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Architectural problems in earthquake resisting buildings

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Abstract -Structural Engineers greatest challenge in today's scenario is constructing seismic resistant structure. The challenge further increases due to the increased eye pleasing high rise structure with architectural problems. These architecturally pleasing structures with shape irregularity when subjected to devastating earthquake is a matter of concern. The behavior of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Hence, at the planning stage itself, architects and structural engineers must work together to ensure that the unfavorable features are avoided and a good building configuration is chosen. This paper deals with architectural problems in buildings like Re-entrant corners, setbacks and building with heavy weight on one side.

Key words: Structural Engineers, architects, earthquake, size and geometry, Re-entrant corners, setbacks, heavy weight.

1. INTRODUCTION

1.1 GENERAL

An *earthquake* also known as a quake or tremor is the result of a sudden release of energy in the Earth's crust that creates seismic waves. The most important cause from an engineering point of view, it is believed at present, is the movement of faults which are buried deep below the earth surface. Earthquake causes ground to vibrate and these results a lateral force on the structure.

"Earthquakes don't kill people but poorly built buildings do". Poorly built buildings include poor quality of materials used poor shape of the building and poor design without considering the codal provisions. Several countries including India have experienced severe losses in the past, in terms of human casualty and property; most recent are the Bhuj earthquake of 26th January, 2001; Sumatra Earthquake of 26th December, 2004 leading to Tsunami and Kashmir earthquake of 8th October, 2005. Most of the casualties were due to collapse of poorly constructed buildings in the seismically vulnerable regions.

1.2 ARCHITECTURAL PROBLEMS IN BEHAVIOUR OF A BUILDING

Sometimes the shape of building catches the eye of visitor, sometimes the structural system appeals, and in other occasions both shape and structural system work together to make the structure a Marvel. If the building is irregularly shaped there will be excessive deflection and twisting moment during earthquake. The architectural problem includes the different aesthetically good looking structure with irregularities. The irregularity may be plan or vertical irregularity, this includes soft storey, L-shape, T-shape building, large horizontal size of building and square building with a central opening.

Structures are designated as regular and irregular depending on shape continuity. A regular structure has no significant discontinuities in the plan, vertical configuration or lateral force resisting systems, whereas an irregular structure possesses discontinuities.

The effects that cause seismic action in irregular structures were observed in many recent earthquakes. The symmetry and regularity are usually recommended for a sound design of earthquake resistant structure. However the code does not prohibit the use of irregular shapes. In irregular building the stress distribution is not uniform, which result in the accumulation of stress at certain sections. This stress builds up and failure occurs. Building can be built irregular but proper precautions need to be taken beforehand. Such as additional reinforcements, strengthening, providing sufficient gap between two structures etc.

2. ARCHITECTURAL IRREGULARIRIES

2.1 TORSIONAL IRREGULARITY - DUE TO MASS CONCENTRATION ON ONE SIDE OF THE BUILDING

Torsional irregularity should be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Also to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure. Torsional irregularity can be well explained with a wooden cradle

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Consider a wooden cradle tied identically with two equal ropes to the branch of a tree. Buildings too are like these rope swings; just that they are inverted swings. Buildings vibrate back and forth during earthquakes. The vertical walls and columns are like the ropes, and the floor is like the cradle.

In a building, the main lateral force is contributed by the weight of the floors, walls, and roof, and this force is exerted through the center of mass, usually the geometric center of the floor (in plan). When the load on the building is equally distributed i.e. When centre of mass or centre of gravity of the building coincides with the centre of resistance there will be no torsional effect (Fig1).

This is just the same as when we sit on the cradle at the centre, there will be no twisting of the cradle. But when we sit at the corner of the cradle the mass will be concentrated on the corner of the cradle. Therefore it hoists i.e. moves more on the side we are sitting. Likewise, if the mass on the floor of a building is more on one side (for instance a storage place or heavy equipment is placed on one side of a building) the building moves such that its floors displace horizontally as well as rotate.

