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Bridge Design - Seismic Design of Concrete Bridges

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Module 21: Seismic Design of Concrete Bridges

Learning Objectives

By the end of this section, you will be able to:

- **Apply** Caltrans SDC geometric constraints to size columns, bent caps, and footings.
- **Evaluate** local displacement ductility capacity and global displacement demand for bridge frames.
- **Calculate** seismic shear reinforcement for columns and capacity-protected members.
- **Design** moment-resisting joints and abutment seat widths to ensure structural integrity during seismic hazards.

Executive Summary: This chapter establishes the technical standards for the seismic design of Ordinary Standard Concrete Bridges using a displacement-based "Capacity Design" approach. By designating columns as ductile members and protecting all other components—such as bent caps, superstructures, and footings—to remain essentially elastic, the bridge is designed to withstand extreme seismic events without collapsing. The process requires balancing frame stiffness, verifying ductility through pushover analysis, and meticulous detailing of "No-Splice Zones" and joint reinforcement to ensure reliable plastic hinging and energy dissipation.

Introduction

This chapter provides guidance on the seismic design of Ordinary Standard Concrete Bridges as defined in Caltrans **Seismic Design Criteria (SDC)**, Version 1.7. The information is based on the SDC, AASHTO LRFD Bridge Design Specifications with California Amendments, and Caltrans Bridge Memo to Designers (MTD). It includes technical considerations, procedural flowcharts, and a three-span continuous CIP/PS box girder bridge design example.

Design Considerations

Preliminary Member and Reinforcement Sizes

Bridge design is iterative. Refinements for Extreme Events Limit States occur after Strength and Service Limit States are satisfied. Engineers must consider seismic requirements early, particularly span configuration and member sizing.

Sizing the Column and Bent Cap

- (1) Column size SDC specifies the following dimensions:

Equation 21-1:

$$0.70 \leq \frac{D_c}{D_s} \leq 1.00$$

Where:

- **D_c** = column cross sectional dimension in the direction of interest (in.)
- **D_s** = depth of superstructure at the bent cap (in.)

Equation 21-2:

$$0.7 \leq \frac{D_{ftg}}{D_c}$$

Where:

- **D_{ftg}** = depth of footing (in.)
- **D_c** = column cross sectional dimension in the direction of interest (in.)

The minimum width for joint shear transfer:

Equation 21-3:

$$B_{cap} = D_c + 2$$

Where:

- **B_{cap}** = minimum width for joint shear transfer (ft)
- **D_c** = column cross sectional dimension in the direction of interest (in.)

Column Reinforcement Requirements

- **Longitudinal Reinforcement**

Area limits (A_{st}) relative to gross area (A_g):

Equation 21-4:

$$A_{st,max} = 0.04A_g$$

Where:

- **A_{st,max}** = maximum area of longitudinal reinforcement
- **A_g** = gross area of column section



Equation 21-5:

$$A_{st,min} = 0.01A_g \text{ (for columns), } A_{st,min} = 0.005A_g \text{ (for Pier walls)}$$

Where:

- **A_{st,min}** = minimum area of longitudinal reinforcement
- **A_g** = gross area of column or pier wall cross section

💡 **Design Tip:** A column A_{st} of 0.015 * A_g is a reliable starting point.

- **(2) Transverse Reinforcement**

Either spirals or hoops are acceptable; however, **hoops are preferred** per MTD 20-9.

- **Inside the Plastic Hinge Region:**

Equation 21-6:

$$\rho_s = \frac{4A_b}{D's}$$

Where:

- **ρ_s** = volumetric ratio of spiral or hoop reinforcement
- **A_b** = Area of transverse reinforcement bar (in.²)
- **D'** = Confined core dimension (in.)
- **s** = Spacing (in.)
- **Outside the Plastic Hinge Region:** Lateral reinforcement must be at least 50% of the minimum required inside the hinge.
- **(3) Spacing Requirements**

⚠️ **Safety Constraint:** Maximum spacing in the plastic hinge region shall not exceed the smallest of: 1/5 of the least column dimension (1/2 for piers), 6 times the nominal diameter of longitudinal bars, or 8 inches.

