USS

Structural Report
Analysis and Design of Horizontally Curved Steel Bridge Girders
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Prepared for United States Steel Corporation

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1. The California Division of Highways designed this steel curved girder approach for their Pasadena-Golden State Freeway located in Los Angeles.

2. The smooth lines used on this North Freeway overpass in Houston, Texas, typify the design freedom curved steel girder's afford.

3. Notice the sweeping lines of the upper overpass utilizing the curved girder design in comparison to the lower one that uses the short, simple-span chord stringers.
Why curved steel girders?

Fifty years ago, highway bridges were located by determining the most convenient crossing site, with little or no regard to the general alignment of the roadway. After the bridge location was established, the highway designer or surveyor laid out the highway to meet the bridge.

During the last several decades, this situation has reversed and now bridges must fit the highway alignment that has been predetermined by many other considerations. The increasingly frequent occurrence of structures on curved alignment is presenting real problems to engineers, especially in the design of urban freeways where multi-level interchanges must be built within tight geometric restrictions.

The present day emphasis on good appearance is also an important factor. Welding has helped to produce structures with smooth surfaces, interrupted by a minimum amount of detail. Outside vertical stiffeners are no longer used on many highway girders. There is a general streamlining of parapets, railings, expansion details, concrete deckwork, and lighting fixtures.

The use of curved supporting beams or girders in a structure on curved alignment is a natural outgrowth of this trend toward aesthetic design. However, such practice has been slow in gaining widespread acceptance, due to the difficulty in mathematically analyzing curved girders.

A number of curved steel girder bridges have been designed and built since 1950. Pictures of several of these bridges are shown in this brochure. Photograph No. 1 shows a curved ramp superstructure consisting of four curved girders tied together by diaphragms and a lateral system. This ramp is part of the Pasadena Golden State Freeway located in Los Angeles, California. Another curved girder bridge built in Houston, Texas, appears in Photograph No. 2. Photograph No. 4 shows the superstructure of a curved ramp for the Intercity Viaduct in Kansas City, Kansas. It consists of two welded continuous girders connected by floorbeams spaced at intervals along the span.

Along with aesthetic considerations, curved girders offer certain technical advantages where structures must be built to fit curved highway alignment. The roadway slab design and construction become much simpler because the stringer spacing and parapet overhang from the exterior stringer are constant over the entire length of structure. This provides equally spaced slab reinforcement, a more uniform stress distribution, and panel forms which can be re-used as pouring progresses.

In addition, curved girders permit the designer to make use of continuous construction and its inherent advantages in situations where he might otherwise be limited to simple spans. Continuous spans make more efficient use of materials as well as eliminating many undesirable expansion details. A stiffer structure is obtained and in some cases more vertical clearance is available due to the use of shallower girders.

Curved girders also permit the designer to use longer spans, where necessary, in multi-level interchange ramps where choice of locations of substructure are often limited because the substructure of the upper ramps must clear the lower roadways. The use of straight girders to span the same distance may mean a complicated framing system in order to support the deck properly. When high substructures are involved, the use of longer spans may also prove to be a saving.

Fabrication costs of curved girders may be slightly higher than straight girders in some instances. However, the many technical merits previously discussed should more than offset the higher fabrication costs so that there should be no economic disadvantage in the use of curved bridge girders. The major advantages of curved girders are appearance and simplicity in arrangement, details, and construction.
Figure 2 illustrates the derivation of the basic equations of continuity of the sample curved girder bridge at panel points 3 and 3'. Figure 2(a) shows the distorted shape of the individual girder due to external loads. Shown in Figure 2(b) are distortions produced by the redundant forces. These distortions are generally in a counter-acting direction to the distortions due to external loading.

\[ \Delta_3 \]
\[ \Delta'_3 \]
\[ \Omega_3 \]
\[ \Omega'_3 \]
\[ \Psi_3 \]
\[ \Psi'_3 \]
\[ \Theta_{F3} \]
\[ \Theta_{F3'} \]
\[ \Delta F_3 \]

