



Combining Systems, Irregularities, Redundancy and Vertical Seismic Forces

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Presentation Topics

Dumb things Brent wishes the code didn't let us do:

- Combinations of Lateral Systems 12.2.2 & 12.2.3
- Structural Irregularities 12.3.2 & 12.3.3
- Redundancy 12.3.4
- Vertical Seismic Load Effects 12.4.2


(Except where noted, all references are from ASCE 7-16)



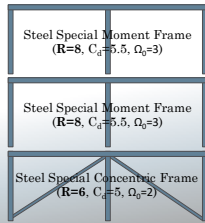


Combinations of Lateral Systems

- Combinations in Different Directions: Allowed. Use R , C_d and Ω_0 for each system in it's respective direction.
- Combinations in the Same Direction:
 - Vertical Combinations 12.2.3.1
 - Higher R above
 - Higher R below
 - Horizontal Combinations 12.2.3.3
 - Dual systems 12.2.5.1
 - Other systems
 - Systems on different lines of resistance
 - Two-Stage Analysis 12.2.3.2



Vertical Combos – Higher R Above




Use- (R=8, $C_d=5.5$, $\Omega_o=3$)

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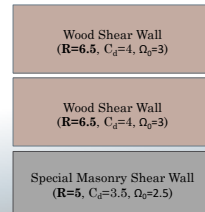
Multiply reactions at interface by $8 / 6 = 1.33$ (Before using them in Load Combinations)

Use- (R=6, $C_d=5$, $\Omega_o=2$)

Elevation



Vertical Combos – Higher R Above




Use- (R=6.5, $C_d=4$, $\Omega_o=3$)

Use- (R=6.5, $C_d=4$, $\Omega_o=3$)

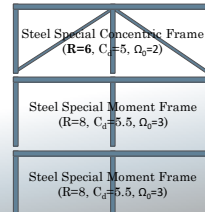
Multiply reactions at interface by $8 / 6 = 1.33$ (Before using them in Load Combinations)

Use- (R=5, $C_d=3.5$, $\Omega_o=2.5$)

Elevation



Vertical Combos – Lower R Above




Use- (R=6, $C_d=5$, $\Omega_o=2$)

Exceptions:

1. Rooftop structures up to 2 stories and 10% of total structure weight.
2. Other supported structures up to 10% of total structure weight.
3. Detached one- and two-family light framed dwellings.

Elevation



Vertical Combos – Lower R Above

Elevation

Use- ($R=4$, $C_d=3.5$, $\Omega_0=2$)

Exceptions:

1. Rooftop structures up to 2 stories and 10% of total structure weight.
2. Other supported structures up to 10% of total structure weight.
3. Detached one- and two-family light framed dwellings.

Horizontal Combos – Dual Systems

- Moment Frames combined with Steel, Concrete or Masonry Braced Frames/Shear Walls
- Moment Frames must be capable of resisting 25% of the prescribed seismic forces.
- Use R , C_d and Ω_0 specified in the Dual System section of Table 12.2-1
- Distribute forces based on stiffness.

Elevation (In-Line)

Plan (Offset)

Horizontal Combos – Other Systems

- Use lower R value and corresponding C_d and Ω_0 values.
- Distribute forces based on stiffness.

Elevation (In-Line)

Plan (Offset)

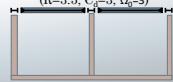
Use- ($R=2.5$, $C_d=2.5$, $\Omega_0=1.25$)

Horizontal Combos – Independent Lines of Resistance

It is permitted to use different R values on each line of resistance if the following are true:

1. Structure is Risk Category I or II.
2. Max two stories above grade.
3. Light-frame construction or flexible diaphragms.

