STUDY OF TORSIONAL EFFECT UNDER SEISMIC CONDITION ON BUILDING WITH IRREGULARITIES

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Abstract - *Today's diverse architectural design trends have produced tall buildings of various forms, such as twisted, tilted, and free forms, as can be seen in the infinity Tower in Dubai, Veer Towers in Las Vegas and Phare Tower project in Paris. The structural efficiency of each system, in conjunction with building forms, heights and height-to-width aspect ratios, is studied; parametric structural models are generated to investigate the impacts of variation of important geometric configuration of complex-shaped tall buildings. Structures may be irregular due to non-uniform distribution of mass, stiffness, strength or due to their structural form. For regular structures, simple analysis techniques such as the Equivalent Static Method have been calibrated against advanced analysis methods, such as the Inelastic Dynamic Time-History Analysis.*

The Indian Standard code IS-1983:2002 (Part-1) defines a number of structural irregularities. The code suggests a different approach of analysis for irregular structures. In this paper, response of a 10-storeyed plane frame to lateral loads is studied for mass and stiffness irregularities in the elevation. Hence proper understanding of the seismic behavior of irregular building needs to be studied and a proper guideline is to found out.

The aim of this project is to study the effect of various types of irregularities in building regarding its seismic behavior. To analyze the structural frames and develop guidelines regarding the seismic analysis of irregular building.

Objectives:

1. *To understand behavior of structural systems with horizontal and vertical irregularities.*
2. *To understand seismic design guidelines for structure with irregularities.*
3. *To anlyse and design structure with horizontal and vertical irregularities*.

Key Words: *Torsional effect on building, shear force, seismic force, irregularities*

1. INTRODUCTION

High rise buildings have become a common feature in all megacities of India. The Indian standard 1893-2002(I) recommends simple and symmetric configuration from earthquake safety point of view for all high rise building. The code also restricts Horizontal and Vertical Irregularities in the structure as these may result in enormous amount of torsion at various levels in the building. Though it is not feasible to rule out irregularity, horizontal or vertical in the building adequate treatment and design precautions are necessary to make the structure seismic resistant. The effect of these irregularities especially in relevance to the torsional effect is not extensively studied and the available literature does not indicate substantial theoretical base in estimating generation of torsion due to irregularities.

In the past, several major earthquakes have exposed the shortcomings in buildings, which had caused them to damage or collapse. It has been found that regular shaped buildings perform better during earthquakes. The structural irregularities cause non-uniform load distribution in various members of a building. There must be a continuous path for these inertial forces to be carried from the ground to the building weight locations. A gap in this transmission path results in failure of the structure at that location. There have been several studies on the irregularities, viz., evaluation of torsional response of multi-storey buildings using equivalent static eccentricity (Tabatabaei and Saffari, 2011), three dimensional damage index for RC buildings with planar irregularities (Jeong and Elnashai, 2006), seismic response of vertically irregular frames with pushover analysis (Chintanapakdee, Chopra, 2004) and evaluation of mass, strength and stiffness limits for regular buildings specified by UBC (Valmundsson and Nau, 1997), etc

1.1 Types of Irregularities in Buildings –

1.1.1 Plan Irregularities

Types of plan irregularities

1. **Torsion Irregularity**
2. **Re-entrant Corners**
3. **Diaphragm Discontinuity**
4. **Out-of-Plane Offsets**
5. **Non-parallel Systems**

1.1.2 Vertical Irregularities

Types of vertical irregularities

1. **Stiffness Irregularity —Soft Storey**
2. **Stiffness Irregularity —Extreme Soft Storey**
3. **Mass Irregularity**
4. **Vertical Geometric Irregularity**

5. **In -Plane Discontinuity in Vertical Elements Resisting Lateral Force**
6. **Discontinuity in Capacity- Weak Storey**

2. REVIEW OF LITERATURE

2.1 Overview

The Chapter 2 presents a critical appraisal of the previous work published in the literature. Some papers are examined based on irregularities in the building and its seismic effect, accordingly objectives were framed and analysis is carried out.

