Bridge Design - Seismic Design of Concrete Bridges

Course Number: CE-02-413

PDH: 12

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Course Author: Mathew Holstrom

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CHAPTER 21
SEISMIC DESIGN OF CONCRETE BRIDGES

21.1 INTRODUCTION

This course is intended primarily to provide guidance on the seismic design of Ordinary Standard Concrete Bridges as defined in *Caltrans Seismic Design Criteria* (*SDC*), Version 1.7 (Caltrans 2013). Information presented herein is based on *SDC* (Caltrans 2013), AASHTO *LRFD Bridge Design Specifications* (AASHTO 2012) with *California Amendments* (Caltrans 2014), and other Caltrans Structure Design documents such as *Bridge Memo to Designers* (*MTD*). Criteria on the seismic design of nonstandard bridge features are developed on a project-by-project basis and are beyond the scope of This course.

Section 21.2 describes general seismic design considerations including pertinent formulae, interpretation of Caltrans *SDC* provisions, and a procedural flowchart for seismic design of concrete bridges. In the second part, i.e., Section 21.3, a seismic design example of a three-span continuous cast-in-place, prestressed (CIP/PS) concrete box girder bridge is presented to illustrate various design applications following the seismic design procedure flowchart. The example is intended to serve as a model seismic design of an ordinary standard bridge using the current *SDC* Version 1.7 provisions.

21.2 DESIGN CONSIDERATIONS

21.2.1 Preliminary Member and Reinforcement Sizes

Bridge design is inherently an iterative process. It is common practice to design bridges for the Strength and Service Limit States and then, if necessary, to refine the design of various components to satisfy Extreme Events Limit States such as seismic performance requirements. In practice, however, engineers should keep certain seismic requirements in mind even during the Strength and Service Limit States design. This is especially true while selecting the span configuration, column size, column reinforcement requirements, and bent cap width.

21.2.1.1 Sizing the Column and Bent Cap

(1) Column size

SDC Section 7.6.1 specifies that the column size should satisfy the following equations:

$$0.70 \leq \frac{D_c}{D_s} \leq 1.00 \qquad (SDC\ 7.6.1\text{-}1)$$

$$0.7 \leq \frac{D_{ftg}}{D_c} \qquad (SDC\ 7.6.1\text{-}2)$$

where:

D_c = column cross sectional dimension in the direction of interest (in.)
D_s = depth of superstructure at the bent cap (in.)
D_{ftg} = depth of footing (in.)

If $D_c > D_s$, it may be difficult to meet the joint shear, superstructure capacity, and ductility requirements.

(2) Bent Cap Width

SDC Section 7.4.2.1 specifies the minimum cap width required for adequate joint shear transfer as follows:

$$B_{cap} = D_c + 2 \quad \text{(ft)} \qquad (SDC\ 7.4.2.1\text{-}1)$$

21.2.1.2 Column Reinforcement Requirements

(1) Longitudinal Reinforcement

Maximum Longitudinal Reinforcement Area, $A_{st,\max} = 0.04 \times A_g$ (*SDC* 3.7.1-1)

Minimum Longitudinal Reinforcement Area:

$$A_{st,\min} = 0.01(A_g) \quad \text{for columns} \qquad (SDC\ 3.7.2\text{-}1)$$

$$A_{st,\min} = 0.005(A_g) \quad \text{for Pier walls} \qquad (SDC\ 3.7.2\text{-}2)$$

where:

A_g = the gross cross sectional area (in.^{2})

Normally, choosing column $A_{st} = 0.015(A_g)$ is a good starting point.

(2) Transverse Reinforcement

Either spirals or hoops can be used as transverse reinforcement in the column. However, hoops are preferred (see *MTD* 20-9) because of their discrete nature in the case of local failure.

- Inside the Plastic Hinge Region

The amount of transverse reinforcement inside the analytical plastic hinge region (see *SDC* Section 7.6.2 for analytic plastic hinge length formulas), expressed as volumetric ratio, ρ_s, shall be sufficient to ensure that the column meets the performance requirements as specified in *SDC* Section 4.1.

$$\rho_s = \frac{4(A_b)}{D'(s)}$$ for columns with circular or interlocking cores (*SDC* 3.8.1-1)

For rectangular columns with ties and cross ties, the corresponding equation for ρ_s , is:

$$\rho_s = \frac{A_v}{D_c' s} \qquad \text{(SDC 3.8.1-2)}$$

where:

A_v = sum of area of the ties and cross ties running in the direction perpendicular to the axis of bending (in.^{2})

D_c' = confined column cross-section dimension, measured out to out of ties, in the direction parallel to the axis of bending (in.)

s = transverse reinforcement spacing (in.)

In addition, the transverse reinforcement should meet the column shear requirements as specified in *SDC* Section 3.6.3.

- Outside the Plastic Hinge Region

As specified in *SDC* Section 3.8.3, the volume of lateral reinforcement outside the plastic hinge region shall not be less than 50 % of the minimum amount required inside the plastic hinge region and meet the shear requirements.

(3) Spacing Requirements

The selected bar layout should satisfy the following spacing requirements for effectiveness and constructability:

- Longitudinal Reinforcement
  Maximum and minimum spacing requirements are given in *AASHTO* Article 5.10 (2012).

- Transverse Reinforcement
  According to *SDC* Section 8.2.5, the maximum spacing in the plastic hinge region shall not exceed the smallest of:

- $\frac{1}{5}$ of the least column cross-section dimension for columns and ½ of the least cross-section dimension for piers
- 6 times the nominal diameter of the longitudinal bars
- 8 in.

Outside this region, the hoop spacing can be and should be increased to economize the design.

21.2.1.3 Balanced Stiffness

(1) Stiffness Requirements

For an acceptable seismic response, a structure with well-balanced mass and stiffness across various frames is highly desirable. Such a structure is likely to respond to a seismic activity in a simple mode of vibration and any structural damage will be well distributed among all the columns. The best way to increase the likelihood that the structure responds in its fundamental mode of vibration is to balance its stiffness and mass distribution. To this end, the *SDC* recommends that the ratio of effective stiffness between *any* two bents within a frame or between any two columns within a bent satisfy the following:

$$\frac{k_i^e}{k_j^e} \geq 0.5 \qquad \text{For constant width frame} \qquad (SDC\ 7.1.1\text{-}1)$$

$$2 \geq \left(\frac{k_i^e / m_i}{k_j^e / m_j}\right) \geq 0.5 \qquad \text{For variable width frame} \qquad (SDC\ 7.1.1\text{-}2)$$

SDC further recommends that the ratio of effective stiffness between *adjacent* bents within a frame or between *adjacent* columns within a bent satisfies the following:

$$\frac{k_i^e}{k_j^e} \geq 0.75 \qquad \text{For constant width frame} \qquad (SDC\ 7.1.1\text{-}3)$$

$$1.33 \geq \left(\frac{k_i^e / m_i}{k_j^e / m_j}\right) \geq 0.75 \qquad \text{For variable width frame} \qquad (SDC\ 7.1.1\text{-}4)$$

where:

k_i^e = smaller effective bent or column stiffness (kip/in.)

m_i = tributary mass of column or bent i (kip-sec^2/ft)

k_j^e = larger effective bent or column stiffness (kip/in.)

m_j = tributary mass of column or bent j (kip-sec^2/ft)

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