Common Challenges in Wood Lateral System Layouts

Crescent Terminus
Lord Aeck Sargent
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WoodWorks
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Mid-rise
Low-rise
Creative structures are becoming increasingly common to differentiate projects in the highly competitive commercial and multi-family construction markets. However, their aesthetically pleasing shapes can create challenging lateral load paths and structural irregularities that are difficult to define and resolve. This presentation will explore lateral system layout challenges that often occur during the schematic design of wood framed buildings.

Topics will include cantilever diaphragm design, impacts of large openings at elevators and stairs, discontinuous shearwalls, relative stiffness issues between shear walls and diaphragms, vertical and horizontal offsets in lateral force-resisting systems, and combinations of different lateral systems (such as masonry shearwalls and wood sheathed shearwalls). Actual design examples will be included throughout the presentation to give real world context for these common challenges.
Typical Review Process

- Overlay shear walls from floor to floor to see if they stack or are discontinuous.
- Determine the diaphragm boundary, including the effects of openings and location of supporting walls (most important task).
- Identify irregularities and load path challenges (offset walls and/or diaphragms, discontinuous chords, etc.).
- Create comments and possible solutions to the issues for consideration.
- Zoom meeting optional.
Example 1 - Stairwells and elevator Shafts

- **Stairwell 1st Floor**: In-plane, not stacked, no discontinuity
- **Stairwell 2nd Floor**: Intermediate offset in diaphragm
- **Unsupported wall**: Should not be a SW
- **Floor framing**: In-plane, not stacked, no discontinuity
- **Horizontal offset in diaphragm**: dis-continuous chord
- **Collector**: Unsupported wall. Should not be a SW
- **1st flr. SWs**: Unsupported wall. Should not be a SW
- **2nd flr. SWs**: In-plane, not stacked, no discontinuity
Example 1 - Possible solutions

First determine if opening is small enough to ignore. Can ignore if all 4 items are met:

Opening size criteria
1. 0.15W diaph.
2. 0.15L diaph.
3. Edge dist. 3x
4. A.R all 4 sides

Solution: Since there is no opportunity to create SWs below, use TD (No new members)

No diaphragm shear acting on member. Can’t be part of diaphragm chord
Example 2 - Stairwells and Cantilever Diaphragms

- **1st Floor (NTS)**
  - **Stairwell locations**
  - **Garage**
  - **Balcony Above**
  - **Non-shear walls. Option-moment frames or other approved systems. (Owner did not want them)**
  - **Wall locations of stories above**
  - **Horizontally offset SWs, vertically discontinuous above**

- **2nd flr. SWs**
- **3rd flr. SWs**
- **Collector**

- **Original layout did not use these available SWs**

- **20' to 24'**

- **Additional notes:**
  - If no interior SWs (Exceeds 35' limit)
Example 2-Cont.

Large offset in diaphragm (dis-continuous chord) unless shears and chord continuity can be created

Dis-continuous SWs. Causes conc. force at end of cantilever and must comply with 12.3.3.3.

Dis-continuous SWs. Creates transfer force in diaphragm-12.10.1.1, \( \Omega_o \).

This diaphragm is cantilevered unless connected into adjacent diaphragm by collector

Large offset in diaphragm (dis-continuous chord)
Example 2-Cont.

Large offset in diaphragm (Sub-chord)

Large pop-up section open at roof (Typ.)

Dis-continuous SWs. Causes conc. force at end of cantilever.

Discontinuous SWs at 2nd floor

Dis-continuous SWs at 3rd floor.

Creates transfer force in diaphragm-12.10.1.1, $\Omega_0$.

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

3rd Floor
(NTS)

This pop-up is open to below and will create an offset in the diaphragm at the roof
This is an open front structure. No shear walls.

Fences, not walls.

Hard spots.

Vertical Offset and Cantilever Diaphragms
Example 3- Diaphragm Multiple Horizontal and Vertical Offsets

- Load path into high diaphragm
- Transfer of dis-continuous chord forces-significant nail slip in transfer assembly??
- Alternate solution using HT trusses if open roof framing
- Standard bottom chord truss, rafters, or HT truss. Each type has its own unique problems and solutions.

Section 1

- Load path into high diaphragm
- Chord Location
- Shear transfer?

Section 2

- Multiple trusses to resist downward force
- Shear panel system if closed ceiling only
- Alternate solution using HT trusses if open roof framing

Single Story

Chord

Collector typ.

Ridge

TD

Load path into high diaphragm

All glass entry

Chord

Large opening in diaphragm

Loads

Chord

All glass entry

Chord

Ridge

Ridge

Chord

Multiple trusses to resist downward force

Truss at ridge

Chord

Location
Example 4 - Large Openings and Pop-up Roof

- Planned SW
- Roof access hatch
- GL Bm.
- Open
- GL Bm.
- GL Bm.
- Open
- GL Bm.

