The Design of Common Irregularities in Buildings

Design of Concrete Diaphragm and Collectors
Seismic Design Category D
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Overview

Diaphragm - Introduction

Diaphragm - Introduction

Definition per 2024 IBC §202:

- "A horizontal or sloped system acting to transfer lateral force to the vertical-resisting elements. When the word 'diaphragm' is used, it shall include horizontal bracing systems."

Purpose

- Transfer lateral Inertia Mass to vertical elements of Lateral Load Resisting System (LLRS).
- Connect various components of the vertical LLRS with appropriate strength and stiffness to result in intended building response per design.
- Support gravity loading such as floor, ceiling, partitions, cladding, etc.
- Resist wall out-of-plane force.

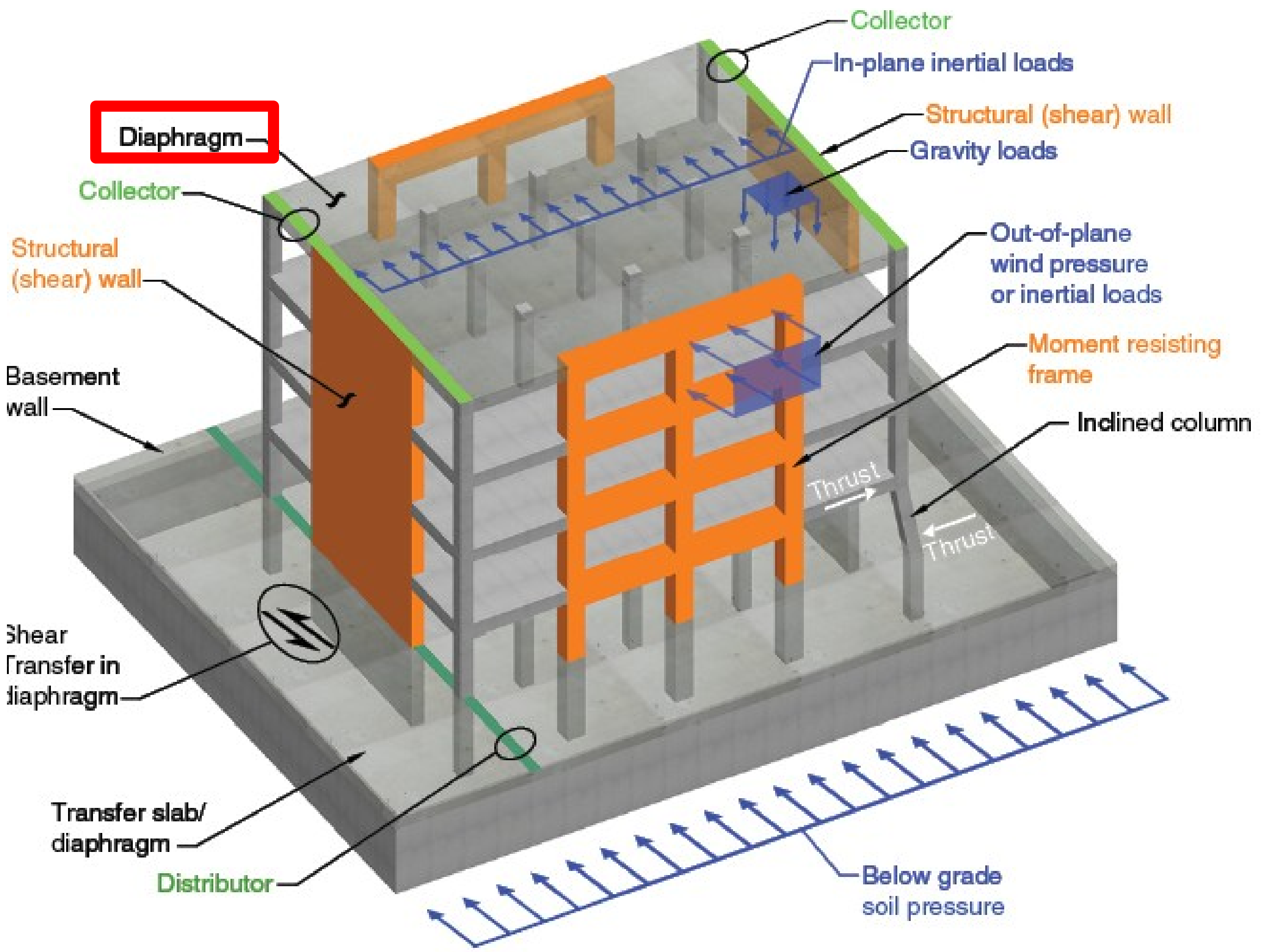
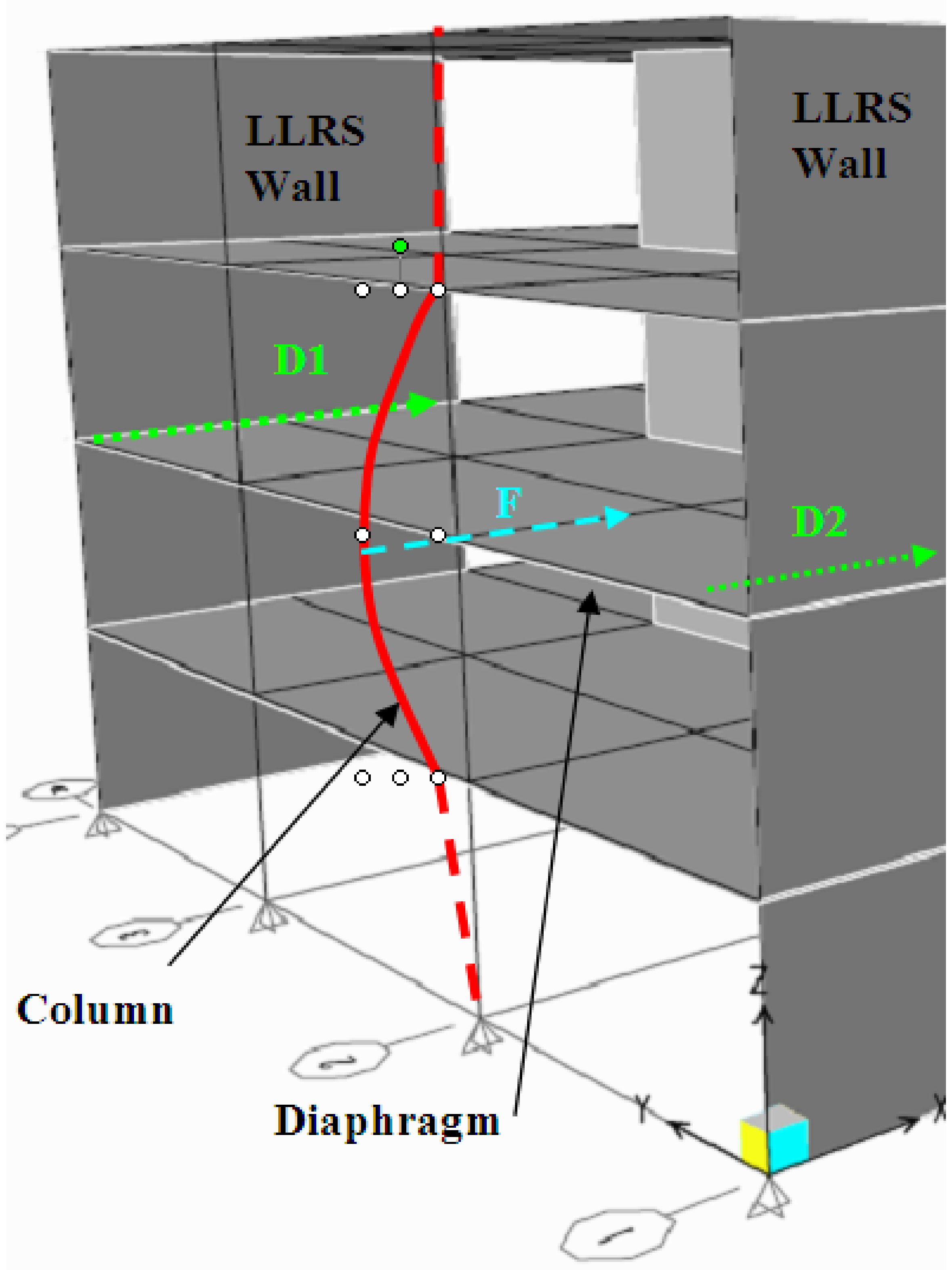


Fig. R12.1.1—Typical diaphragm actions.

ACI 318 Fig R12.1.1

Diaphragm - Purpose

Diaphragm stabilize both vertical gravity and LLRS from buckling laterally when attached to diaphragm.



The required diaphragm restraining force, *F*, to prevent the column from buckling outward in the x-direction at the third floor.

(The column restraining force, *F*, is transferred first through the beam/column connection and secondly by attachments across the beam interface into diaphragm.)

The diaphragm shear D1 or D2 transferring a portion of Force, *F*, to the LLRS vertical element.

Note that the diaphragm also restrains the gravity column and LLRS wall from buckling in the y direction.

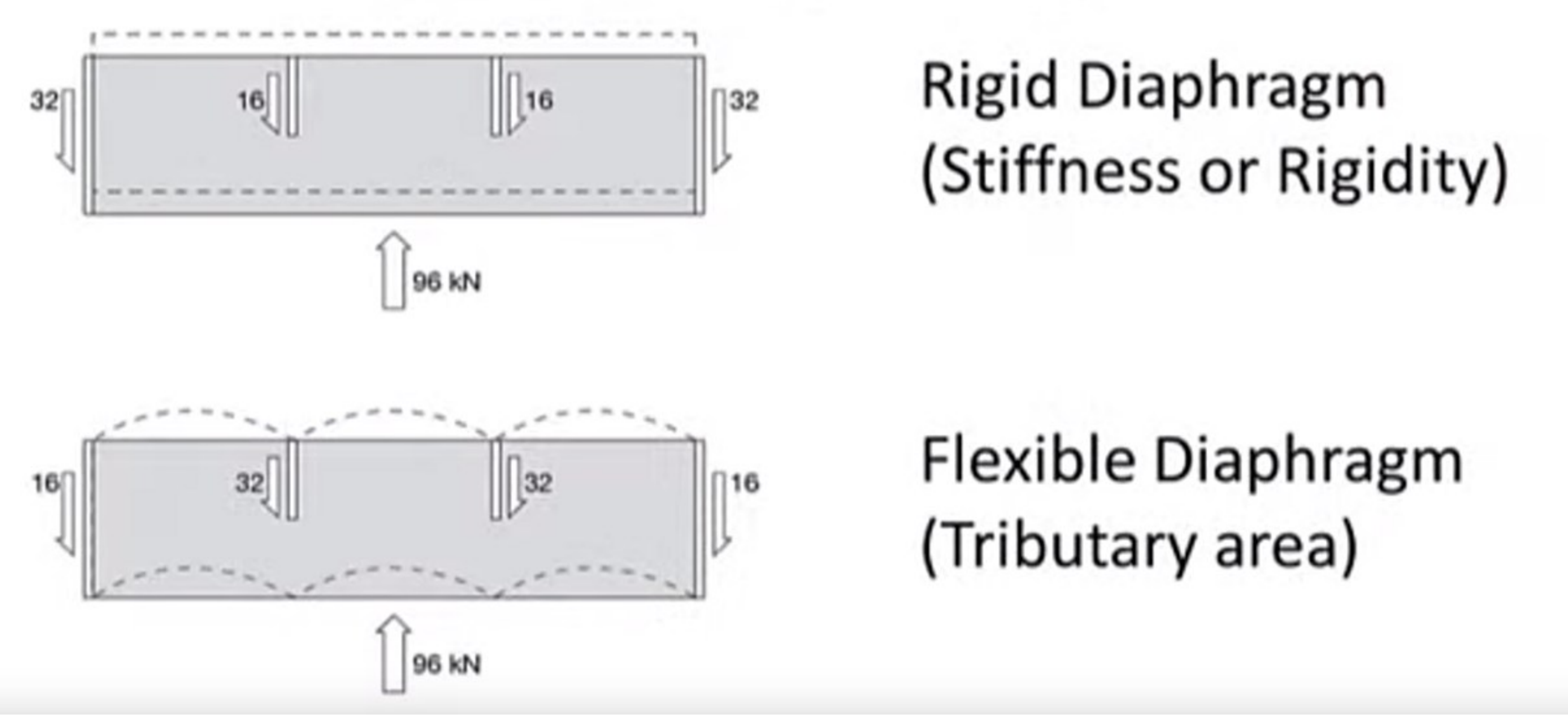
Diaphragm - Introduction

Diaphragm Intended Behavior

- Diaphragms are designed essentially for linear behavior.
- Diaphragms are to remain relatively stiff and damage free and effectively transfer inertial forces to LLRS.

Diaphragm Types: Classified into three main types based on stiffness

- Flexible
- Rigid
- Semirigid: Structural analysis explicitly consider the stiffness of the diaphragm.



Rigid vs Flexible Diaphragm Behavior

Diaphragm Behavior - Flexible

ASCE 7-22, §12.3.1.1:

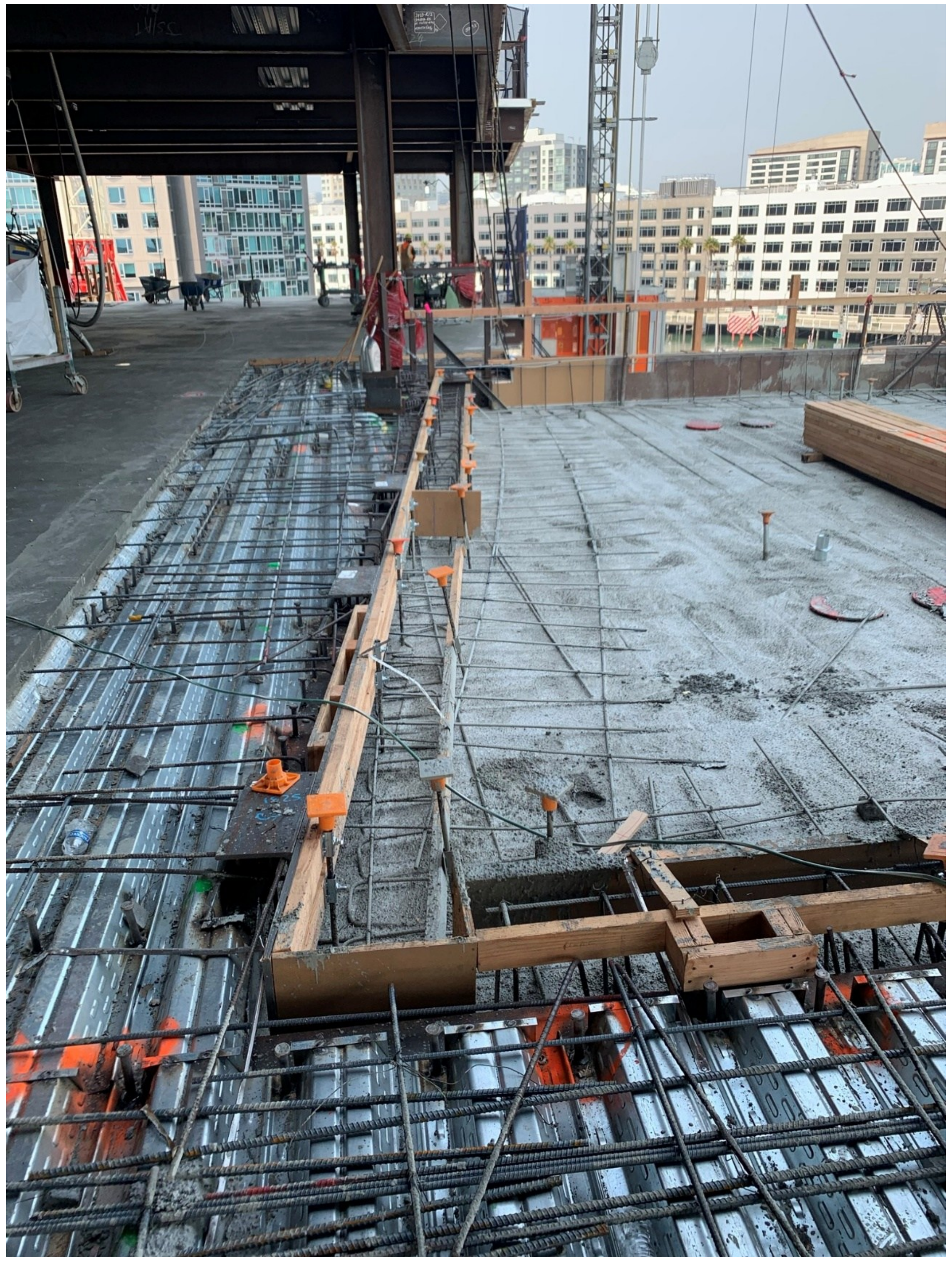
- Diaphragms constructed of untopped steel decking or wood structural panels are permitted to be idealized as flexible if any of the following condition exist:
  - Vertical elements are steel braced frames; steel and concrete composite braced frame; or concrete, masonry, steel, or steel and concrete composite shear walls.
  - One or two-family dwellings.
  - Light frame construction with some restrictions:
    - Nonstructural topping should be 1.5" or less.
    - Vertical LLRS complies with allowable story drift.

Light Frame Wood Construction

Diaphragm Behavior - Rigid

ASCE 7-22, §12.3.1.2:

- Concrete slab or concrete-filled metal deck.
- Span-to-depth ratios of 3 or less.
- Do not have Type 2 (Reentrant Corner), 3 (Diaphragm Discontinuity), 4 (Out-of-Plane Offset), and 5 (Nonparallel System) Horizontal Structural Irregularity.



Concrete Metal Deck

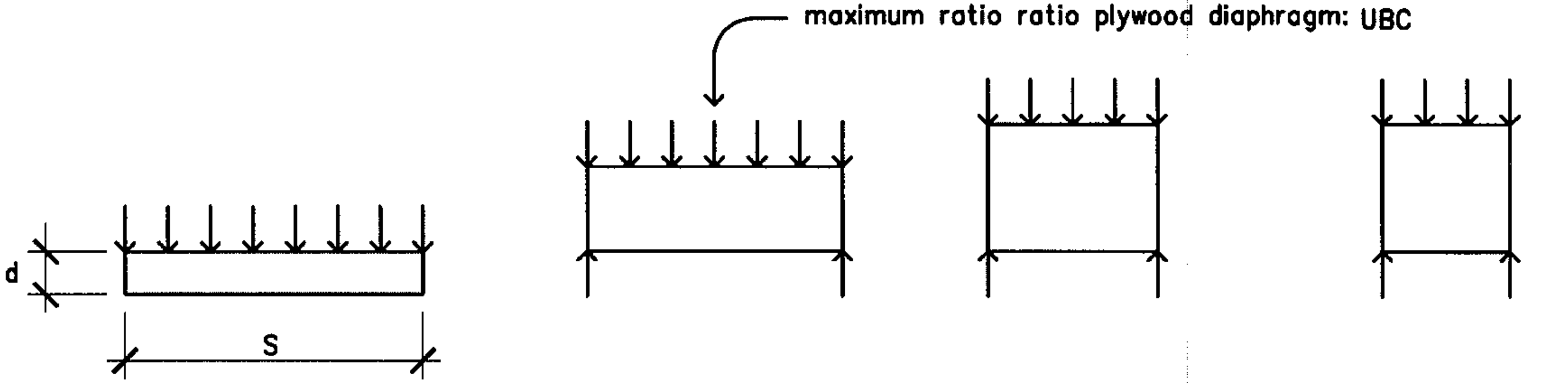
Diaphragm Behavior - Rigid

- Real Diaphragm Behavior: Concrete
- The Rigid diaphragm assumption can often reasonably approximate a concrete diaphragm.
- Reinforced concrete floor slabs and concrete-filled metal deck can often be reasonably approximated by rigid diaphragm behavior, provided that diaphragm is significantly stiffer than the vertical frames or shear walls.

