3. FLOWCHARTS

Main Design Steps

Start

Determine bridge materials, span arrangement, girder spacing, bearing types, substructure type and geometry, and foundation type

Assume deck slab thickness based on girder spacing and anticipated girder top flange

Analyze interior and exterior girders, determine which girder controls

Is the assumed thickness of the slab adequate for the girder spacing and the girder top flange width?

YES

Design the deck slab

Design the controlling girder for flexure and shear

Design bearings

NO

Revise deck slab thickness

Section in Example

Design Step 2.0

Design Step 4.2

Design Step 4.2

Design Step 4.0

Design Steps 5.6 and 5.7

Design Step 6.0
Main Design Steps (cont.)

1. Design integral abutments
   - Design intermediate pier and foundation
   - End

Section in Example

- Design Step 7.1
- Design Step 7.2
Deck Slab Design

Start

Assume a deck slab thickness based on girder spacing and width of girder top flange

Determine the location of the critical section for negative moment based on the girder top flange width (S4.6.2.1.6)

Determine live load positive and negative moments (A4)

Determine dead load positive and negative moment

Determine factored moments (S3.4)

Design main reinforcement for flexure (S5.7.3)

Determine longitudinal distribution reinforcement (S9.7.3.2)

Section in Example

Design Step 4.2

Design Step 4.6

Design Step 4.7

Design Steps 4.8 and 4.9

Design Step 4.8

Design Step 4.12
Deck Slab Design (cont.)

1. For Slabs on Continuous Beams:
   Steel beam - Determine area of longitudinal reinforcement in the deck in negative moment regions of the girders (S6.10.3.7)
   Concrete Simple Spans Made Continuous for Live Load - Determine the longitudinal slab reinforcement at intermediate pier areas during the design of the girders (S5.14.1.2.7b)

Determine strip width for overhang (S4.6.2.1.3) or where applicable, use S3.6.1.3.4

Determine railing load resistance and rail moment resistance at its base (S13.3)

Design overhang reinforcement for vehicular collision with railing + DL (Case 1 and Case 2 of SA13.4.1)

Determine factored moments from DL + LL on the overhang (Case 3 of SA13.4.1)

Design overhang reinforcement for DL + LL

Determine the controlling case for overhang reinforcement, Case 1, Case 2 or Case 3

Detail reinforcement

End
General Superstructure Design
(Notice that only major steps are presented in this flowchart. More detailed flowcharts of the design steps follow this flowchart)

Start

1. Assume girder size based on span and girder spacing

2. Determine noncomposite dead load (girder, haunch and deck slab) for the interior and exterior girders

3. Determine composite dead load (railings, utilities, and future wearing surface) for the interior and exterior girders

4. Determine LL distribution factors for the interior and exterior girders

5. Determine unfactored and factored force effects

6. Determine the controlling girder (interior or exterior) and continue the design for this girder

Section in Example

Design Step 2.0
Design Step 5.2
Design Step 5.2
Design Step 5.1
Design Step 5.3
General Superstructure Design (cont.)

1. Determine long-term and short-term prestressing force losses
   - Design for flexure under Service Limit State
   - Design for flexure under Strength Limit State
   - Design for shear under Strength Limit State
   - Check longitudinal reinforcement for additional forces from shear

   Did the girder pass all design checks and the calculations indicate the selected girder size leads to an economical design?
   - NO
     - Select a different girder size or change strand arrangement
   - YES
     - End

Section in Example

Design Step 5.4
Design Step 5.6
Design Step 5.7
Live Load Distribution Factor Calculations

1. Determine the type of cross-section, Table S4.6.2.2.1-1
2. Determine the $K_g$ factor (S4.6.2.2.1)
3. For skewed bridges, determine the skew correction factor for moment (if allowed by the owner) (S4.6.2.2.2e) and for shear (S4.6.2.2.3c)
4. Determine LL distribution factors for moment for the interior girder under single lane and multi-lane loading (S4.6.2.2.2b)
5. Determine LL distribution factor for shear for the interior girder under single lane and multi-lane loading (S4.6.2.2.3a)
6. Apply the skew correction factor

Section in Example

Design Step 5.1
Design Step 5.1.3
Design Step 5.1.6
Design Step 5.1.5
Design Step 5.1.7
Design Step 5.1.8
Live Load Distribution Factor Calculations (cont.)