(a)
(b)
(c)

\[ \begin{align*}
1) & \quad (\Delta_3 + \tau_3) - (\Delta'_3 + \tau'_3) = \Delta F_3 \\
& \quad (\Omega_3 + \psi_3) - (\Omega'_3 + \psi'_3) = \Theta_{F3}
\end{align*} \]

\[ \begin{align*}
e) \quad 1) & \quad \frac{(\Delta_3 + \frac{\Omega_3 \omega_3 p + \cdots + \Theta_3 + \psi_3 \omega_3 p + \cdots + \tau_3 + \psi_3 \omega_3 p + \cdots + \Theta_{F3} L^2}{2 E F F}}{\Delta F_3} \\
& \quad = \frac{\frac{\Omega_3 L^2}{2 E F F} - \frac{\tau_3 L}{E F F}}{\Theta_{F3}}
\end{align*} \]

Figure 2. Equations of continuity at panel points 3 and 3'

The combined effect of 2(a) and 2(b) appears in 2(c) as the final distorted shape of the complete structure at this section, with the floorbeam now shown. Two statements, regarding distortions, may be made at each floorbeam location as follows:

1. The algebraic difference in the deflections of the two girders is equal to the differential deflection of the two ends of the floorbeam.
2. The algebraic difference in the twists of the two girders is equal to the differential rotation of the two ends of the floorbeam.

These statements, in the form of mathematical equations, are given in Figure 2(d).
In terms of the unknown shears and torques $V_0, V_1, V_2,\ldots, V_9; V'_0, V'_1, V'_2,\ldots, V'_9; T_0, T_1, T_2,\ldots, T_9;\ T'_0, T'_1, T'_2,\ldots, T'_9,$ equations (1) and (2) appear as in Figure 2(e). Two such equations can be written at every floorbeam location, providing 22 distortion equations with 44 unknowns. However, the 44 unknowns can be reduced to 22 unknowns by considering the equilibrium condition of each floorbeam. A free body diagram of the floorbeam at panel points 3 or 3' is shown in Figure 3. Applying the conditions of equilibrium to this free body, the following equations are obtained.

(3) $V'_3 = -V_3$

and

(4) $T'_3 = V_3 L - T_3$

Equations (3) and (4) can be written for every floorbeam. If equations (3) and (4) are substituted into equations (1) and (2), as stated in Figure 2(e), the result is a set of 22 equations with 22 unknowns, in terms of the outside girder redundants $V$ and $T$ only. This indicates the structure is statically indeterminate to the 22nd degree.

In order to solve equations (1) and (2), the distortion characteristics of the girders due to vertical loads and torques must be computed. These values constitute the coefficients of the unknowns and are described as follows:

$\delta_{AB_i}$, the deflection at $A$ due to a unit vertical load at $B$.

$\omega_{AB_i}$, the twist at $A$ due to a unit vertical load at $B$.

$\delta_{AB_i}$, the deflection at $A$ due to a unit torque at $B$.

$\omega_{AB_i}$, the twist at $A$ due to a unit torque at $B$.

Thus, in the example presented, $\delta_{3,10}$ indicates the deflection at 3 due to a unit vertical load at 10, and $\omega_{3,10}$ indicates the rotation at 3 due to a unit torque at 10, etc.

The principle of virtual work states that:

$$
\delta_{AB} = \sum_{i=1}^{50} \frac{M_{nds}}{EI} + \sum_{i=1}^{50} \frac{T_{lds}}{GJ} = \sum_{i=1}^{50} \frac{M_{nds}}{EI} + \sum_{i=1}^{50} \frac{T_{lds}}{GJ}
$$

where:

a) $M$ and $T$ are the moment and torque due to the actual loadings.

b) $m$ and $t$ are the moment and torque due to unit loads at the point where distortions are desired.

c) $ds$ is the differential arc distance along the curved girder.

d) $EI$ and $GJ$ are flexural and torsional stiffnesses of the curved girder.

The rigorous analysis stated in this report was accomplished with the aid of a Bendix G15 Computer. The distortion coefficients were obtained by dividing each curved girder into fifty segments and numerically computing:

$$
\sum_{i=1}^{50} \frac{M_{nds}}{EI} + \sum_{i=1}^{50} \frac{T_{lds}}{GJ}
$$

The ultimate values needed to design the curved girders are the internal shear, torque and moment in each girder. These internal forces can be computed once the redundant forces are known.
A simplified method for the analysis of open framing curved girder bridges

It is evident that the rigorous analysis, which calls for the calculation of distortion coefficients and the solution of simultaneous equations, is beyond the practicality of longhand computations. Even with the G15 computer, it was a very time-consuming task. Therefore, a simplified method of sufficient engineering accuracy would be of great value. The first step of the proposed simplified method is to isolate each curved girder under consideration and straighten it out to its full developed length. The external load is then applied to the girder considering it supported at its developed span lengths and the moment diagram is constructed by standard procedures for continuous beams. This diagram is called the primary moment diagram.

