

Guide Specifications for Design and Construction of Segmental Concrete Bridges

Second Edition
1999



American Association of
State Highway and
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GUIDE SPECIFICATIONS FOR DESIGN AND CONSTRUCTION OF SEGMENTAL CONCRETE BRIDGES 1999



American Association of State Highway and Transportation Officials
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PREFACE

This Second Edition of the *Guide Specifications for Design and Construction of Segmental Concrete Bridges* was prepared for use in conjunction with the *Standard Specifications for Highway Bridges, Sixteenth Edition, 1996*, and subsequent interim revisions to these specifications. The second edition of the guide specifications was developed by a broad-based committee organized by the American Segmental Bridge Institute. The committee included representatives of State Departments of Transportation, the Federal Highway Administration, academicians, consulting engineers, contractors, and suppliers. The second edition of the guide specifications was subsequently studied and approved by the Highway Subcommittee on Bridges and Structures, as part of the 1998 AASHTO ballot process.



DIVISION I

DESIGN SPECIFICATIONS

SECTION A GENERAL REQUIREMENTS AND MATERIALS

1.0 APPLICATION

1.1 General

These specifications are intended for design of longitudinally and/or transversely post-tensioned bridges utilizing normal weight or sand-lightweight concrete constructed with either precast or cast-in-place box segments of single or multiple cells, or combinations thereof, as well as simple span and continuous segmental beam-type bridges. The specifications include provisions for design of segmental substructures. The specifications pertain to bridges of all sizes and are not restricted to bridge span lengths of 500 feet or less. Unless otherwise stated or superseded by these specifications, the provisions of the Sixteenth Edition of the *AASHTO Standard Specifications for Highway Bridges* are intended to apply to the design of segmental concrete bridges.

1.2 Notations

Notations are in accordance with *AASHTO Standard Specifications for Highway Bridges* and the following:

- A = area of concrete surrounding a bar, sq. in. (See Commentary, Section 18.2.)
- A = static segment weight (Section 7.4.3)
- A = reaction (See Fig. 26-2.)
- A_{cc} = area of concrete in compression chord, sq. in.
- A_{cn} = area of one face of a truss node region, sq. in.
- A_{cp} = area enclosed by outside perimeter of concrete cross section, sq. in.
- A_{cs} = area of inclined compression strut, sq. in.
- A_g = gross area of concrete cross section, sq. in.
- A_k = area of the base of all shear keys in the failure plane, sq. in. (Section 12.2.21)
- A_t = total area of additional longitudinal reinforcement to resist torsion, sq. in. (Section 12.3.8)
- A_o = area enclosed by shear flow path, sq. in. (Section 12.2.10)
- A_s = area of nonprestressed tensile reinforcement, sq. in.
- A_s' = area of compression reinforcement, sq. in.
- A_s^* = area of prestressed reinforcement in tension zone, sq. in.
- A_t = area of one leg of continuous, closed transverse torsion reinforcement within a distance s , sq. in.

A_v = area of transverse shear reinforcement within a distance s , sq. in.

a = portion of single span, end span, or span adjacent to cantilever arm subject to shear lag effects (See Fig. 3-1.)

b = web width, in. (See Section 11.2.)

b = top or bottom flange width either side of web (See Section 3.3.2.)

b_e = minimum effective shear flow web or flange width to resist torsional stresses, in. (See Sections 12.2.10 and 12.3.1.)

b_m = effective width of flange (See Figs. 3-1 and 3-2.)

b_n = effective flange width for lateral distribution of post-tensioning force (See Fig. 3-4.)

b_{no} = web width at anchorage of post-tensioning force (See Fig. 3-4.)

b_o = web width (See Fig. 24-1.)

b_s = effective top or bottom flange width coefficient at supports and for cantilever arms (See Figs. 3-1 and 3-2.)

b_w = minimum web width, in. (See Section 12.2.5.)

b_w = web width, in. (See Section 11.2.)

b_1 = width of cantilever flange of box girder (See Fig. 3-3.)

b_2 = width of half of interior top flange of box girder (See Fig. 3-3.)

b_3 = width of half of interior bottom flange of box girder (See Fig. 3-3.)

CE = weight of specialized construction equipment

CLE = longitudinal construction equipment load

CLL = construction live load, normally taken as 10 psf

c = portion of continuous span adjacent to interior support subject to shear lag effects (See Fig. 3-1.)

D = sum of dead load of structure (DL), superimposed dead load (SDL), and permanent effects of erection loads (EL)

DIFF = differential (unbalanced) dead load from one cantilever

DL = dead load of structure only

d = distance from the extreme compression fiber to the centroid of the longitudinal tension reinforcement, in. For prestressed concrete members, the greater of the distance from the extreme compression

fiber to the centroid of the prestressed tension reinforcement or $0.8h$ may be used.

