Lateral 101 for Architects

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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

  ![ 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

Other Factors

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

Degree of complexity = Greater cost
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

CH. 26 - 30

ASCE 7-22

Minimum Design Loads and Associated Criteria for Buildings and Other Structures
**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
Diaphragms
Span Between Shear walls
Wind into Lines of Resistance (Shear walls) as Distributed Loads

Pressure increases with height

Application Multi-Story
Seismic Forces

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

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

ASCE 7-22
CH. 11 & 12
Simple Box System

Application Single Story

(Relationship between ground movement and response of the mass of the structure)
Diaphragms
Span Between Shear walls
Seismic into Lines of Resistance (Shear walls)

Application Multi-Story
Diaphragms
Span Between Shear walls
Seismic into Lines of Resistance (Shear walls)

Application Multi-Story

Unit strip load to floor or roof

Drift

First (primary) mode shape

(ELF procedure)

Actual displaced shape caused by an irregularity

Ground movement

Soft-Story Irregularity shown

Base shear = \( V = C_s W = \frac{S_{DS}W}{R} \)

Short period

The lower the response factor the higher the base shear. Based on ductility.

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)

Rigid diaphragms

Moment Frames

Braced Frame

Ground motion

Inertia forces

Heavy masses

1st Mode

2nd Mode

Ground moves

Starts to respond in opposite direction

Modal Analysis
Different floors responding in different directions

Uniform torsion

Opposing torsion

Vertial Accel.

3rd Mode

Uniform rotation

Rotating in opposite directions

Higher modes
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Shear Wall Configurations

- Single story
- Multi-story

Based on ductility

\[ R_{GWB} = 2, \ R_{WSP} = 6.5 \]
Braced Frames/Trusses

Timber Braced Frame

Steel Braced Frame

Timber Truss - Braced Frame

R = 1, 1.5

R = 3.25 to 8

Source: StructurLam
Hybrid Wood/Steel Braced Frames

R=3.25 to 8
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
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Why Have the Codes Changed?

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

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

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

Research, Testing

Seismic
(soft story)
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 – *Horizontal 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.
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

The more wall rotation, the less stiff it becomes

Requires elements supporting discontinuous shear walls or frames to be designed with the over-strength factor.
Type 5 **Horizontal Non-parallel System Irregularity**

Requirements varies on SDC B, 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.
Type 2-Geometric **Vertical** 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

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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.
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

**Section 1**

- 1st flr. SWs
- 2nd flr. SWs
- 3rd flr. SWs
- Collector

**Plan**

- Dis-cont. SWs
- SW line offset out
- Horizontal offset at roof diaphragm. Dis-cont. chord

**Section 2**

- SW
- Bm/collector
- 3rd flr
- Ends of wall supported by joists
- 2nd flr
- Joist/collector

**Section 3**

- SW
- SW line offset in

- Vertical deflection of floor framing member adds to wall rotation. Changes wall stiff.

**ASCE 7-16 12.3.3.3**

- SW1
- SW2
- SW3

**Elev.**

- Stairs
- Discont SWs
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Redundancy

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

Case 1
- Min. 2 walls
- Reduction in story strength < 35% by removing 1 wall

Case 2

Case 3

Case 4
- Open front
- Removed or failed wall
- Stability now taken by sidewalls

V

No Redundancy
Example Plan 2-story

1st Floor
- Lobby 2-story

2nd Floor
- Open to below
- SW line offset in
- Need collector for re-entrant corner
- Need collector to tie SWs together
- Need collector for diaphragm edge support and act as chord

Case 1
- All SWs stack,
- Very redundant,
- Simple rectangular diaphragms

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Walls below
Walls above at 2nd floor
Example Plan 2-story

Lobby 2-story

1st Floor

2nd Floor

Diaphragm Layout N/S

Diaph. 1

Diaph. 2

Diaph. 3

Walls below

Walls above at 2nd floor

Case 1
Example Plan 2-story

1st Floor

Lobby 2-story

2nd Floor

Diaphragm Layout E/W

Loads

Diaph. 1

Diaph. 2

Diaph. 3

SW line offset in

Open to below

Walls below

Walls above at 2nd floor

Case 1
Example Plan 2-story

Removing 2nd floor SWs

1st Floor

- Lobby 2-story

2nd Floor

- Open to below

SW above removed. Roof diaphragm cantilevers

- Cantilever diaphragm at roof

No changes in SW locations

Case 2

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

Walls above removed

Walls below

Walls above at 2nd floor
Example Plan 2-story

Start removing 1st floor SWs

Columns needed to resist overturning forces from wall above

Need beams, columns to support discontinuous SWs

High load SW below

Discontinuous SW

Open to below

Cantilever diaphragm at 2nd floor

SW stacks but is high-load and causes redundancy problems

• Several discontinuous SWs,
• Redundancy lost

Case 3
Example Plan 2-story

Start removing 1st floor SWs

If wall removed, 2nd floor
Diaphragm cantilevers in 2 directions and creates a concentrated force at end of cantilever from wall above

1st Floor

Lobby 2-story

2nd Floor

Open to below

Walls below removed

Walls below

Walls above at 2nd floor

• Several discontinuous SWs,
• Redundancy lost
• Cantilever diaphragm at 2nd floor

Case 4
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Force Distribution Due to Diaphragm/SW stiffness

Unit with Exterior Wall

- Full support (SW rigid)
- Partial support (Decreasing SW stiffness)
- No support

Seismic Loads Support

Rigid or spring Support??

Exterior shear walls

Condition A

Flexible diaphragm

Condition B

Loads shift

Condition C

Full cantilever, no exterior wall support
No significant exterior wall support. Conserv. to design as cantilever
Most load goes to corridor walls. Check Diaph./SW stiffness, use RDA to design diaphragm
Can be idealized as flexible diaphragm
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.
This concludes The American Institute of Architects Continuing Education Systems Course.

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