Diaphragm Behavior - Rigid

- Diaphragms has special properties when compared to a Beam:
  - The span-to-depth ratio is usually small – plane sections are not likely to remain plane.
  - As span-to-depth ratio decreases, diaphragm deformation characteristic approaches that of Deep Beam – Deflection primary caused by shear strain rather than flexure
- Reading Material:
  - NEHRP Technical Brief No. 3 and 5

Diaphragm Stiffness

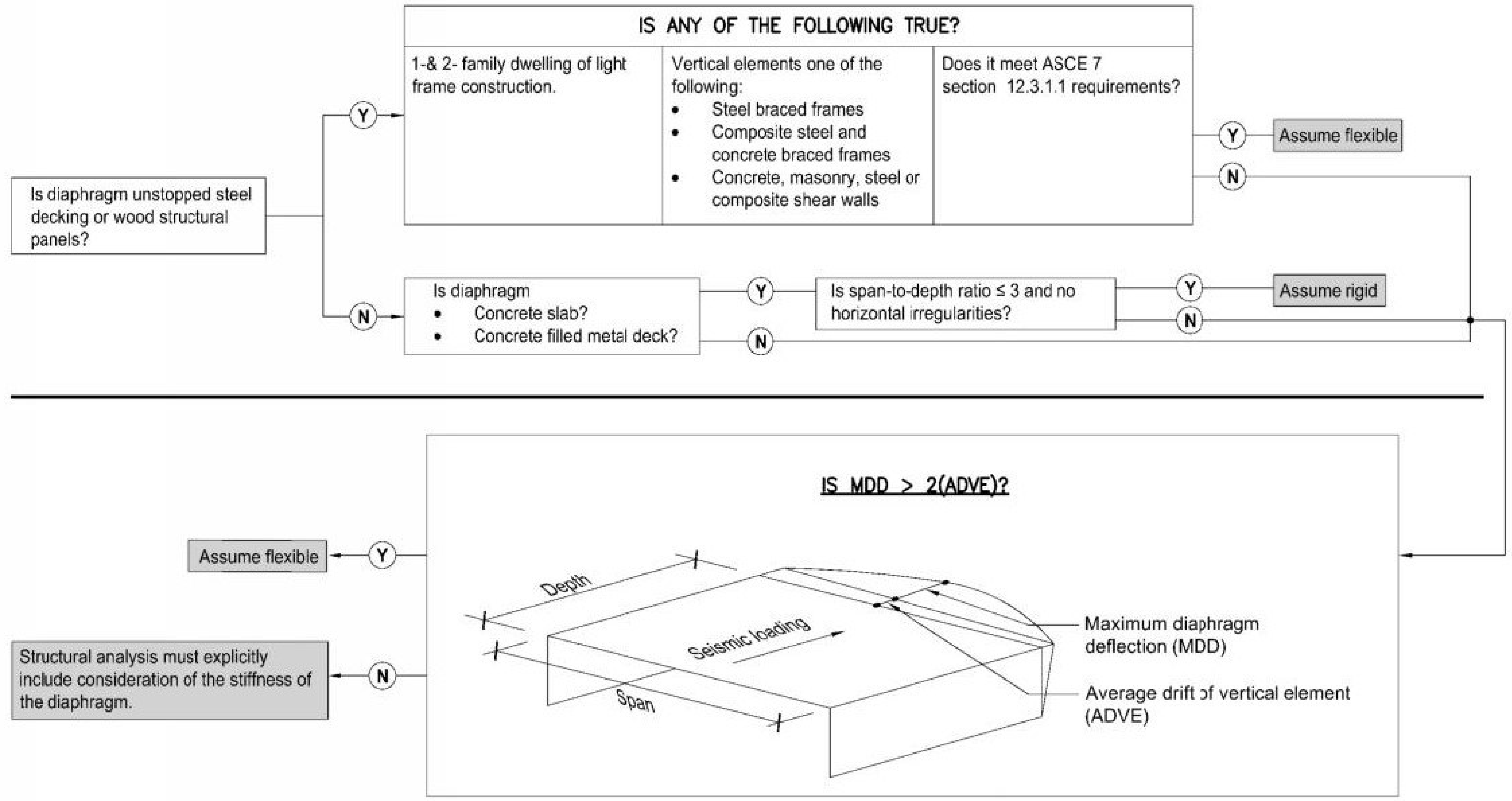


s/d ratio	10	4	2	1.25
basic nature	moderately stiff beam	stiff beam	marginally stiff beam	deep beam
major deflection due to	flexure	flexure & shear	shear	shear

FIGURE-4 Behavior of horizontal diaphragms related to depth-to-span ratios.

Reference: simplified building design to wind and earthquake forces- James Ambrose and Dimitry Vergun

Diaphragm Classification Flow Chart



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Methods to Calculating Diaphragm Force

- Traditional Design Method
  - Prescriptive code procedure using ASCE 7-22, §12.10.1

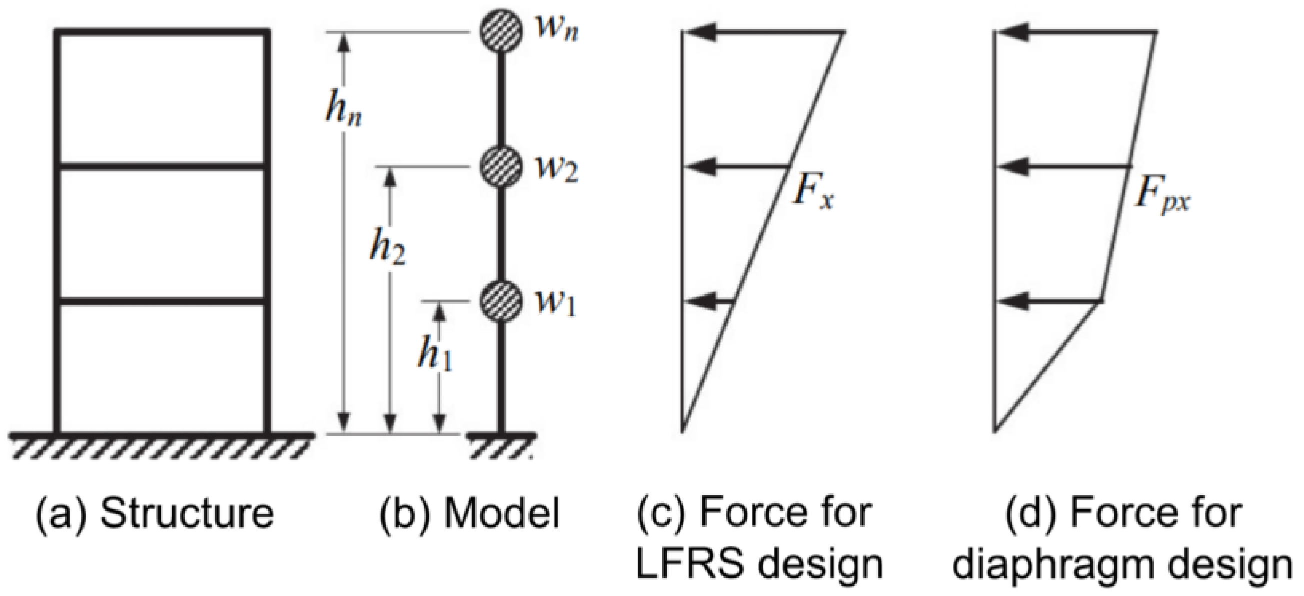
$$0.2S_{DS}I_e w_{px} \le F_{px} = \frac{\sum_x^{i=n} F_i}{\sum_x^{i=n} w_i} w_{px} \le 0.4S_{DS}I_e w_{px}$$

- Alternative Design Method
  - Precast concrete diaphragm in SDC C, D, E, and F must be designed with alternative design method.
  - ASCE 7-22, §12.10.3

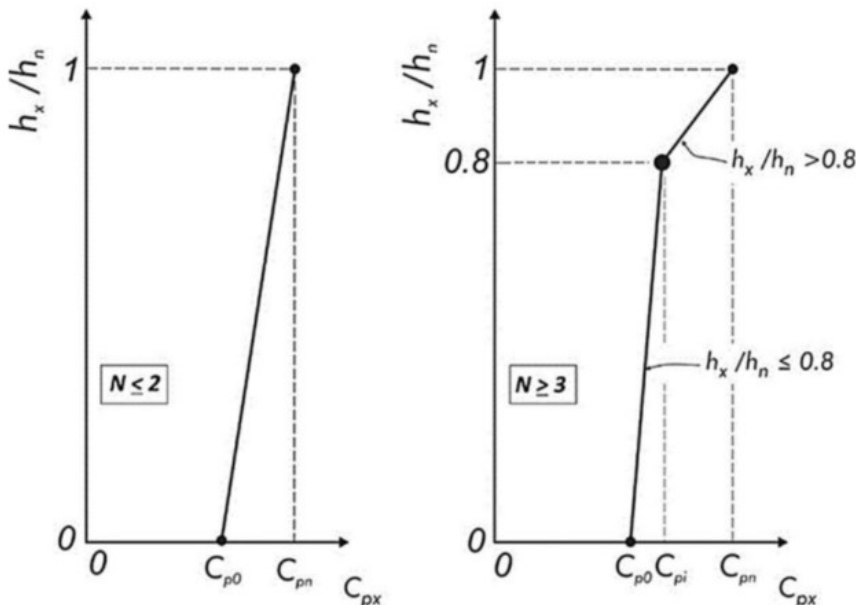
$$0.2S_{DS}I_e w_{px} \le F_{px} = \frac{C_{px}}{R_s} w_{px}$$

- Alternative Diaphragm Design Provisions for One-Story Structures with Flexible Diaphragms and Rigid Vertical Elements.
  - ASCE 7-22, §12.10.4

$$F_{px} = C_{s-diaph}(w_{px})$$



Traditional Design Method



Alternative Design Method

Collector - Introduction

Collector - Introduction

Definition per 2024 IBC § 202:

- "A horizontal diaphragm element parallel and in line with the applied force that collects and transfers diaphragms shear forces to the vertical elements of the lateral force-resisting system or distributes forces within the diaphragm, or both."

Purpose

- Collect and transfer diaphragm shear forces to vertical LLRS.
- ASCE 7-22, §12.10.2.1: For SDS C, D, E, or F collector elements and their connection must be designed for overstrength with seismic force, except structures braced entirely by wood light-frame shear wall.
- Above requirement ensures that inelastic energy dissipation occurs in ductile LLRS instead of Collectors, Diaphragms, and Connection.

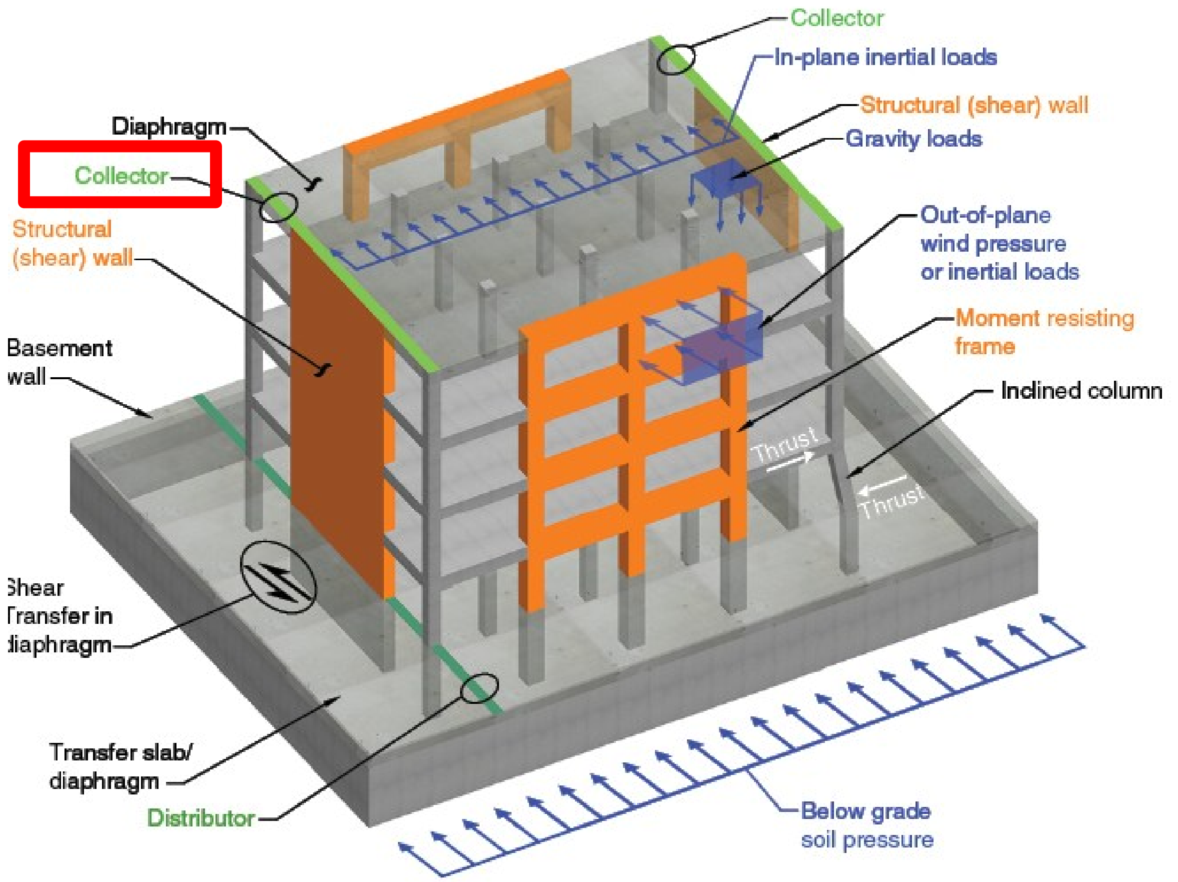


Fig. R12.1.1—Typical diaphragm actions.

ACI 318 Fig R12.1.1

Collector - Introduction

- Global Ductility Reduction "R" used to reduce Elastic Response Spectrum demands on LLRS.
  - Implies adequate overstrength is provided in Diaphragms, Collectors, and Connection.
  - Above elements remain elastic and all yielding and inelastic energy dissipation occurs in LLRS.
  - Per ACI 318-19 Commentary R18.12.2.1:
    - Desirable to limit inelastic behavior of Floor and Roof Diaphragms.
    - Preferable for elastic behavior to occur only in the intended locations of vertical LLRS detailed for ductile response.

Design Example
4 Story Concrete Building

Design Example - Description

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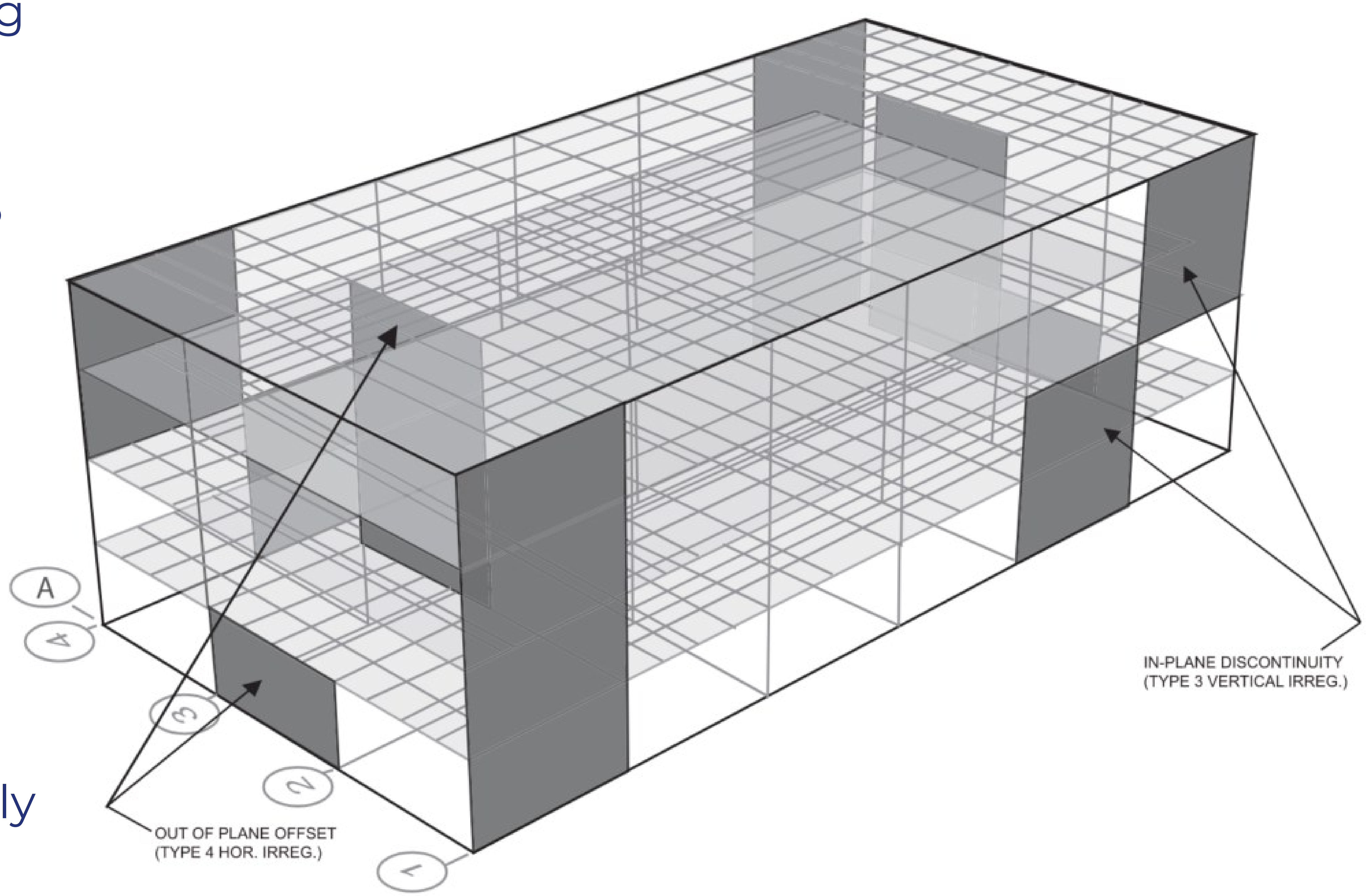
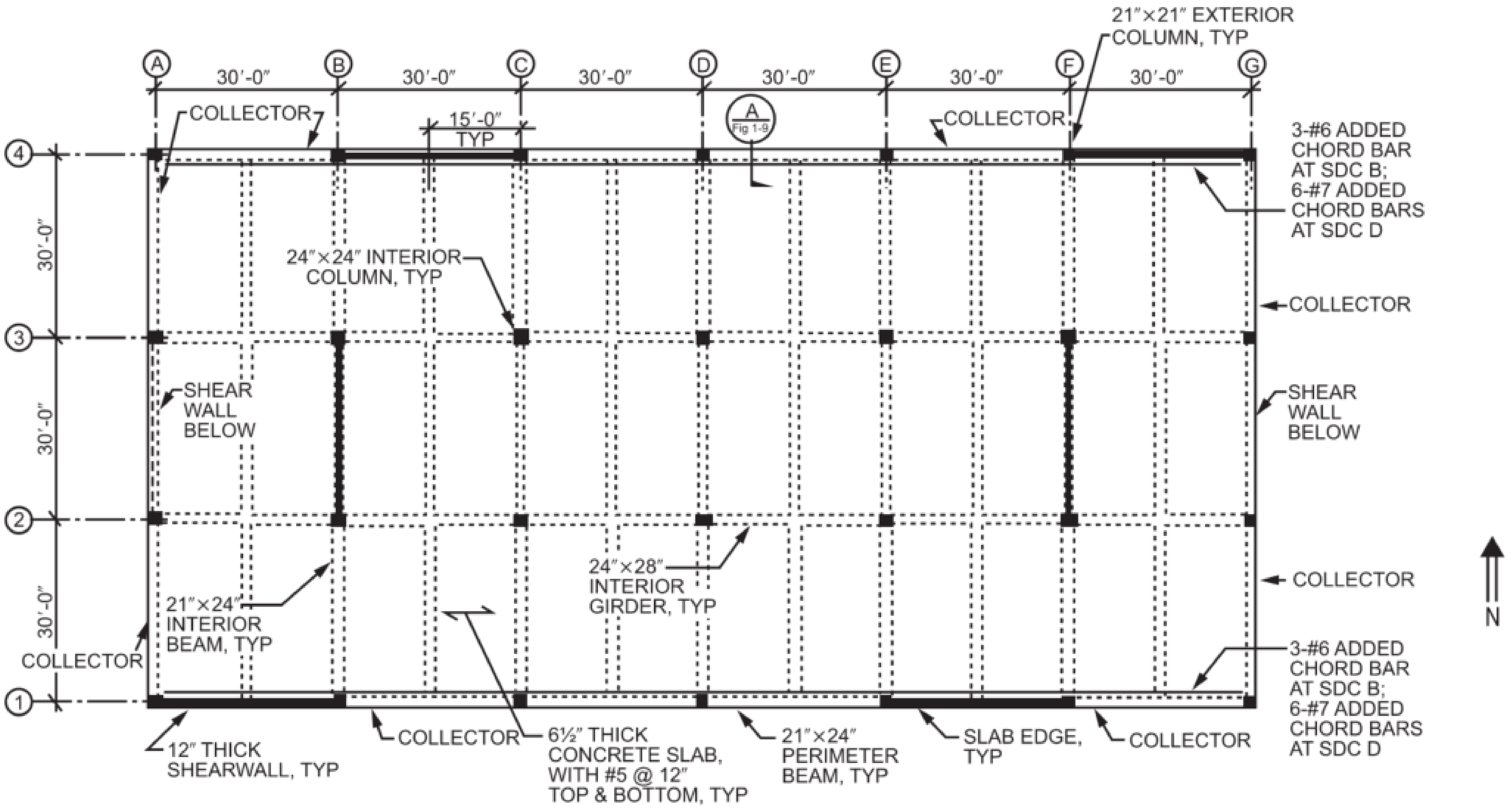
- Building located in Pasadena, CA
- Site Class D (Stiff Soil)
- Occupancy Category II
- Four-story concrete building
- Concrete flat slab system with shear wall and collector beams at the perimeter
- f'c = 4000 psi; fy = 60,000 psi
- Governing codes: IBC 2021, **ASCE 7-22**, and **ACI 318-19**
- Typical flat slab reinforcing of #5@12" OC each way, top and bottom.

