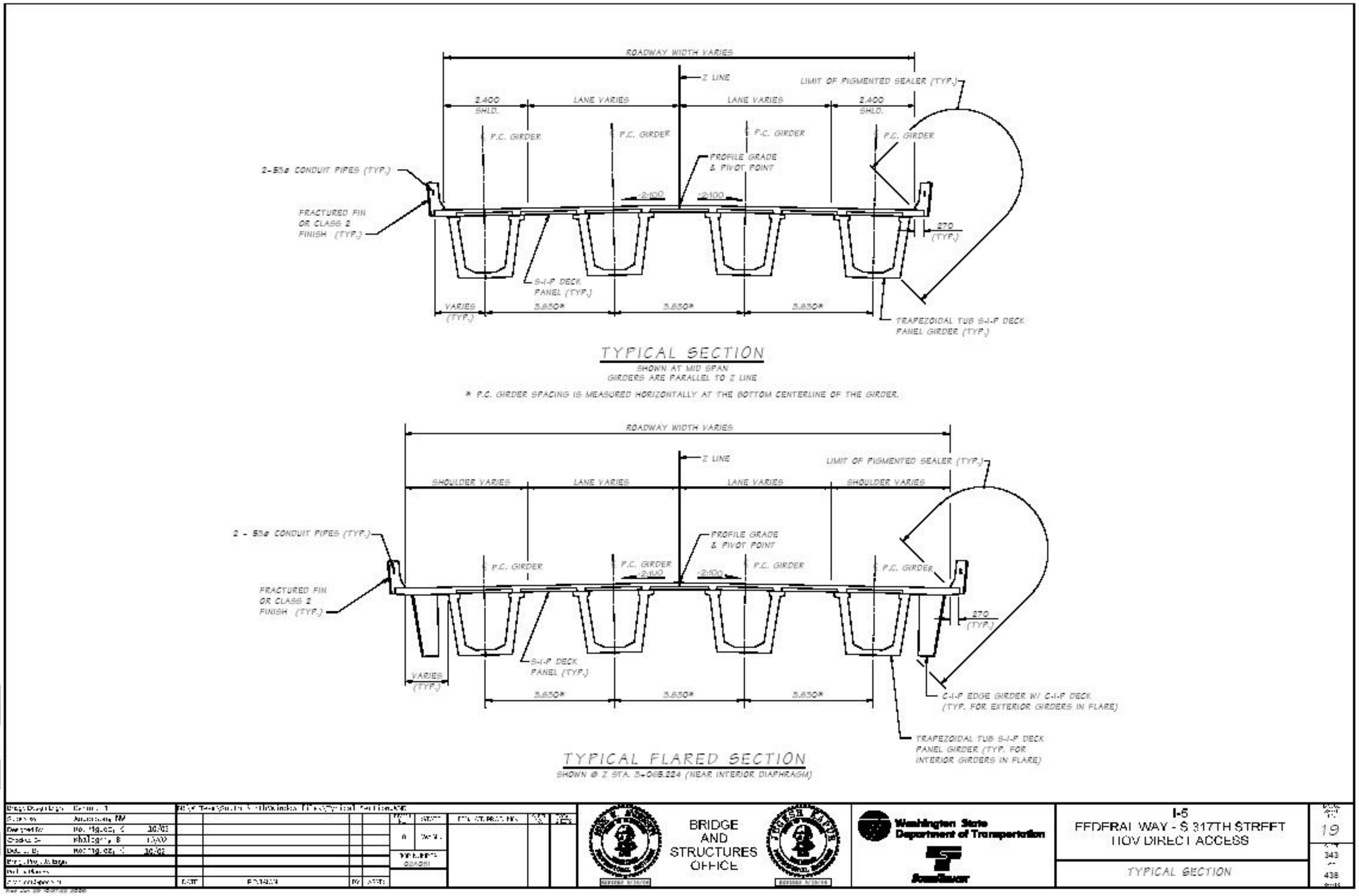
WSDOT software tools are part of its open source software effort, the Alternate Route Project. This software may be freely downloaded from the WSDOT web site at http://www.wsdot.wa.gov/eesc/bridge.

## Conclusion

Washington State Department of Transportation continues to innovate in the application of precast girder technology. Through the use of turnkey design systems, standardization and innovation, the economies and possibilities of precast concrete are virtually endless. The S. 317$^{th}$ Street HOV Direct Access Bridge project illustrates another opportunity to use the durability, constructability and aesthetic appeal of precast concrete.

## Appendix A – S. 317th Street HOV Direct Access Bridge – Plan and Typical Section




ROADWAY WIDTH VARIES
Z LINE
LIMIT OF PIGMENTED SEALER (TYP.)
2.400
SHLD.
LANE VARIES
LANE VARIES
2.400
SHLD.
℄ P.C. GIRDER
℄ P.C. GIRDER
℄ P.C. GIRDER
℄ P.C. GIRDER
2-53ø CONDUIT PIPES (TYP.)
PROFILE GRADE
& PIVOT POINT
-2.100
-2.100
FRACTURED FIN
OR CLASS 2
FINISH (TYP.)
270
(TYP.)
S-I-P DECK
PANEL (TYP.)
VARIES
(TYP.)
3.830*
3.830*
3.830*
TRAPEZOIDAL TUB S-I-P DECK
PANEL GIRDER (TYP.)
TYPICAL SECTION
SHOWN AT MID SPAN
GIRDERS ARE PARALLEL TO Z LINE
* P.C. GIRDER SPACING IS MEASURED HORIZONTALLY AT THE BOTTOM CENTERLINE OF THE GIRDER.
ROADWAY WIDTH VARIES
Z LINE
LIMIT OF PIGMENTED SEALER (TYP.)
SHOULDER VARIES
LANE VARIES
LANE VARIES
SHOULDER VARIES
2 - 53ø CONDUIT PIPES (TYP.)
PROFILE GRADE
& PIVOT POINT
℄ P.C. GIRDER
℄ P.C. GIRDER
-2.100
-2.100
℄ P.C. GIRDER
℄ P.C. GIRDER
FRACTURED FIN
OR CLASS 2
FINISH (TYP.)
270
(TYP.)
S-I-P DECK
PANEL (TYP.)
VARIES
(TYP.)
3.830*
3.830*
3.830*
C-I-P EDGE GIRDER W/ C-I-P DECK
(TYP. FOR EXTERIOR GIRDERS IN FLARE)
TRAPEZOIDAL TUB S-I-P DECK
PANEL GIRDER (TYP. FOR
INTERIOR GIRDERS IN FLARE)
TYPICAL FLARED SECTION
BRIDGE
AND
STRUCTURES
OFFICE
Washington State
Department of Transportation
I-5
FEDERAL WAY - S 317TH STREET
HOV DIRECT ACCESS
TYPICAL SECTION
19
343
438

## Appendix B – Prestress Losses

The refined method of predicting losses presented in the AASHTO LRFD specifications can be extended to single span spliced-girder bridges where the post-tensioning is done in a single stage. The loss prediction formulas for post-tensioning that is applied before deck placement are summarized below.