Suhaib Salawdeh: - in their paper presented is to investigate and develop seismic design guidelines for two types of vertical irregular buildings; (i) vertical irregularity associated with steps in building plan area (core walls full height and frames that have more bays at base of building than at top), and (ii) vertical irregularity associated with core walls that stop around mid-height of the building. The work develops a Direct Displacement Based Design (DDBD) approach which is used to design 12 and 4 story case study buildings of each structural type. Non-linear time-history analyses are then used to verify the performance of the method and the results indicate that the DBD approach is very effective for frame wall structures with setbacks and is reasonably effective for frame-wall structures possessing cores that stop at intermediate levels. Experience from past earthquakes shows that irregular buildings are prone to severe damage. Where the irregularity is due to changes in stiffness, strength, mass or setback of one floor to that of an adjacent floor. From the study of various structural failures, it was found that a soft and/or weak story in any building poses a high risk of damage during a seismic event (Das and Nau, 2003).

K.Moon:- Today's diverse architectural design trends have produced tall buildings of various forms, such as twisted, tilted, and free forms, as can be seen in the Infinity Tower in Dubai, Veer Towers in Las Vegas and Phare Tower project in Paris. This paper studies various structural system design options for these complex-shaped tall buildings and their performances. For each complex form category, tall buildings are designed with different contemporary structural systems, such as diagrids, braced tubes and outrigger systems. The structural efficiency of each system, in conjunction with building forms, heights and height-to-width aspect ratios, is studied. Parametric structural models are generated to investigate the impacts of variation of important geometric configurations of complex-shaped tall buildings. The models are then exported to structural engineering software for analyses and design. Based on the study results, comparative structural efficiency of different structural systems for tall buildings of each complex form category is estimated.

Tall buildings, which emerged in the U.S. in the late nineteenth centuries, are now constructed in major cities throughout the world. While the early design of tall buildings culminated with the dominance of the International Style, which prevailed for decades and produced prismatic Miesian style towers all over the world, today's pluralism in architectural design has produced tall buildings of many different forms, including more complex forms such as twisted, tilted and free forms. The amount of available information on design and construction of complex-shaped tall buildings is relatively small due to the lack of accumulated experience. This paper studies performance-based structural design options for various complex-shaped tall buildings to provide preliminary design guidelines. Structural designs of tall buildings are generally governed by lateral stiffness rather than strength. As the height of a building becomes taller, the amount of structural material required to resist lateral loads is increased drastically due to the premium for height. The performance of the structural systems in this study is measured primarily by their lateral stiffness. Parametric structural models are generated using appropriate computer programs such as Rhino and Grasshopper to investigate the impacts of the variation of important geometric configurations of complex-shaped tall buildings, including the rate of twist, angle of tilting and degree of fluctuation of free form. The models are exported to structural engineering software such as SAP 2000 for analyses, design and comparative studies.

G.F. Dargush: - In this paper, we develop a parallel genetic algorithm-based approach for discrete optimal design of passively damped structural systems within an uncertain seismic environment. The primary structure may contain metallic yielding dampers, viscous fluid dampers or visco elastic solid dampers of various sizes, distributed throughout the building. For each candidate design, a series of nonlinear transient dynamic analyses are conducted within a spatially-distributed seismic environment consistent with the USGS Gutenberg-Richter model for eastern North America. A graphical user interface also is created to enable visual display of evolving designs and to interactively interrogate the design database. Several examples are considered to elucidate the methodology and to assess the potential benefits of the evolutionary approach for seismic design and retrofit. While this methodology is sufficiently general to consider a broad range of structural systems, here the emphasis is placed on steel frame buildings with structural irregularities.

Passive energy dissipation systems are now widely used for the seismic control of civil engineering structures and a wide variety of device types are available, including metallic yielding dampers, friction dampers, viscous fluid dampers and visco elastic dampers (e.g., Soong [1]; Constantine [2]). While the introduction of these passive energy dissipation concepts and systems presents the structural engineer with considerable freedom in a seismic design and retrofit, further guidance may be needed to help direct the design process. In order to address this issue, several simplified design procedures have been in development over the past decade (e.g., FEMA [3-6]). These procedures are oriented mostly toward the design of simple uniform structures. Alternatively, one may attempt to develop new computational approaches that can provide insight into seismic performance, as well as design guidance both for simple structural systems and for more complicated irregular structures. Here we adopt this latter approach and continue our development of an evolutionary approach for a seismic design and retrofit with special focus on irregular structures. Previous research on the application of genetic algorithms to passively damped structures includes the work by Singh [7-9] and Dargush [10-14]. In particular, we extend the latter approach by introducing a parallel genetic algorithm for the discrete optimal design of passively damped structures within an uncertain seismic environment. The primary irregular structure may contain a number of metallic yielding dampers, viscous fluid dampers and/or visco elastic solid dampers over a range of sizes. The seismic environment is characterized in a manner consistent with the USGS database for eastern North America (Frankel [15, 16]) and the synthetic ground motion generation algorithm developed by Papageorgiou [17] is utilized for each realization. In order to estimate seismic performance for each potential design configuration, a series of transient dynamic analyses are conducted utilizing an explicit state-space approach. A graphical user interface is also created to enable a visual display of the evolving designs and to provide a means to interactively interrogate the database. Several examples are examined in order to elucidate the methodology and to assess the potential benefits of the approach for a seismic design of irregular structures.

