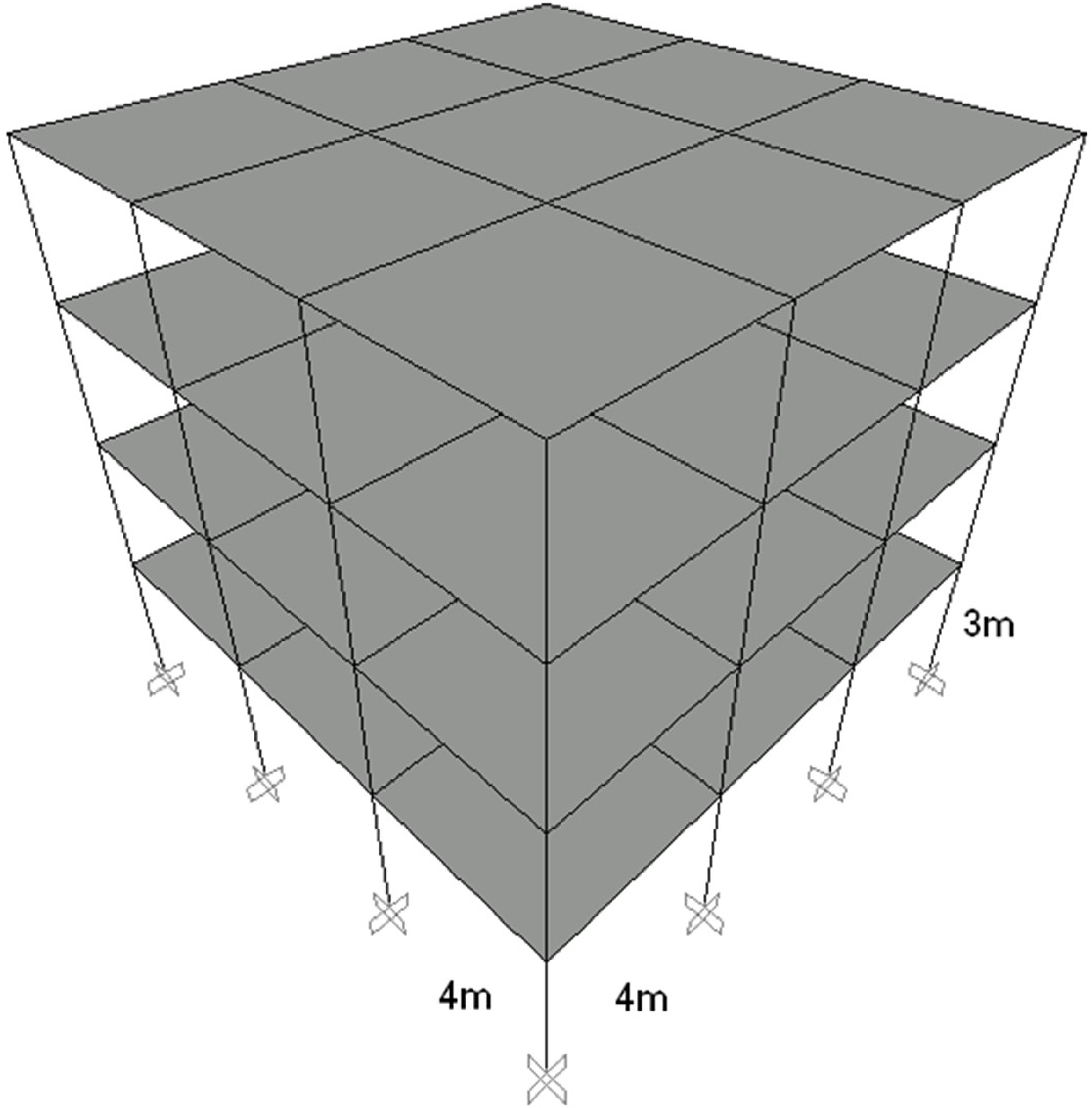
Example

- 4-storey RC slab-beam structure shown with dimensions next page
- 10cm slab, square beams and columns 35cm dims.
- superimposed loads=130kg/m^2, E=35GPa, μ=0.2, ρ=2.5t/m^3
- Find base shear and its distribution across height in x-direction if structure is located in Nablus on rock and is subjected to earthquake using:
- 1. Equivalent lateral force method and IBC2012 response spectrum.
- 2. Response spectrum dynamic analysis method and IBC2012 response spectrum.
- 3. Time history analysis method and structure is subjected to Elcentro earthquake

Example



Example

$$soil - type = B$$

$$PGA = 0.2g \qquad S_S = 0.50 \qquad S_1 = 0.25$$

$$F_a = F_v = 1$$

$$S_{DS} = S_S F_v = 0.50$$

$$S_{D1} = S_1 F_v = 0.25$$

Example

From Tables 11.6-1 and 11.6-2, the seismic design category for risk category 1 and 2 and for Sds=0.5 and Sd1=0.25 is: C or D

Structure with no irregularities and not exceeding 48m in height, ELF is permitted

Example

- $$V = C_s W$$

$$C_s = \frac{S_{D1}}{(R/I)T} \le \frac{S_{DS}}{(R/I)}$$

$$C_s = \frac{0.25}{(3/1).4} = 0.208 \le \frac{0.5}{(3/1)} = 0.167$$

Example

- Area=12*12=144m^2 /floor
- Slab mass=144*0.1*2.5=36t/floor
- Superimposed=144*.13=18.7t/floor
- Beam mass=(8*12)(0.35)(0.25)*2.5=21t/floor
- Column mass=16*3(0.35^2)*2.5=14.7t/floor
- Floor mass=36+18.7+21+14.7=90.4t
- Structure mass=90.4*4=361.6t
- V=0.167*361.6*9.81=592kN
- SAP result=591kN

Example

-

$$F_x = C_{vx} V$$

$$C_{vx} = \frac{W_x h_x^k}{\sum_{i=1}^{n} W_i h_i^k}$$

$$k = 1 : T \leq 0.5 \sec, k = 2 : T > 2.5 \sec$$

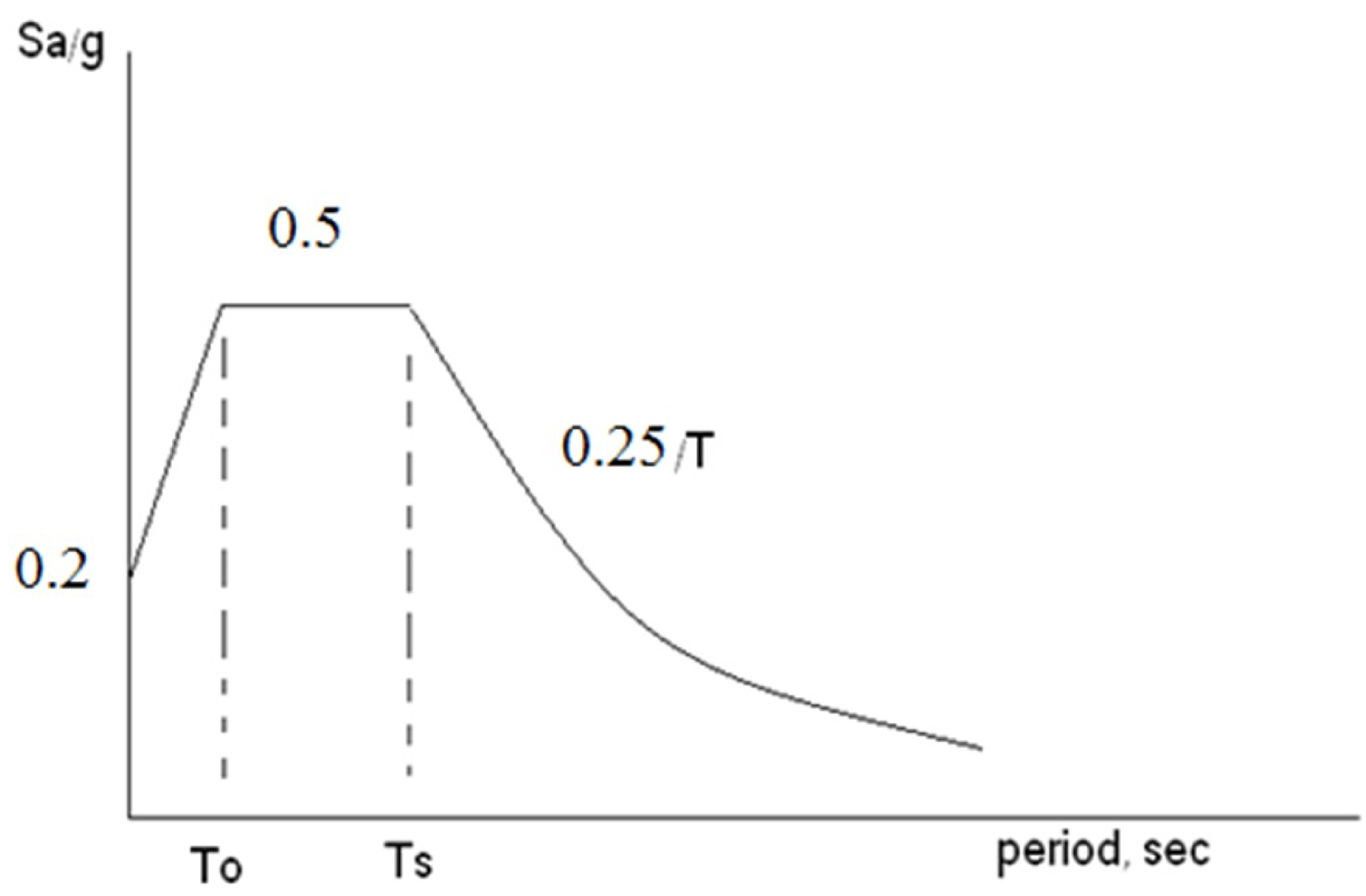
Example

story	W_x	h_x	$W_x h_x$	F_x	V
4	90.4	12	1084	237	
3	90.4	9	814	178	237
2	90.4	6	542	118	415
1	90.4	3	271	59	533
			2711	592	592

Example

Response spectrum

- Dynamic analysis will be performed using the following:
- scale factor=g/(2R/3I)=9.8/2=4.9
- The factor 2/3 is used to counteract the 2/3 reduction in response
- The result is: V=495kN



