Lateral 101 for Architects

December 5, 2023

Presented by

Terry Malone, WoodWorks

1430 Q / The HR Group Architects / Buehler Engineering / photo Greg Folkins Photography

- This presentation is not intended to recommend or say, “Don’t do this!” but simply provides basic concepts of lateral analysis needing consideration during the beginning phases of design/layout.

- Early coordination with between the architect and engineer will produce better results.

- Keep an open mind to structural changes that might be beneficial to the project.

Plans Set in Stone

No room to modify. Can be costly.

- The structural engineer is responsible for selecting the lateral force-resisting system best fits the project and for the development of complete load paths.

A Brief word on Costs

Simple structures

More complex structures

Exterior SWs

Cantilever diaphragms

Degree of complexity = Greater cost

Other Factors

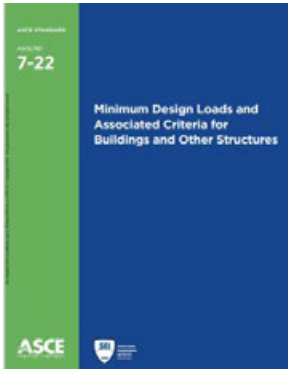
- Complicated load paths $$
- Complicated framing or connections $$
- Building irregularities $$$
- Areas of high seismicity or wind $$$

Presentation Contents

- **Basic lateral wind and seismic forces**
- **Basic types of lateral resisting systems**
- **Structural irregularities-How buildings respond to lateral forces**
    - **Horizontal Irregularities**
    - **Vertical Irregularities**
- **Other structural issues**
    - **Redundancy- 2-Story Example**
    - **Diaphragm, shear wall stiffness**

Wind Forces

ASCE 7-22



CH. 26 - 30

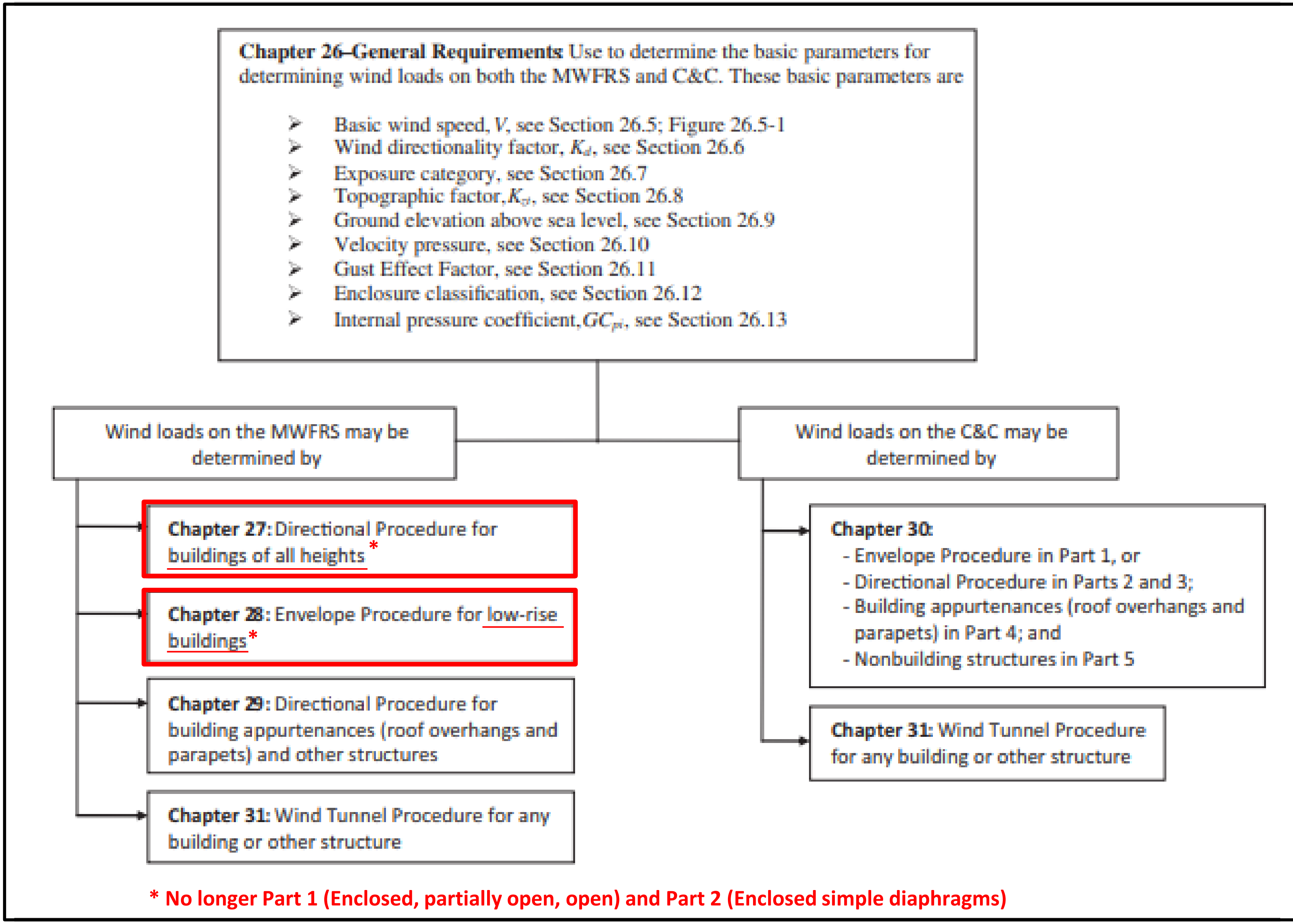
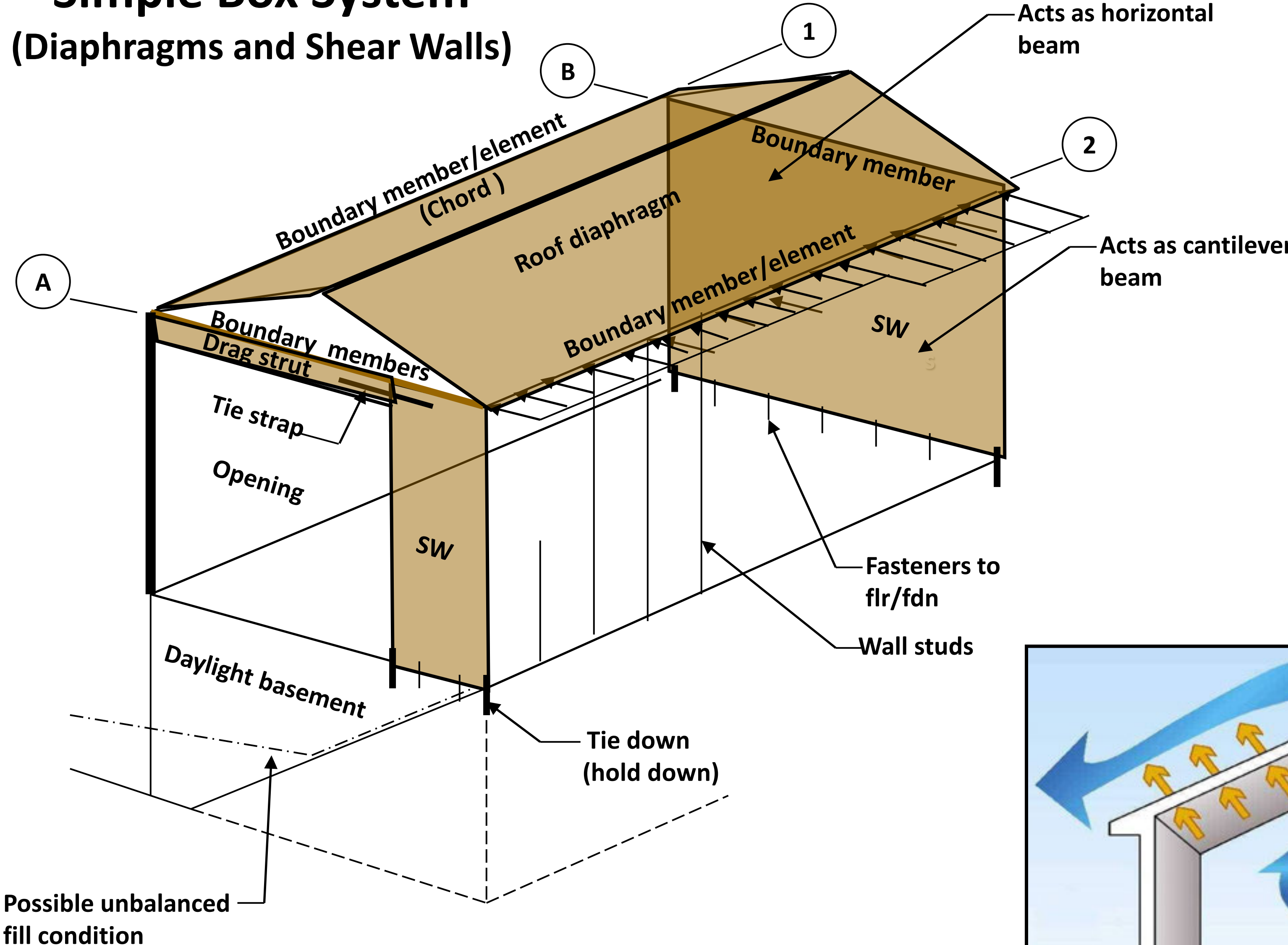


Figure 26.1-1. Outline of process for determining wind loads.

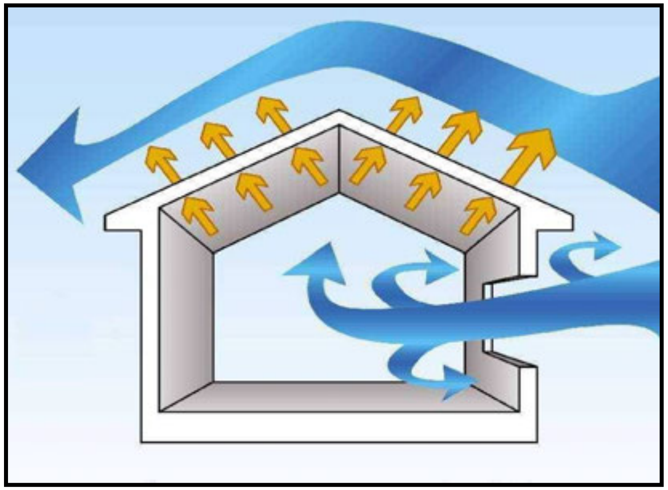
MWFRS loads:

- **Directional: Pressure coefficients applied to windward, leeward, and sidewalls to properly address the internal wind forces.**
- **Envelope: Pressure coefficients represent “pseudo” loading on exterior surfaces.**

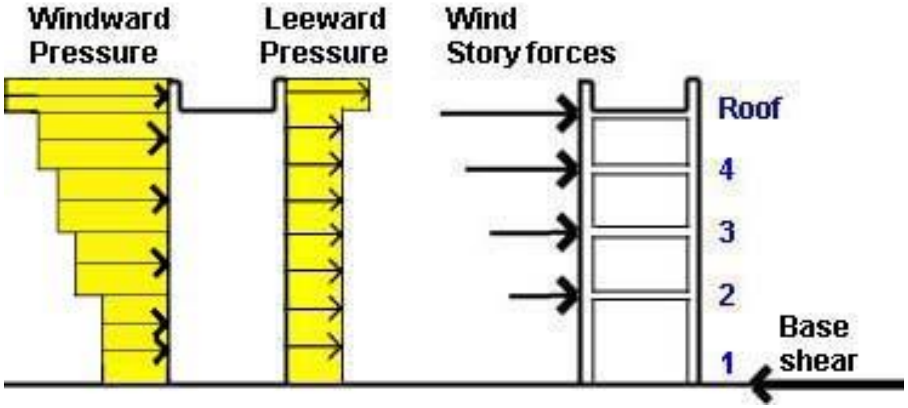
Simple Box System
(Diaphragms and Shear Walls)



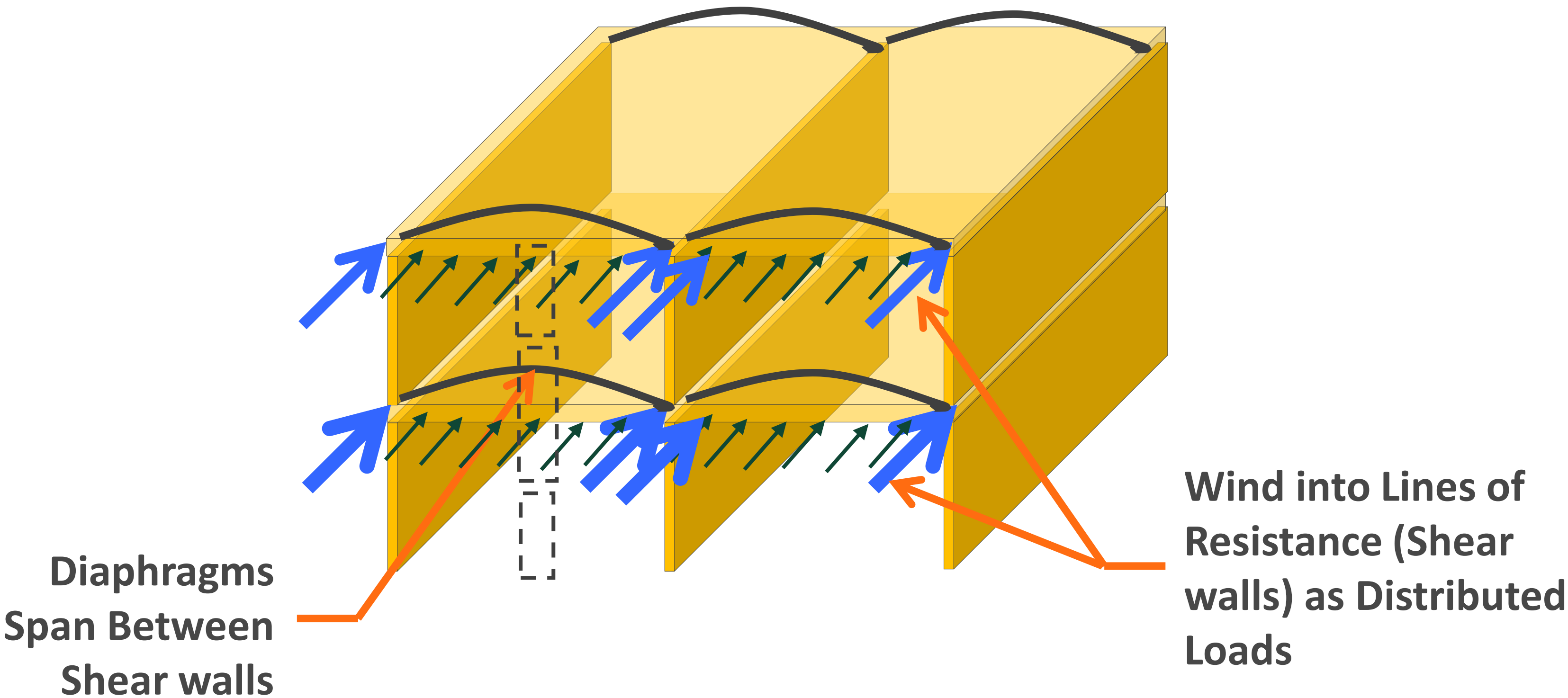
Application Single Story



Method can include internal pressures



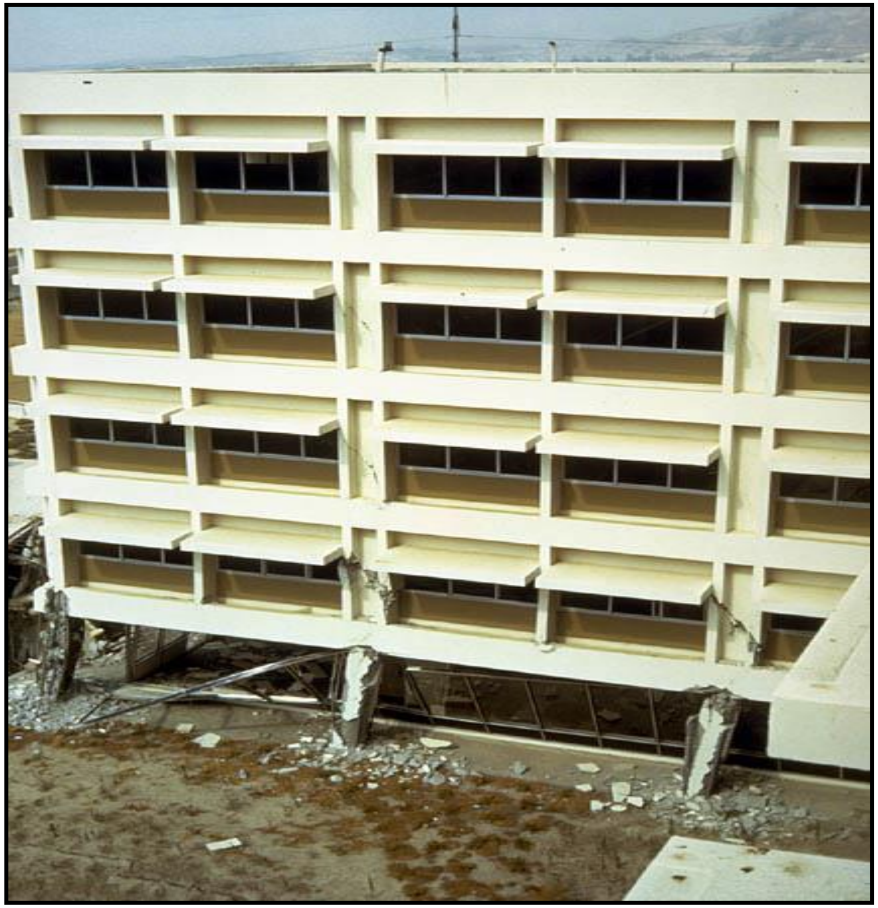
Pressure increases with height



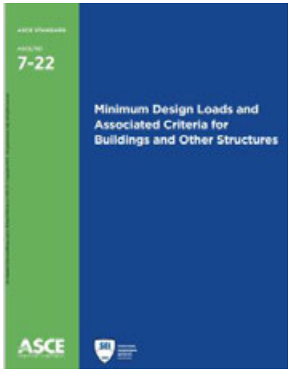
Application Multi-Story

Seismic Forces

Seismic-101...How does it work (or not work)?