Design Example - Description

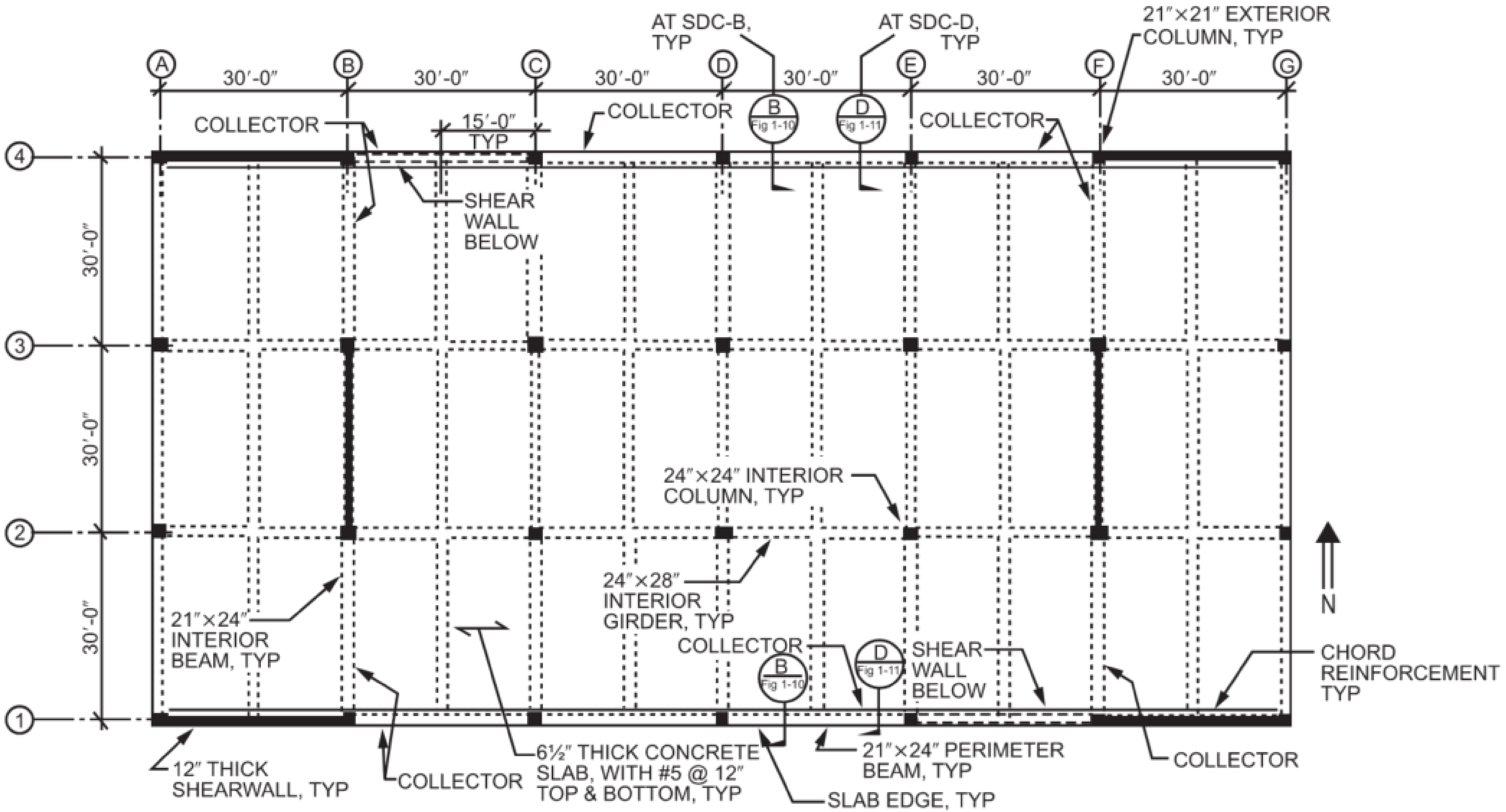
- 3-D Computer Model of the Building
  - Rigid diaphragm all levels
  - Cracked stiffness modifier of 0.35 for shear wall
  - Pinned supports at base for gravity columns
  - Stiffness modifier of 0.0001 for gravity columns
  - Fixed support at base for shear walls
  - Building self-weight automatically calculated the program



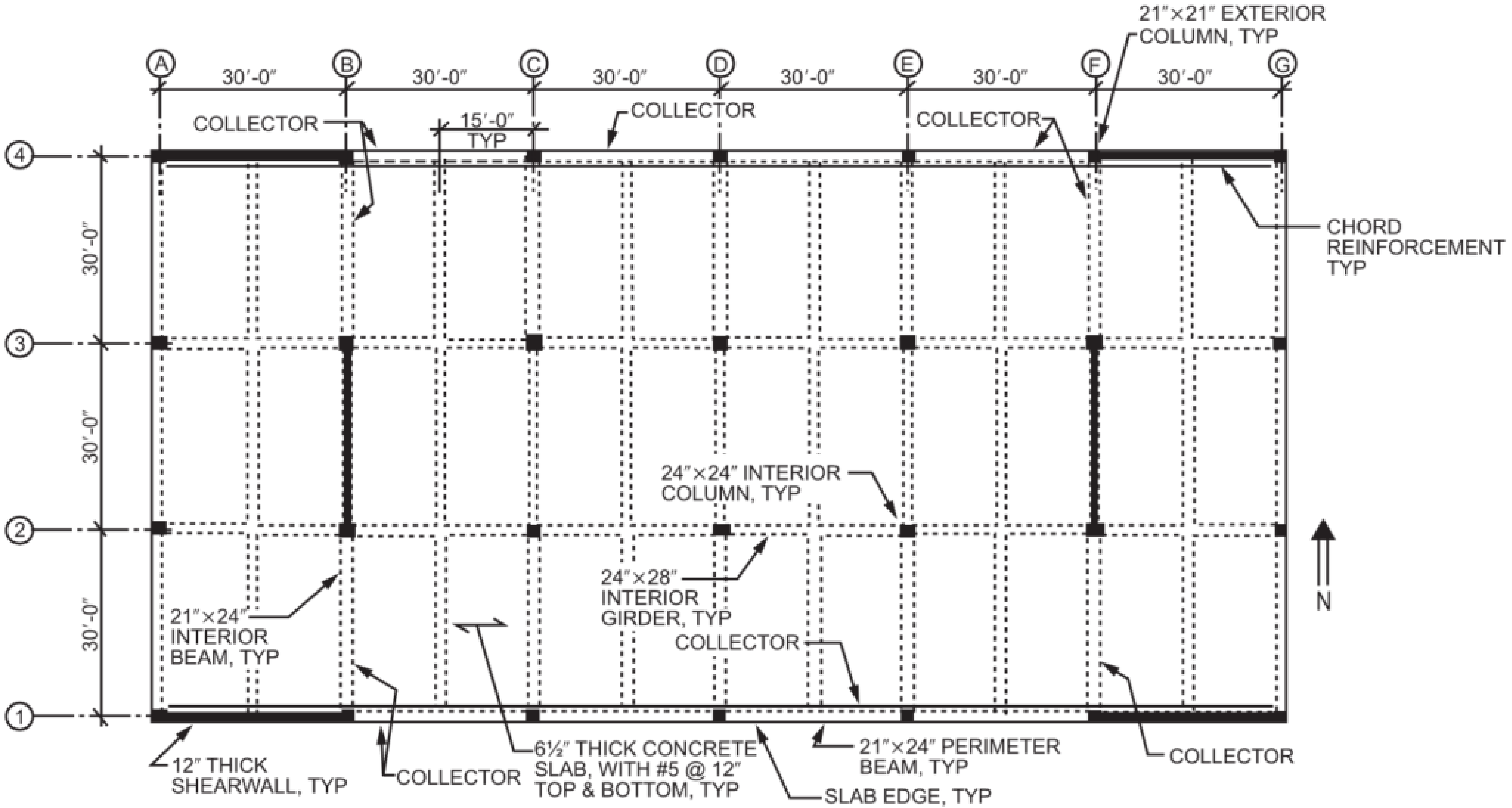
3-D View of the Structure



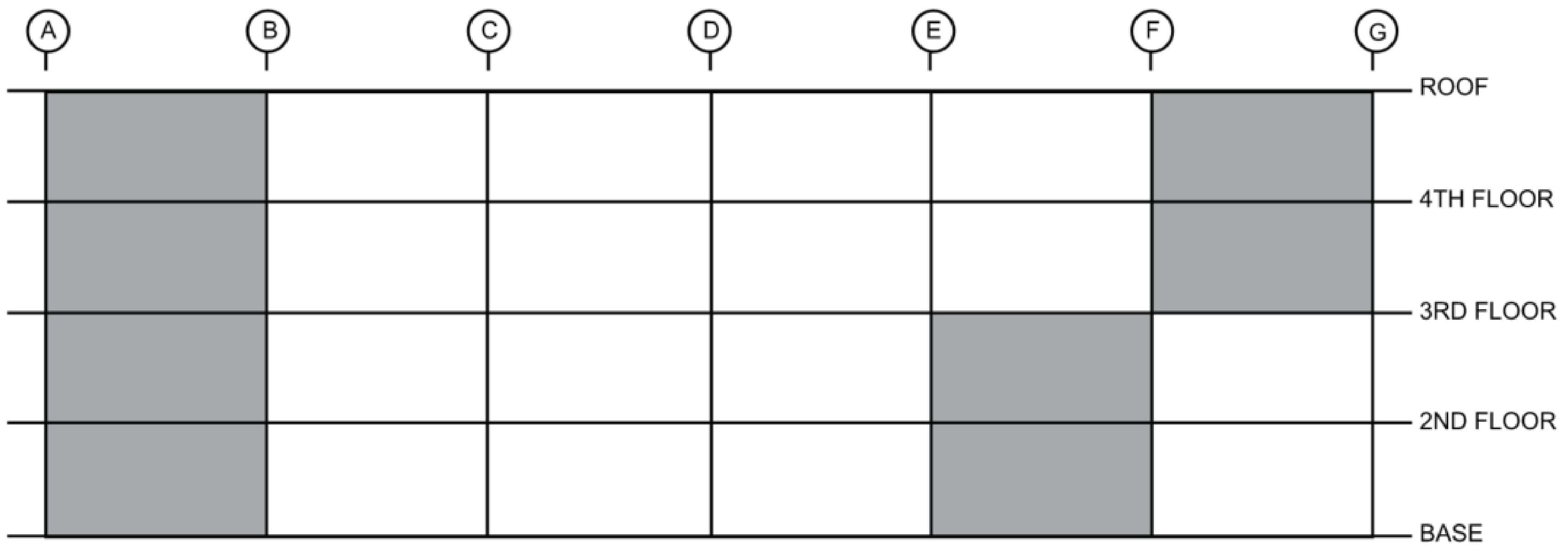
2nd Level Floor Plan



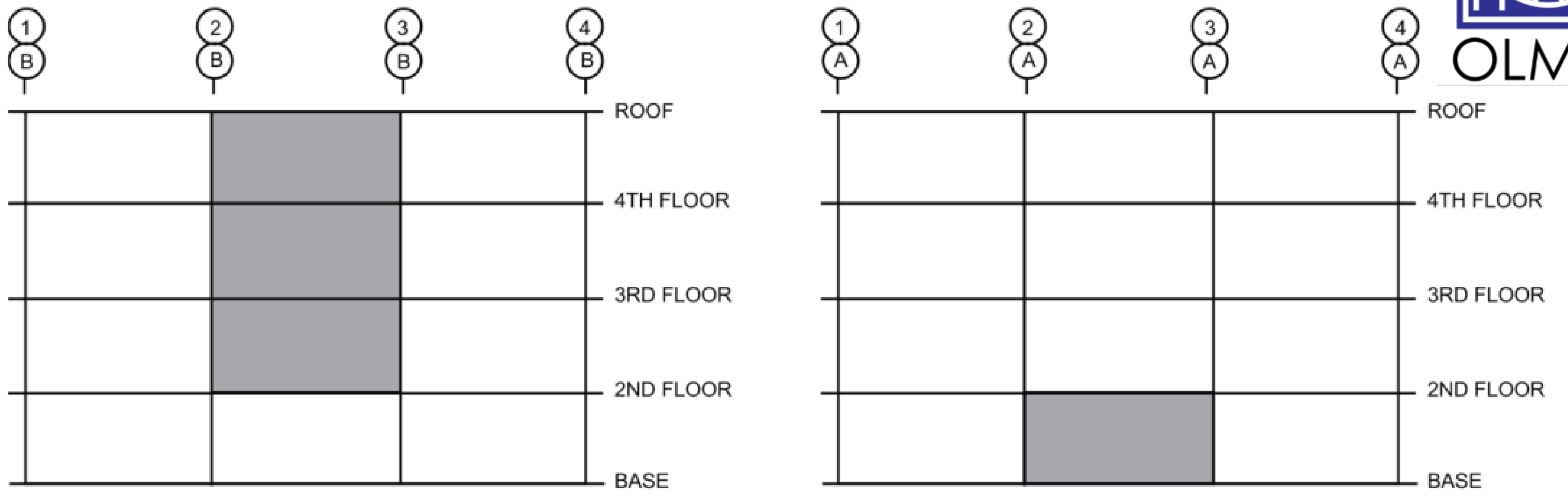
3rd Level Floor Plan



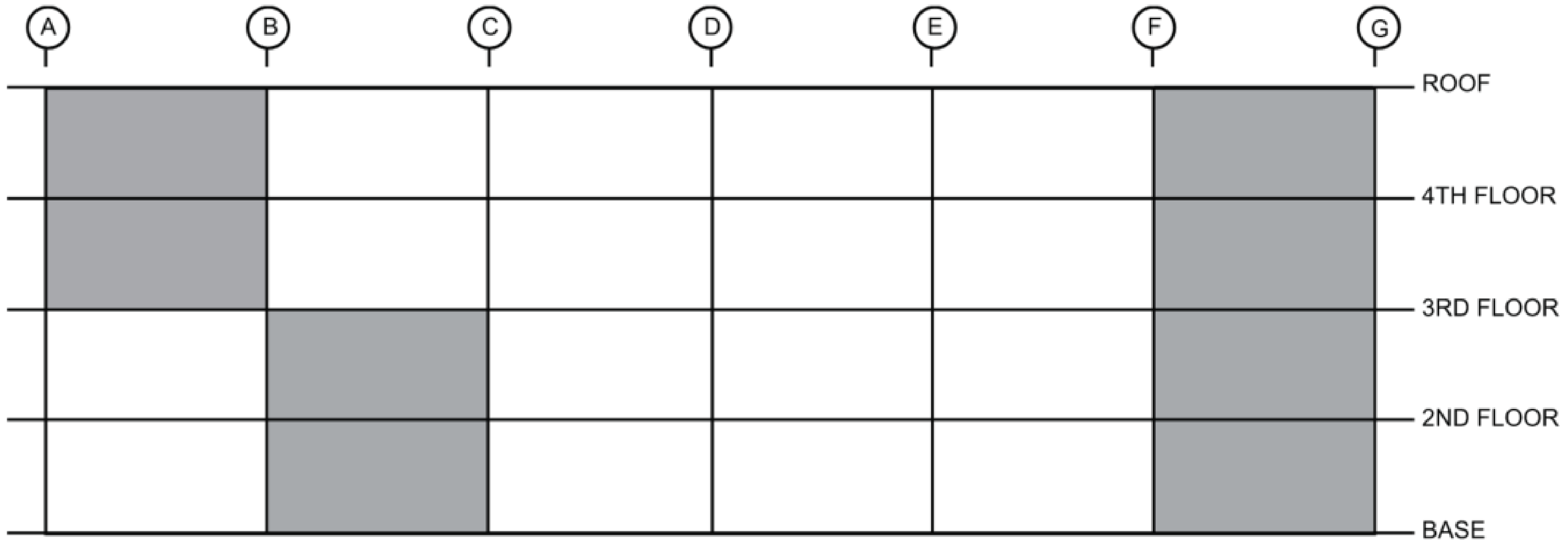
4th Level Floor Plan



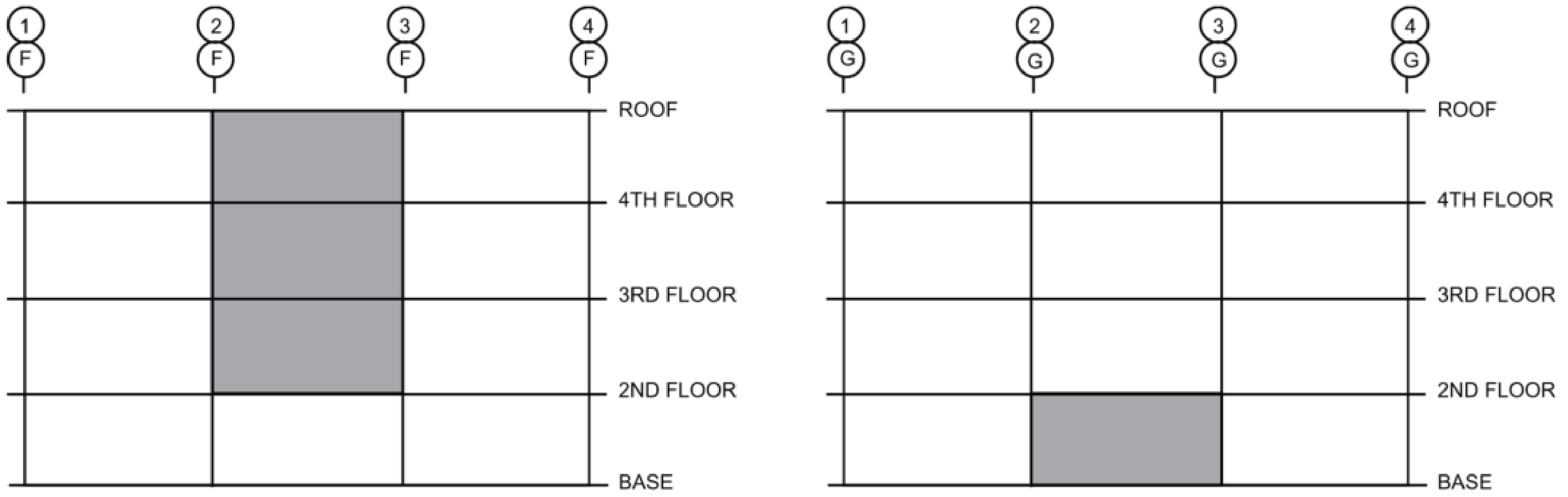
E-W Elevation (Grid 1)



N-S Elevation (Grid B/A)



E-W Elevation (Grid 4)



N-S Elevation (Grid F/G)