Example

time history

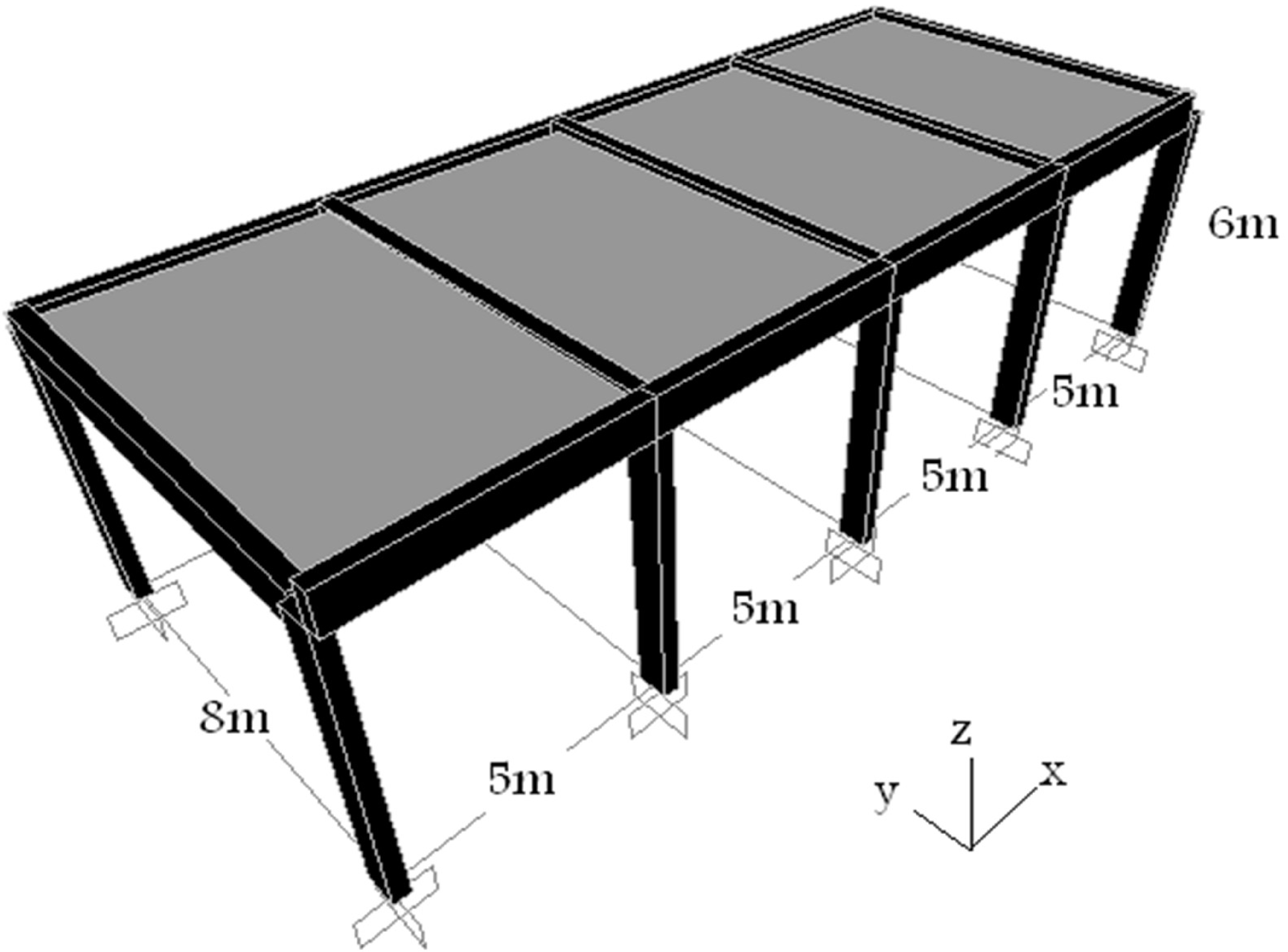
- The earthquake should be modified to suit the location. The PGA= 0.37g for elcentro. Thus multiply by (.2/0.37) for equivalent earthquake.
- Instead of doing nonlinear analysis, we can do linear analysis and use: (R/I) scale factor=0.01*.2/.37R=0.0018, the result will be V=327kN

Earthquake design through a detailed example

A detailed design example

- 1-storey RC slab-beam factory structure: fixed foundations, 4 spans 5m bays in x and a single 8m span in y, 6m elevation
- E=24GPa, μ=0.2, γ=24.5kN/m^3
- Cylinder concrete strength=25MPa, steel yield=420MPa
- 25cm one-way slab, drop beams 30cmX80cm (6cm cover), columns 30X60cm reinforced on two faces.
- superimposed loads=5kN/m^2, live load=9kN/m^2
- Structure in a seismic area zone 4 on rock (soil type B)
- Find base shear and its distribution across frames in y-direction if:
  - structure is composed of ordinary frames
  - structure is composed of intermediate MRF
  - structure is composed of special moment frame
- Design the structure for each case

A detailed design example



Ordinary frame analysis and design by SAP

- According to ACI R10.11.1 use the following modifiers for gross inertia:
  - Beam 0.35
  - Column 0.7
  - One way slab (0.35, 0.035)
- For ordinary frames R=3

Gravity equilibrium checks

- D:
  - Slab=20X8X(0.25X24.5+5)=1780kN
  - Beams=(5X8+2X20)X.55X.3X24.5=323kN
  - Columns=10X6X.3X.6X24.5=265kN
  - Sum=2368kN
- L:
  - R =20X8X9=1440KN

A detailed design example

Lateral equilibrium checks: Equivalent method

$$soil - type = B \qquad S_s = 1$$

$$F_a = F_v = 1 \qquad S_1 = 0.5$$

$$S_{DS} = S_s F_a = 1$$

$$S_{D1} = S_1 F_v = 0.5$$

Modal Analysis $T_y = 0.52 \sec$

$$T = 0.047 H_N^{0.9} = 0.24 \sec$$

A detailed design example

Lateral equilibrium checks

$$C_s = \frac{S_{D1}}{(R/I)T} \le \frac{S_{DS}}{(R/I)}$$

$$C_s = \frac{0.5}{(3/1)\,0.24} = 0.69 \le \frac{1}{(3/1)} = 0.333$$

$$V = C_s W = 0.333 X \;\; 2368 = 789 \text{ kN}$$

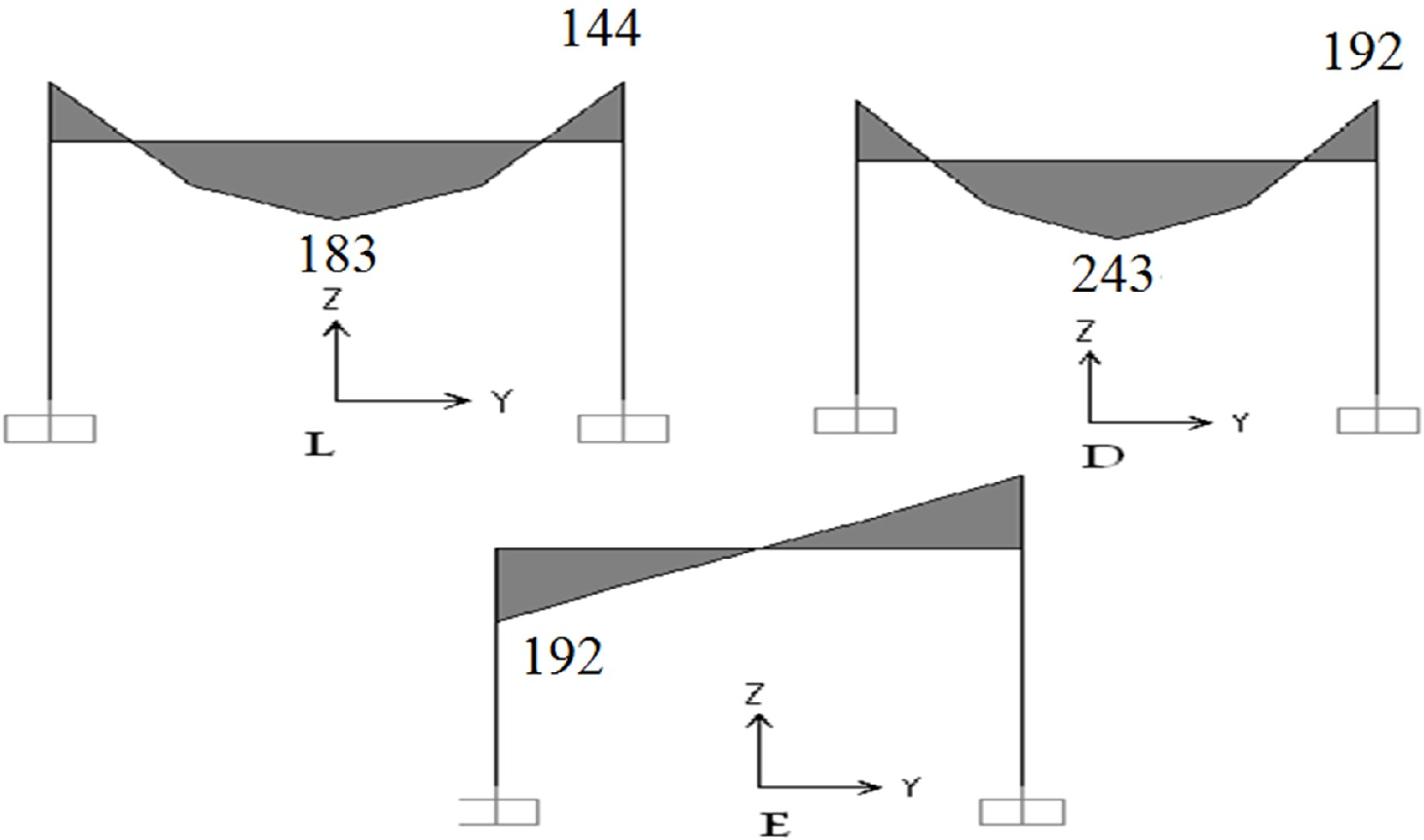
A detailed design example

- SAP results:

OutputCase Text	CaseType Text	GlobalFX KN	GlobalFY KN	GlobalFZ KN	GlobalMX KN-m	GlobalMY KN-m	GlobalMZ KN-m	GlobalX m
DEAD	LinStatic	3.086E-14	-1.776E-14	1568	000000001307	2.274E-13	1.954E-13	0
superimposed	LinStatic	2.065E-14	-8.882E-15	800	000000008669	000000004945	-5.684E-14	0
live	LinStatic	3.642E-14	-5.329E-14	1440	000000001216	000000005571	1.101E-13	0
eqy	LinStatic	000000007221	-789.242	000000001954	4735.4537	000000004334	000000008374	0

A detailed design example

BM in beams in interior middle frame (kN.m)