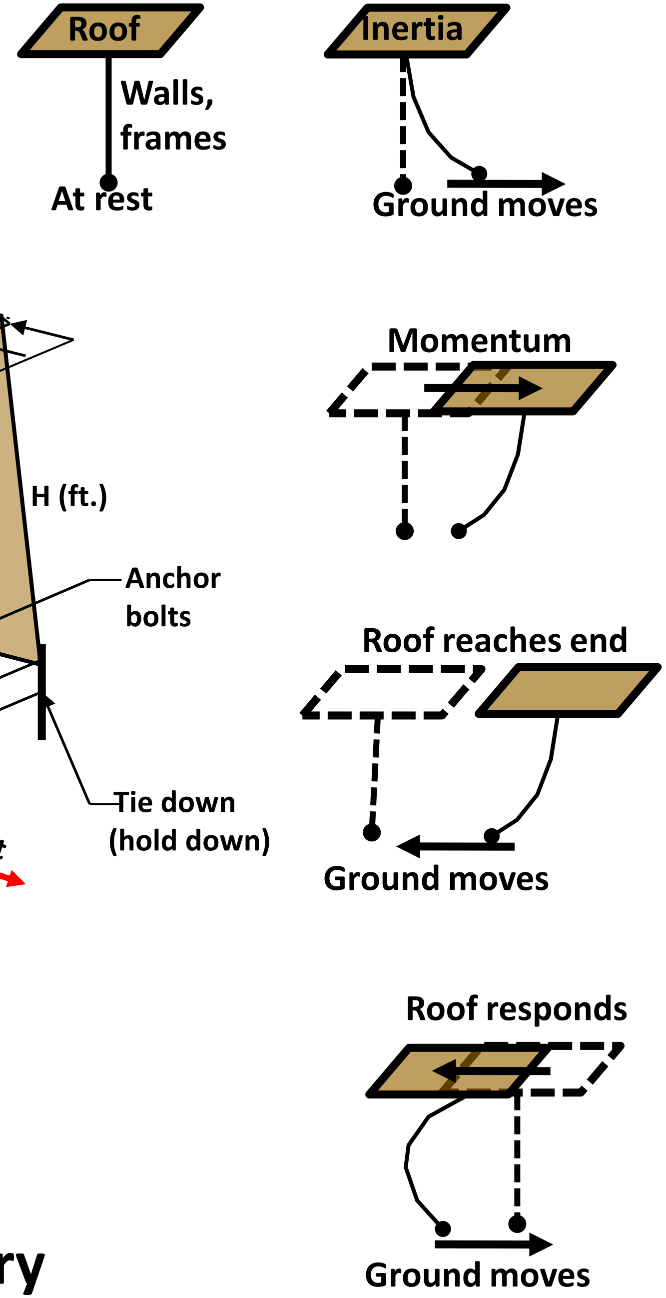
ASCE 7-22

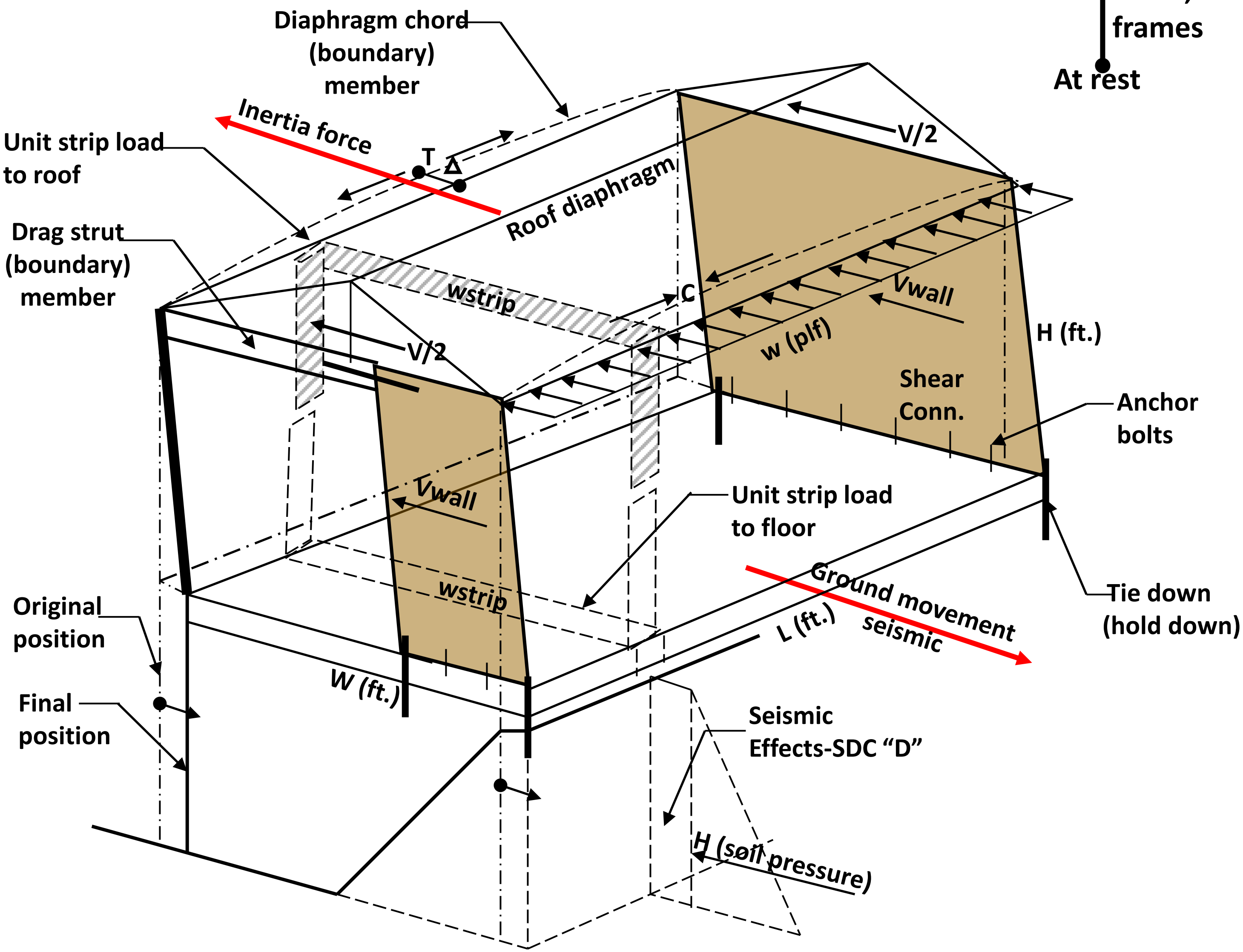


CH. 11 & 12

What are the response characteristics of the structure?
(How will the structure move or respond to a lateral force?)

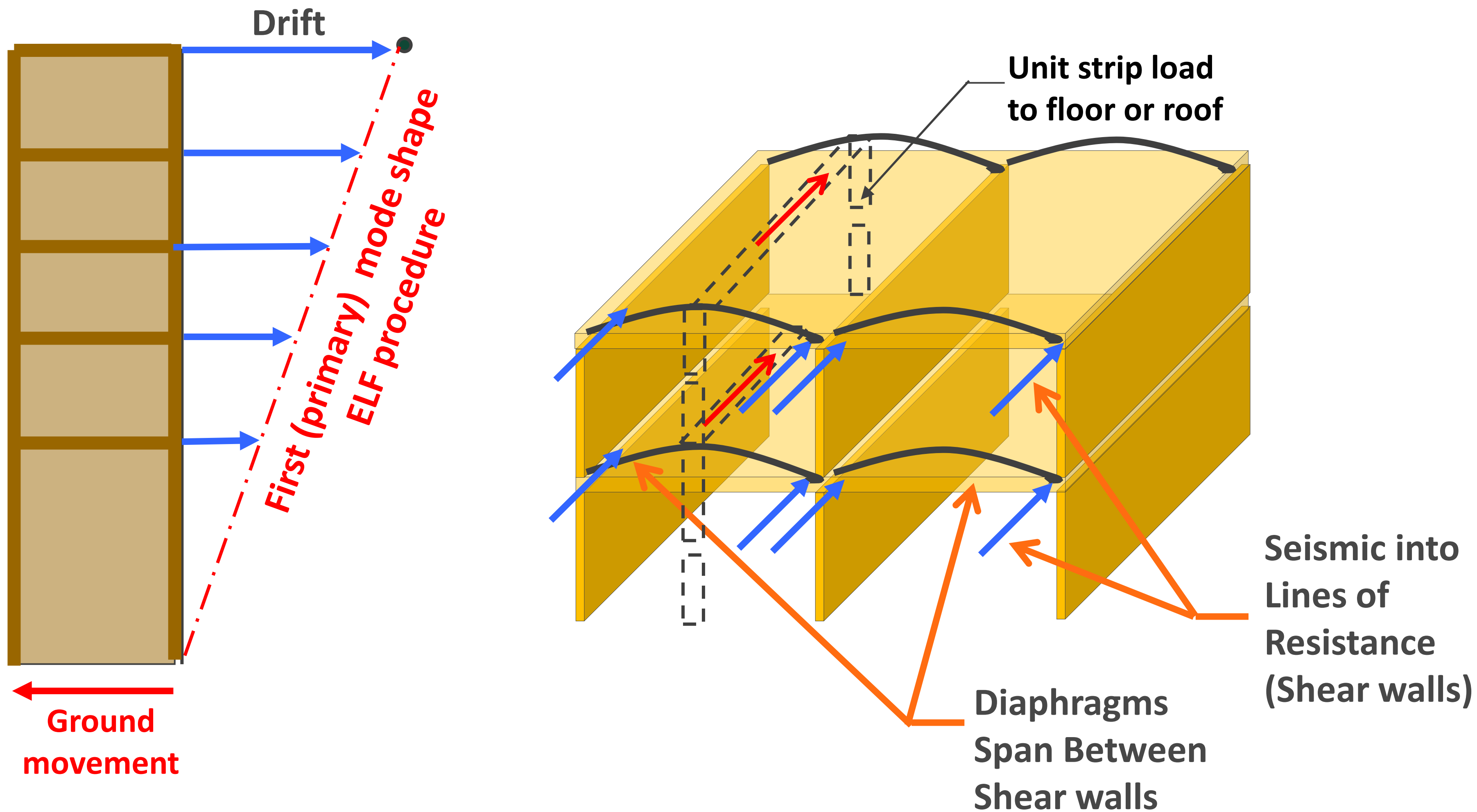
Simple Box System



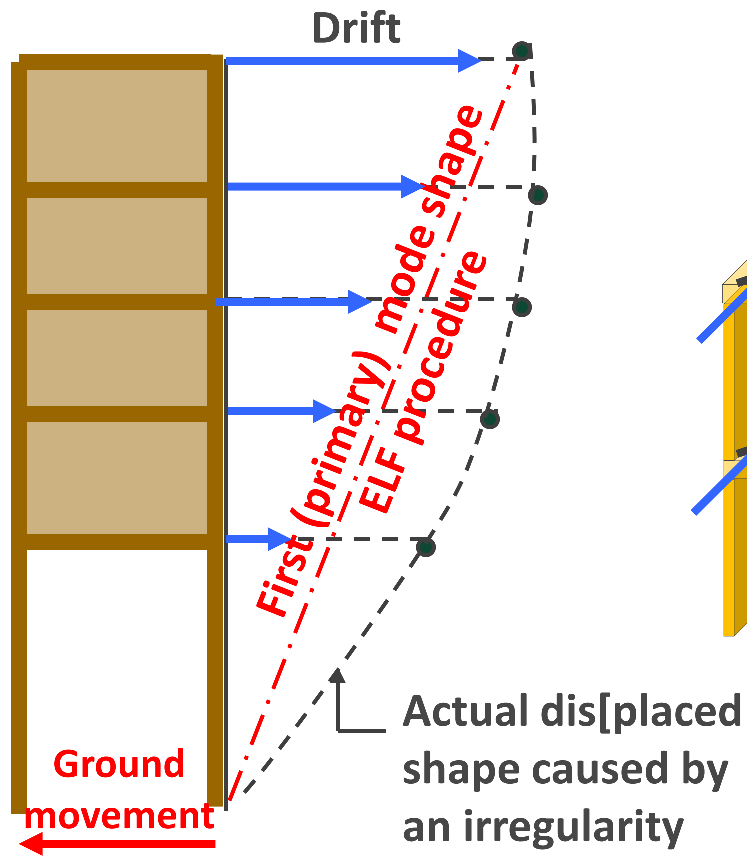


Application Single Story

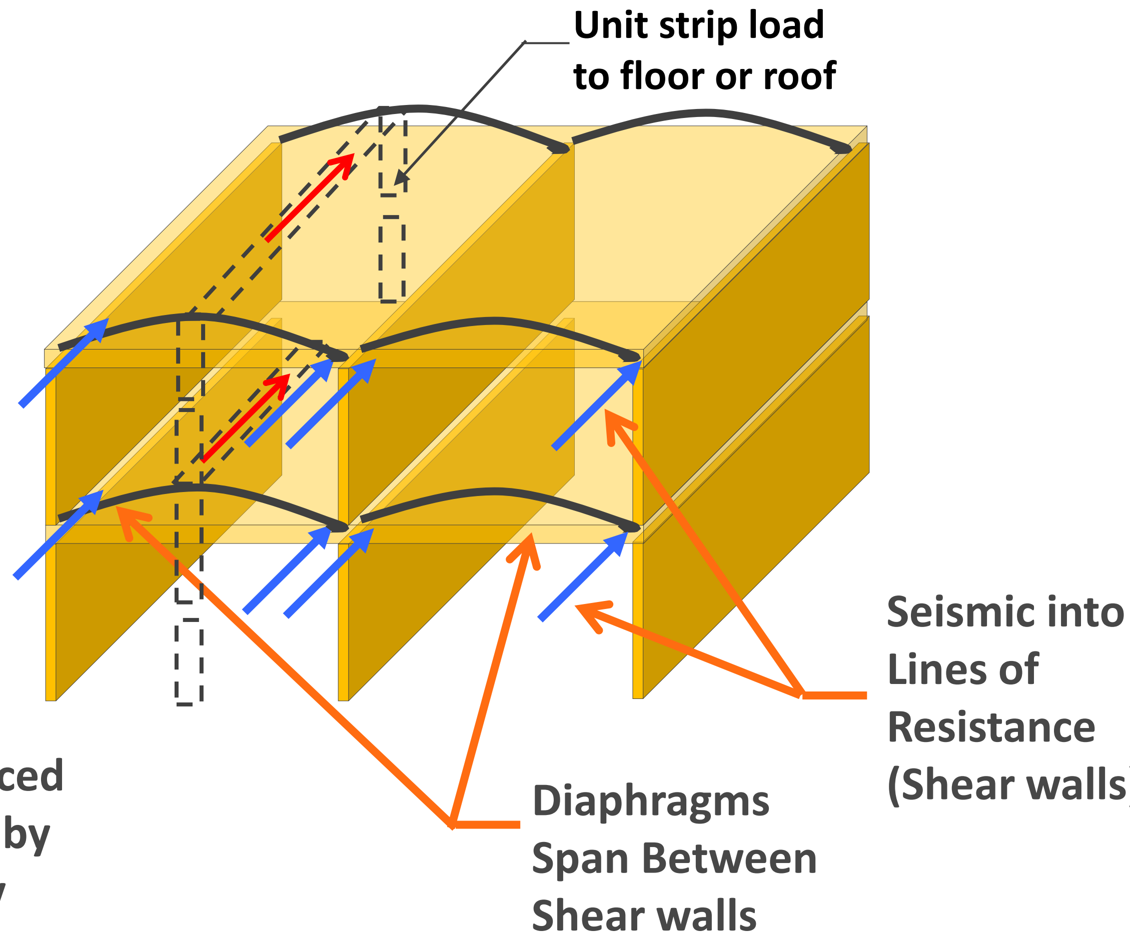
(Relationship between ground movement and response of the mass of the structure)



