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Parametric Study on Seismic Response of Mid-Rise RCC Buildings and Impact of Irregularities on Seismic Performance of these Buildings in Bhutan

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Abstract: ***The seismic behaviour of reinforced concrete (RCC) buildings is strongly influenced by structural irregularities, stiffness variation and overall building configuration. This research evaluates the seismic response of mid-rise RCC structures with different plan and vertical irregularities under earthquake conditions relevant to Bhutan. Structural models including regular, L-shaped and T-shaped buildings were analysed using Response Spectrum Analysis in ETABS according to IS 1893 (Part 1):2016 provisions. The effect of masonry infill walls was incorporated through equivalent diagonal strut modelling. Different structural cases, including soft-storey conditions, were examined to assess their influence on seismic performance. Important response parameters such as storey displacement, inter-storey drift, base shear and stiffness were compared for all models. The analysis showed that irregular structures are more vulnerable to seismic effects due to increased torsion and deformation demands, whereas infill walls improve stiffness and reduce lateral movement. The study emphasizes the need for proper seismic design and stiffness distribution in earthquake-resistant RCC buildings.***

Keywords: ***Seismic Response, Structural Irregularity, Soft Storey, ETABS, Response Spectrum Analysis, Infill Walls.***

I. INTRODUCTION

Bhutan is located in the seismically active Himalayan region, where continuous tectonic movement between the Indian and Eurasian plates makes the country vulnerable to earthquakes. Past seismic events in Bhutan and neighbouring regions have demonstrated that reinforced concrete (RCC) buildings with structural irregularities are more susceptible to damage during strong ground motions.

Several researchers have investigated the seismic behaviour of irregular RCC buildings using analytical methods such as Response Spectrum Analysis and Time History Analysis. Previous studies reported that plan irregular structures like L-shaped and T-shaped buildings experience greater deformation and drift compared to regular buildings. Research has also shown that masonry infill walls significantly influence stiffness and lateral load resistance of RCC frames.

The present study evaluates the seismic response of regular and irregular mid-rise RCC buildings under Bhutanese seismic conditions using ETABS software and Response Spectrum Analysis as per IS 1893 (Part 1):2016.

II. MATERIALS AND METHODS

The present research focuses on assessing the seismic performance of mid-rise reinforced cement concrete (RCC) buildings having different structural configurations under earthquake conditions applicable to Bhutan. Three structural layouts, namely regular rectangular, L-shaped and T-shaped buildings, were selected for the investigation. Numerical modelling and analysis were carried out using ETABS following the guidelines of IS 1893 (Part 1):2016.

The seismic analysis was carried out considering Seismic Zone V with medium soil condition as per IS 1893 (Part 1):2016. The importance factor was taken as 1.0, the response reduction factor was considered as 5 for the Special Moment Resisting Frame (SMRF) and a damping ratio of 5% was adopted for the analysis. The live loads and concrete properties were assigned in accordance with the relevant Indian Standard codal provisions.

The building models were composed of RCC beams, columns and slabs designed with standard material properties commonly adopted in reinforced concrete construction. Dynamic seismic analysis was performed using the Response Spectrum Method to evaluate the structural response under earthquake loading. Important response parameters such as storey displacement, inter-storey drift, base shear and lateral stiffness were studied for each model.

The masonry infill walls were modelled using equivalent diagonal compression struts designed in accordance with the provisions of IS 1893 (Part 1): 2016 to simulate the stiffness contribution of infill walls under seismic loading.

Different structural conditions were analysed by varying the presence of infill walls at different storey levels in order to simulate soft-storey behaviour. Comparative evaluation of regular and irregular buildings was carried out to understand the influence of stiffness discontinuity and plan irregularity on seismic response.