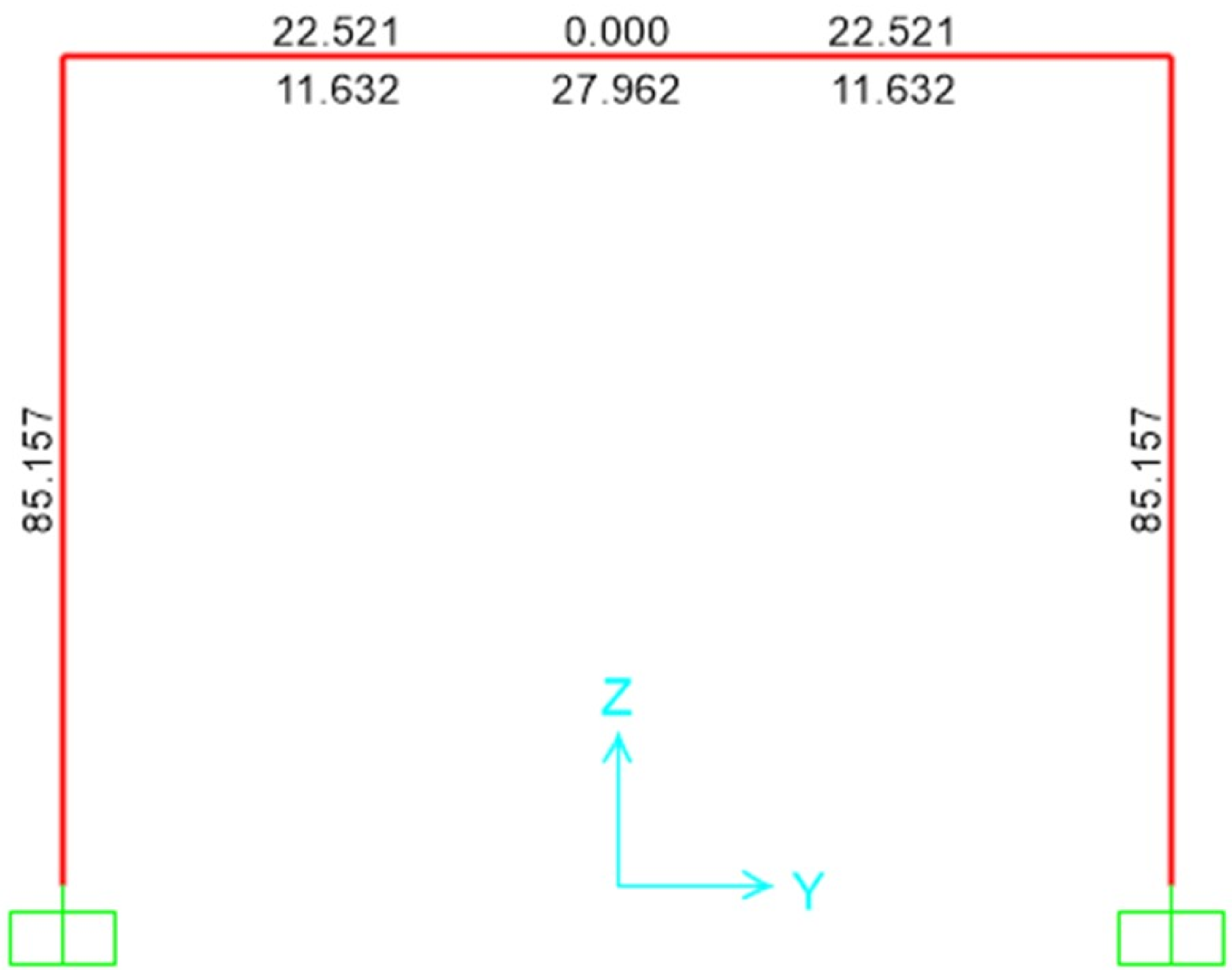


A detailed design example

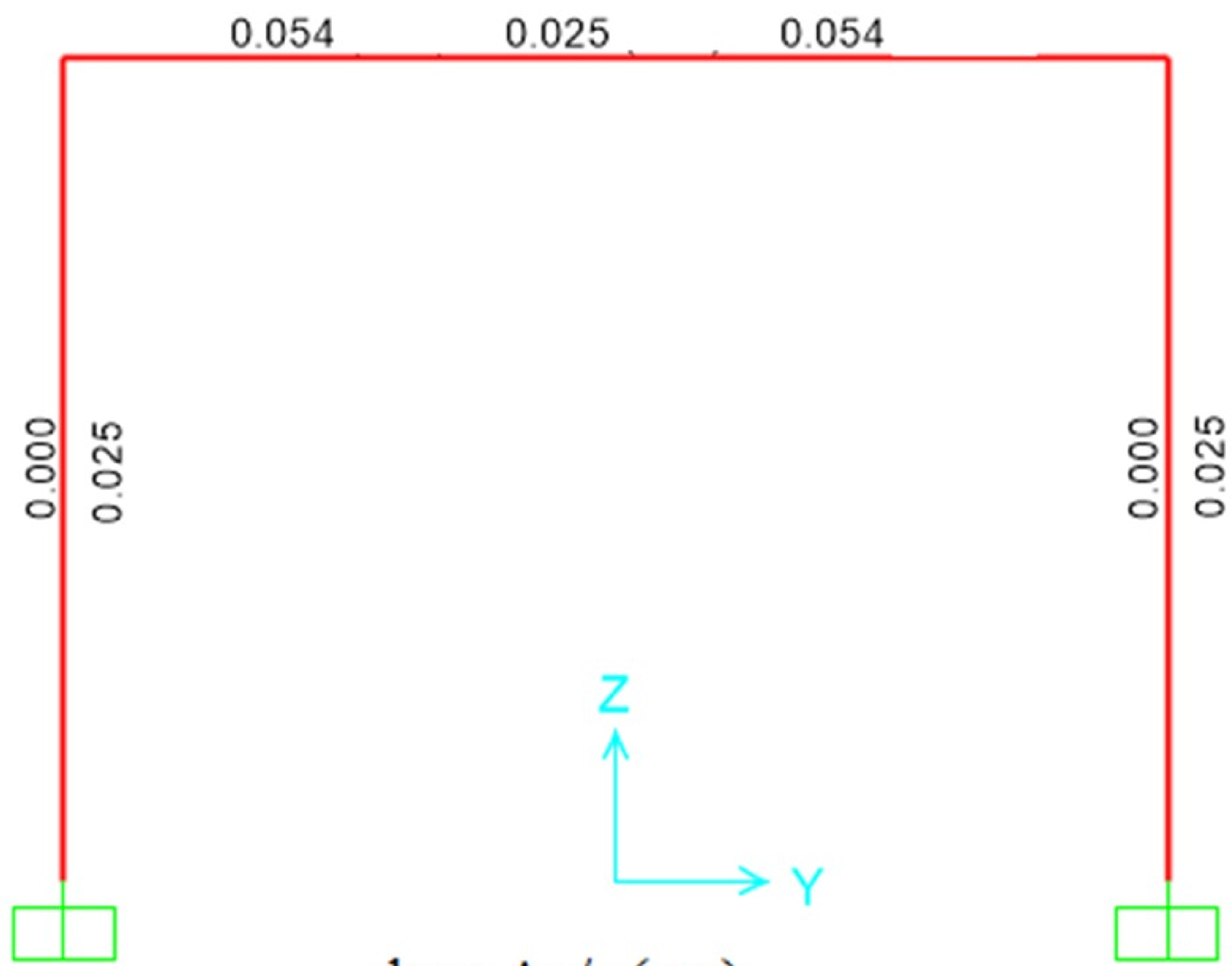
- Conceptual check for dead
  - W_d=(.25X24.5+5)X5=55.6kN/m
  - M_d=55.6X8^2 /8=445kN.m (compare with 243+192=435kN.m ok)
- Conceptual check for live
  - W_L=9X5=45kN/m
  - M_L=45X8^2 /8=360kN.m (compare with 183+144=327kN.m ok)

A detailed design example

Reinforcement calculation



flexure (cm2)



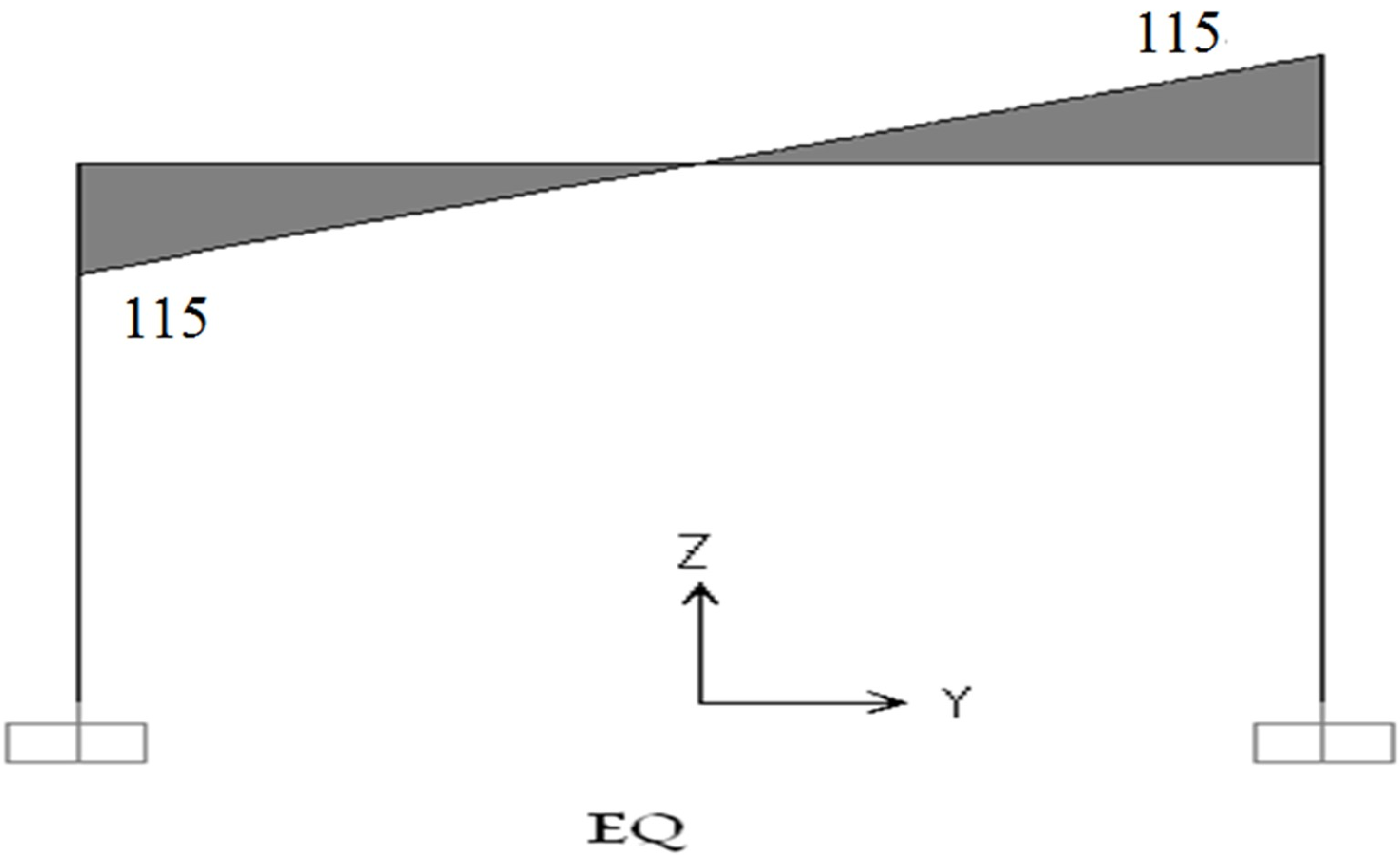
shear Av/s (cm)