Balanced Stiffness

- **Stiffness Requirements**

Stiffness and mass must be balanced to ensure the structure responds in a simple mode of vibration.

Equation 21-7:


$$\frac{k_{ei}}{k_{ej}} \geq 0.5 \text{ (For constant width frame)}$$

Equation 21-8:

$$\frac{k_{ei}}{k_{ej}} \geq 0.75$$

Where:

- **k_{ei}** = effective stiffness of the smaller column or frame element
- **k_{ej}** = effective stiffness of the larger column or frame element

 **Calculation Note:** Target dead load axial forces at approximately 10% of ultimate compressive capacity ($P_u = A_g f'_c$) to prevent brittle compression failure.

Balanced Frame Geometry

The ratio of fundamental periods for adjacent frames must satisfy:

Equation 21-9:

$$\frac{T_i}{T_j} \geq 0.7$$

Where:

- **T_i** = period of the less flexible frame
- **T_j** = period of the more flexible frame

Minimum Local Displacement Ductility Capacity

SDC Section 3.1 requires each ductile member to have a minimum ductility capacity (u_c) of 3.

Equation 21-10:

$$\Delta_c = \Delta_{colY} + \Delta_p$$

Where:

- Δ_c = local displacement ductility capacity
- Δ_{colY} = idealized yield displacement
- Δ_p = idealized plastic displacement capacity

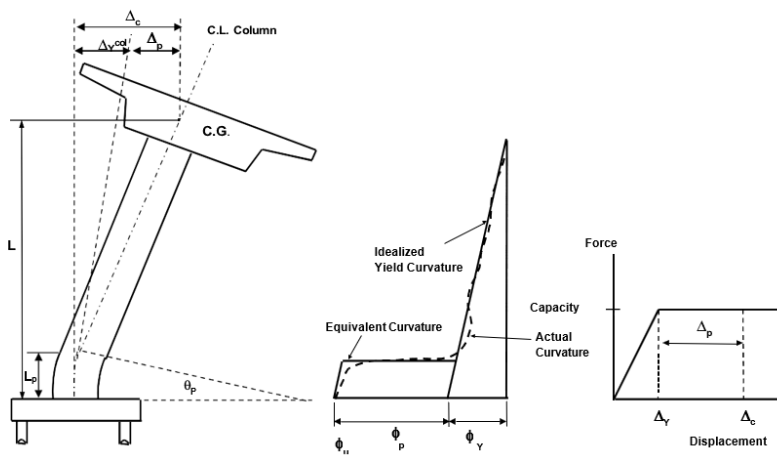


Figure SDC 3.1.3-1: Local Displacement Capacity – Cantilever Column with Fixed Base

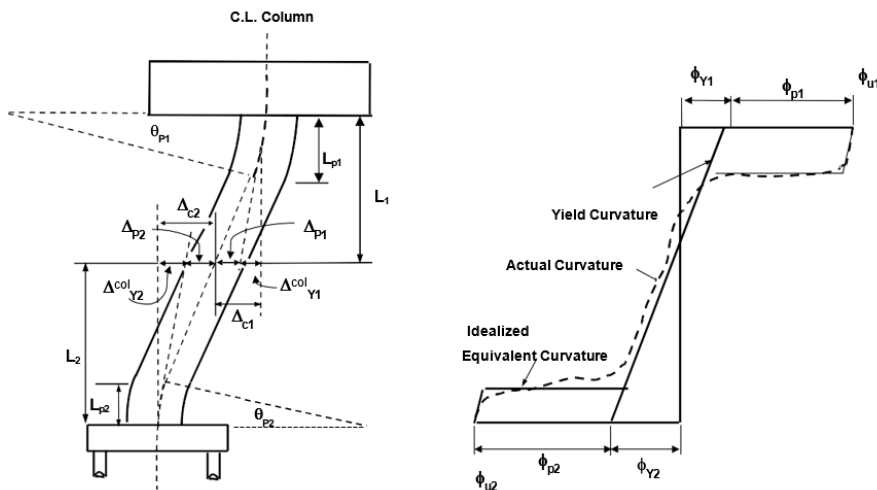


Figure SDC 3.1.3-2: Local Displacement Capacity – Framed Column, Assumed as Fixed-Fixed



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