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A Comparative Study of Geometry and Locations of Shear Walls on Regular and Irregular RC Structures by Using Response Spectrum Analysis

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Abstract

Objectives: The current study intended to compare the geometry and location of shear walls on regular and irregular structures. **Method**: Using the software Response Spectrum method in ETABS, the dynamic parameters of irregular and regular structures with varied shear wall positions have been compared in this research. **Findings**: The output completely favours the system with shear wall rather than the system without a shear wall. The oscillation period of the RC frame structure with the shear wall is reduced by 50% to 60% when compared to the oscillation period of the RC frame G+14 multi-story structure without a shear wall. Stiffness and dynamic parameters also favour Regular buildings with the shear wall. **Novelty**: The novelty of this work is the comparative study of regular and irregular structures by considering both the parameters like the location of the shear wall along with geometry and material nonlinearity.

Keywords: Shear Wall; RCC Structures; Irregular RC Structures; Dynamic analysis; Response spectrum method

1 Introduction

A multi-story building's response to strong seismic activity depends on its structural design. It is well accepted that uneven configuration, whether in plan or height, is one of the major factors leading to collapse during earthquakes. When the reasons for earthquake damage are investigated during the architectural design process, the disintegration of a structure under earthquake forces frequently begins. The phase of architecture design, which is the most crucial in earthquake-resistant building design, determines how the structural system will be organized. The research emphasises that this design phase has the greatest potential to change building prices like this.[(1)]. The majority of the urban infrastructure consists of erratic constructions. Analysis and design are more challenging when these buildings are constructed in seismically active regions. Such anomalies may lead to stress concentrations and force flow halt. When the centre of rigidity and mass are out of alignment, an uneven configuration of stiffness and mass of parts may cause a significant torsional force. The variations in mass and stiffness along the height axis cause such buildings' dynamic qualities to differ from those of a normal building. It is well-known that erratic constructions—One of the main reasons structures fall during earthquakes is because they are irregular, whether in height or design. Consequently, irregular constructions, particularly those found in seismic zones, should be taken seriously[(2)]. Real buildings include imperfections for both cosmetic and functional purposes. The type, severity, and location of any anomalies influence how much the reactions differ from one another. The proper selection of these variables during design improves structure performance. Structures often contain a range of abnormalities, thus making predictions based on just one of them may not be correct[(3,4)]. The configuration of stiffness, mass, as well as vertical geometric, demonstrate several inconsistencies. The stiffness irregularity is discovered to have the greatest impact on the reaction of all the solitary defects of all types that have been evaluated. Among examples with patterns of irregularities, the design with vertical geometric, stiffness, and mass imperfections has demonstrated the best response. The outcomes of the research will help in the careful design of asymmetrical structures without affecting their output[(5)]. Risk-oriented strategies are essential in nations where rehabilitation of existing structures should take precedence over new construction endeavours. Reducing these structures' vulnerability is a high issue because they still comply with more out-of-date regulatory frameworks[(6)]. Shear-walled constructions perform more linearly under lateral loadings than non-shear-walled ones. In addition to increasing the structure's strength and stiffness, a shear wall reduces lateral movement. Lowering the displacement values in the same directions is accomplished by the longitudinal and transverse shear wall provisions[(7)]. The fundamental characteristics that earthquake-resistant structures must possess are a strong structural foundation, at least minimal elastic stiffness, at least minimal lateral strength, and acceptable ductility. For a building to function well during an earthquake, it needs to have four fundamental characteristics: a straightforward, regular construction, enough ductility, lateral strength, and stiffness. Buildings with basic regular geometries and evenly distributed stiffness and mass in elevation and plan sustain substantially less damage than those with erratic designs. There are different irregularities as per the codal provisions of Indian standards. Torsion Irregularity is a common thing which is in consideration. If the floor diaphragms are stiff in terms of the vertical structural factors that resist the lateral forces in their own plan. Torsional irregularity is deemed to occur when the biggest storey drift, evaluated with design irregularity, at one end of the structure across from an axis is 1.2 times greater than the mean of the storey drifts at the two ends of the building. Where the earthquake load depends on the mass centre. The opposing force acts on the structure at the centre of lateral resistance also referred to as the centre of stiffness[(8–11)]. When the centre of stiffness and mass are not in the same location, torsion problems occur. When the spacing between the centre of mass and stiffness increases, buildings are subject to significant torsional moments that force them to twist around the rigid structural part (rigid core). The amount of the torsional moment, which results from an eccentricity between the centre of mass and the stiffness of a structure, is determined by the eccentricity ratio. Extreme torsion may force structural elements to exceed their torsional moment capacity or cause the entire configuration to bend beyond its lateral deflection limit. Thus, torsional irregularities have the potential to lead to structural system failure. Additionally, torsional irregularity may result in the pounding of nearby structures that are not adequately spaced from one another. Simply raise the strength of the structural components facing the weak direction of the building or lower the strength of the structural elements facing the strong direction to avoid the torsion effects on buildings. Designing structural systems devoid of imperfections, including torsional irregularity, is undoubtedly the best solution[(10,12–14)]. Re-entrant corners are important when evaluating irregularities. The design layouts of the structure and its lateral force-resisting system have re-entrant corners if the structure's projections outside the re-entrant corners are 15% more than the design dimensions in the specified direction. Torsion and a difference in the stress-induced in separate building wings that concentrates tension at the corner are the two main effects of re-entrant corners. Any irregularity is undesirable in an earthquake-resistant system because it results in an abrupt change in the structure's stiffness or strength. In an earthquake, buildings with simple and predictable architecture are likely to fare better.[(15)]. The interior columns near the re-entrant corners receive greater earthquake loads than other interior columns. They, therefore, require more ductile. Diaphragms with sudden changes in stiffness or discontinuities, for instance, those whose effective stiffness changes over 50% from one level to the next or those having open or cut-out parts that are 50% greater than the gross enclosed diaphragm part. Continuities in a lateral force resistance path, including offsets of vertical parts that are not in the plane, are also considered an irregularity[(16,17)]. The principal orthogonal axis, the lateral force resistant elements or both are not parallel to or symmetric about the vertical elements opposing the lateral force. Furthermore, this fits the definition of irregularity[(9)].

