2. EXAMPLE BRIDGE

2.1 Bridge geometry and materials

Bridge superstructure geometry

Superstructure type:	Reinforced concrete deck supported on simple span prestressed girders made continuous for live load.
Spans:	Two spans at 110 ft. each
Width:	55'-4 ½" total 52'-0" gutter line-to-gutter line (Three lanes 12'- 0" wide each, 10 ft. right shoulder and 6 ft. left shoulder. For superstructure design, the location of the driving lanes can be anywhere on the structure. For substructure design, the maximum number of 12 ft. wide lanes, i.e., 4 lanes, is considered)
Railings:	Concrete Type F-Parapets, 1'- 8 ¼" wide at the base
Skew:	20 degrees, valid at each support location
Girder spacing:	9'-8"
Girder type:	AASHTO Type VI Girders, 72 in. deep, 42 in. wide top flange and 28 in. wide bottom flange (AASHTO 28/72 Girders)
Strand arrangement:	Straight strands with some strands debonded near the ends of the girders
Overhang:	3'-6 ¼" from the centerline of the fascia girder to the end of the overhang
Intermediate diaphragms:	For load calculations, one intermediate diaphragm, 10 in. thick, 50 in. deep, is assumed at the middle of each span.

Figures 2-1 and 2-2 show an elevation and cross-section of the superstructure, respectively. Figure 2-3 through 2-6 show the girder dimensions, strand arrangement, support locations and strand debonding locations.

Typically, for a specific jurisdiction, a relatively small number of girder sizes are available to select from. The initial girder size is usually selected based on past experience. Many jurisdictions have a design aid in the form of a table that determines the most likely girder size for each combination of span length and girder spacing. Such tables developed using the HS-25 live loading of the AASHTO Standard Specifications are expected to be applicable to the bridges designed using the AASHTO-LRFD Specifications.

The strand pattern and number of strands was initially determined based on past experience and subsequently refined using a computer design program. This design was refined using trial and error until a pattern produced stresses, at transfer and under service loads, that fell within the permissible stress limits and produced load resistances greater than the applied loads under the strength limit states. For debonded strands, S5.11.4.3 states that the number of partially debonded strands should not exceed 25 percent of the total number of strands. Also, the number of debonded strands in any horizontal row shall not exceed 40 percent of the strands in that row. The selected pattern has 27.2 percent of the total strands debonded. This is slightly higher than the 25 percent stated in the specifications, but is acceptable since the specifications require that this limit "should" be satisfied. Using the word "should" instead of "shall" signifies that the specifications allow some deviation from the limit of 25 percent.

Typically, the most economical strand arrangement calls for the strands to be located as close as possible to the bottom of the girders. However, in some cases, it may not be possible to satisfy all specification requirements while keeping the girder size to a minimum and keeping the strands near the bottom of the beam. This is more pronounced when debonded strands are used due to the limitation on the percentage of debonded strands. In such cases, the designer may consider the following two solutions:

- *Increase the size of the girder to reduce the range of stress, i.e., the difference between the stress at transfer and the stress at final stage.*
- *Increase the number of strands and shift the center of gravity of the strands upward.*

Either solution results in some loss of economy. The designer should consider specific site conditions (e.g., cost of the deeper girder, cost of the additional strands, the available under-clearance and cost of raising the approach roadway to accommodate deeper girders) when determining which solution to adopt.

Bridge substructure geometry

Intermediate pier: Multi-column bent (4 – columns spaced at 14'-1")
Spread footings founded on sandy soil
See Figure 2-7 for the intermediate pier geometry

End abutments: Integral abutments supported on one line of steel H-piles supported on bedrock. U-wingwalls are cantilevered from the fill face of the abutment. The approach slab is supported on the integral abutment at one end and a sleeper slab at the other end.
See Figure 2-8 for the integral abutment geometry

Materials

<u>Concrete strength</u>

Prestressed girders: Initial strength at transfer, f'_{ci} = 4.8 ksi
28-day strength, f'_c = 6 ksi
Deck slab: 4.0 ksi
Substructure: 3.0 ksi
Railings: 3.5 ksi

<u>Concrete elastic modulus</u> (calculated using S5.4.2.4)
Girder final elastic modulus, E_c = 4,696 ksi
Girder elastic modulus at transfer, E_{ci} = 4,200 ksi
Deck slab elastic modulus, E_s = 3,834 ksi