Design for D, L and E

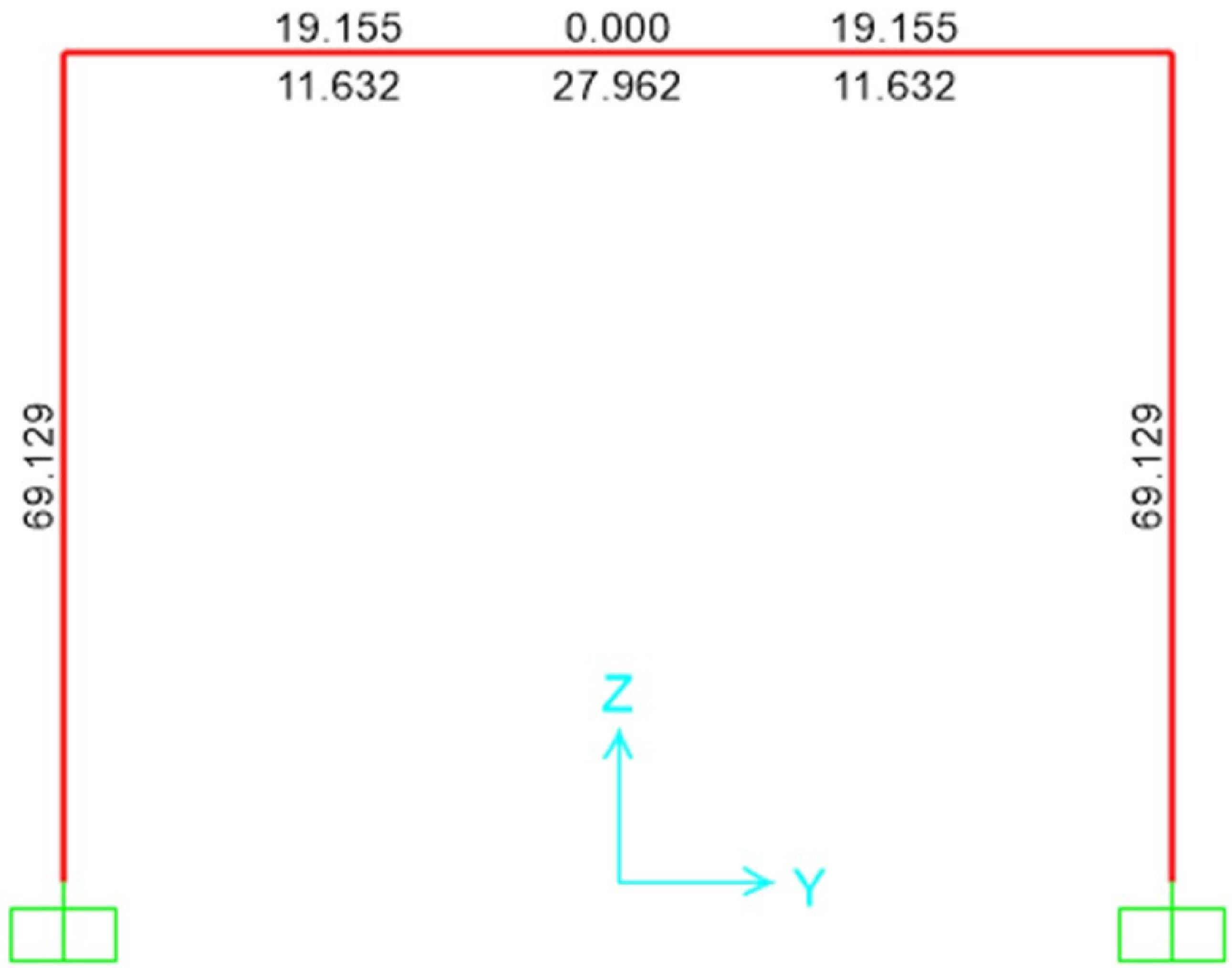
- Conceptual check for EQ:
- Limits
  - Lateral force for each frame=789/5=158kN
  - M_E=0 to (158/2)X6/2=236kN.m (compare with 192kN.m)

