Composite Steel I-girder Bridges

1. Behavior of Composite Steel I-Girder Bridges (7.1.1)
2. Steel I-Girder Bridge Grid-Modeling Consideration (7.1.3)
3. Principle and Modeling of Steel I-Girder Bridges (7.2)
4. Behavior of Composite Steel Box-Girder Bridges (8.1)
5. Principle and Modeling of Steel Box-Girder Bridges (8.2)

Principle and Modeling of Steel I-girder Bridges

1. Beam Charts: standard beam design charts and other design aids for approximate analysis:
2. Line Girder Analysis Method: “approximate” method in the AASHTO LF
3. Grid Analysis Method
4. Plate and Eccentric Beam Analysis Methods
5. 3D FEM Analysis Methods (next)
Line Girder Modeling

AASHTO LRFD live load distribution factor design equations for shear and moment is recommended for rating.

- Assumed constant deck width, parallel beams with about the same stiffness
- Developed for "design" trucks
- Developed to bound within that structural type
- Limited ranges of applicability. (When exceeded, the LRFD specifications mandate refined analysis.)

Influence Lines for Moment & Shear

- Moment
- Shear

Composite Steel I-girder Stresses

- Total normal stress: a combination of axial stress, major axis bending stress, minor axis bending stress (not included), and warping normal (lateral bending) stress.
- Total shear stress is the sum of vertical shear stress, horizontal shear stress (not included), St. Venant torsional shear stress (generally relatively small), and warping shear stress (ignored due to different locations).

Grid Analysis

- Default support condition:
  1. Vertical fix
  2. Bending & torsional free (may be altered by spring constants, explained later)
- Girders: Special-made curved element or conventional straight element
- Cross-frames: X-, K- or invert K- type; internally converted from the flexibility matrix to 3 x 3 stiffness matrix, functionally similar to the Timoshenko beam with 3 D.O.F. at each end.
- Diaphragms: Diaphragm is considered as conventional transverse girder with 3 D.O.F.
- Deck/connection of the deck to girders: Composite action is considered for the longitudinal girders, Equivalent deck area between nodes may be considered for deck action.
Steel I-girder Bridge Grid Modeling Consideration

- The original torsional constant for most common structural shapes, $J$, can be approximated by Equation 7.2 $J = \sum bt^3 / 3$
- The effective (equivalent) torsional constant, $K_{te}$, developed by Fu and Hsu (1994), can be expressed as
  $$K_{te} = J \frac{\cosh \frac{h}{2}}{\cosh \frac{h}{2} - 1.0} C$$
- NCHRP Project 12-79 Report 725 (2012) with two equivalent equations with warping fixity at each end of a given unbraced length $L_p$ (equation 7.5a) and warping fixity at one end and warping free boundary conditions (Equation 7.5b) where $J_{eq}$ is equivalent to $K_{te}$ in Equation 7.3.
  $$J_{eq}(\phi - \phi) = J \left[ 1 - \frac{\sinh(\phi L_p)}{\phi L_p} + \frac{[\cosh(\phi L_p) - 1]^2}{\phi L_p \sinh(\phi L_p)} \right]^{\frac{1}{2}}$$
  $$J_{eq}(\phi - \phi) = J \left[ 1 - \frac{\sinh(\phi L_p)}{\phi L_p \cosh(\phi L_p)} \right]^{\frac{1}{2}}$$

Steel I-girder Bridge Grid Modeling Consideration

A shear-deformable (Timoshenko) beam element representation of the cross-frame.

1. The equivalent moment of inertia is determined first based on pure flexural deformation of the cross-frame (zero-shear). The cross-frame is supported as a cantilever at one end, and is subjected to a force couple applied at the corner joints at the other end (Figure 7.5)

   $$I_{eq} = \frac{ML}{\theta}$$

   $$\theta = \frac{2a}{L}$$

2. Using an equivalent Timoshenko beam element rather than an Euler-Bernoulli element, the cross-frame is still supported as a cantilever but is subjected to a unit transverse shear at its tip (Figure 7.6).

   $$A_{eq} = \frac{V_{L}}{G(\frac{V_{L}}{30} \delta_{eq})}$$

Principle and Modeling of Steel I-girder Bridges

5. 3D FEM Analysis Methods
   - In-plane shell -beam model
   - 3D brick-shell model
   - 3D shell-beam model
   - 3D shell-shell model
   - 3D brick-beam model

