16.6 POST-TENSIONING EXISTING STEEL GIRDERS – STRESS CALCULATIONS

16.6.1 GENERAL

This BDM provides stress calculation procedures for post-tensioned existing steel girder sections. Design criteria and stress limits for strengthening existing steel girders for live loads by post-tensioning are specified in STP 16.6 (Caltrans, 2021). This BDM complies with the stress limits for strengthened steel girders as specified in STP 16.6 and AASHTO-CA BDS-8 (AASHTO, 2017; Caltrans, 2019).

If the existing steel girder satisfies serviceability requirements at the Service II limit state as specified in Article 6.10.4.2 (AASHTO, 2017), the stress limit checks after losses for the strengthened steel flange and the concrete deck are not required since the post-tensioning improves the serviceability of the existing girder. However, the stress limit checks for prestressing steel are always required.

Per STP 16.6 and BDM 16.4 (Caltrans, 2022), acquiring actual material properties through the physical test of existing concrete, structural steel, and reinforcement is preferred. However, in the absence of physical test results, specified minimum materials properties of existing concrete, structural steel, and reinforcement found from as-built plans or “Report of Completion – Bridges”, may be used.

In stress calculations, a consistent sign convention should be used. Each term in the stress equations should be positive when in tension and negative when in compression.

16.6.2 BASIC ASSUMPTIONS

The following assumptions should be used in the stress calculations for post-tensioned existing steel girder sections:

- The as-built construction method and the sequential loading history are known. In the absence of the as-built construction information, unshored construction is assumed.
- For composite sections in negative flexure, both short-term and long-term section properties may include longitudinal reinforcement within the effective width of the concrete deck if shear connectors meet the requirements specified in Article 6.10.10 (AASHTO, 2017).
- Section properties of the strengthened steel girder should include prestressing steel.
- The permanent loads before post-tensioning are applied to the existing long-term section.

- The Permanent load due to the self weight of the prestressing steel may be ignored.
- The initial prestressing force is applied to the existing short-term composite section.
- Permanent loads after the post-tensioning and the effective prestressing force are applied to the strengthened long-term composite section.
- Transient loads are applied to the strengthened short-term composite section.

16.6.3 STRESS LIMITS

Stress limits, F_{SL}, for a post-tensioned existing steel girder section as specified in STP 16.6 and AASHTO-CA BDS-8 (AASHTO, 2017; Caltrans, 2019) are listed in Table 16.6.3-1.

Table 16.6.3-1 Stress Limits for Post-tensioned Steel Girder Sections

Location	Stress Type	Service II Load Case	F_{SL}
Prestressing steel	Tension	Before prestress losses due to the sum of initial prestress and permanent loads	$0.75f_{pu}$ (CA Table 5.9.2.2)
	Tension	After losses due to the sum of effective prestress, permanent loads, and transient loads	$0.8f_{py}$ (CA Table 5.9.2.2)
Steel flange (composite section)	Compression	Before prestress losses due to the sum of initial prestress and permanent loads*	$0.95R_hF_{yfa}$ (Article 6.10.4.2.1)
	Tension	After losses due to the sum of effective prestress, permanent loads, and transient loads	$0.95R_hF_{yfa}$ (Article 6.10.4.2.1)
Steel flange (noncomposite section)	Compression	Before prestress losses due to the sum of initial prestress and permanent loads*	$0.80F_{yfa}$ (Article 6.10.4.2.1)
	Tension	After losses due to the sum of effective prestress, permanent loads, and transient loads	$0.80F_{yfa}$ (Article 6.10.4.2.1)
Concrete deck (composite section)	Tension	Before prestress losses due to the sum of initial prestress and permanent loads	$2\,f_{ra}$ (Article 6.10.4.2.1)
	Compression (for shored construction)	After losses due to the sum of effective prestress, permanent loads, and transient loads	$0.6\,f'_{ca}$ (Article 6.10.4.2.1)

*Note: Except for composite sections in positive flexure in which the web satisfies the requirement of Article 6.10.2.1.1, the stress limit for compression flange without consideration of flange lateral bending shall also be taken as F_{crw} (Article 6.10.4.2.1).