A detailed design example

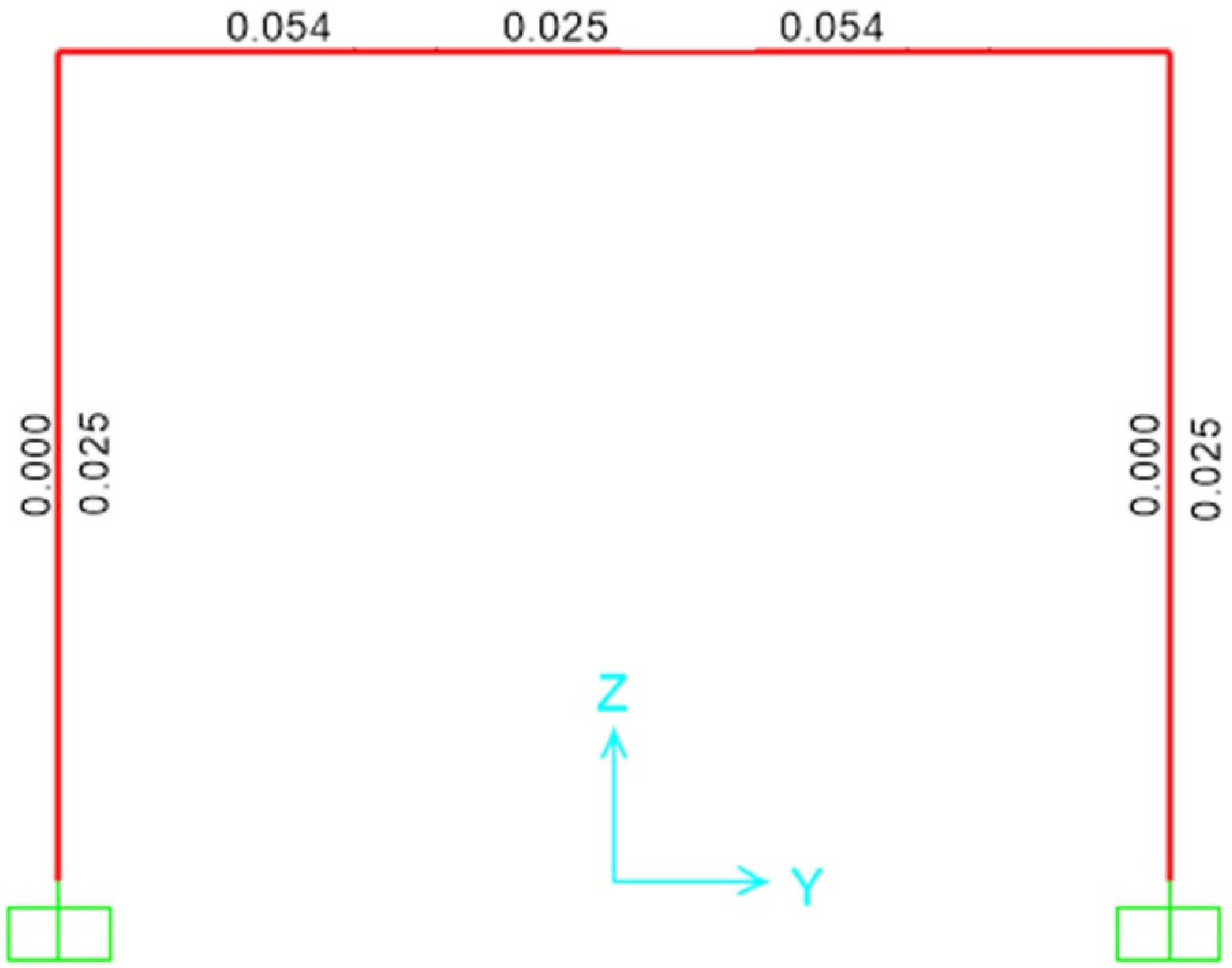
Design intermediate MRF
R=5



Design for D, L and E



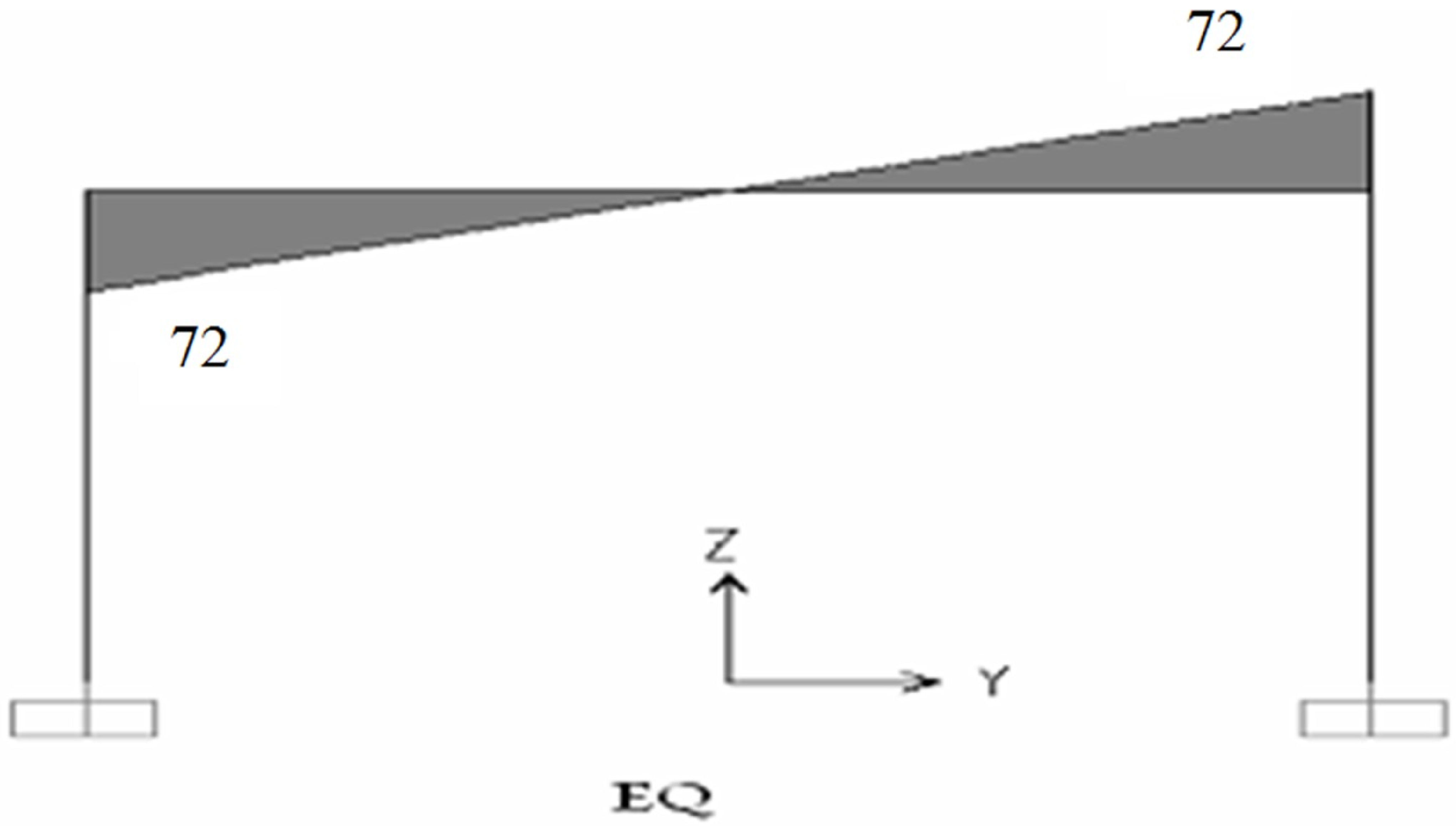
flexure (cm2)



shear Av/s (cm)

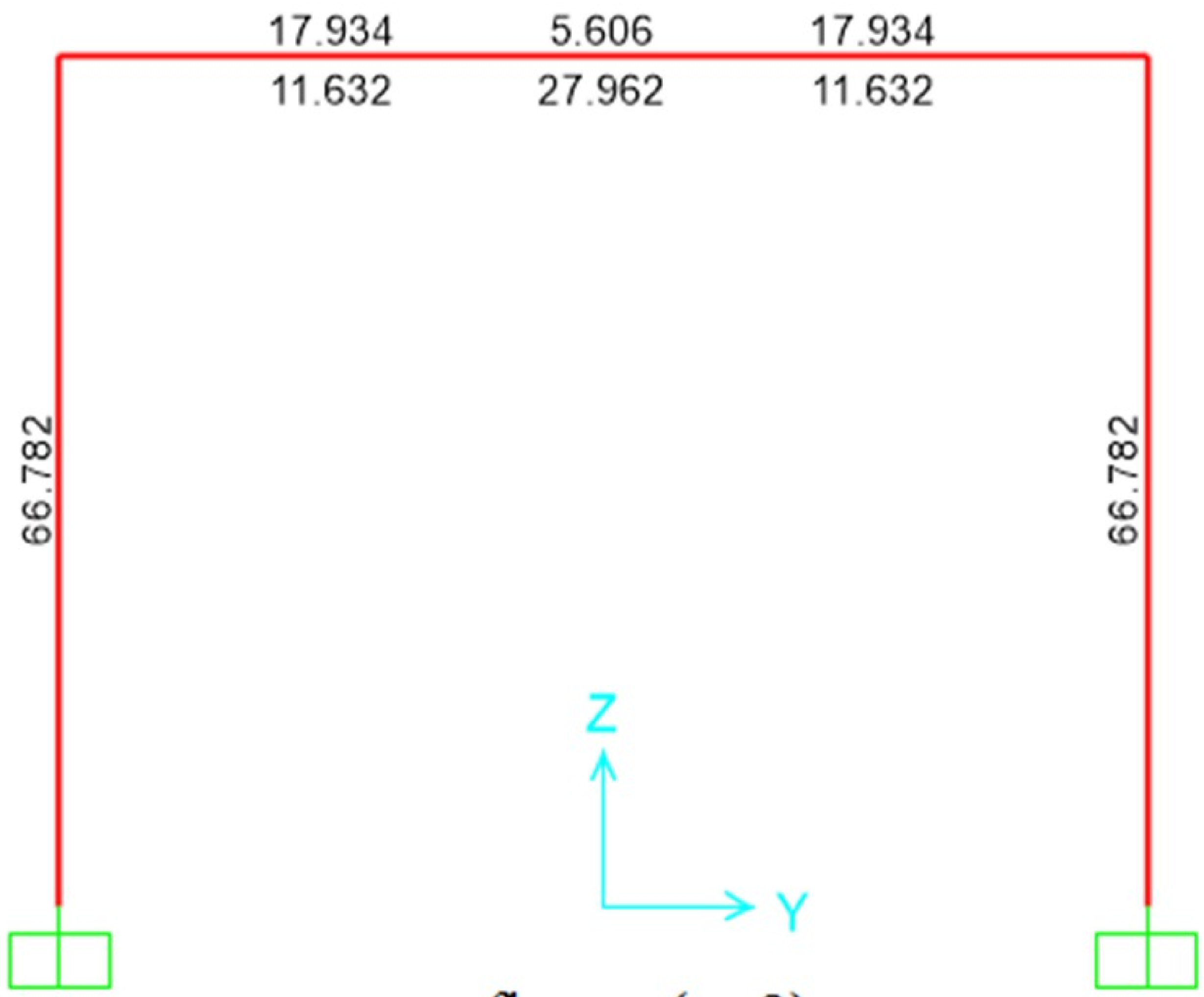
A detailed design example

Design Special SMF
R=8

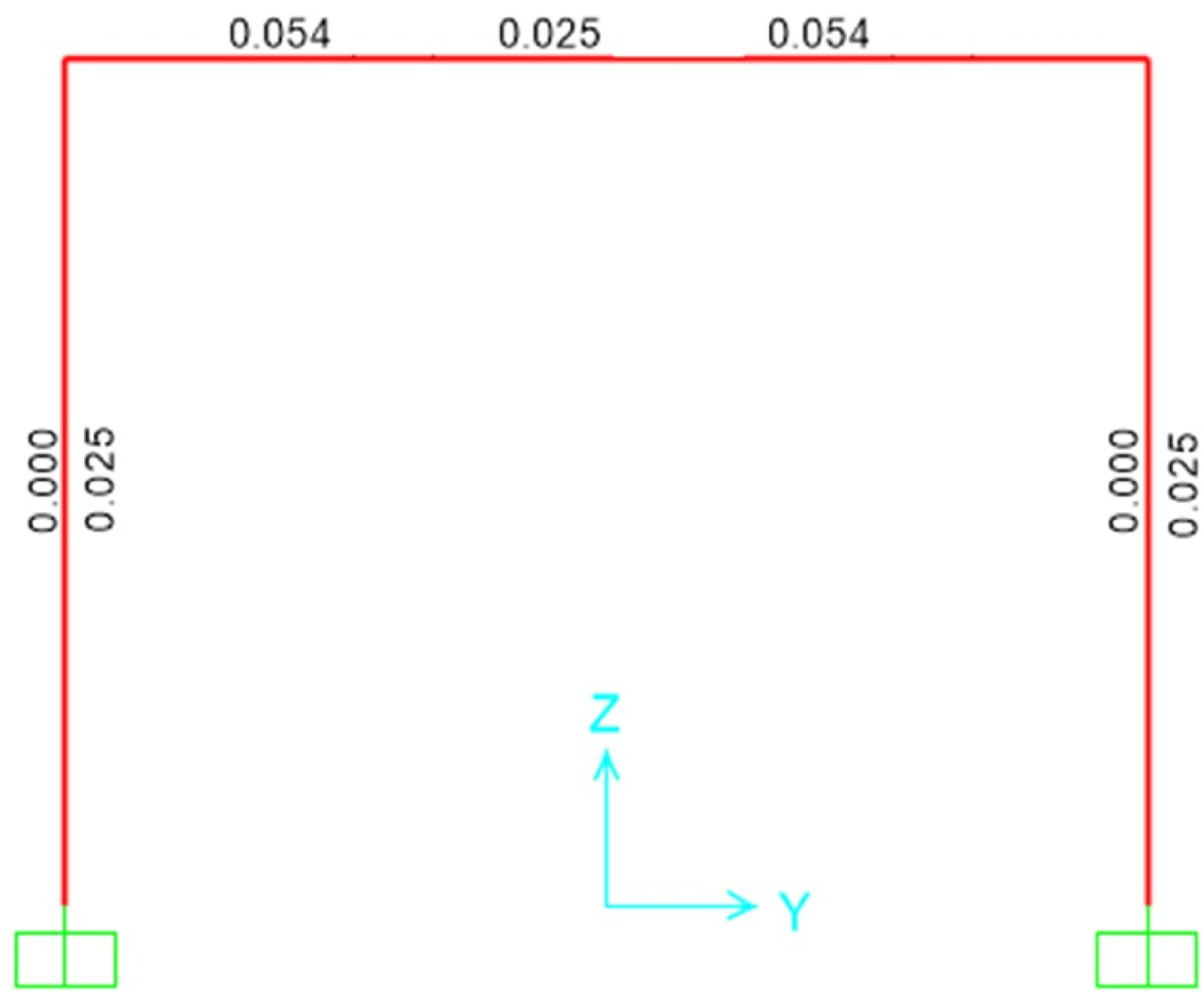


A detailed design example

Design for D, L and E



flexure (cm2)



shear Av/s (cm)

End of design codes

Let Learning Continue

Structural configuration (regular or irregular)

- Plan Configuration
  – ASCE 7-10 12.3.2.1
- Vertical Configuration
  – ASCE 7-10 12.3.2.2

Plan Structural Irregularities

- 1a - Torsional Irregularity
- 1b - Extreme Torsional Irregularity
- 2 - Re-entrant Corners
- 3 - Diaphragm Discontinuity
- 4 - Out-of-plane Offsets
- 5 - Nonparallel Systems

