Horizontal Irrégularités (ASCE-05)

TABLE 12.3-1 HORIZONTAL STRUCTURAL IRREGULARITIES

	Irregularity Type and Description	Reference Section	Seismic Design Category Application
1a.	**Torsional Irregularity** is defined to exist where the maximum story drift, computed including accidental torsion, 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 12.8.4.3 12.7.3 12.12.1 Table 12.6-1 Section 16.2.2	D, E, and F C, D, E, and F B, C, D, E, and F C, D, E, and F D, E, and F B, C, D, E, and F
1b.	**Extreme Torsional Irregularity** is defined to exist where the maximum story drift, computed including accidental torsion, 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** 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** is defined to exist where there are 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.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
4.	**Out-of-Plane Offsets Irregularity** is defined to exist where there are discontinuities in a lateral force-resistance path, such as out-of-plane offsets of the vertical elements.	12.3.3.4 12.3.3.3 12.7.3 Table 12.6-1 16.2.2	D, E, and F B, C, D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F
5.	**Nonparallel Systems-Irregularity** is defined to exist where the vertical lateral force-resisting elements are not parallel to or symmetric about 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

Horizontal Irrégularités (ASCE-05)

Hz Irreg.	Explanation
1a	**Torsional Irregularity** is defined to exist where the maximum story drift, computed including accidental torsion, 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 semi-rigid.
1b	**Extreme Torsional Irregularity** is defined to exist where the maximum story drift, computed including accidental torsion, 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 semi rigid.
2	**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.

Horizontal Irrégularités (ASCE-05)

Hz Irreg.	Explanation
3	**Diaphragm Discontinuity Irregularity** is defined to exist where there are 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.
4	**Out-of-Plane Offsets Irregularity** is defined to exist where there are discontinuities in a lateral force-resistance path, such as out-of-plane offsets of the vertical elements.
5	**Nonparallel Systems-Irregularity** is defined to exist where the vertical lateral force-resisting elements are not parallel to or symmetric about the major orthogonal axes of the seismic force-resisting system.

Horizontal Irrégularités (12.3.3.4)

12.3.3.4 Increase in Forces Due to Irregularities for Seismic Design Categories D through F. For structures assigned to Seismic Design Category D, E, or F and having a horizontal structural irregularity of Type 1a, 1b, 2, 3, or 4 in Table 12.3-1 or a vertical structural irregularity of Type 4 in Table 12.3-2, the design forces determined from Section 12.8.1 shall be increased 25 percent for connections of diaphragms to vertical elements and to collectors and for connections of collectors to the vertical elements. Collectors and their connections also shall be designed for these increased forces unless they are designed for the load combinations with overstrength factor of Section 12.4.3.2, in accordance with Section 12.10.2.1.

Horizontal Irrégularités (12.8.4.3)

12.8.4.3 Amplification of Accidental Torsional Moment. Structures assigned to Seismic Design Category C, D, E, or F, where Type 1a or 1b torsional irregularity exists as defined in Table 12.3-1 shall have the effects accounted for by multiplying M_{ta} at each level by a torsional amplification factor (A_x) as illustrated in Fig. 12.8-1 and determined from the following equation:

$$A_x = \left(\frac{\delta_{max}}{1.2\delta_{avg}}\right)^2 \qquad (12.8\text{-}14)$$

Horizontal Irrégularités (12.8.4.3)

where

δ_{max} = the maximum displacement at Level x (in. or mm) computed assuming $A_x = 1$

δ_{avg} = the average of the displacements at the extreme points of the structure at Level x computed assuming $A_x = 1$ (in. or mm)

EXCEPTION: The accidental torsional moment need not be amplified for structures of light-frame construction.

The torsional amplification factor (A_x) is not required to exceed 3.0. The more severe loading for each element shall be considered for design.

Horizontal Irrégularités (12.7.3)

12.7.3 Structural Modeling. A mathematical model of the structure shall be constructed for the purpose of determining member forces and structure displacements resulting from applied loads and any imposed displacements or P-Delta effects. The model shall include the stiffness and strength of elements that are significant to the distribution of forces and deformations in the structure and represent the spatial distribution of mass and stiffness throughout the structure.

Horizontal Irrégularités (12.7.3)

Structures that have horizontal structural irregularity Type 1a, 1b, 4, or 5 of Table 12.3-1 shall be analyzed using a 3-D representation. Where a 3-D model is used, a minimum of three dynamic degrees of freedom consisting of translation in two orthogonal plan directions and torsional rotation about the vertical axis shall be included at each level of the structure. Where the diaphragms have not been classified as rigid or flexible in accordance with Section 12.3.1, the model shall include representation of the diaphragm's stiffness characteristics and such additional dynamic degrees of freedom as are required to account for the participation of the diaphragm in the structure's dynamic response. In addition, the model shall comply with the following:

Horizontal Irrégularités (12.7.3)

a. Stiffness properties of concrete and masonry elements shall consider the effects of cracked sections.

b. For steel moment frame systems, the contribution of panel zone deformations to overall story drift shall be included.

