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LRFD Seismic Bridge Design

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5.5.3—Substructure

The intermediate columns or piers should also be modeled as space frame members. Long, flexible columns should be modeled with intermediate nodes at the third points in addition to the joints at the ends of the columns. The model should consider the eccentricity of the columns with respect to the superstructure. Foundation conditions at the base of the columns and at the abutments may be modeled using equivalent linear spring coefficients.

5.6—EFFECTIVE SECTION PROPERTIES

5.6.1—Effective Reinforced Concrete Section Properties for Seismic Analysis

Because elastic analysis assumes a linear relationship between stiffness and strength, analysis of concrete members shall consider that they display nonlinear response before reaching their idealized yield limit state.

Section properties, flexural stiffness, E_cI_{eff}, shear stiffness parameter $(GA)_{eff}$, and torsional stiffness G_cJ_{eff}, shall reflect the cracking that occurs before the yield limit state is reached. The effective moments of inertia, I_{eff} and J_{eff}, shall be used to obtain realistic values for the structure's period and the seismic demands generated from ESA and EDA analyses.

5.6.2—E_cI_{eff} and $(GA)_{eff}$ for Ductile Reinforced Concrete Members

The effective moment of inertia I_{eff} should be used when modeling ductile elements. I_{eff} may be estimated by Figure 5.6.2-1, or the slope of the M-ϕ curve between the origin and the point designating the first reinforcing bar yield shall be taken as:

$$E_cI_{eff} = \frac{M_y}{\phi_y} \qquad (5.6.2\text{-}1)$$

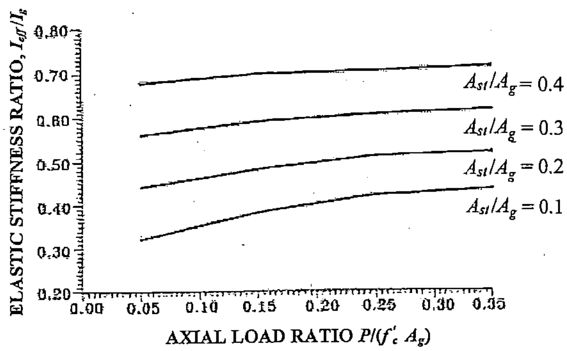
where:

M_y = moment capacity of section at first yield of the reinforcing steel (kip-in.)

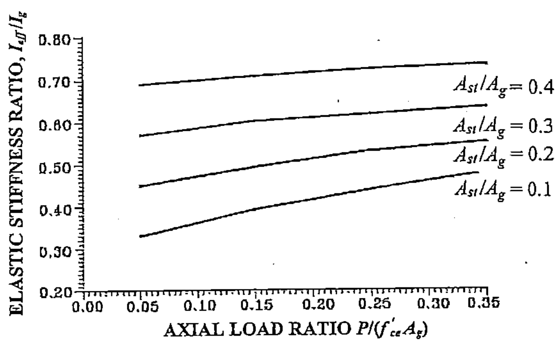
ϕ_y = curvature of section at first yield of the reinforcing steel including the effects of the unfactored axial dead load (1/in.)

E_c = modulus of elasticity of concrete (ksi)

I_{eff} = effective moment of inertia of the section based on cracked concrete and first yield of the reinforcing steel (in.^{4})



(a) Circular Sections



(b) Rectangular Sections

Figure 5.6.2-1—Effective Flexural Stiffness of Cracked Reinforced Concrete Sections

Typically the unfactored axial gravity load and expected material properties shall be used when determining the effective properties.

The M-ϕ analysis parameters shall be taken as specified in Articles 8.4 and 8.5.

For pier walls in the strong direction, the shear stiffness parameter $(GA)_{eff}$ may be determined as follows:

$$(GA)_{eff} = G_c A_{ew} \frac{I_{eff}}{I_g} \tag{5.6.2-2}$$

where:

$(GA)_{eff}$ = effective shear stiffness parameter of the pier wall (kip)

G_c = shear modulus of concrete (ksi)

A_{ew} = cross-sectional area of pier wall (in.^{2})

I_g = gross moment of inertia taken about the weak axis of the reinforced concrete cross-section (in.^{4})

I_{eff} = effective moment of inertia taken about the weak axis of the reinforced concrete cross-section calculated from Eq. 5.6.2-1 or Figure 5.6.2-1 (in.^{4})

For prestressed concrete piling used in pile bents as the energy dissipation elements of the ERS, the effective stiffness ranges between $0.6I_g$ and $0.75I_g$, and conservative values from this range may be used in SDC B. For SDC C and D, moment-curvature analysis shall be used to determine the effective moments of inertia. For capacity protected elements in pile foundations, the stiffnesses shall be chosen with regard to the loading level expected.

5.6.3—I_{eff} for Box Girder Superstructures

The determination of I_{eff} for box girder superstructures should include consideration of the following:

- I_{eff} in box girder superstructures is dependent on the extent of cracking and the effect of the cracking on the element's stiffness.
- I_{eff} for reinforced concrete box girder sections may be estimated between $0.5I_g$ and $0.75I_g$. The lower bound represents lightly reinforced sections and the upper bound represents heavily reinforced sections.
- The location of the centroid of the prestressing steel and the direction of bending have a significant impact on how cracking affects the stiffness of prestressed members. Multimodal elastic analysis is incapable of capturing the variations in stiffness caused by moment reversal. Therefore, no stiffness reduction is recommended for prestressed concrete box girder sections.

5.6.4—I_{eff} for Other Superstructure Types

Reductions to I_g similar to those specified for box girders may be used for other superstructure types and cap beams. A more refined estimate of I_{eff} based on M-ϕ analysis may be warranted for lightly reinforced girders and precast elements.

5.6.5—Effective Torsional Moment of Inertia

The determination of the torsional stiffness should include consideration of the following:

- A reduction of the torsional moment of inertia is not required for bridge superstructures.
- The torsional stiffness of concrete members can be greatly reduced after the onset of cracking.
- The torsional moment of inertia for columns shall be reduced as follows:

$$J_{eff} = 0.2 J_g \qquad (5.6.5\text{-}1)$$

where:

J_{eff} = effective torsional (polar) moment of inertia of reinforced concrete section (in.^{4})

J_g = gross torsional (polar) moment of inertia of reinforced concrete section (in.^{4})