**Prestressing**

**Relaxation**

Initial

$$\Delta f_{pR0} = \frac{\log(24t_i)}{40}\left(\frac{f_{pj}}{f_{py}} - 0.55\right) f_{pj}$$

Before Post-Tensioning

$$\Delta f_{pR1_{ipt}} = \frac{t_{pt} - t_i}{t_d - t_i}\Delta f_{pR1}$$

$$\Delta f_{pR1} = \frac{f_{pt}}{K_L}\left(\frac{f_{pt}}{f_{py}} - 0.55\right)$$

$$f_{pt} = f_{pj} - \Delta f_{pR0} - \Delta f_{pES1}$$

Post-Tensioning to Deck Placement

$$\Delta f_{pR1_{ptd}} = \left(\frac{t_d - t_{pt}}{t_d - t_i}\right)\Delta f_{pR1}$$

After Deck Placement

$$\Delta f_{pR1_{ptd}} = \left(\frac{t_d - t_{pt}}{t_d - t_i}\right)\frac{f_{pt}}{K_L}\left(\frac{f_{pt}}{f_{py}} - 0.55\right)$$

$$f_{pt} = f_{pj} - \Delta f_{pF} - \Delta f_{pA} - \Delta f_{pES3}$$

**Elastic Shortening/Gain**

Initial

$$\Delta f_{pES1} = \frac{E_p}{E_{ci}} f_{cgps}$$

$$f_{cgps} = \frac{F_{ps}}{A_g} + \frac{F_{ps}e_{ps}^2}{I_g} - \frac{M_g e_{ps}}{I_g}$$

Due to Post-Tensioning

$$\Delta f_{pES2} = \frac{E_p}{E_c} f_{cgps2}\ \Delta f_{pES2}$$

$$f_{cgps2} = \frac{F_{pt}}{A_g} + \frac{F_{pt}e_{pt}e_{ps}}{I_g} - \frac{M_{assembly}e_{ps}}{I_g}$$

Due to Deck Placement

$$\Delta f_{pED1} = \frac{E_p}{E_c}\Delta f_{cd1}$$

$$\Delta f_{cd1} = -\frac{(M_{slab} + M_{diaphragm} + M_{other1})e_{ps}}{I_g}$$

Due to Superimposed Dead Loads $$\Delta f_{pED2} = \frac{E_p}{E_c}\Delta f_{cd2}$$

$$\Delta f_{cd2} = -\frac{\left(M_{barrier} + M_{overlay} + M_{other2}\right)e_{cps}}{I_c}$$

**Shrinkage**

Shrinkage of Girder before Post-Tensioning $$\Delta f_{pSR_{ipt}} = \varepsilon_{bipt} E_p K_{id}$$

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}}\frac{A_{ps}}{A_g}\left(1 + \frac{A_g e_{ps}^2}{I_g}\right)\left[1 + 0.7\psi_b\left(t_f, t_i\right)\right]}$$

Shrinkage of Girder between Post-Tensioning and Deck Placement $$\Delta f_{pSR_{ptd}} = \varepsilon_{bptd} E_p K_{id}$$

$$\varepsilon_{bptd} = \varepsilon_{bid} - \varepsilon_{bipt} = k_{vs}k_{hs}k_f\left[k_{td}\left(t_d\right) - k_{td}\left(t_{pt}\right)\right]0.48\times 10^{-3}$$

Shrinkage of Girder after Deck Placement $$\Delta f_{pSD} = \varepsilon_{bdf} E_p K_{df}$$

$$K_{df} = \frac{1}{1 + \frac{E_p}{E_{ci}}\frac{A_{ps}}{A_c}\left(1 + \frac{A_c e_{cps}^2}{I_c}\right)\left[1 + 0.7\psi_b\left(t_f, t_i\right)\right]}$$

Shrinkage of Deck $$\Delta f_{pSS} = \frac{E_p}{E_c}\Delta f_{cdf} K_{df}\left[1 + 0.7\psi_b\left(t_f, t_d\right)\right]$$

$$\Delta f_{cdf} = \frac{\varepsilon_{ddf} A_d E_{cd}}{\left[1 + 0.7\psi_b\left(t_f, t_d\right)\right]}\left(\frac{1}{A_c} + \frac{e_{cps} e_d}{I_c}\right)$$

$$\varepsilon_{ddf} = \varepsilon\left(t_f - t_d\right)$$

**Creep**

Creep of Girder before Post-Tensioning $$\Delta f_{pCR_{ipt}} = \frac{E_p}{E_{ci}} f_{cgps}\psi_b\left(t_{pt}, t_i\right)K_{id}$$

Creep of Girder between Post-Tensioning and Deck Placement

$$\Delta f_{pCR_{ptd}} = \frac{E_p}{E_{ci}} f_{cgps}\left[\psi_b\left(t_d, t_i\right) - \psi_b\left(t_{pt}, t_i\right)\right]K_{id}$$

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}}\frac{A_{ps}}{A_g}\left(1 + \frac{A_g e_{ps}^2}{I_g}\right)\left[1 + \chi\psi_b\left(t_d, t_i\right)\right]}$$

Creep of Girder after Deck Placement

$$\Delta f_{pCD} = \frac{E_p}{E_{ci}} f_{cgps}\left[\psi_b\left(t_f, t_i\right) - \psi_b\left(t_d, t_i\right)\right]K_{df} + \frac{E_p}{E_c}\Delta f_{cd}\psi_b\left(t_f, t_d\right)K_{df} \geq 0.0$$

$$\Delta f_{cd} = \Delta f_{cd1} + \Delta f_{cd2}$$

Creep of Girder Concrete caused by Post-Tensioning

$$\Delta f_{pCD2} = \frac{E_p}{E_c} f_{cgps2} \psi_b(t_f, t_{pt}) - \frac{E_p}{E_c} \frac{A_{pt}}{A_g} \left(1 + \frac{A_g e_{pt} e_{ps}}{I_g}\right) [1 + \chi \psi_b(t_f, t_{pt})] \Delta f_{pCD3} \geq 0$$