The next step is to construct a similar diagram having as its ordinates the ordinates of the primary moment diagram divided by the horizontal radius of the curved girder. This is referred to as the $M/R$ diagram and its purpose is best explained with the aid of Figure 4.

A portion of the flange of a straight girder is shown in Figure 4(a). Ignoring flexural stresses carried by the web, the internal force at any point along the flange is equal to the moment at that point divided by the depth of the beam.

(1) $F = M/d$

Figure 4. Forces in flange due to curvature
By curving the flange along an arc of radius \( R \), as would be the case in a curved girder, radial components of these internal forces are developed as shown in Figure 4(b) as a distributed force, \( q \).

The magnitude of \( q \) can best be derived by the equilibrium condition for a very small segment of a girder as shown in Figure 4(c) where the direction of \( q \) is reversed. Radial force \( q \) and axial force \( F \), vary along the girder length. However, for a very small segment of the girder, \( q \) and \( F \) may be considered constant. Writing the equilibrium equation in the \( Y \) direction:

\[
2qR \Delta \theta = 2F \sin \Delta \theta
\]

For small angles:

\[
\Delta \theta \approx \sin \Delta \theta
\]

Reducing: \( 2qR = 2F \)

or \( (2) \quad q = F/R \)

Combining equations (1) and (2)

(3) \[ q = M/dR \]

or

(4) \[ qd = M/R \]

The \( M/d \) internal forces developed in the top and bottom flanges are equal in magnitude but opposite in direction in the two flanges. Consequently, their radial components \( q \) are also equal in magnitude but opposite in direction, representing a couple (or a torque) equal to \( (qd) \). Therefore, the \( M/R \) diagram is, in fact, a torque diagram per unit length acting on the girder due to curvature. The \( M/R \) diagram is now applied as a distributed load acting laterally on the developed length of the girder which is now considered supported at each point of torsional restraint, or in other words, at each diaphragm or floorbeam. Since the \( M/R \) loading is really torque per foot, it is evident the support reactions at the floorbeams due to this lateral loading are then the concentrated resisting torques developed by the floorbeams to restrain twisting of the curved girder. Although the girder is actually continuous over the support at each floorbeam, it was concluded that this continuity can be ignored and the reactions at the floorbeams due to the \( M/R \) loading determined by simple beam action would be sufficiently accurate. After computing the reactions, the shear diagram can be constructed. The shear diagram is the internal torque diagram of the curved girder. After applying these steps to both girders of the system and obtaining the concentrated torques at both ends of the floorbeams, the end shears of each floorbeam can be computed by the equations of static equilibrium. These end shears are then applied, as vertical concentrated loads, to the girder which is again considered supported at its developed span lengths. The moment diagram for this loading is constructed and referred to as the secondary moment diagram. Thus, the simplified method becomes a method of convergence, as a secondary \( M/R \) diagram, a secondary torque diagram and secondary end shears could be produced and applied to the developed girder, and so on. However, it was determined that any affect beyond the secondary moment diagram is negligible. Therefore, if the secondary moment diagram is added to the primary moment diagram, the result is the final bending moment diagram for the curved girder. The first torque diagram is assumed to be the final torque diagram for the curved girder. Using these final torques and bending moments, the girder can be designed by conventional methods.

For design offices in which electric computers are available, one may prefer to solve the simplified method by a direct solution rather than the method of convergence. It is not difficult to express the simplified method in the form of simultaneous equations by utilizing the following relationships:

a. Final moment in the girder at any point is the sum of the developed girder moment under external loads and the moment due to floorbeam end shears.

b. The end shears of each floorbeam is directly related to its end moments by the conditions of static equilibrium.

c. The end moments in the floorbeam divided by the depth of the girder give the radial forces applied to the girder flange at floorbeam points. In order to keep the flange in equilibrium, the radial forces can in turn be expressed in terms of final moment in the girder, the radius and depth of the girder and the spacing of the floorbeams.