3.ANALYSIS OF STRUCTURE

To investigate the development of torsion with an introduction of irregularity at various floors an arbitrary structure is created, here column 1(middle column), column 2(side column) and column 3(corner column) were chosen for critical investigation of torsion with introduction of irregularity at various floors. The study was carried out in three phases:

1. Analysis of arbitrary structure with systematic introduction of irregularity.
2. Analysis of realistic structure defined for case 1.
3. Analysis of predesigned structure with irregularities as per case 1.

Load case considered is 1.5(DL+EQZ).

3.1 STRUCTURE AND CASES CONSIDERED – Preliminary Analysis

To initiate the effect of irregularities on torsion and shear of these columns 8 different cases as detailed below were considered and for all these cases the structure was analysed using STAAD.Pro, shear and torsion at all floor levels in these 3 columns was noted and documented. The observations are presented in tabular as well as graphical form. A comparison between case 0 and case 8 effects on all floors is presented

Case0	Normal case containing all panels.
Case 1	One panel of dimension 5m×5m is removed on sixth floor.
Case 2	Two panels of dimension 5m×5m is removed on sixth floor.
Case 3	Three panels of dimension 5m×5m is removed on sixth floor.
Case 4	Four panels of dimension 5m×5m is removed on sixth floor.
Case 5	Five panels of dimension 5m×5m is removed on sixth floor.
Case 6	Six panels of dimension 5m×5m is removed on sixth floor.
Case 7	Seven panels of dimension 5m×5m is removed on sixth floor.
Case 8	Eight panels of dimension 5m×5m is removed on sixth floor.

Table No.3.1 Table showing 8 diff irregularity cases

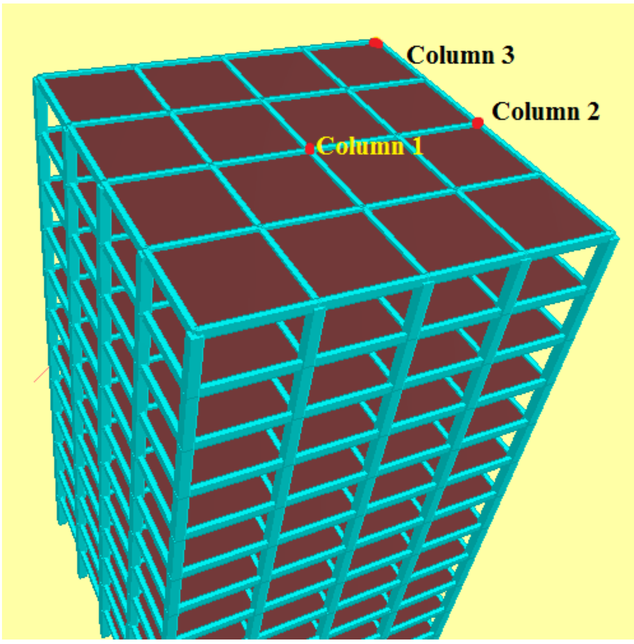
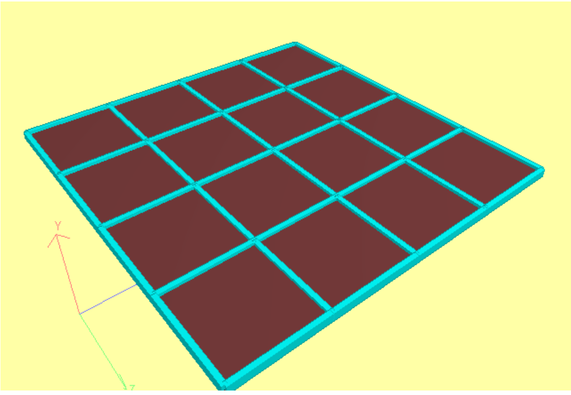
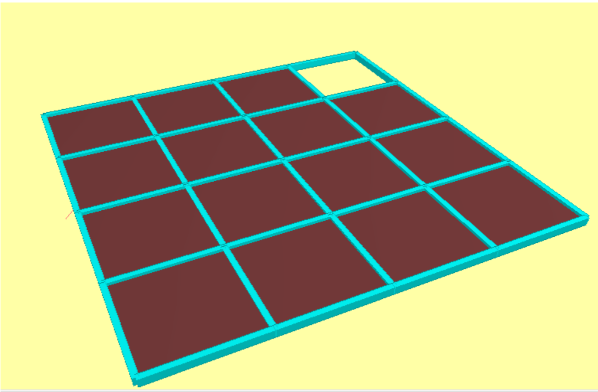