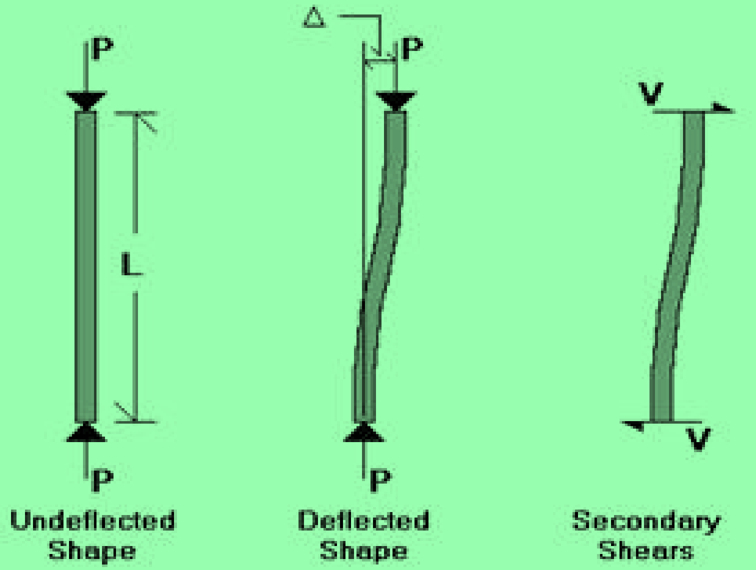
Horizontal Irrégularités (12.12.1)

12.12.1 Story Drift Limit. The design story drift (Δ) as determined in Sections 12.8.6, 12.9.2, or 16.1, shall not exceed the allowable story drift (Δ_a) as obtained from Table 12.12-1 for any story. For structures with significant torsional deflections, the maximum drift shall include torsional effects. For structures assigned to Seismic Design Category C, D, E, or F having horizontal irregularity Types 1a or 1b of Table 12.3-1, the design story drift, Δ, shall be computed as the largest difference of the deflections along any of the edges of the structure at the top and bottom of the story under consideration.

What is P-Delta Analysis?

When a model is loaded, it deflects. The deflections in the members of the model may induce secondary moments due to the fact that the ends of the member may no longer be vertical in the deflected position. These secondary effects for members can be accurately approximated through the use of P-Delta analysis.

This type of analysis is called "P-Delta" because the magnitude of the secondary moment is equal to "P", the axial force in the member, times "Delta", the distance one end of the member is offset from the other end.



$$P * \Delta = V * L$$

Horizontal Irrégularités (12.12.1)

Step 1: The model is loaded with the Applied loads (P shown above)

Step 2: The model deflects Δ, and the secondary shear force (V) is calculated for every member;

$$V = \frac{P * \Delta}{L}$$

Step 3: The model is re-solved (internally) with the secondary shear forces applied (V shown above).

Step 4: The displacements for this new solution are compared to those obtained from the previous solution. If they fall within the convergence tolerance, the solution has converged. If not, return to Step 2 and repeat.

The convergence tolerance is found in the **Model Settings** and is set by default to **0.5%**.

Horizontal Irrégularités (12.12.1)

TABLE 12.12-1 ALLOWABLE STORY DRIFT, Δ_a[a,b]

Structure	Occupancy Category		
	I or II	III	IV
Structures, other than masonry shear wall structures, 4 stories or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate the story drifts.	$0.025h_{sx}$[c]	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures [d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

[a] h_{sx} is the story height below Level x.
[b] For seismic force–resisting systems comprised solely of moment frames in Seismic Design Categories D, E, and F, the allowable story drift shall comply with the requirements of Section 12.12.1.1.
[c] There shall be no drift limit for single-story structures with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts. The structure separation requirement of Section 12.12.3 is not waived.
[d] Structures in which the basic structural system consists of masonry shear walls designed as vertical elements cantilevered from their base or foundation support which are so constructed that moment transfer between shear walls (coupling) is negligible.

Horizontal Irrégularités (12.3.1)

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. Unless a diaphragm can be idealized as either flexible or rigid in accordance with Sections 12.3.1.1, 12.3.1.2, or 12.3.1.3, the structural analysis shall explicitly include consideration of the stiffness of the diaphragm (i.e., semirigid modeling assumption).

Diaphragm, rigid. A diaphragm is rigid for the purpose of distribution of story shear and torsional moment when the lateral deformation of the diaphragm is less than or equal to two times the average story drift.

Horizontal Irrégularités (ASCE-05)

Horizontal structural irregularities are identified in Table 12.3-1. There are five types of horizontal irregularities:

1a. Torsional Irregularity — to be considered when diaphragms are not flexible as determined in §12.3.1.2

1b. Extreme Torsional Irregularity — to be considered when diaphragms are not flexible as determined in §12.3.1.2

2. Re-entrant Corner Irregularity.

3. Diaphragm Discontinuity Irregularity.

4. Out-of-plane Offsets Irregularity.

5. Nonparallel Systems – Irregularity.

Horizontal Irrégularités (ASCE-05)

Type 1a and 1b. When the ratio of maximum story drift to average story drift exceeds the given limit, there is the potential for an unbalance in the inelastic deformation demands at the two extreme sides of a story. As a consequence, the equivalent stiffness of the side having maximum deformation will be reduced, and the eccentricity between the centers of mass and rigidity will be increased along with the corresponding torsions. An amplification factor A_x is to be applied to the accidental torsion M_{ta} to represent the effects of this unbalanced stiffness, §12.8.4.1 to 12.8.4.3.

