APPENDIX F – MODELING ASSUMPTIONS

Steel I Sections, Cast-In-Place Concrete Tee Beams, Concrete I Sections and Bulb Tee Sections (AASHTO Types A, E, & K)

These slab-on-girder section types are modeled using standard grillage techniques. All elements are modeled using a basic three-dimensional frame element. Bridges of types *a* and *k* are assumed to be composite.

The section properties of the longitudinal girders are computed using the material properties of the deck. The composite area, moment of inertia, and torsional constant are computed for the girder and then transformed to the deck material by multiplying them by the modular ratio. The moment of inertia is computed considering the composite neutral axis and the parallel axis theorem. These values are then output to the grillage model. For the concrete tee beams (type *e*), the sections properties for the beams are simply computed and used.

The deck elements properties are computed based on a tributary area approach. Each deck element is assumed to have the height of the deck thickness and the width of half the deck element spacing on each side of the element being considered. For type *e* bridges, the deck element properties are computed using the thickness of the top flange of the tee section.

Cast-In-Place Multicell Box Beams (AASHTO Type D)

The grillage analysis of cast-in-place multicell box beam bridges is based on the work of Song, et al (120). A method for modeling these types of bridges using a grillage method is outlined in this paper and summarized here.

A grillage model was compared with a finite element model using shell elements for all member components. It was shown that the bending moment from the grillage model compared very well with the bending moment computed from the shell element model. The maximum moment from the shell element model was about 5% larger than that from the grillage model. At other locations, the moment from the grillage model was generally within 5% of the finite element model. Good agreement between the two models was also shown for the shear force distribution and deflections. The difference in the deflections was generally less than 5%.

The following procedure for the calculation of grillage properties has been taken directly from the report.

Longitudinal Girders. The longitudinal girders are generally divided into interior and exterior girders, with one set of section properties for the interior girders, and another set of properties for the exterior girders.

- Moments of Inertia -
- Figure **F-1** shows the tributary area used for calculating the moment of inertia for exterior and interior girders of the box-girder bridge. The moment of inertia is first calculated about the centroidal axis of the individual girder, and then transformed to the centroidal axis of the entire box-girder using the parallel axis theorem. The resulting I-values about the centroidal axis of the entire box-girder are then used for the grillage model.
- Shear Areas – The shear force in the box-girder is assumed to be resisted entirely by the webs. The shear of the longitudinal girder is given by:

$$A_s = (h)(t_w) \tag{F-1}$$

where h = height of the web, and t_w = thickness of the web.

For an inclined web, the appropriate shear area is less obvious, but its influence on the distribution of internal forces is not significant since the response of the girders is dominated by flexural deformation. Consequently, Equation B-1 is also used to estimate the shear area of an inclined web.

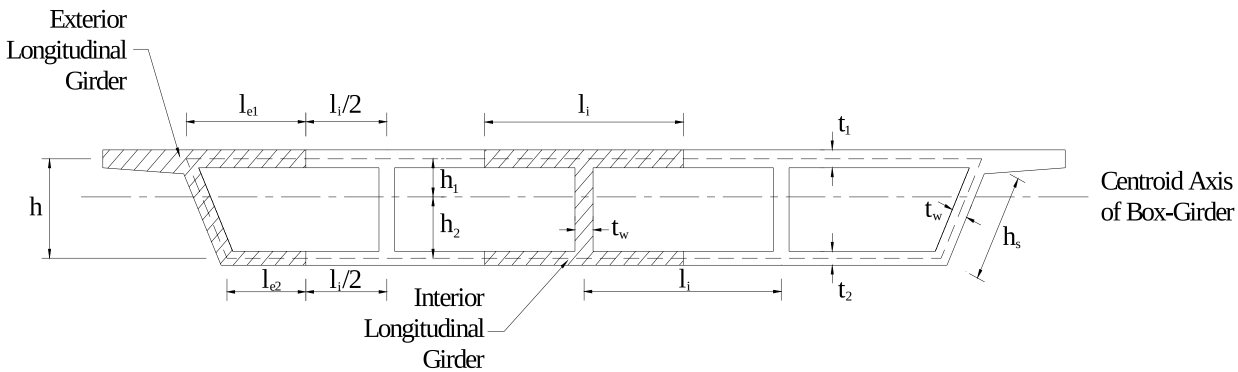

Figure F-1: Tributary Area for Calculating the Moment of Inertia of Exterior and Interior Longitudinal Girders