- d = shear key dimension (See Fig. 24-1.)
- d_c = thickness of cover from tension fiber to center of bar, in. (See Commentary, Section 18.2.)
- d_o = total depth of section (See Fig. 24-1.)
- d_p = distance from extreme compression fiber to centroid of prestressing reinforcement, in. (See Section 11.2.)
- E_{cm} = secant modulus of elasticity, psi (See Commentary, Section 6.5.)
- E_{eff} = effective modulus of elasticity for long term loads considering creep deformations, psi (See Commentary, Section 6.5.)
- EL = permanent effect of erection loads (final state)
- e = eccentricity of reaction (See Fig. 26-2.)
- e = base of Napierian logarithms
- F_r = radial force due to tendon curvature, kips per ft. (See Section 16.3.)
- f'_c = specified compressive strength of concrete at 28 days, psi
- $\sqrt{f'_c}$ = square root of specified compressive strength of concrete, psi (See Section 12.2.6 for limit.)
- f'_{ci} = compressive strength of concrete at time of initial prestress, psi
- f_{cn} = compressive stress in the concrete node regions, psi. (See Section 12.4.6.)
- f_{cu} = crushing strength of diagonally cracked concrete, psi. (See Section 12.4.4.)
- f_{pc} = compressive stress in concrete after allowance for all prestress losses, psi Critical stress to be determined at:
 - a) the centroid of the cross section resisting external loads, or
 - b) the junction of the web and compression flange when the centroid lies within the flange, or
 - c) in composite members, the stress at (a) or (b) for stresses due to both prestress and the moments resisted by the precast member acting alone.
- f_s = stress in nonprestressed reinforcement under erection loads (See Commentary Section 18.2.)
- f'_s = ultimate strength of prestressing steel, psi
- f_{st} = steel stress at beginning of time intervals t_1 , psi
- f_{su} = average stress in nonprestressed reinforcement at ultimate load, psi
- f^*_{su} = average stress in prestressed reinforcement at ultimate load, psi
- f_{sy} = Specified yield strength of nonprestressed reinforcement
- f'_y = specified minimum yield strength of compression reinforcement, psi (See Section 11.2.)

- f_y^* = yield point stress of prestressing steel, psi
- H = horizontal force in bottom flange and web (See Fig. 26-2.)
- h = overall thickness of member, in. (See Section 12.2.18.)
- h = depth of shear key, in. (See Fig. 24-1.)
- IE = impact load from equipment
- $K = \sqrt{1+f_{pc}} / (2\sqrt{f'_c})$ (See Section 12.2.10.)
- k = friction wobble coefficient, per foot (See Section 10.2.)
- l = span length (See Fig. 3-1.)
- l = tendon length from jacking end to point x (See Section 10.2.)
- l_i = effective span length (See Fig. 3-1.)
- l_i = length of tendon between anchorages (See Section 11.2.)
- M_u = factored moment at section, in.-lb.
- N_s = Number of support hinges crossed by the tendon (draped tendons only) (See Section 11.2.)
- N_{uc} = factored compressive axial force normal to cross section, lb. (See Section 12.2.10.)
- N_{ut} = factored tensile axial force normal to cross section, lb. (See Section 12.2.10.)
- P_{cp} = outside perimeter of the concrete cross section, in. (See Section 12.2.10.)
- P_h = perimeter of centerline of outermost continuous closed transverse reinforcement, in.
- P_j = tendon jacking force, kips (See Sections 16.3 and 16.6.1.)
- R = force in plane of web (See Fig. 26-2.)
- R = tendon radius of curvature, ft. (See Section 16.3.)
- R = rib shortening and creep effects (See Sections 7.2 and 7.4.1.)
- R_{lr} = loss of prestress due to steel relaxation, low relaxation strand, psi
- R_{sr} = loss of prestress due to steel relaxation, stress relieved steel, psi
- S = shrinkage effects (See Section 7.4.1.)
- S_u = force in a truss member due to factored loads, lb.
- SDL = superimposed dead load
- s = spacing of shear or torsion reinforcement measured parallel to the longitudinal axis of the member, in.
- s = bar spacing, in. (See Commentary, Section 18.2.)
- T = sum of effects of thermal rise or fall (TRF) and thermal gradient (TG)
- TG = thermal differential from top flange to bottom flange, degrees Fahrenheit
- TG = temperature gradient, degrees Fahrenheit
- TRF = thermal rise or fall, degrees Fahrenheit

T_c = torsional cracking moment, in.-lb. (See Section 12.2.10.)
 T_n = nominal torsion resistance, in.-lb. (See Section 12.3.7.)
 T_o = tendon stress at jacking end. (See Section 10.2.)
 T_u = factored torsion at section, in.-lb.
 T_x = tendon stress at x feet from jacking end (See Section 10.2.)
 t = thickness of wall, in. (See Section 23.3.)
 t = time at end of time interval, hour (See Section 10.4.)
 t_1 = time at anchorage of prestressing steel taken as 1/24 of a day, or any time at the beginning of a time interval, hours (See Section 10.4.)
 U = load due to segment unbalance on opposite cantilever ends
 V_c = nominal shear strength provided by concrete, lb.
 V_n = nominal shear force resisted by member, lb.
 V_{nj} = nominal strength of Type B joint (See Section 12.2.21.)
 V_p = vertical component of the effective prestressing, lb. (See Sections 12.1.5.1 and 12.1.5.2.)
 V_s = nominal shear resisted by the 45° truss model as measured by the stirrup capacity, lb.
 V_u = factored shear force at section, lb.
 V_{uj} = strength of Type B joint (See Section 12.2.21.)
 WUP = wind uplift on cantilever
 X_u = the clear length of the constant thickness portion of a wall between other walls or fillers between walls, in. (See Section 23.3.)
 Z = correction dimension for location of center of gravity of tendon bundle in duct, in. (See Section 11.5.)
 Z = quantity for detailing of reinforcement to control flexural cracking during erection (See Section 18.2 and Commentary Section 18.2.)
 ϕ = strength reduction factor (See Section 7.3.)
 ϕ_b = strength reduction factor for bearing (See Section 7.3.)
 ϕ_c = creep coefficient, ratio of creep strain to elastic strain
 ϕ_f = strength reduction factor for flexure (See Section 7.3.)
 ϕ_j = strength reduction factor for design of Type B (dry) joints (See Sections 7.3 and 12.2.21.)
 ϕ_v = strength reduction factor for shear and diagonal tension (See Section 7.3.)
 μ = friction coefficient (per radian)

α = total angular deviation from jacking end to point x, radians

β_1 = factor on concrete strength. β_1 shall be taken as 0.85 for concrete strengths f'_c up to 4000 psi. For strengths above 4000 psi, β_1 shall be reduced continuously at a rate of 0.05 for each 1000 psi of strength in excess of 4000 psi, but β_1 shall not be taken as less than 0.65.