**Total Prestress Loss**

Total Loss $$\Delta f_{pT} = \Delta f_{pI} + \Delta f_{pLT}$$

Long Term Losses $$\Delta f_{pLT} = \Delta f_{pPT} + \Delta f_{pDeck} + \Delta f_{pFinal}$$

Initial Losses $$\Delta f_{pI} = \Delta f_{pR0} + \Delta f_{pES1}$$

Losses from Initial to PT $$\Delta f_{pPT} = \Delta f_{pES2} + \Delta f_{pCRipt} + \Delta f_{pSRipt} + \Delta f_{pR1ipt} + \Delta f_{pCD2}$$

Losses from PT to Deck Placement $$\Delta f_{pDeck} = \Delta f_{pED1} + \Delta f_{pCRptd} + \Delta f_{pSRptd} + \Delta f_{pR1ptd}$$

Losses from Deck Placement to Final $$\Delta f_{pFinal} = \Delta f_{pED2} + \Delta f_{pCD} + \Delta f_{pSD} + \Delta f_{pSS} + \Delta f_{pR2}$$

**Post-Tension**

**Friction**

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

**Anchor Set**

Anchor Set $$\Delta f_{pA} = \frac{2x \Delta f_{pF}}{L}$$

$$x = \sqrt{\frac{\Delta_{set} E_p L}{\Delta f_{pF}}}$$

**Elastic Shortening/Gain**

Initial $$\Delta f_{pES3} = \frac{N-1}{2N} \frac{E_p}{E_c} f_{cgpt}$$

$$f_{cgpt} = \frac{F_{pt}}{A_g} + \frac{F_{pt} e_{pt}^2}{I_g} - \frac{M_{assembly} e_{pt}}{I_g}$$

Due to Deck Placement $$\Delta f_{pED3} = \frac{E_p}{E_c} \Delta f_{cd3}$$

$$\Delta f_{cd3} = -\frac{(M_{slab} + M_{diaphragm} + M_{other1}) e_{pt}}{I_g}$$

Due to Superimposed Dead Loads $$\Delta f_{pED4} = \frac{E_p}{E_c} \Delta f_{cd4}$$

$$\Delta f_{cd4} = -\frac{(M_{barrier} + M_{overlay} + M_{other2}) e_{cpt}}{I_c}$$

**Shrinkage**

Shrinkage of Girder between Post-Tensioning and Deck Placement $\Delta f_{pSR} = \varepsilon_{bptd} E_p K_{id}$

$$\varepsilon_{bptd} = \varepsilon_{bid} - \varepsilon_{bipt} = k_{vs} k_{hs} k_f \left[k_{td}(t_d) - k_{td}(t_{pt})\right] 0.48 \times 10^{-3}$$

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}} \frac{A_{pt}}{A_g}\left(1 + \frac{A_g e_{pt}^2}{I_g}\right)\left[1 + 0.7\psi_b(t_f, t_i)\right]}$$

Shrinkage of Girder after Deck Placement $\Delta f_{pSD} = \varepsilon_{bdf} E_p K_{df}$

$$K_{df} = \frac{1}{1 + \frac{E_p}{E_{ci}} \frac{A_{pt}}{A_g}\left(1 + \frac{A_g e_{pt}^2}{I_g}\right)\left[1 + 0.7\psi_b(t_f, t_i)\right]}$$

Shrinkage of Deck $\Delta f_{pSS} = \frac{E_p}{E_c} \Delta f_{cdf} K_{df}\left[1 + \psi_b(t_f, t_d)\right]$

$$\Delta f_{cdf} = \frac{\varepsilon_{ddf} A_d E_{cd}}{\left[1 + \psi_b(t_f, t_d)\right]}\left(\frac{1}{A_c} + \frac{e_{cpt} e_d}{I_c}\right)$$

$$\varepsilon_{ddf} = \varepsilon(t_f - t_d)$$

**Creep**

Creep of Girder between Post-Tensioning and Deck Placement $\Delta f_{pCR_{ptd}} = \frac{E_p}{E_c} f_{cgpt} \psi_b(t_d, t_{pt}) K_{ipt}$

$$K_{ipt} = \frac{1}{1 + \frac{E_p}{E_{ci}} \frac{A_{pt}}{A_g}\left(1 + \frac{A_g e_{pt}^2}{I_g}\right)\left[1 + \chi\psi_b(t_d, t_i)\right]}$$

Creep of Girder after Deck Placement

$$\Delta f_{pCD} = \frac{E_p}{E_{ci}} f_{cgpt}\left[\psi_b(t_f, t_i) - \psi_b(t_d, t_i)\right] K_{df} + \frac{E_p}{E_c} \Delta f_{cd} \psi_b(t_f, t_d) K_{df} \geq 0.0$$

$$\Delta f_{cd} = \Delta f_{cd3} + \Delta f_{cd4}$$

Creep of Girder Concrete caused by Prestressing

$$\Delta f_{pCD3} = \frac{E_p}{E_{ci}} f_{cgpt2}\left[\psi_b(t_f, t_i) - \psi_b(t_{pt}, t_i)\right] - \frac{E_p}{E_{ci}} \frac{A_{ps}}{A_g}\left(1 + \frac{A_g e_{ps} e_{pt}}{I_g}\right)\left[1 + \chi\psi_b(t_f, t_i)\right] \Delta f_{pCD2} \geq 0$$