2 Methodology

Response spectrum technique must be utilized for irregular structures with a height larger than 12m in zones IV and V (Z = 0.24, zone factor), under Article of IS 1893 (PART 1): 2002. Zones II and III are denoted by Z values of 0.10 and 0.16, respectively, as are zones higher than 40 metres (Z values of 0.36 and 0.36, respectively). Each component of a structure should be constructed for strength based on the outcomes of an elastic analysis, according to the force-based design principle, which is employed in code design techniques. Seismic analyses of structures that only take into account the maximum ground acceleration values as in comparable static methods or linear static methods fall short of fully understanding their behaviour because the response of the building depends on its inherent frequency content and dynamic aspects. RSA (Response spectrum analysis), a kind of linear dynamic analysis, directly calculates the maximum reaction of the structure from the design spectrum, which displays the design earthquake taking into account the site's features and the building's qualities[13]. The building's inherent vibration modes, which are based on the stiffness and mass distribution along the structure's height, determine the seismic forces in RSA. The SRSS (square root of the sum of squares) method will be applied to both directional and modal combinations. However, this approach ignores the structure's behaviour in nonlinear regions. Building seismic behaviour has been thoroughly studied using non-linear dynamic (time history analysis). To provide a more realistic representation of the most likely collapse and deformation process developed in a structure, this analysis attempts to design a scenario that duplicates earthquake ground motions in real-time[8,18].

The present work calculates the numerical seismic response of frames with various configurations using the finite element-based programme ETABS. The main inputs are the geometry of the frame, which comprises the storey and column sizes, the total mass of the floor, the damping ratio, elastic modulus, as well as seismic information. It is expected that the material's elastic modulus is 20000MPa. With a 5% damping ratio, Rayleigh damping is presumably possible. A load is applied before the structure is at rest, which is another assumption made. A structural reaction, including base shear, stiffness, storey displacement and drift, as well as natural time and frequency, is the ultimate result.

3 Structural Modelling Details

For the analysis, a fifteen-story structure with a 3 m-high storey height and a regular and irregular plan scaled frame is taken into consideration. The frame features five bays in the width and seven bays in the length direction. Each bay has a length and width measurement of 5 m and 4.5 m, respectively.