- <u>Torsional Constants</u> – The torsional rigidity of the box-girder is assumed to be provided by the closed section as shown in Figure F-2, with no contributions to torsional rigidity from the interior webs or the overhang portion of the top flange. The torsional constant per unit width *c* of the box-girder is approximated by:

$$c = \frac{2h^2 t_1 t_2}{t_1 + t_2} \tag{F-2}$$

where h = height of the box-girder, t_1 and t_2 = top and bottom flange thickness, respectively. For the exterior longitudinal girders of the grillage model, the torsional constant is given by the torsional constant per unit width c times the equivalent width of the exterior girder l_e* i.e.,

$$C_{ext} = cl_e^* = \frac{2h^2 t_1 t_2 l_e^*}{t_1 + t_2} \tag{F-3}$$

where the equivalent width $l_e^* = \frac{1}{2}\left(l_{e1} + l_{e2}\right)$. For the interior longitudinal girders of the grillage model, the torsional constant is given by:

$$C_{\text{int}} = cl_i = \frac{2h^2 t_1 t_2 l_i}{t_1 + t_2} \tag{F-4}$$

where l_i = the distance between the webs of the box-girder for interior cells.

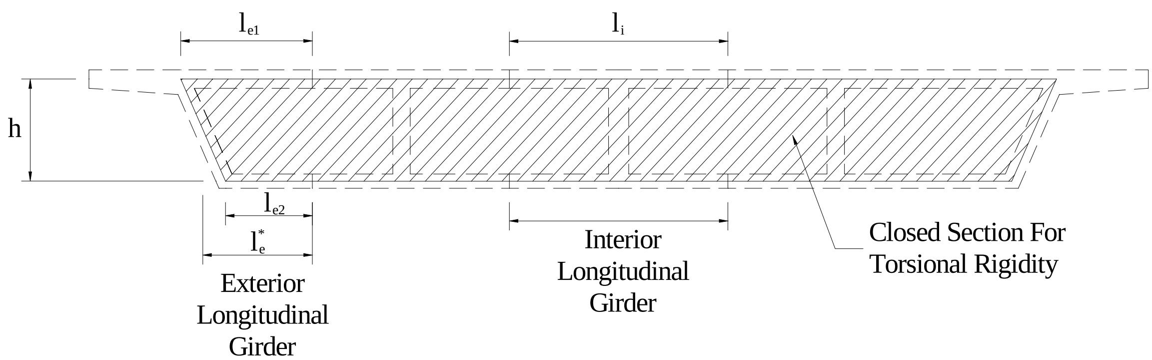

Figure F-2: Closed Section for Calculating the Torsional Constants of the Longitudinal Girders

Transverse Girders. Transverse girders of the grillage model are divided into exterior and interior girders as well. Top and bottom flanges as well as end diaphragms are included in the calculations for the section properties of the exterior transverse girder. For the interior transverse girders, however, only the top and bottom flanges are included unless intermediate diaphragms are present.

- Moment of Inertia -

- Figure **F-3** shows the tributary areas for the moment of inertia of the exterior and interior transverse girders. The I-values are taken about the centroidal axis of the entire box-girder, similar to the I-values for longitudinal girders. The moment of inertia per unit width of the transverse girder is given by:

$$i_{transverse} = \frac{1}{12}\left(t_1^3 + t_2^3\right) + t_1 h_1^2 + t_2 h_2^2 \qquad \text{(F-5)}$$

where h_1 and h_2 are the distances from the centroids of the top and bottom flanges to the centroid of the entire box-girder, respectively, and t_1 and t_2 are the thicknesses of the top and bottom flange, respectively. The I-value of the interior transverse girders without a middle diaphragm is given by:

$$I_{transverse}^{\text{int}} = \left(i_{transverse}\right)\left(l_{transverse}^{\text{int}}\right) \qquad \text{(F-6)}$$

where $l_{transverse}^{\text{int}}$ is the spacing of the transverse girders in the grillage model. For interior transverse girders with a diaphragm, and for exterior transverse girders with an end diaphragm, the moment of inertia of the diaphragm is added i.e.,

$$I_{transverse}^{\text{int}(with\ diaphragm)} = I_{diaphragm} + \left(\sum l_{eff}\right)\left(i_{transverse}\right) \qquad \text{(F-7)}$$

$$I_{transverse}^{ext} = I_{diaphragm} + \left(l_{end}\right)\left(i_{transverse}\right) \qquad \text{(F-8)}$$

where $I_{diaphragm}$ is the I-value of the diaphragm about the centroidal axis of the entire box-girder, $\sum l_{eff}$ is the sum of slab tributary lengths for the middle diaphragm, and l_{end} = tributary length for the end diaphragm (see Figure **F-3**). In this study, the spacing of the transverse girders is generally taken as one-tenth of the span length unless unusual geometry is encountered in the bridge structure.