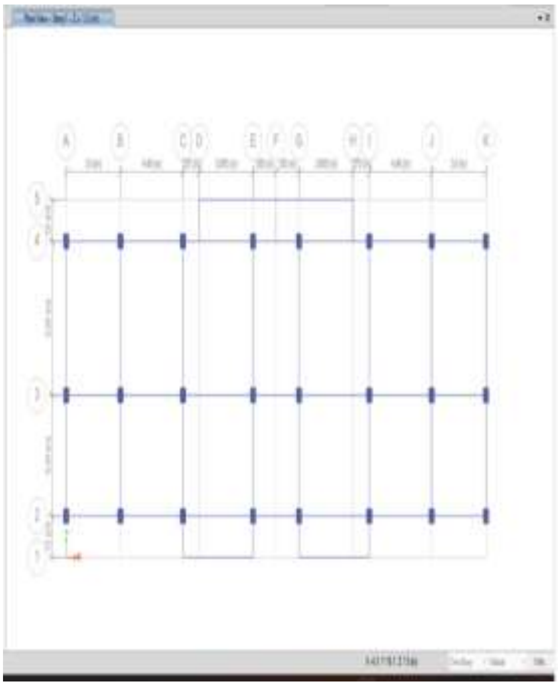

Figure 1: G+4 Regular RCC Building

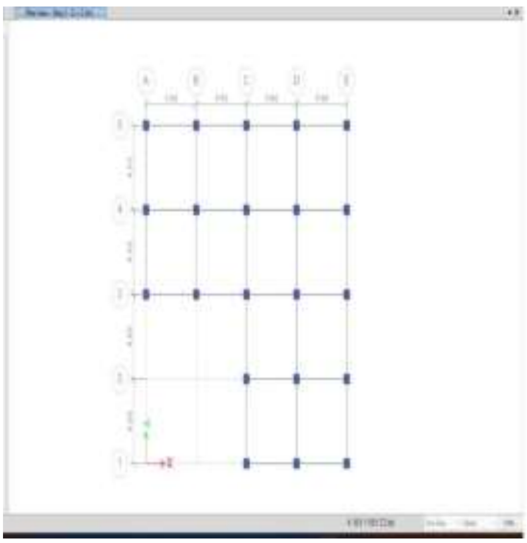

Figure 2: G+4 L- Shaped RCC Building

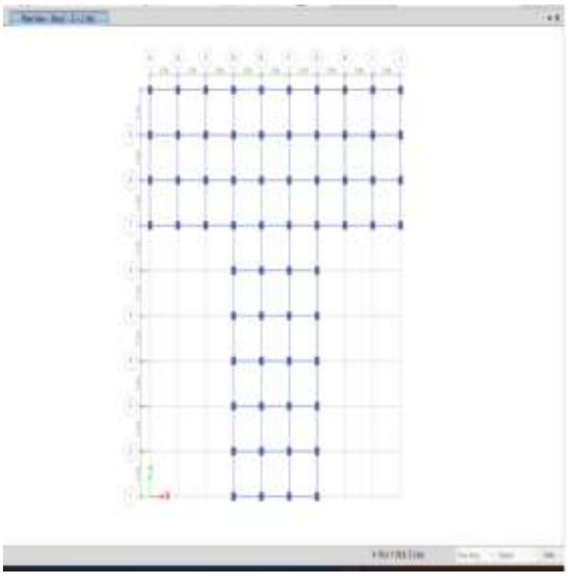

Figure 3: G+4 T-Shaped RCC Building

III. RESULTS AND DISCUSSIONS

The seismic response of the reinforced concrete (RCC) building models was evaluated using Response Spectrum Analysis in ETABS as per IS 1893 (Part 1): 2016. Three building configurations, namely Regular, L-shaped and T-shaped buildings, all being G+4, were analysed under different infill wall conditions to study the influence of structural irregularities and masonry infill walls on seismic performance. The response parameters considered in the study include storey displacement, storey drift, base shear, natural time period and storey stiffness. All the seismic parameter graphs exhibited a similar trend pattern, with variations observed only in their magnitudes. Following were the four cases considered for all the three building models:

Case 1- All floors with wall load only (No struts).
Case 2- Wall loads + Struts on all floors.
Case 3- Wall loads + No struts at Ground floor.
Case 4- Wall loads + No struts at Ground floor + First floor.

3.1 Storey Displacement:

Storey displacement represents the lateral movement of each floor level under seismic excitation. The variation of displacement along the height of the buildings was studied in both X and Y directions for all structural cases.

The analysis results showed that the displacement increased gradually from the base towards the top storey in all building models. The maximum

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displacement was observed at the roof level due to cumulative lateral deformation along the height of the structure.

Among the different building configurations, the regular building exhibited comparatively lower displacement values due to its uniform distribution of mass and stiffness. In contrast, the L-shaped and T-shaped buildings showed higher displacement values because of plan irregularity and torsional effects generated during seismic loading.

The buildings modelled with equivalent diagonal struts representing masonry infill walls showed significantly reduced displacement compared to the bare frame models. The presence of infill walls increased the overall lateral stiffness of the structures and restricted excessive lateral movement. However, when struts were removed at the ground floor and first floor levels, a soft storey effect developed, resulting in a sudden increase in displacement at those levels.