Design Example – Seismic Loading

- Seismic Design Category (SDS) D
- Risk Category: II; I_e = 1.0
- S_S = 1.5
- S_1 = 0.39
- S_{MS} = 1.5g
- S_{M1} = 0.7449g
- S_{DS} = 2/3 S_{MS} = 1.0g
- S_{D1} = 2/3 S_{M1} = 0.5g

- R = 5.0 (Special Reinforced Concrete Shear Wall)
- Ω0 = 2.5; Cd = 5; ρ = 1.0

- Seismic parameters are obtained from the ASCE Hazard tool.
- **https://ascehazardtool.org/**

Design Example – Seismic Loading

Design Base Shear

$$V = C_s W$$ ASCE 7 Eq. 12.8-1

Governing East-West Direction

$$C_s = \frac{S_{DS}}{\left(\frac{R}{Ie}\right)} = \frac{1.0}{\left(\frac{5.0}{1.0}\right)} = 0.200 \text{ (Governs in East-West direction)}$$ ASCE 7 Eq. 12.8-3

$$V = 0.200(14,684\,\text{k}) = \underline{\underline{2937\,\text{k}}}$$

Governing North-South Direction

$$C_s = \frac{S_{D1}}{T\left(\frac{R}{Ie}\right)} = \frac{0.50}{0.52\left(\frac{5.0}{1.0}\right)} = 0.192 \text{ (Governs in North-South direction)}$$ ASCE 7 Eq. 12.8-4

$$V = 0.192(14,684\,\text{k}) = \underline{\underline{2819\,\text{k}}}$$

Table 1-5. Vertical distribution of seismic forces for the North-South direction (SDC D)

Level	w_x (k)	h_x (ft)	$w_x h_x^k$ (k-ft)	$\frac{w_x h_x^k}{\sum w_i h_i^k}$ (%)	F_x (k)	F_{tot} (k)
Roof	3524	60	220734	38.9	1095.2	1095
4th Floor	3720	45	174231	30.7	864.5	1960
3rd Floor	3720	30	115661	20.4	573.9	2534
2nd Floor	3720	15	57411	10.1	284.9	2819
Σ	14684		568037		2819	

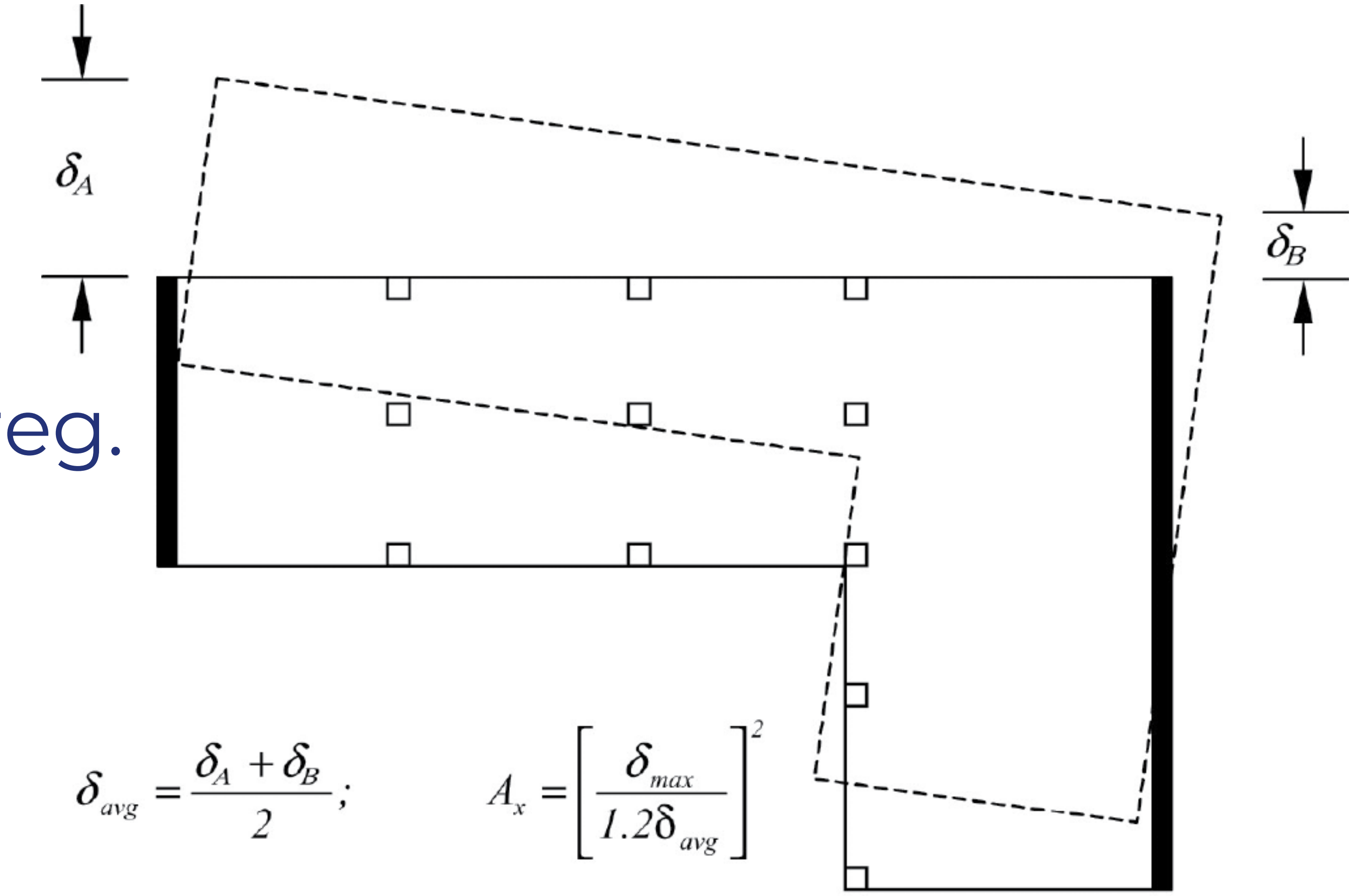
Table 1-6. Vertical distribution of seismic forces for the East-West direction (SDC D)

Level	w_x (k)	h_x (ft)	$w_x h_x^k$ (k-ft)	$\frac{w_x h_x^k}{\sum w_i h_i^k}$ (%)	F_x (k)	F_{tot} (k)
Roof	3524	60	211446	38.7	1137.0	1137
4th Floor	3720	45	167404	30.6	900.0	2037
3rd Floor	3720	30	111603	20.4	600.0	2637
2nd Floor	3720	15	55801	10.2	300.0	2937
Σ	14684		546255		2937.0	

Vertical Distribution of Seismic Forces

Design Example – Seismic Loading

- Accidental Torsion, ASCE 7-22, §12.8.4.2:
  - Accidental torsion of 5% shall be applied for rigid and semi-rigid diaphragms with following irregularity:
    - SDC B structure with Type 1 horiz. Irreg. and Torsional Irregularity Ratio (TIR) exceed 1.4.
    - SDC C, D, E, or F structure with Type 1 horiz. Irreg. (TIR exceed 1.2).
- Torsional Amplification, ASCE 7-22, §12.8.4.3:
  - Accidental torsional moment shall be amplified where Type 1 horiz. Irreg. exists (TIR exceed 1.2) .
- Example building **does not have Type 1 horiz. Irreg.** (TIR does not exceed 1.2) and application of accidental torsion moments is **not required**. However, design example included accidental torsion.



ASCE 7-22 Figure 12.8-1

Design Example – Diaphragm Demands

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Calculate diaphragm design force at each level per ASCE 7-22, § 12.10.1.1

$$F_{px} = \frac{\sum_{n}^{i=x} F_i}{\sum_{n}^{i=x} w_i} w_{px}$$

ASCE 7-22, Eq. 12.10-1

- F_{px} = Diaphragm design force at level x
- F_i = Design force applied to level I
- w_i = Weight tributary to level I
- w_{px} = Weight tributary to the diaphragm at level x

Design Example – Diaphragm Demands

Minimum diaphragm design force:

$$F_{px} = 0.2 S_{DS} I_e w_{px}$$ ASCE 7-22, Eq. 12.10-2

Lower bound applies to building with low base shear

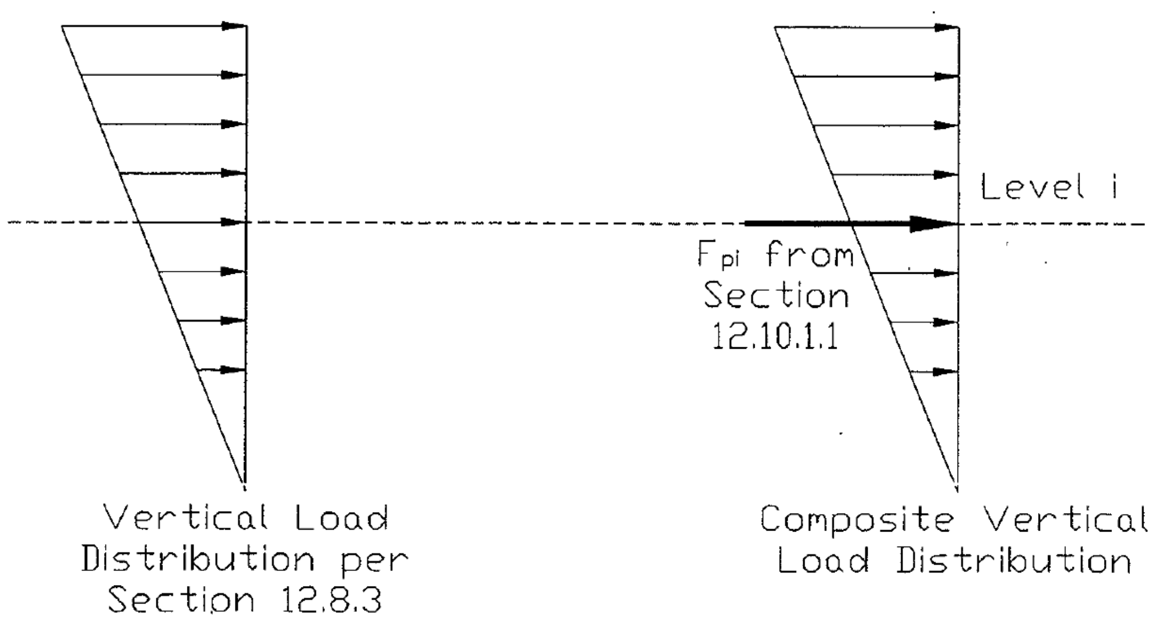
Maximum diaphragm design force:

$$F_{px} = 0.4 S_{DS} I_e w_{px}$$ ASCE 7-22, Eq. 12.10-3

Upper bound applies to building with high base shear

Methods to Calculating Diaphragm Force

1. Simplified Method:
   - Prescriptive code procedure using ASCE 7-22 Eq 12.10-1
   - Requirements:
     - Lateral system and floor plan symmetrical in both directions
     - No irregularities that result in redistribution of seismic forces from other levels through the diaphragms



$$\gamma = \frac{F_{px}}{F_x}$$

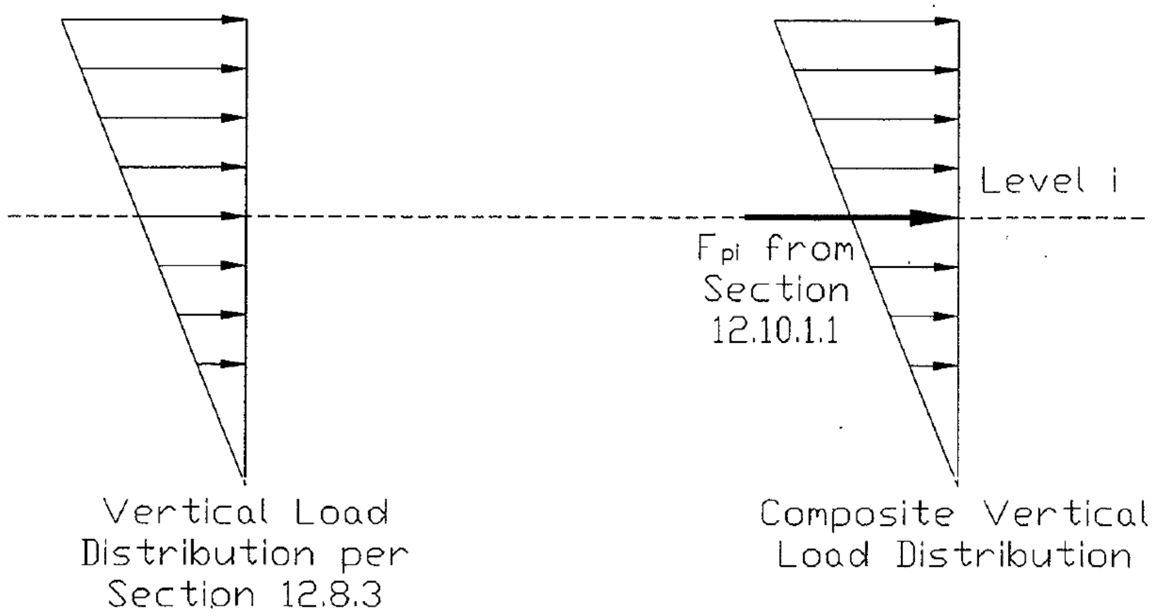
Methods to Calculating Diaphragm Force

1. Simplified Method:

   - Pros:
     - Easy to use

   - Cons:
     - Redistribution of seismic forces from other levels through the diaphragm produces inaccurate results by amplifying those forces as well.

     - Frame discontinuity or decrease in frame shear from level above may produce unconservative results.



$$\gamma = \frac{F_{px}}{F_x}$$

Methods to Calculating Diaphragm Force

2. Correct Method:

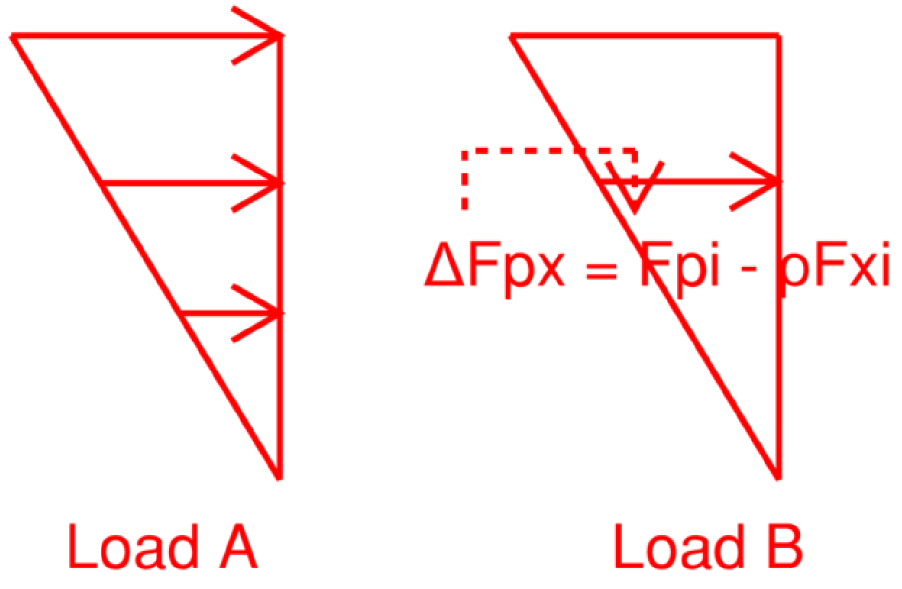
- Step 1: Define Load "A" using ASCE 7-22 Eq. 12.8-12 (Triangular distribution of seismic force):

$$F_x = C_{vx} v \qquad C_{vx} = \frac{w_x h_x^k}{\sum_n^{i=1} w_i h_i^k}$$

- Step 2: Define Load "B" = $\Delta F_{px} = F_{pi} - \rho F_{xi}$ at each level
  - F_{pi}: Diaphragm force per ASCE 7-22, Eq 12.10-1 (Including overstrength, if applicable)

$$F_{px} = \frac{\sum_n^{i=x} F_i}{\sum_n^{i=x} w_i} w_{px}$$

  - F_{xi}: Story shear at each level
  - ρ: Redundancy factor per ASCE 7-22, §12.3.4
- Step 3: Define Load Combo: "A" + Load "B" for each level



Methods to Calculating Diaphragm Force

2. Correct Method:

- Pros:
  - Eliminates calculation of "Gamma" Factor $\gamma = \frac{F_{px}}{F_x}$
  - Straightforward – Post processing using spread sheets
  - Use of "Section Cuts" simplifies diaphragm internal force calculation. Diaphragm has to be modeled as Semi-Rigid.
- Cons:
  - Need analytical model, such as ETABS, SAP, RAM, etc.
  - Lots of upfront work: Tracking load cases and additional load combo

Table 1-7. Diaphragm design forces for the North-South direction (SDC D)

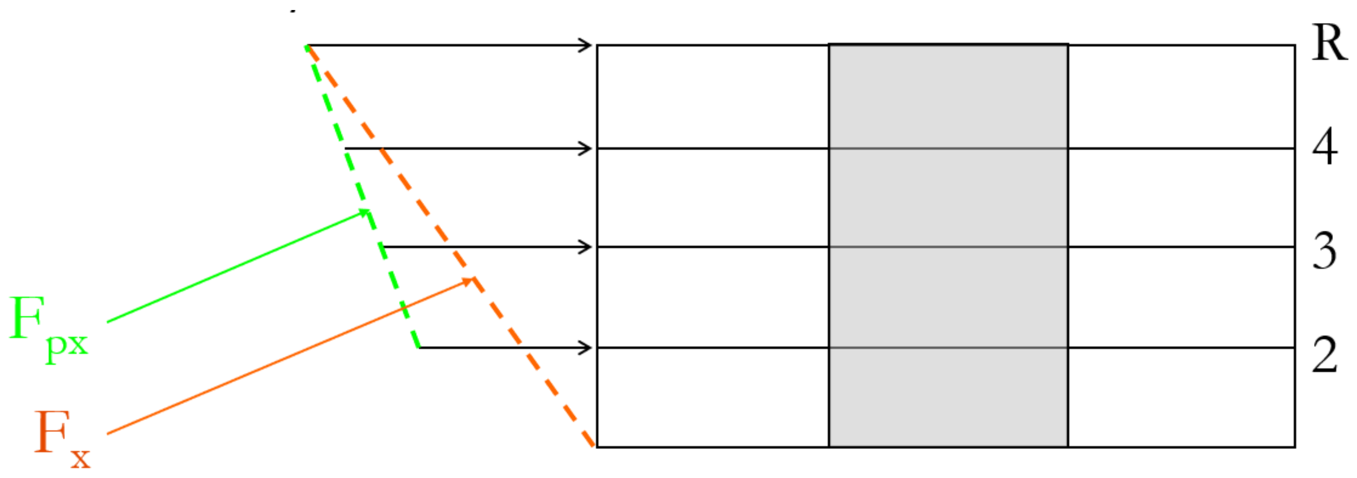
Level	w_{px} (k)	$\sum w_i$ (k)	F_x (k)	$\sum F_i$ (k)	Code diaphragm force $\frac{\sum F_x}{\sum w_{px}}$	Code diaphragm force F_{px} (k)	Code diaphragm force $\gamma = \frac{F_{px}}{F_x}$	Additional Diaphragm Loads (k)
Roof	3524	3524	1095	1095	0.311	1095	1.00	0
4th Floor	3720	7244	865	1960	0.271	1006	1.16	142
3rd Floor	3720	10964	574	2534	0.231	860	1.50	286
2nd Floor	3720	14684	285	2819	0.200*	744	2.61	459
Σ	14684		2819					

* Minimum diaphragm force controls

Table 1-8. Diaphragm design forces for the East-West direction (SDC D)

Level	w_{px} (k)	$\sum w_i$ (k)	F_x (k)	$\sum F_i$ (k)	Code diaphragm force $\frac{\sum F_x}{\sum w_{px}}$	Code diaphragm force F_{px} (k)	Code diaphragm force $\gamma = \frac{F_{px}}{F_x}$	Additional Diaphragm Loads (k)
Roof	3524	3524	1137	1137	0.323	1137	1.00	0
4th Floor	3720	7244	900	2037	0.281	1046	1.16	146
3rd Floor	3720	10964	600	2637	0.240	895	1.49	295
2nd Floor	3720	14684	300	2937	0.200*	744	2.48	444
Σ	14684		2937					

* Minimum diaphragm force controls



Design Example – Irregularities

- Must be checked for horizontal and vertical structural irregularities.