1. Determine the controlling (larger) distribution factors for moment and shear for the interior girder.

Divide the single lane distribution factors by the multiple presence factor for one lane loaded, 1.2, to determine the fatigue distribution factors. (Notice that fatigue is not an issue for conventional P/S girders. This step is provided here to have a complete general reference for distribution factor calculations.)

Repeat the calculations for the exterior girder using S4.6.2.2.2d for moment and S4.6.2.2.3b for shear.

Additional check for the exterior girder for bridges with rigidly connected girders.

End

Section in Example

Design Step 5.1.9

Design Step 5.1.10

Design Step 5.1.15
Creep and Shrinkage Calculations

Start

Calculate the creep coefficient, $\psi(t, t_i)$, for the beam at infinite time according to S5.4.2.3.2.

Calculate the creep coefficient, $\psi(t_i)$, in the beam at the time the slab is cast according to S5.4.2.3.2.

Calculate the prestressed end slope, $\theta$.

Calculate the prestressed creep fixed end actions

Calculate dead load creep fixed end actions

Determine creep final effects

Section in Example

Design Step C1.2
Design Step C1.3
Design Step C1.4
Design Step C1.5
Design Step C1.6
Design Step C1.7
Creep and Shrinkage Calculations (cont.)

1. Calculate shrinkage strain in beam at infinite time according to S5.4.2.3.3.
2. Calculate shrinkage strain in the beam at the time the slab is cast (S5.4.2.3.3).
3. Calculate the shrinkage strain in the slab at infinite time (S5.4.2.3.3).
4. Calculate the shrinkage driving end moment, \( M_s \).
5. Analyze the beam for the shrinkage fixed end actions.
6. Calculate the correction factor for shrinkage.
7. Calculate the shrinkage final moments.
8. End

Section in Example

- Design Step C2.1
- Design Step C2.2
- Design Step C2.3
- Design Step C2.5
- Design Step C2.6
- Design Step C2.7
- Design Step C2.8
Prestressing Losses Calculations

Start

Determine the stress limit immediately prior to transfer in the prestressing strands for the prestressing steel used (S5.9.3)

Determine Instantaneous Losses (S5.9.5.2) for pretensioned members, only Elastic Shortening (S5.9.5.2.3a) is considered

Will the lump sum method or the refined method for time-dependent losses be used?

Lump Sum

Determine the lump sum time-dependent losses (S5.9.5.3)

Refined

Determine shrinkage loss (S5.9.5.4.2)

Determine creep loss (S5.9.5.4.3)

Section in Example

Design Step 5.4.2

Design Step 5.4.3

Design Step 5.4.6.1

Design Step 5.4.6.2
Prestressing Losses Calculations (cont.)

1. Determine relaxation loss at transfer (S5.9.5.4.4b)
   - Determine time-dependent losses after transfer as the total time-dependent losses minus relaxation losses at transfer

2. Determine losses due to relaxation after transfer (S5.9.5.4.4c)
   - Determine total time-dependent losses after transfer by adding creep, shrinkage and relaxation losses

   - Determine stress in strands immediately after transfer as the stress prior to transfer minus instantaneous losses
   - Determine final stress in strands as stress immediately prior to transfer minus sum of instantaneous loss and time-dependent losses after transfer

End

Section in Example

Design Step 5.4.6.3
Design Step 5.4.7
Design Step 5.4.4
Design Step 5.4.8
Flexural Design

Start

Design controlling girder (interior)

Determine compression and tension stress limits at transfer

Determine final compression and tension stress limits

Calculate initial service moment stress in the top and bottom of the prestressed girder

Calculate final service moment stress in the top and bottom of the prestressed girder

Are service stresses within stress limits?