1.3 Definitions

Definitions are in accordance with AASHTO *Standard Specifications for Highway Bridges* and the following:

Anchorage Blister - Build-out in the web, flange, or web-flange junction to provide area for one or more tendon anchorages.

Closure - Cast-in-place concrete segment or segments used to complete a span.

Deviation Saddle - Build-out in the web, flange, or web-flange junction to provide for change of direction of an external tendon.

External Tendon - Tendon located outside the flanges or webs of the structural member, generally inside the box girder cell.

Internal Tendon - Tendon located within the flanges or webs (or both) of the structural member.

General Bursting Forces - Bursting forces due to all of the tendons anchored at a cross section. Dependent on the overall concrete dimensions, and the magnitude direction and location of the total prestressing force anchored.

Low Relaxation Steel - Prestressing strand in which the steel relaxation losses have been substantially reduced by additional manufacturing procedures (stretching at elevated temperature).

Partially Bonded Tendons - Tendons initially external to the concrete cross section which are encased in the cross section over a portion of their length by use of a supplementary concrete pour and reinforcement ties.

Sand-Lightweight Concrete - Concrete mix with lightweight coarse aggregate and a normal weight sand fine aggregate.

2.0 MATERIALS

2.1 Concrete

Structural concrete used in segmental construction shall have a minimum 28-day strength of 4500 psi or greater as specified by the Engineer. The required concrete strength at the time of stressing shall be determined in accordance with Section 9.2.

2.2 Reinforcement

2.2.1 Prestressing Steel

Prestressing steel shall conform to the requirements of AASHTO *Standard Specifications for Highway Bridges* Article 9.3.1.

2.2.2 Reinforcing Steel

Reinforcing steel shall be in accordance with AASHTO *Standard Specifications for Highway*

Bridges, Article 8.3, or as otherwise noted in Division II, Sections 3.2.2 and 3.2.3.

In aggressive environments, special design and construction measures shall be taken for corrosion protection of all bridge deck reinforcement, including any reinforcement projecting from the web into the deck.



SECTION B ANALYSIS

3.0 METHODS OF ANALYSIS

3.1 General

Elastic analysis and beam theory may be used to determine design moments, shears, and deflections. The effects of creep, shrinkage and temperature differentials shall be considered, as well as the effects of shear lag. Shear lag shall be considered in accordance with the provisions of Section 3.3. Analysis for earthquake loads shall be in accordance with Division I-A, Seismic Design, Section 4 of the *AASHTO Standard Specifications for Highway Bridges*.

3.2 Strut-and-Tie Models

Strut-and-tie models may be used for analysis in areas of load or geometrical discontinuity.

3.3 Effective Flange Width

3.3.1 General

Effective flange width for service load stress calculations may be determined by elastic analysis procedures,^{5, 6, 52} by the provisions of Section 3.3.1 of the 1991 Ontario Highway Bridge Design Code,⁷ or by the provisions of Section 3.3.2.^{8, 44}

3.3.2 Effective Flange Width

Section properties for analysis and for calculation of the effects of bending moments and shear forces may be based on the flange widths specified in this section, or may be based on flange widths determined by other procedures listed in Section 3.3.1. The effects of unsymmetrical loadings on effective flange width may be disregarded.

The effective flange width, b_e , (see Figure 3-3) may be assumed equal to the full flange width, b , if:

1. $b \leq 0.1 \ell_1$ (ℓ_1 = effective span length)
2. $b \leq 0.3d_o$ (d_o = web height)

For flange widths, b , greater than $0.3d_o$ or $0.1 \ell_1$, the effective width may be determined in accordance with Figures 3-1 and 3-2. The value of b_{es} , the effective flange width in the support area, shall be determined using the greater of the effective span lengths adjacent to the support. If b_{em} , the effective flange width in the mid-span area, is less than b_e in a span, the pattern of the effective width within the span may be determined

by the connecting line of the effective support widths, b_e at adjoining support points. However, the effective width, b_e , shall not be greater than b .

If the construction procedure is such that the configuration of a span within a unit changes, the final configuration may be used in the determination of the effective flange widths.

The section properties for normal forces may be based on the pattern according to Figure 3-4, or may be determined by more rigorous analytical procedures.

Stresses due to bending, shear, and normal forces may be determined by using their corresponding section properties.

The capacity of a cross section may be determined by considering the full flange width effective.

4.0 TRANSVERSE ANALYSIS

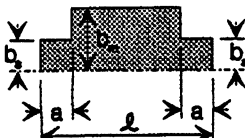
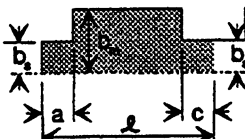
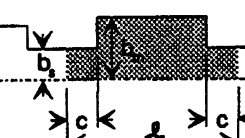
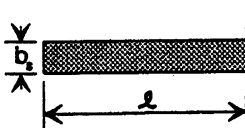
The transverse design of box girder segments for flexure shall consider the segment as a rigid box frame. Flanges shall be analyzed as variable depth sections considering the fillets between the flange and webs. Wheel loads shall be positioned to provide maximum moments, and elastic analysis shall be used to determine the effective longitudinal distribution of wheel loads for each load location. Consideration shall be given to the increase in web shear and other effects on the cross section resulting from eccentric loading or unsymmetrical structure geometry.

Influence surfaces⁽¹¹⁾⁽¹²⁾⁽¹³⁾ or other elastic analysis procedures may be used to evaluate live load plus impact moment effects in the top flange of the box section.

Transverse elastic and creep shortening due to prestressing and shrinkage shall be considered in the transverse analysis.