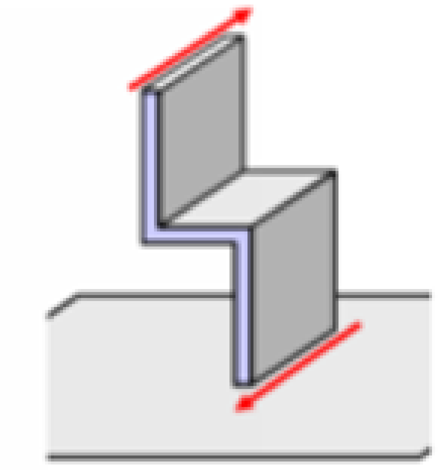
- The example problem has following irregularities:

  - Horizontal Irregularity Type 4
    - Out-of-Plane Offset Irregularity

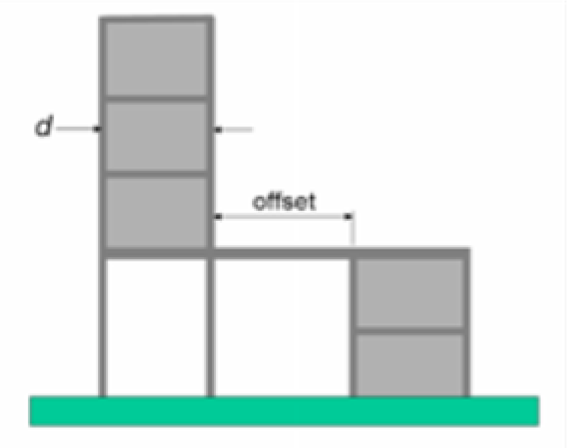
  - Vertical Irregularity Type 3
    - In-Plane Discontinuity in Vertical Lateral Force-Resisting Element

- **This presentation focuses on design of collector and diaphragm for In-Plane Discontinuity (Vert. Irreg. Type 3).**

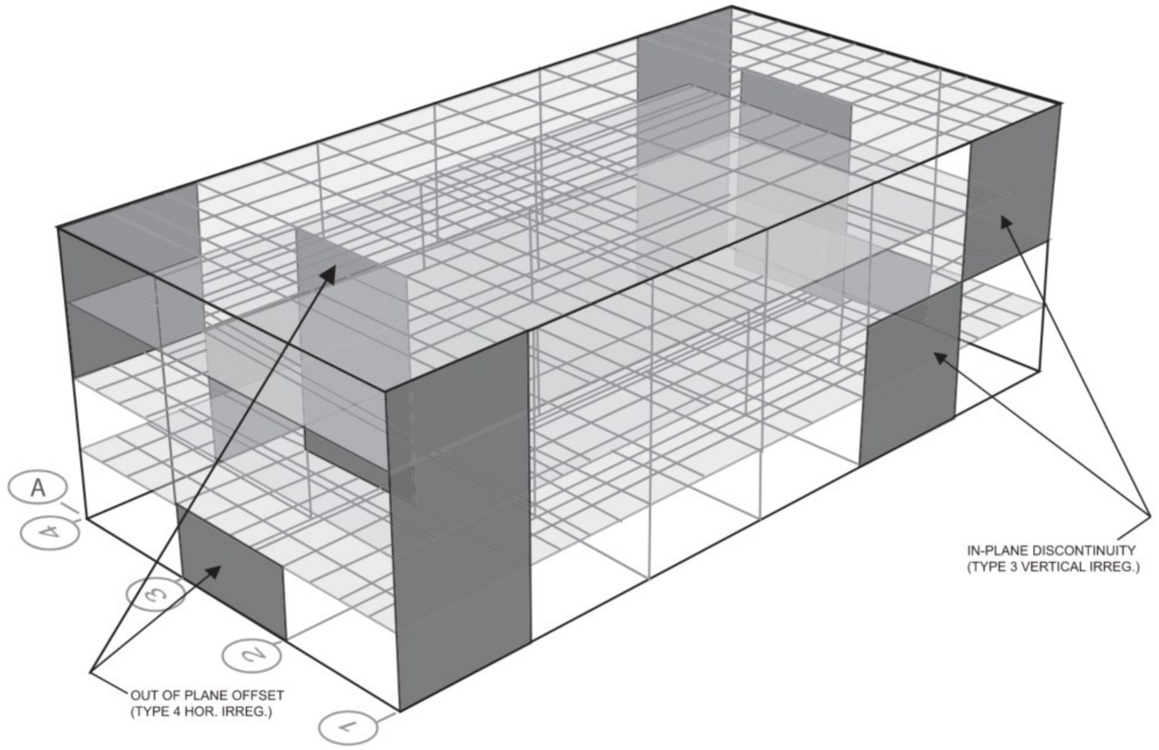
- Due to irregularities, connection of diaphragm to vertical elements and to collectors shall be designed for increased 25%.



Horiz. Irreg. Type 4



Vert. Irreg. Type 3



3-D View of the Structure

Design Example – 2nd Lv Diaphragm Shear

- 3D analysis use semi-rigid diaphragm – explicitly consider the stiffness of diaphragm.
- Diaphragm force distribution can be captured in the semi-rigid diaphragm analysis
  - Cracked concrete property
- Using ETABS "Section Cuts"
- Visualize diaphragm behaving as a deep beam, laterally supported at the two ends (Grid A and G)

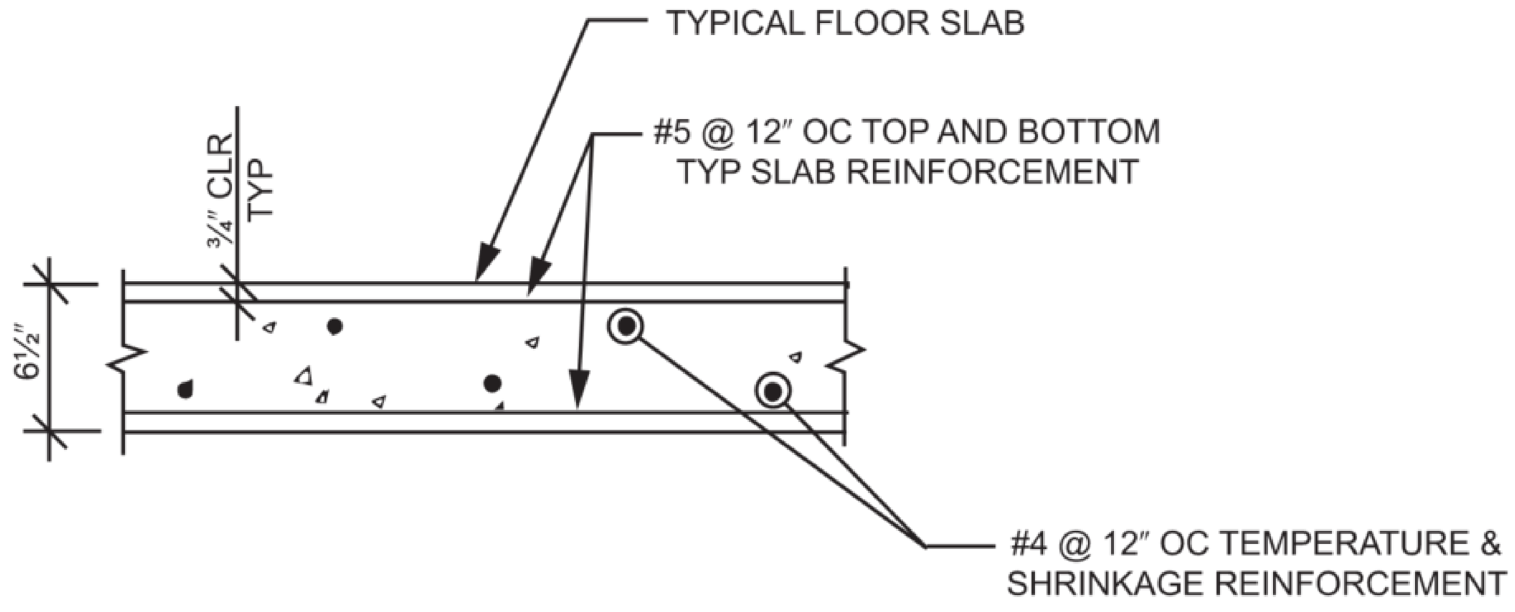
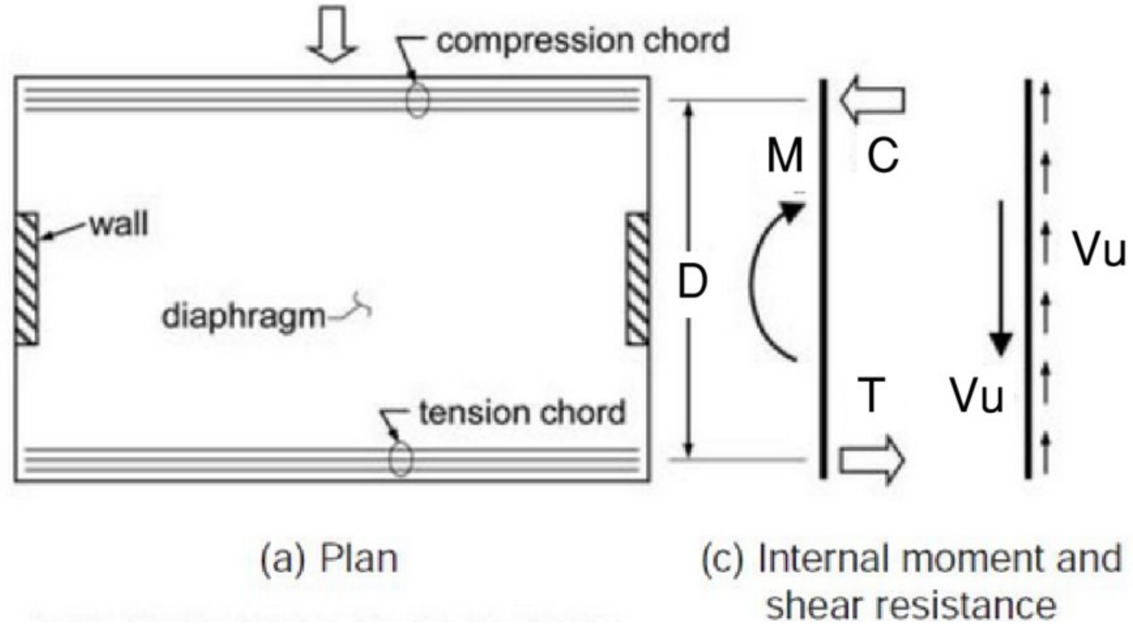


Figure 1-1. Typical concrete slab section

Slab Cross Section



Diaphragm Analysis Idealization

Design Example – 2nd Lv Diaphragm Shear

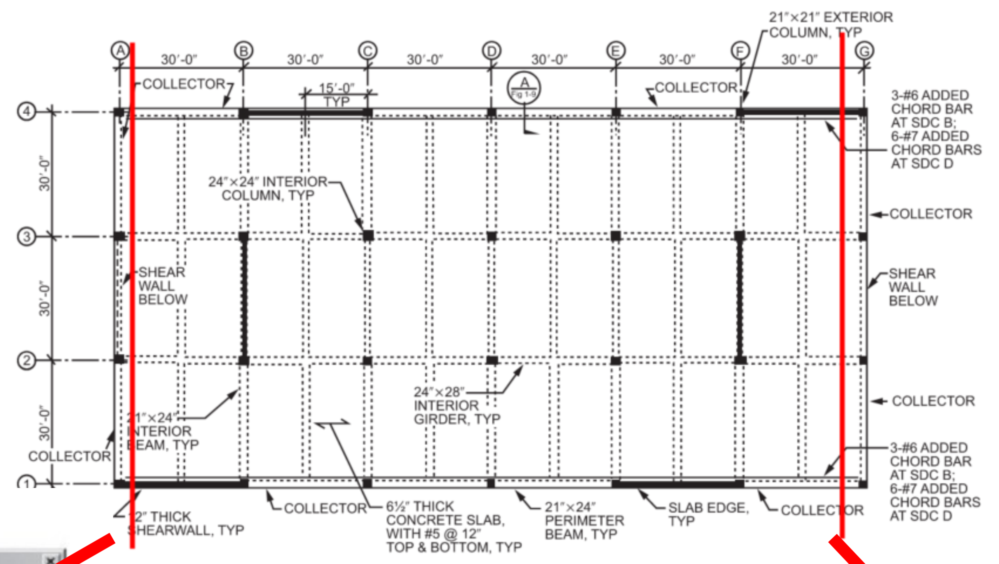


Figure 1-2. 2nd level floor plan

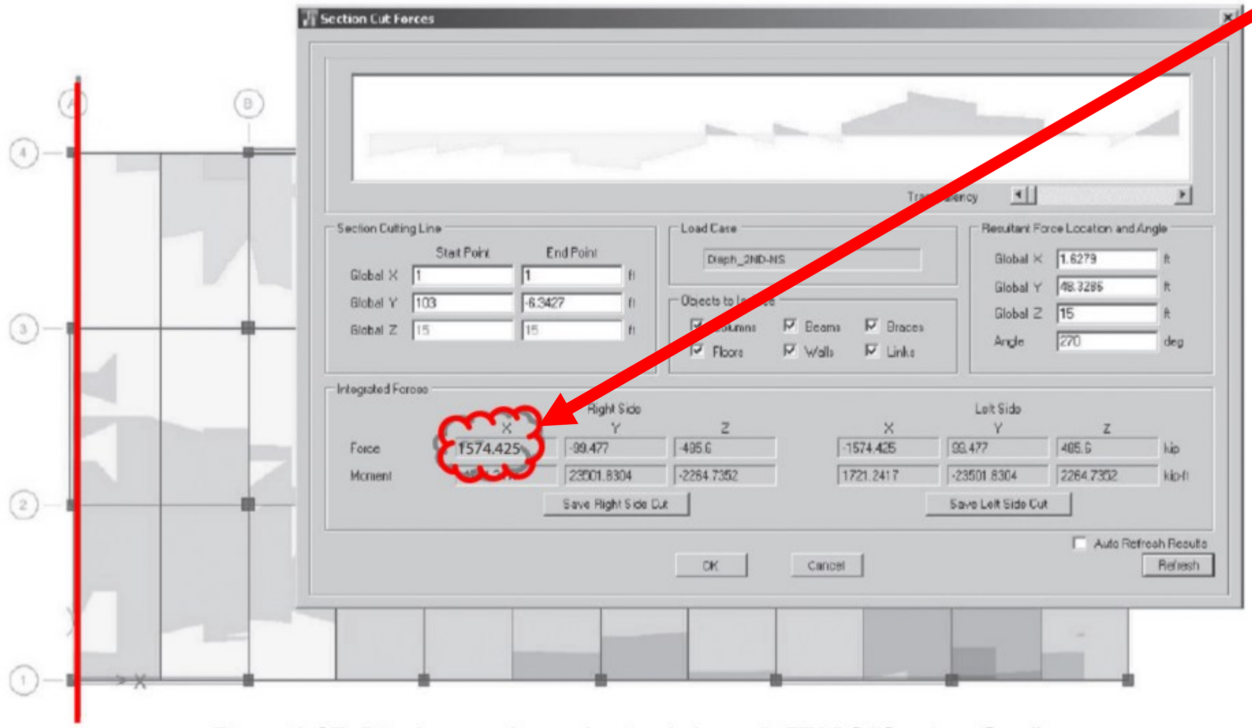


Figure 1-27. Diaphragm shear obtained through ETABS "Section Cuts"

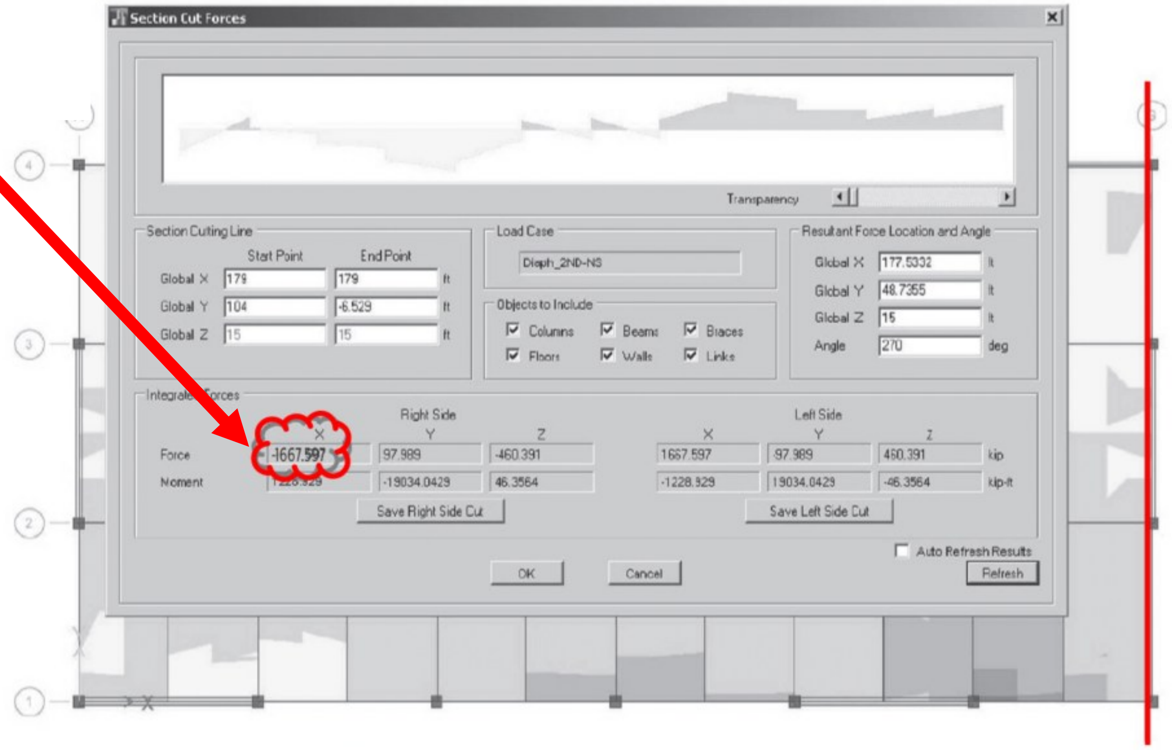


Figure 1-27A. Diaphragm shear obtained through ETABS "Section Cuts"

$$V_{udA} = \frac{V_{udA}}{L_{dA}} = \frac{1574.4\ k}{90\ ft} = 17.49\ klf$$

$$V_{udG} = \frac{V_{udG}}{L_{dA}} = \frac{1667.6\ k}{90\ ft} = \boxed{18.53\ klf}$$ ← Govern

Design Example – 2nd Lv Diaphragm Shear

- In-plane shear strength of 6 ½" concrete floor slab

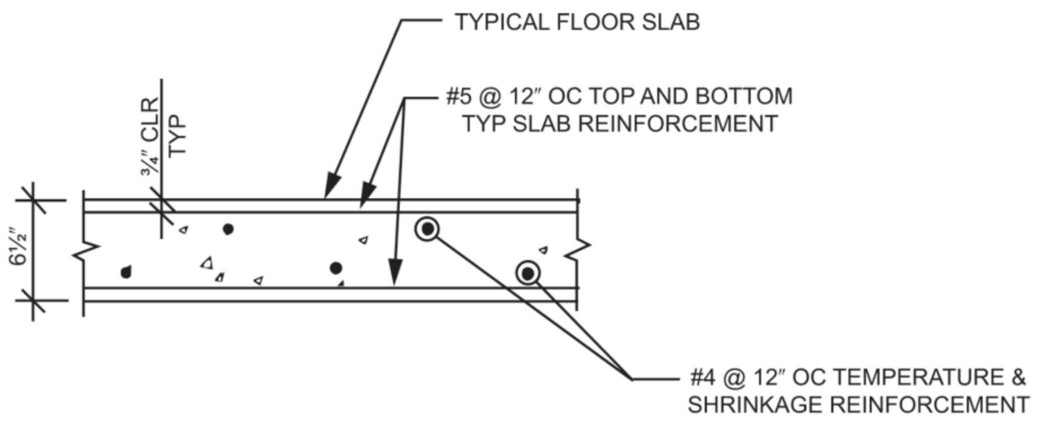


Figure 1-1. Typical concrete slab section

$$\phi V_n = \phi A_{cv}\left(2\lambda\sqrt{f'} + \rho_t f_y\right)$$

  - Φ = 0.60 per ACI 318-19, § 21.2.4.2
  - Acv = Gross area of concrete
  - λ = 1.0 for normal-weight concrete per ACI 318-19, §19.2.4.3