Application Multi-Story



Soft-Story Irregularity shown



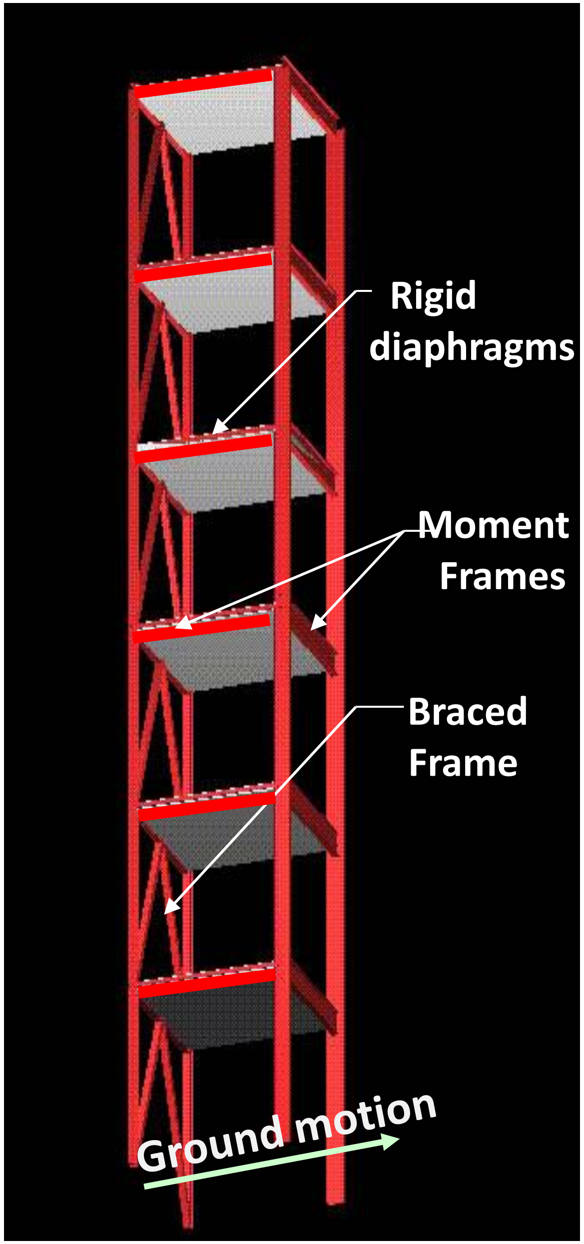
Base shear=$V = C_s W = \frac{S_{DS} W}{R}$ ← The lower the response factor the higher the base shear. <u>Based on ductility</u>.

Short period

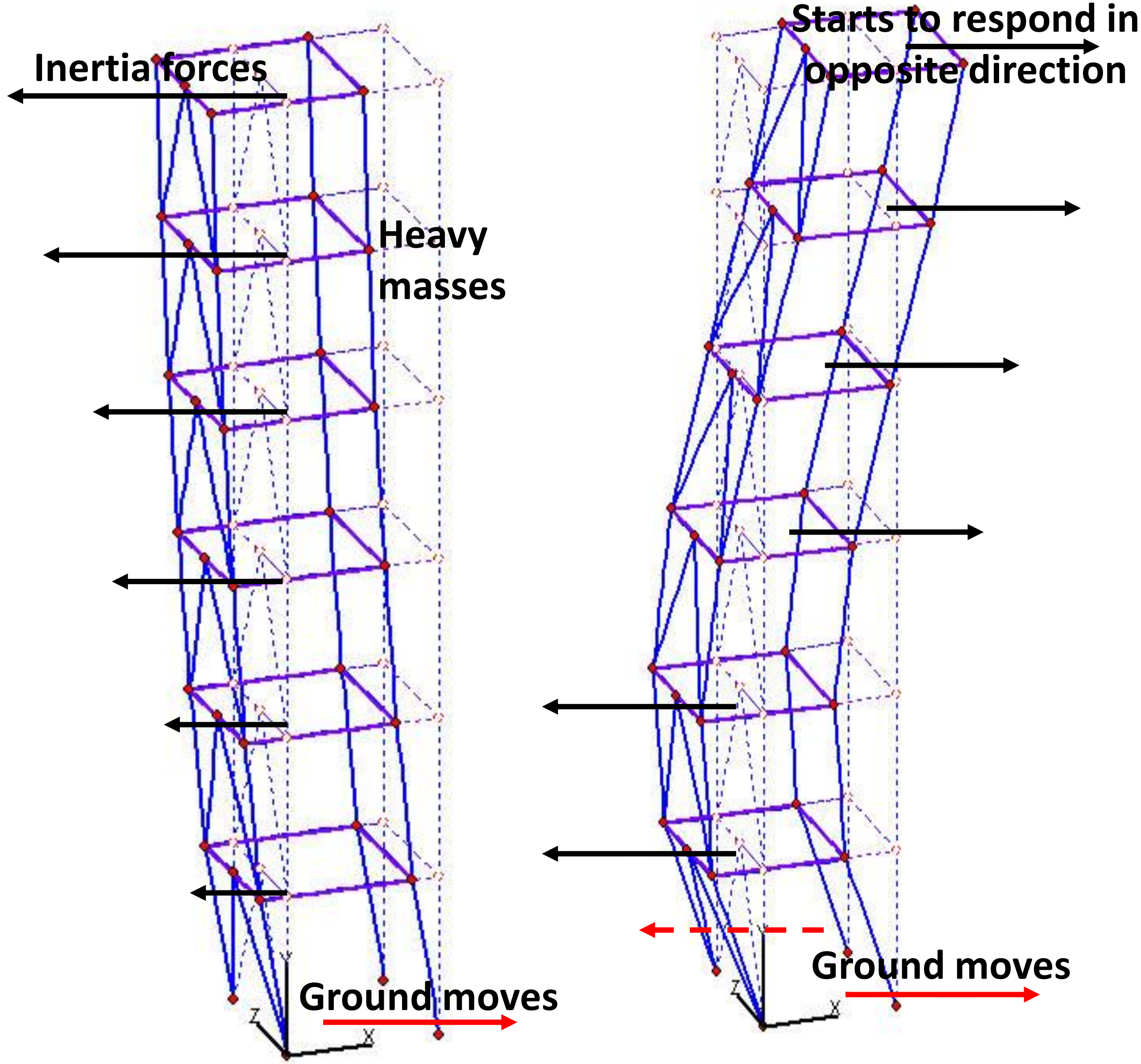
Where S_{DS}=spectral response acceleration, R=response modification coefficient

Ductility: Ability to be deformed without losing toughness; pliable, not brittle.

Application Multi-Story

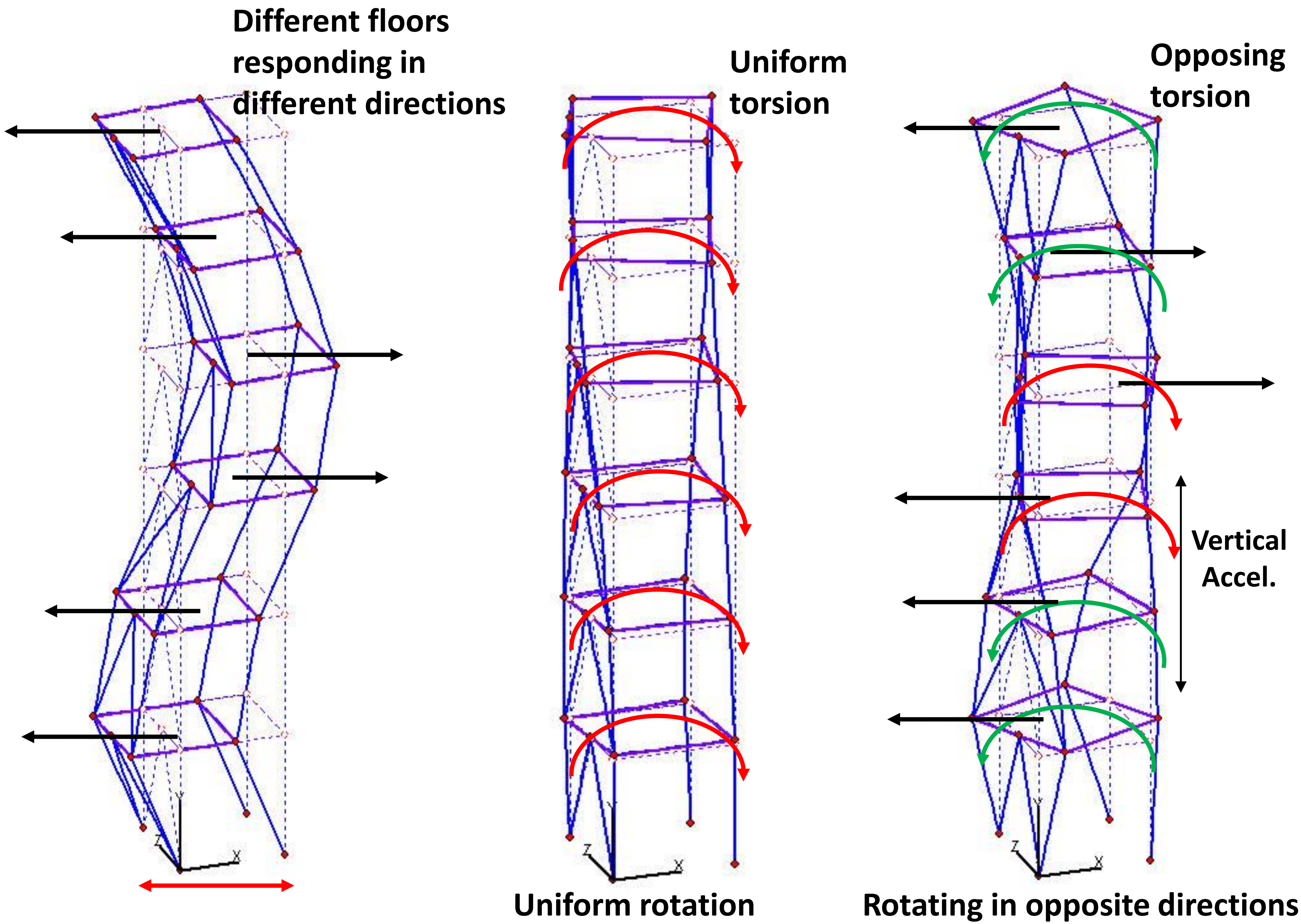


Different Stiffnesses
(Torsionally Irregular)



1st Mode **2nd Mode**

Modal Analysis



3rd Mode

Higher modes

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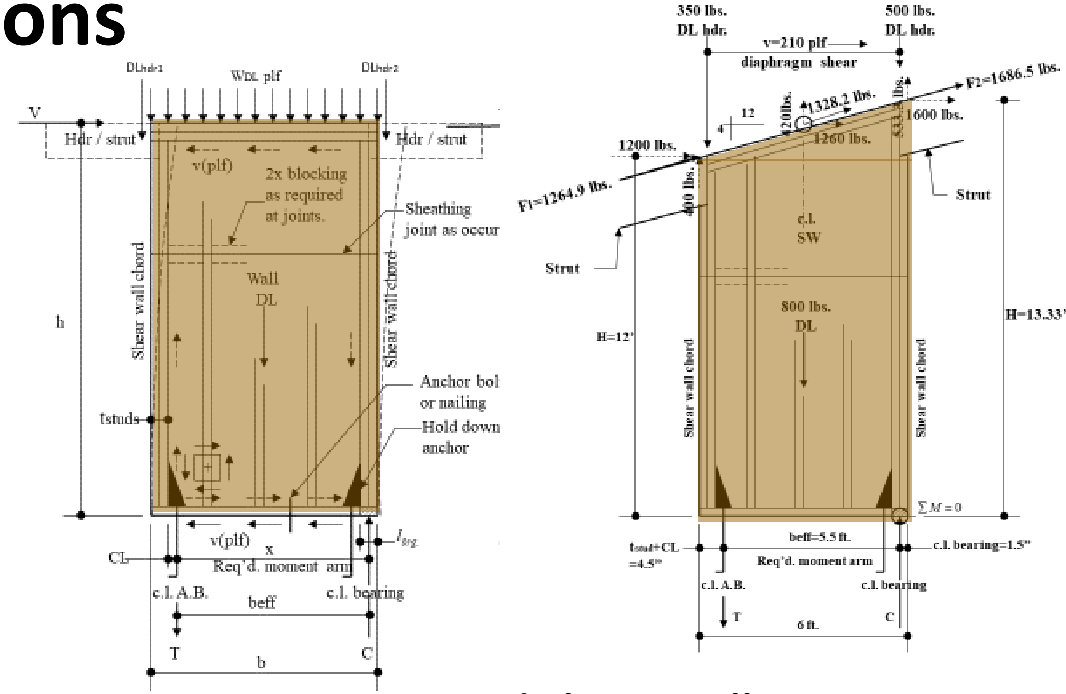
Shear Wall Configurations