Structural configuration (regular or irregular)

Type	Description	Reference Section	Seismic Design Category Application
1a.	**Torsional Irregularity:** Torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure. Torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.4 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 Section 16.2.2	D, E, and F B, C, D, E, and F C, D, E, and F C, D, E, and F D, E, and F B, C, D, E, and F
1b.	**Extreme Torsional Irregularity:** Extreme torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.4 times the average of the story drifts at the two ends of the structure. Extreme torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.1 12.3.3.4 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 Section 16.2.2	E and F D B, C, and D C and D C and D D B, C, and D
2.	**Reentrant Corner Irregularity:** Reentrant corner irregularity is defined to exist where both plan projections of the structure beyond a reentrant corner are greater than 15% of the plan dimension of the structure in the given direction.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
3.	**Diaphragm Discontinuity Irregularity:** Diaphragm discontinuity irregularity is defined to exist where there is a diaphragm with an abrupt discontinuity or variation in stiffness, including one having a cutout or open area greater than 50% of the gross enclosed diaphragm area, or a change in effective diaphragm stiffness of more than 50% from one story to the next.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
4.	**Out-of-Plane Offset Irregularity:** Out-of-plane offset irregularity is defined to exist 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.	12.3.3.3 12.3.3.4 12.7.3 Table 12.6-1 Section 16.2.2	B, C, D, E, and F D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F
5.	**Nonparallel System Irregularity:** Nonparallel system irregularity is defined to exist where vertical lateral force-resisting elements are not parallel to the major orthogonal axes of the seismic force-resisting system.	12.5.3 12.7.3 Table 12.6-1 Section 16.2.2	C, D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F

Type 1: Torsional Irregularities

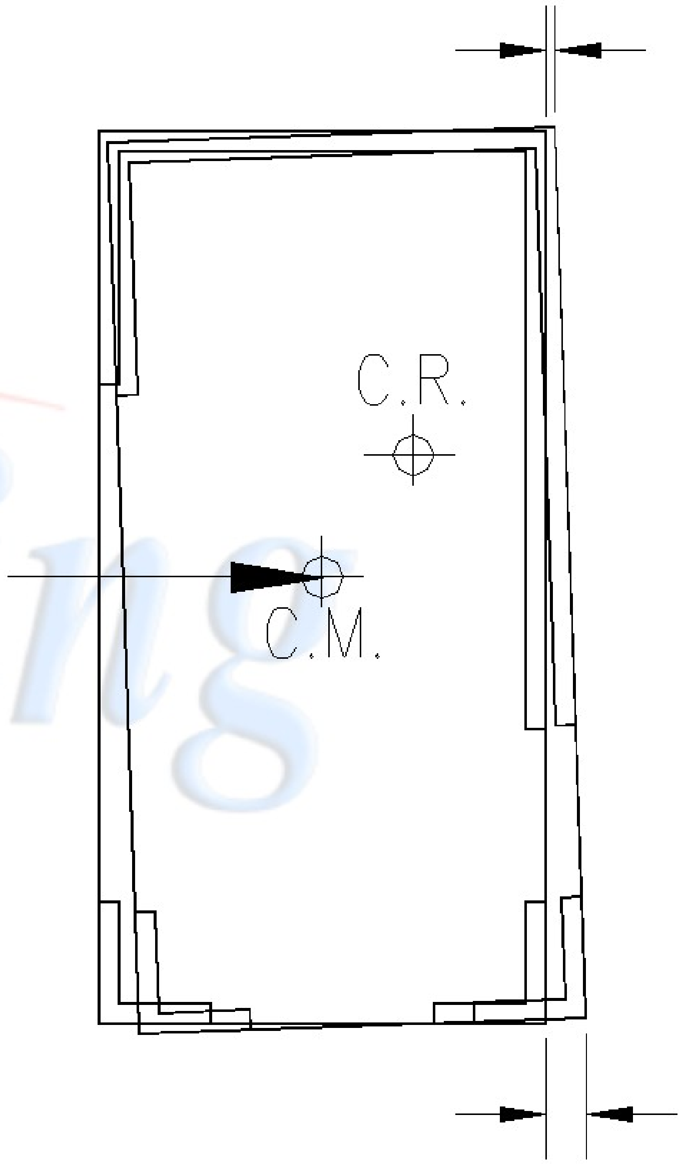
1a - **Torsional Irregularity**

- larger story drift more than 1.2 times average story drift

1b - **Extreme Torsional Irregularity**

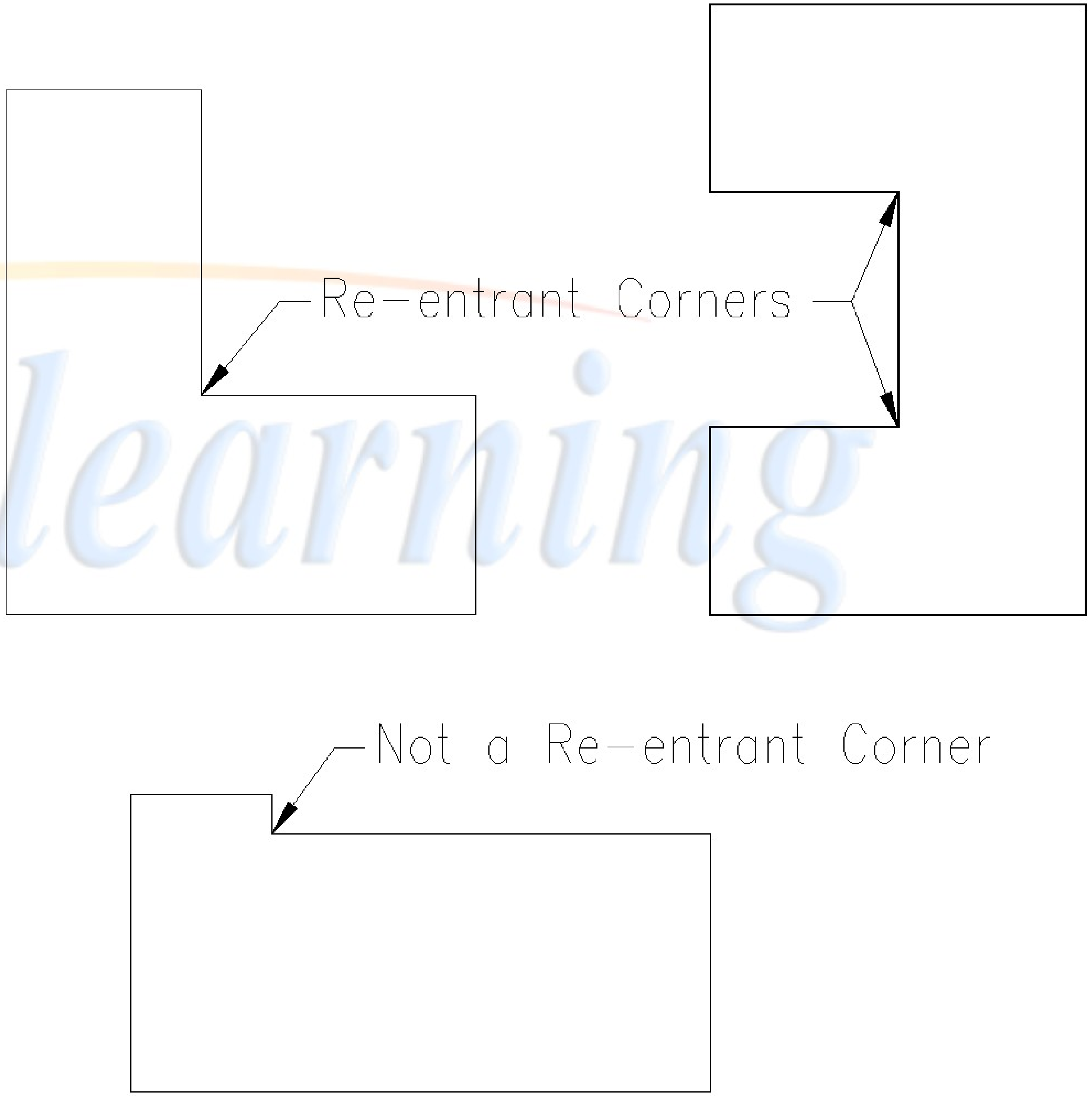
- larger story drift more than 1.4 times average story drift
- Not permitted in Design Categories E & F

Design forces for lateral force connections to be increased 25% in Design Categories D, E, & F.



Type 2: Re-entrant Corners

- Both projections beyond the corner are more than 15% of the plan dimension of the structure in the same direction



Type 3: Diaphragm Discontinuities

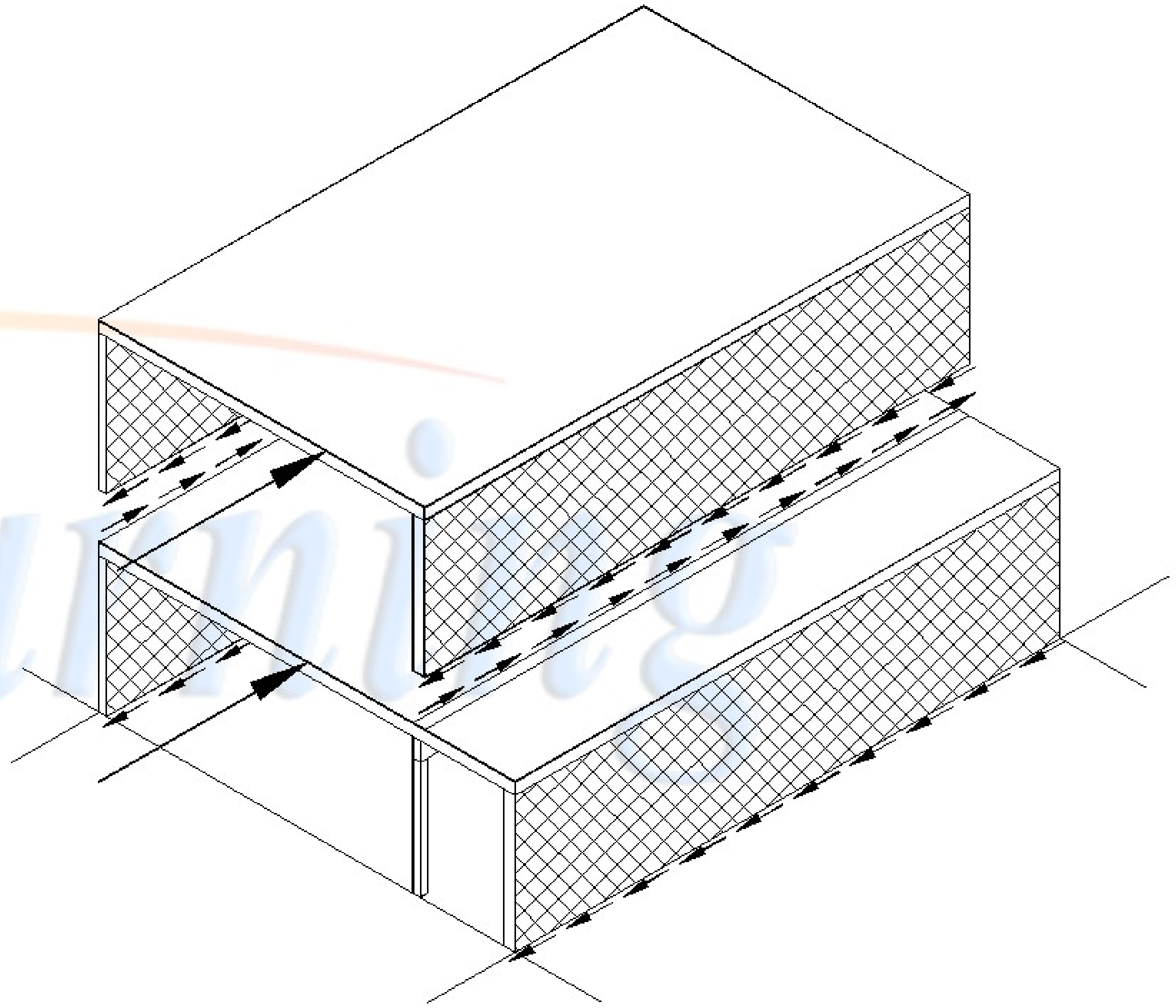
- Diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50% of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50% from one story to the next.