Fig . Rendered View of Model





3.2 Values Calculated By Stadd. Pro

Floors	Case 0	case 8
11	-266.466	-265.378
10	-402.032	-401.211
9	-580.087	-579.306
8	-750.295	-748.952
7	-919.694	-928.194
6	-1086.77	-1052.77
5	-1251.5	-1198.79
4	-1413.53	-1370.76
3	-1571.84	-1525.3
2	-1721.34	-1674.53
1	-1846.53	-1800.48

Floors	Case 0	case 8
11	0	-0.024
10	0	0.021
9	0	0.18
8	0	0.66
7	0	1.849
6	0	3.252
5	0	3.085
4	0	-2.07
3	0	-4.037
2	0	-4.599
1	0	-4.294

Table no 3.1 Shear for col .1

Table no. 3.2 Torsion for col.1

4. RESULTS AND DISCUSSION

4.1 Overview:

In this chapter graphs are drawn from the important tabulated results and observations based are discussed.

To understand the effect of horizontal irregularities on torsion and shear an arbitrary building of (G+10) floors was considered. The details are given fig (5.1to 5.9). The building plan is 20m×20m containing 16 panels of size 5m×5m each. Arbitrary configuration of building was chosen to link the effect of shift in CG in X and Z direction and reduction in area on three different columns. Three different columns are column1 (central column), column2 (side faced column), and column3 (corner column).

4.2 EFFECT OF HORIZONTAL IRREGULARITY AT SIXTH FLOOR ON VARIOUS FLOORS

4.2.1 Effect on Central Column

Fig. indicates that with the increase in horizontal irregularity torsion increases . It clearly indicates that torsion goes on increasing as we move from case 0 to case8. Another significant finding is that in a centrally located column the torsion is higher with the introduction of irregularity at that floor and goes on reducing at storeys away from the floor if we move towards the top of building. The torsion is practically negligible in top few floors however the torsion on floors below the floor under consideration goes on increasing in magnitude but with opposite direction.

Above observations clearly indicates that even a centrally located column must be thoroughly checked for torsion especially in all lower floors where irregularity is induced. Adequate precautions must be taken in designing of this column. As far as effect as effect in shear (Z direction) there is marginal change at floors under consideration and floors below however there is no significant effect of this irregularity in floors above in irregularity induced floors.