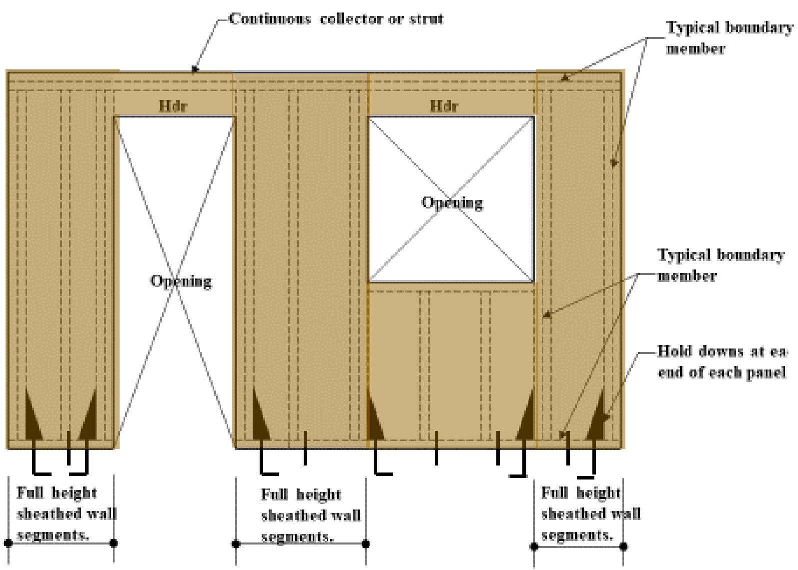
- Single story
- Multi-story

$R_{GWB}=2$, $R_{WSP}=6.5$

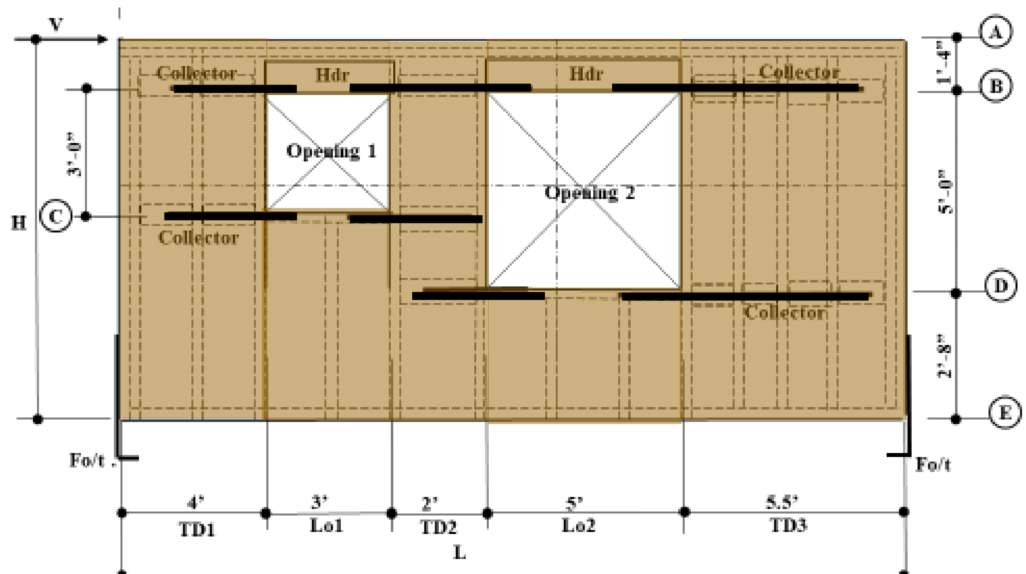
Based on ductility



Segmented Shear Walls



Segmented/Perforated Shear Walls



FTAO Shear Walls

Braced Frames/Trusses

R=1, 1.5

Timber Braced Frame

Timber Braced Frame

Steel Braced Frame **R=3.25 to 8**

Source: StructurLam

Timber Truss- Braced Frame

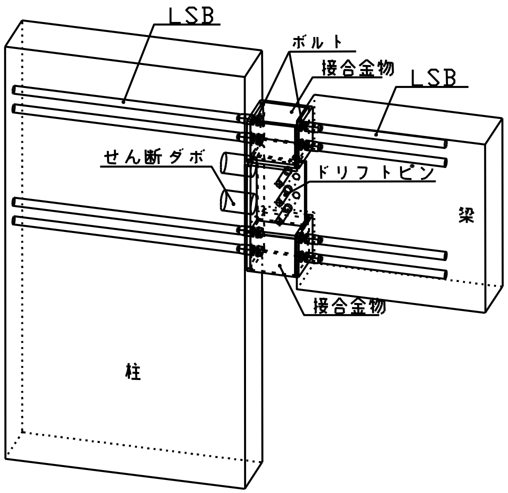
Hybrid Wood/Steel Braced Frames

R=3.25 to 8

The Bullitt Center
Architect: The Miller Hull Partnership
Photo: John Stamets

Moment Frames

R=3.5 to 8



Glue lam Moment-Frame

Prefabricated Steel Moment-Frame

Glue lam Tudor Arch Moment-Frame

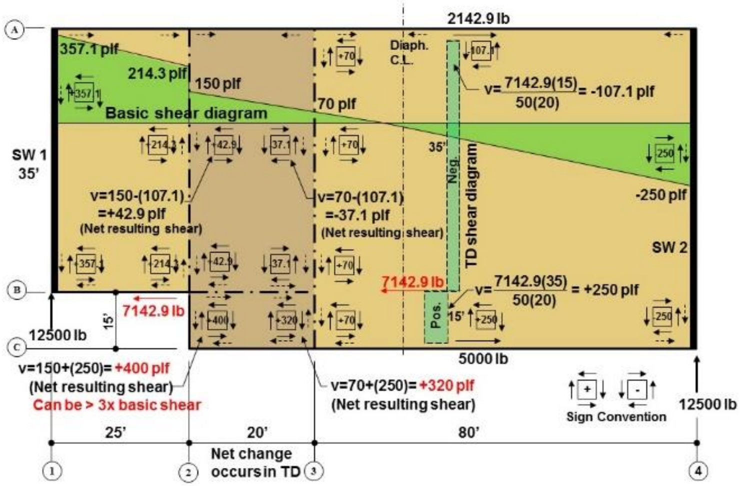
Prefabricated Steel Moment-Frame

Hybrid Wood/Steel Proprietary Systems

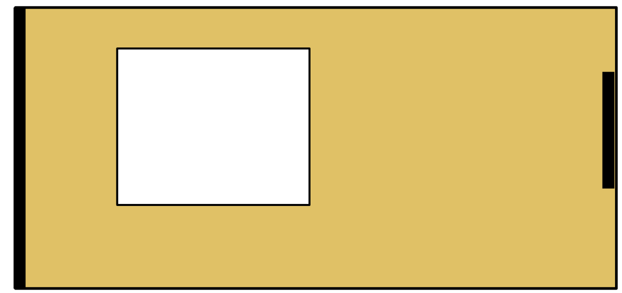
Source: hardyframe.com

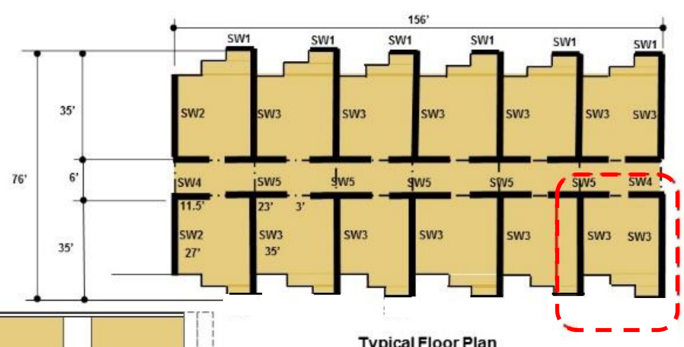
Diaphragm Configurations

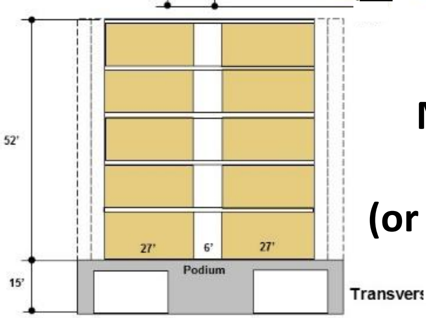
Offset Diaphragms



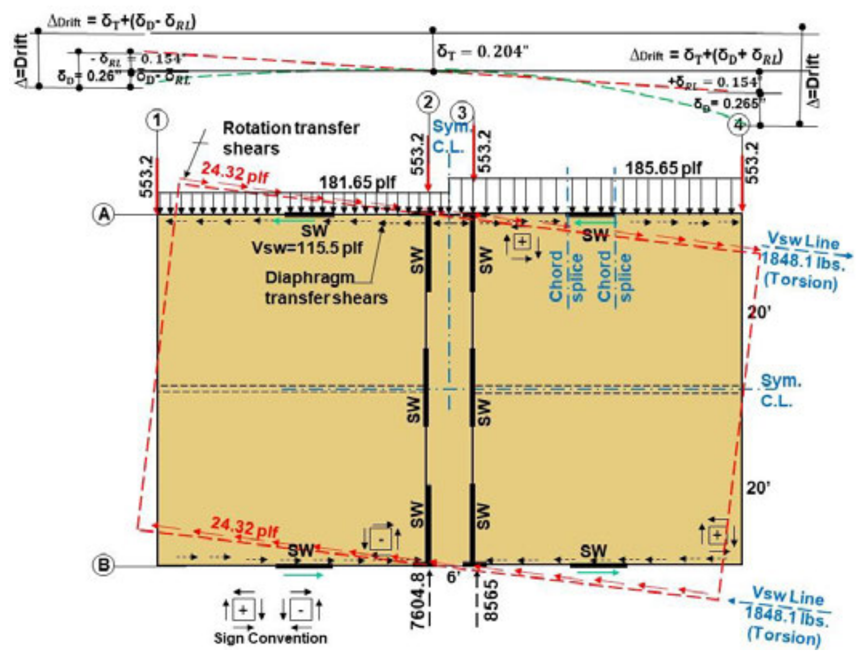
Diaphragms with large openings







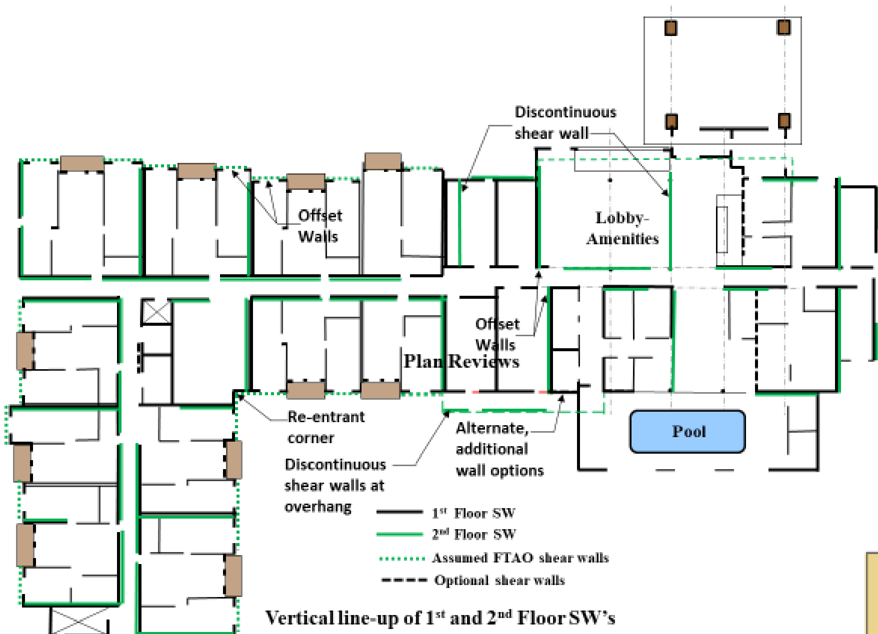
Mid-rise Design with Horizontal Offsets (or Cantilever diaphragms)



Cantilever Diaphragms

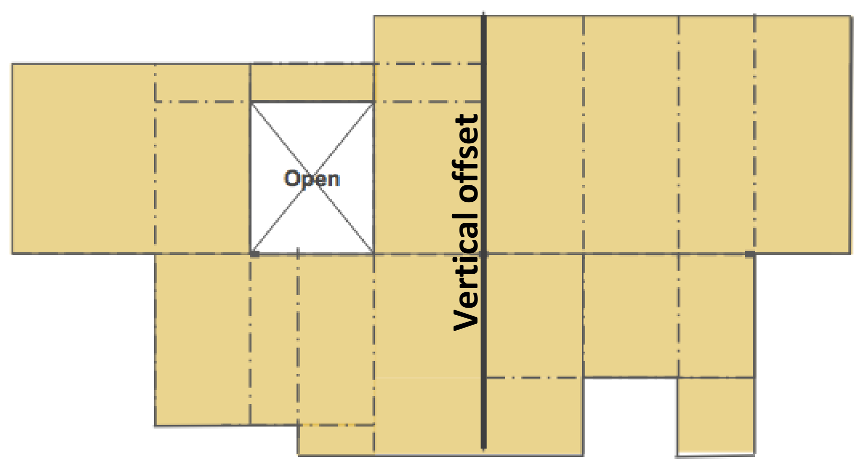
Additional Diaphragm Configurations

- Typical floor plan results in diaphragm offsets, re-entrant corners, discontinuities, openings
- Diaphragm openings, discontinuities = higher concentrated, localized forces
- Vertical offsets



Re-entrant corners

Highly Irregular Shapes



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Why Have the Codes Changed?

Many code changes have been based on major wind and seismic events, research, and testing.

Wind

- Narrow shear walls.
- Large openings.
- Elevated Piling (soft story)

- What are seismic irregularities and how do they impact the structural response?
- What causes them?

Seismic

(soft story)

Research, Testing

Suggested Review of Irregularities:

- Observe the plan layouts.
- Think about the difference in stiffness throughout the structure, story by story.
- What are weak points in the structure?
- How will the structure move/respond?
- What about load paths (Simple or complex)?

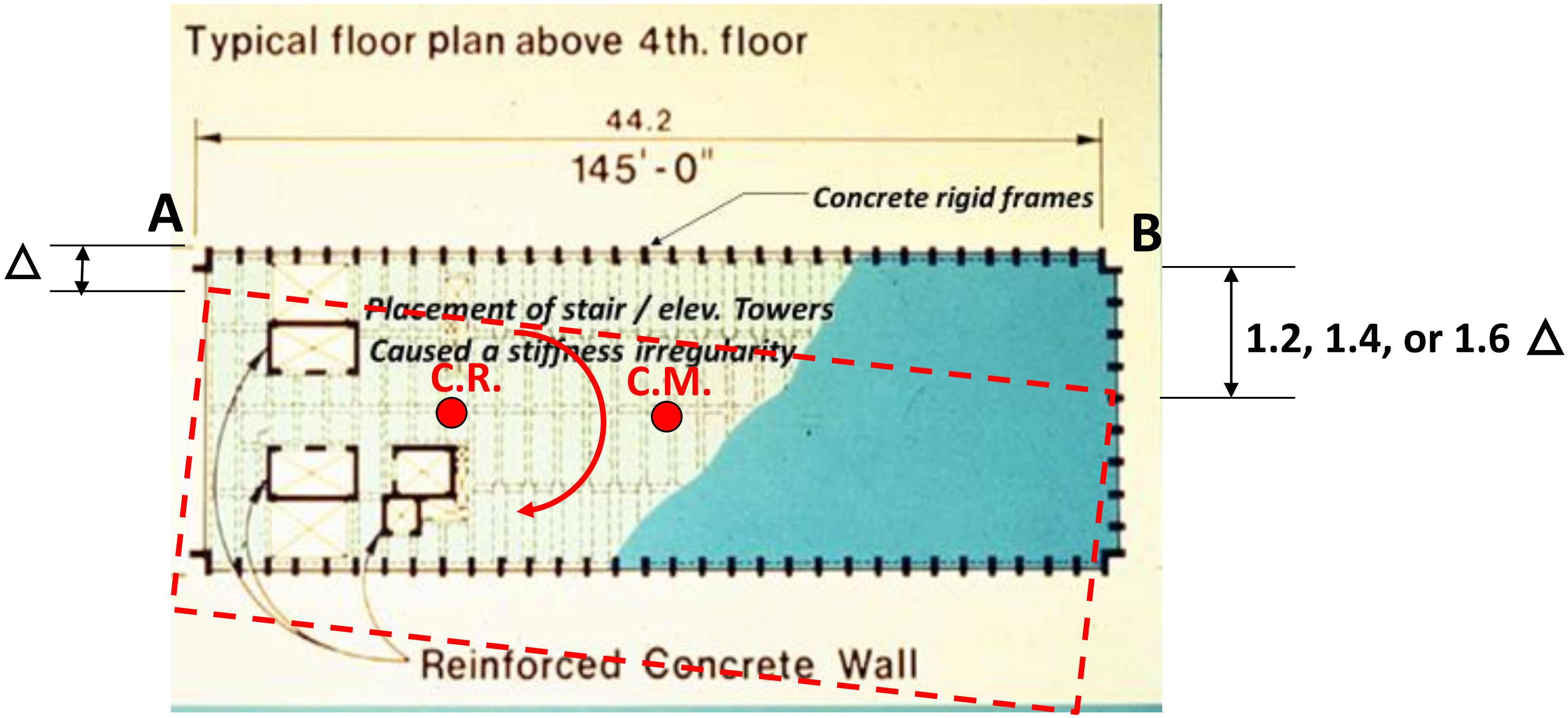
Type 1 -Horizontal Torsional Irregularity

Requirements vary depending on SDC, B-F

Either:

- **More than 75% of any story's lateral strength below the diaphragm is provided at or on one side of the center of mass, or**

- **When the Torsional Irregularity Ratio (TIR) exceeds 1.2. The story lateral strength is the total strength of all seismic-resisting elements sharing the story shear for the direction under consideration.**