- <u>Shear Areas</u> – For the transverse girder, an equivalent shear area is calculated to account for the possible distortion of the box-girder. The shear area is determined such that, for a given shear force, the shear deformation of the transverse grillage element is approximately equal to the distortion of the cells in the box-girder. Such an approach results in an equation for the shear area per unit with, which is given by:

$$a_s = \left(\frac{t_1^3 + t_2^3}{l_i^2}\right)\left[\frac{t_w^3 l_i}{t_w^3 l_i + \left(t_1^3 + t_2^3\right)h}\right]\frac{E}{G} \tag{F-9}$$

where E and G are Young's and shear moduli, respectively, and l_i = web distance for the interior cells. The ratio E/G may be replaced by $2(1+v)$ where v = Poisson's ratio. The shear area of the interior transverse girders without a middle diaphragm is given by:

$$As_{transverse}^{\text{int}} = a_s l_{transverse}^{\text{int}} = \left(\frac{t_1^3 + t_2^3}{l_i^2}\right)\left[\frac{t_w^3 l_i}{t_w^3 l_i + \left(t_1^3 + t_2^3\right)h}\right]\frac{E}{G} l_{transverse}^{\text{int}} \tag{F-10}$$

where $l_{transverse}^{\text{int}}$ is the spacing of the transverse girders in the grillage model. For interior transverse girders with a middle diaphragm, however, the shear area of the middle diaphragm is added, i.e.,

$$As_{transverse}^{\text{int}(with\ diaphragm)} = ht_{mid} + a_s\left(\sum l_{eff}\right) \tag{F-11}$$

where h is the height of the box-girder (center-to-center distance between the top flange and the bottom flanges), and t_{mid} is the thickness of the middle diaphragm, $\sum l_{eff}$ is the sum of slab tributary lengths for the interior transverse girder. For exterior transverse girders, the shear area of the end diaphragm is added as well, i.e.,

$$As_{transverse}^{ext} = ht_{end} + a_s l_{end} \tag{F-12}$$

where h = height of the box-girder (center-to-center distance between top and bottom flanges), and t_{end} = thickness of the end diaphragm, l_{end} = tributary area for the exterior transverse girder (see

Figure **F-3**).

- <u>Torsional Constants</u> – For transverse girders, the contributions to the torsional constant from the top and bottom flanges is the same as that in the longitudinal direction, and is given by equation F-2. For the interior transverse girders without a diaphragm, the torsional constant is thus given by:

$$C_{transverse}^{\text{int}} = \frac{2h^2 t_1 t_2 l_{transverse}^{\text{int}}}{t_1 + t_2} \tag{F-13}$$

For interior transverse girders with a middle diaphragm, the torsional constant is given by the sum of torsional constants from the middle diaphragm and the top and bottom flanges. Thus the torsional constant for the interior transverse girder is given by:

$$C_{transverse}^{\text{int}(with\ diaphragm)} = \frac{2h^2 t_1 t_2 \left(\sum l_{eff}\right)}{t_1 + t_2} + \frac{3}{10}\frac{h^3 t_{mid}^3}{\left(h^2 + t_{mid}^2\right)} \tag{F-14}$$

where $\sum l_{eff}$ is the sum of slab tributary lengths for the interior transverse girder with a middle diaphragm. For exterior transverse girders, the torsional constant is given by the sum of torsional constants from the end diaphragm and the top and bottom flanges. Thus the torsional constant for exterior transverse girders is given by:

$$C_{transverse}^{ext} = \frac{2h^2 t_1 t_2 l_{end}}{t_1 + t_2} + \frac{3}{10}\frac{h^3 t_{end}^3}{\left(h^2 + t_{end}^2\right)} \tag{F-15}$$

where l_{end} is the tributary length of the top and bottom flanges for the exterior transverse girder.