- For the 6 ½" concrete slab with #5 @ 12" OC, top and bottom:

$$\rho_t = \frac{0.62}{12 \times 6.5} = 0.00795$$

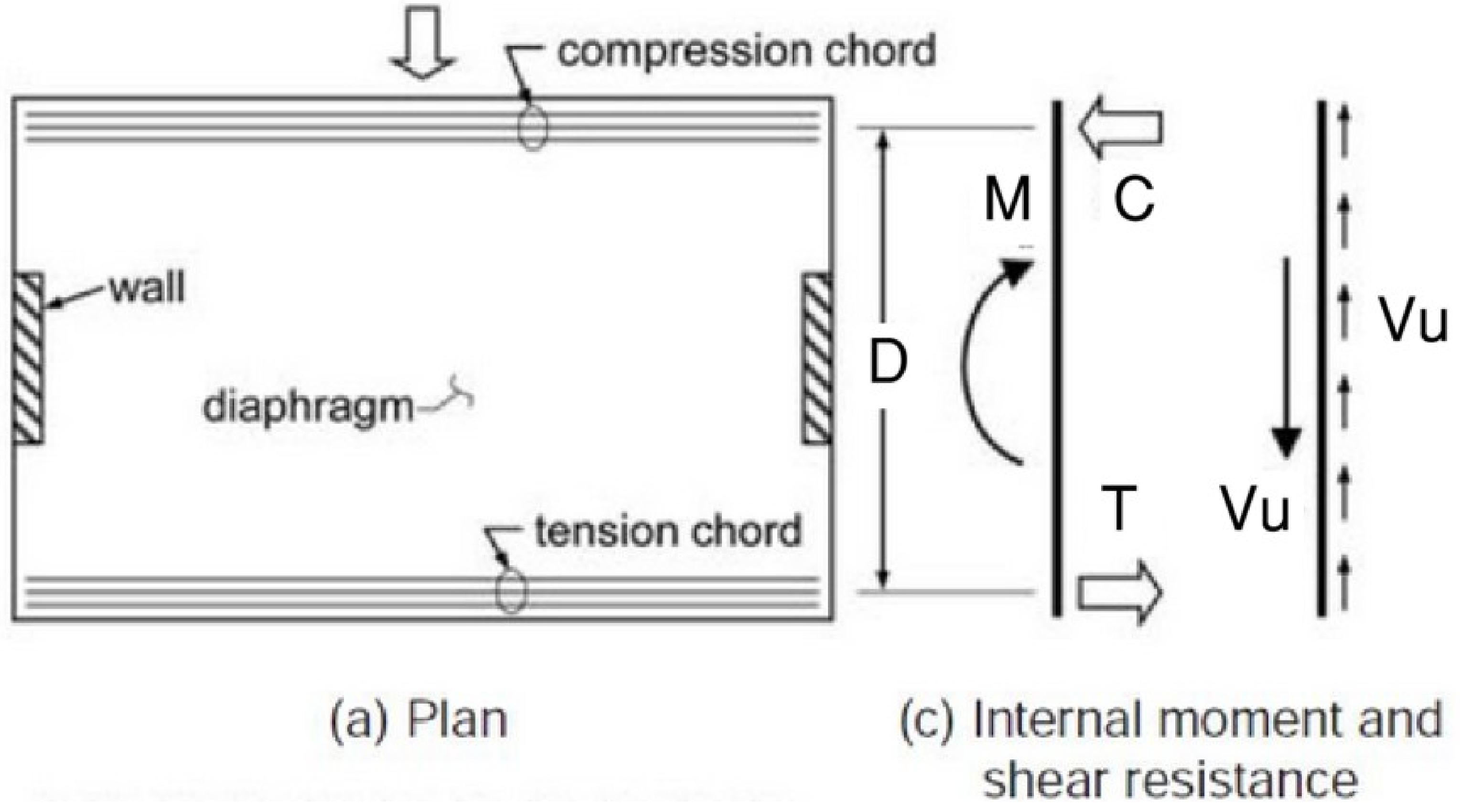
$$\phi V_n = (0.6)(6.5in)\left(\frac{12in}{ft}\right)\left(2 \times 1 \times \sqrt{4000psi} + 0.00795 \times 60{,}000psi\right)\left(\frac{1kip}{1000lbs}\right) = 28.24klf$$

$$\phi V_{n,max} = \phi A_{cv}\left(8\sqrt{f'}\right) = 23.68klf$$ ACI 318-19, §18.12.9.2

$$\phi V_n = 23.68 \geq V_{udG} = 18.53klf$$ Slab is OK

Design Example – 2nd Lv Chord Design

- Using ETABS "Section Cuts"
- Visualize diaphragm behaving as a deep beam, laterally supported at the two ends (Grid A and G)
- Chord forces: $T = C = \frac{M}{D}$



Diaphragm Analysis Idealization

Design Example – 2nd Lv Chord Design

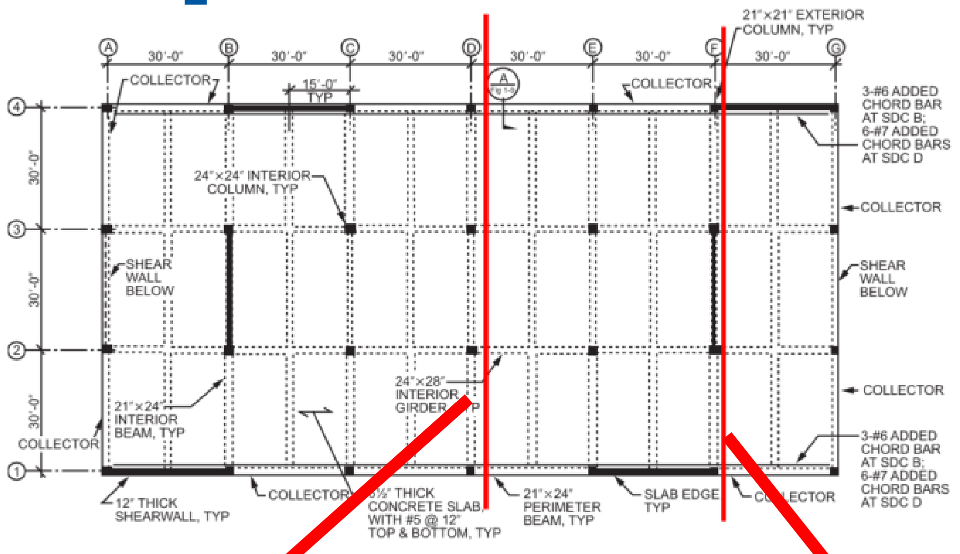


Figure 1-2. 2nd level floor plan

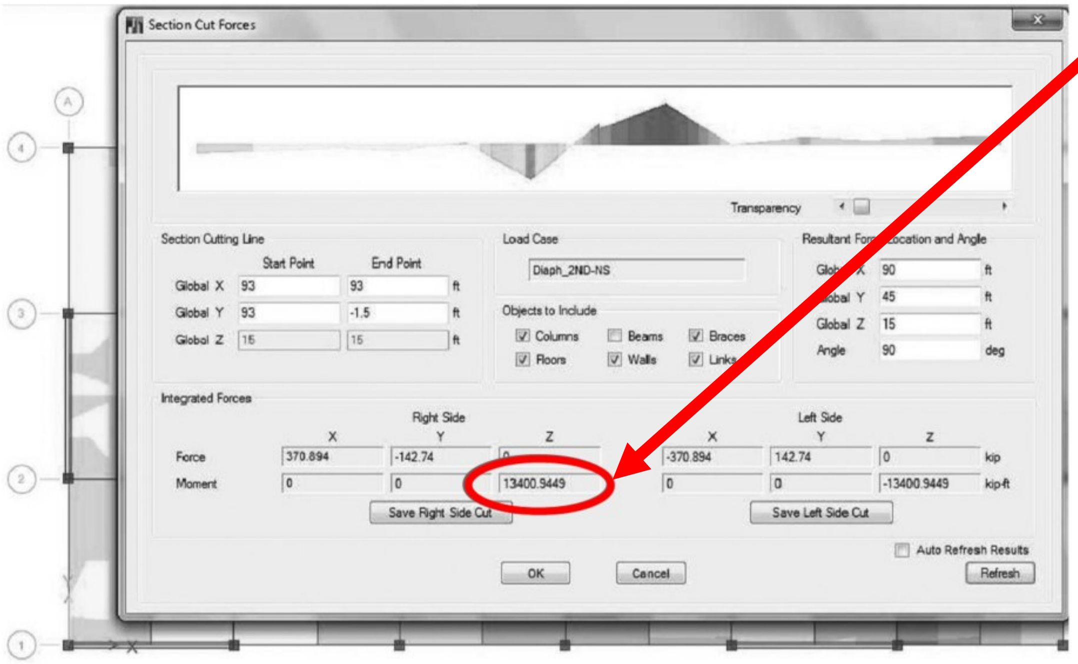


Figure 1-28. Moment at gridline B obtained through ETABS "Section Cuts"

M = 13400.94 k-ft ← Govern

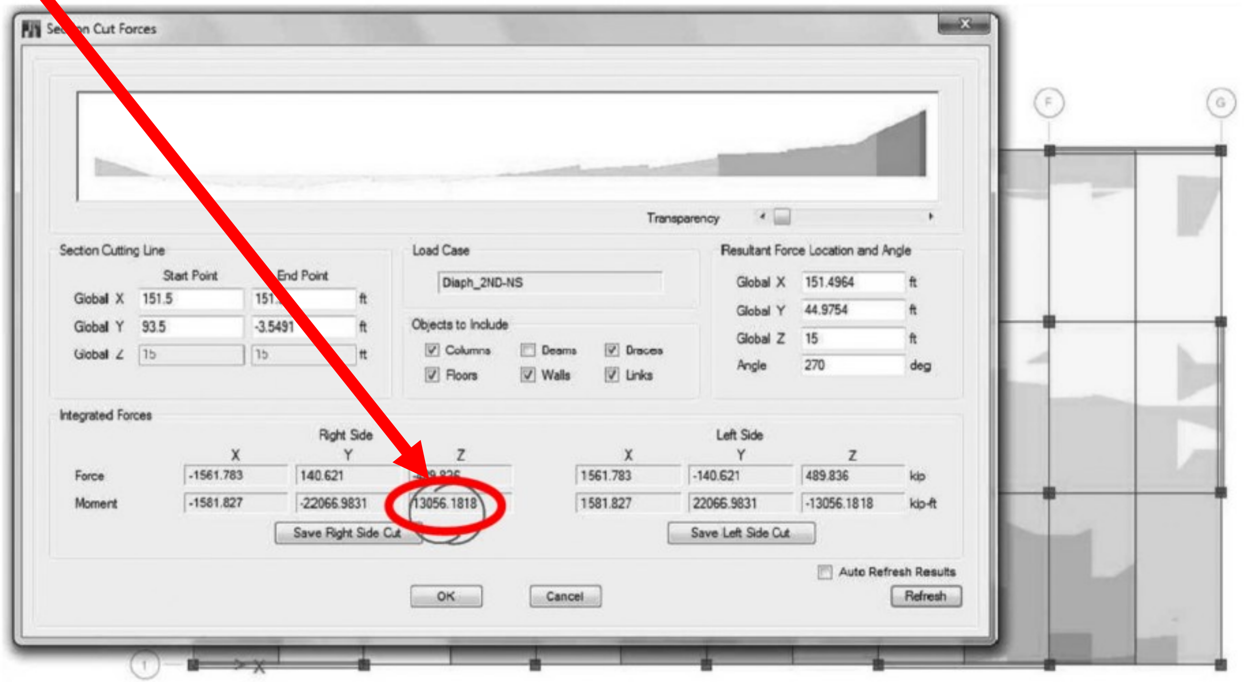


Figure 1-30. Moment at gridline F obtained through ETABS "Section Cuts"

M = 13056.18k-ft

Design Example – 2nd Lv Chord Design

- D = 95% of total diaphragm depth

$$M_u = 13400.94\ k - ft$$

$$D = 0.95(90ft) = 85.5ft$$

- Increase design diaphragm force by 25% per ASCE 7-22, § 12.3.3.5.

$$T_u = \frac{M_u}{D} = \frac{1.25 \times 13400.94k - ft}{85.5ft} = 195.92k$$

$$A_s = \frac{T_u}{\phi f_y} = \frac{195.92k}{(0.9)(60ksi)} = 3.62in^2$$

- Provide (6) #7 barat at the slab edge.

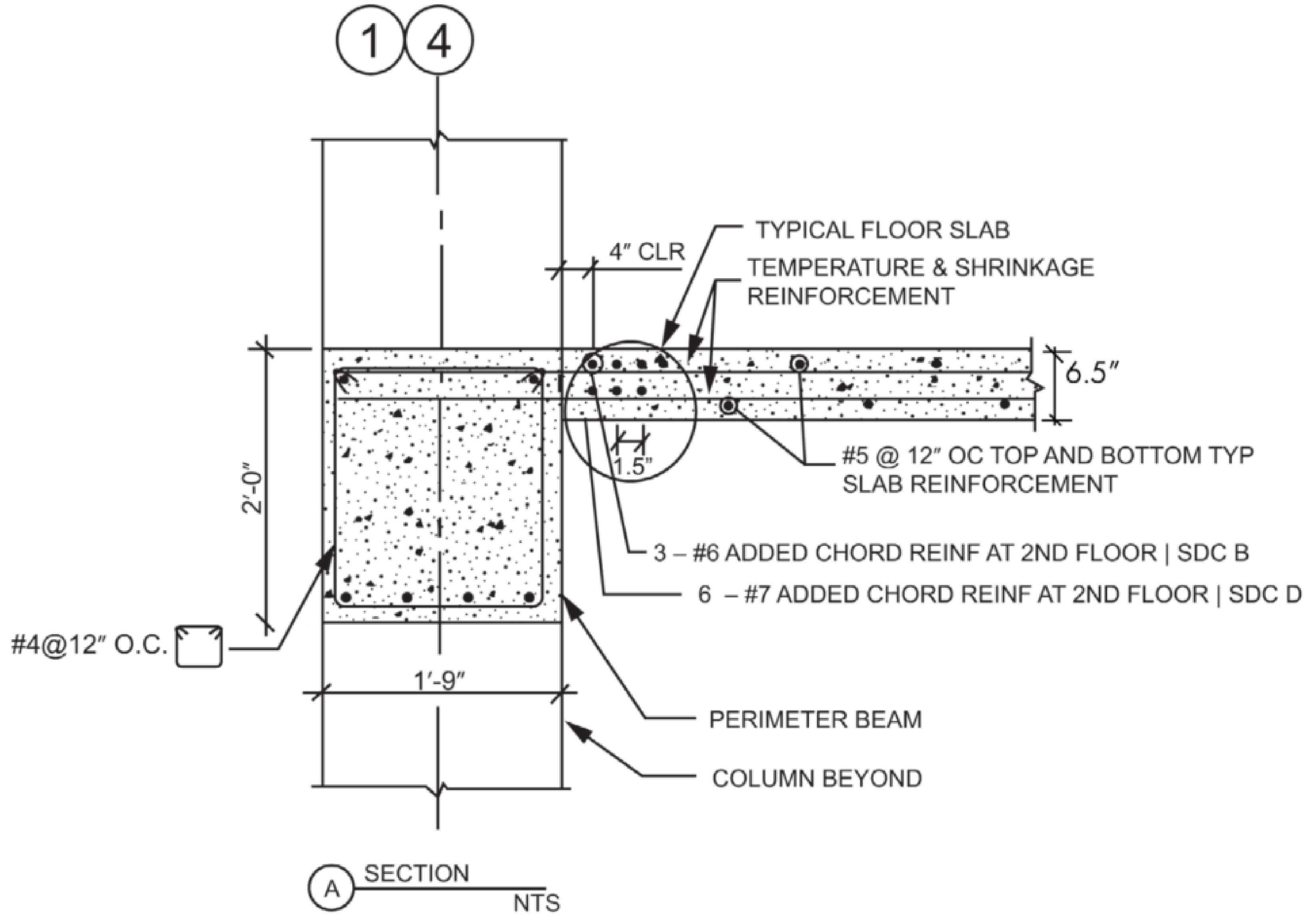


Figure 1-9. Perimeter beam detail showing chord reinforcement

Chord Detail

Design Example – 3^{rd} Lv Collector Design

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- ASCE 7-22, §12.3.3.4 requires overstrength consideration per ASCE 7, § 12.4.3 for collector beam and column supporting the discontinuous shear wall.
- In addition, the connection of the beam to column should be designed using the overstrength factor.
  - The connection between the discontinuous shear wall and the supporting beams need only be designed for loads required for shear wall and overstrength is **NOT required** to be considered. (See ASCE 7-22 Commentary §C12.3.3.4)
  - Footing for columns supporting discontinuous shear wall to be designed using overstrength factor with use of ultimate bearing capacity value.

