CHAPTER 2
DESIGN OF REINFORCED CONCRETE STRUCTURES FOR EARTHQUAKE FORCES

2.1 Introduction

2.1.1 General

A 20-story reinforced concrete office building is designed following the requirements of the International Building Code (IBC), 2012 and 2015 editions, and ASCE 7-10. The building is located on IBC Site Class D. Both dynamic and static lateral force procedures are used as the basis of design.

The building is symmetrical about both principal plan axes. Along each axis a dual system (special reinforced concrete shear walls with special moment-resisting frames or SMRF) is utilized for resistance to lateral forces.

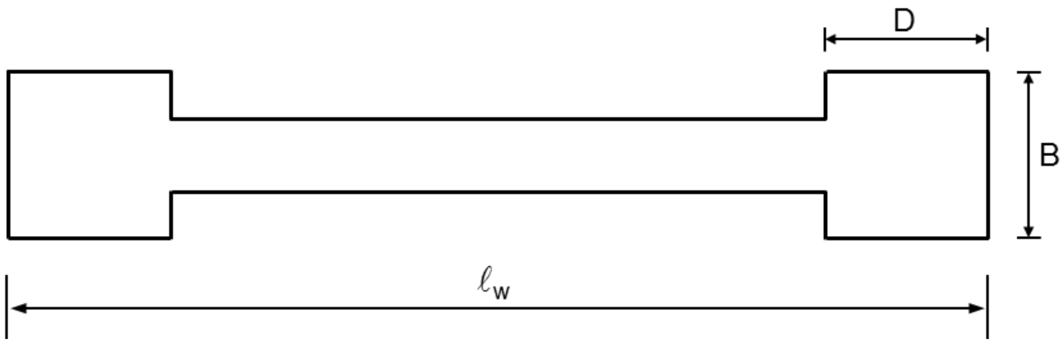
A Dual System is defined as a structural system with the following features (ASCE 7-10 Section 12.2.5.1):

> **12.2.5.1 Dual Systems.** For a dual system, the moment frames shall be capable of resisting at least 25 percent of the design seismic forces. The total seismic force resistance is to be provided by the combination of the moment frames and the shear walls or braced frames in proportion to their rigidities.

2.1.2 Design criteria

A typical plan and elevation of the example building are shown in Figures 2-1 and 2-2, respectively. The member sizes for the structure are chosen as follows:

Beams	34 × 24 in. (width = 34 in.)
Interior columns	40 × 40 in.
Exterior columns	34 × 34 in.
Shear walls:	
Grade to 10th floor	16 in. thick
10th floor to 17th floor	14 in. thick
17th floor to roof	12 in. thick
Shear wall boundary elements	38 × 38 in.