**Relaxation**

Before Deck Placement $\Delta f_{pR1_{ptd}} = \left(\frac{t_d - t_{pt}}{t_d - t_i}\right) \frac{f_{pt}}{K_L}\left(\frac{f_{pt}}{f_{py}} - 0.55\right)$

$$f_{pt} = f_{pj} - \Delta f_{pF} - \Delta f_{pA} - \Delta f_{pES3}$$

After Deck Placement $\Delta f_{pR2} = \Delta f_{pR1}$

**Total Post-Tension Loss**

Total Loss $\Delta f_{pT} = \Delta f_{pI} + \Delta f_{pLT}$

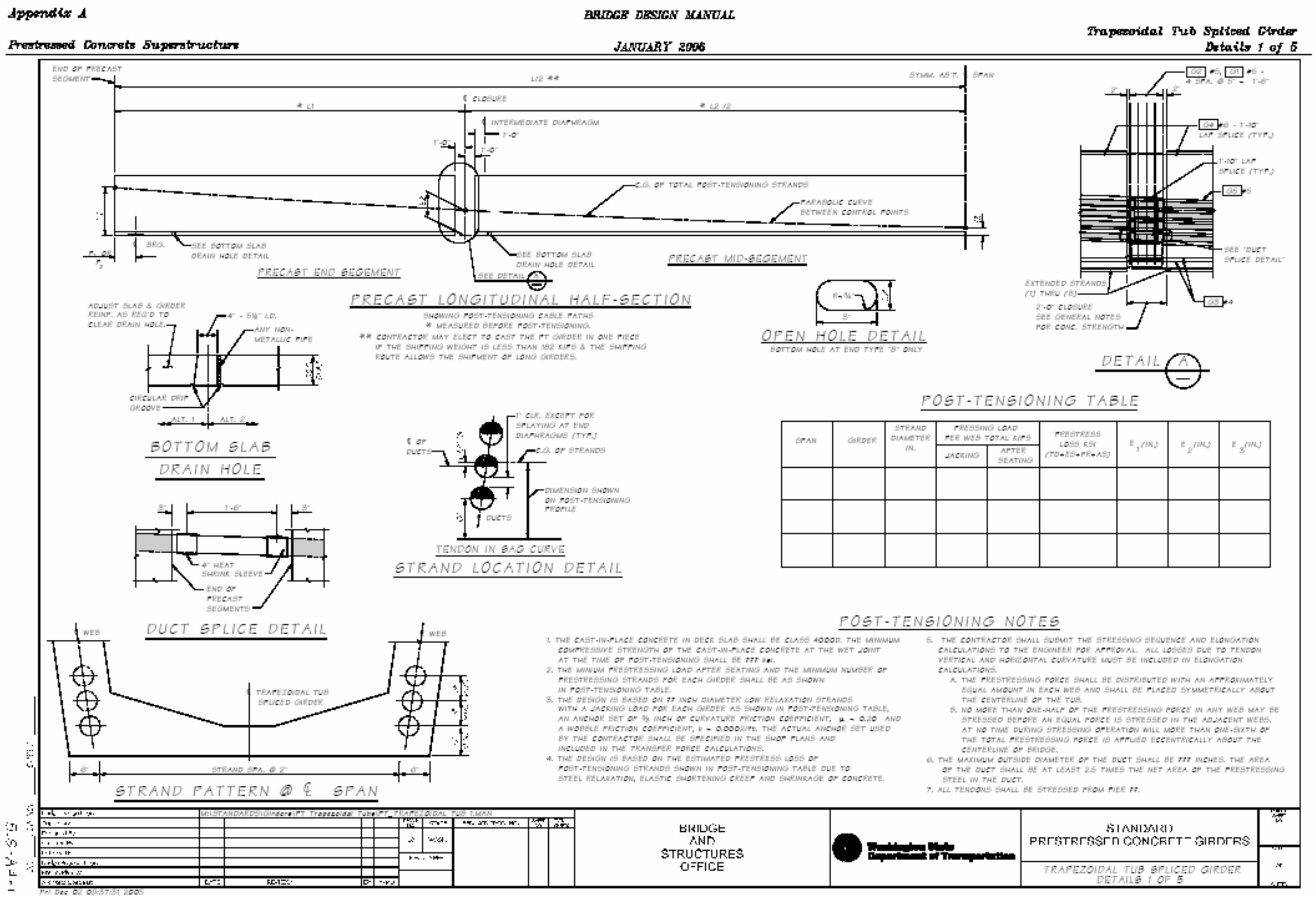
Initial Loss $\Delta f_{pI} = \Delta f_{pF} + \Delta f_{pA} + \Delta f_{pES3}$

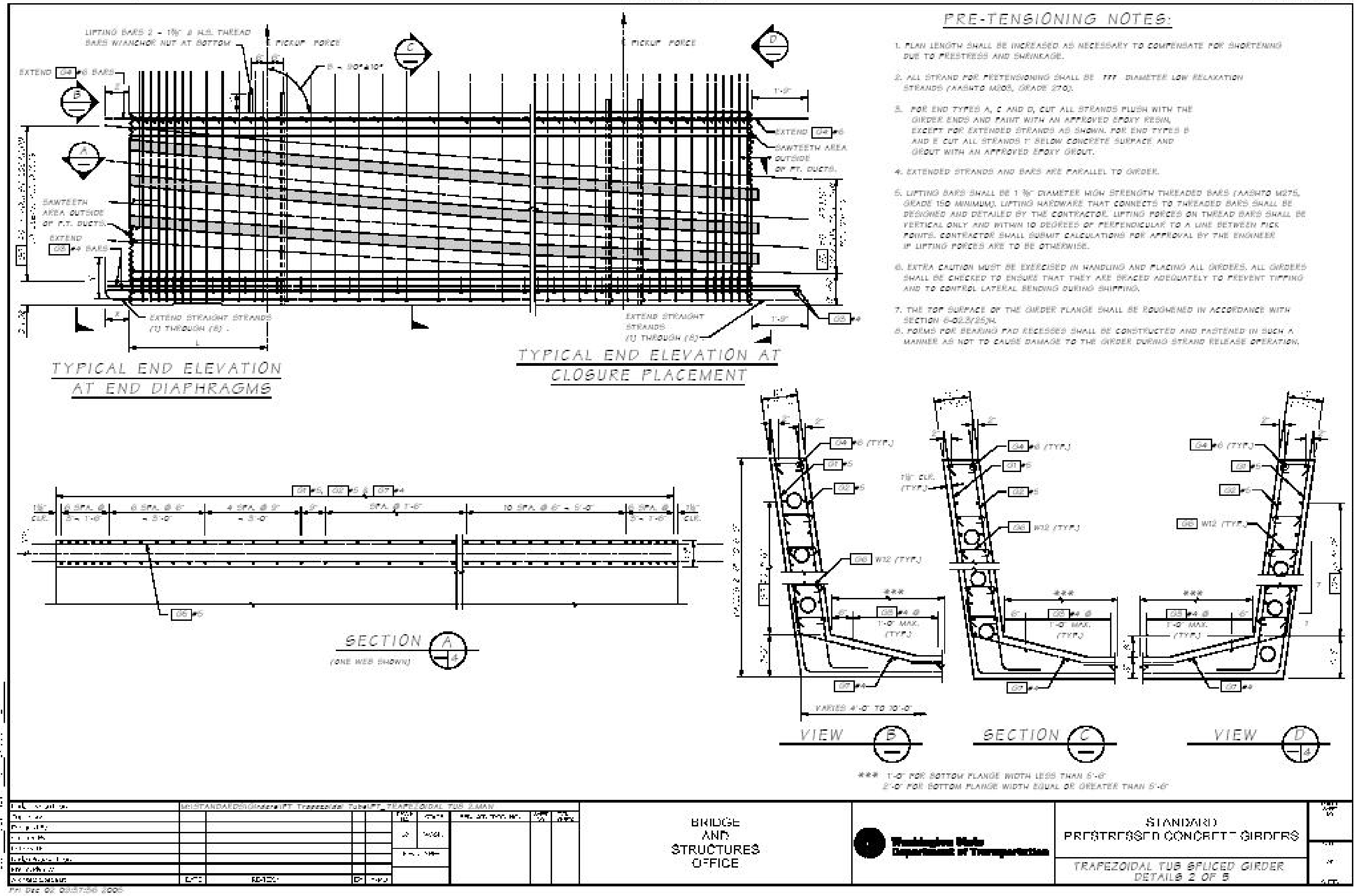
Long Term Loss $\Delta f_{pLT} = \Delta f_{pDeck} + \Delta f_{pFinal}$

