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Bridge Design - Concrete Columns

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Module 1: Concrete Columns

Learning Objectives

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

- **Identify** the standard design loads and limit states for bridge columns according to AASHTO and Caltrans specifications.
- **Evaluate** slenderness effects and **calculate** magnified moments for braced and unbraced compression members.
- **Analyze** combined axial and flexural strength requirements using interaction diagrams and compatibility expressions.

Executive Summary: Bridge columns are critical structural elements that transfer superstructure loads to the foundation while resisting lateral forces from seismic, wind, and service loads. Professional design requires a rigorous multi-stage analysis—integrating longitudinal and transverse structural modeling—to account for slenderness effects, material non-linearity, and complex load combinations across Strength, Service, and Extreme Event limit states.

Introduction

Columns are structural elements that support the superstructure, transfer vertical loads from the superstructure to the foundation, and resist the lateral loads acting on the bridge due to seismic and various service loads.

Types of Columns

Columns are categorized along two parameters: shape and height.

Column Shapes Column sections are usually round, rectangular, solid, hollow, octagonal, or hexagonal.

Column Height Columns are classified as either **short** or **tall** according to their **effective slenderness ratio**:

Equation 1.2-1: Effective Slenderness Ratio = $\frac{Kl_u}{r}$

Where:

- **K** = effective length factor
- **l_u** = unsupported length of a compression member
- **r** = radius of gyration



Design Loads

The considered design loads as specified in AASHTO 3.3.2 are:

- **Dead loads (DC)**
- **Added dead loads (DW)**
- **Design vehicular live loads:** HL-93 (Truck + Lane) or (Tandem + Lane) including dynamic load allowance (IM).
- **Permit vehicle (P15)** including dynamic load allowance (IM).
- **Wind loads (WS, WL)**
- **Braking force (BR)**
- **Thermal effects (TU)**
- **Prestress shortening effects (CR, SH)**
- **Prestressing secondary effects (PS)**

Design Criteria

Columns are designed for Service, Strength, and Extreme Event limit states. The Extreme Event I limit state must comply with the current Caltrans Seismic Design Criteria (SDC) version 1.7. Columns should be designed as ductile members to deform inelastically for several cycles without significant degradation of strength or stiffness under design earthquake demand.

Limit States

Columns are designed for three primary limit states:

- Strength Limit State
- Service Limit State
- Extreme Event Limit State

Forces

Bridge columns are subjected to axial loads, bending moments, and shears in both the longitudinal and transverse directions of the bridge.

Approximate Evaluation of Slenderness Effects

Slenderness of the compression member is based on the ratio of $K * l_u / r$. Slenderness effect is ignored if:

- $K * l_u / r < 22$ (members not braced against sidesway).
- $K * l_u / r < 34 - 12 * (M1 / M2)$ (members braced against sidesway).

Where:

- **M1** = smaller end moment, positive for single curvature flexure.
- **M2** = larger end moment, positive for single curvature flexure.
- **r** = 0.25 * column diameter for circular columns.
- **r** = 0.3 * column dimension in buckling direction for rectangular columns.

⚠ **Safety Constraint:** If $K * l_u / r$ exceeds 100, columns may experience appreciable lateral deflections. A more detailed second-order non-linear analysis should be considered.

Moment Magnification Method

Factored moments may be increased to reflect effects of deformation:

Equation 1.5-1:

$$M_c = \delta_b M_{2b} + \delta_s M_{2s}$$

Where:

- **M_c** = magnified factored moment
- **M_{2b}** = moment due to factored gravity loads (no sidesway), always positive
- **M_{2s}** = moment due to factored lateral or gravity loads (resulting in sidesway), always positive
- **δ_b** = magnification factor for braced members
- **δ_s** = magnification factor for unbraced members

Equation 1.5-2:

$$\delta_b = \frac{C_m}{1 - \left(\frac{P_u}{\phi_k P_e}\right)} \geq 1$$

Where:

- **δ_b** = magnification factor for braced members
- **C_m** = equivalent uniform moment diagram factor
- **P_u** = factored axial load
- **φ_k** = stiffness reduction factor
- **P_e** = critical buckling load

Equation 1.5-3:

$$\delta_s = \frac{1}{1 - \frac{\sum P_u}{\phi_k \sum P_e}}$$

Where:

- δ_s = magnification factor for unbraced members
- $\sum P_u$ = total factored axial load for all columns in a story
- ϕ_k = stiffness reduction factor
- $\sum P_e$ = total critical buckling load for all columns in a story supporting lateral loads

Equation 1.5-4 (Euler Buckling Load):

$$P_e = \frac{\pi^2 E_c I}{(K l_u)^2}$$

Where:

- E_c = elastic modulus of concrete
- I = moment of inertia
- ϕ_k = stiffness reduction factor (0.75 for concrete, 1 for steel)
- C_m = $0.6 + 0.4 * (M_{1b} / M_{2b})$ (for braced members without transverse loads)

Combined Axial and Flexural Strength

Interaction Diagrams

Interaction diagrams for reinforced concrete sections are created assuming a series of strain distributions. Short column strength is governed by material strength achieved when the extreme concrete compression fiber reaches a strain of 0.003.

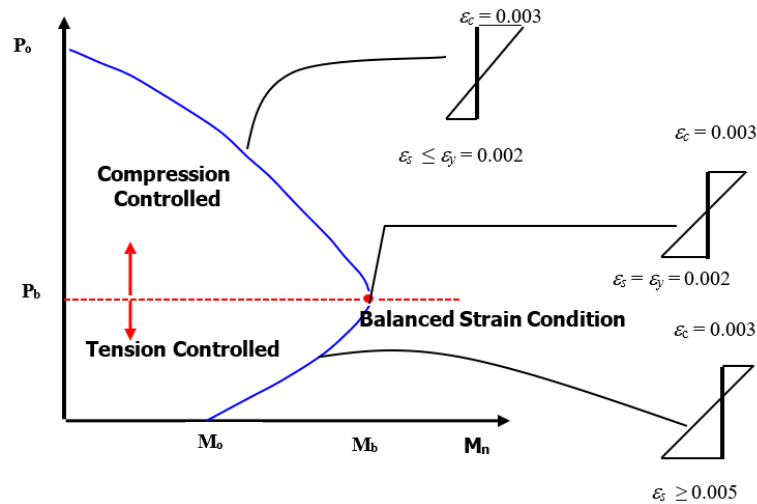


Figure 1.6-1 Typical Strength Interaction Diagram for Reinforced Concrete Section with Grade 60 Reinforcement

Failure Modes

- **Tension controlled:** Net tensile strain in extreme steel ≥ 0.005 when concrete reaches 0.003 strain.
- **Compression controlled:** Net tensile strain in extreme steel ≤ 0.002 when concrete reaches 0.003 strain.
- **Balanced strain condition:** Concrete strain (0.003) and steel yield strain (0.002) reached simultaneously.

Pure Compression

Factored axial resistance (P_r) is determined as follows:

Equation 1.6-1 (Spiral Reinforcement):

$$P_r = \phi \times 0.85 \times [0.85f'_c(A_g - A_{st}) + A_{st}f_y]$$

Where:

- P_r = factored axial resistance
- ϕ = resistance factor
- f'_c = specified compressive strength of concrete
- A_g = gross area of section
- A_{st} = total area of longitudinal reinforcement
- f_y = specified yield strength of reinforcement



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