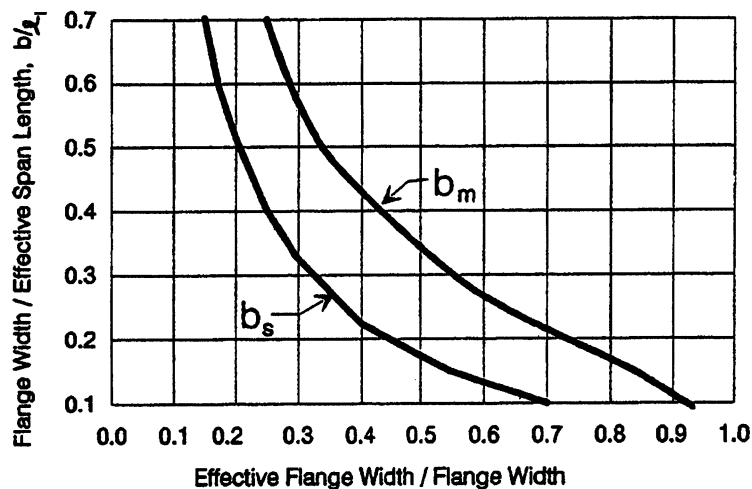
The effect of secondary moments due to prestressing shall be included in stress calculations under service loads. In calculating flexural and shear capacity under factored loads, the secondary moments or shears induced by prestressing (with a load factor of 1.0) shall be added algebraically to the moments and shears due to factored dead and live loads.

The transverse design of beam type segmental bridge decks may be in accordance with the provisions of the *AASHTO Standard Specifications for Highway Bridges*, Section 3.24.3.1.

System	Pattern of Effective Flange Widths	Effective Span Length for use with Figure 4-2
Single-Span Girder		$\ell_i = \ell$
End Span of Continuous Girder		$\ell_i = 0.8 \ell$
Inner Span of Continuous Girder		$\ell_i = 0.6 \ell$
Cantilever Arm		$\ell_i = 1.5 \ell$

$a = \text{largest } b, \text{ but not exceeding } 0.25 \ell$
 $c = 0.1 \ell$

Fig. 3-1



For $b/\ell_i \geq 0.7$:

$$b_m = 0.173 \ell_i$$

$$b_s = 0.104 \ell_i$$

Where b_m = effective flange width near mid-span
 b_s = effective flange width near support

Fig. 3-2

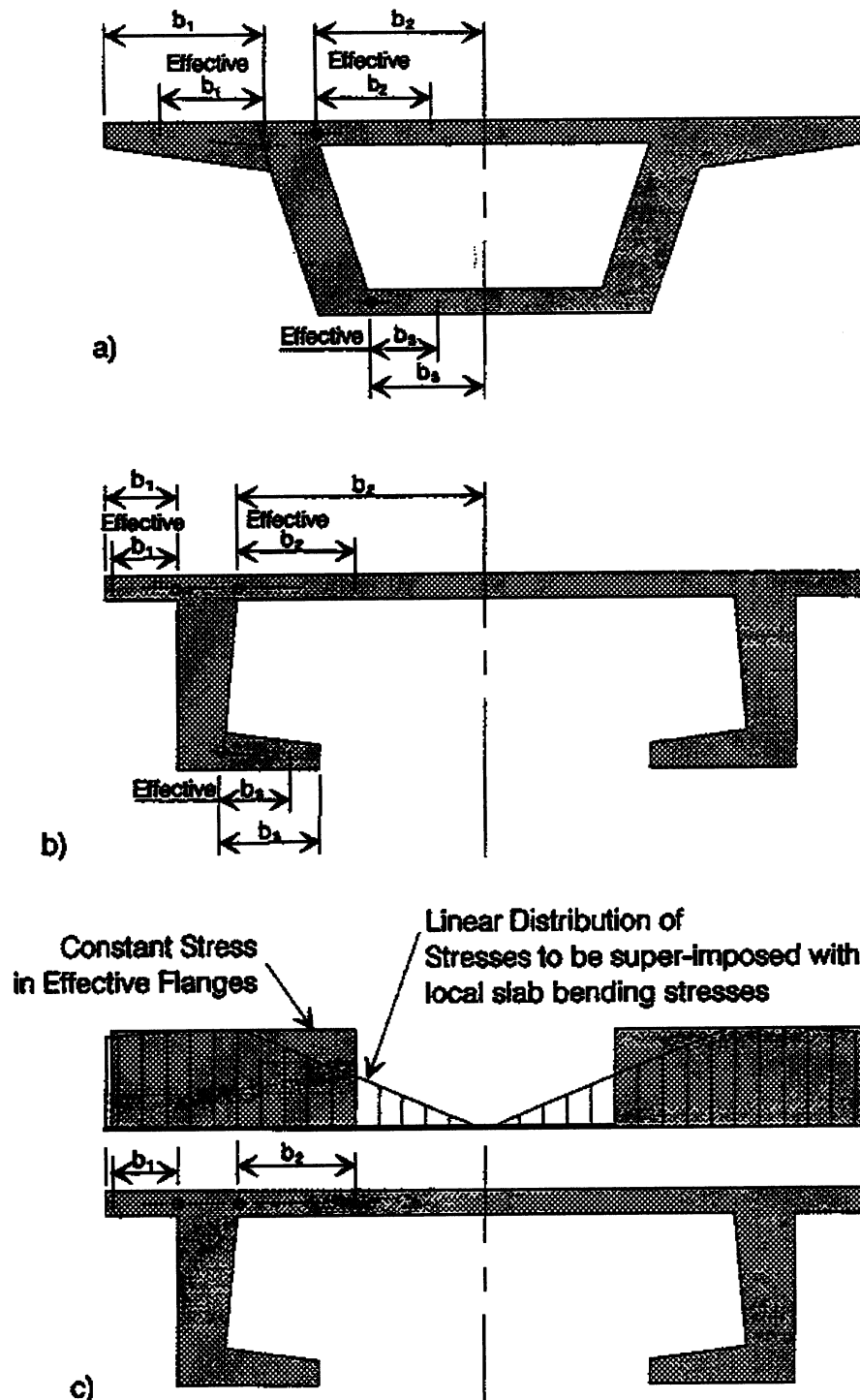


Fig. 3-3. Cross Sections and Corresponding Effective Flange Widths for Bending and Shear