Design Example – 3rd Lv Collector Design

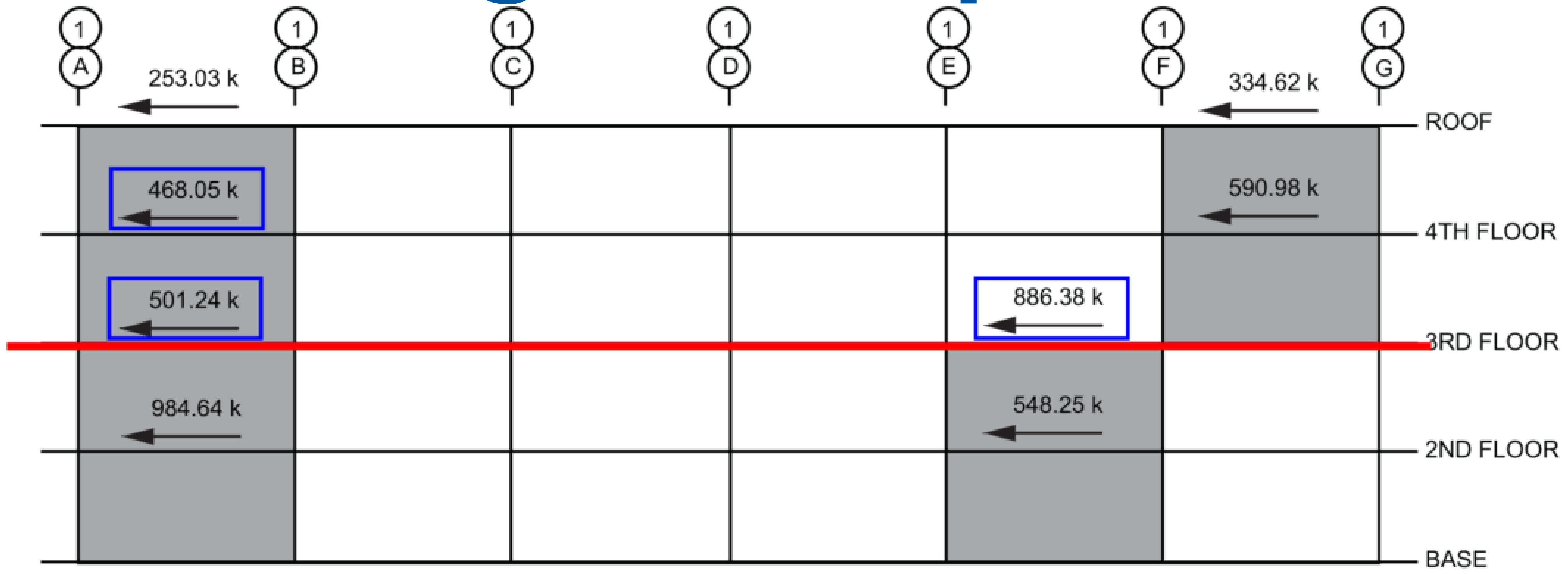


Figure 1-31. Concrete shear wall forces by level, wall on gridline 1

Grid 1 Elevation

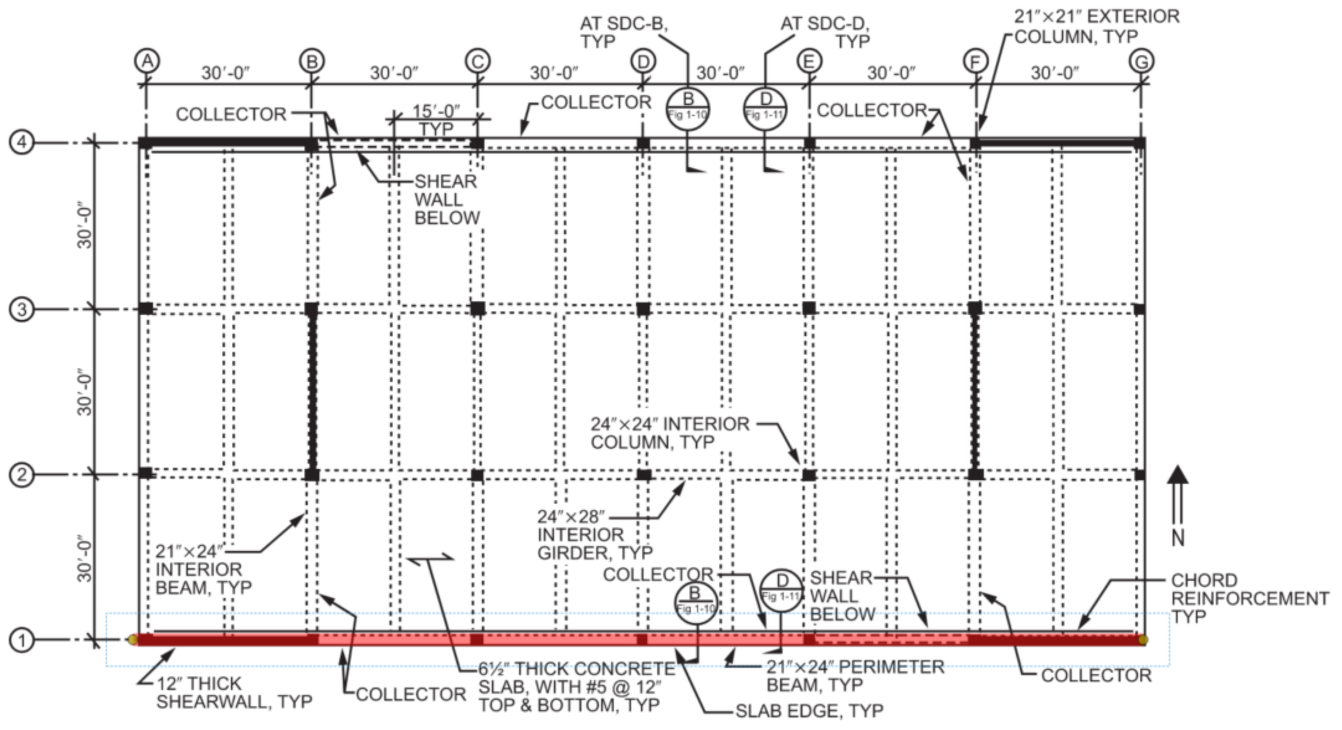
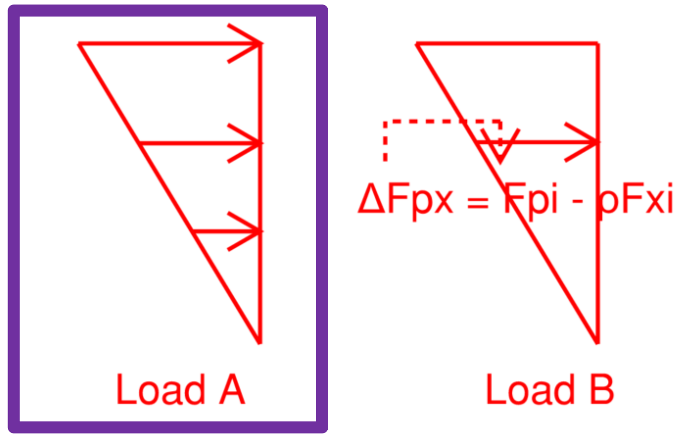


Figure 1-3A. 3rd level floor plan

3rd Level Floor Plan

- Total diaphragm force due to the code level seismic story force, Fx (Load A):

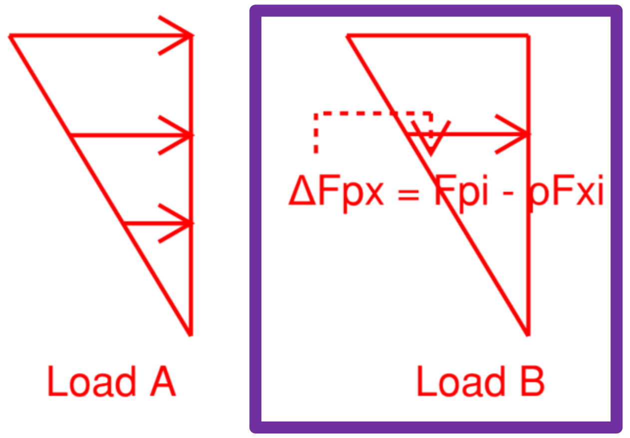
$$F_{diaphragm(Line\ 1)} = 886.38k + (501.2k - 468.05k) = 919.55k$$



Design Example – 3rd Lv Collector Design

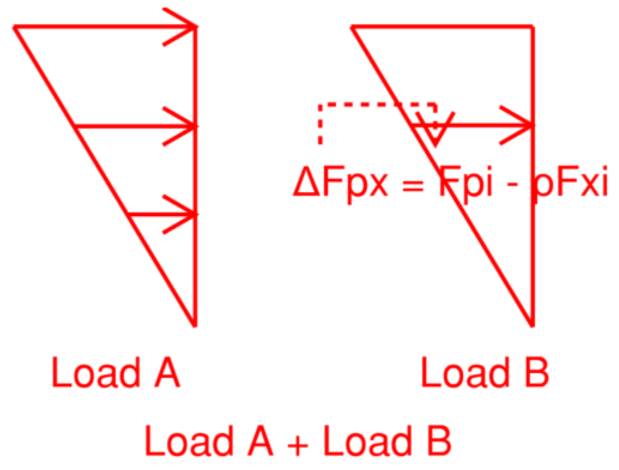
- Additional load (Load B), $\Delta F_{pxDrag} = F_{pxDrag} - F_x$
  - ΔF_{pxDrag}: Overstrength(Ω_0) amplified diaphragm force at the considered level
  - F_{pxDrag}: Per ASCE 7-22, §12.10.2.1, maximum of the below three values:
    - $\Omega_0 F_x$ = (2.5)(600 k) = 1500 k
    - $\Omega_0 F_{px}$ = (2.5)(895 k) = 2237.5 k ← Govern
    - $F_{px,Min} = 0.2 S_{DS} I_e W_{px}$ = 744 k

$$\Delta F_{pxDrag} = F_{pxDrag} - F_x = 2238k - 600k = 1638k$$



Design Example – 3rd Lv Collector Design

- In ETABS, load case for ΔF_{pxDrag} is created
  - 1638 k story shear is applied at 3rd Level
  - ETABS "Section Cuts" is used to calculate the shear force at Line 1 on 3rd Level due to ΔF_{pxDrag}



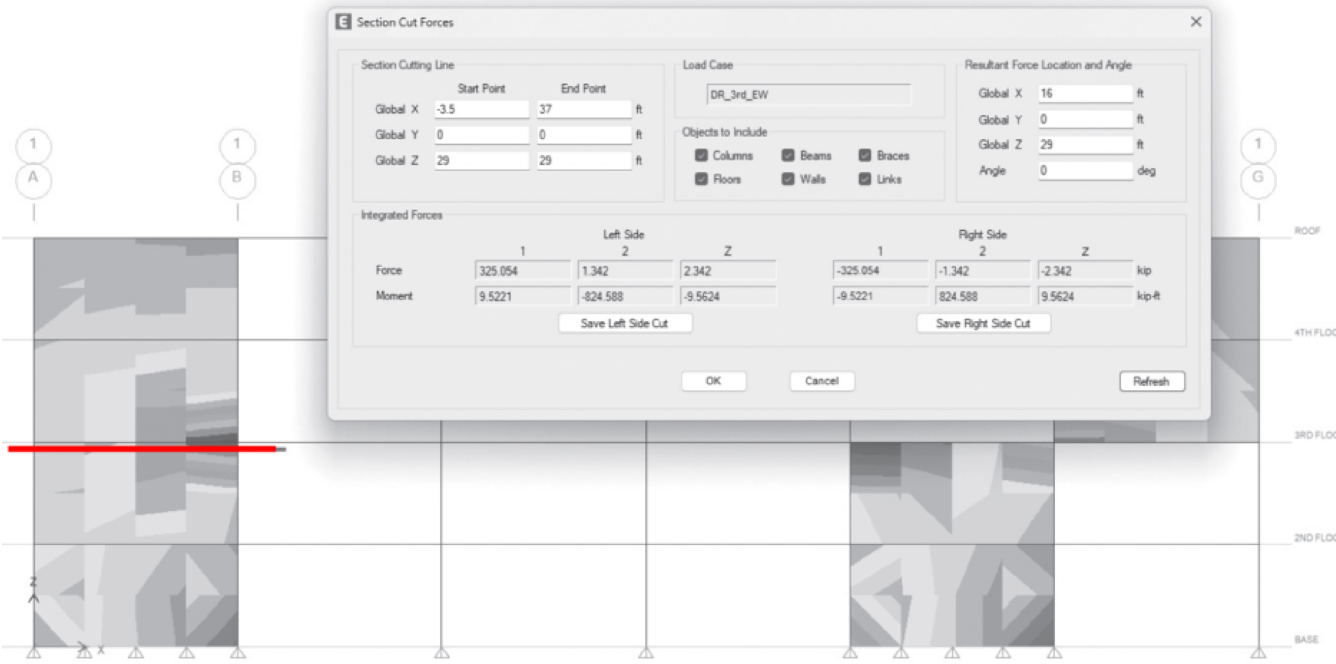


Figure 1-35. Section cut to obtain wall shear due to $F_{px\text{-}Drag}$—3rd floor wall on gridline 1 and between A /B

Shear at Wall btw A/B = 325.05 kip

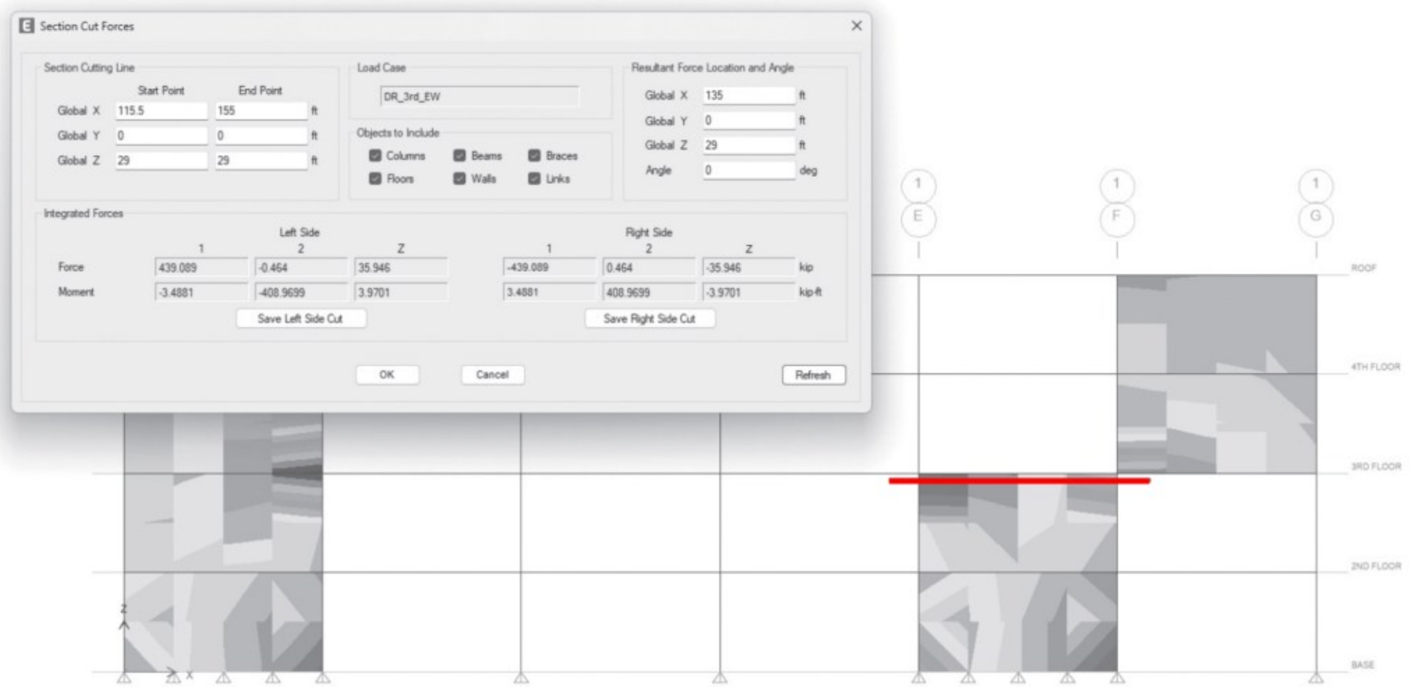


Figure 1-34. Section cut to obtain wall shear due to $F_{px\text{-}Drag}$—3rd floor wall on gridline 1 and between E /F

Shear at Wall btw E/F = 439.09 kip

$$F_{pxDrag(Line\ 1)} = F_{diaphragm(Line\ 1)} + \Delta F_{pxDrag\_wall1} + \Delta F_{pxDrag\_wall2}$$

$$F_{pxDrag(Line\ 1)} = 919.55k + 325.05k + 439.09k = 1683.7k$$

Design Example – 3rd Lv Collector Design

- Distributed diaphragm and wall resistance force:

$$v_{diaph} = \frac{F_{px-Drag}}{L_{diaph}} = \frac{1683.7k}{180ft} = 9.35klf$$

$$v_{wall-1} = \frac{\rho Q_E}{L_{wall}} = \frac{(1.0)(325.05k + 33.19k)}{30ft} = 11.94klf$$

$$v_{wall-2} = \frac{\rho Q_E}{L_{wall}} = \frac{(1.0)(439.09k + 886.38k)}{30ft} = 44.18klf$$

$$30ft(9.35klf - 11.94klf) = -77.6k$$

$$-77.6k + 90ft(9.35klf) = 764.3k$$

$$T_u = C_u = 764.3k$$

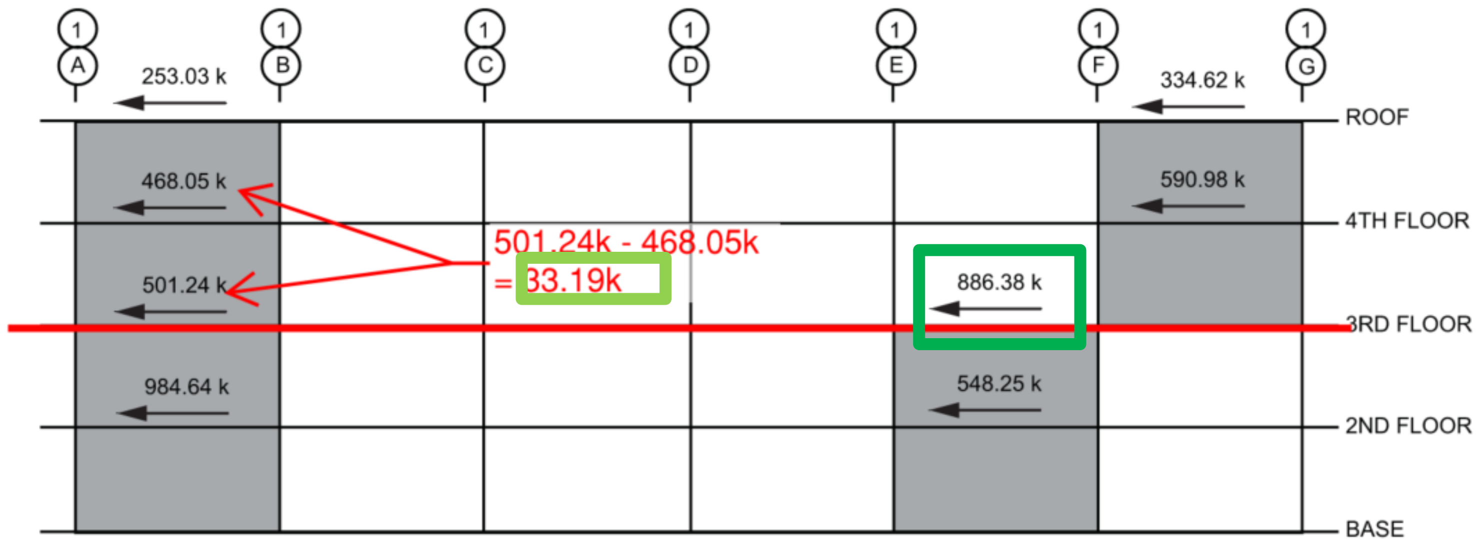


Figure 1-31. Concrete shear wall forces by level, wall on gridline 1

Grid 1 Elevation

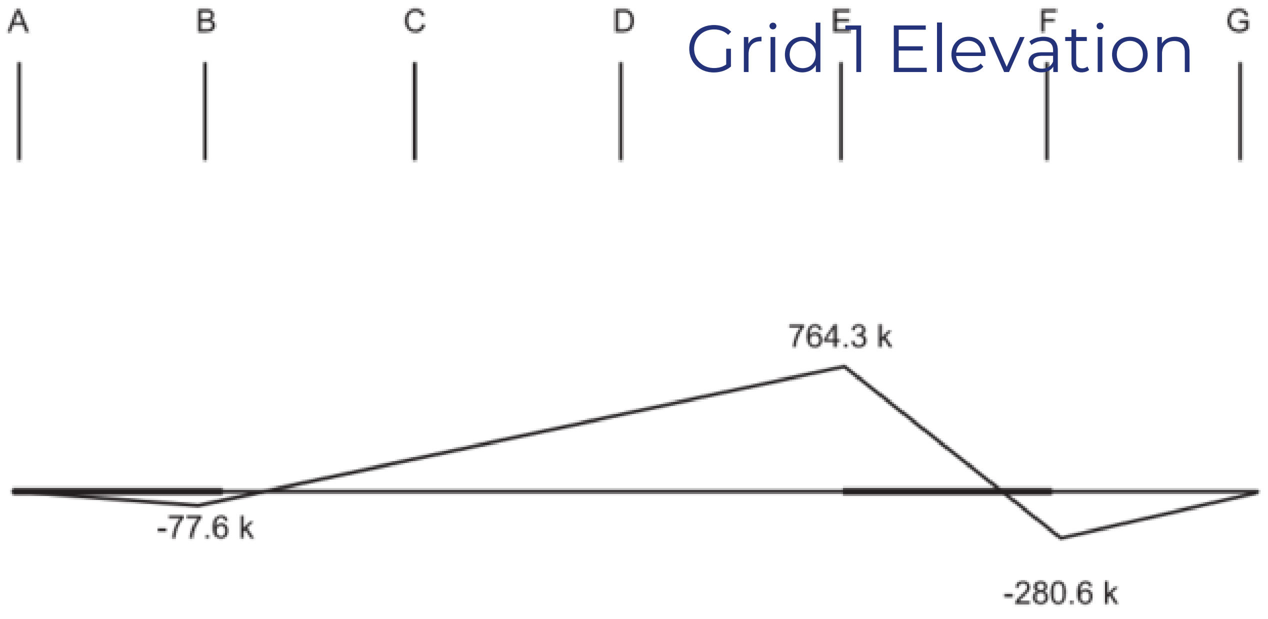


Figure 1-36. Distributed diaphragm force and collector diagram for 3rd floor collector on line B

Design Example – 3rd Lv Collector Design

- Check axial force demand on Grid 1 due to chord force for seismic force acting in N-S direction.