Plan of shear wall

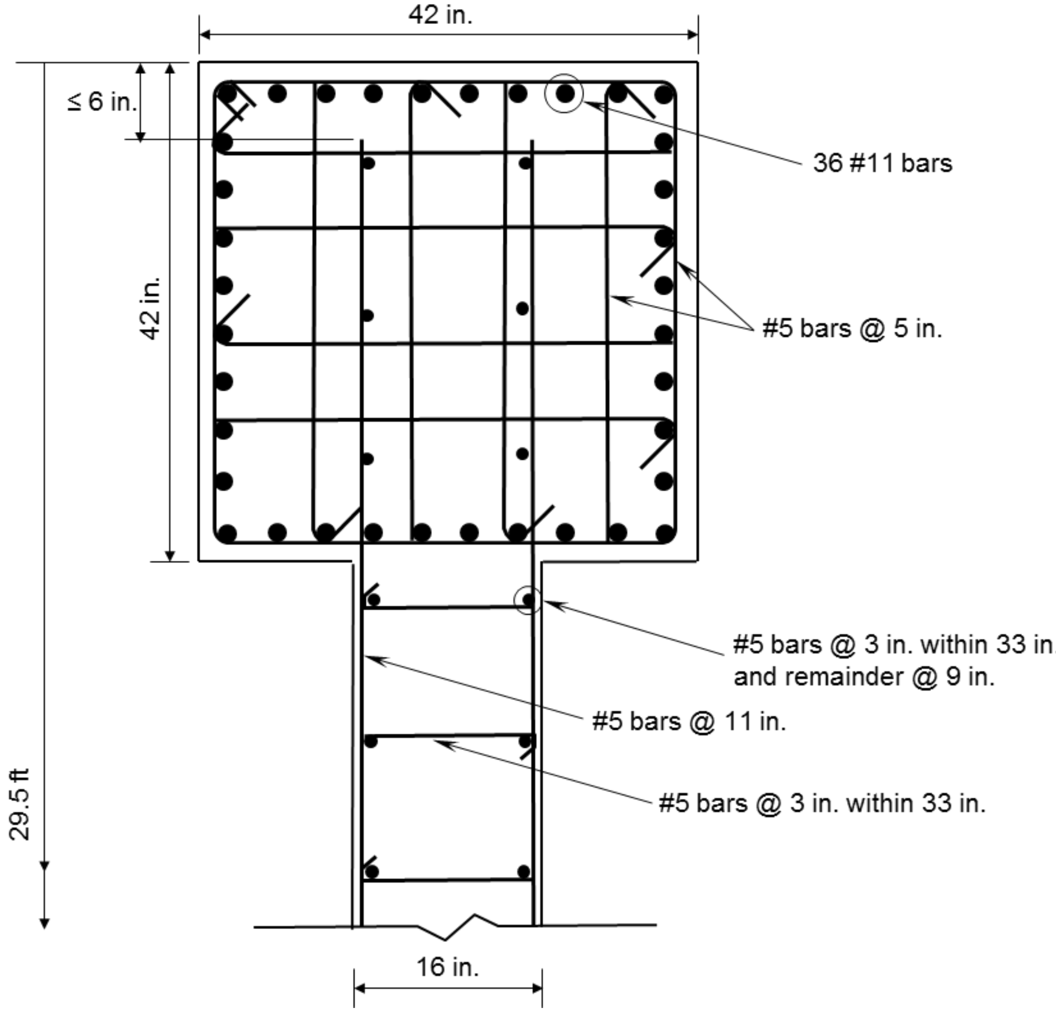


Figure 2-4. Reinforcement Details for Shear Wall C2-D2 (between Level 1 and Level 2) by Equivalent Lateral Force Procedure

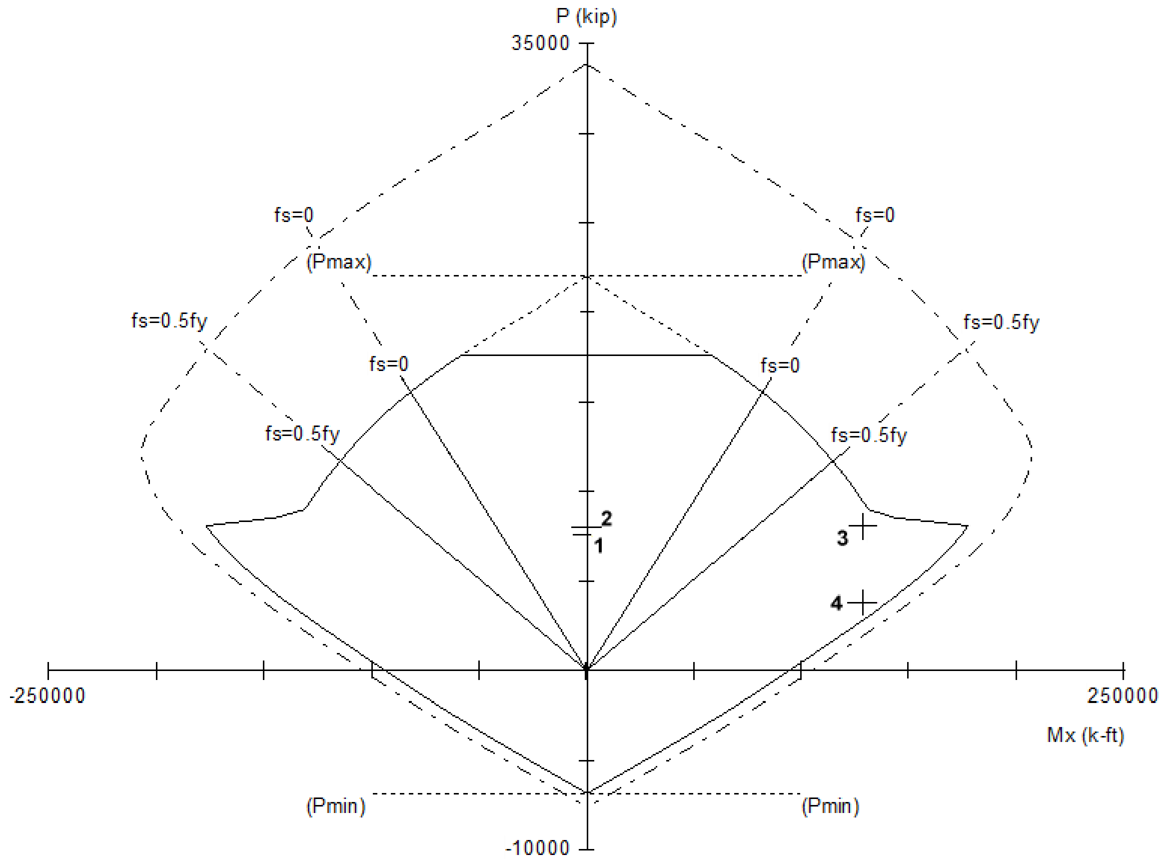


Figure 2-5. Design Strength Interaction Diagram for Shear Wall C2-D2 (between Level 1 and Level 2) by Equivalent Lateral Force Procedure

Using 2-No. 5 vertical bars @ 11 in. o.c.