F_{crw} = nominal web bend-buckling resistance determined as specified in Article 6.10.1.9 (ksi)

F_{yfa} = actual yield strength of steel flange (ksi)

f'_{ca} = actual concrete compressive strength (ksi)

f_{ra} = actual modulus of rupture of concrete (ksi)

$$f_{ra} = \begin{cases} 0.24\sqrt{f'_{ca}} & \text{for normal weight concrete (ksi)} \quad \text{(Article 6.10.1.7)} \\ 0.24\lambda\sqrt{f'_{ca}} & \text{for light weight concrete (ksi)} \quad \text{(Article 5.4.2.6)} \end{cases}$$

λ = concrete density modification factor

$$\lambda = \begin{cases} 4.7\dfrac{f_{cta}}{\sqrt{f'_{ca}}} & \text{where } f_{cta} \text{ is specified} \quad \text{(AASHTO 5.4.2.8-1)} \\ 0.75 \le \lambda = 7.5w_c \le 1.0 & \text{where } f_{cta} \text{ is not specified} \quad \text{(AASHTO 5.4.2.8-2)} \end{cases}$$

f_{cta} = actual splitting tensile strength of concrete (ksi)

f_{pu} = specified tensile strength of prestressing steel (ksi)

f_{py} = specified yield strength of prestressing steel (ksi)

R_h = hybrid factor

w_c = unit weight of concrete (kcf)

16.6.4 STRESSES BEFORE LOSSES

The stresses in a post-tensioned existing steel girder section at the Service II limit state load case (1) before prestress losses due to the sum of the initial prestress, and permanent loads may be determined, as shown in this section.

16.6.4.1 Composite Sections – Unshored Construction

The stress in the steel flanges:

$$f_{sf} = \frac{M_{SD1}}{S_{NC}} + \frac{M_{SD2}}{S_{LT}} + \frac{P_j}{A_{ST}} + \frac{P_j e_{ST}}{S_{ST}} \quad (16.6.4\text{-}1)$$

where:

A_{ST} = short-term composite section area of the existing girder (in.^{2})

e_{ST} = eccentricity of prestressing force, distance from the centroid of prestressing steel to the neutral axis of the short-term composite elastic section of the existing girder (in.)

f_{sf} = stress in post-tensioned steel girder flange at the Service II limit state (ksi)

M_{SD1} = moment due to the factored permanent load at the Service II limit state applied to the steel section of the existing girder before the concrete deck has hardened or is made composite (kip-in.)

M_{SD2} = moment due to the factored permanent load at the Service II limit state applied to the long-term composite section of the existing steel girder after the concrete deck has hardened or is made composite (kip-in.)

P_j = prestressing jacking force before losses (kip)

S_{NC} = noncomposite elastic section modulus of the existing girder (in.^{3})

S_{LT} = long-term composite elastic section modulus of the existing girder (in.^{3})

S_{ST} = short-term composite elastic section modulus of the existing girder (in.^{3})

The stress in the concrete deck:

$$f_{sd} = \frac{M_{SD2}}{3nS_{LTd}} + \frac{P_j}{nA_{ST}} + \frac{P_j e_{ST}}{nS_{STd}} \quad (16.6.4\text{-}2)$$

where:

n = modular ratio

f_{sd} = stress in the extreme fiber of the concrete deck at the Service II limit state (ksi)

S_{STd} = short-term composite elastic section modulus for the concrete deck of the existing girder (in.^{3})

S_{LTd} = long-term composite elastic section modulus for the concrete deck of the existing girder (in.)

16.6.4.2 Composite Sections – Shored Construction

The stress in the steel flanges:

$$f_{sf} = \frac{M_{SD}}{S_{LT}} + \frac{P_j}{A_{ST}} + \frac{P_j e_{ST}}{S_{ST}} \quad (16.6.4\text{-}3)$$

where:

M_{SD} = moment due to the factored permanent loads at the Service II limit state applied to the existing girder before post-tensioning (kip-in.)

The stress in the concrete deck:

$$f_{sd} = \frac{M_{SD}}{3nS_{LTd}} + \frac{P_j}{nA_{ST}} + \frac{P_j e_{ST}}{nS_{STd}} \quad (16.6.4\text{-}4)$$

16.6.4.3 Noncomposite Sections

The stress in the steel flanges:

$$f_{sf} = \frac{M_{SD}}{S_{NC}} + \frac{P_j}{A_{NC}} + \frac{P_j e_{NC}}{S_{NC}} \quad (16.6.4\text{-}5)$$

where:

A_{NC} = noncomposite section area of the existing girders (in.^{2})

e_{NC} = eccentricity of prestressing force, distance from the centroid of prestressing steel to the neutral axis of the noncomposite existing girder section (in.)

16.6.4.4 Stress in Prestressing Steel

The stress in the prestressing steel:

$$f_{spj} = \frac{P_j}{A_{ps}} \quad (16.6.4\text{-}6)$$

where:

f_{spj} = stress in the prestressing steel before losses at prestressing jacking stage (ksi)

A_{ps} = area of prestressing steel (in.^{2})

16.6.5 STRESSES AFTER LOSSES

For composite sections, the stresses in a post-tensioned steel girder section at the Service II limit state load case (2) after prestress losses due to the sum of effective prestress force after losses, permanent loads, and transient loads may be determined as follows.