Significant unbraced length

Steel tube moment frame or wood diagonal braces for stability

Blue columns do not go down to foundation. Stop at top of beam

Roof access hatch

Large opening. Requires a very special design

Possible approaches

(Plan rotated 90 degrees)
Example 5
Large Cantilever Diaphragm, Stairwells, and Diaphragm Horizontal Offset
Example 6 - Multiple cantilever Diaphragms and Stairwell-Stiffness issues

Ground Floor

- Glass typ.
- SW (Typ.)
- Outside Dining
- SW
- SW

Dining Area

Mezzanine / Roof

- Glass typ.
- SW
- SW
- SW
- SW
- CLT roof
- Open Below
- Open Below
- Possible SW Depending on A.R. of wall
- No wall above Mezzanine (Open)

Not initially designated as a shear wall

Possible SW Depending on A.R. of wall
Seismic Response

Example 6-Cont.

- Mezzanine rotation resisted by either column or SW
- Cantilever mezzanine diaphragm
- Mezzanine shear is distributed into collector then into the SW below
- Roof beams/collectors

SW

Mez.

C.M

C.R

Stairs

SW (Typ.)
Example 6-Cont.

Mezzanine rotation resisted by either column or SW

Mezzanine and CLT roof diaphragms can rotate in opposite directions at higher modes

Cantilever mezzanine diaphragm

Mezzanine shear is distributed into collector then into the SW

Roof beams/collectors

Seismic Response
Example 7 - Vertically Offset Shear Walls and Cantilever Diaphragm

Section 1

Dis-cont. SWs

SW line offset out

Horizontal offset at roof diaphragm. Dis-cont. chord

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

Loads

Section 2

SW line offset in

SW3

Ends of wall supported by joists

2nd flr

2nd flr

Bm/collector

3rd flr

SW

Joist/collector

SW2

SW

3rd flr

2nd flr

Section 3

SW1

3rd flr

2nd flr

Elev.

Cantilever Diaphragm at 2nd floor

SW 2

Transfer force to diaphragm

Dis-cont. SW

2

1

3

Dis-cont. SWs

SW 1

SW 2

SW 3

Stairs

Stairs

Casements

Dis-cont. SWs

Plan

1st flr. SWs

2nd flr. SWs

3rd flr. SWs

Collector

SW 1

SW 2

SW 3

ASCE 7-16

12.3.3.3

Vertical deflection

1st flr. SWs

2nd flr. SWs

3rd flr. SWs

Collector

Vertical deflection

of floor framing
member adds to wall rotation.
Changes wall stiff.
Stacked and Offset SWs
Example 8 - In-plane Offset Shear Walls

Offset Shear Walls

Non-Discontinuous SWs

Discontinuous SWs

Upper SWs are dis-cont. at these locations

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12.3.3.3
12.3.1 Diaphragm Flexibility: The structural analysis shall consider the relative stiffnesses of diaphragms and the vertical elements of the seismic force-resisting system.

Flexible, Semi-rigid, or Rigid diaphragms?

12.3.1.1 Allows wood diaphragms to be idealized as flexible provided:

1. Vertical elements are stiffer than diaphragm (Steel frames, masonry or concrete).
2. One- and two-family dwellings
3. Light-framed construction where (both):
   a. Non-structural 1 ½” conc. topping over WSP diaphragms.
   b. Each line of vertical elements in of SFRS complies with allowable story drift.

NEHRP Seismic Design Technical Brief No.10, Section 6.3 and ASCE 7-16 commentary: Most light-framed wood diaphragms are semi-rigid.
Combined lateral system issues—CMU/WSP, GWB/WSP, steel frames/wood SWs

- 12.2.2-Combinations in different orthogonal directions- use $R$, $\Omega_o$, $C_d$ for each direction

- 12.2.3-Combinations in same direction- use lowest $R$, $\Omega_o$, $C_d$

  Difference in base shear
  
  $R_{wsp} = 6.5$
  
  $R_{gwb} = 2 = 3.25 \times \Omega_o$  Seismic force can be larger than wind force
  
  $R_{ord \, cmu} = 2 = 3.25 \times \Omega_o$
  
  $R_{int \, cmu} = 3.5 = 1.88 \times \Omega_o$
  
  $R_{spec \, cmu} = 5 = 1.3 \times \Omega_o$

- 12.2.3.1-Vertical combinations:
  
  1. If lower sys. has lowest $R$, $\Omega_o$, $C_d$, use upper $R$, $\Omega_o$, $C_d$ for upper sys. and lower $R$, $\Omega_o$, $C_d$ for lower syst. Multiply lower sys. by ratio of upper/lower.
  
  2. If upper sys. has lower $R$, $\Omega_o$, $C_d$, use upper $R$, $\Omega_o$, $C_d$ for both.

- 12.2.3.3-Horizontal combinations:

  Use lowest $R$ for that direction, $\Omega_o$, and $C_d$ shall be consistent with $R$ value used.

  Exception: Least $R$ value in each independent line of LFR if all three conditions are met:
  
  1. In Risk Category I or II.
  
  2. 2-stories or less AGP.
  
  3. Use of light-framed construction or flexible diaphragm.

  $R$ used for design of the diaphragm shall not be greater than least $R$ value used in that direction.
This Concludes the Presentation on:

Common Challenges in Wood Lateral System Layouts

Q & A

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Thank You

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