<u>Reinforcing steel</u>
Yield strength, f_y = 60 ksi

<u>Prestressing strands</u>
0.5 inch diameter low relaxation strands Grade 270
Strand area, A_{ps} = 0.153 in^2
Steel yield strength, f_{py} = 243 ksi
Steel ultimate strength, f_{pu} = 270 ksi
Prestressing steel modulus, E_p = 28,500 ksi

Other parameters affecting girder analysis

Time of Transfer = 1 day
Average Humidity = 70%

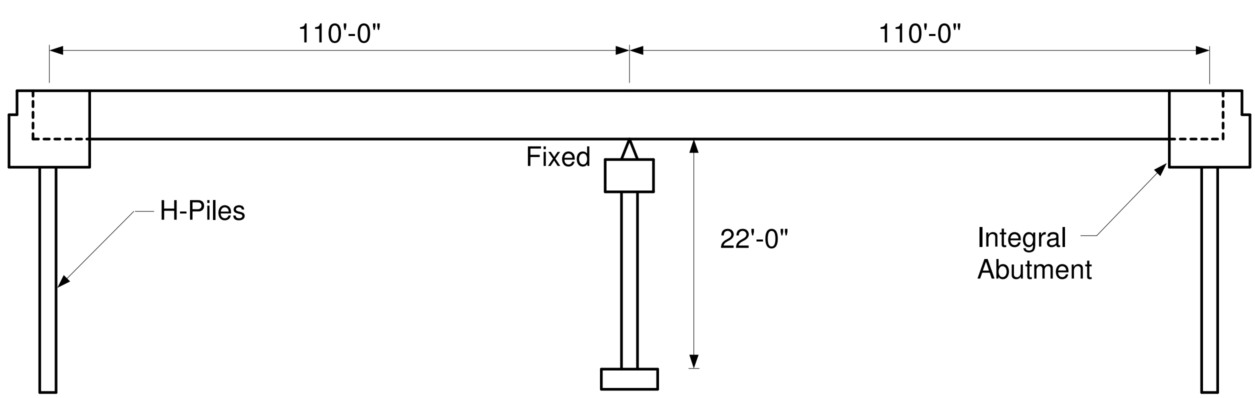


Figure 2-1 – Elevation View of the Example Bridge

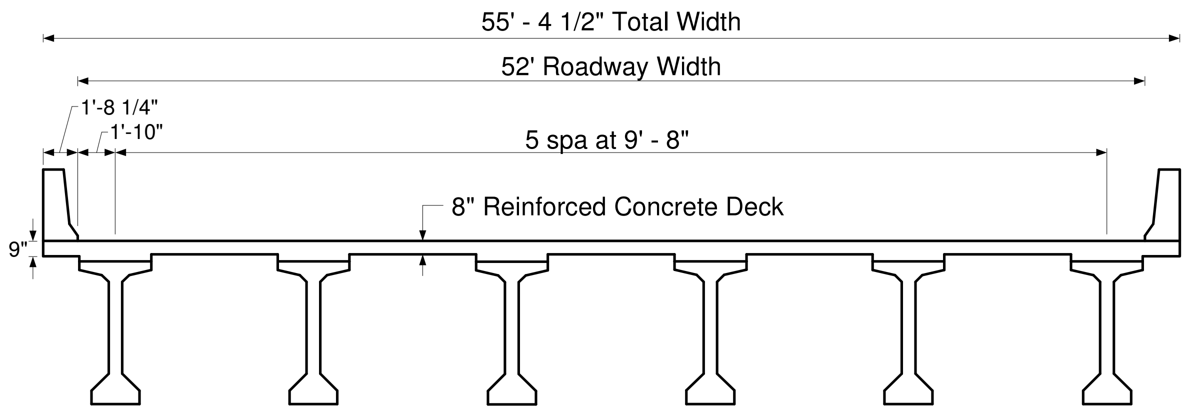


Figure 2-2 – Bridge Cross-Section

2.2 Girder geometry and section properties

Basic beam section properties

Beam length, L	= 110 ft. – 6 in.
Depth	= 72 in.
Thickness of web	= 8 in.
Area, A_g	= 1,085 in^2
Moment of inertia, I_g	= 733,320 in^4
N.A. to top, y_t	= 35.62 in.
N.A. to bottom, y_b	= 36.38 in.
Section modulus, S_{TOP}	= 20,588 in^3
Section modulus, S_{BOT}	= 20,157 in^3
CGS from bottom, at 0 ft.	= 5.375 in.
CGS from bottom, at 11 ft.	= 5.158 in.
CGS from bottom, at 54.5 ft.	= 5.0 in.
P/S force eccentricity at 0 ft., $e_{0'}$	= 31.005 in.
P/S force eccentricity at 11 ft., $e_{11'}$	= 31.222 in.
P/S force eccentricity at 54.5 ft, $e_{54.5'}$	= 31.380 in.