Type 2. The opening and closing deformation response or flapping action of the projecting legs of the building plan adjacent to re-entrant corners can result in concentrated forces at the corner point. Elements must be provided to transfer these forces into the diaphragms.

Horizontal Irrégularités (ASCE-05)

Type 3. Excessive openings in a diaphragm can result in a flexible diaphragm response along with force concentrations and load path deficiencies at the boundaries of the openings. Elements must be provided to transfer the forces into the diaphragm and the structural system.

Type 4. The out-of-plane offset irregularity represents the irregular load path category. In this case, shears and overturning moments must be transferred from the level above the offset to the level below the offset, and there is a horizontal offset in the load path for the shears.

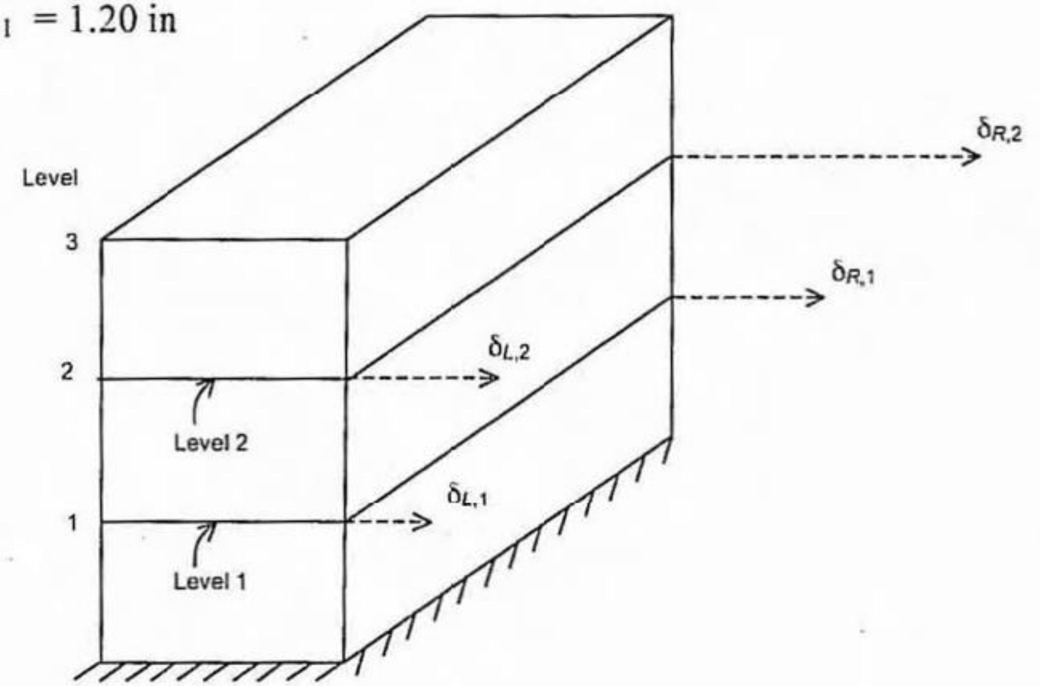
Type 5. The response deformations and load patterns on a system with nonparallel lateral-force-resisting elements can have significant differences from those of a regular system. Further analysis of deformation and load behavior may be necessary.

Horizontal Irrégularités (ASCE-05)-Type-1

A three-story special moment-resisting frame building has rigid floor diaphragms. Under code-prescribed seismic forces, including the effects of accidental torsion, it has the following elastic displacements δ_{xe} at Levels 1 and 2.

$\delta_{L,2} = 1.20$ in $\quad \delta_{R,2} = 1.90$ in

$\delta_{L,2} = 1.00$ in $\quad \delta_{R,1} = 1.20$ in



Horizontal Irrégularités (ASCE-05)-Type-1

1. **Determine if a Type 1a or Type 1b torsional irregularity exists at the second story**

If it does:

2. **Compute the torsional amplification factor A_x for Level 2**

A Type 1a torsional irregularity is considered to exist when the maximum story drift, including accidental torsion effects, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts of the two ends of the structure, see §12.8.6 for story drift determination

Horizontal Irrégularités (ASCE-05)-Type-1

1. **Determine if a Type 1a torsional irregularity exists at the second story**

Referring to the above figure showing the displacements δ_{xe} due to the prescribed lateral forces, this irregularity check is defined in terms of story drift $\Delta_x = (\delta_x - \delta_{x-1})$ at ends *R* (right) and *L* (left) of the structure. Torsional irregularity exists at Level *x* when

$$\Delta_{max} > 1.2(\Delta_{avg}) > \frac{1.2(\Delta_{L,x} + \Delta_{R,x})}{2}$$