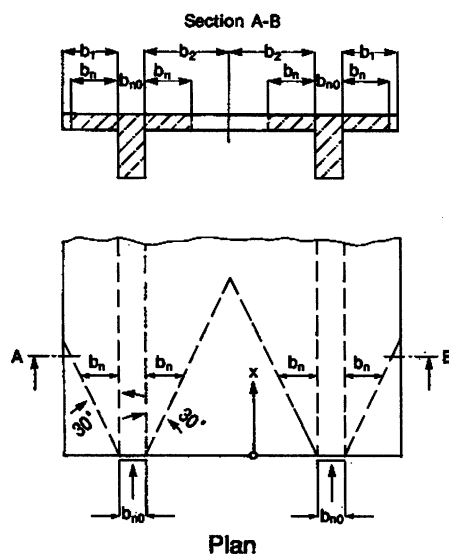


Fig. 3-4. Effective Flange Widths b_n for Normal Forces

5.0 LONGITUDINAL ANALYSIS

5.1 General

Longitudinal analysis shall be in accordance with the provisions of Section 3.0. Longitudinal analysis of segmental concrete bridges shall consider a specific construction method and construction schedule, as well as the time-related effects of concrete creep, shrinkage, and prestress losses.

The effect of secondary moments due to prestressing shall be included in stress calculations at service limit states. In calculating flexural and shear capacity requirements under factored loads, the secondary moments or shears induced by prestressing (with a load factor of 1.0) shall be added algebraically to the moments and shears due to factored dead and live loads.

5.2 Erection Analysis

Analysis of the structure during the construction stage shall consider the construction load combinations, stresses, and stability considerations outlined in Section 7.4.

5.3 Analysis of the Final Structural System

The final structural system shall be analyzed for redistribution of erection stage moments resulting from the effects of creep and shrinkage, and from any change in the statical system, including the closure of joints. Thermal effects on the final structural system shall be considered in accordance with the AASHTO *Standard Specifications for Highway Bridges*, Section 3.16, and Section 6.4 of these guide specifications. The effect of prestress losses occurring after closure shall be evaluated in accordance with Section 10.0. Multiple presence of live load shall be evaluated in accordance with the provisions of AASHTO *Standard Specifications for Highway Bridges*, Section 3.12. The maximum moments resulting from the above analyses shall be utilized for stress calculations under service loads, and shall be utilized in conjunction with the combinations of loads specified in the AASHTO *Standard Specifications for Highway Bridges*, Section 3.22, for determination of required flexural strength.

SECTION C DESIGN

6.0 LOADS

6.1 General

All loadings shall be in accordance with the *AASHTO Standard Specifications for Highway Bridges* except as provided below.

6.2 Dead Loads

Unit weight of concrete (including rebar)—155 pounds per cubic foot or as determined for the project. Weight of diaphragms, anchor blocks, or any other deviations from the typical cross section shall be included in the dead load calculations.

6.3 Erection Loads

6.3.1 Erection loads comprise all loadings arising from the designer's anticipated system of temporary supporting works and/or special erection equipment to be used in accordance with the assumed construction sequence and schedule. The assumed erection loads and acceptable closure forces due to misalignment corrections shall be stated on the drawings. Due allowance shall be made for all effects of any changes of the static structural scheme during construction and the application, changes or removal of the assumed temporary supports of special equipment taking into account residual "built-in" forces, moments, deformations, secondary post-tensioning effects, creep, shrinkage and any other strain induced effects.

6.3.2 All elements of the bridge shall be designed for the anticipated construction system assumed by the Engineer and shown on the plans. Any changes by the Contractor in the construction method or in the design shall comply with Sections 28.2 or 28.3.

6.4 Thermal Effects

6.4.1 Normal Mean Temperature

Unless more precise local data are available, normal mean temperature for the location shall be taken as the average of the January and July values from Figures 6-1 and 6-2,²⁰ respectively.

6.4.2 Seasonal Variation

a. For the purposes of design of the structure, the minimum and maximum overall temperatures for the location shall be taken from Figures 6-1 and 6-2, respectively, unless more precise local data are available.

b. The temperature setting variations for bearings and expansion joints shall be stated on the bridge plans.

6.4.3 Thermal Coefficient

The coefficient of thermal expansion used to determine temperature effects shall be taken as 6.0×10^{-6} per degree Fahrenheit for normal weight concrete and 5.0×10^{-6} for sand-lightweight concrete unless more precise data are available.