Interior beam composite section properties

Effective slab width = 111 in. (see calculations in Section 2.3)

Deck slab thickness = 8 in. (includes ½ in. integral wearing surface which is not included in the calculation of the composite section properties)

Haunch depth = 4 in. (maximum value - notice that the haunch depth varies along the beam length and, hence, is ignored in calculating section properties but is considered when determining dead load)

Moment of inertia, I_c = 1,384,254 in^4
N.A. to slab top, y_{sc} = 27.96 in.
N.A. to beam top, y_{tc} = 20.46 in.
N.A. to beam bottom, y_{bc} = 51.54 in.
Section modulus, $S_{TOP\ SLAB}$ = 49,517 in^3
Section modulus, $S_{TOP\ BEAM}$ = 67,672 in^3
Section modulus, $S_{BOT\ BEAM}$ = 26,855 in^3

Exterior beam composite section properties

Effective Slab Width = 97.75 in. (see calculations in Section 2.3)

Deck slab thickness = 8 in. (includes ½ in. integral wearing surface which is not included in the calculation of the composite section properties)

Haunch depth = 4 in. (maximum value - notice that the haunch depth varies along the beam length and, hence, is ignored in calculating section properties but is considered when determining dead load)

Moment of inertia, I_c = 1,334,042 in^4
N.A. to slab top, y_{sc} = 29.12 in.
N.A. to beam top, y_{tc} = 21.62 in.
N.A. to beam bottom, y_{bc} = 50.38 in.
Section modulus, $S_{TOP\ SLAB}$ = 45,809 in^3
Section modulus, $S_{TOP\ BEAM}$ = 61,699 in^3
Section modulus, $S_{BOT\ BEAM}$ = 26,481 in^3