Horizontal Irrégularités (ASCE-05)-Type-1

where

$$\Delta_{L,2} = \delta_{L,2} - \delta_{L,1}$$

$$\Delta_{R,2} = \delta_{R,2} - \delta_{R,1}$$

$$\Delta_{av} = \frac{\Delta_{L,2} + \Delta_{R,2}}{2}$$

Horizontal Irrégularités (ASCE-05)-Type-1

Determining story drifts at Level 2

$$\Delta_{L,2} = 1.20 - 1.00 = 0.20 \text{ in}$$

$$\Delta_{R,2} = 1.90 - 1.20 = 0.70 \text{ in}$$

$$\Delta_{avg} = \frac{0.20 + 0.70}{2} = 0.45 \text{ in}$$

$$\Delta_{max} = 0.70 \ldots \; (\Delta_{R,2})$$

Horizontal Irrégularités (ASCE-05)-Type-1

Checking 1.2 criteria

$$\frac{\Delta_{max}}{\Delta_{avg}} = \frac{0.7}{0.45} = 1.55 > 1.2$$

$\therefore$ Torsional irregularity exists – Type 1a.

Check for extreme torsional irregularity

$$\Delta_{max} > 1.4(\Delta_{avg})$$

$$\frac{\Delta_{max}}{\Delta_{avg}} = \frac{0.70}{0.45} = 1.55\text{...thus, extreme torsion irregularity exists – Type 1b.}$$

Horizontal Irrégularités (ASCE-05)-Type-1

2. **Compute amplification factor A_x for Level 2** §12.8.4.3

When torsional irregularity exists at a Level x, the accidental torsional moment M_{ta} must be increased by an amplification factor A_x. This must be done for each level, and each level may have a different A_x value. In this example, A_x is computed for Level 2.
Note that A_x is a function of the displacements as opposed to/versus the drift.

$$A_x = \left(\frac{\delta_{max}}{1.2\delta_{avg}}\right)^2 \quad \text{(IBC Eq 16-44)}$$

Horizontal Irrégularités (ASCE-05)-Type-1

$$\delta_{max} = 1.90 \text{ in} \ldots (\delta_{R,2})$$

$$\delta_{avg} = \frac{\delta_{L,3} + \delta_{R,3}}{2} = \frac{1.30 + 1.90}{2} = 1.60 \text{ in}$$

$$A_2 = \left(\frac{1.90}{1.2(1.60)} \right)^2 = 0.98 < 1.0 \ \ldots \text{ Note } A_x \text{ shall not be less than } 1.0$$

$$\therefore \text{ use } A_x = 1.0.$$

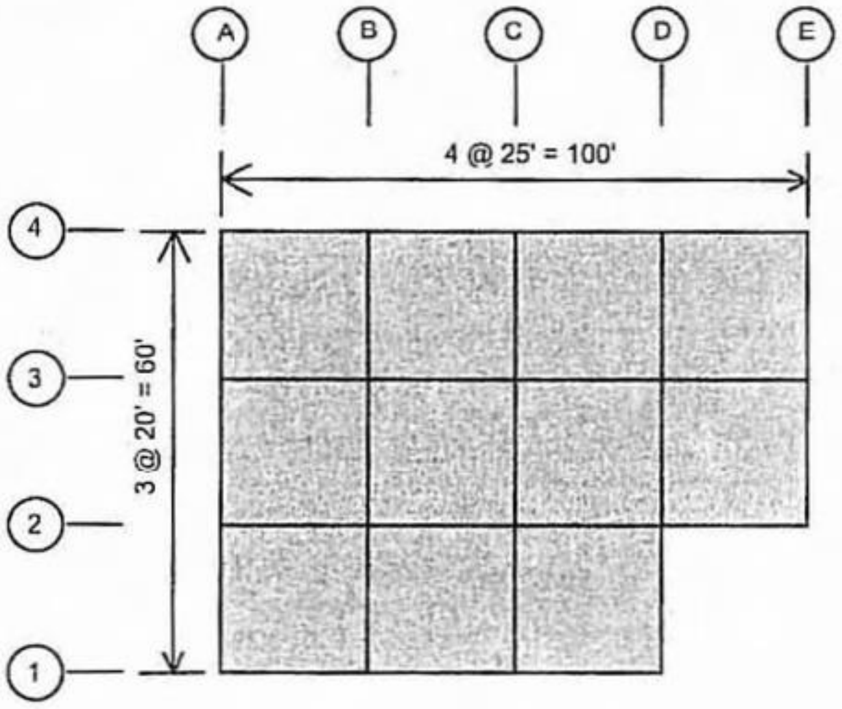
Horizontal Irrégularités (ASCE-05)-Type-1

For cases of large eccentricity and low torsional rigidity, the static force procedure can result in a negative displacement on one side and a positive on the other. For example, this occurs if $\delta_{L,3} = -0.40$ in. and $\delta_{R,3} = 1.80$ in. The value of δ_{avg} in Equation 12.8-14 should be calculated as the algebraic average.

$$\delta_{avg} = \frac{\delta_{L,3} + \delta_{R,3}}{2} = \frac{(-40) + 1.80}{2} = \frac{1.40}{2} = 0.70 \text{ in}$$

Horizontal Irrégularités (ASCE-05)-Type-2

The plan configuration of a ten-story special moment frame building is as shown below.