16.6.5.1 Composite Sections – Unshored Construction

The stress in the steel flanges:

$$f_{sf} = \frac{M_{SD1}}{S_{NC}} + \frac{M_{SD2}}{S_{LT}} + \frac{M_{SDp}}{S_{LTs}} + \frac{M_{SL}}{S_{STs}} + \frac{P_e}{A_{LTs}} + \frac{P_e e_{LTs}}{S_{LTs}} \quad (16.6.5\text{-}1)$$

where:

A_{LTs} = long-term composite section area of the strengthened girder (in.^{2})

e_{LTs} = eccentricity of prestressing force, distance from the centroid of prestressing steel to the neutral axis of the long-term composite section of the strengthened girder (in.)

M_{SL} = moment due to the factored transient load at the Service II limit state applied to the short-term composite section of the strengthened girder (kip-in.)

M_{SDp} = moment due to the factored permanent loads at the Service II limit state applied to the long-term composite section of the strengthened girder after post-tensioning (kip-in.)

S_{STs} = short-term composite elastic section modulus of the strengthened girder (in.^{3})

S_{LTs} = long-term composite elastic section modulus of the strengthened girder (in.^{3})

P_e = effective prestress force after losses (kip)

16.6.5.2 Composite Sections – Shored Construction

The stress in the steel flanges:

$$f_{sf} = \frac{M_{SD}}{S_{LT}} + \frac{M_{SDp}}{S_{LTs}} + \frac{M_{SL}}{S_{STs}} + \frac{P_e}{A_{LTs}} + \frac{P_e e_{LTs}}{S_{LTs}} \quad (16.6.5\text{-}2)$$

The stress in the concrete deck:

$$f_{sd} = \frac{M_{SD}}{3nS_{LTd}} + \frac{M_{SDp}}{3nS_{LTsd}} + \frac{M_{SL}}{nS_{STsd}} + \frac{P_e}{3nA_{LTs}} + \frac{P_e e_{LTs}}{3nS_{LTsd}} \quad (16.6.5\text{-}3)$$

where:

S_{LTsd} = long-term composite elastic section modulus for the concrete deck of the strengthen girder (in.^{3})

S_{STsd} = short-term composite elastic section modulus for the concrete deck of the strengthen girder (in.^{3})

16.6.5.3 Noncomposite Sections

The stress in the steel flanges:

$$f_{sf} = \frac{M_{SD}}{S_{NC}} + \frac{M_{SDp}}{S_{NCs}} + \frac{M_{SL}}{S_{NCs}} + \frac{P_e}{A_{NCs}} + \frac{P_e e_{NCs}}{S_{NCs}} \quad (16.6.5\text{-}4)$$

where:

A_{NCs} = noncomposite section area of the strengthened girders (in.^{2})

S_{NCs} = noncomposite section modulus of the strengthened girders (in.^{2})

16.6.5.4 Stress in the Prestressing Steel

The stress in the prestressing steel for composite sections:

$$f_{sps} = f_{pe} + \frac{M_{SDp} e_{LTs}}{n_p I_{LTs}} + \frac{M_{SL} e_{STs}}{n_p I_{STs}} \quad (16.6.5\text{-}5)$$

$$n_p = \frac{E_s}{E_p} \quad (16.6.5\text{-}6)$$

where:

E_p = modulus of elasticity of prestressing steel (ksi)

E_s = modulus of elasticity of steel (ksi)

E_{STs} = eccentricity of prestressing force, distance from the centroid of prestressing steel to the neutral axis of the short-term composite section of the strengthened girder (in.)

n_p = modular ratio for prestressing steel

f_{pe} = effective prestress stress in prestressing steel after losses (ksi)

f_{sps} = stress in the prestressing steel after losses at the Service II limit state (ksi)

I_{STs} = short-term composite section moment of inertia of the strengthened steel girder (in.^{4})

The stress in the prestressing steel for noncomposite sections:

$$f_{sps} = f_{pe} + \frac{M_{SDp} e_{NCs}}{n_p I_{NCs}} + \frac{M_{SL} e_{NCs}}{n_p I_{NCs}} \qquad (16.6.5\text{-}7)$$

where:

e_{NCs} = eccentricity of prestressing force, distance from the centroid of prestressing steel to the neutral axis of the noncomposite section of the strengthened girder (in.)

I_{NCs} = noncomposite section moment of inertia of the strengthened girder (in.^{4})

16.6.6 REFERENCES

1. AASHTO. (2017). *AASHTO LRFD Bridge Design Specifications*, 8th Edition, American Association of State Highway and Transportation Officials, Washington, DC.
2. Caltrans. (2019). *California Amendments to AASHTO LRFD Bridge Design Specifications – 8th Edition*, California Department of Transportation, Sacramento, CA.
3. Caltrans. (2021). *Structure Technical Policy: 16.6, Design Criteria for Strengthening Steel Girders for Live Loads,* California Department of Transportation, Sacramento, CA.
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