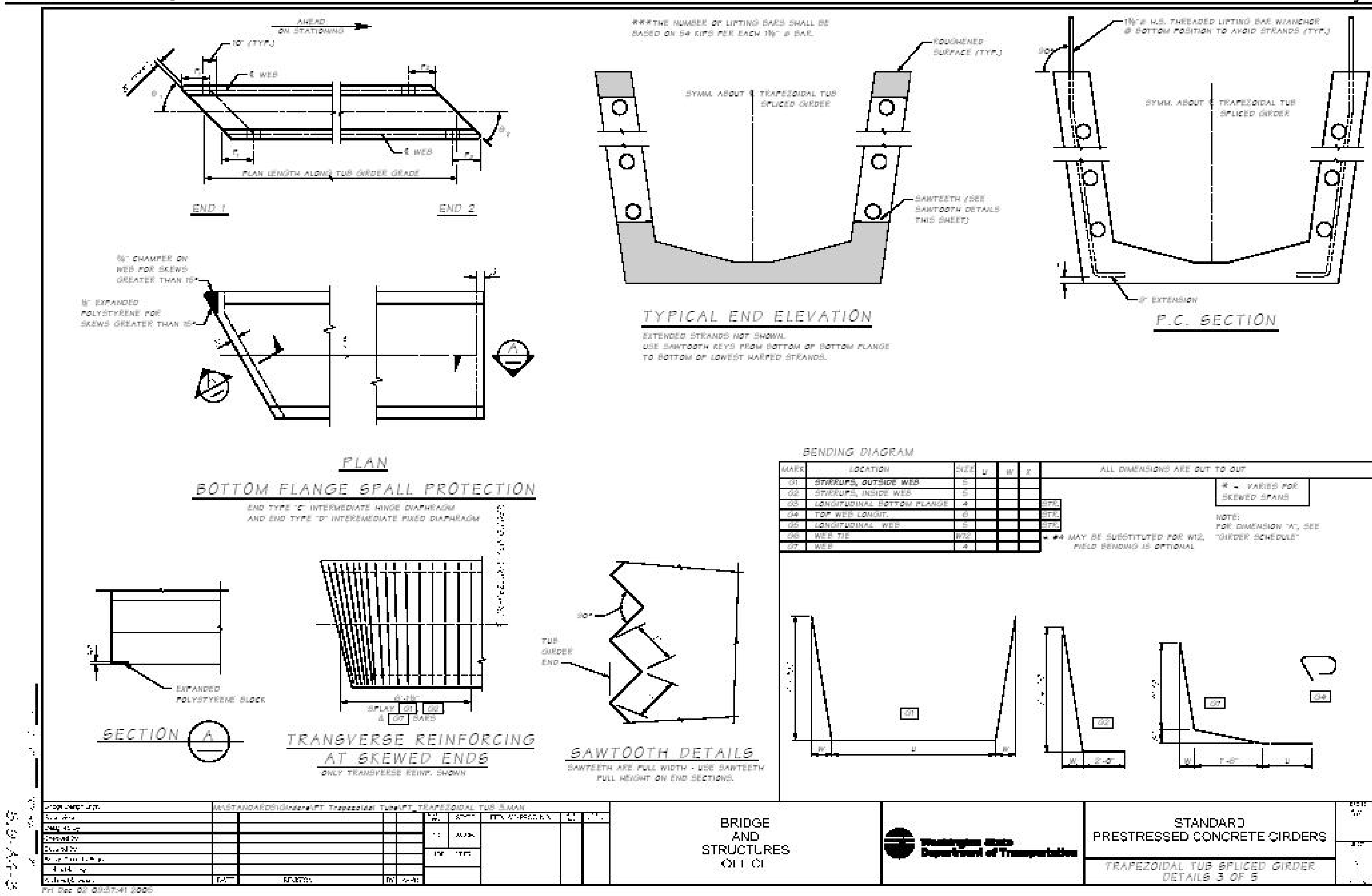
PT to Deck Placement $\Delta f_{pDeck} = \Delta f_{pED3} + \Delta f_{pSRptd} + \Delta f_{pCRptd} + \Delta f_{pR1ptd}$