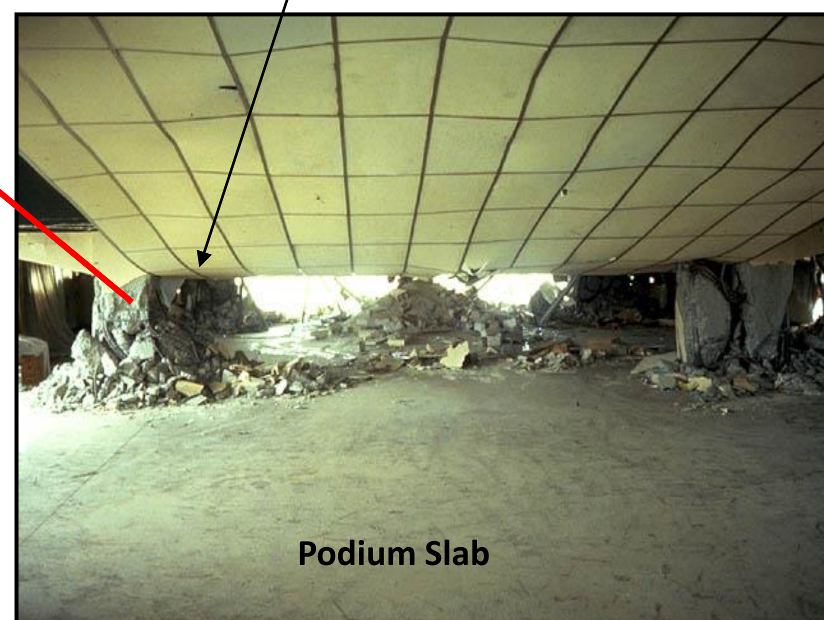
Rigid conc. SW's supported by columns

Not an Architectural Feature

Rigid SW at far end

Concrete columns supporting Rigid SW's

Torsional Irregularity

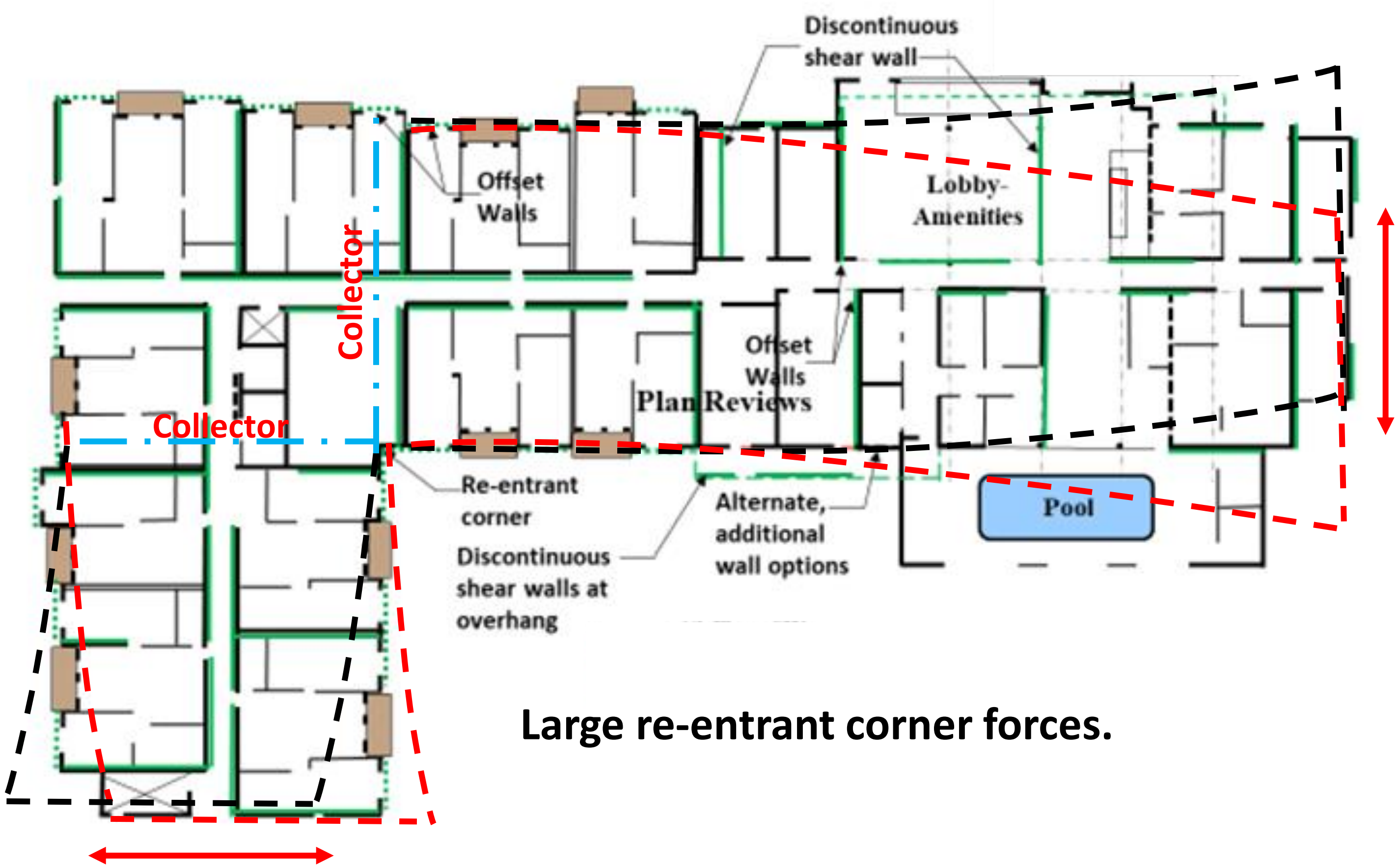


Type 2 – <u>Horizontal</u> Re-entrant Corner Irregularity

SDC D, E, F

Irregularity exists where both projections of a structure beyond a re-entrant corner are greater than 20% of the plan dimension in the given direction.

Use to be 15%

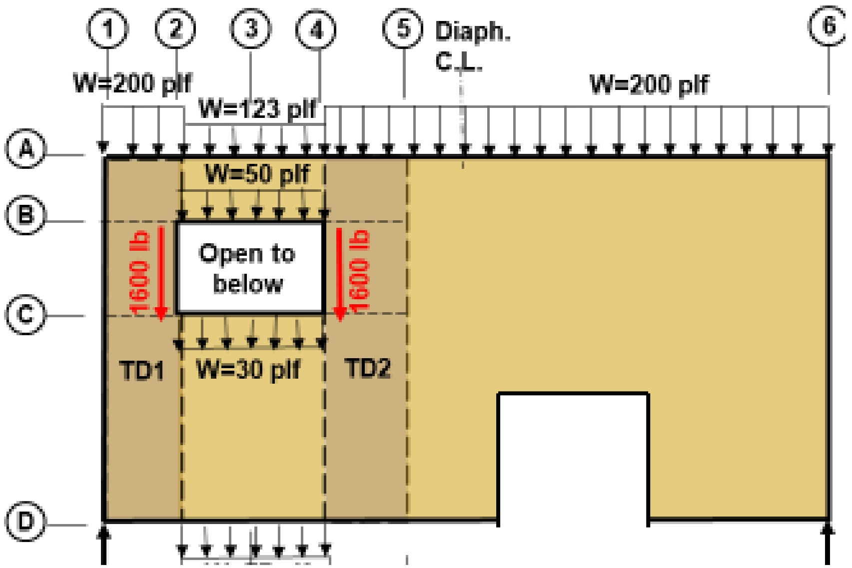


Large re-entrant corner forces.

Type 3 Horizontal Diaphragm Discontinuity Irregularity

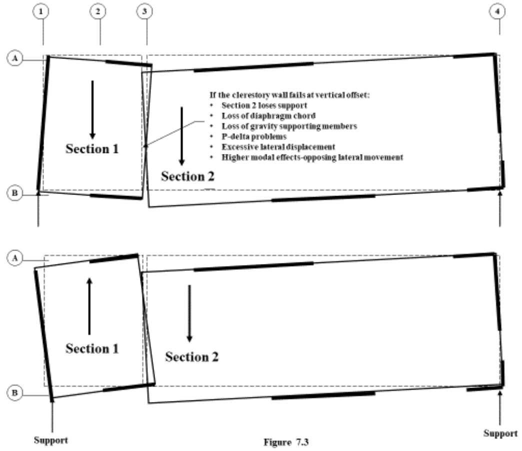
SDC D, E, F

Irregularity exists if when diaphragms have abrupt discontinuities or variations in stiffness, including one that has a cutout or open area greater than 25% of the gross enclosed diaphragm area, or a change in effective diaphragm stiffness of more than 50% from one story to the next.

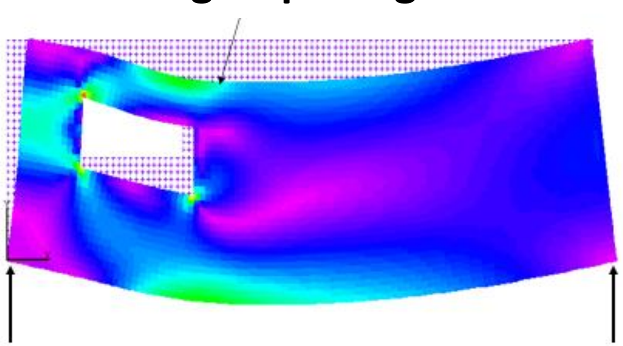


Open-front, cantilever diaphragm

Vertical Offset



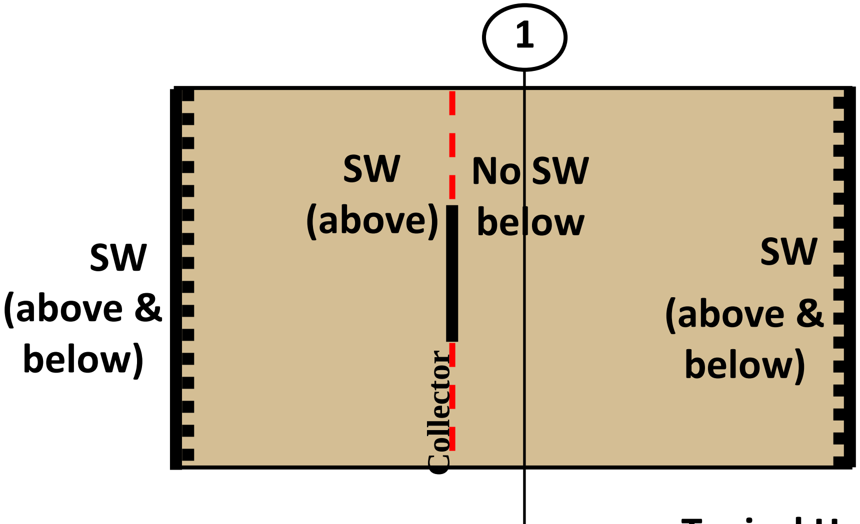
Large Opening

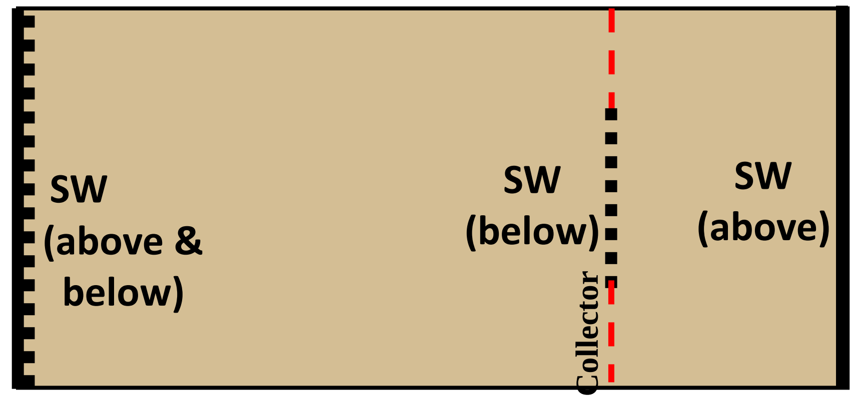


Type 4 Horizontal Out-of-plane Offset Irregularity

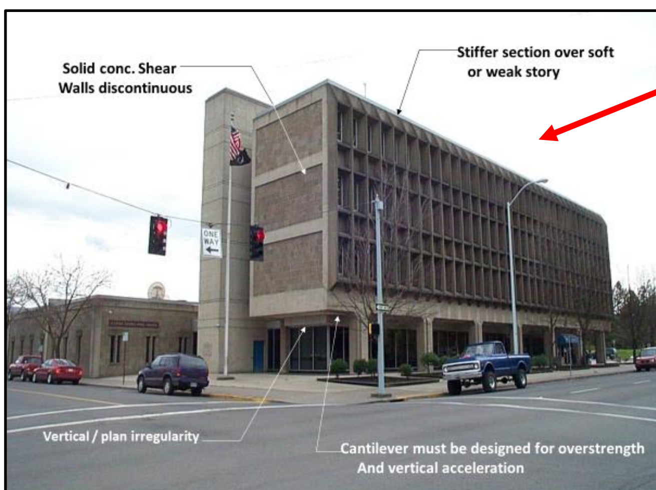
SDC B, C, D, E, F

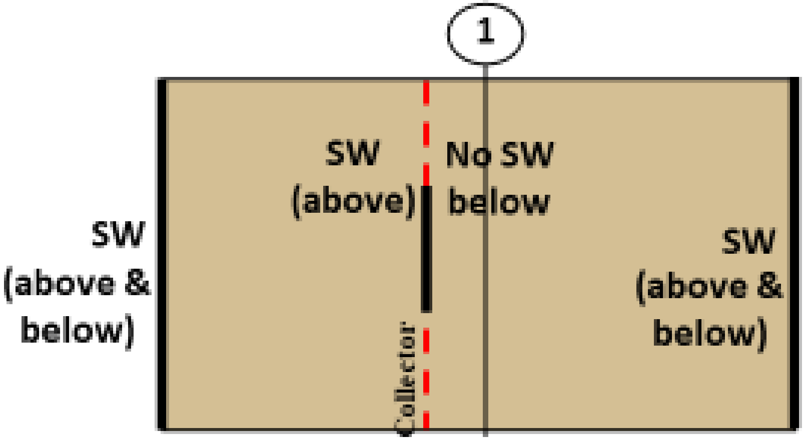
Irregularity exists where there is a discontinuity in a lateral force-resistance path, such as an out-of-plane offset of at least one of the vertical elements.



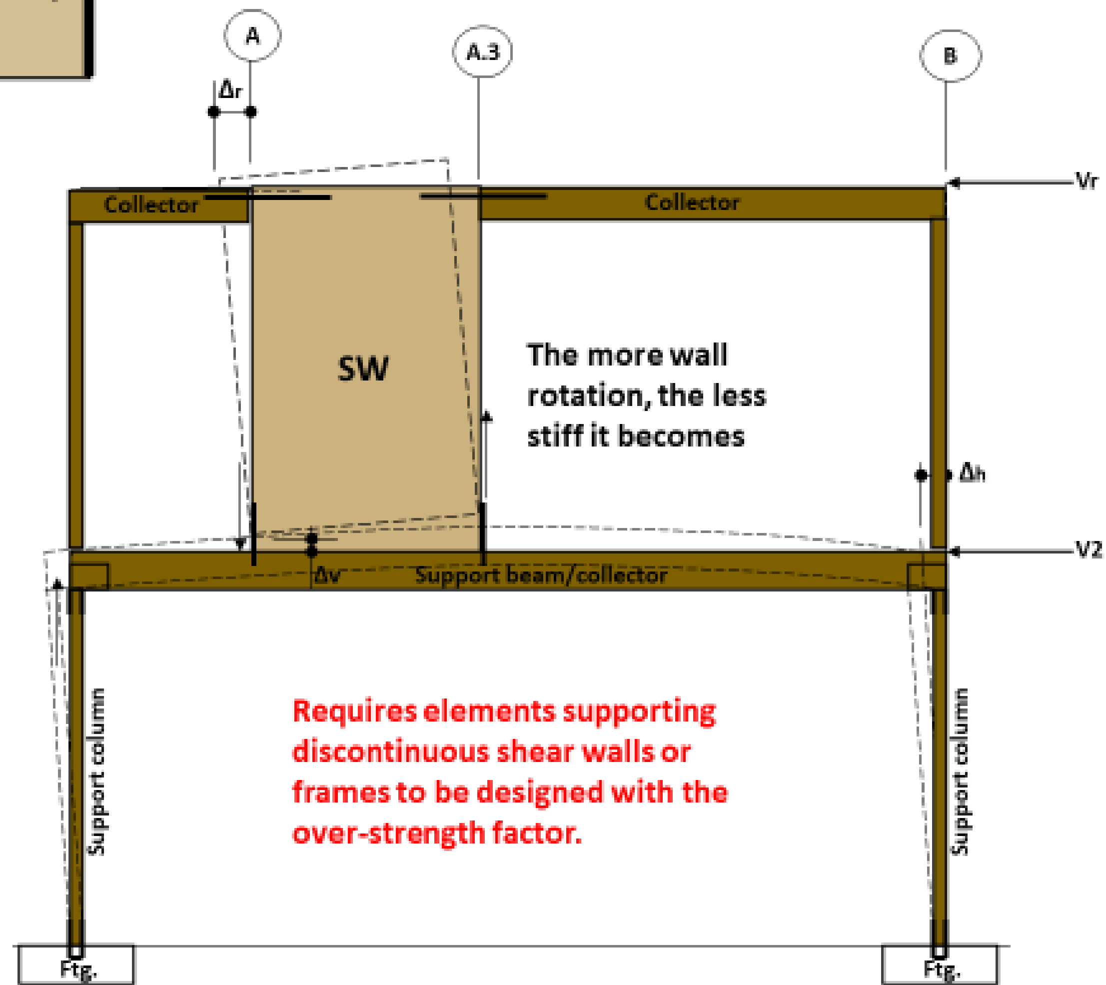


Typical Horizontal Offsets
(Requires overstrength of supporting members)