1. **Determine if there is a Type 2 re-entrant corner irregularity**

Horizontal Irrégularités (ASCE-05)-Type-2

A Type 2 re-entrant corner irregularity exists when the plan configuration of a structure and its lateral-force-resisting system contain re-entrant corners, where both projections of the structure beyond a re-entrant corner are greater than 15 percent of the plan dimension of the structure in the direction considered.

The plan configuration of this building, and its lateral-force-resisting system, has re-entrant corner dimensions as shown. For the sides on line 1, the projection beyond the re-entrant corner is

$$100 \text{ ft} - 75 \text{ ft} = 25 \text{ ft}$$

This is $\frac{25}{100}$ or 25 percent of the 100-ft plan dimension . . . More than 15 percent.

For the sides on line E, the projection is

$$60 \text{ ft} - 40 \text{ ft} = 20 \text{ ft}$$

Horizontal Irrégularités (ASCE-05)-Type-2

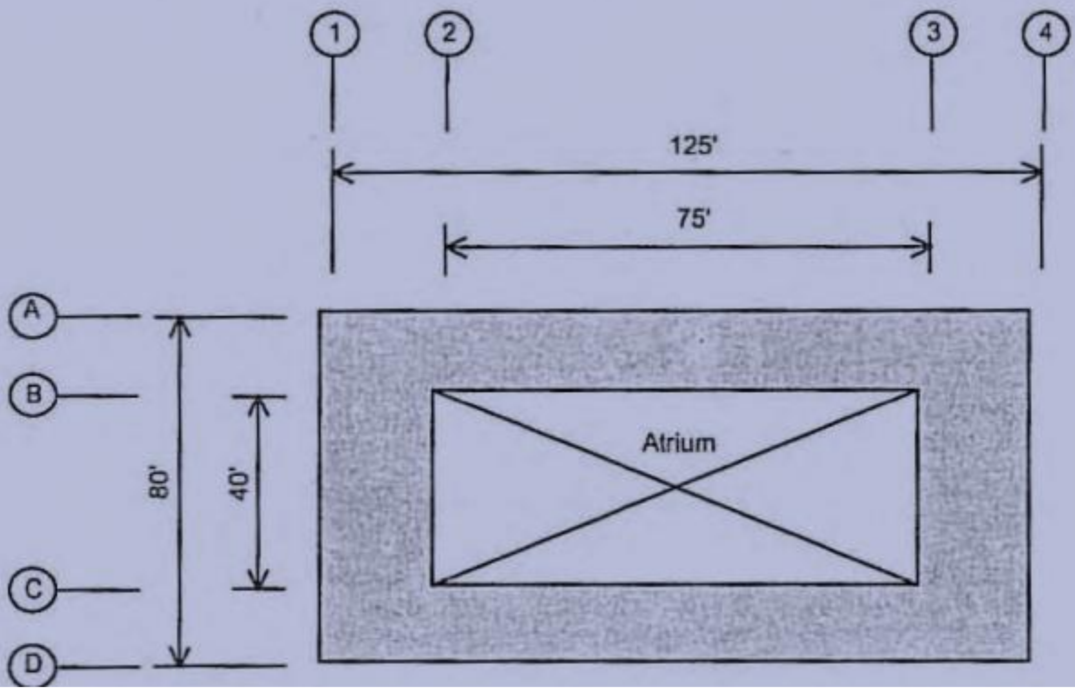
This is $\frac{20}{60}$ or 33.3 percent of the 60-ft plan dimension . . . More than 15 percent.

Since both projections exceed 15 percent, there is a re-entrant corner irregularity.

$\therefore$ Re-entrant corner irregularity exists.

Horizontal Irrégularités (ASCE-05)-Type-3

A five-story concrete building has a bearing wall system located around the perimeter of the building. Lateral forces are resisted by the bearing walls acting as shear walls. The floor plan of the second floor of the building is shown below. The symmetrically placed open area in the diaphragm is for an atrium, and has dimensions of 40 feet by 75 feet. All diaphragms above the second floor are without significant openings.



Horizontal Irrégularités (ASCE-05)-Type-3

1. Determine if a Type 3 diaphragm discontinuity irregularity exists at the second floor level

The first check is for gross area

Gross enclosed area of the diaphragm is 80 ft × 125 ft = 10,000 sq ft

Area of opening is 40 ft × 75 ft = 3000 sq ft

50 percent of gross area = 0.5(10,000) = 5000 sq ft

3000 < 5000 sq ft

∴ No diaphragm discontinuity irregularity exists.

Horizontal Irrégularités (ASCE-05)-Type-3

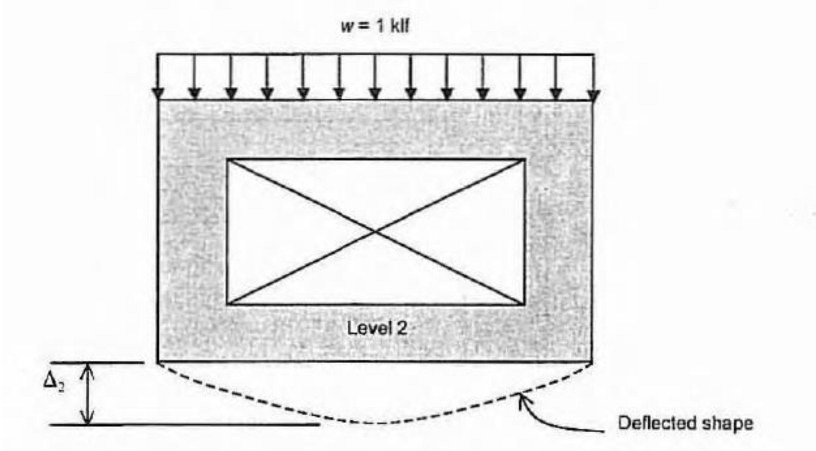
The second check is for stiffness.