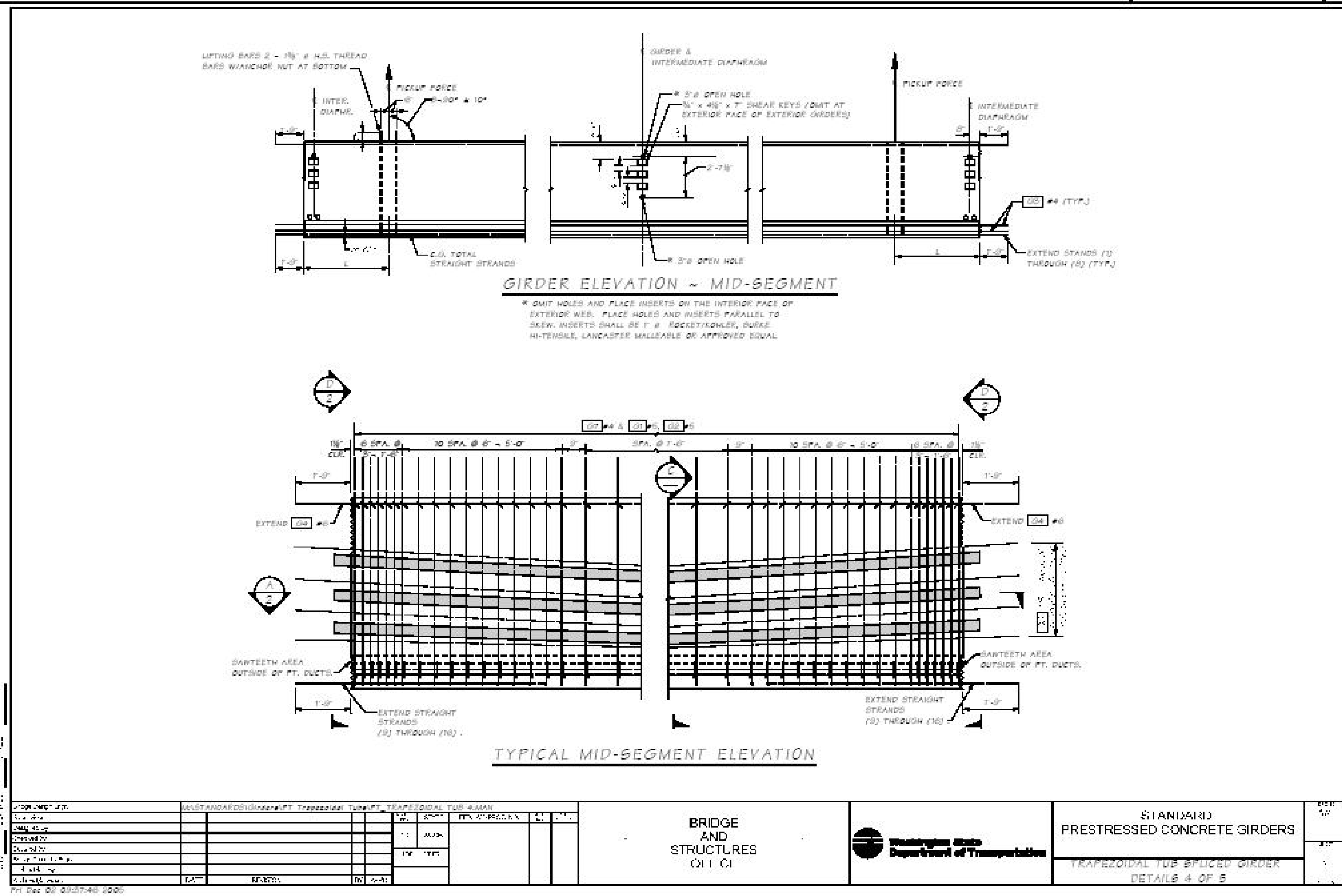
Deck Placement to Final $\Delta f_{pFinal} = \Delta f_{pED4} + \Delta f_{pSD} + \Delta f_{pSS} + \Delta f_{pCD} + \Delta f_{pCD3} + \Delta f_{pR2}$

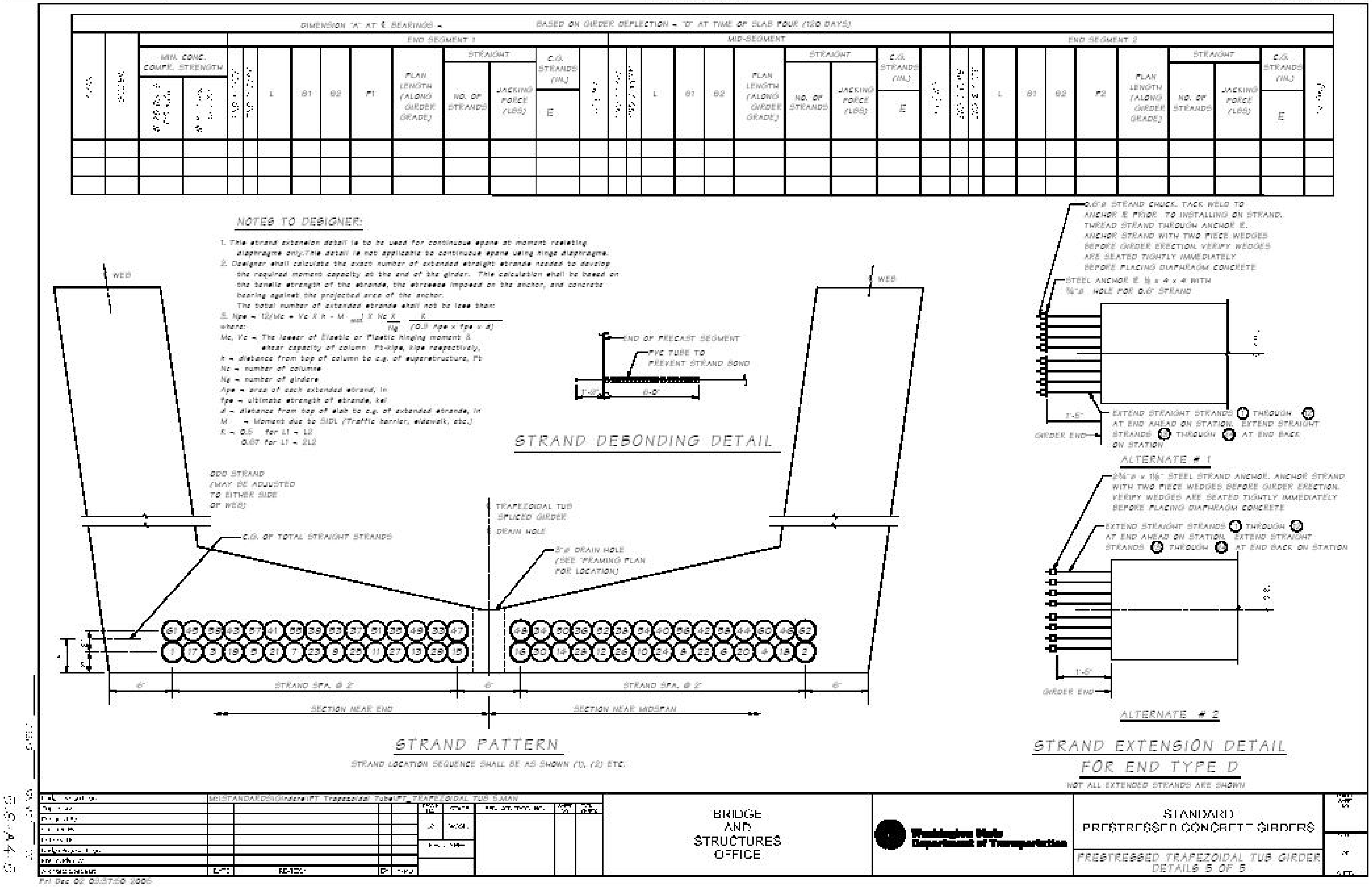
## Appendix C – WSDOT Standard Spliced Girder Details