Plan

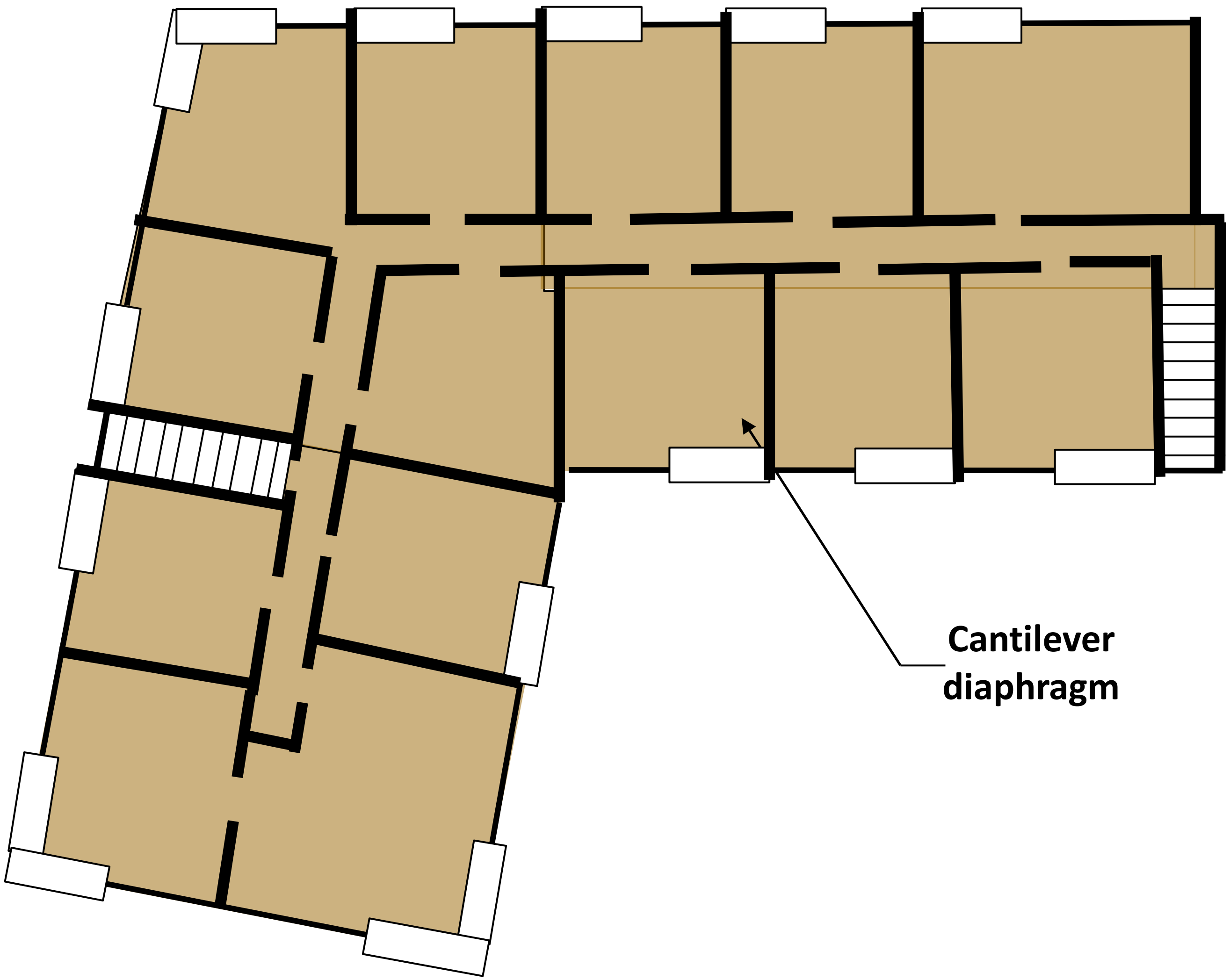


1 **Section**

Type 5 <u>Horizontal</u> Non-parallel System Irregularity

Requirements varies on SDC <u>B</u>, C, D, E, F

Irregularity exists where vertical lateral force-resisting elements are not parallel to the major orthogonal axes of the seismic force-resisting system



Type 1a stiffness-Soft Story Vertical Irregularity

Exists where there is a story in which the lateral stiffness is less than 70% of that in the story above or, where there are at least three stories above, less than 80% of the average stiffness of the three stories above.

Type 1b Stiffness–Extreme Soft Story Vertical Irregularity

Prohibited in SDC E, F

Exists where there is a story in which the lateral stiffness is less than 60% of that in the story above or, where there are at least three stories above, less than 70% of the average stiffness of the three stories above.

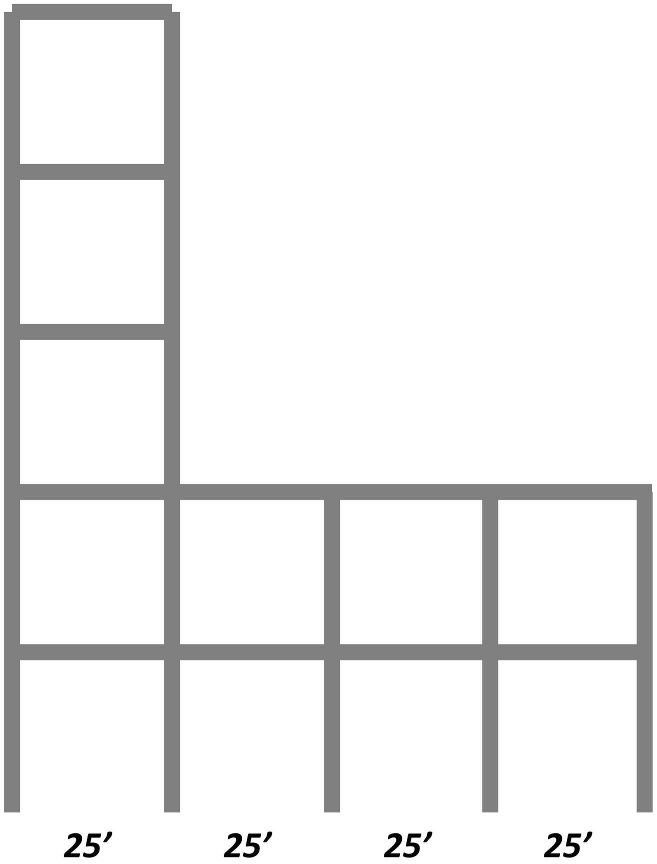
URM

Olive View Hospital 1971 San Fernando EQ

URM

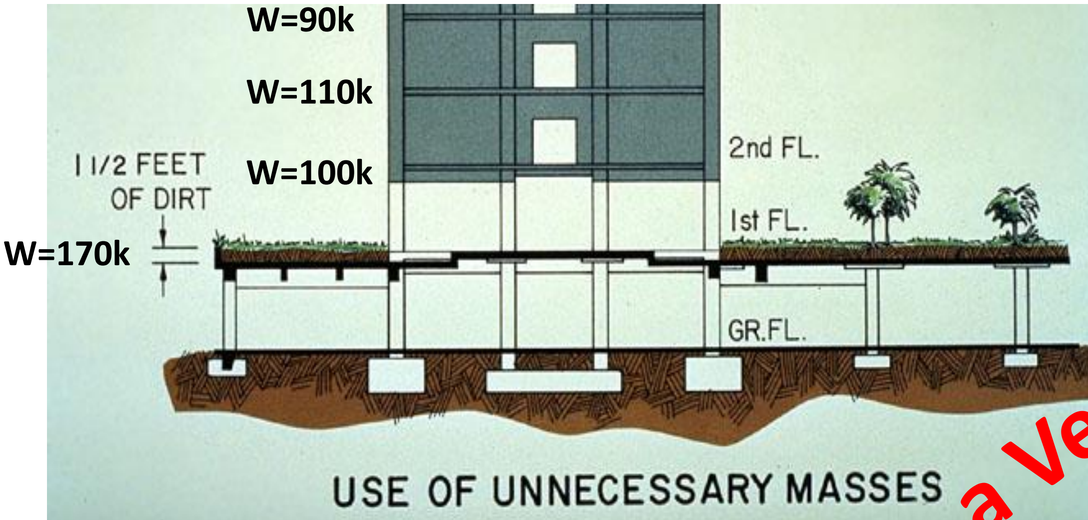
Type 2-Geometric <u>Vertical</u> Irregularity-Horizontal offset

Exists where the horizontal dimension of the seismic force-resisting system in any story > 130% of adjacent story dimension



Type 2-Vertical Irregularity-Weight (mass) Irregularity

Story mass> 150% of adjacent story mass



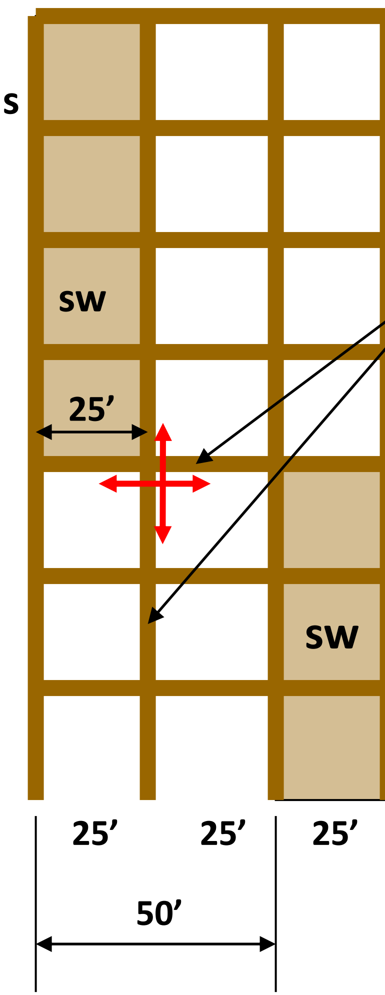
No longer listed as a Vertical Irregularity

Type 3 In-plane Discontinuity in Vertical Force-resisting Element-
Vertical Irregularity

SDC B, C, D, E, F

Exists where there is an in-plane offset of a vertical seismic force-resisting element resulting in overturning demands on supporting structural elements.

Discontinuous SW



Overstrength design required

- Overturning load path discontinuity
- Shear load path discontinuity

4a. Discontinuity in Lateral Strength–Weak Story Vertical Irregularity

Exists where the story lateral strength is less than that in the story above. The story lateral strength is the total lateral strength of all seismic force-resisting system elements resisting the story shear for the direction under consideration.

Prohibited in SDC E, F

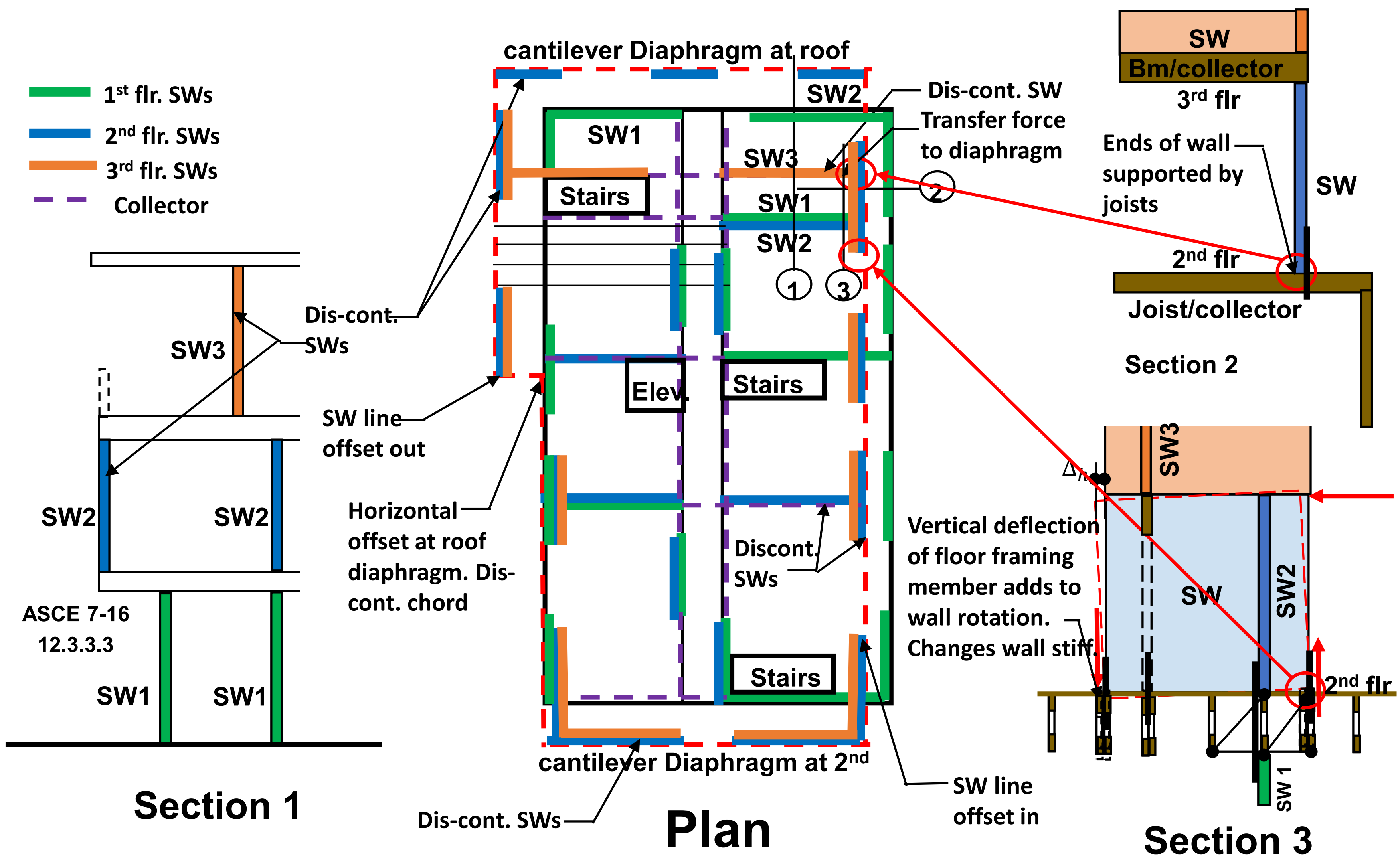
4b. Discontinuity in Lateral Strength–Extreme Weak Story Vertical Irregularity

Prohibited in SDC E, F

Exist where the story lateral strength is less than 65% of that in the story above. The story lateral strength is the total lateral strength of all seismic force-resisting system elements resisting the story shear for the direction under consideration.

Vertically and Horizontally Offset Shear Walls and Cantilever Diaphragm

Type 4 Horizontal Out-of-plane Offset Irregularity



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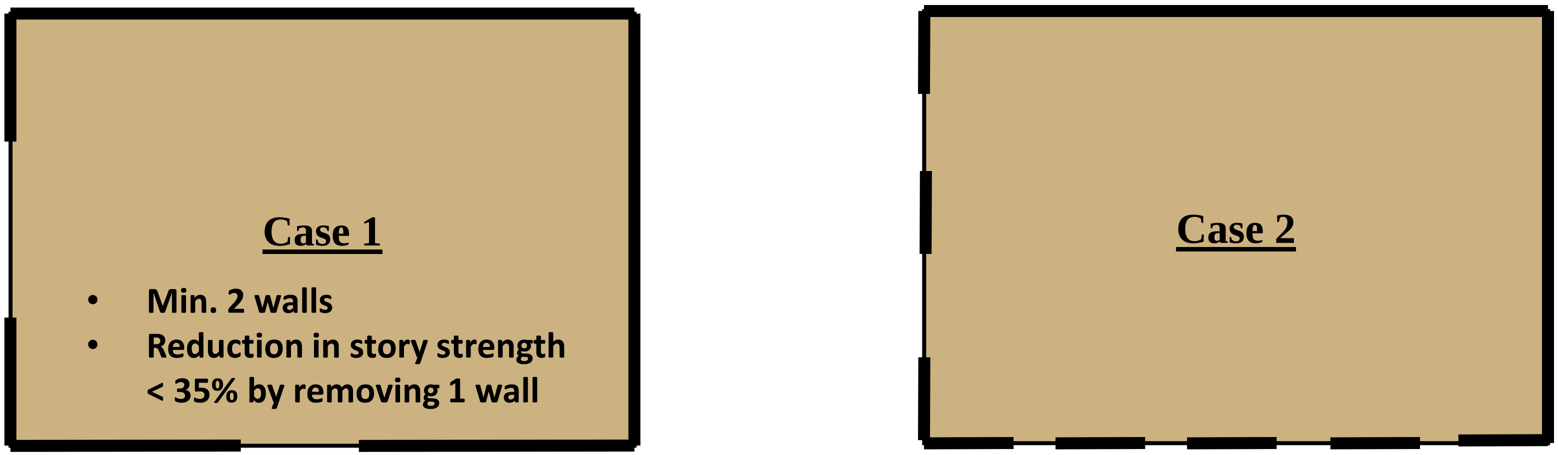
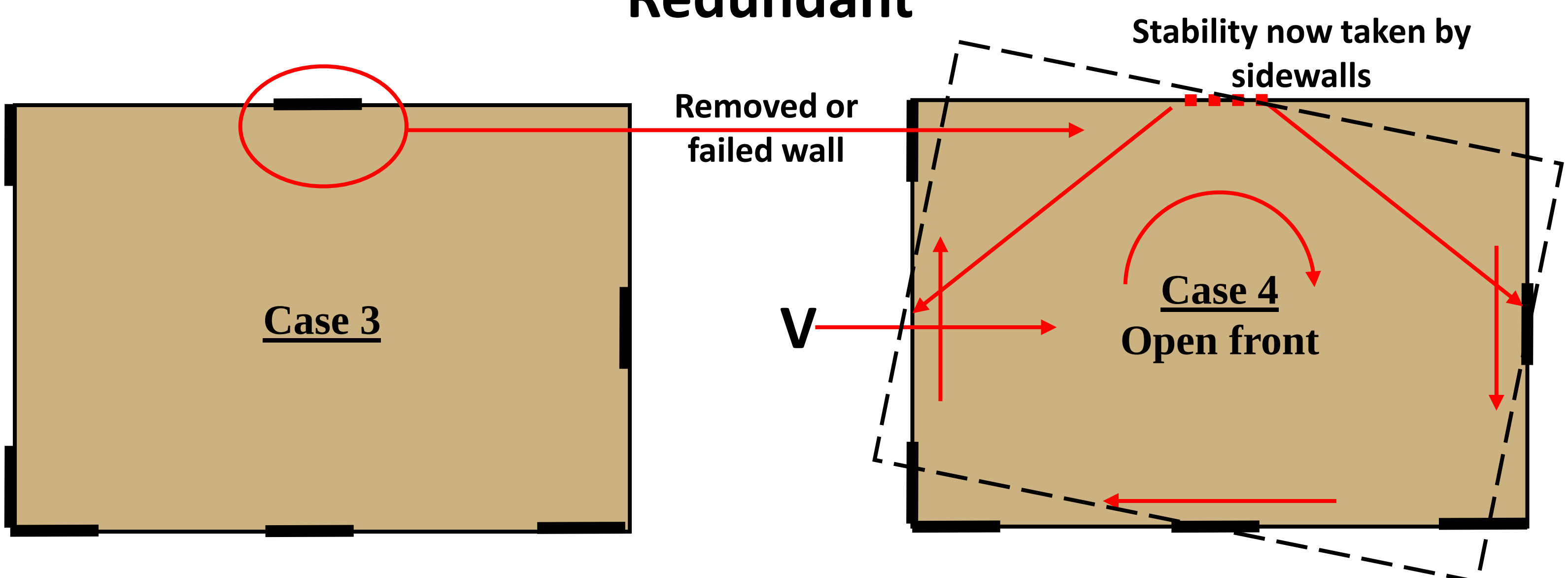
Redundancy