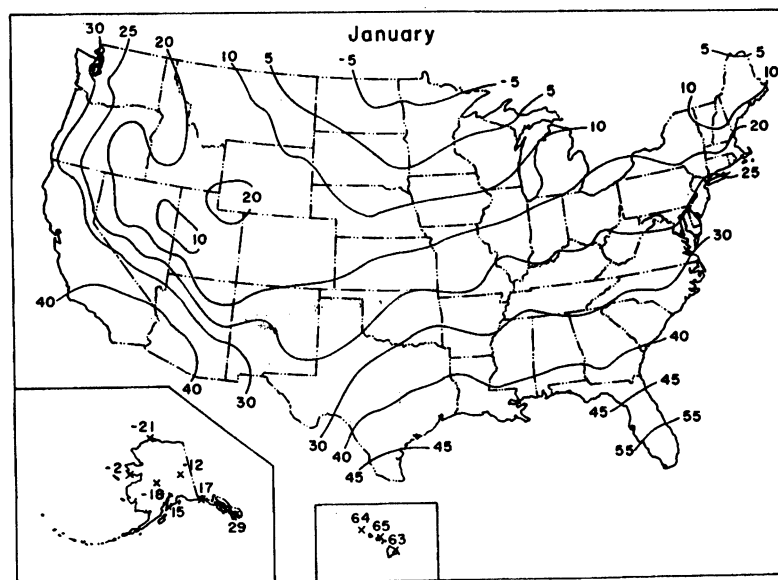


Fig. 6-1. Normal daily minimum temperature (°F) for January

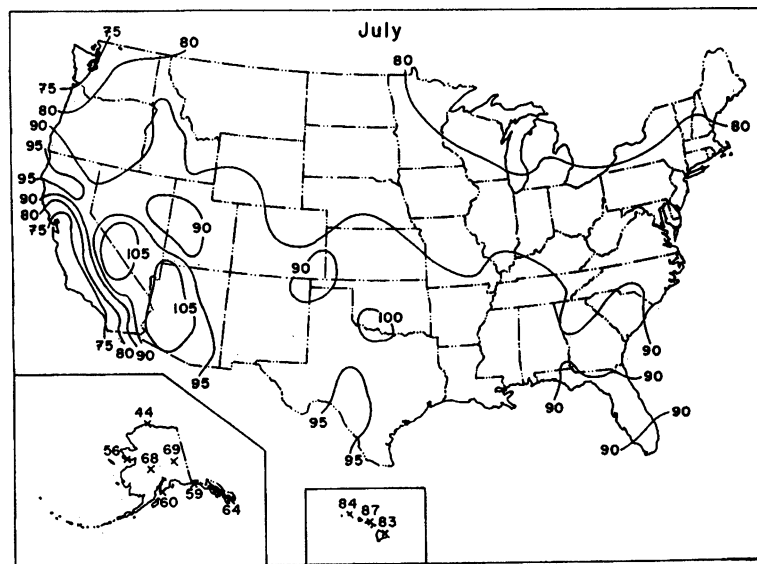


Fig. 6-2. Normal daily maximum temperature (°F) for July

6.4.4 Temperature Gradient

For the purpose of this article, the country shall be subdivided into zones as indicated in Figure 6-3. Positive temperature gradient (TG) values for the zones shall be taken as specified for various deck surface conditions in Table 6-1. Negative temperature values shall be obtained by multiplying the values specified in Table 6-1 by -0.30 for plain concrete surfaces and -0.20 for surfaces with 2-inch asphalt topping.

The vertical temperature gradient shall be taken as shown in Figure 6-4.

The dimension "A" in Figure 6-4 shall be taken as:

- 12.0 inches for superstructures that are 16.0 inches or more in depth
- for sections shallower than 16.0 inches, "A" shall be 4.0 inches less than the actual depth

Temperature value T_3 shall be taken as 0.0, unless a site-specific study is made to determine an appropriate value, but shall not exceed 5°F.

Where temperature gradient is considered, internal stresses and structure deformations due to both positive and negative temperature gradients may be determined in accordance with the provisions of the AASHTO Guide Specifications—*Thermal Effects in Concrete Bridge Superstructures*, Appendix A, 1989.²⁰

Table 6-1. Basis for Temperature Gradients

Plain Concrete Surface or Asphalt Topping		
Zone	T1(F°)	T2(F°)
1	54	14
2	46	12
3	41	11
4	38	9

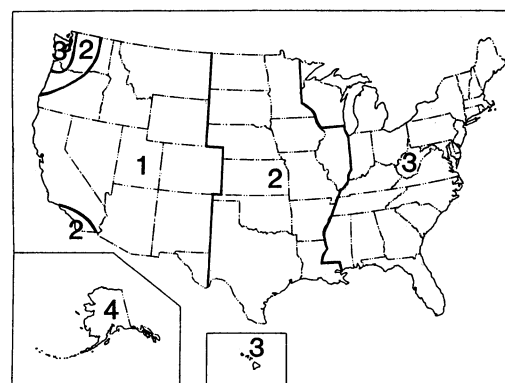


Fig. 6-3. Solar Radiation Zones for the United States

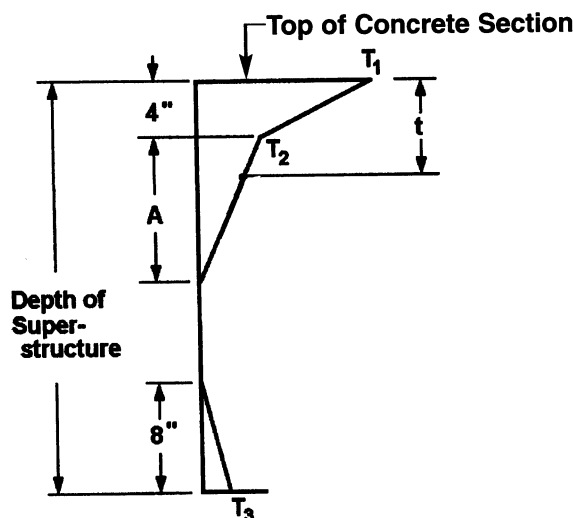


Fig. 6-4. Positive Vertical Temperature Gradient

6.5 Creep and Shrinkage

Effects due to creep and shrinkage strains shall be calculated in accordance with the provisions of Section 5.3. The creep coefficient ϕ_c may be evaluated in accordance with the provisions of the ACI Committee 209 Report,¹⁷ the CEB-FIP Model Code,¹⁸ or by a comprehensive test program. Creep strains and prestress losses which occur after closure of the structure cause a redistribution of the forces. Stresses shall be calculated for this effect based on an assumed construction schedule stated on the plans.

6.6 Post-Tensioning Force

The structure shall be designed for both initial and final post-tensioning forces. For determining the final post-tensioning forces, prestress losses shall be calculated for the construction schedule stated on the plans. The final post-tensioning forces used in service load stress calculations shall be based on the most severe condition at each location along the structure.

