Concrete Columns in High-Rise Buildings

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DEFORMATION COMPATIBILITY OF COLUMNS IN HIGH RISE BUILDINGS
A Designer’s Perspective
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OVERVIEW
• Project Description
• Designer’s Perspective
• Deformation Compatibility – ACI 318-11
• Conceptual Approach
• Example
• Questions

PROJECT DESCRIPTION
• ~40 Story Hotel and Condominium
• Seattle, Washington
• Concrete Strengths up to 9 ksi

PROJECT DESCRIPTION – LATERAL SYSTEM
• Special Reinforced Concrete Walls
• Exceeded the IBC Height Limit
• Non-Linear Response History Analysis
• Peer Reviewed
• Flexural Yielding of Wall and Coupling Beams
• Maximum Interstory Drift 1.8%
PROJECT DESCRIPTION – GRAVITY SYSTEM

- Mildly Reinforced Concrete Flat Plate
- 8’ Thick, spanning 23 feet
- Deformation Compatibility of Joints

DESIGNER’S PERSPECTIVE

Priorities

- Life Safety (Code compliance or equivalent)
- Owner’s Interests
  - Cost
  - Schedule
  - Performance
- My Interests
  - Least effort to meet the above
  - Engineering is driven by drawings
  - Drawings are driven by construction

DEFORMATION COMPATIBILITY – ACI 318-11

CALCULATING FORCES

ACI 21.13 Commentary

Models used to determine design displacement of buildings should be chosen to produce results that conservatively bound the values expected of the design earthquake and should include, as appropriate, effects of concrete cracking, foundation flexibility, and deformation of floor and roof diaphragms.

DEFORMATION COMPATIBILITY – ACI 31-11

ACI 21.13.3.3

21.13.4.3

$ f'_c = 8,000 \text{ psi} \quad \rho = 2.5\% $
EXAMPLE – DESIGN STEPS

• Determine $M_p$ for Floor Framing
• Determine $\phi P_{n,min}$ and $\phi P_{n,max}$ for Column Based on $3M_p/2$
• Compare $P_{n,min}$ and $P_{n,max}$ to Acceptable Range for $P_n$
• Determine Minimum Confinement
• Check Shear Capacity Based on Minimum Confinement

EXAMPLE - DETERMINE $M_p$ FOR SLAB

$M_p = A_p (1.25f_p)(1 - 0.59 \frac{A_p f'_c}{b d f'_p})$

Where:
- $b = 23(12) = 276^\prime$
- $d = 8 - 0.75 - 0.25 = 7^\prime$
- $A_p = \#4 @ 13^\prime = \frac{20015}{13} (0.2) = 4.25 \text{ in}^2$
- $f_p = 60 \text{ ksi}$
- $f'_c = 6 \text{ ksi}$

$M_p = 184 \text{ k-ft}$

POSTIVE MOMENT CAPACITY

EXAMPLE - DETERMINE $M_p$ FOR SLAB

$M_p = A_p (1.25f_p)(1 - 0.59 \frac{A_p f'_c}{b d f'_p})$

Where:
- $b = 23(12) = 276^\prime$
- $d = 8 - 0.75 - 0.25 = 7^\prime$
- $A_p = 75 + 78 = (9)\#4 + (11)\#5 = 5.58 \text{ in}^2$
- $f_p = 60 \text{ ksi}$
- $f'_c = 6 \text{ ksi}$

$M_p = 238 \text{ k-ft}$

NEGATIVE MOMENT CAPACITY

EXAMPLE - DETERMINE AXIAL COLUMN CAPACITY

$2M_p/2 = (184 \times 238) / 2 = 211 \text{ k-ft}$

MOMENT DEMAND

EXAMPLE - DETERMINE AXIAL COLUMN CAPACITY

AXIAL CAPACITY – X AXIS
EXAMPLE – COMPARE $P_{U,MIN}$ AND $P_{U,MAX}$

- Minimum $P_u$ for 18x24 column, 8 ksi, 2.54% reinforcing is 1,114 kips in column L-12 at the sixth floor.
- Maximum $P_u$ for 18x24 column, 8 ksi, 2.54% reinforcing is 1,608 kips in column L-12 at the seventh floor.
- These demands are well within range established based on $M_p$.

EXAMPLE – MINIMUM CONFINEMENT

- Since $P_u > 0.35P_0$, ACI 21.13.3.3 Controls.
- Maximum Tie Spacing Is The Larger Of:
  - 6db of smallest longitudinal bar (#8) = 6 inches
  - 6 inches
  - $a_t = 4.4 \left( \frac{14 - h_b}{3} \right)$

EXAMPLE – MINIMUM CONFINEMENT

- Tie Area Is One-Half That Required by ACI 21.6.4.4:

$$A_{sh} = 0.3 \frac{f'_y}{f'c} \left[ \left( \frac{A_{st}}{A_{sh}} \right) - 1 \right]$$

$$A_{sh} = 0.09 \frac{f'_y}{f'c}$$

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EXAMPLE – MINIMUM CONFINEMENT

MINIMUM CONFINEMENT AREA

EXAMPLE – SHEAR STRENGTH

SHEAR DEMAND

QUESTIONS?