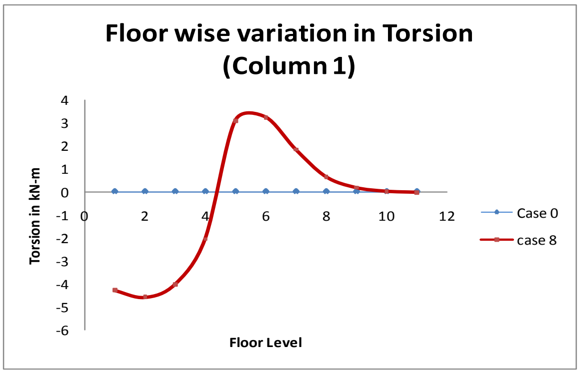


Fig No. 4.1 Variation in Torsion for col 1

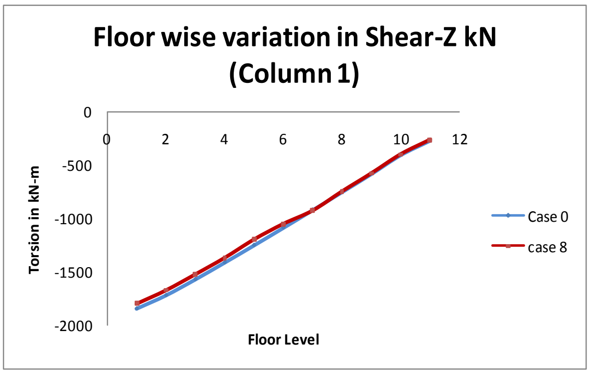


Fig No. 4.2 Variation in shear for col 1

4.2.2 Effect on Side Column

The behaviour under torsion of this column is someway similar to that of central column however the magnitude of torsion of floors under consideration is much higher than adjacent floors. Its effect on lower floors is similar to central column but on higher floors torsion may be induced. As far as shear in Z direction is considered, the effect is similar to that of central column.

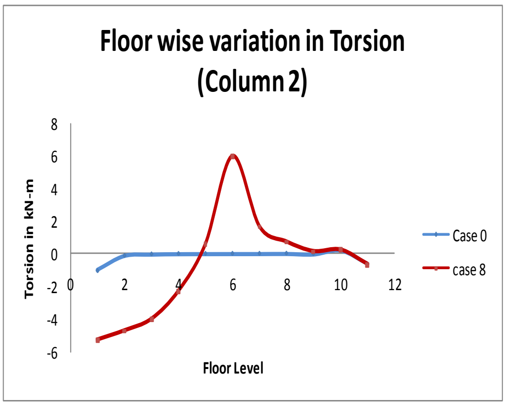


Fig No. 4.3 Variation in Torsion for col 2

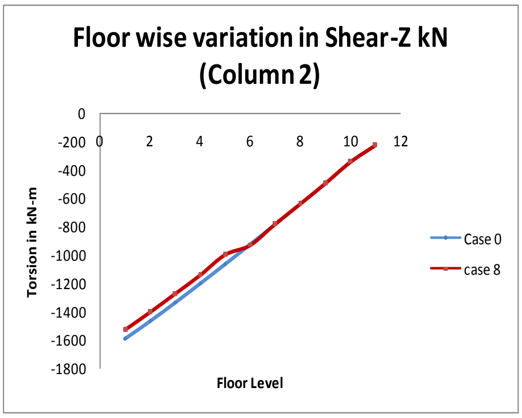


Fig No. 4.4 Variation in shear for col 2

4.2.3 Effect on Corner Column

The effect of irregularity at sixth floor has a relevance of shift in CG and area reduction on torsion. However the effect is very erratic in nature torsion will be maximum at floor where irregularity is induced but it may have reduction then increase and again reduction if we go below the floor under consideration. Torsion may be practically zero in few floors above the floor under consideration but again there may be torsion in top few floors.

So corners column must be critically analysed at all floors and designed for torsion considering the effect of irregularities. The effect of shear in corner column is similar to that of central or side column. One of the most important finding of this study indicates that if horizontal irregularities are induced upto some floors there may not be significant variation in horizontal shear in all floors above that floor.