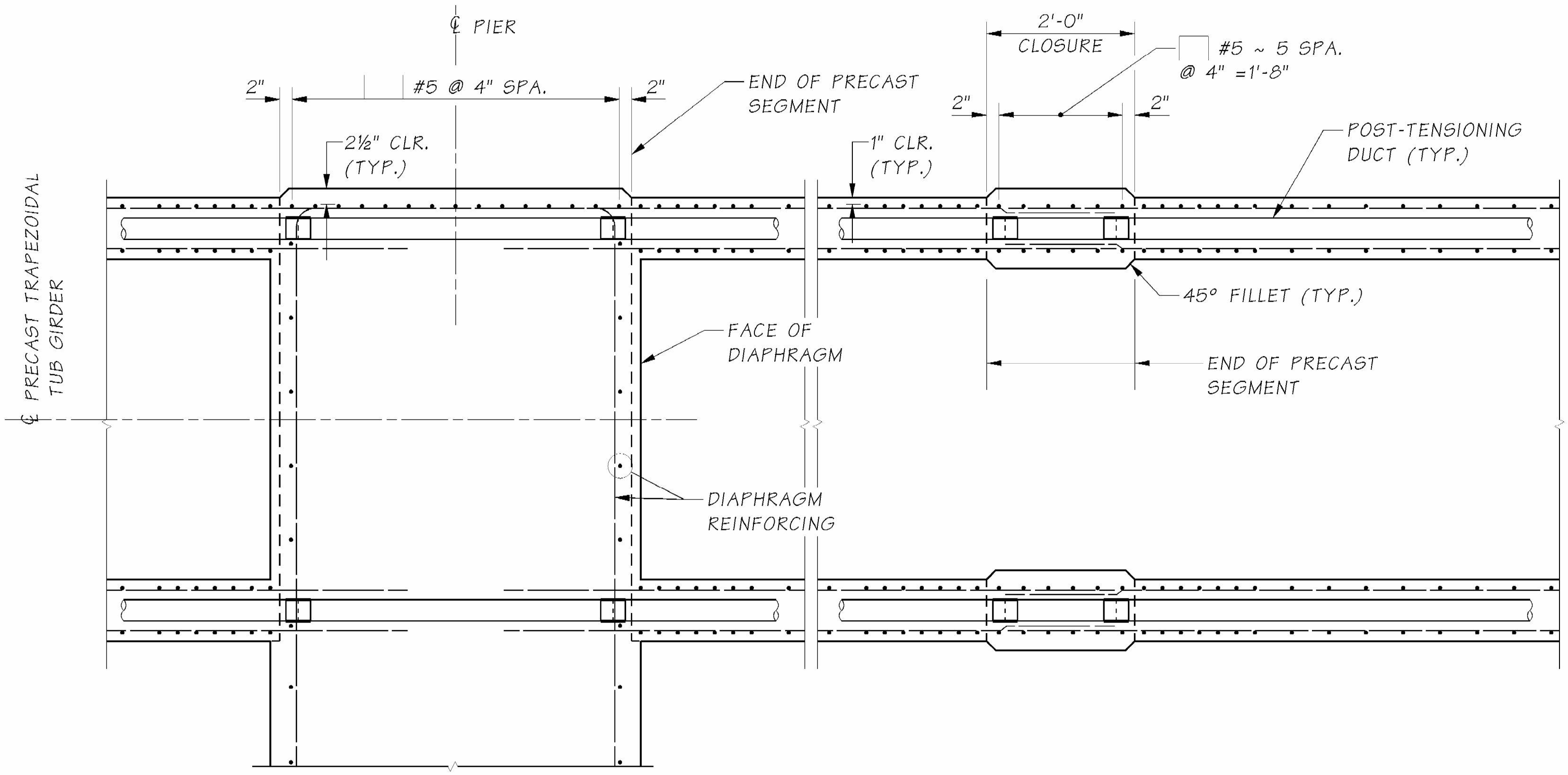



PRE-TENSIONING NOTES:
1. PLAN LENGTH SHALL BE INCREASED AS NECESSARY TO COMPENSATE FOR SHORTENING DUE TO PRESTRESS AND SHRINKAGE.
2. ALL STRAND FOR PRETENSIONING SHALL BE ??? DIAMETER LOW RELAXATION STRANDS (AASHTO M203, GRADE 270).
3. FOR END TYPES A, C AND D, CUT ALL STRANDS FLUSH WITH THE GIRDER ENDS AND PAINT WITH AN APPROVED EPOXY RESIN, EXCEPT FOR EXTENDED STRANDS AS SHOWN. FOR END TYPES B AND E CUT ALL STRANDS 1" BELOW CONCRETE SURFACE AND GROUT WITH AN APPROVED EPOXY GROUT.
4. EXTENDED STRANDS AND BARS ARE PARALLEL TO GIRDER.
5. LIFTING BARS SHALL BE 1 3/8" DIAMETER HIGH STRENGTH THREADED BARS (AASHTO M275, GRADE 150 MINIMUM). LIFTING HARDWARE THAT CONNECTS TO THREADED BARS SHALL BE DESIGNED AND DETAILED BY THE CONTRACTOR. LIFTING FORCES ON THREAD BARS SHALL BE VERTICAL ONLY AND WITHIN 10 DEGREES OF PERPENDICULAR TO A LINE BETWEEN PICK POINTS. CONTRACTOR SHALL SUBMIT CALCULATIONS FOR APPROVAL BY THE ENGINEER IF LIFTING FORCES ARE TO BE OTHERWISE.
6. EXTRA CAUTION MUST BE EXERCISED IN HANDLING AND PLACING ALL GIRDERS. ALL GIRDERS SHALL BE CHECKED TO ENSURE THAT THEY ARE BRACED ADEQUATELY TO PREVENT TIPPING AND TO CONTROL LATERAL BENDING DURING SHIPPING.
7. THE TOP SURFACE OF THE GIRDER FLANGE SHALL BE ROUGHENED IN ACCORDANCE WITH SECTION 6-02.3(25)H.
8. FORMS FOR BEARING PAD RECESSES SHALL BE CONSTRUCTED AND FASTENED IN SUCH A MANNER AS NOT TO CAUSE DAMAGE TO THE GIRDER DURING STRAND RELEASE OPERATION.
TYPICAL END ELEVATION AT END DIAPHRAGMS
TYPICAL END ELEVATION AT CLOSURE PLACEMENT
SECTION A
VIEW B
SECTION C
VIEW D
*** 1'-0" FOR BOTTOM FLANGE WIDTH LESS THAN 5'-6"
2'-0" FOR BOTTOM FLANGE WIDTH EQUAL OR GREATER THAN 5'-6"
BRIDGE AND STRUCTURES OFFICE
Washington State Department of Transportation
STANDARD PRESTRESSED CONCRETE GIRDERS
TRAPEZOIDAL TUB SPLICED GIRDER DETAILS 2 OF 5


END 1
END 2
PLAN
BOTTOM FLANGE SPALL PROTECTION
TYPICAL END ELEVATION
P.C. SECTION
BENDING DIAGRAM
SECTION A
TRANSVERSE REINFORCING AT SKEWED ENDS
SAWTOOTH DETAILS
BRIDGE AND STRUCTURES
STANDARD PRESTRESSED CONCRETE GIRDERS
TRAPEZOIDAL TUB SPLICED GIRDER DETAILS 3 OF 5


GIRDER ELEVATION ~ MID-SEGMENT
TYPICAL MID-SEGMENT ELEVATION
BRIDGE AND STRUCTURES
Washington State Department of Transportation
STANDARD PRESTRESSED CONCRETE GIRDERS
TRAPEZOIDAL TUB SPLICED GIRDER DETAILS 4 OF 5