In combining the above relationships, final equations can be written with only the intermediate floorbeam end shears as unknowns. For the sample problem of eight intermediate floorbeams, eight simultaneous equations are required. Once the end shears are known, the torque and moment in the girder can be readily solved by the relationships used in deriving the simultaneous equations. By utilizing matrix algebra, it is evident that influence lines for end shears, moments and torques can be determined conveniently by this method.
Rigorous analysis and simplified method compared

From the virtual work expression \( \int \frac{Mmds}{EI} + \int \frac{Tlds}{GJ} \) it is evident that the distortion characteristics, and hence the entire rigorous analysis of a curved beam depends on \( I \) and \( J \), the bending and torsional moments of inertia of the girder. However, \( J \) is a difficult quantity to determine as it varies greatly depending on whether or not the section is free to warp. The simplified method depends on \( I \), but it does not depend on \( J \). This raises the question of just how sensitive the rigorous analysis can be to \( J \), if both methods of analysis are to yield comparable results.

To study the effect of \( J \), solutions of the sample structure were run with two different \( J \) values varying by a factor of 100. For uniform loading conditions, the results of the two rigorous analyses, along with the values obtained from the simplified method, are shown superimposed in Figure 5.

The sample structure, as shown in Figure 1, has a bridge centerline radius of 250' and the radii of outside and inside girders are 264' and 236', respectively. Both spans are equal, at 80' along the outside girder. The 11 floorbeams are equally spaced at 16' centers on the outside girder. The section properties for the 3'-6" deep girders are \( I = 12,290 \text{ in.}^4 \) and \( J = 594 \text{ in.}^4 \) or \( 5.94 \text{ in.}^4 \). \( J = 594 \text{ in.}^4 \) is based on warping restraint at approximately every eight feet along the length of the outside girder. \( J = 5.94 \text{ in.}^4 \) is based on no warping restraint). The floorbeams have an \( I = 1,500 \text{ in.}^4 \).

The left hand side of Figure 5 shows the torque and moment diagrams for the outside girder when both girders are subjected to a load of 1 kip/ft. These values represent the loading condition corresponding to dead load (i.e., both girders uniformly loaded) and are given for:

1. Simplified Method plotted as a solid line.
2. Rigorous Method with \( J = 594 \text{ in.}^4 \) plotted as a dashed line.
3. Rigorous Method with \( J = 5.94 \text{ in.}^4 \) plotted as a dotted line.

These diagrams are qualitatively typical of all cases studied in the project. Note the abrupt steps in the torque diagram at each floorbeam point. Note also that the moment diagram is a smooth curve, much the same shape as in a straight beam.

The maximum torque magnitudes of only 15.7 to 18.4 kip-ft. that must be resisted by the curved girder indicates that most of the torsion due to curvature is resisted by interaction of the two girders. Due to the end shears of the floorbeams, the maximum negative moment in the outside curved girder increases by 37 to 59 kip-ft. in excess of the 800 kip-ft. which would exist if the beam were straight.

As shown in the plotted diagrams, good correlation exists between the approximate and rigorous methods. A very noticeable and important point is that large changes of \( J \) have apparently little effect on the rigorous solution. A percentage comparison between the simplified and rigorous solutions is shown in the tables of Figure 5, using the simplified method as a base. Two loading conditions are presented: The upper table is for both girders uniformly loaded representing the dead load of the structure. The lower table represents a live load or unbalanced condition with only the outside girder loaded.

For dead load, moments by the rigorous method are from 2.6% lower to 2.8% higher than moments by the simplified method. Torques by the rigorous method are from 19.8% lower to 5.1% higher than the torques by the simplified method. Thus, the moments check well. The torques, while differing in some instances by large percentages, are computed conservatively at these points by the simplified method.

For live load, the percentage differences in moments and torques at the loaded girder are approximately the same as for dead load, still providing good similarity between the simplified and rigorous methods. In any instance where the simplified method computes the value on the unsafe side, percentage differences are small.