Steel Ordinary Moment Frame
($R=3.5$, $C_d=3$, $\Omega_p=3$)



Wood Shear Wall
($R=6.5$, $C_d=4$, $\Omega_p=3$)

Plan View

Use- ($R=3.5$, $C_d=3$, $\Omega_p=3$)

Flexible Wood Diaphragm

Use- ($R=6.5$, $C_d=4$, $\Omega_p=3$)



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Vertical Combos – Two-Stage Analysis

- Typically used when light-framing is sitting on a concrete podium structure.
- Lower stiffness must be 10x the upper stiffness. (Stiffness = Shear/Drift)
- Period of the whole limited to 1.1x the period of the upper.
- Upper structure can be designed as if the lower was the structure's base.
- Lower is designed including reactions from the upper with the reactions having been multiplied by

$$\frac{R_{upper}/D_{upper}}{R_{lower}/D_{upper}}$$



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Structural Irregularities

- Horizontal Irregularities 12.3.2.1 (Table 12.3-2)
- Vertical Irregularities 12.3.2.2 (Table 12.3-3)
- I will generally only address SDC D, E or F in these slides. Some requirements are removed for SDC B and C.

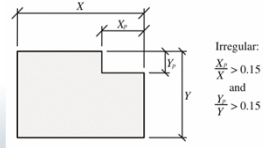


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Horizontal Irregularity – Type 2

Code Penalties-

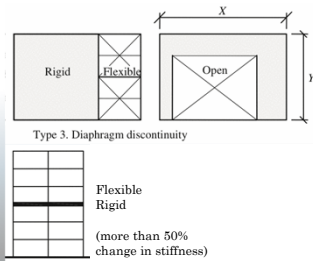
- 25% increase in diaphragm/collector connection forces.
- E.L.F. is not allowed if structure exceeds 160 ft in height.



Horizontal Irregularity – Type 3

Code Penalties-

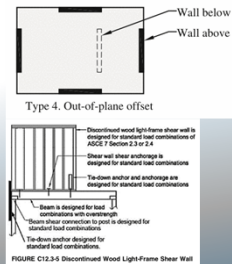
- 25% increase in diaphragm/collector connection forces.
- E.L.F. is not allowed if structure exceeds 160 ft in height.



Horizontal Irregularity – Type 4

Code Penalties-


- Use Q_u on all gravity elements supporting the wall/frame above.
- Use Q_u on the connections to the gravity elements if the above wall/frame was required to be designed using Q_u (i.e. column in braced frame).
- 25% increase in diaphragm/collector connection forces.
- 3D analysis model is required unless all diaphragms are flexible.
- E.L.F. is not allowed if structure exceeds 160 ft in height.
- Accidental torsion required in time-history analysis.



Horizontal Irregularity – Type 5

Code Penalties-

- Have to either-
 - Simultaneously apply 100% of load in one direction with 30% of the load in the orthogonal direction. Or-
 - Perform 3D response time-history analysis with simultaneous orthogonal ground motion pairs (related to fault normal/parallel for near-fault sites.)
- 3D analysis model is required.
- E.L.F. is not allowed if structure exceeds 160 ft in height.
- Accidental torsion required in time-history analysis.



Type 5. Nonparallel system

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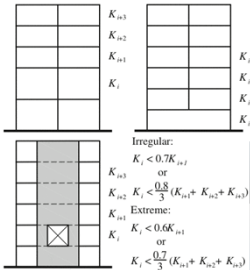
Vertical Irregularity – Type 1a & 2b

Only applies if the story drift of any story is more than 130% of an adjacent story drift-not including the roof.

Doesn't apply to single story structures or two-story structures assigned to SDC B, C or D

Code Penalties-

- 1b is prohibited in SDC E and F ($S_1 \geq 0.75$).
- E.L.F. prohibited unless light-framed or two-story and Risk Category I or II.



Type 1. Stiffness — Soft Story

Irregular:

$$K_i < 0.7K_{i+2}$$

or

$$K_{i+2} < \frac{0.8}{3} (K_{i+1} + K_{i+2} + K_{i+3})$$

Extreme:

$$K_i < 0.6K_{i+1}$$

or

$$K_i < \frac{0.7}{3} (K_{i+1} + K_{i+2} + K_{i+3})$$

Type 2. Weight (Mass)

Irregular:

$$M_i > 1.5M_{i+1}$$

or

$$M_i > 1.5M_{i+2}$$

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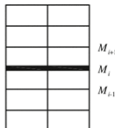
Vertical Irregularity – Type 2

Only applies if the story drift of any story is more than 130% of an adjacent story drift-not including the roof.

Doesn't apply to single story structures or two-story structures assigned to SDC B, C or D

Code Penalties-

- E.L.F. prohibited unless light-framed or two-story and Risk Category I or II.