END SEGMENT 1
MID-SEGMENT
END SEGMENT 2
NOTES TO DESIGNER:
STRAND DEBONDING DETAIL
SECTION NEAR END
SECTION NEAR MIDSPAN
STRAND PATTERN
ALTERNATE # 1
ALTERNATE # 2
STRAND EXTENSION DETAIL
FOR END TYPE D
BRIDGE
AND
STRUCTURES
OFFICE
STANDARD
PRESTRESSED CONCRETE GIRDERS
PRESTRESSED TRAPEZOIDAL TUB GIRDER
DETAILS 5 OF 5




Thickened closure pour

## Appendix D – Typical Span Capability Chart



| Girder Type | Girder Spacing (ft) | Span Length (ft) | End Segments | Middle Segment | Spliced Post-Tensioned Girder | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | No. of Straight Strands | No. of Straight Strands | PT Ducts ~ Strands/Duct (Duct #4 @ Bottom) | | | | Jacking Force* (kips) | Tendon Force after Seating* (kips) | Tendon Loss* (kips) | E1 (in) | E3 (in) |
| | | | | | 1 | 2 | 3 | 4 | | | | | |
| U54PTG4 | 8 | 135 | 4 | 6 | - | - | 11 | 22 | 2904 | 2636 | 570 | 20.0 | 8.9 |
| | 14 | 150 | 4 | 14 | - | 2 | 22 | 22 | 4048 | 3708 | 760 | 31.5 | 10.1 |
| U54PTG5 | 9 | 135 | 4 | 8 | - | - | 12 | 22 | 2992 | 2764 | 578 | 19.7 | 9.0 |
| | 15 | 150 | 4 | 14 | - | 6 | 22 | 22 | 4400 | 4032 | 826 | 29.8 | 10.9 |
| U54PTG6 | 10 | 135 | 4 | 6 | - | - | 18 | 22 | 3520 | 3200 | 684 | 18.3 | 9.5 |
| | 16 | 145 | 4 | 14 | - | 8 | 22 | 22 | 4576 | 4196 | 852 | 29.0 | 11.2 |
| U66PTG4 | 8 | 155 | 4 | 8 | - | - | 15 | 22 | 3256 | 2944 | 648 | 18.9 | 9.3 |
| | 14 | 170 | 4 | 16 | - | 7 | 22 | 22 | 4488 | 4088 | 864 | 29.4 | 11.0 |
| U66PTG5 | 9 | 155 | 4 | 8 | - | - | 17 | 22 | 3432 | 3110 | 678 | 18.5 | 9.4 |
| | 15 | 170 | 4 | 16 | - | 10 | 22 | 22 | 4752 | 4334 | 910 | 29.3 | 11.3 |
| U66PTG6 | 10 | 155 | 4 | 8 | - | - | 21 | 22 | 3784 | 3434 | 742 | 17.7 | 9.7 |
| | 16 | 165 | 4 | 14 | - | 12 | 22 | 22 | 4928 | 4500 | 940 | 27.7 | 11.7 |
| U78PTG4 | 8 | 175 | 4 | 10 | - | - | 19 | 22 | 3608 | 3262 | 722 | 18.1 | 9.6 |
| | 16 | 190 | 4 | 20 | - | 15 | 22 | 22 | 5192 | 4718 | 1014 | 26.8 | 12.1 |
| U78PTG5 | 9 | 180 | 4 | 10 | - | 2 | 22 | 22 | 4048 | 3692 | 776 | 31.5 | 10.1 |
| | 17 | 195 | 4 | 22 | - | 21 | 22 | 22 | 5720 | 5202 | 1110 | 25.2 | 12.6 |
| U78PTG6 | 10 | 180 | 4 | 10 | - | 6 | 22 | 22 | 4400 | 4018 | 840 | 29.8 | 10.9 |
| | 18 | 190# | 4 | 20 | 2 | 22 | 22 | 22 | 5896 | 5400 | 1104 | 395.0 | 12.9 |

**Span Capability of Post-Tensioned Trapezoidal Tub Girders Without Top Flange**

*Table 5.6-A8.2*