It may be concluded that the rigorous solution is not sensitive to large changes in \( J \). The fact that \( J \) is not important does strengthen the argument that the simplified method, in which \( J \) is completely irrelevant, can be compatible with the true solutions to the stresses in horizontally curved bridge girders.
**INTERNAL FORCES – OUTSIDE GIRDER**

Both Girder Uniformly Loaded

**COMPARISON**

**SIMPLIFIED & RIGOROUS METHODS**

Both Girder Uniformly Loaded

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<tr>
<th>Item</th>
<th>Outside Girder</th>
<th>Inside Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Pos. Moment</td>
<td>-1.5%</td>
<td>-1.3%</td>
</tr>
<tr>
<td>Max. Neg. Moment</td>
<td>+1.3%</td>
<td>+2.7%</td>
</tr>
<tr>
<td>Max. Torque</td>
<td>-10.3%</td>
<td>+5.1%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Outside Girder</th>
<th>Inside Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Pos. Moment</td>
<td>-4.2%</td>
<td>-3.2%</td>
</tr>
<tr>
<td>Max. Neg. Moment</td>
<td>+2.3%</td>
<td>+4.2%</td>
</tr>
<tr>
<td>Max. Torque</td>
<td>-25.9%</td>
<td>+3.1%</td>
</tr>
</tbody>
</table>

Values for the Simplified Method are used as base in percentage computations.

**LEGEND**

- Simplified Method
- Rigorous Method, J=594 in.⁴
- Rigorous Method, J=5.94 in.⁴

Figure 5. Comparison of results by simplified and rigorous methods
Design of a two span continuous bridge by the simplified method

The following example illustrates the design of a horizontally curved bridge girder with open framing construction by the simplified method in a step-by-step procedure.

Step 1
Define the geometry of the bridge. Estimate the girder section and compute the dead load per foot on each girder.
Step 2
Isolate the outside girder and straighten it out to its full developed length. Apply the dead load to the girder considering it supported at its developed span lengths. Compute reactions for this girder and draw the primary shear and moment diagrams.
Step 3

Divide ordinates of the moment diagram by the radius of the girder and draw the $M/R$ diagram. Apply the $M/R$ diagram as a lateral distributed load on the developed length of the girder which is now assumed to be a series of simple spans supported by the floorbeams. Compute simple beam reactions at each floorbeam. These reactions are the concentrated torques developed at the ends of the floorbeams.

**TORQUE LOADING & SIMPLE BEAM REACTIONS DUE TO DEAD LOAD**

Outside Girder

$$R_0 = R_{10} = \frac{16}{24} \left[ (7 \times 0) + (6 \times 3.76) - 4.65 \right]$$

2nd degree curve

$$R_1 = R_9 = \frac{16}{12} \left[ 0 + (10 \times 3.76) + 4.65 \right]$$

$$R_2 = R_8 = \frac{16}{12} \left[ 3.76 + (10 \times 4.65) + 2.69 \right]$$

$$R_3 = R_7 = \frac{16}{12} \left[ 4.65 + (10 \times 2.69) - 2.14 \right]$$

$$R_4 = R_6 = \frac{16}{12} \left[ 2.69 - (10 \times 2.14) - 9.81 \right]$$

$$R_5 = \frac{16}{12} \left[ -2.14 - (10 \times 9.81) - 2.14 \right]$$

Inside Girder

$$= 11.94 \text{ kN} \times 0.813 \# = 9.71 \text{ kN}$$

$$= 56.3 \text{ kN}$$

$$= 70.6 \text{ kN}$$

$$= 39.2 \text{ kN}$$

$$= -38.0 \text{ kN}$$

$$= -102.4 \text{ kN} \times 0.813 = -83.3 \text{ kN}$$

\* See Page 155, Bibliography (1)

\* For Inside Girder Reactions, use the following relationship:

$$\frac{I.G. \text{ Reaction}}{O.G. \text{ Reaction}} = \left( \frac{I.G. \text{ Radius}}{O.G. \text{ Radius}} \right)^2 \times \frac{I.G. \text{ D.L.}}{O.G. \text{ D.L.}} = \left( \frac{236}{264} \right)^2 \times \frac{3.00}{2.95} = 0.813$$
Step 4

Compute the end shears on the floorbeams. Apply these end shears, as vertical concentrated loads, to the girder which is again considered supported at its developed span lengths. Calculate the secondary shear and moment diagrams.