Table 1. Structural Dimensions

Plan Area of the regular structure	787.5m^2
Plan Area of the Irregular structure	652.5m^2
Floor-to-floor height	3m
Number of Stories	15
Beam size	400x230mm, 300x450mm
Column Size	400x400mm, 300x600mm
Slab thickness	150mm
Zone factor	0.36
Shear wall	230mm
Live load	3KN/m^2
Damping	5%
Soil type	Medium
Importance factor	1
Materials Used	M30 Concrete and Fe415 Steel
Response Reduction Factor	5
Seismic Zone	V

Figures 1 and 2 shows the elevation of the regular and irregular structure. Four different types of shear wall locations have been considered in the regular and irregular plans. Figures 3 and 4 show the Different model dimensions.

Model 1- Bare Frame

Model 2- Shear wall placed in the middle of structure (core Shear wall)

Model 3- C shaped shear wall placed at the centre of the periphery in 4 directions

Model 4- L shaped shear walls at the corners of the structure

4 Result and Discussion

The examination of regular frames with various shear wall placements and geometries produced results that were compared to those of irregular frames. Table 1 provides the parametric study of Regular Structures.

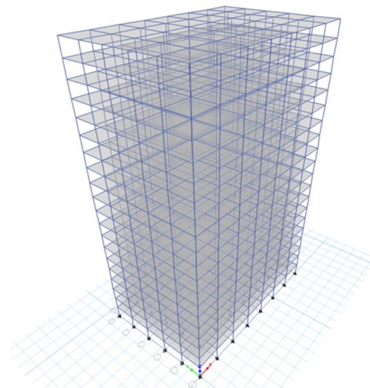

Fig 1. Elevation of Regular Building Plan

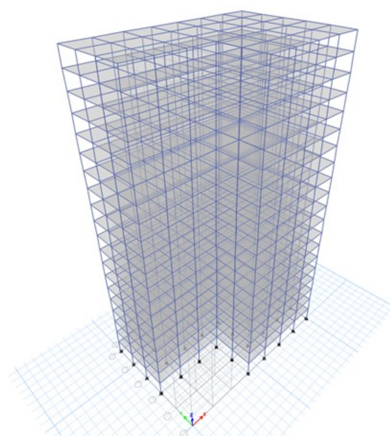

Fig 2. Elevation of Irregular Building Plan

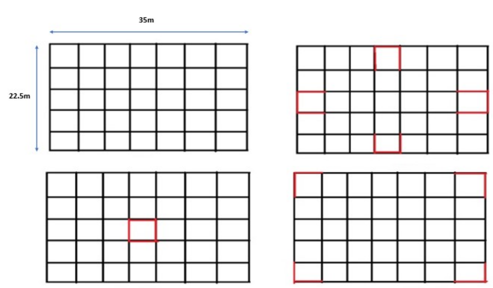

Fig 3. Plan of Different Shear Wall Positions in RegularBuildings

Table 2. Details of ParametricStudy of Regular Structures

Model No	Storey displacement	Storey drift	Stiffness	Time period	Frequency
1	2608.506	0.064	600507	2.851	0.351
2	1721.08	0.0322	1027219	2.272	0.44
3	1177	0.0317	2193914	1.878	0.533
4	1501.62	0.0305	1619738	2.121	0.471