7.0 LOAD FACTORS

7.1 General

In the final working condition, service or strength load combinations shall be in accordance with AASHTO *Standard Specifications for Highway Bridges*, Section 3.2.2, with consideration of the additional load combinations of Section 7.2. Strength reduction factors, ϕ , shall be in accordance with Section 7.3.

During construction, load combinations, allowable stresses, and stability shall be in accordance with Section 7.4. Prior to grouting, the allowable concrete tensile stress during construction shall be zero for structures utilizing internal grouted tendons.

7.2 Additional Load Combinations

The permanent effects of creep and shrinkage shall be added to all AASHTO loading combinations with a load factor of 1.0.

7.2.1 Erection Loads at End of Construction

The final state erection loads (EL) are defined as the final accumulated “built-in” forces and moments resulting from the construction process.

7.2.2 Additional Thermal Loading Combination

7.2.2.1 For existing service load combinations including full live load plus impact, a load factor of 0.50 shall be applied for temperature gradient.

In addition to AASHTO service load combinations, the following load combination shall apply:

$$DL+SDL+EL+\beta_E E+B+SF+R+S+TG$$

$$\leq 100\% \text{ Allowable Stress}$$

LOADING

Dead Load Structure Only:	DL
Superimposed Dead Load:	SDL
Erection Loads (final state):	EL
Thermal-Rise or Fall	TRF
Thermal-Differential	TG
Creep Effects	R

$$D=(DL+SDL+EL)$$

$$T=(TRF+TG)$$

See AASHTO *Standard Specifications for Highway Bridges*, Section 3.22.1, for other definitions.

7.2.2.2 For all factored load combinations, a load factor of zero (0) shall be applied to differential temperature effects (TG).

7.3 Strength Reduction Factors

7.3.1 The strength reduction factors, ϕ_f and ϕ_v , for flexure and shear, respectively, shall consider both the type of joint between segments and the degree of bonding of the post-tensioning system provided. The appropriate value of ϕ_v from Section 7.3.6 shall be used for shear and torsional effect calculations in Section 12.

7.3.2 Since the post-tensioning provided may be a mixture of fully bonded tendons and unbonded or partially bonded tendons, the strength reduction factor at any section shall be based upon the bonding conditions for the tendons providing the majority of the prestressing force at the section.

Table 7-1. Strength Reduction Factors for Segmental Construction

	ϕ_f Flexure	ϕ_v Shear	ϕ_j Joint
Normal Weight Concrete			
Fully Bonded Tendons			
Type A Joint	0.95	0.90	-
Unbonded or Partially Bonded Tendons			
Type A Joint	0.90	0.85	-
Type B Joint	0.85	0.85	0.75
Sand-Light Weight Concrete			
Fully Bonded Tendons			
Type A Joint	0.90	0.70	-
Unbonded or Partially Bonded Tendons			
Type A Joint	0.85	0.65	-
Type B Joint	0.80	0.65	0.60

7.3.3 In order for a tendon to be considered as fully bonded to the cross section, it must be bonded beyond the critical section for a development length not less than that required by AASHTO *Standard Specifications for Highway Bridges*, Section 9.28.1. Shorter embedment lengths are permissible if demonstrated by full size tests and approved by the Engineer.

7.3.4 Cast-in-place concrete joints, and wet concrete or epoxy joints between precast units, shall be considered as Type A joints.

7.3.5 Dry joints between precast units shall be considered as Type B joints.

7.3.6 Strength reduction factors, ϕ , shall be taken as presented in Table 7-1, and the following provisions of this section.

The strength reduction factor for direct shear capacity of dry joints, ϕ_j , shall be used in conjunction with Section 12.2.21.

The strength reduction factor for bearing, ϕ_b , shall be taken as 0.70 for all types of construction. This value shall not be applied to bearing stresses under anchorage plates for post-tensioning tendons.

7.4 Construction Load Combinations, Stresses and Stability

7.4.1 Erection Loads During Construction

Erection loads as defined by AASHTO and as stated on the plans shall be as follows:

a. Dead load of structure (DL): Unit weight of concrete (including rebar) - 155 pcf or as determined for the project. Weight of diaphragms, anchor blocks, or

any other deviations from the typical cross section shall be included in the dead load calculations.

b. Differential load from one cantilever (DIFF): This only applies to balanced cantilever construction. The load is 2% of the dead load applied to one cantilever.

c. Superimposed dead load (SDL): This does not normally apply during construction. If it does, it should be considered as part of the dead load (DL).

d. Distributed construction live load (CLL): This is an allowance for miscellaneous items of plant, machinery and other equipment apart from the major specialized erection equipment. Distributed load allowance is 10 psf. In cantilever construction, distributed load shall be taken as 10 psf on one cantilever and 5 psf on the other. For bridges built by incremental launching, construction live load may be taken as zero.

e. Specialized construction equipment (CE): This is the load from any special equipment such as a launching gantry, beam and winch, truss or similar major item. This also includes segment delivery trucks and the maximum loads applied to the structure by the equipment during the lifting of segments.

f. Impact load from equipment (IE): To be determined according to the type of machinery anticipated. For very gradual lifting of segments, where the load involves small dynamic effects, the impact load may be taken as 10 percent.

g. Longitudinal construction equipment load (CLE): The longitudinal force from the construction equipment.

h. Segment unbalance (U): This applies primarily to balanced cantilever construction but can be extended to include any "unusual" lifting sequence which may not be a primary feature of the generic construction system.