Requirements varies on SDC B, C, D, E, F

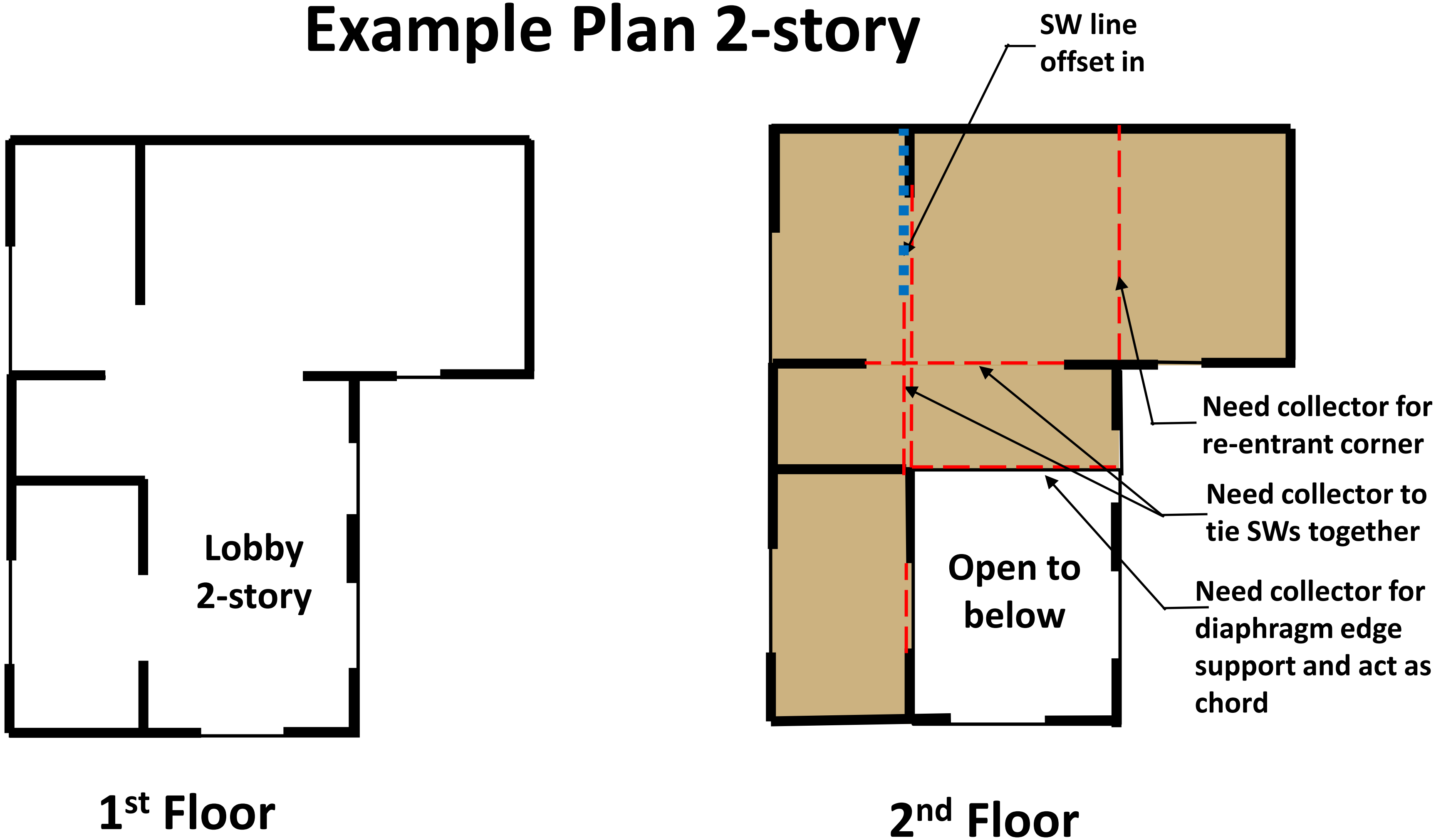


Redundant



No Redundancy

Example Plan 2-story



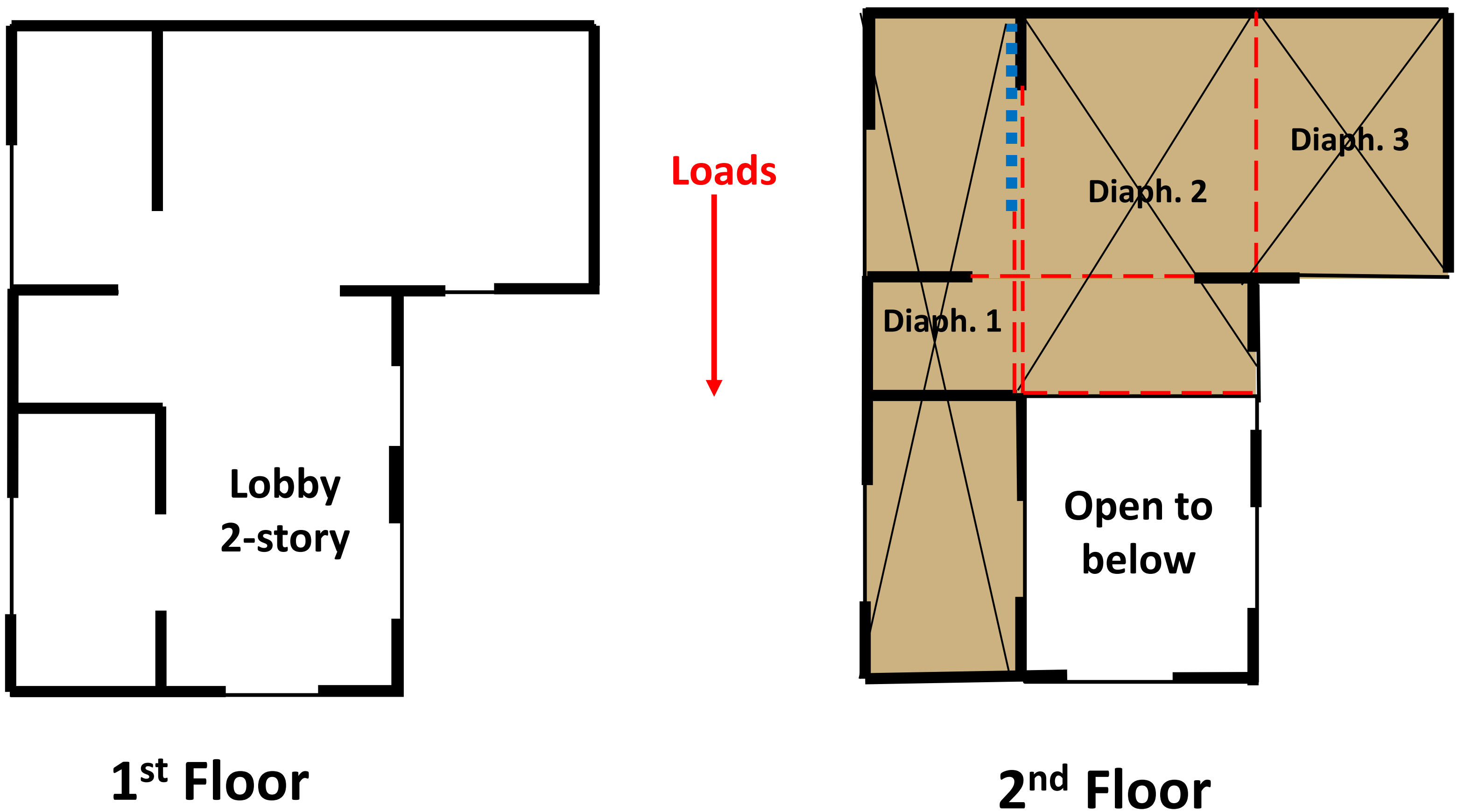
- All SWs stack,
- Very redundant,
- Simple rectangular diaphragms

Walls below

Walls above at 2nd floor

Case 1

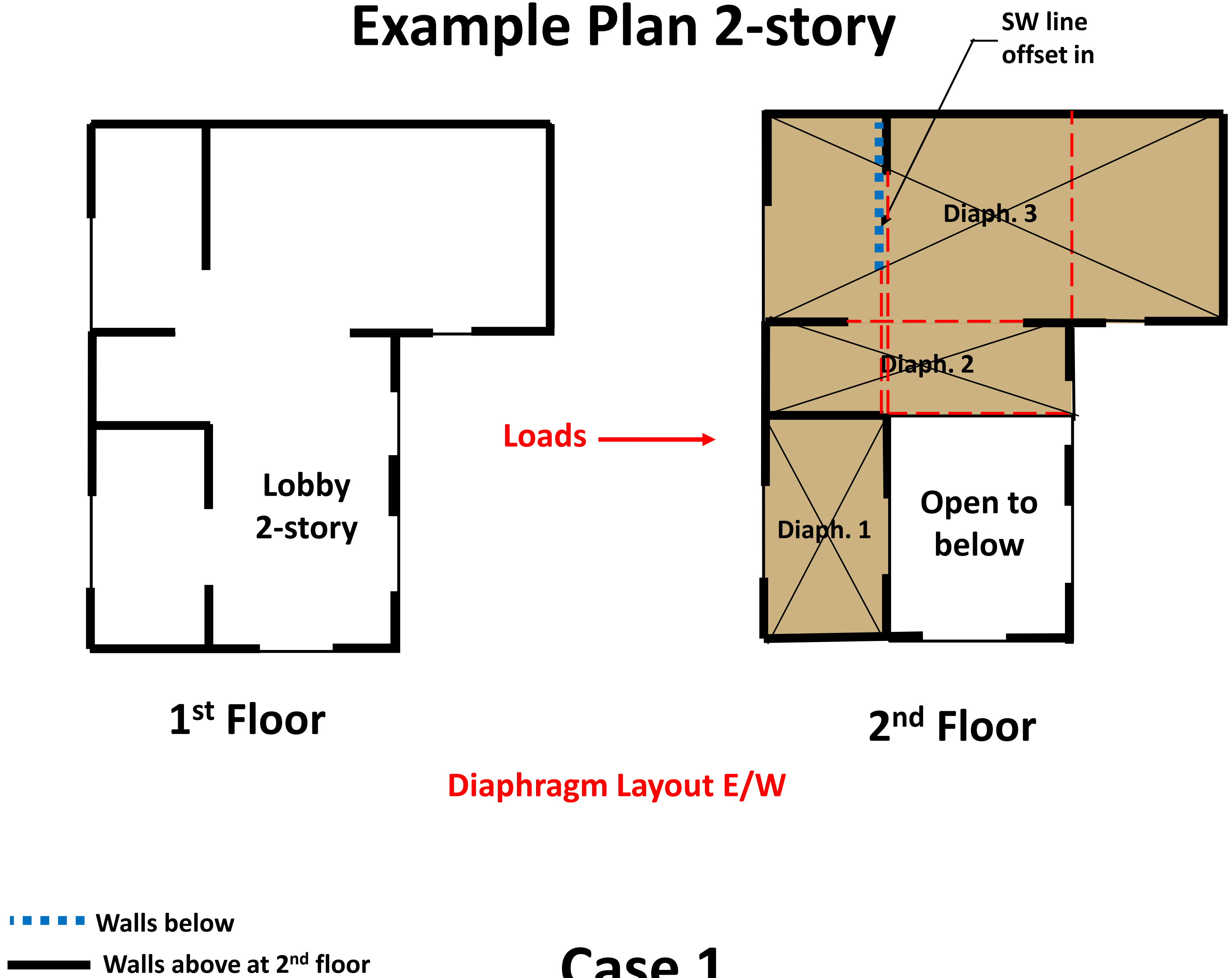
Example Plan 2-story



Diaphragm Layout N/S

Case 1

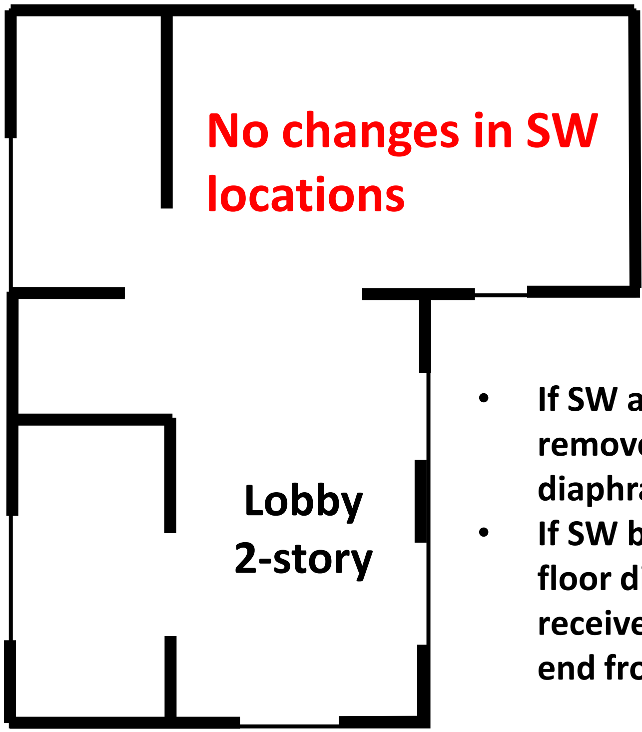
Example Plan 2-story



Case 1

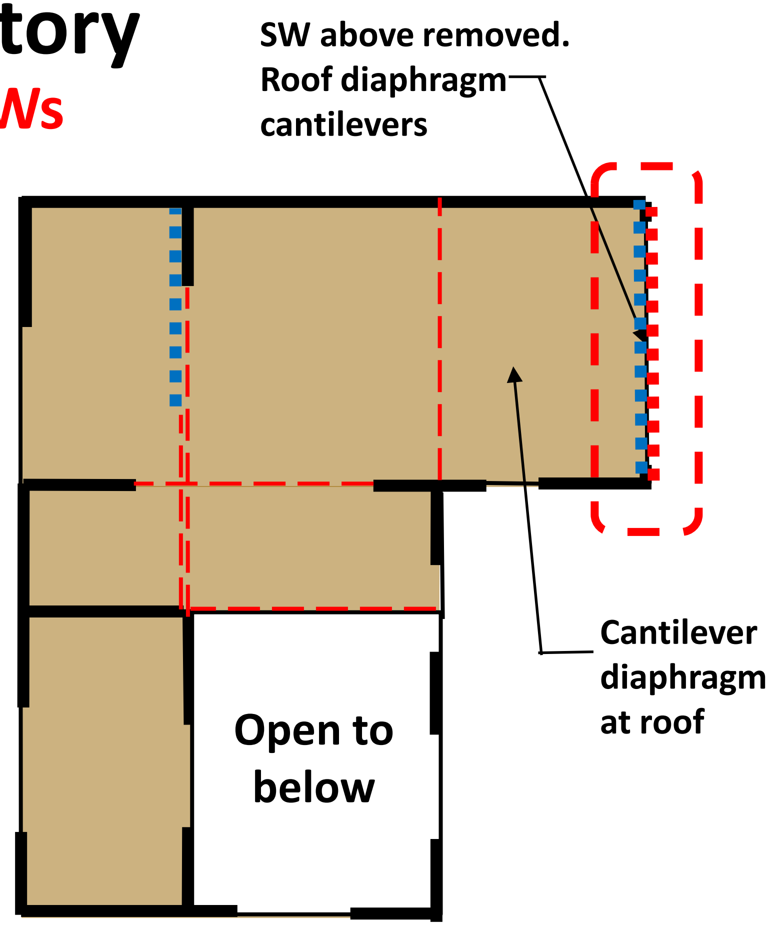
Example Plan 2-story

Removing 2nd floor SWs



1st Floor

- If SW above and below are removed, Roof and 2nd floor diaphragms cantilever
- If SW below removed, only 2nd floor diaphragm cantilevers and receives a concentrated force at end from SW above