Similarly in a building with unequal structural members the floor twists about vertical axis and displace horizontally. Likewise, buildings which have walls only on two sides (or one side) and flexible frames along the other, twist when shaken at the ground level (Fig1).

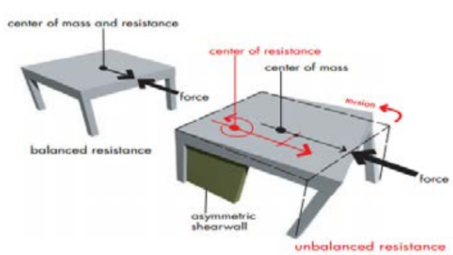

Fig1: Torsional forces

Torsional forces are created in a building by a lack of balance between the location of the resisting elements and the arrangement of the building mass. This is referred to as eccentricity between the center of mass and the center of resistance, which makes a building subjected to ground motion. This makes different portions at the same floor level to move horizontally by different amounts, rotate around its centre of resistance creating torsion. This torsional force induces more damage in the frames and walls on the side that moves more.

A (G+5) multi storey plan of torsional irregular structure as per IS 1893(Part I):2002 is considered for the study. Modeling, analysis and design of the structure is done by STAAD Pro software. Building model and plan considered is shown in Figure

Fig2: Plan of the building considered

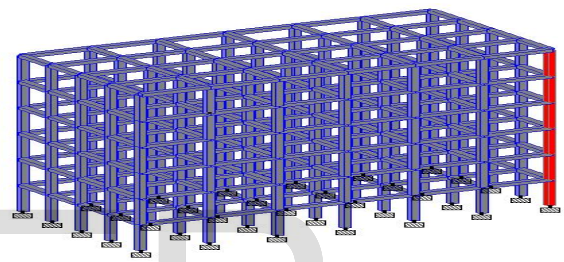

Fig3: Model of the building considered

(Red colored column shows the most critical column)

TABLE 1

PRELIMINARY DATA

Bay dimensions	4.0m x 4.0m
No. of storeys	G+10
Storey height	3.0 m
Beam dimension	450mm x 450mm
Column dimension	450mm x 450mm
Slab thickness	130mm
Support conditions	Fixed
Beam Releases	Axial force

ISSN 2229-5518

LOADING CONSIDERATION

Loads acting on the structure are dead load (DL), Live Load (IL) and Earthquake Load (EL)

- DL: Self weight of the structure, Floor load and Wall loads
- LL: Live load 3 kN/sq.m is considered
- Seismic Load cases: Zone: III, IV, V
- Response reduction factor: 5
- Importance factor: 1.5
- Damping: 5

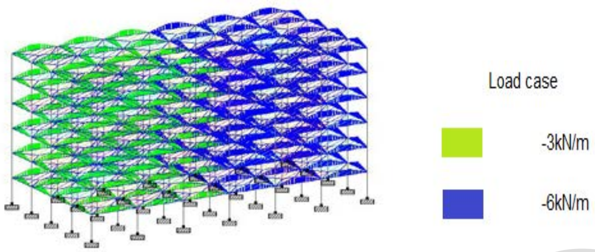

Fig4: Load consideration on the structure

TABLE 2

RESULTS: ANALYSIS AND DESIGN

Particulars	Gravity Design	Earthquake Design		
		Zone lll	Zone IV	Zone V
Axial Force (Fx) kN	1116.20	1430.89	1672.0	2033.71
Shear (Fy) kN	9.882	7.8461	7.861	7.883
Shear (Fz) kN	5.425	63.938	94.274	140.425
Bending Moment (Mz) kN-m	26.068	10.556	10.587	10.632
Bending Moment (My) kN-m	14.474	155.06	229.961	342.61
Torsion (kN-m)	0.025	0.064	0.107	0.17
Deflection (mm)	2.667	5.393	8.090	12.134
Area of steel required (sq.mm)	1620	2035.75	4398.22	6872.23