YES

1

NO

Select a different girder size or change strand arrangement

Section in Example

Design Step 5.6.1.1

Design Step 5.6.2.1

Design Step 5.6.1.2

Design Step 5.6.2.2
Flexural Design (cont.)

1. Design the longitudinal steel at top of girder

2. Calculate factored flexural resistance, $M_r$, at points of maximum moment (S5.7.3.1)

   - Check the nominal capacity versus the maximum applied factored moment
     - NG: Select a different girder size or change strand arrangement
     - OK: Go to step 3

3. Check the maximum and minimum reinforcement (S5.7.3.3.2)

   - NG: Select a different girder size or change strand arrangement
   - OK: Go to step 3

4. Check negative moment connection at intermediate pier

   - NG: Design Step 5.6.4.1 and 5.6.4.2
   - OK: Design Step 5.6.5.1

Section in Example

- Design Step 5.6.3
- Design Step 5.6.4
Flexural Design (cont.)

3. Check moment capacity versus the maximum applied factored moment at the critical location for negative moment.

4. Check service crack control in negative moment region (S5.5.2)

5. Check positive moment connection at intermediate pier

6. Check fatigue in prestressed steel (S5.5.3) (Notice that for conventional prestressed beams, fatigue does not need to be checked)

7. Calculate required camber in the beams to determine bearing seat elevations

8. Determine the haunch thickness

9. Calculate required camber in the beams to determine probable sag in bridge

Section in Example

Design Step 5.6.5.1

Design Step 5.6.5.1

Design Step 5.6.5.2

Design Step 5.6.6

Design Step 5.6.7.1

Design Step 5.6.7.2

Design Step 5.6.7.3
Flexural Design (cont.)

4

Optional live load deflection check (S2.5.2.6.2)

End

Section in Example

Design Step 5.6.8
Shear Design – Alternative 1, Assumed Angle $\theta$

1. Start
2. Determine $b_v$ and $d_v$
   
   Eq. S5.8.2.9
3. Calculate $V_p$
4. Calculate shear stress ratio, $\nu_u/f'_c$
5. If the section is within the transfer length of any strands, calculate the average effective value of $f_{po}$
6. If the section is within the development length of any reinforcing bars, calculate the effective value of $A_s$
7. Assume value of shear crack inclination angle $\theta$
8. Calculate $e_x$ using Eq. S5.8.3.4.2-1

Design Step 5.7.2.1
Design Step 5.7.2.2
Design Step 5.7.2.5
Shear Design – Alternative 1, Assumed Angle $\theta$ (cont.)

1

Is assumed value of $\theta$ greater than the value determined based on calculated $e$?

- YES
- NO

2

Use the value last determined for $\theta$

YES

Is assumed value of $\theta$ too conservative, i.e., too high?

- YES
- NO

3

Determine transverse reinforcement to ensure $V_u \leq \phi V_n$, Eq. S5.8.3.3

4

Check minimum and maximum transverse reinforcement requirements, S5.8.2.5 and S5.8.2.7

5

Can longitudinal reinforcement resist required tension? Eq. S5.8.3.5

- YES
- NO

6

Design Step 5.7.2.5

Design Step 5.7.2.3 and 5.7.2.4

Design Step 5.7.6
Shear Design – Alternative 1, Assumed Angle $\theta$ (cont.)