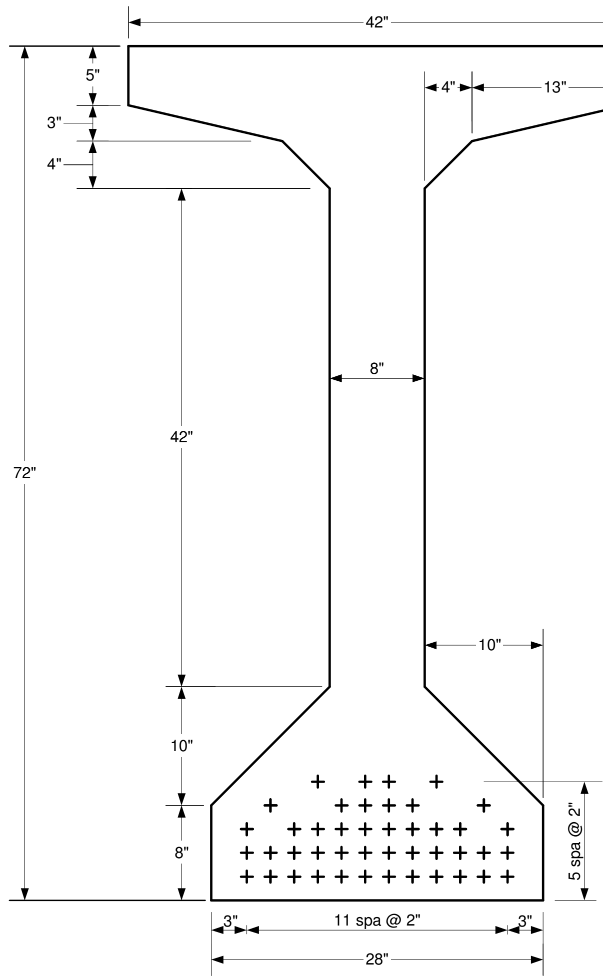


Figure 2-3 – Beam Cross-Section Showing 44 Strands

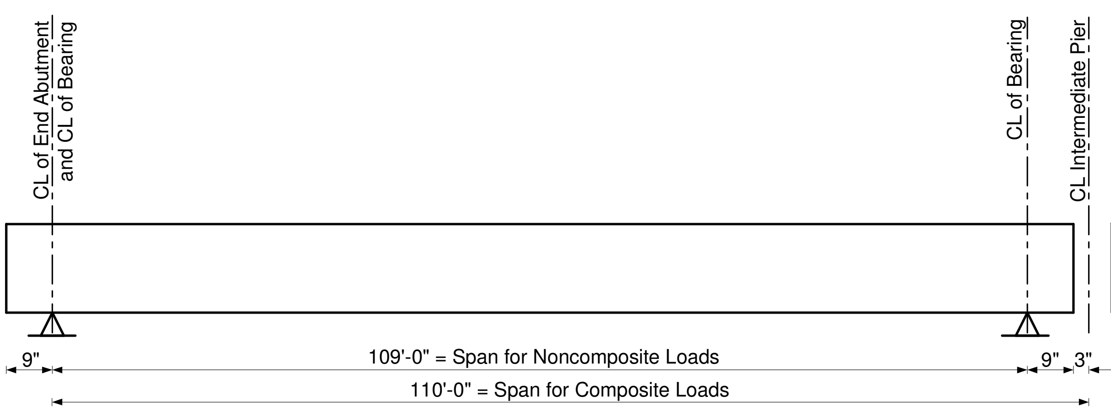