Modeling of Steel I-girder Bridges – 3D FEM Analysis

Table 7.1 – Conversion of FEM stress resultants to beam moments and shears

<table>
<thead>
<tr>
<th>GIRDER #1</th>
<th>MAX</th>
<th>FORCES</th>
<th>0.28 k-N</th>
<th>3.19 k-N</th>
<th>0.58 k-N</th>
<th>9.95 k-N</th>
<th>1.12 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>top &amp; bottom length</td>
<td>4.0 ft</td>
<td>side length</td>
<td>2.234 ft</td>
<td>thickness</td>
<td>0.052 ft</td>
<td>top element h shear</td>
<td>883.38 k</td>
</tr>
<tr>
<td>bottom element h shear</td>
<td>-1009.66 k</td>
<td>bottom element v shear</td>
<td>-378.38 k</td>
<td>-117.29 k</td>
<td>1.12 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TORSION</td>
<td>-2.45 k-N</td>
<td>MOMENT</td>
<td>3114.33 k-ft</td>
<td>108.29 k</td>
<td>SHEAR</td>
<td>-635.01 k</td>
<td>1.12 ft</td>
</tr>
</tbody>
</table>

$\theta = \frac{2a}{L}$

$I_{eq} = \frac{ML}{\theta}$

$A_{eq} = \frac{V_{L}}{G(\frac{V_{L}}{30} \delta_{eq})}$
Principle and Modeling of Steel I-girder Bridges

- Sample Influence Surfaces of a Curved Steel I-girder Bridges (a) Inner Girder In-span Bending Moment at C; (b) Inner Girder Interior Support Bending Moment at G; (c) Outer Girder Interior Support Bending Moment at D; (d) Second Interior Girder Interior Support Reaction at F

Grid Model Spring Elements to model Different Boundary Conditions
(Ramp FR-A over SR 6060, Pittsburgh, PA)

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Figure 8.1 - Steel box girders:
(a) Unstiffened closed box girder;
(b) Unstiffened tub girder with lateral bracing;
(c) Stiffened closed box girder

Equivalent thickness of the top bracing for the quasi-closed box

<table>
<thead>
<tr>
<th>Type No.</th>
<th>Type of lateral bracing</th>
<th>Equivalent thickness $t_{eq}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\frac{2b}{A_f}$ + $\frac{4d}{A_d} + \frac{2l}{(3A_d)}$</td>
<td>$\frac{E}{G}d^3/3A_d + \frac{2lb}{A_f}$</td>
</tr>
<tr>
<td>2</td>
<td>$\frac{2b}{A_f}$ + $\frac{4d}{A_d} + \frac{4b}{A_v} + \frac{\lambda^2}{(6A_d)}$</td>
<td>$\frac{E}{G}d^3/(2A_d) + \frac{2lb}{(6A_d)}$</td>
</tr>
<tr>
<td>3</td>
<td>$\frac{2b}{A_f}$ + $\frac{4d}{A_d} + \frac{\lambda^2}{(6A_d)}$</td>
<td>$\frac{E}{G}d^3/(2A_d) + \frac{\lambda^2}{(6A_d)}$</td>
</tr>
<tr>
<td>4</td>
<td>$\frac{2b}{A_f}$ + $\frac{4d}{A_d} + \frac{\lambda^2}{(6A_d)}$</td>
<td>$\frac{E}{G}d^3/(2A_d) + \frac{\lambda^2}{(6A_d)}$</td>
</tr>
</tbody>
</table>

Composite Steel Box-girder Bridges

- Figure 8.9 illustrates the general box girder normal stresses which can occur in a curved or skewed box-shaped girder.
- Closed box sections are extremely efficient at carrying torsion by means of St. Venant torsional shear flow (Figure 8.10). When combined with vertical shear in the webs, this shear flow is always subtractive in one web and additive in the other.
Box Girder Bottom Flange under In-plane Action

(a) Unstiffened plate with small aspect ratio a/b
(b) Unstiffened plate with large aspect ratio a/b
(c) Stiffened plate

Modeling of a Twin-box Girder Bridge

• 2D Grillage model
• 3D Brick-Shell model
• 3D Shell-Shell model

High Load Multi-Rotational bearings for Girder Bridges

(a) Disk bearing
(b) Pot bearing
(c) Spherical bearing

3D Beam Element Model with Boundary Conditions and Their Reactions