**END SHEARS ON FLOORBEAMS DUE TO DEAD LOAD**

\[ V = \frac{T + T'}{L} \]

\[ T_0 = 11.94 \text{ kips} \]
\[ T_0' = 9.71 \text{ kips} \]
\[ L = 28' \]

\[ V_0 = V_{10} = \frac{(11.94 + 9.71)}{28} = 0.77 \text{ kips} \]
\[ V_1 = V_{9} = \frac{(56.3 + 45.8)}{28} = 3.65 \text{ kips} \]
\[ V_2 = V_{8} = \frac{(70.6 + 57.4)}{28} = 4.37 \text{ kips} \]
\[ V_3 = V_{7} = \frac{(39.2 + 31.9)}{28} = 2.54 \text{ kips} \]
\[ V_4 = V_{6} = \frac{(-38.0 - 30.9)}{28} = -2.46 \text{ kips} \]
\[ V_5 = (-102.4 - 63.3) ÷ 28 = -6.63 \text{ kips} \]

**SECONDARY DEAD LOAD ON OUTSIDE GIRDER**

Floor Beam Shears 0.77'k 365'k 457'k 2.54'k 24'k 663'k 246'k 254'k 457'k 365'k 0.77'k

Secondary Shear \( V_{DL'} \) (Kip)

Secondary Moment \( M_{DL'} \) (Kip-ft.)
Step 5

Compute stresses in the girder due to torque. As previously described, the torque in the girder is caused by radial forces $q$ in the flanges. Therefore, analyzing stresses in the girder due to torque is the same as analyzing stresses in the girder flanges due to $q$ forces.

Taking either the top or bottom flange as a horizontal beam, the applied load $q$ is resisted by concentrated reactions from the floorbeams. The magnitude of these reactions can be obtained by simply dividing the end moments of the floorbeams by the depth, $d$, of the girder. It is obvious then by dividing all values used or computed in Step 3 by the depth $d$, one obtains the loading diagram $q$ on the flange as well as the reactions from the floorbeams to keep it in equilibrium. It should be pointed out again that for simplicity of calculation, the floorbeam reactions in Step 3 were computed as simple beam reactions. Therefore, if these reactions are used, the flange is also considered simply supported at the floorbeam points. The lateral bending stress thus computed will be generally somewhat higher than the actual bending stress computed when the flange is treated as a continuous beam. If more accuracy is desired, the flange may be treated as a beam continuous over several spans at the point of investigation.

Step 6

Steps similar to 2, 3, 4 and 5 would now be repeated for live load. Influence lines could be utilized as in the design of any continuous girder. These steps are omitted from the example.

Step 7

Compute the maximum bending stresses at critical locations in the girder. As an illustration, dead load bending stresses at the center support are computed.
Step 8
Compute the maximum shearing stresses at critical locations in the girder. As an illustration, dead load shearing stresses adjacent to the center support are computed.

### Step 8
**Dead Load Shearing Stresses Adjacent to Center Support**

\[
\text{Primary Shear: } s = \frac{V_{OL}}{A_{web}} = \frac{150.4}{46 \times 0.50} = 6.54 \text{ ksf}
\]

(Step 2)

\[
\text{Secondary Shear: } s = \frac{V_{OL}}{A_{web}} = \frac{3.55}{46 \times 0.50} = 0.15 \text{ ksf}
\]

(Step 4)

**Total Shearing Stress:** \[ s = 6.69 \text{ ksf} \]

---

**Summary**

Horizontally curved bridge girders are an evolution of the trend toward aesthetic structural design. In addition to the primary advantage of improved appearance, curved girders also incorporate certain technical advantages of continuity and simplicity of details.

Closed Framing Construction, consisting of two or more girders connected by diaphragms and lateral bracing, generally has low torsional stresses. Opened Framing Construction, made up of two or more girders connected only by diaphragms or floorbeams, is more sensitive to the effects of torsion and requires a more detailed analysis. With the aid of a digital computer a rigorous mathematical analysis may be accomplished, solving for the unknown or redundant forces by simultaneous equations.

A simplified method of analysis was shown for the Open Framing girder systems. Good correlation was achieved between results obtained by the rigorous analysis and results calculated by the simplified method. The simplified method is a convenient and reliable tool for designing horizontally curved girder bridges of the Open Framing System. It eliminates the involved mathematics otherwise necessary, thus enabling the engineers to apply the merits of curved girder construction to many problems encountered in the design of urban highway bridges.
Bibliography