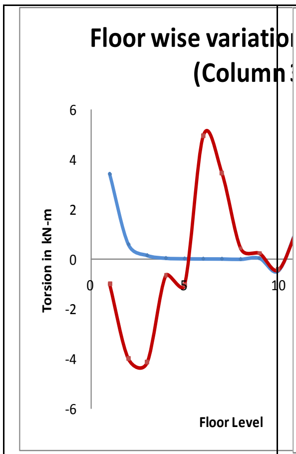


Fig No. 4.5 Variation in Torsion for col 3

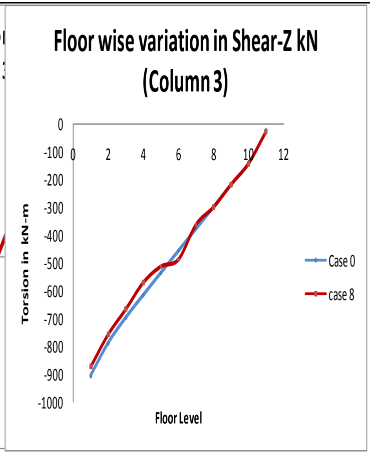


Fig No. 4.6 Variation in shear for col 1

4.3 Effect of Horizontal Irregularity on Sixth Floor on Various Floors

4.3.1 Effect on Central Column

Fig indicates that increase in the horizontal irregularity results in increase in torsion. Initially without the introduction of any irregularity, the torsion is zero. But when irregularity is introduced at sixth floor (case 8) then it is found that the torsion is suddenly increased on that floor. This also reflects that magnitude of torsion is higher at floor where irregularity is introduced but goes on decreasing on the floors above where the torsion is practically negligible. But the floors below experiences twisting moment. This clearly indicates that proper precaution should be taken while designing the centrally located column. As far as the effect in shear (Fz), there is marginal change at floors under consideration and floors below. However there is no significant effect in the floors above the irregularity induced floors.

4.3.2 Effect on Side Column

Initially the torsion in the side column is similar to that of central column. Similar behaviour in torsion increment can be seen when irregularity is induced. Sixth floor, where irregularity is introduced experiences torsion to greater magnitude and it goes on decreasing as we move up. However on the floor below the torsion goes on reducing but in opposite manner. This indicates that twisting point is observed on the floor where irregularity is observed. Looking on to the shear force (Fz) there is no substantial effect. Some change in force is experienced on the floor where the irregularity is introduced and the floors below. But on the floors above there is no change in the force.

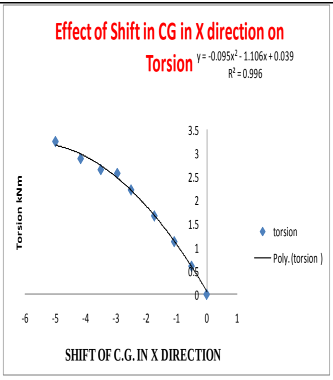


Fig No 4.7 Relevance of CG to Torsion for col.1

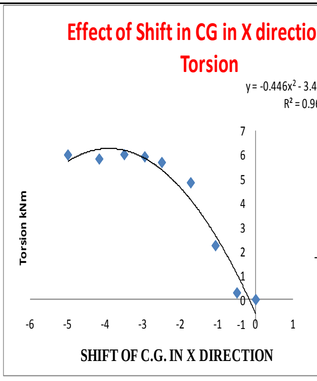


Fig No4.8 Relevance of CG toTorsion for col.2

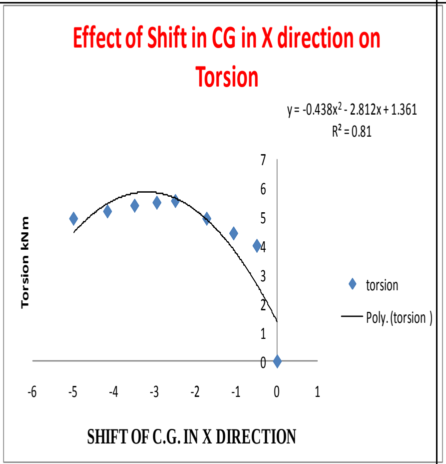


Fig No 4.9 Relevance of CG to Torsion for col.3

An attempt was made to find out relevance of shift in CG in X and Z direction on development of torsion on that particular floor. Table (4.43,4.44 and 4.45) indicates that development of shear as well as torsion due to induction of step by step irregularity at sixth floor on central, side, and corner column.

Fig. indicates relevance of shift in CG in X direction on torsion, it is realised that the shift in CG in X direction results in the development of torsion in middle as well as side column. However development of torsion in corner column may be due to some additional effects than the shift in CG in X direction.

5. CONCLUSIONS

1. Stiffness irregularity results in development of higher amount of torsion than mass irregularity.

2. Irregularity induced at any floor level results in development of substantial torsion at adjoining floors and floors below it. The effect is significantly low of floors above where irregularity is induced.

3. Irregularity linked torsional development in column located in middle part of structure and sideways can be predicted, however there can be erratic development of torsion in corner column. Thus critical analysis of corner column is essential for lateral loads.

4. Torsional development in middle as well as side column can be correlated with shift in CG and reduction in floor area if an irregularity is brought in structure at particular floor level.

5. Preliminary design is essential for estimating development of torsion due to lateral loads as otherwise it may lead to higher values of torsion at every location.

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