CONCLUSION:

In a building in which the mass is approximately evenly distributed in plan (typical of a symmetrical building with uniform floor, wall and column masses) the ideal arrangement is that the earthquake resistant elements should be symmetrically placed, in all directions, so that no matter in which direction the floors are pushed, the structure pushes back with a balanced stiffness that prevents rotation. Excessive torsional behavior of the structure will occur due to torsional irregularity. This twisting action in plan, results in undesirable and possibly dangerous concentrations of stress due to which the structure fails. This failure occurs where there is maximum movement of structural elements or twisting.

METHOD TO REDUCE THIS EFFECT

Past study of the structures have shown that during earthquake excessive torsional behavior will severely affect the building. So it is best to minimize (if not completely avoid) this twist by ensuring that buildings have symmetry in plan. If this twist cannot be avoided, special calculations need to be done to account for this additional shear forces in the design of buildings; the Indian seismic code (IS 1893, 2002) has provisions for such calculations. In practice, some degree of torsion is always present, and the building code makes provision for this.

2.2 RE-ENTRANT CORNERS

Plan configurations of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15 percent of its plan dimension in the given direction. Weak points occur where the concrete slab forms an internal corner because of overall shape of the building. This internal corner in a T-shape, L-shape, C-shape and O-shape of the building is referred to as re-entrant corner.

A re-entrant corner creates a tensile stress concentration to create at the corner as a slab tries to linearly shrink and move in two directions at right angles to each other. At the re-entrant corner the stiffness is high which results in the

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high stress concentration at the re-entrant corner. As the stress increases, failure occurs at the re-entrant corner.

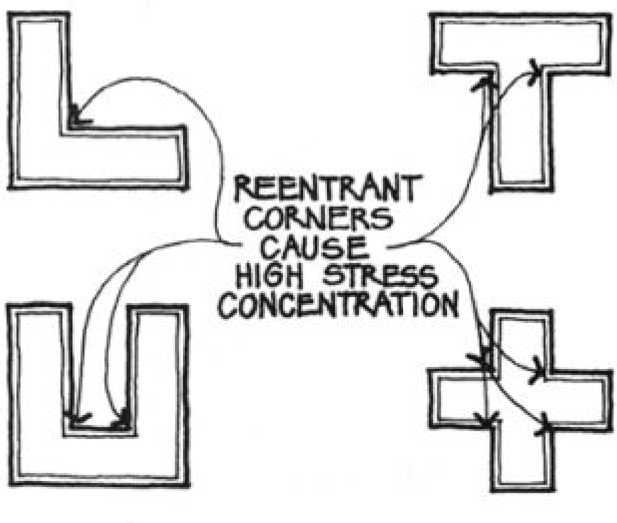

Fig5: Re-entrant corner

T-SHAPE BUILDING - RE-ENTRANT

T-shape contains two re-entrant corners. Hence these corners are under high stress. The inner corner column is very stiff due to the presence of two slabs along different directions. Hence due to variation in the stiffness a high concentration of stress is developed at these corners. Hence requires higher section and more reinforcements to be safe in higher seismic zones. The reinforcement required is studied in the following case study.

PROBLEM DEFINITION: A (G+5) multi storey T-shape irregular structure as per IS 1893(Part I):2002 is considered for the study. Modeling, analysis and design of the structure are done by STAAD Pro software. Plan of the building considered is shown in Figure6.