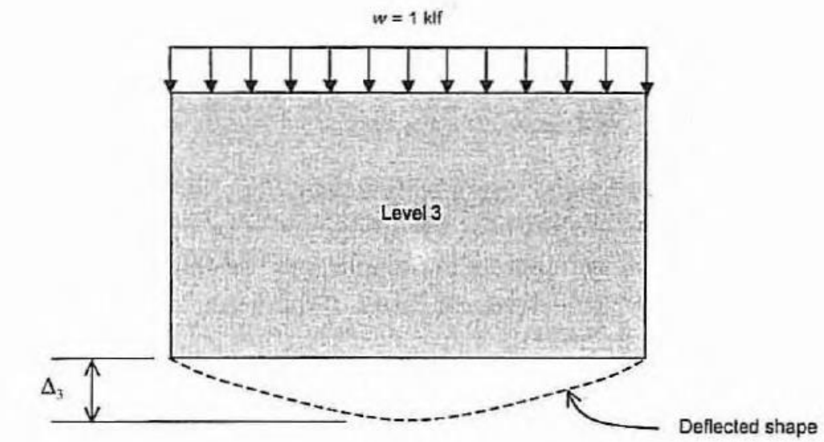
The stiffness of the second floor diaphragm with its opening must be compared with the stiffness of the solid diaphragm at the third floor. If the change in stiffness exceeds 50 percent, a diaphragm discontinuity irregularity exists for the structure.

This comparison can be performed as follows.

Find the simple beam mid-span deflections Δ_2 and Δ_3 for the diaphragms at Levels 2 and 3, respectively, due to a common distributed load *w* such as 1 klf.

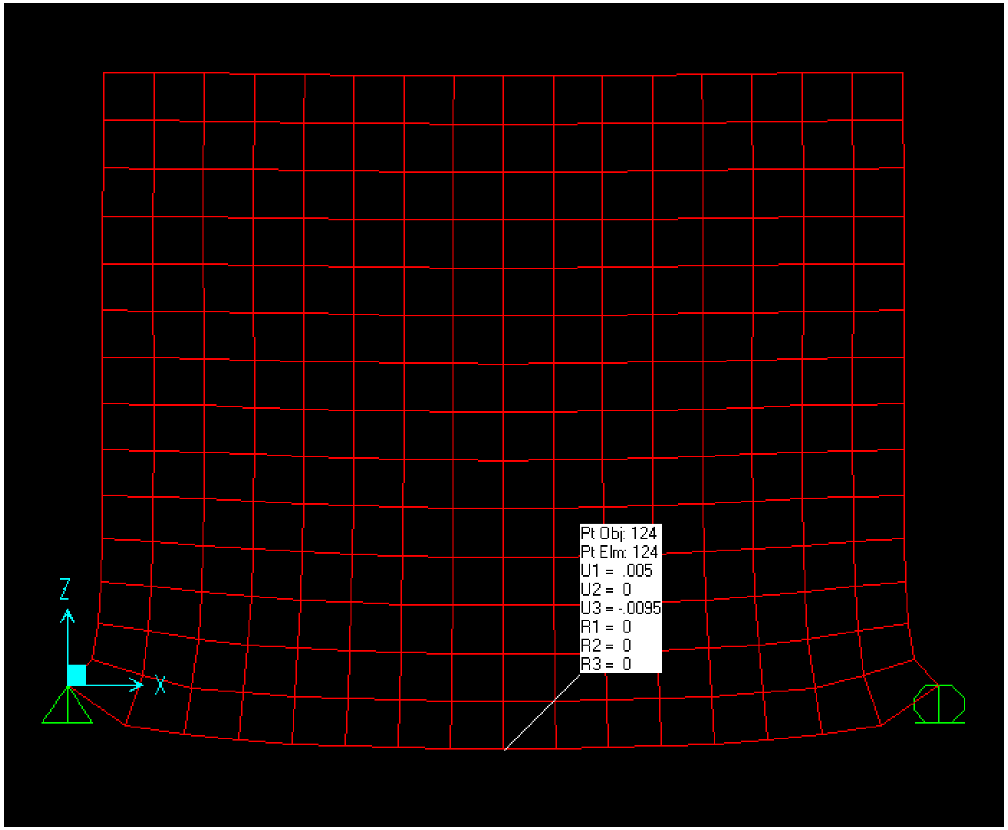
Horizontal Irrégularités (ASCE-05)-Type-3