- Design forces for lateral force connections to be increased 25% in Design Categories D, E, & F.

Type 4: Out-of-Plane Offsets

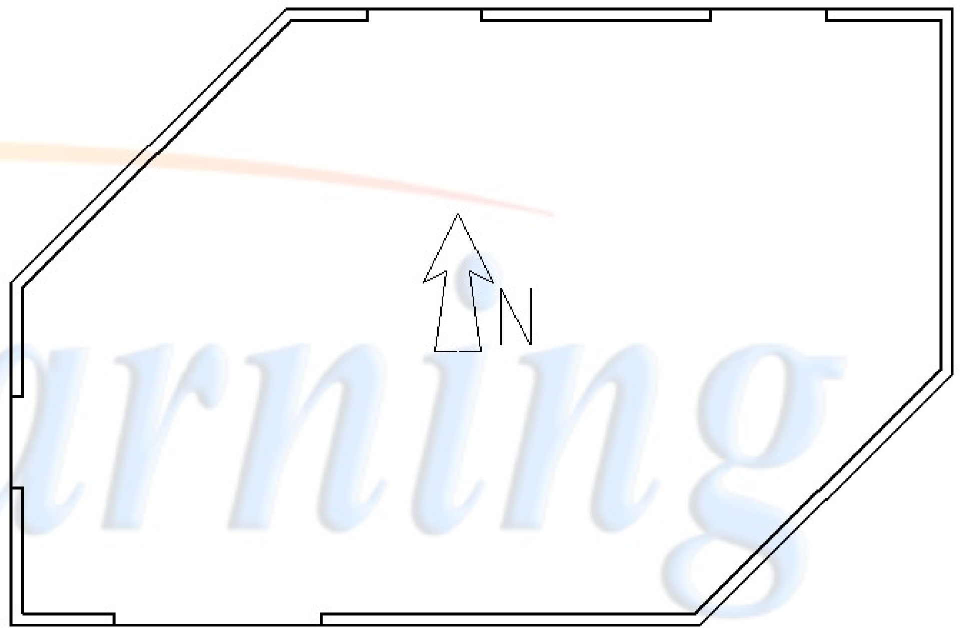
- Discontinuities in a lateral force resistance path, such as out-of-plane offsets of the vertical elements.

- Design forces for lateral force connections to be increased 25% in Design Categories D, E, & F.



Type 5: Nonparallel Systems

- The vertical lateral force-resisting elements are not parallel to or symmetric about the major orthogonal axes of the lateral force resisting system.



- Analyze for forces applied in the direction that causes the most critical load effect for Design Categories C - F.

Vertical Irregularities

- 1a - Stiffness Irregularity -Soft Story
- 1b - Stiffness Irregularity - Extreme Soft Story
- 2 - Weight (Mass) Irregularity
- 3 - Vertical Geometry Irregularity
- 4 - In-plane Discontinuity in Vertical Lateral Force Resisting Elements
- 5a - Discontinuity in Lateral Strength- Weak Story irregularity
- 5b - Discontinuity in Lateral Strength- Extreme Weak Story irregularity

Structural configuration (regular or irregular)

Type	Description	Reference Section	Seismic Design Category Application
1a.	**Stiffness-Soft Story Irregularity:** Stiffness-soft story irregularity is defined to exist where there is a story in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.	Table 12.6-1	D, E, and F
1b.	**Stiffness-Extreme Soft Story Irregularity:** Stiffness-extreme soft story irregularity is defined to exist where there is a story in which the lateral stiffness is less than 60% of that in the story above or less than 70% of the average stiffness of the three stories above.	12.3.3.1 Table 12.6-1	E and F D, E, and F
2.	**Weight (Mass) Irregularity:** Weight (mass) irregularity is defined to exist where the effective mass of any story is more than 150% of the effective mass of an adjacent story. A roof that is lighter than the floor below need not be considered.	Table 12.6-1	D, E, and F
3.	**Vertical Geometric Irregularity:** Vertical geometric irregularity is defined to exist where the horizontal dimension of the seismic force-resisting system in any story is more than 130% of that in an adjacent story.	Table 12.6-1	D, E, and F
4.	**In-Plane Discontinuity in Vertical Lateral Force-Resisting Element Irregularity:** In-plane discontinuity in vertical lateral force-resisting elements irregularity is defined to exist where there is an in-plane offset of a vertical seismic force-resisting element resulting in overturning demands on a supporting beam, column, truss, or slab.	12.3.3.3 12.3.3.4 Table 12.6-1	B, C, D, E, and F D, E, and F D, E, and F
5a.	**Discontinuity in Lateral Strength–Weak Story Irregularity:** Discontinuity in lateral strength–weak story irregularity is defined to exist where the story lateral strength is less than 80% of that in the story above. The story lateral strength is the total lateral strength of all seismic-resisting elements sharing the story shear for the direction under consideration.	12.3.3.1 Table 12.6-1	E and F D, E, and F
5b.	**Discontinuity in Lateral Strength–Extreme Weak Story Irregularity:** Discontinuity in lateral strength–extreme weak story irregularity is defined to exist where the story lateral strength is less than 65% of that in the story above. The story strength is the total strength of all seismic-resisting elements sharing the story shear for the direction under consideration.	12.3.3.1 12.3.3.2 Table 12.6-1	D, E, and F B and C D, E, and F

Type 1: Stiffness Irregularities

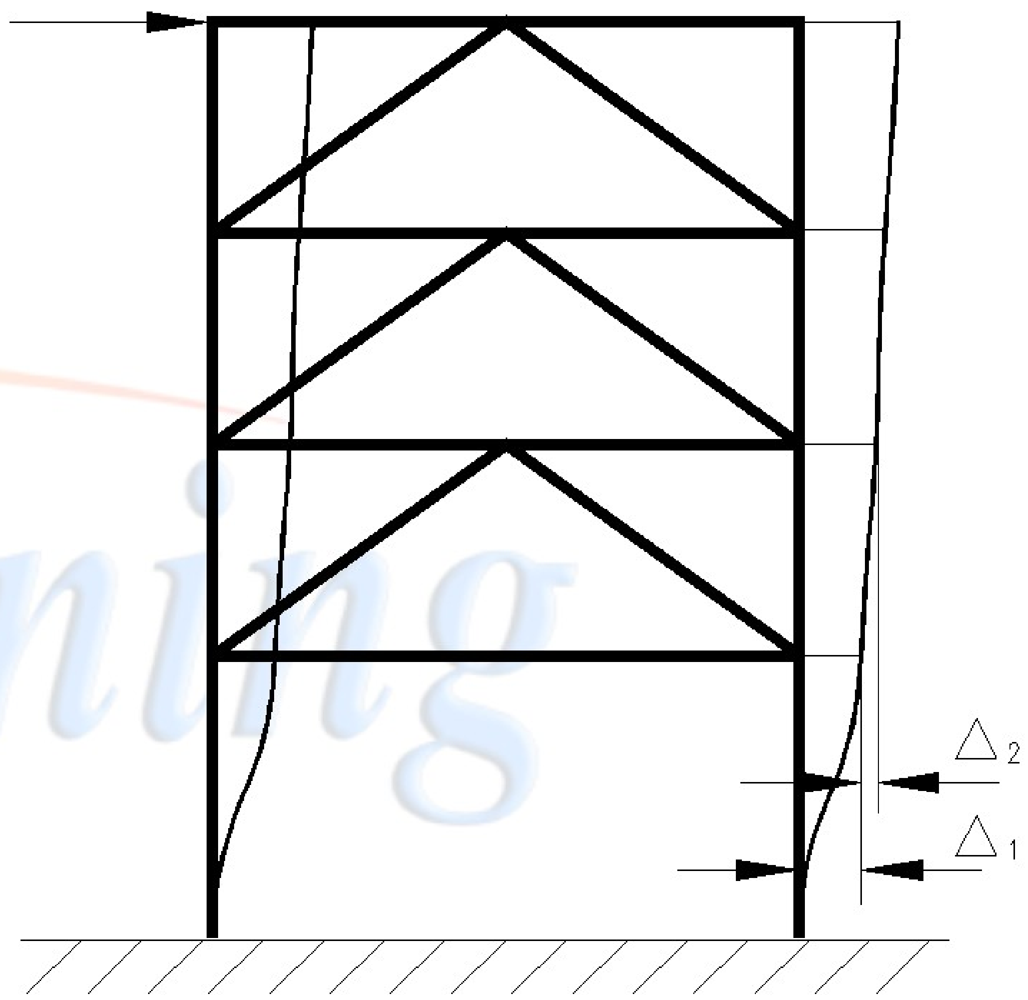
1a - Soft Story

the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.

1b - Extreme Soft Story

the lateral stiffness is less than 60% of that in the story above or less than 70% of the average stiffness of the three stories above.