$\rho_\ell = 0.0035 \;>\; 0.0025$ O.K.

ACI 318 Section 21.9.4.1

For $h_w/\ell_w = 8.64 > 2.0$
$\alpha_c = 2$
For normal-weight concrete, $\lambda = 1$

$$V_n = A_{cv}\,(\alpha_c\lambda\sqrt{f'_c} + \rho_t f_y) \qquad \text{(ACI 318 Eq. 21-7)}$$
$$= 5664\,[2\times1\times\sqrt{4000} + 0.0043\times60{,}000]/1000$$
$$= 2178 \text{ kips}$$

In accordance with ACI 318 Section 21.9.4.4, V_n must not exceed $8A_{cv}\sqrt{f'_c}$

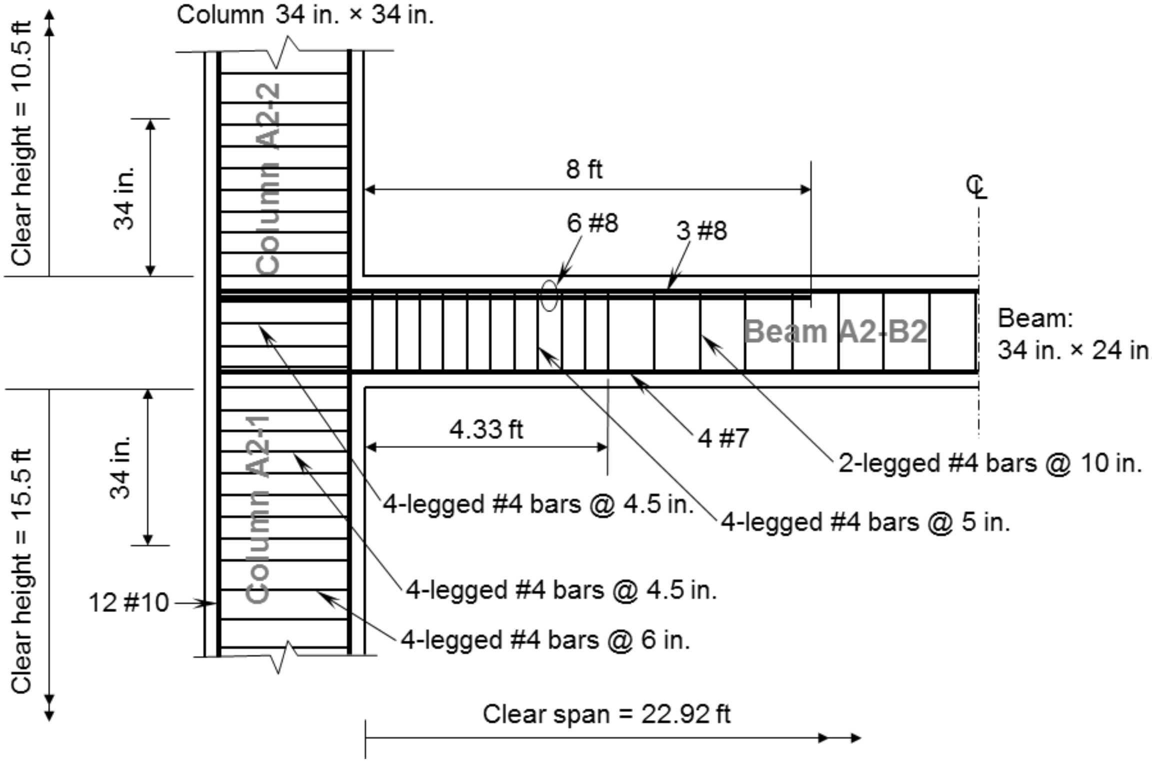


Figure 2-10. Reinforcement Arrangements in End Beam A2-B2, Column A2-1 (between Level 1 and Level 2) and Column A2-2 (between Level 2 and Level 3)

In addition, center-to-center spacing of longitudinal bars that are transversely supported by a stirrup cannot exceed 14 in.

$$\text{Top} = \frac{34 - 2\times1.5 - 2\times0.5}{5}\times 2 = 12\,\text{in.} < 14\,\text{in.} \quad ....\text{OK}$$

Since, the bottom bars will be placed based on the stirrup locations, maximum distance between two transversely supported bars is the same as above.