Figure 2-4 – General Beam Elevation

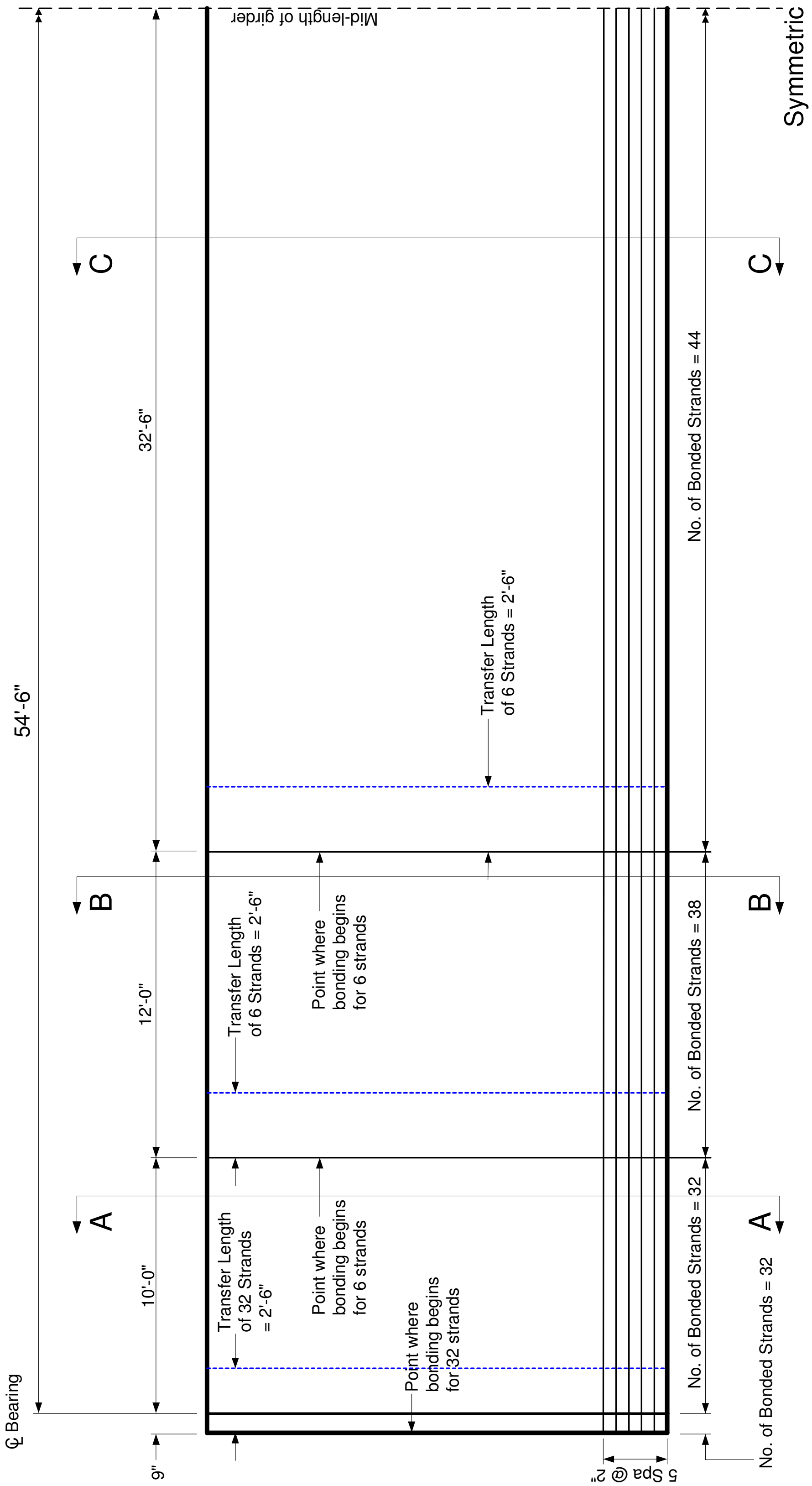
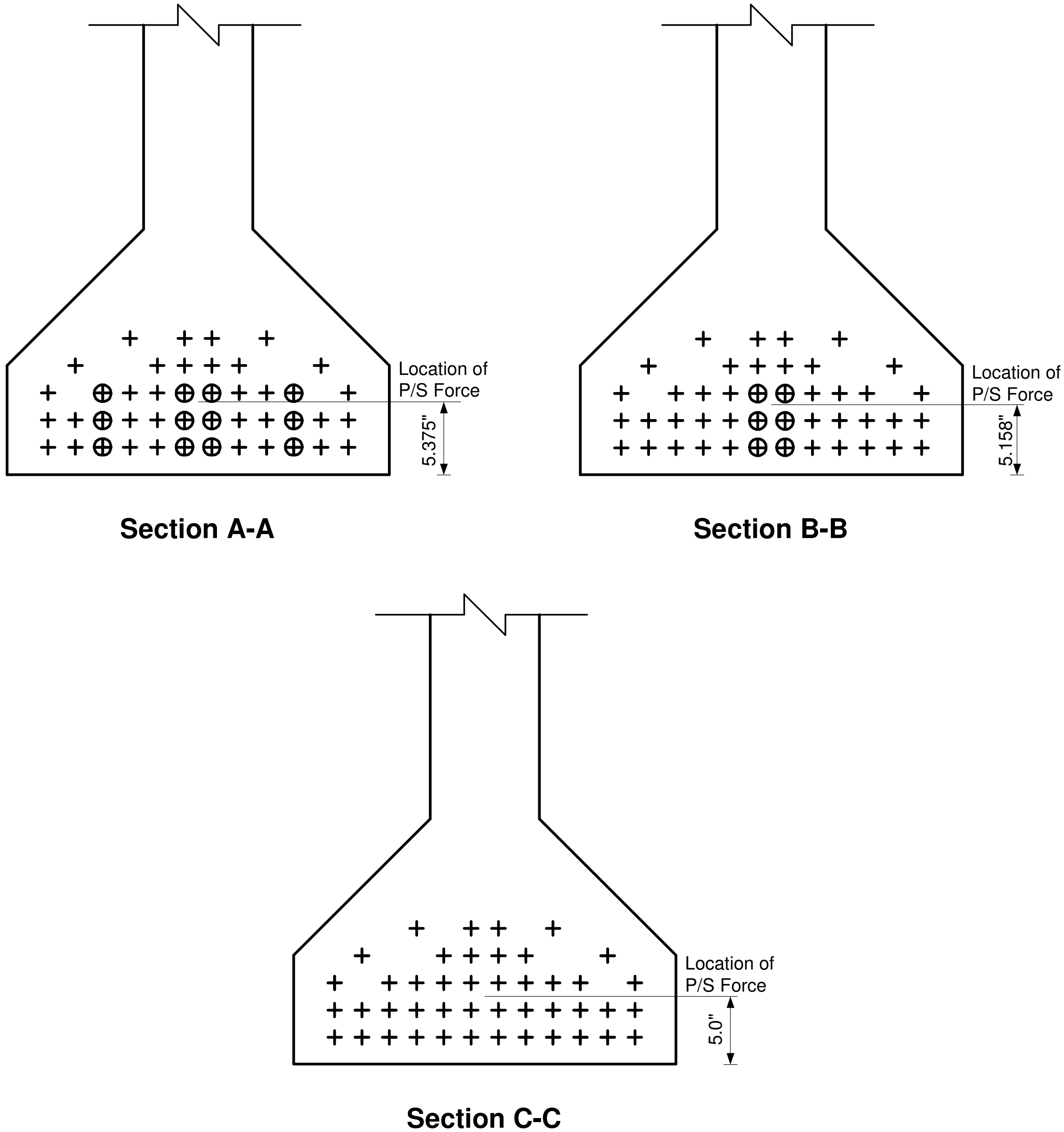