Type 2. Weight (Mass)

Irregular:

$$M_i > 1.5M_{i+1}$$

or

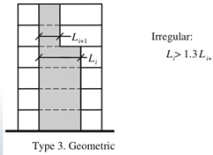
$$M_i > 1.5M_{i+2}$$

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Vertical Irregularity – Type 3

Code Penalties-

- E.L.F. prohibited unless light-framed or two-story and Risk Category I or II.



Type 3. Geometric



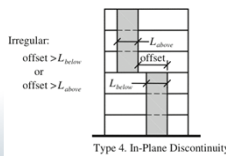
Vertical Irregularity – Type 4

- Use Ω_0 on all gravity elements supporting the wall/frame above.

- Use Ω_0 on the connections to the gravity elements if the above wall/frame was required to be designed using Ω_0 (i.e. column in braced frame).

- 25% increase in diaphragm/collector connection forces.

- E.L.F. is not allowed if structure exceeds 160 ft in height.



Type 4. In-Plane Discontinuity



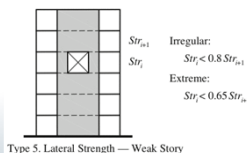
Vertical Irregularity – Type 5a & 5b

Code Penalties-

- 5a is prohibited in SDC E and F ($S_1 \geq 0.75$).

- 5b is prohibited in SDC D. (limited to 2 stories in SDC B and C, or could be designed with Ω_0).

- E.L.F. is not allowed if structure exceeds 160 ft in height.




Type 5. Lateral Strength - Weak Story



Structural Redundancy

Calculation Process-


- $\rho = 1$ for buildings when-
 - SDC B&C
 - Drift and P-delta effects
 - Load combinations using Ω_D .
 - Diaphragm loads from 12.10.1.1
 - Out-of-plane wall/anchorage loads from 12.11
- Otherwise, a redundancy factor, ρ , is calculated for each orthogonal direction and equals 1.3 unless the conditions for Table 12.3-3 are met for each story resisting more than 35% of the base shear.



Structural Redundancy

Process -

1. Modify the building as follows based on the LFRS system to create the worst condition. For-
 - **Braced Frames** - eliminate a brace/brace connection
 - **Moment Frames** - pin both ends of any one moment frame beam
 - **Cantilever Columns** - pin base of one of the columns
 - **Shear Walls** - remove either a wall or pier with a height/width ratio greater than 1.0 (tall and skinny).
(Hint - Start with the element taking the most force.)
2. $\rho = 1.3$ if-
 - The story strength is reduced by more than 33% or-
 - The modified structure has an extreme torsional irregularity (Horizontal Irregularity Type 1b)



Redundancy

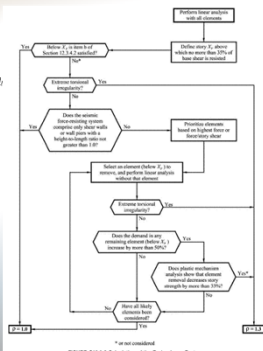




FIGURE 610-3M Calculation of the Redundancy Factor, ρ




Structural Redundancy

Why is it required?

- R-Value is based on a minimum level of redundancy.
- Because structures are redundant, we can design for lower forces.
- Spaghetti example.







Vertical Seismic Load Effects

- Earthquakes waves are not just lateral. They move up and down too. The situation is worsened at near-fault sites.
 - Near-fault sites.
- Example of 6.1M Christchurch Earthquake.
 - Eyewitnesses saw people get thrown in the air. (Similar reports in Magna.)
 - 1.0g recorded vertical ground accelerations.
- Normal faults like the Wasatch may create higher vertical accelerations than strike-slip faults.
- In ASCE 7-10 the load combinations including E_v were buried in Chapter 12, so it was often overlooked. It was moved to Chapter 2 in ASCE 7-16, so hopefully it won't be missed as often.
- Minimum vertical accelerations on cantilevers. 12.4.4

12.4.4 Minimum Upward Force for Horizontal Cantilevers for Seismic Design Categories D through F. In structures assigned to Seismic Design Category D, E, or F, horizontal cantilever structural members shall be designed for a minimum net upward force of 0.2 times the dead load in addition to the applicable load combinations of Section 12.4.





Questions?