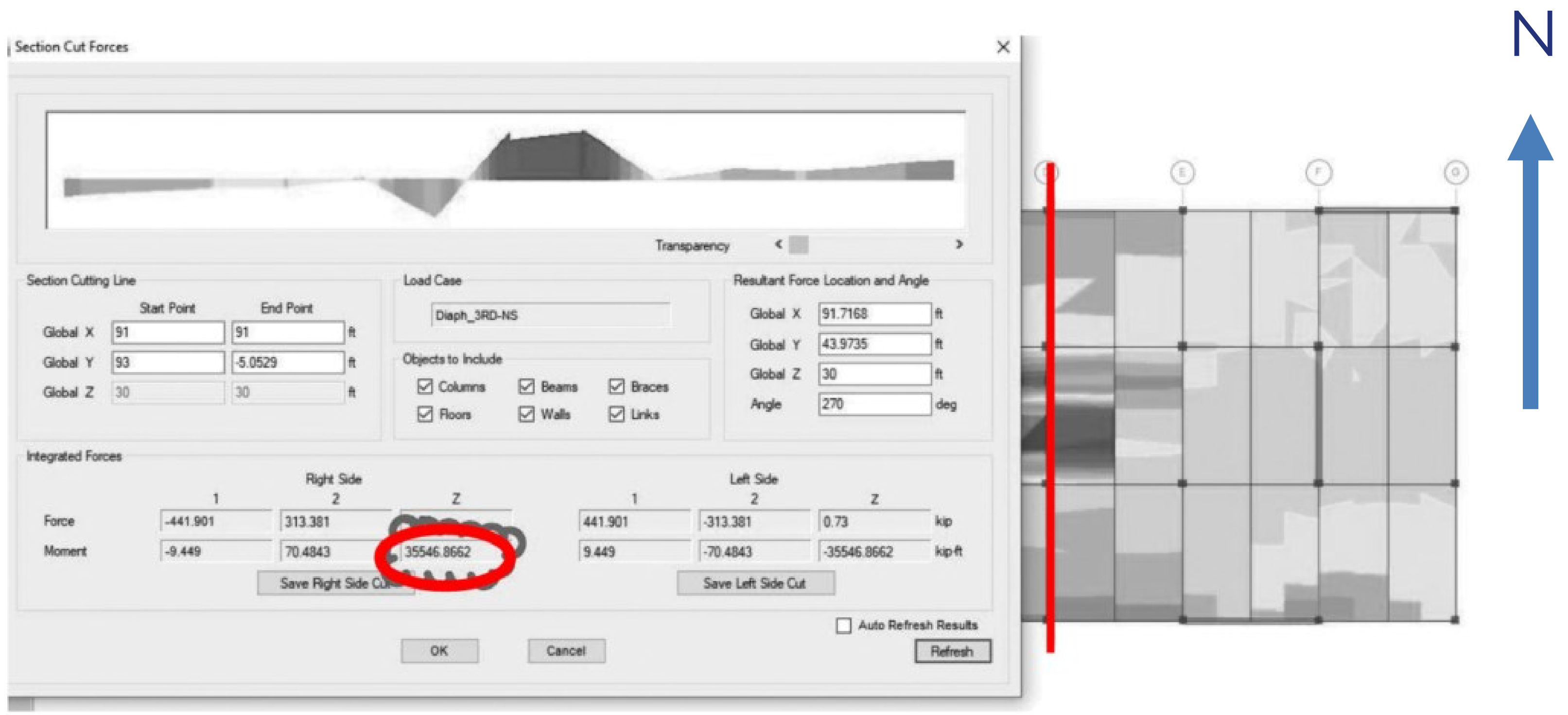


Figure 1-37. Moment at gridline D using "Section Cuts"

M = 35,546.87 k-ft

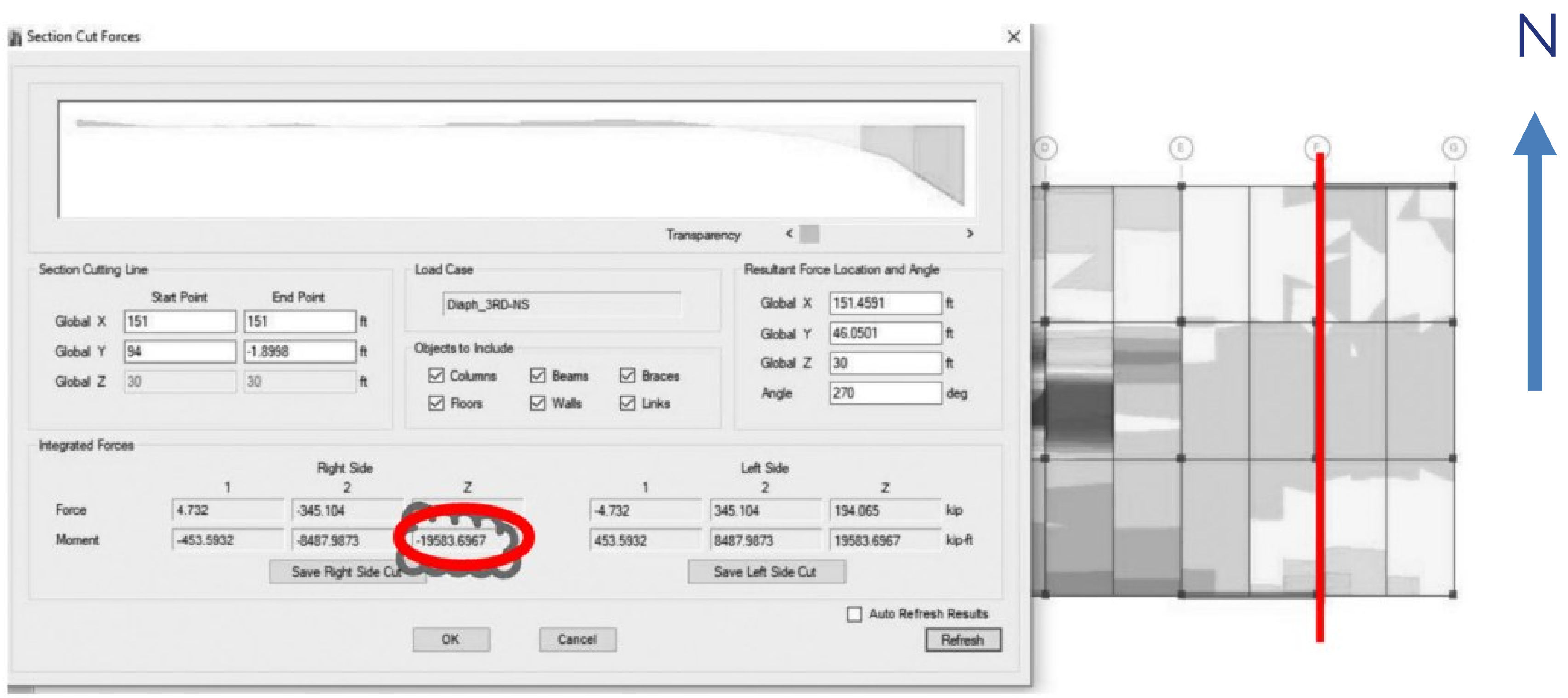


Figure 1-38. Moment at gridline F using "Section Cuts"

M = 19,583.70 k-ft

$$M_u = 35{,}547\ k - ft$$

$$D = 0.95(90ft) = 85.5ft$$

$$T_u = \frac{M_u}{D} = \frac{35{,}547k - ft}{85.5ft} = 416k$$

← Does not govern

Design Example – 3rd Lv Collector Design

- Collector beam design
  - Collector beam size: 21”x24”

$$(M_{gravity})_u = 34k - ft[(1.2 + 0.2S_{DS})D + 0.5L]$$

$$P_u = \pm 764.3k$$

  - Interaction diagram created for the collector beam:
    - Use (8) #9 @ bottom, (6) #9 @ top, (2) #8 @ each side

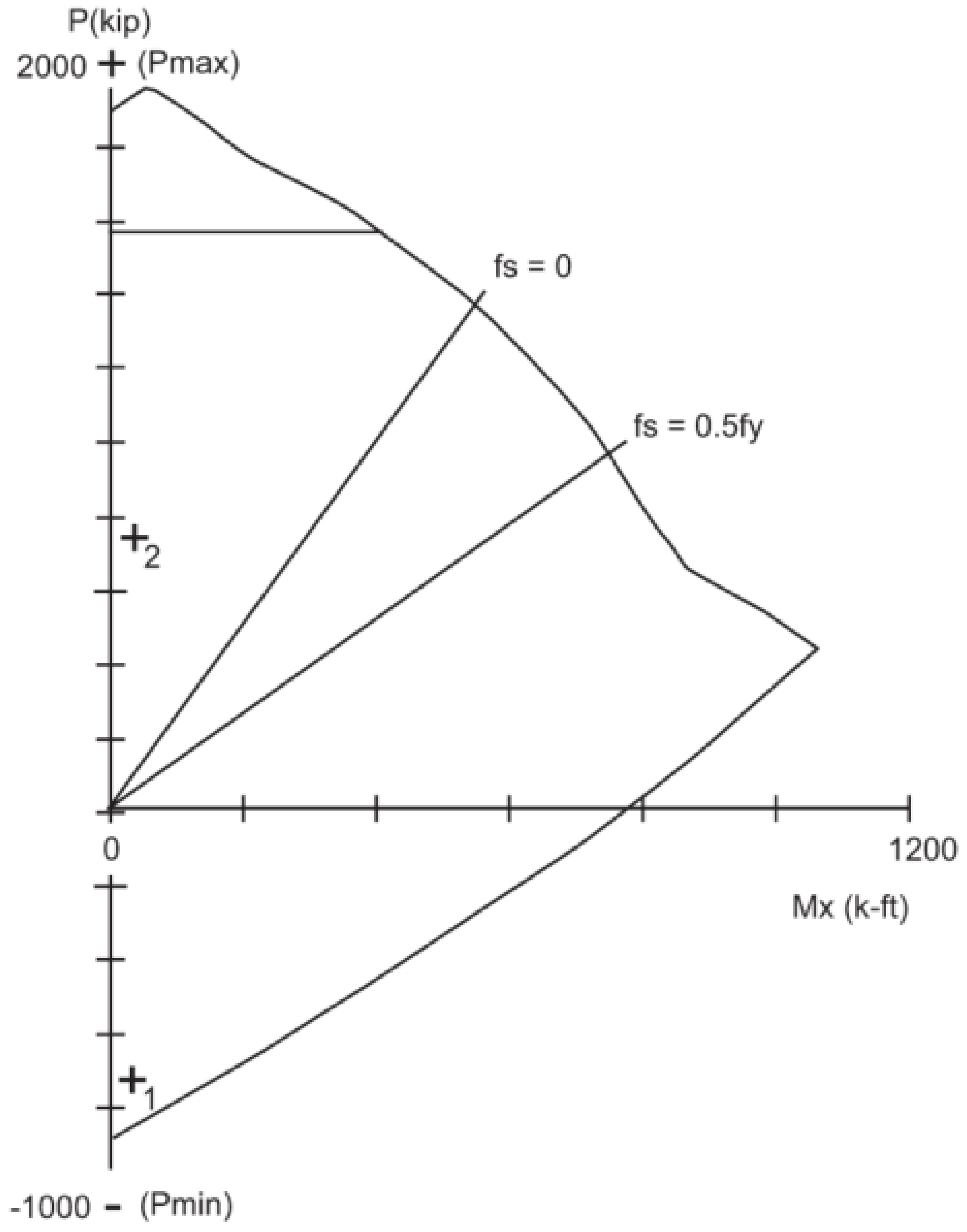


Figure 1-39. P-M diagram for 3rd floor collector line on gridline 1

Design Example – 3rd Lv Collector Design

- Collector beam design
  - Special transverse reinforcement per ACI 318-19, §18.12.7.6 is required for collector elements with compressive stress exceeding 0.2 f'c.
    - Permitted to be discontinued at sections where calculated compressive stress is less than 0.15 f'c
    - Since overstrength is used, the stress criterion must also be increased: 0.2 f'c → 0.5 f'c, 0.15 f'c → 0.4 f'c

$$f_c = \frac{C_u}{A_g} = \frac{764.3k}{(21in)(24in)} = 1.52ksi = 0.38f'_c \leq 0.5f'_c$$

Design Example – 3rd Lv Collector Design

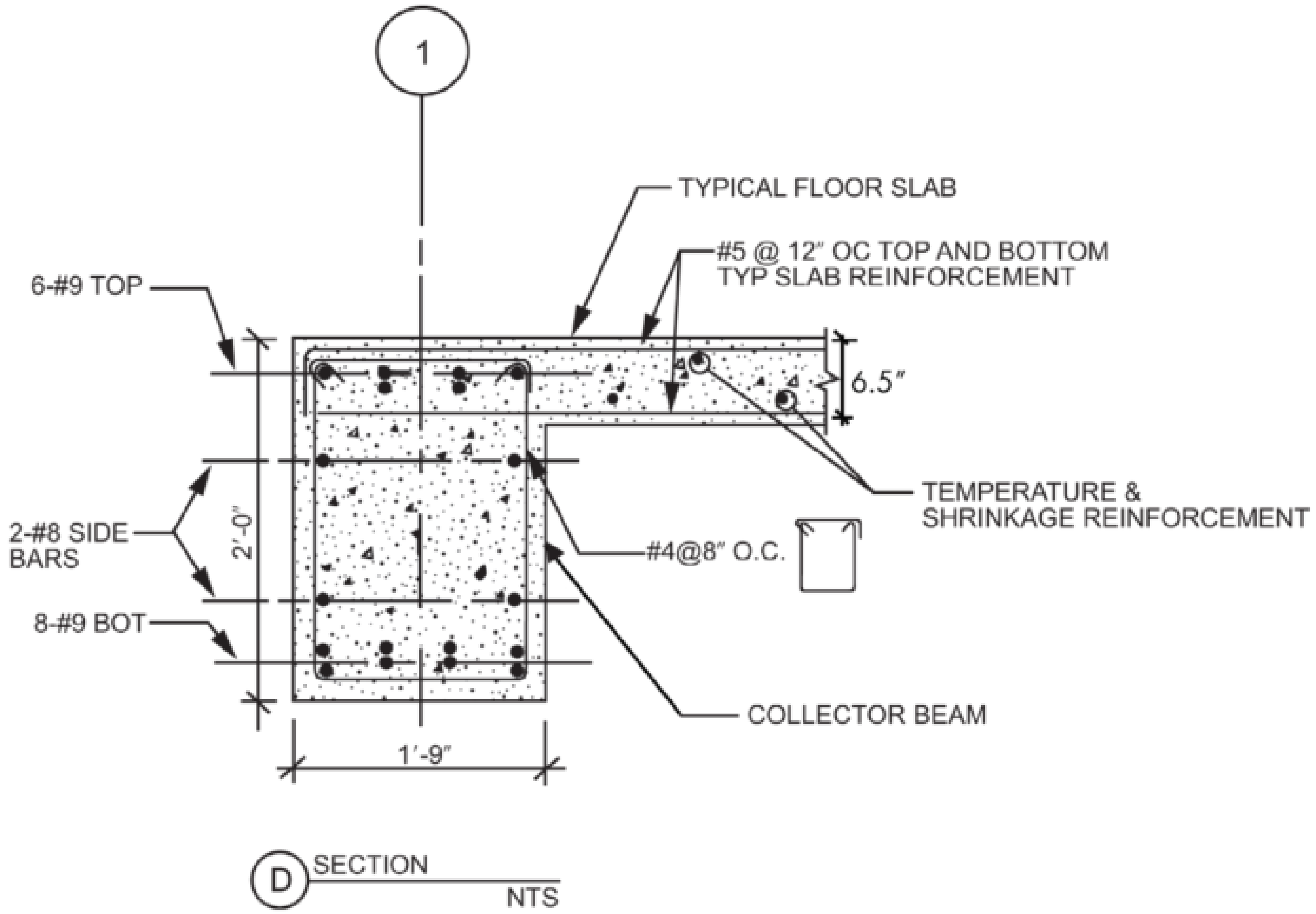


Figure 1-11. Beam/Collector detail for SDC D

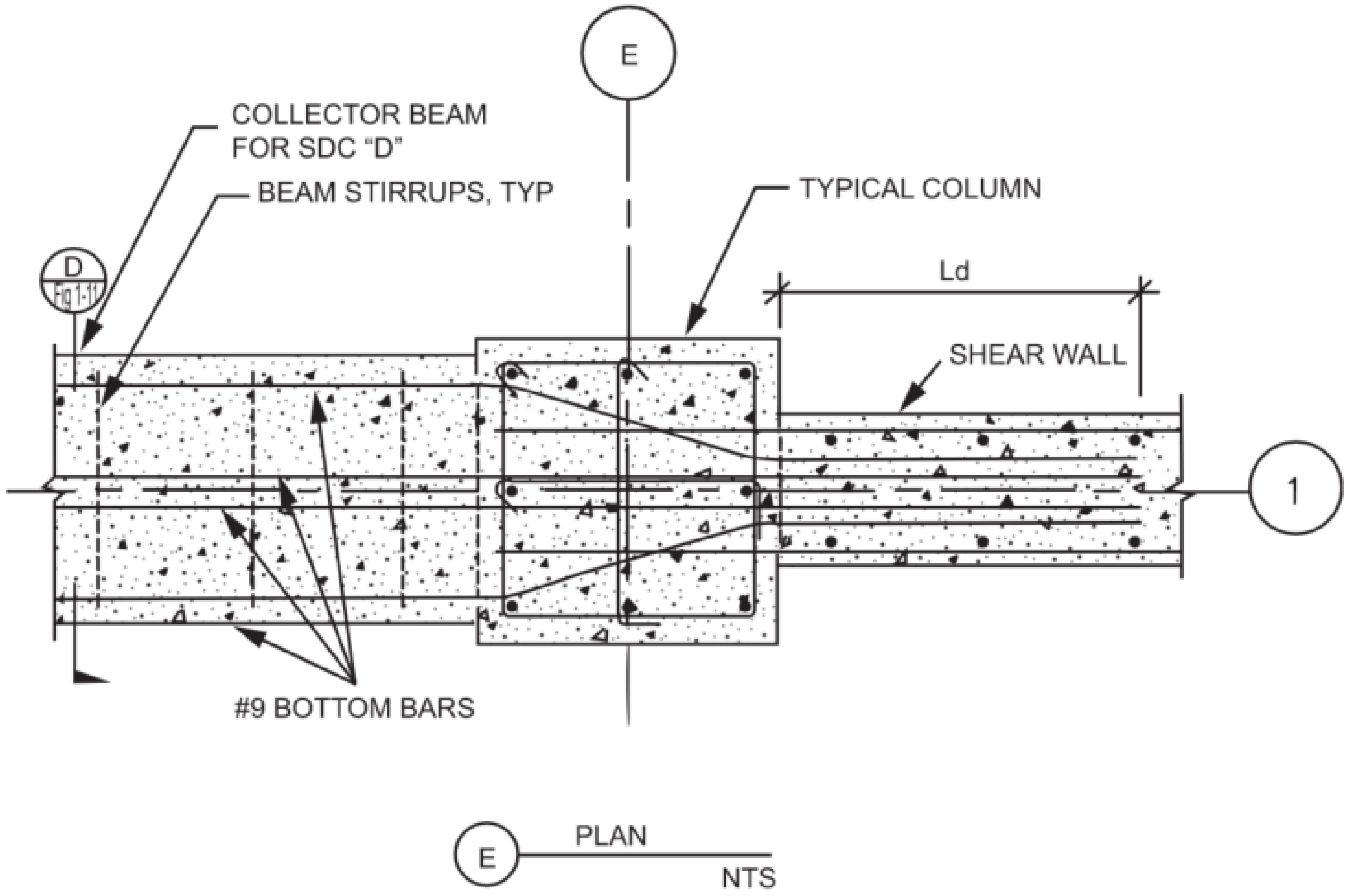


Figure 1-12. Plan detail at collector/shear wall interface

Permitted Analytical Procedures - ASCE 7-22

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- Major change regarding the use of analysis procedures when compared to ASCE 7-16.
- In ASCE 7-16, Equivalent Lateral Force (ELF) procedure was **not permitted for certain height and irregularity condition**. See ASCE 7-16, Table 12.6-1.
- Table 12.6-1 **has been deleted** in ASCE 7-22.

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Procedure, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9.1, or Linear Response History Analysis, Section 12.9.2[a]	Nonlinear Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding two stories above the base	P	P	P
	Structures of light-frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft (48.8 m) in structural height	P	P	P
	Structures exceeding 160 ft (48.8 m) in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft (48.8 m) in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

Permitted Analytical Procedures - ASCE 7-22

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- ASCE 7-22 allows ELF procedure for all cases with **no restriction**.
- According to the commentary, ELF procedure provided **more consistent story shear, overturning moment, and story drift results** than Modal Response Spectrum Analysis (MRSA). Procedure when compared to nonlinear dynamic response at design level EQ.
- Commentary also states there may be unusual situations where MRSA design values exceed those of ELF – **Engineering judgement is required for use of MRSA over ELF**.

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Questions?