Figure 2-5 – Elevation View of Prestressing Strands



+ - Bonded Strand

⊕- Debonded Strand

For location of Sections A-A, B-B and C-C, see Figure 2-5

Figure 2-6 – Beam at Sections A-A, B-B, and C-C

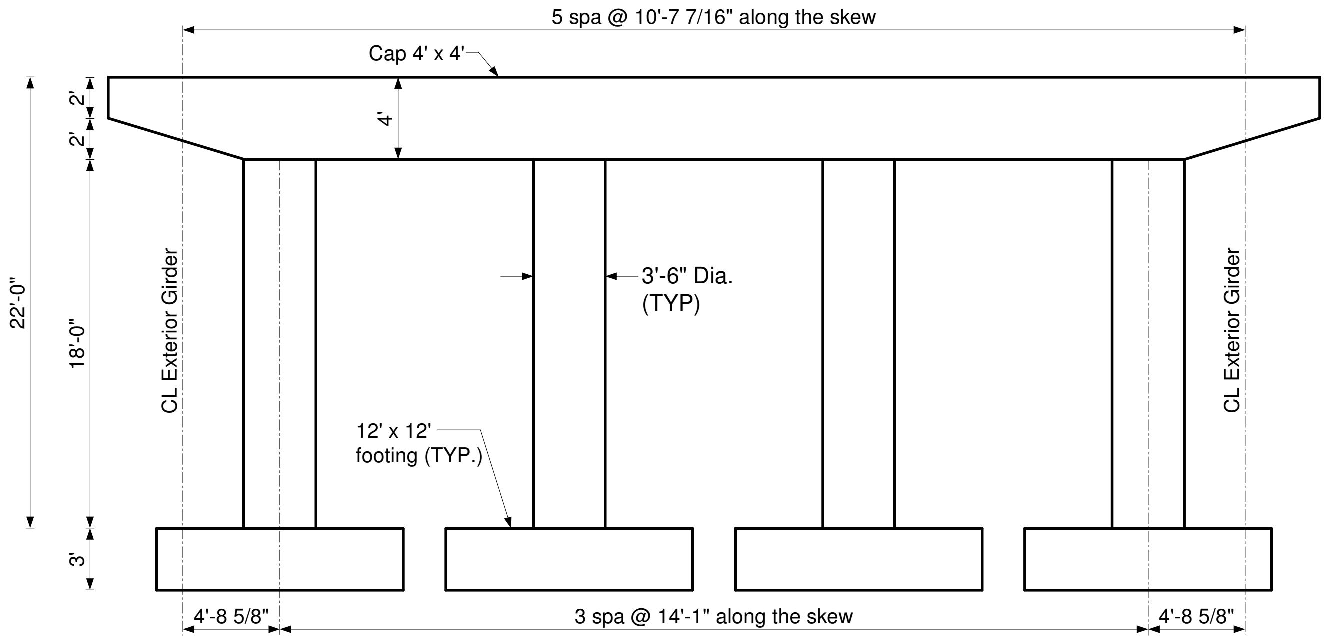


Figure 2-7 – Intermediate Bent

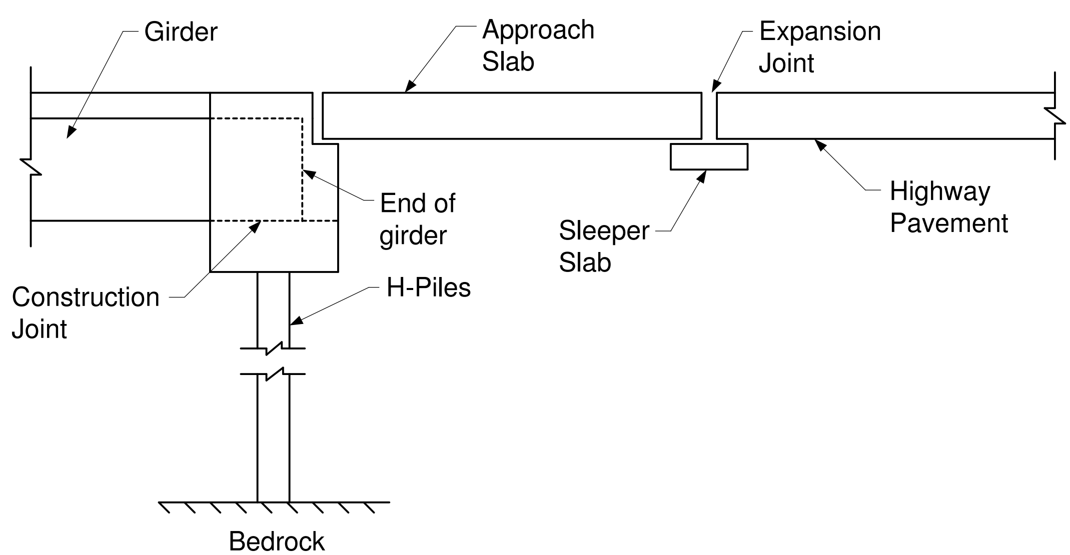


Figure 2-8 – Integral Abutment

2.3 Effective flange width (S4.6.2.6)

Longitudinal stresses in the flanges are distributed across the flange and the composite deck slab by in-plane shear stresses, therefore, the longitudinal stresses are not uniform. The effective flange width is a reduced width over which the longitudinal stresses are assumed to be uniformly distributed and yet result in the same force as the non-uniform stress distribution if integrated over the entire width.

The effective flange width is calculated using the provisions of S4.6.2.6. See the bulleted list at the end of this section for a few S4.6.2.6 requirements. According to S4.6.2.6.1, the effective flange width may be calculated as follows:

For interior girders:
The effective flange width is taken as the least of the following:

- One-quarter of the effective span length = 0.25(82.5)(12)
  = 247.5 in.

- 12.0 times the average thickness of the slab,
  plus the greater of the web thickness = 12(7.5) + 8 = 104 in.
  or
  one-half the width of the top flange of the girder = 12(7.5) + 0.5(42)
  = <u>111 in.</u>

- The average spacing of adjacent beams = 9 ft.- 8 in. or 116 in.

The effective flange width for the interior beam is 111 in.

For exterior girders:
The effective flange width is taken as one-half the effective width of the adjacent interior girder *plus* the least of:

- One-eighth of the effective span length = 0.125(82.5)(12)
  = 123.75 in.

- 6.0 times the average thickness of the slab,