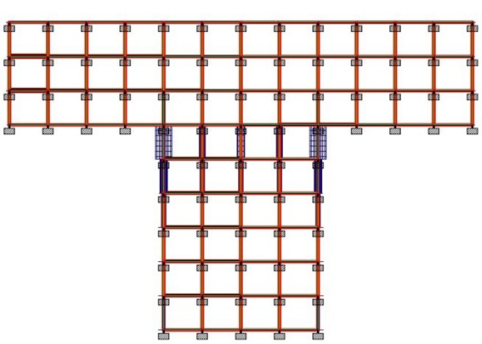

Fig6: Plan

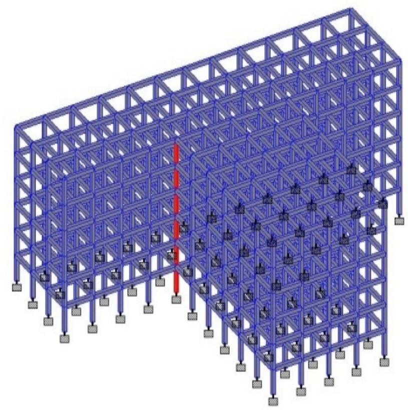

Fig7 : T-shape building showing one of the critical section (red column)

LOADING CONSIDERATION

Loads acting on the structure are dead load (DL), Live Load (IL) and Earthquake Load (EL)

- DL: Self weight of the structure, Floor load and Wall loads
- LL: Live load 3kN/sq. m is considered
- SL: Zone: IV
- Soil type: II
- Response reduction factor: 5
- Importance factor: 1.5
- Damping: 5%

TABLE 3

PRELIMINARY DATA

Bay dimensions	4.0m x 4.0m
No. of storeys	G+10
Storey height	3.0 m
Beam dimension	450mm x 450mm
Column dimension	450mm x 450mm

ISSN 2229-5518

Slab thickness	130mm
Support conditions	Fixed
Beam Releases	Axial force

RESULTS:

Axial force, shear, moment carrying capacity, torsion and deflection are given in the table4.

TABLE 4

BENDING, SHEAR, TORSION AND REINFORCEMENT

Axial Force (Fx) kN	1815.659	1967.314	4980.45	2000.02
Shear (Fy) kN	3.507	2.396	2.07	1.581
Shear (Fz) kN	14.34	114.332	170.162	253.875
Bending Moment (Mz) kN-m	3.651	2.624	2.317	1.857
Bending Moment (My) kN-m	197.347	206.218	308.055	460.801
Torsion (kN-m)	0.212	0.256	0.391	0.594
Deflection (mm)	1.56	3.77	5.66	8.49
Area of steel required (sq.mm)	1809.55	2261.95	4908.7322	6872.23

CONCLUSIONS: At the re-entrant corner the stiffness is high which results in the high stress concentration at the re-entrant corner. As the stress increases, failure occurs at the re-entrant corner. A shrinkage stress is developed at the re-entrant corner of the concrete slab.

METHOD TO REDUCE: It must have additional reinforcement as cracks are likely to develop from this point. It is sufficient to use an additional layers of trench mesh a minimum of 2m long laid diagonally across the re-entrant corner as shown in the figure below-

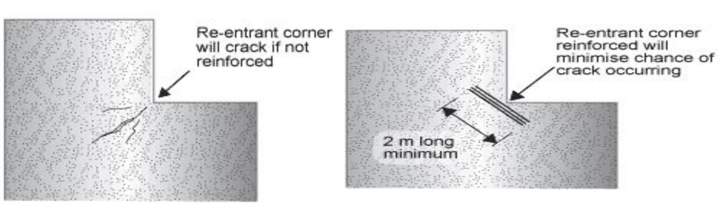

Fig8.Method to reduce Re-entrant corner

Re-entrant corners cause high stress concentration. If a re-entrant corner is unavoidable, it should be strengthened using drag struts in the portions which is under high stress which is shown by the red colour in the figure below, or preferably a seismic separation should be provided.

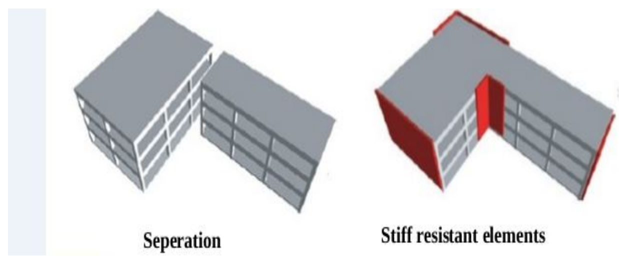

Fig9: Seismic separation of a building and a banded together by additional steel strut

L-SHAPE - VERTICAL GEOMETRIC IRREGULARITIES

Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent store.