2.7.2.4 Negative reinforcing bar cutoff

The negative reinforcement at the joint face is 6-No.8 bars. The location where 3 of the 6 bars can be terminated will be determined. Note that 3-No.8 bars must be continuous throughout the length of the beam to satisfy the minimum reinforcement requirements of ACI 318 Section 21.5.2.1.

The loading used to find the cutoff point of the 3-No.8 bars is 0.7 times the dead load in combination with the probable flexural strengths (M_{pr}) at the ends of the members (fourth load combination, representing a condition where the vertical component of the earthquake counteracts dead load effects), as this combination will produce the longest bar cutoff lengths.

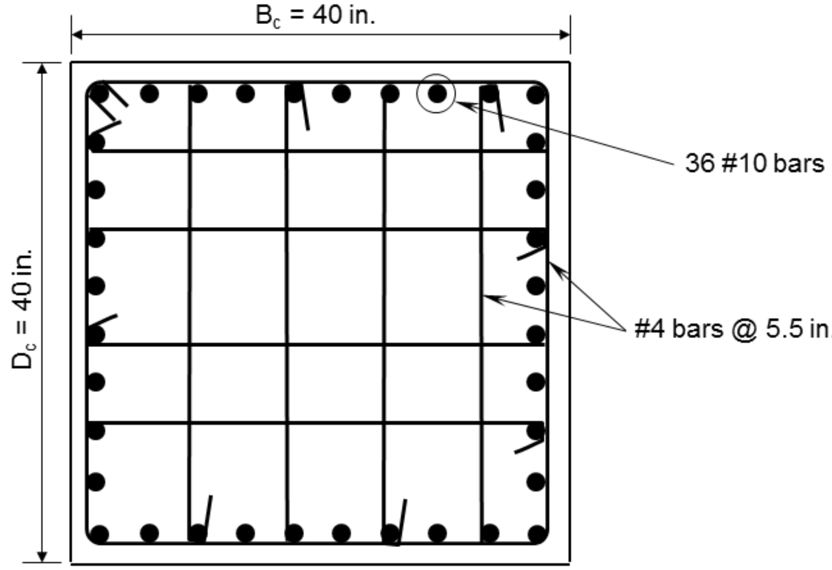


Figure 2-13. Reinforcement Details for Interior Columns B2-1 and B2-2

$\phi\ 0.8\ P_o = \phi\ 0.8\ \{0.85 f_c' \ (A_g - A_{st}) + A_{st} f_y\} = 4174$ kips > 3506 kips for Column B2-1
> 3320 kips for Column B2-2

Figure 2-14 shows the P-M interaction diagram for the interior columns.

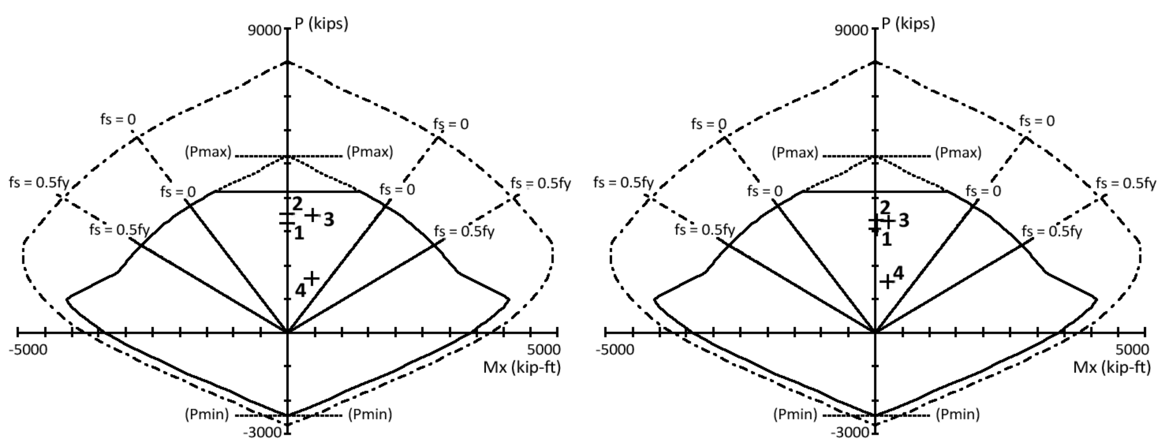


Figure 2-14. P-M Interaction Diagrams for Columns B2-1 (left) and B2-2 (right)

2.8.2.2 General

ACI 318 Section 21.6 applies to frame members

(i) resisting earthquake forces and