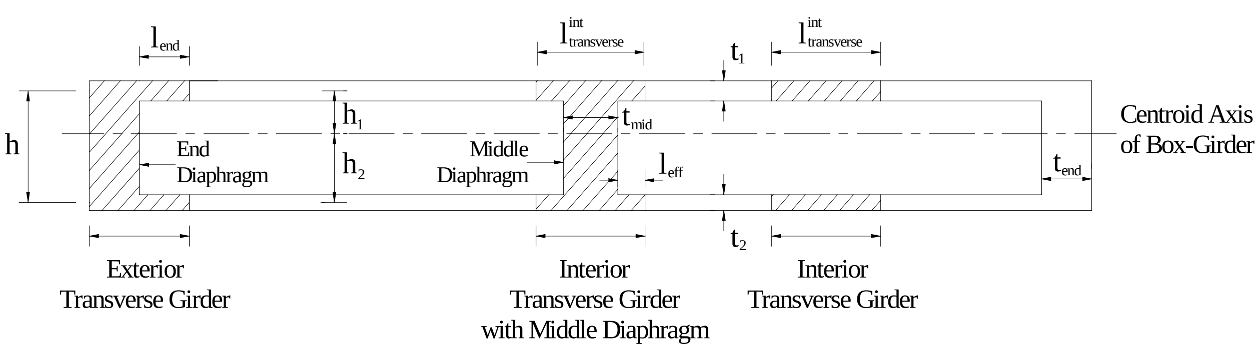

Figure F-3: Tributary Area for Moment of Inertia and Torsional Constants of Transverse Girders

NCHRP 12-26 Data

The data from the NCHRP 12-26 bridge set is only available in limited format. The format only includes the basic section properties of each girder or box. For example, Table F-1 shows the data available for steel slab-on-girder bridges from Arizona. The data available is not enough to generate a BRASS data file and calculate distribution factors using the various simplified methods and a grillage analysis.

Table F-1 – Sample NCHRP 12-26 Data

Arizona: Steel													
Seq. No.	Span Length (ft)	Width (E-E) (ft)	Skew Angle (deg)	Number of Girders	Girder Spacing (ft)	Girder Depth (ft)	Slab Thickness (in)	Overhang (ft)	Width (C-C) (ft)	Date	Eccentricity (in)	Girder Inertia (in^4)	Girder Area (in^2)
3	67.00	34.00	20.00	4	8.83	2.92	7.00	3.76	30.00	1961	21.69	11282.00	53.50
4	67.00	34.00	20.00	4	8.83	2.92	7.00	3.76	30.00	1961	21.69	11282.00	53.50
5	73.00	34.00	20.00	4	8.83	2.92	7.00	3.76	30.00	1961	21.69	11282.00	53.50
6	77.00	34.00	20.00	4	8.83	2.92	7.00	3.76	30.00	1961	21.69	11282.00	53.50
7	86.00	34.00	20.00	4	8.83	2.92	7.00	3.76	30.00	1961	21.69	11282.00	53.50
8	53.00	35.00	30.00	4	9.33	2.75	7.00	3.51	30.00	1958	20.05	6699.00	38.30
9	67.00	35.00	30.00	4	9.33	2.75	7.00	3.51	30.00	1958	20.05	6699.00	38.30
10	46.00	35.17	9.77	4	8.83	3.00	7.50	4.34	30.00	1959	21.75	9739.00	47.10
11	79.00	35.17	9.77	4	8.83	3.00	7.50	4.34	30.00	1959	21.75	9739.00	47.10
12	44.73	25.17	20.00	4	7.00	1.33	9.00	-	22.00	1934	-	-	-
13	30.00	34.00	0.00	5	7.50	2.00	7.75	2.00	32.00	1937	15.92	2364.00	24.70
14	40.00	34.00	0.00	5	7.50	2.00	7.75	2.00	32.00	1937	15.92	2364.00	24.70

In order to accurately model each bridge, the available data were converted into an equivalent cross section. Each girder depth, moment of inertia, area, and eccentricity is input into Microsoft Excel, and a program utilizing the Solver utility in Excel creates I-section dimensions that result in the same cross section properties as those listed in the NCHRP 12-26 tables. The values determined by the spreadsheet are top flange thickness, top flange width, web depth, web thickness, bottom flange thickness, and bottom flange width. Table F-2 shows the results of the generation of an equivalent I section for Seq. No. 5 from Table F-1.

Table F-2 – Generated Equivalent I Section Dimensions

Generated Properties For Arizona Steel Seq. No. 5		
I Section Dimension	Units	Value
web depth, d [1]	mm	838.4746027
web thickness tw [1]	mm	16.17265824
top flange width, bft [1]	mm	399.7907981
top flange thickness, tft [1]	mm	24.44464625
bottom flange width, bfb [1]	mm	399.9755299
bottom flange thickness, tfb [1]	mm	27.87264556

It should be noted that multiple span bridges used in the NCHRP 12-26 study were split into single span bridges for analysis. In other words, a three span bridge with spans of 100 feet, 120 feet, and 130 feet would be entered into the dataset as three separate single-span bridges, one of 100 feet, one of 120 feet, and one of 130 feet. Note that Seq. Nos. 5, 6, and 7 from Table F-1 have the same properties except for the span length. These three entries represent one three-span bridge that was split into three separate bridges. For the purposes of this research, we re-combined the bridges that were obviously taken from a multi-span bridge. Therefore, the number of bridges analyzed will be less than the number listed as included in the NCHRP 12-26 study.