3. Check bursting resistance (S5.10.10.1)

4. Can you use excess shear capacity to reduce the longitudinal steel requirements in Eq. S5.8.3.5-1?
   - YES
   - NO

5. Provide additional longitudinal reinforcement

6. Choose values of $\theta$ and $\beta$ corresponding to larger $\varepsilon_{x'}$, Table S5.8.3.4.2-1

Check confinement reinforcement (S5.10.10.2)

Check horizontal shear at interface between beam and deck (S5.8.4)

End
Shear Design – Alternative 2, Assumed Strain $\varepsilon_x$

1. **Start**
2. Determine $b_v$ and $d_v$
   
   Eq. S5.8.2.9

3. Calculate $V_p$

4. Calculate shear stress ratio, $\nu_u/f'_c$

5. If the section is within the transfer length of any strands, calculate the average effective value of $f_{po}$

6. If the section is within the development length of any reinforcing bars, calculate the effective value of $A_s$

7. Assume value of $\varepsilon_x$ and take $\theta$ and $\beta$ from corresponding cell of Table S5.8.3.4.2-1

8. Calculate $\varepsilon_x$ using Eq. S5.8.3.4.2-1

Section in Example

Design Step 5.7.2.1

Design Step 5.7.2.2

Design Step 5.7.2.5
Shear Design – Alternative 2, Assumed Strain $\varepsilon_x$ (cont.)

1. Is calculated $\varepsilon_x$ less than assumed value?
   - YES
   - NO

2. Is assumed value of $\varepsilon_x$ too conservative, i.e., too high?
   - YES
   - NO

3. Determine transverse reinforcement to ensure $V_u \leq \phi V_n$, Eq. S5.8.3.3

4. Check minimum and maximum transverse reinforcement requirements S5.8.2.5 and S5.8.2.7

5. Can longitudinal reinforcement resist required tension? Eq. S5.8.3.5
   - YES
   - NO

Section in Example

Design Step 5.7.2.5

Design Step 5.7.2.3 and 5.7.2.4

Design Step 5.7.6
Shear Design – Alternative 2, Assumed Strain $\varepsilon_x$ (cont.)

4. Check bursting resistance (S5.10.10.1)

5. Can you use excess shear capacity to reduce the longitudinal steel requirements in Eq. S5.8.3.5-1?
   - YES
   - NO

6. Provide additional longitudinal reinforcement

7. Choose values of $\theta$ and $\beta$ corresponding to larger $\varepsilon_x'$, Table S5.8.3.4.2-1

Check confinement reinforcement (S5.10.10.2)

Check horizontal shear at interface between beam and deck (S5.8.4)

End

Section in Example

- Design Step 5.7.4
- Design Step 5.7.5
- Design Step 5.7.7
Steel-Reinforced Elastomeric Bearing Design – Method A (Reference Only)

Start

Determine movements and loads at pier support (S14.4)

Calculate required plan area based on compressive stress limit (S14.7.6.3.2)

Determine dimensions L and W of the bearing, W is taken to be slightly less than the width of the girder bottom flange (S14.7.5.1)

Determine the shape factor for steel-reinforced elastomeric bearings according to S14.7.5.1

Determine material properties (S14.7.6.2)

Check compressive stress. Determine the maximum allowed shape factor using total load and live load stresses for the assumed plan area (S14.7.6.3.2)

Assume elastomer layer maximum thickness and number of layers

1
Steel-Reinforced Elastomeric Bearing Design – Method A (Reference Only) (cont.)

1. Recalculate the shape factor

Determine maximum stress associated with the load conditions inducing the maximum rotation (S14.7.6.3.5)

Check stability of the elastomeric bearing (S14.7.6.3.6)

Reinforcement for steel-reinforced elastomeric bearings is designed according to S14.7.5.3.7

Did bearing pass all checks?