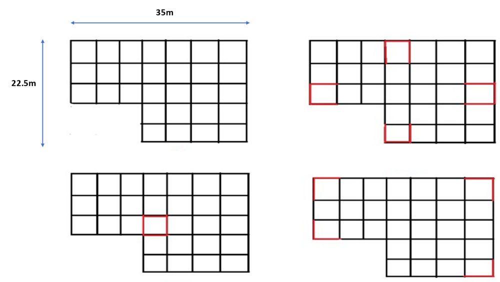

Fig 4. Plan of Different Shear Wall Positions in IrregularBuildings

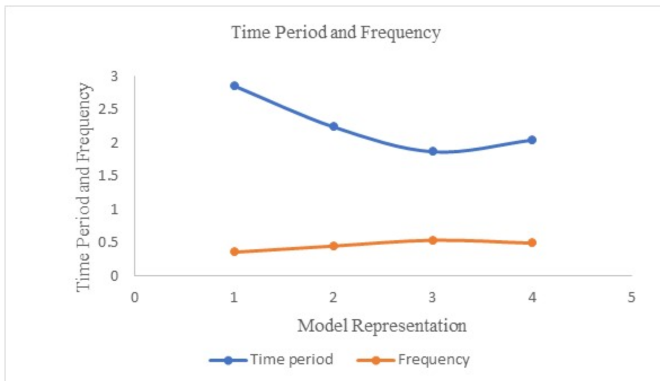

Fig 5. Comparison of the Time and Frequency of Different Models

According to the results of the investigation, it is evident that constructions with regular plans are more resistant to seismic pressures. Former studies have been done on the basis of regular structures and found the best positions of the shear wall by comparing dynamic parameters [19,20]. That was favoured by many characteristics including storey displacement, drift, and stiffness. Even when taking into account dynamic characteristics, the regularly scheduled structures exhibit notable improvements. The shear wall that is kept at the center-periphery of the outer bay will aid to withstand the lateral forces better than any other models, according to the geometry and placement analysis. For model 3 compared to model 4, the storey displacement indicates a decrease of about 28%. The story drift is significantly reduced by adding a shear wall to the structure's central perimeter. As compared to bare frames, structures with lateral load-resisting systems have remarkable stiffness.

Table 3. Details of ParametricStudy of Irregular Structures

Model No	Storey displacement	Storey drift	Stiffness	Time period	Frequency
1	2639.17	0.0641	516452	2.853	0.351
2	1694.17	0.0169	940359	2.237	0.447
3	1166.15	0.0321	1973988	1.865	0.536
4	1401.62	0.0307	1558318	2.042	0.49

It is very evident that the building's rigidity increased in comparison to the bare frame. As per the output, when shear walls are put at different locations, the fundamental natural lifespan of the building reduces. Due to weaker lateral stiffness, RC frame buildings without shear walls perform poorly during earthquake excitation when compared to RC frame buildings with shear walls [21]. When referring to seismically vulnerable places, adding structural elements like an RC shear wall can be used to improve the performance of the RC frame structure under horizontal loads. If the oscillation time of the structure is shorter, then the stiffness and mass of the structure are greater [20]. The fact that the oscillation period of the RC frame structure with the shear wall is reduced by 50% to 60% when compared to the oscillation period of the RC frame G+14 multi-story structure without a shear wall reveals that the structure with the shear wall has a higher stiffness than the structure without the shear wall.

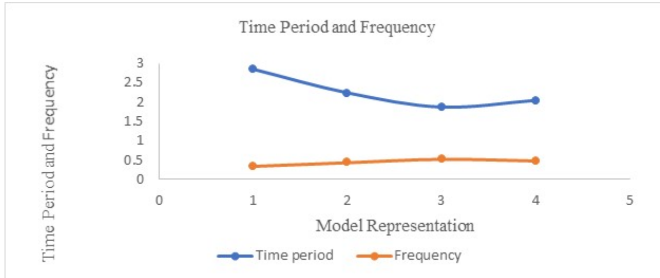

Fig 6. Comparison of the Time period and frequency of Different models

Table 4. Comparison of Model 3 in Regular and Irregular Structures

Model	Storey Displacement(mm)	Storey Drift(mm)	Stiffness(N/m)	Time Period(s)	Frequency (Rad/S)
Regular	1177	0.0317	2193914	1.878	0.533
Irregular	1166.15	0.0321	1973988	1.865	0.536

For irregular structures also the shear wall at the centre of the periphery shows more resistance to seismic forces. Both in Regular and Irregular structures model 3 dominates in all parametric studies. Table 3 represents the comparative study of Regular and Irregular model 3.

Finally comparing the irregular and regular structures of model 3, it is shown that when compared to regular buildings, displacement in X and Y dimensions is less in irregular buildings. That is a slight variation only. Stiffness and dynamic parameters also favour Regular buildings with the shear wall.

5 Conclusion

Studies are being done on the structural behaviour of multi-story frames with regular and irregular structures as well as strange combinations. The findings show that irregularity has a vital impact on the structural response. In all of the examples that were looked at, there is a change in response for frames that have one or more irregularities in comparison to the typical configuration. The results of the current investigation demonstrate that anomalies do not necessarily result in an enhanced response. The fact that the oscillation period of the RC frame structure with the shear wall is reduced by 50% to 60% when compared to the oscillation period of the RC frame G+14 multi-story structure without a shear wall reveals that the structure with the shear wall has a higher stiffness than the structure without the shear wall. An asymmetrically designed structure has a higher lateral force resisting capacity than an irregular structure when comparing the seismic response of a regular building with an irregular structure. Shear wall positions have their significance. To provide in-depth commentary it is necessary to analyze more structures with various shear wall positions.

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