Similar trends were observed for the remaining building models in both X and Y directions; therefore, only representative graphs are presented.

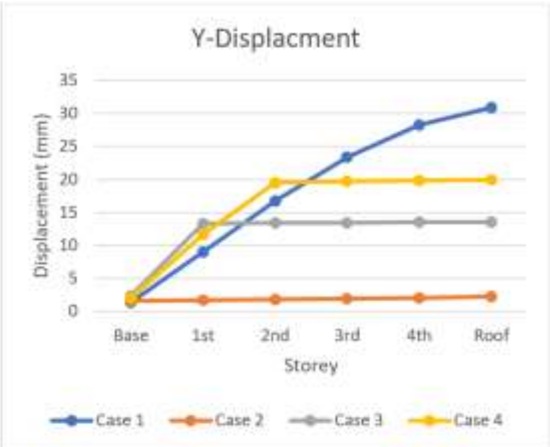

Figure 4: Storey Displacement of Regular RCC Structure

3.2 Storey Drift:

Storey drift is defined as the relative lateral displacement between two consecutive floors and is considered one of the most important parameters in seismic design.

The results indicated that storey drift values were generally higher in irregular buildings compared to the regular building. The maximum drift was observed in the middle storeys of the buildings, where lateral flexibility was comparatively higher.

The L-shaped and T-shaped buildings exhibited larger drift values due to uneven stiffness distribution and torsional behaviour. Buildings with soft storey conditions, particularly those without struts at the ground floor and first floor levels, showed a significant increase in inter-storey drift. This behaviour indicates concentration of deformation at weaker storeys, which may lead to structural damage during strong earthquakes.

The inclusion of masonry infill walls reduced storey drift considerably by enhancing the stiffness of the structural system. The drift values obtained from the analysis were compared with the permissible drift limits specified in IS 1893 (Part 1): 2016, and the models with infill walls demonstrated improved compliance with code requirements.

Figure 5: Storey Drift Variation in T-Shaped RCC Building

3.3 Base Shear:

Base shear represents the total lateral seismic force acting at the base of the structure and depends on the mass, stiffness and dynamic characteristics of the building.

The results showed that buildings with masonry infill walls attracted higher base shear values compared to buildings without struts. This increase in base shear is attributed to the higher stiffness provided by the infill walls, which reduced the natural time period of the structures and increased seismic force demand.

Among the different configurations, the regular building exhibited comparatively stable base shear distribution due to its symmetrical geometry. The irregular buildings showed variations in base shear response because of eccentricity and irregular load transfer mechanisms.

The findings indicate that while infill walls improve stiffness and reduce displacement, they also increase the seismic force attracted by the structure. Therefore, the contribution of masonry infill walls should be properly considered during seismic analysis and design.

Figure 6: Base Shear Response of Regular RCC Building

3.4 Natural Time Period:
The fundamental natural time period of a structure is an important dynamic property that influences seismic response.
The analysis results indicated that buildings with infill walls, represented by Diagonal struts, had lower natural time periods compared to bare frame models due to increased lateral stiffness. The regular building exhibited lower time period values than the L-shaped and T-shaped buildings.

The irregular configurations showed relatively higher time periods because of non-uniform stiffness distribution and increased structural flexibility. Buildings with soft storey conditions demonstrated a further increase in time period, indicating reduced stiffness and greater susceptibility to lateral deformation.

The variation in time period clearly demonstrates the influence of structural irregularities and infill wall distribution on the dynamic behaviour of RCC buildings.