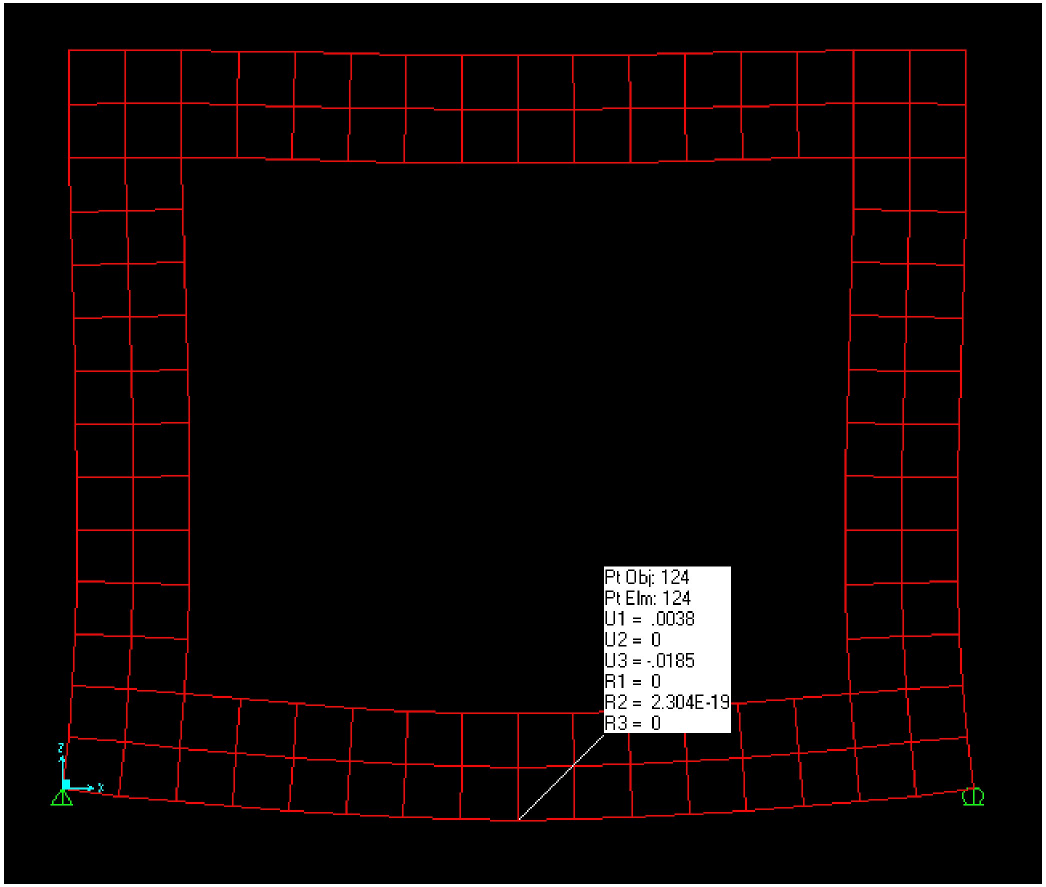


If $\Delta_2 > 1.5\Delta_3$, there is diaphragm discontinuity.

Horizontal Irrégularités (ASCE-05)-Type-3

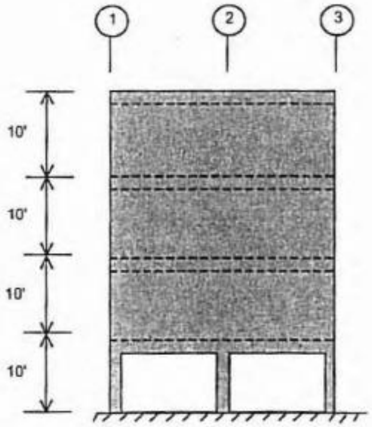


Horizontal Irrégularités (ASCE-05)-Type-3

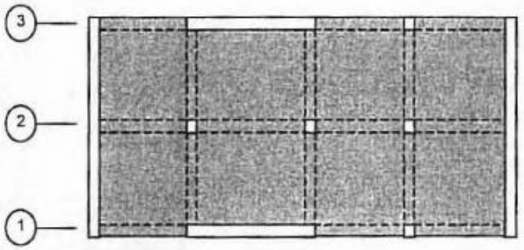


Horizontal Irrégularités (ASCE-05)-Type-4

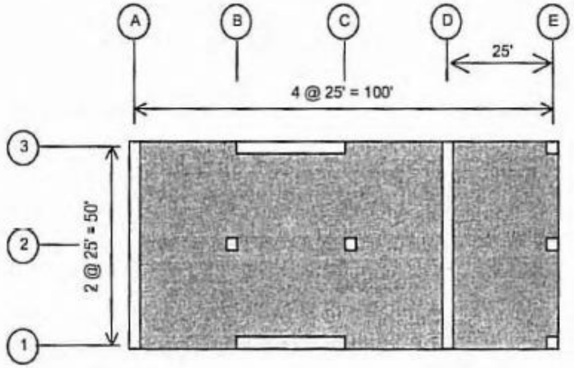
A four-story building has a concrete shear wall lateral-force-resisting system in a building frame system configuration. The plan configuration of the shear walls is shown below.