PROBLEM DEFINITION: A (G+10) multi storey plan of torsional irregular structure as per IS 1893(Part I):2002 is considered for the study. Modeling, analysis and design of the structure is done by STAAD Pro software. Building model and plan considered is shown in Figure10

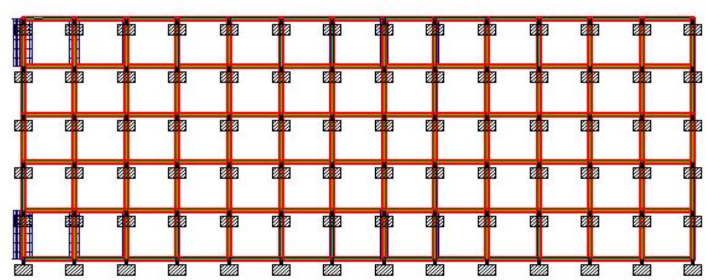

Fig10: Plan of the L-shape building showing torsion

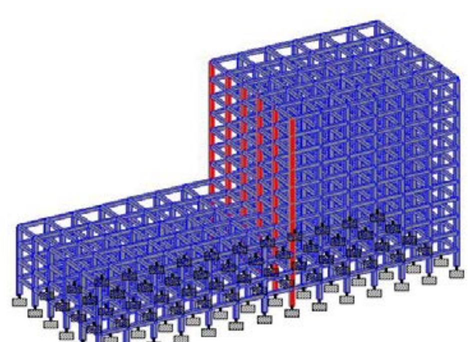

Fig11: Model of L-shaped structure

The red colored columns are the critical columns during an earthquake with this shape of a structure.

TABLE 5

PRELIMINARY DATA

No. of storeys	G+10
Storey height	3.0 m
Beam dimension	450mm x 450mm
Column dimension	450mm x 450mm
Slab thickness	130mm
Support conditions	Fixed
Beam Releases	Axial force

RESULTS:

TABLE 6

ANALYSIS AND DESIGN

Parameters	Gravity Design	Earthquake Design		
		Zone lll	Zone lV	Zone V
Axial Force (Fx) kN	2442.41	3963.67	5027.92	5803.2
Shear (Fy) kN	31.14	30.39	69.04	98.64
Shear (Fz) kN	24.98	84.82	155.15	224.67
Bending Moment (Mz) kN-m	40.5	56.25	103.56	151.68
Bending Moment (My) kN-m	30.85	174.08	289.94	428.26
Torsion (kN-m)	0.02	6.71	10.08	15.12
Deflection (mm)	2.25	6.73	15.89	19.68
Area of steel required (sq.mm)	3412.7	4872.18	6860.89	8835

CONCLUSION: From the above analysis following results may be acquired. The above structure when designed for different seismic zones showed a insufficient reinforcement at the critical section which is shown as red column. At the corner due to the irregular loading at the critical section the column undergoes shrinkage stress.

METHOD TO REDUCE THIS EFFECT: Following method can be adopted to reduce the effect

One of the methods is to provide seismic separation as shown in the fig.5.47 below. This reduces the irregularity.

But it should be placed in such a distance that there will not be any effect of pounding or any other effect.

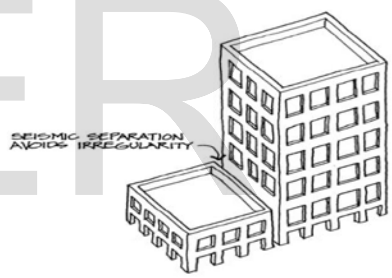

Fig12: L-shape building being seismically separated

III. ACKNOWLEDGEMENT

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