YES

Check if the bearing needs to be secured against horizontal movement (S14.7.6.4)

NO

Change plan dimensions, number of layers, and/or thickness of layers

End
Steel-Reinforced Elastomeric Bearing Design – Method B

1. Determine movements and loads at pier support (S14.4)

2. Calculate required plan area of the elastomeric pad based on compressive stress limit (S14.7.5.3.2)

3. Determine dimensions L and W of the bearing, W is taken to be slightly less than the width of the girder bottom flange (S14.7.5.1)

4. Determine material properties (S14.7.5.2)

5. Check compressive stress. Determine the maximum allowed shape factor using total load and live load stresses for the assumed plan area (S14.7.5.3.2)

6. Calculate maximum elastomer interior layer thickness, $h_{ir}$ (S14.7.5.1)
Steel-Reinforced Elastomeric Bearing Design – Method B (cont.)

1. Recalculate the shape factor (S14.7.5.1)

2. Check compressive deflection if there is a deck joint at the bearing location (S14.7.5.3.3)

3. Check shear deformation (S14.7.5.3.4)

4. Check combined compression and rotation (S14.7.5.3.5)

5. Check stability of elastomeric bearings (S14.7.5.3.6)

Did bearing pass all checks? No

- Change plan dimensions, number of layers, and/or thickness of layers

Yes

Determine steel reinforcement thickness, $h_s$ (S14.7.5.3.7)

End

Section in Example

Design Step 6.1.2.1
Design Step 6.1.2.2
Design Step 6.1.2.3
Design Step 6.1.2.4
Design Step 6.1.2.5
Design Step 6.1.2.6
SUBSTRUCTURE

Integral Abutment Design

Start

Generate applied dead load and live load for the abutment components.

Determine controlling limit state. Factor the loads according to Table S3.4.1-1 to be applied for pile design.

Check pile compressive resistance (S6.15 and S6.9.2). Determine number of piles and corresponding spacing.

Design pile cap reinforcement. Check flexure and shear.

Check the flexure and shear resistance of the backwall.

Design wingwall

Design approach slab for flexure

End

Section in Example

Design Step 7.1.1

Design Step 7.1.2

Design Step 7.1.3.1

Design Step 7.1.4

Design Step 7.1.4.1

Design Step 7.1.5

Design Step 7.1.6
Intermediate Bent Design

1. Generate the loads applied to the intermediate bent components.
2. Determine maximum loads transferred from the superstructure.
3. Analyze the pier cap. Determine the locations of maximum positive moment, negative moment and shear.
4. Design flexural and shear reinforcement in the pier cap.
5. Check limits of reinforcement (S5.7.3.3).
6. Check flexural reinforcement distribution (S5.7.3.4).
7. Check minimum temperature and shrinkage steel (S5.10.8).

Section in Example

Design Step 7.2.1

Design Step 7.2.2

Design Step 7.2.2.4
Intermediate Bent Design (cont.)

1. Check skin reinforcement in components where $d_e$ exceeds 3.0 ft. (S5.7.3.4)

2. Design the columns. Determine the maximum moments and shears in the column

3. Check limits for reinforcement in compression members (S5.7.4.2)

4. Develop the column interaction curve

5. Check slenderness provisions for concrete columns (S5.7.4.3)

6. Determine transverse reinforcement for a compressive member (S5.10.6)

7. Design the footing. Determine applied moments and shears transmitted from the columns

Section in Example

- Design Step 7.2.2.5
- Design Step 7.2.3
- Design Step 7.2.3.1
- Design Step 7.2.3.2
- Design Step 7.2.4
Intermediate Bent Design (cont.)

1. Check flexural resistance (S5.7.3.2)

2. Check maximum and minimum reinforcement (S5.7.3.3)

3. Check distribution of reinforcement for cracking in the concrete (S5.7.3.4)

4. Design footing for maximum shear in the longitudinal and transverse directions (one-way shear and punching (two-way) shear)

5. Foundation soil resistance at the Strength Limit State (S10.6.3)

End

Section in Example

Design Step 7.2.4.1
Design Step 7.2.4.2
Design Step 7.2.4.3
Design Step 7.2.4.4
Design Step 7.2.4.5