Elevation Line E



Typical floor plan



Ground (first) floor plan

Horizontal Irrégularités (12.3.3.3)

12.3.3.3 Elements Supporting Discontinuous Walls or Frames. Columns, beams, trusses, or slabs supporting discontinuous walls or frames of structures having horizontal irregularity Type 4 of Table 12.3-1 or vertical irregularity Type 4 of Table 12.3-2 shall have the design strength to resist the maximum axial force that can develop in accordance with the load combinations with overstrength factor of Section 12.4.3.2. The connections of such discontinuous elements to the supporting members shall be adequate to transmit the forces for which the discontinuous elements were required to be designed.

Horizontal Irrégularités (ASCE-05)-Type-4

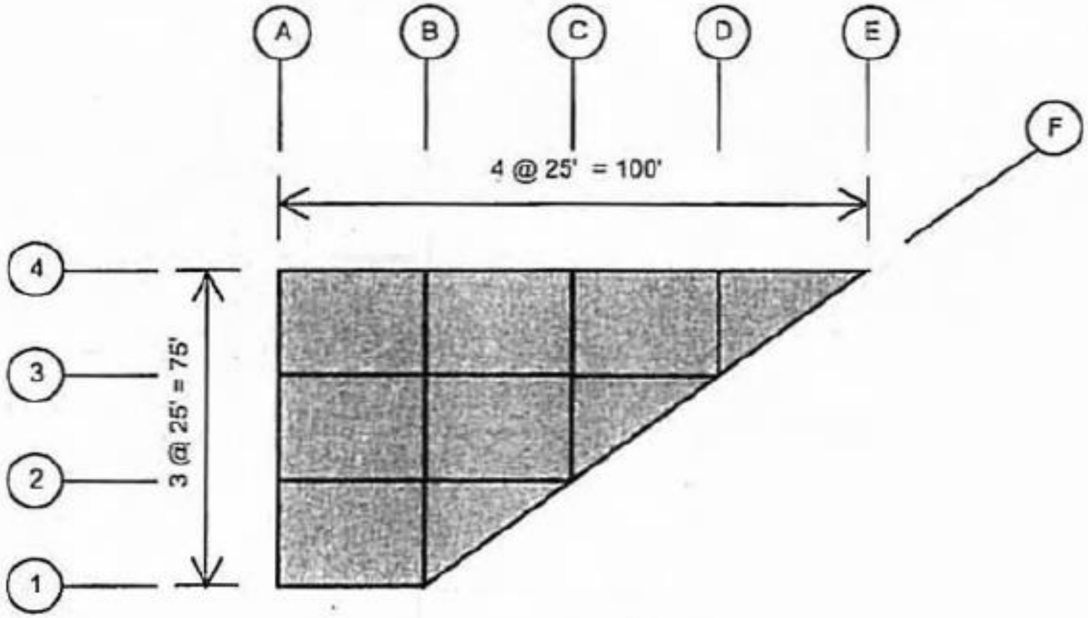
1. **Determine if there is a Type 4 out-of-plane offset irregularity between the first and second stories**

An out-of-plane offset plan irregularity exists when there are discontinuities in a lateral-force path. For example: out-of-plane offsets of vertical lateral-force-resisting elements such as shear walls. The first story shear wall on line D has a 25-foot out-of-plane offset to the shear wall on line E at the second story and above. This constitutes an out-of-plane offset irregularity, and the referenced sections in Table 12.3.2.1 apply to the design.

$\therefore$ Offset irregularity exists.

Horizontal Irrégularités (ASCE-05)-Type-5

A ten-story building has the floor plan shown below at all levels. Special moment-resisting frames are located on the perimeter of the building on lines 1, 4, A, and F.



Typical floor plan

Horizontal Irrégularités (ASCE-05)-Type-5

1. **Determine if a Type 5 nonparallel system irregularity exists**

A Type 5 nonparallel system irregularity is considered to exist when the vertical lateral-force-resisting elements are not parallel to or symmetric about the major orthogonal axes of the building's lateral-force-resisting system.

The vertical lateral-force-resisting frame elements located on line F are not parallel to the major orthogonal axes of the building (i.e., lines 4 and A). Therefore a nonparallel system irregularity exists, and the referenced section in Table 12.3-1 applies to the design, see §12.5.3, §12.7-3, and Table 12.6-1.

∴ A nonparallel system irregularity exists.

A 3-dimensional dynamic analysis is recommended.

Horizontal Irrégularités (ASCE-05)

- As per Section 12.5
  - Analysis can be done for one directions when building is in SDC A or B.
  - Orthogonal direction analysis is required in both the direction when SDC D,E,F.
  - Different types of analysis are also permitted in various SDC's.
  - The detail is given in the next slide.

Ho 05)

TABLE 12.6-1 PERMITTED ANALYTICAL PROCEDURES

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis Section 12.8	Modal Response Spectrum Analysis Section 12.9	Seismic Response History Procedures Chapter 16
B, C	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	All other structures	P	P	P
D, E, F	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	Regular structures with $T < 3.5T_s$ and all structures of light frame construction	P	P	P
	Irregular structures with $T < 3.5T_s$ and having only horizontal irregularities Type 2, 3, 4, or 5 of Table 12.2-1 or vertical irregularities Type 4, 5a, or 5b of Table 12.3-1	P	P	P
	All other structures	NP	P	P

NOTE: P: Permitted; NP: Not Permitted