  plus the greater of half the web thickness = 6.0(7.5) + 0.5(8)
  = 49 in.

  or
  one-quarter of the width of the top flange
  of the basic girder = 6.0(7.5) + 0.25(42)
  = 55.5 in.

- The width of the overhang = 3 ft.- 6 ¼ in. or <u>42.25 in.</u>

Therefore, the effective flange width for the exterior girder is:

(111/2) + 42.25 = 97.75 in.

Notice that:

- *The effective span length used in calculating the effective flange width may be taken as the actual span length for simply supported spans or as the distance between points of permanent dead load inflection for continuous spans, as specified in S4.6.2.6.1. For analysis of I-shaped girders, the effective flange width is typically calculated based on the effective span for positive moments and is used along the entire length of the beam.*

- *The slab thickness used in the analysis is the effective slab thickness ignoring any sacrificial layers (i.e., integral wearing surfaces)*

- *S4.5 allows the consideration of continuous barriers when analyzing for service and fatigue limit states. The commentary of S4.6.2.6.1 includes an approximate method of including the effect of the continuous barriers on the section by modifying the width of the overhang. Traditionally, the effect of the continuous barrier on the section is ignored in the design of new bridges and is ignored in this example. This effect may be considered when checking existing bridges with structurally sound continuous barriers.*

- *Simple-span girders made continuous behave as continuous beams for all loads applied after the deck slab hardens. For two-equal span girders, the effective length of each span, measured as the distance from the center of the end support to the inflection point for composite dead loads (load is assumed to be distributed uniformly along the length of the girders), is 0.75 the length of the span.*