Not permitted in Design Categories E & F

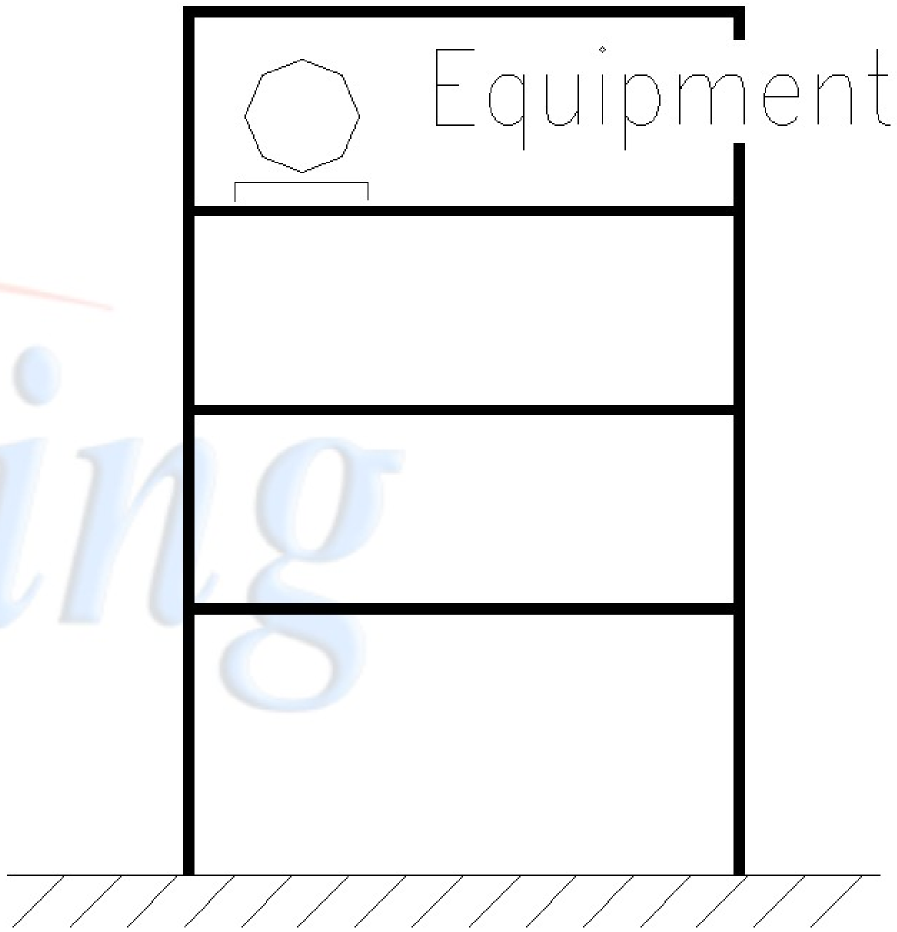


Soft $\frac{1}{\Delta_1} < 0.7 \frac{1}{\Delta_2}$

Extreme Soft $\frac{1}{\Delta_1} < 0.6 \frac{1}{\Delta_2}$

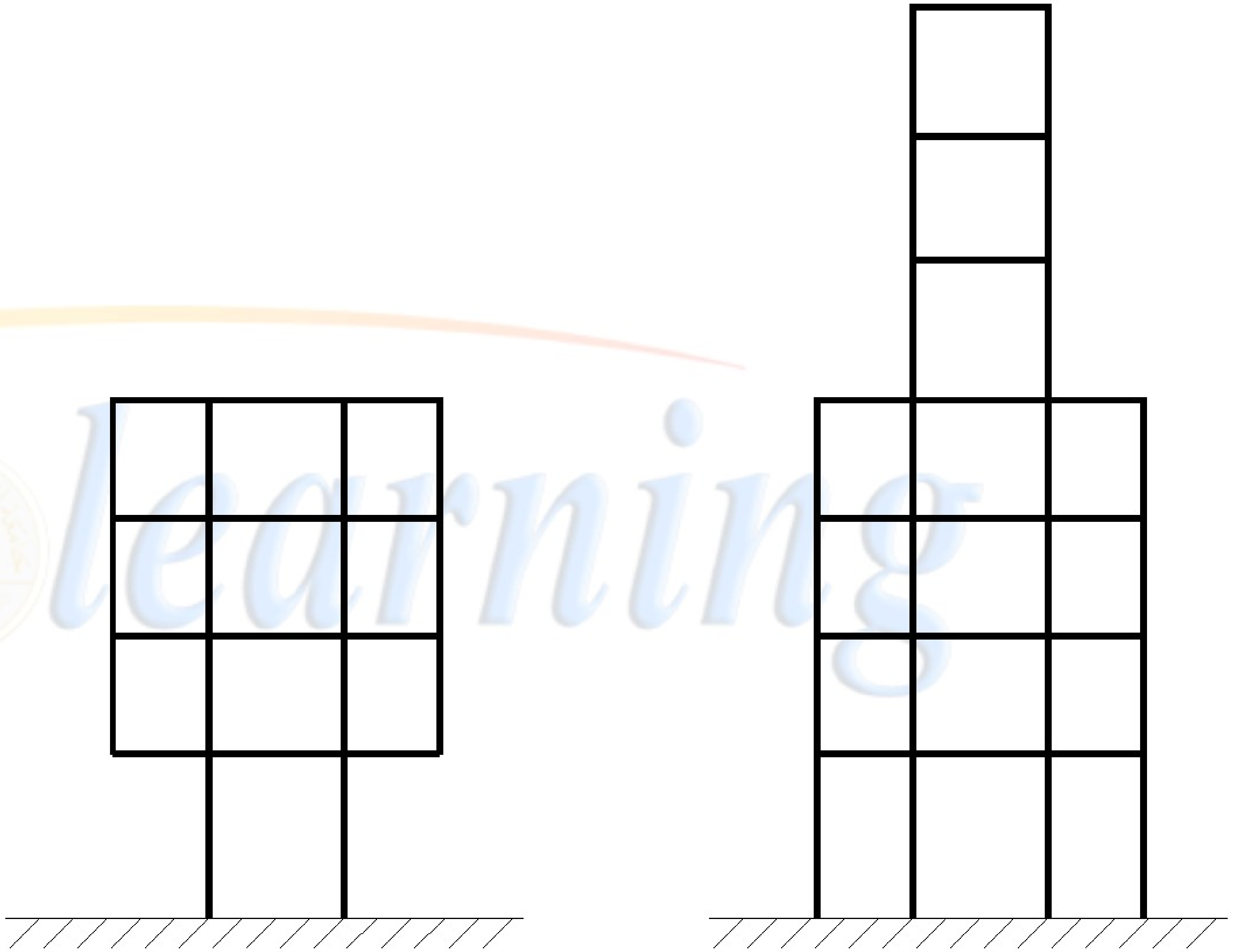
Type 2: Weight (Mass) Irregularity

- Mass irregularity shall be considered to exist where the effective mass of any story is more than 150% of the effective mass of an adjacent story. A roof that is lighter than the floor below need not be considered.



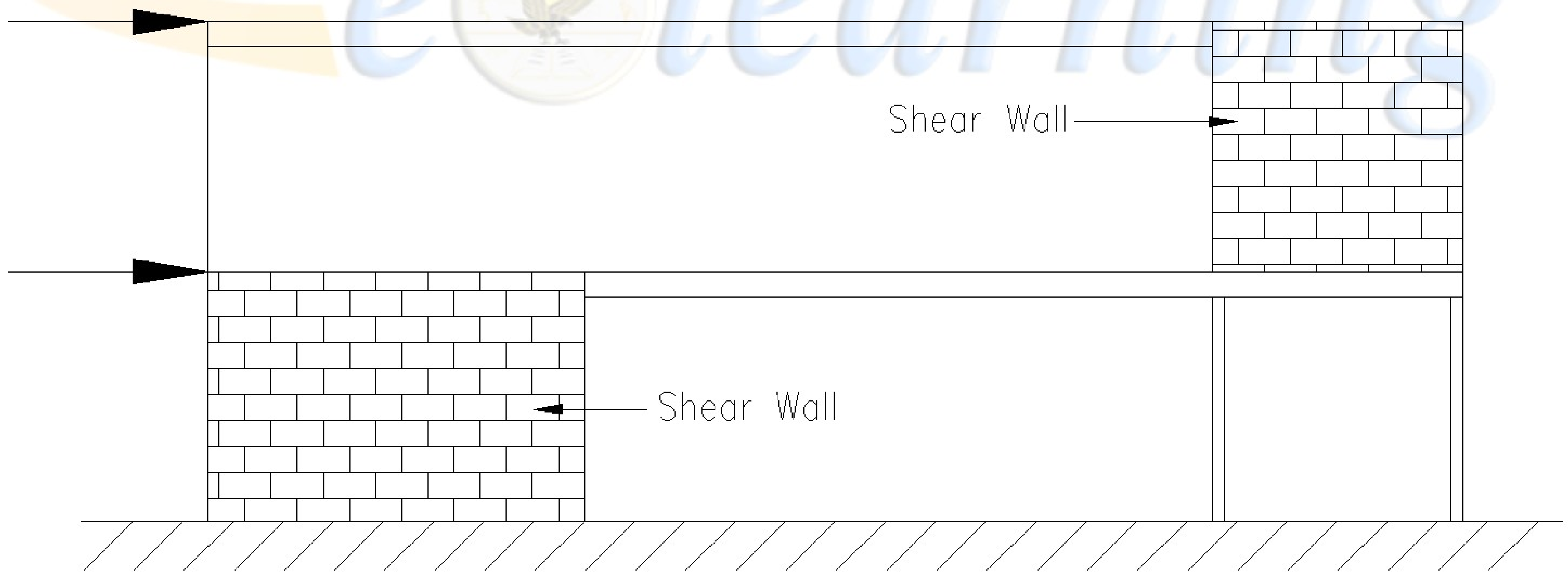
Type 3: Vertical Geometry Irregularity

- Vertical geometry irregularity shall be considered to exist where the horizontal dimension of the lateral force-resisting system in any story is more than 130% of that in an adjacent story.



Type 4: In-Plane Discontinuity in Vertical Lateral Force Resisting Elements

- An in-plane offset of the lateral force-resisting elements greater than the length of those elements or a reduction in stiffness in the resisting element in the story below.
- Design forces for lateral force connections to be increased 25% in Design Categories D, E, & F.



Type 5: Discontinuity in Capacity - Soft Story

- A weak story is one in which the story lateral *strength* is less than 80% of that in the story above. The story strength is the total strength of all seismic-resisting elements sharing the story shear for the direction under consideration.
- Do not confuse STIFFNESS with STRENGTH.
- Not permitted in Design Categories E & F.