Table 7-2
ALLOWABLE TENSILE STRESSES FOR
CONSTRUCTION LOAD COMBINATIONS

Load Combinations Coefficients													Segmental Substructure Only						
Superstructure and Substructure																			
Dead Loads		Live Loads			Wind Loads			(1) **** Allowable		(2)**** Super-structure Only Including (R + S + T) Allowable		(3)**** Excluding (R + S + T)(R + S + T) Allowable		(4)**** Including (R + S + T)(R + S + T) Allowable					
Combination	DL	DIFF	U	CLL	CE	IE	CLE	W	WUP	WE	Stress	(R + S + T)	Stress	β_E^{***}	B	SF	Stress	Stress	Comments
a	1	1	0	1	1	1	0	0	0	0	$6\sqrt{f_c}$	1	$7\sqrt{f_c}$	β_E	1	1	$6\sqrt{f_c}$	$7\sqrt{f_c}$	
b	1	0	1	1	1	1	0	0	0	0	$6\sqrt{f_c}$	1	$7\sqrt{f_c}$	β_E	1	1	$6\sqrt{f_c}$	$7\sqrt{f_c}$	
c	1	1	0	0	0	0	0	0.7*	0.7	0	$6\sqrt{f_c}$	1	$7\sqrt{f_c}$	1	1	1	$7\sqrt{f_c}$	$7\sqrt{f_c}$	
d	1	1	0	1	1	0	0	0.7*	1	0.7	$7\sqrt{f_c}$	1	$7\sqrt{f_c}$	β_E	1	1	$7\sqrt{f_c}$	$7\sqrt{f_c}$	Equipment not working
e	1	0	1	1	1	1	0	0.3**	0	0.3	$7\sqrt{f_c}$	1	$7\sqrt{f_c}$	β_E	1	1	$7\sqrt{f_c}$	$7\sqrt{f_c}$	Normal Erection
f	1	0	0	1	1	1	1	0.3**	0	0.3	$7\sqrt{f_c}$	1	$7\sqrt{f_c}$	β_E	1	1	$7\sqrt{f_c}$	$7\sqrt{f_c}$	Moving Equipment

The allowable stresses in Columns 1 and 2 apply to the summation of all the loads multiplied by their tabulated coefficients in all the columns to the left. Similarly for Columns 3 and 4 with the exceptions of (R + S + T) as noted.

* Reduction is to allow for lesser probability of maximum wind during construction period.

** Reduction is to allow for limiting wind beyond which construction is halted.

*** The β_E term is as defined in AASHTO Section 3.22.

**** When less than 60% of the tendon capacity is provided by internal tendons, the maximum allowable construction stresses shall be $3\sqrt{f_c}$ for Type A joints, and 0 for Type B joints.

The load "U" is the effect of any out of balance segments or other unusual condition as applicable.

i. Wind uplift on cantilever (WUP): 5 psf (balanced cantilever construction applied to one side only).

j. Accidental release or application of a precast segment load or other sudden impact from an otherwise static load of A: Impact force = 2A.

k. Creep (R)

In accordance with Section 6.5. Creep effects shall be considered as part of rib shortening (R).

l. Shrinkage (S)

In accordance with Section 6.5.

m. Thermal (TRF) and Thermal (TG)

The sum of the effects due to thermal rise and fall (TRF) and differential temperatures (TG) from Section 6.4.

7.4.2 Construction Load Combinations and Allowable Stresses

Stresses shall be checked under the construction load combinations given in Table 7-2. The distribution and application of the individual erection loads (Section 7.4.1) appropriate to a construction phase shall be such as to produce the most unfavorable effects. Table 7-2 is a guide; if more unfavorable conditions may occur with the particular construction system, these shall be taken into account. The maximum allowable construction load compressive stress shall be $0.5f'_c$.

Load factor design need not be used for construction conditions with the exception of Section 7.4.3 below.

7.4.3 Construction Load Combinations Load Factor Design Check

Using capacity reduction factors (ϕ) in accordance with Section 7.3, the strength provided shall not be less than required by the following load factor combinations.

For maximum forces and moments:

$$1.1(DL + DIFF) + 1.3CE + 2A$$

For minimum forces and moments:

$$DL + CE + 2A$$

8.0 SEISMIC DESIGN

Segmental superstructure design with moment resisting column to superstructure connections shall consider the inelastic hinging force (lateral shear force) from columns. The lateral shear force from the column shall be determined from the inelastic flexural capacity of the column by multiplying the nominal flexural capacity by 1.30. Bridge superstructures in seismic zones C and D with moment resisting column to super

structure connections shall be reinforced with ductile details to resist longitudinal and transverse flexural demands produced by column plastic hinging.

Type A joints shall be used in seismic zones C and D. Segment joints shall provide capacity to transfer seismic demands.

Internal tendons shall be provided to support the superstructure dead load with a factor of safety of 1.3 in seismic zones C and D. The average stress in the prestressing steel of the internal tendons for this load case shall be calculated in accordance with Section 11.2. Not more than 50 percent of the total post-tensioning steel force shall be provided by external tendons.

9.0 ALLOWABLE STRESSES

9.1 Prestressing Steel

Tensile stresses in prestressing tendons shall not exceed the following.

9.1.1 Due to tendon jacking force

$$0.80f'_s$$

but not greater than $0.90 f_y^*$

9.1.2 At anchorages and couplers immediately after tendon anchorage

$$0.70f'_s$$

9.1.3 At internal tendon locations immediately after prestress transfer

$$0.83f_y^*$$

but not greater than $0.74f'_s$

9.2 Prestressed Concrete

9.2.1 Temporary stresses before losses due to creep and shrinkage, at the time of application of the prestress (transfer) for both normal weight and sand-light weight concrete:

9.2.1.1 Compression

$$0.60f'_{ci}$$

9.2.1.2 Longitudinal stresses in the precompressed tensile zone:

a. Type A joints with minimum bonded auxiliary reinforcement through the joints sufficient to carry the calculated tensile force at a stress of $0.5 f_y$; internal and external tendons.

$$3.0\sqrt{f'_{ci}} \text{ maximum tension}$$