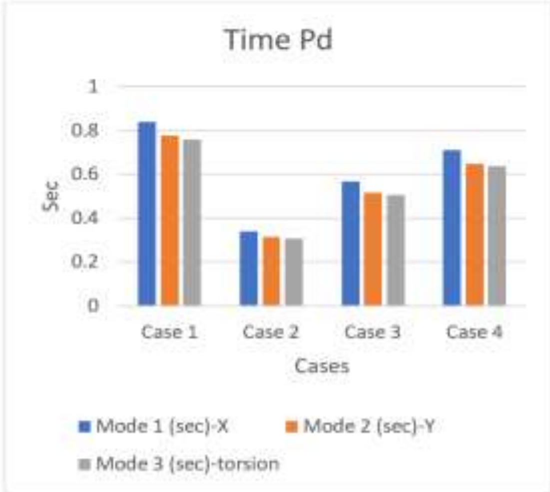

Figure 7: Time Period Variation of T-Shaped RCC Building

3.5 Storey Stiffness:
Storey stiffness plays a major role in controlling lateral displacement and drift during earthquakes.
The results showed that buildings with equivalent diagonal struts possessed significantly higher stiffness compared to buildings without infill wall modelling. The stiffness gradually decreased along the height of the building, which is consistent with typical structural behaviour.
In the soft storey models, a sudden reduction in stiffness was observed at the storeys where struts were removed. This abrupt change in stiffness resulted in concentration of drift and displacement at those levels.
The regular building demonstrated more uniform stiffness distribution, whereas the irregular buildings exhibited uneven stiffness variation due to geometric irregularities and torsional effects.

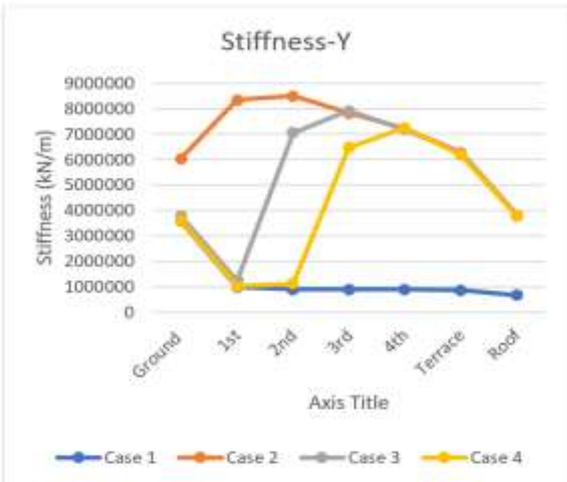

Figure 8: Storey Stiffness Variation in T-Shaped RCC Building

3.6 Discussion of Overall Seismic Behaviour:

The overall results of the study indicate that structural irregularities significantly influence the seismic behaviour of RCC buildings. Plan irregular buildings such as L-shaped and T-shaped configurations exhibited higher displacement, drift and torsional response compared to regular buildings.

Soft storey conditions caused by the absence of masonry infill walls at lower floors resulted in concentration of deformation and reduction in stiffness, making the buildings more vulnerable to seismic damage.

The inclusion of masonry infill walls using equivalent diagonal strut modelling improved the seismic performance of the buildings by increasing stiffness and reducing lateral deformation. However, the increased stiffness also resulted in higher base shear demand.

The findings of the study highlight the importance of maintaining structural regularity, avoiding abrupt stiffness discontinuities and properly considering masonry infill walls in analytical modelling. These observations are particularly important for earthquake-prone regions such as Bhutan, where seismic-resistant design of RCC buildings is essential for improving structural safety and reducing earthquake-induced damage.

IV. CONCLUSIONS

The present study evaluated the seismic performance of mid-rise reinforced concrete (RCC) buildings with regular and irregular configurations under Bhutan seismic conditions using Response Spectrum Analysis as per IS 1893 (Part 1): 2016. The effect of masonry infill walls was incorporated through equivalent diagonal compression strut modelling in accordance with IS code provisions. Based on the analytical results obtained from different structural cases, the following conclusions are drawn:

a. Regular RCC buildings exhibited better seismic performance compared to L-shaped and T-shaped buildings due to their uniform distribution of mass and stiffness.
b. Plan irregular buildings showed higher storey displacement and storey drift because of torsional effects and uneven stiffness distribution during seismic excitation.
c. The inclusion of masonry infill walls through equivalent diagonal strut modelling significantly increased the lateral stiffness of the buildings and reduced storey displacement and drift.
d. Buildings with soft storey conditions, particularly those without struts at the ground floor and first floor levels, exhibited higher displacement and drift concentration, making them more vulnerable to seismic damage.
e. The presence of infill walls increased the base shear demand due to the increase in structural stiffness and reduction in natural time period.
f. The natural time period of irregular buildings was higher than that of regular buildings, indicating increased structural flexibility and susceptibility to lateral deformation.
g. Sudden variation in storey stiffness due to removal of infill walls resulted in stiffness irregularity and concentration of seismic demand at weaker storeys.
h. The study highlights the importance of maintaining structural regularity and considering masonry infill wall effects during seismic analysis and design of RCC buildings in earthquake-prone regions such as Bhutan.
i. Equivalent diagonal strut modelling based on IS 1893 (Part 1): 2016 provides an effective and practical approach for incorporating infill wall behaviour in analytical models used for seismic evaluation.

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