2nd Floor

- All SWs still stack except as noted,
- Still very redundant.
- Same diaphragm layout at 2nd floor

Walls above removed

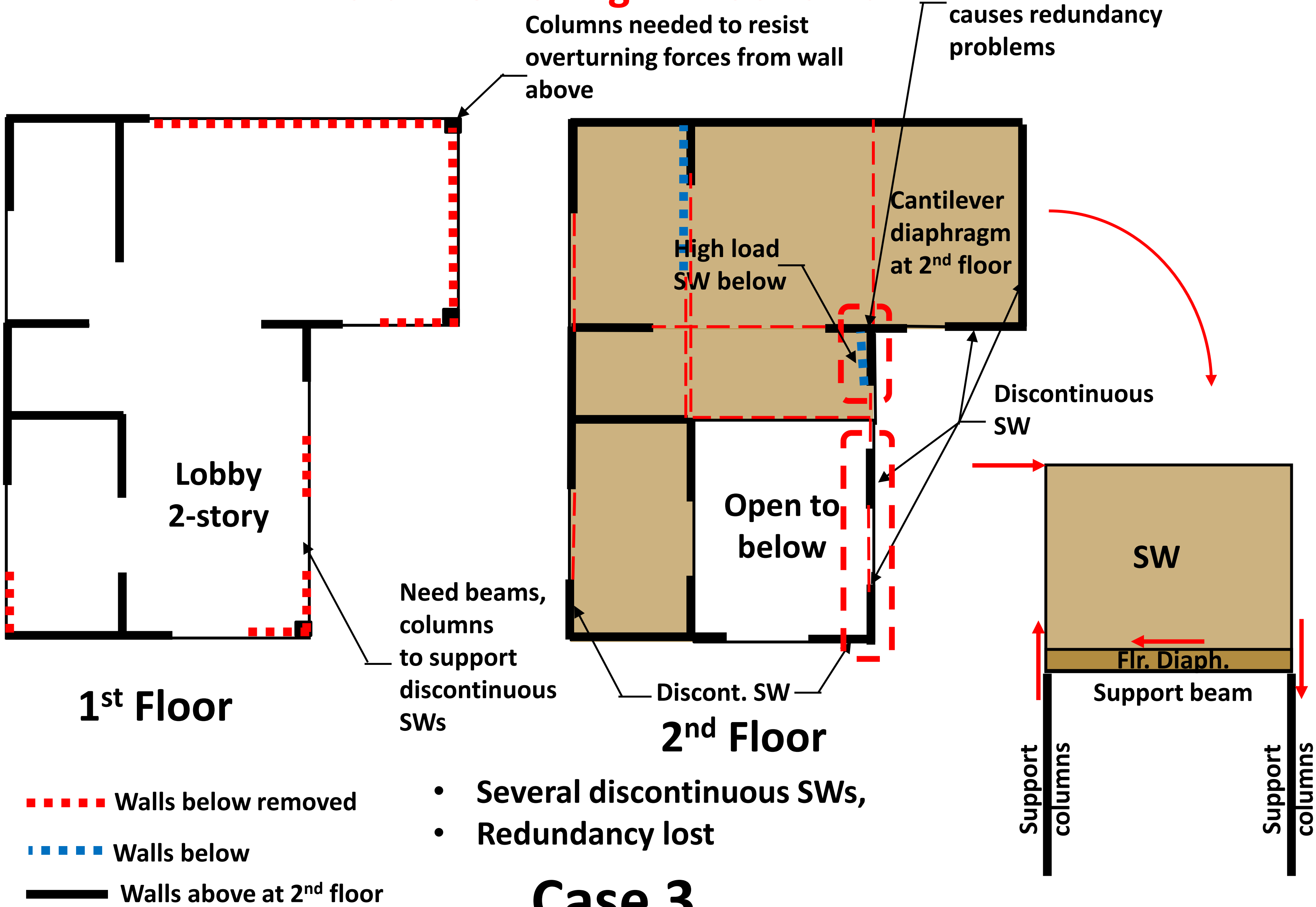
Walls below

Walls above at 2nd floor

Case 2

Example Plan 2-story

Start removing 1st floor SWs

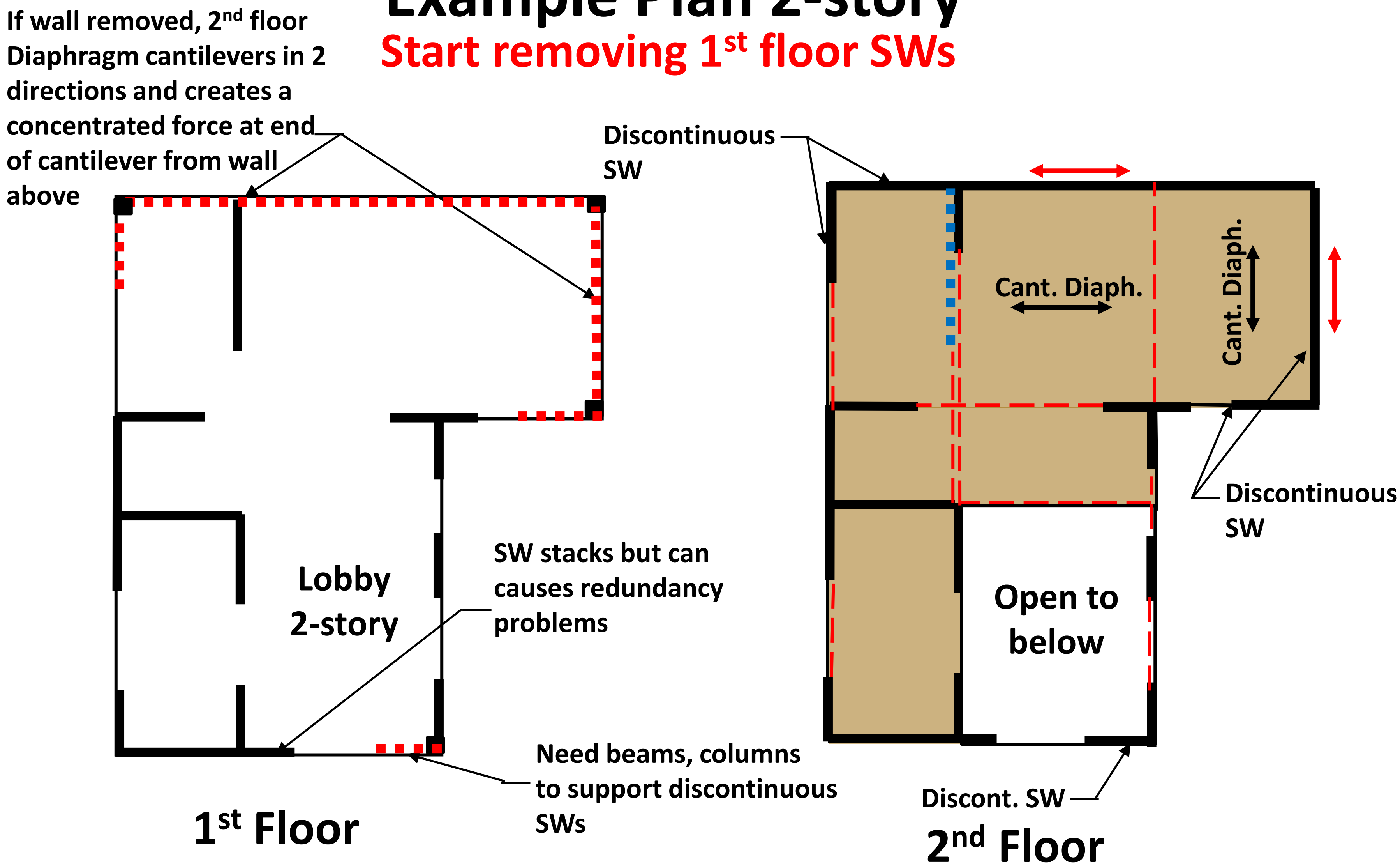


- Several discontinuous SWs,
- Redundancy lost

Case 3

Example Plan 2-story

Start removing 1st floor SWs



- Several discontinuous SWs,
- Redundancy lost
- cantilever diaphragm at 2nd floor

Walls below removed

Walls below

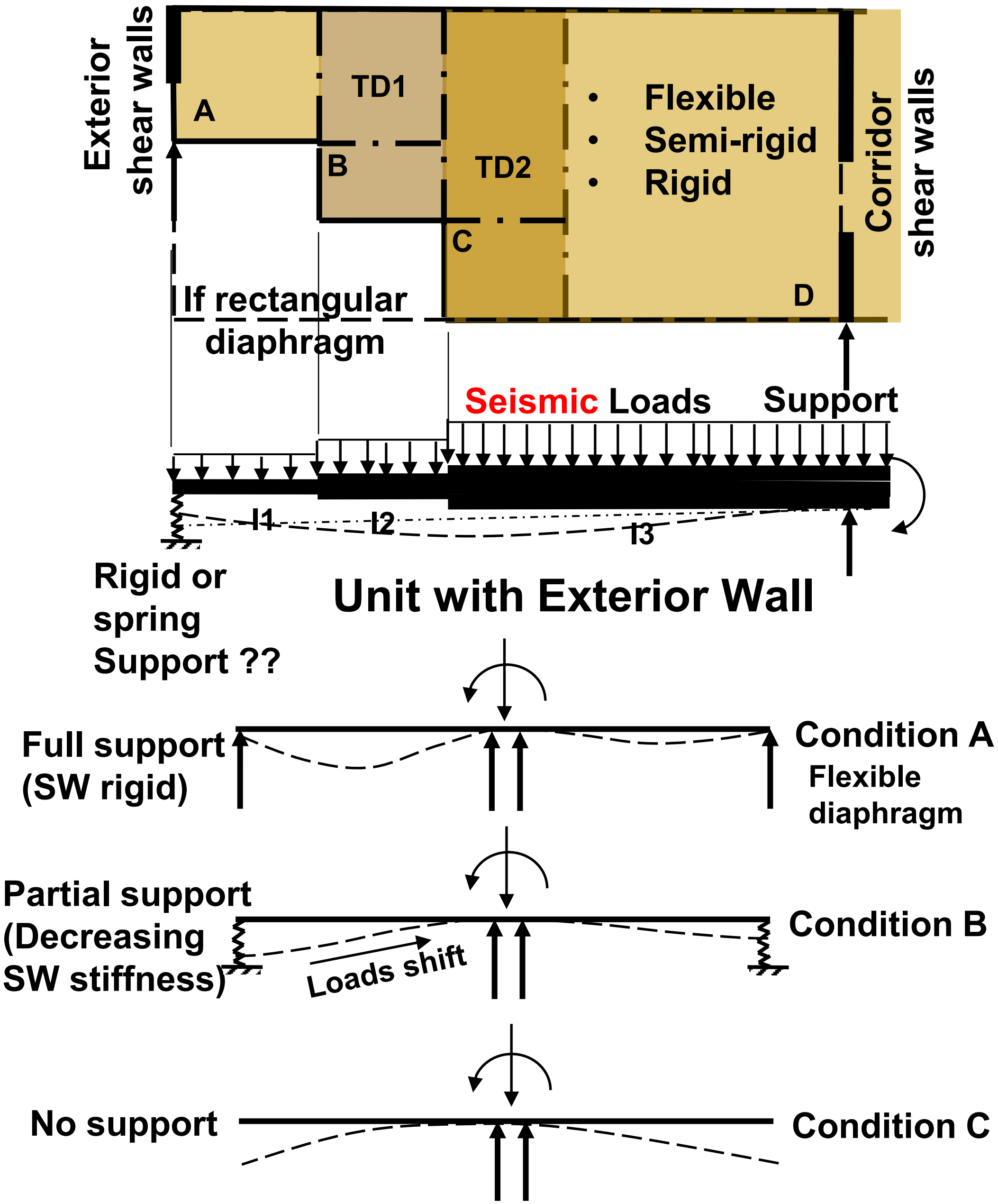
Walls above at 2nd floor

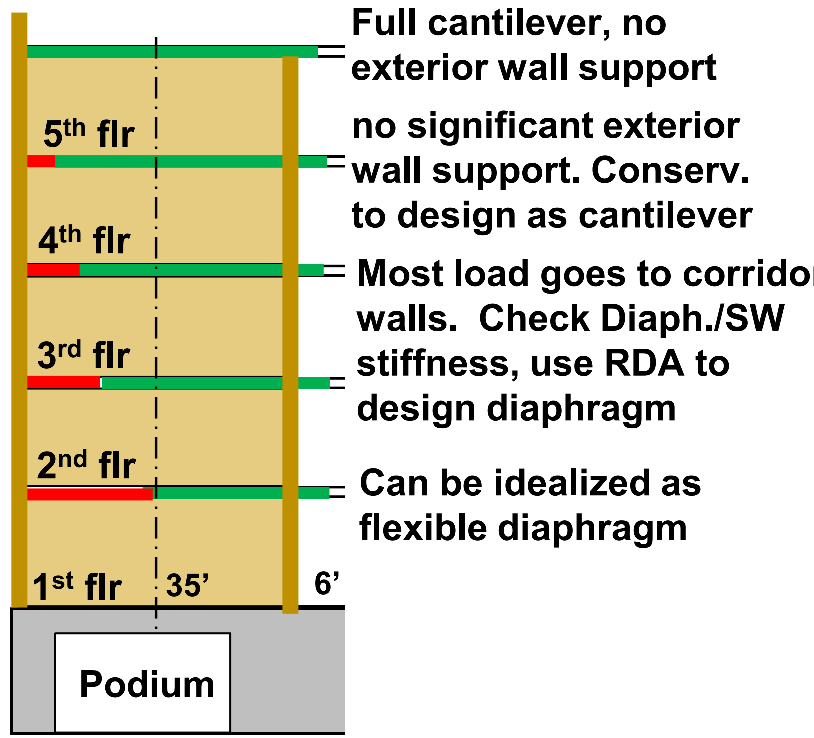
Case 4

Presentation Contents

- Basic lateral forces
- Basic types of lateral resisting systems
- Structural irregularities-How buildings respond to lateral forces
    - Horizontal Irregularities
    - Vertical Irregularities
- **Other structural issues**
    - Redundancy- 2-Story Example
    - **Diaphragm, shear wall stiffness**

Force Distribution Due to Diaphragm/SW stiffness





Conclusions and Final Thoughts

1. Having a basic understanding of how buildings respond to lateral forces (wind and seismic) can help with the development of the architectural plans and communication with engineers.
2. Provide opportunities for a reasonable lateral resisting system and needed changes.
3. Be open to changes, slight modifications.
4. Coordinate early on with the design team so that modifications can be made (sooner than later).
5. Special Considerations:
   - A lack of redundancy or minimal lateral resisting elements can affect building drift which would require increasing the stiffness of the lateral resisting elements, increasing costs.
   - Discontinuous shear walls can impact the design, cost and constructability of diaphragms and the supporting elements.
   - Building offsets and cantilevers can cause building irregularities and/or create difficult lateral load paths.
   - Simple straight line load paths are cheaper and easier to construct than discontinuous load paths.

QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

Terry Malone, PE, SE
WoodWorks – Wood Products Council
Senior Technical Director, Project Resources and Solutions Division
Prescott Valley, Arizona, P 928.775.9119, C 520-822-7773 |
terrym@woodworks.org | woodworks.org

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