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Design Demands of Rc Buildings Due to Irregularities

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Abstract

The RC-framed building is one of the most common construction technique for seismic-resistant structures due to its ductile nature. However, the seismic performance of RC structures can be significantly influenced by different factors, irregularities being one of the most important aspect. Irregularities on buildings increase the lateral seismic forces and inter-storey drifts thus increasing seismic demands in the structural elements. Due to architectural or functional requirements, many times irregularities cannot be avoided even though such arrangements are discouraged in the building codes including the Nepal National Building Code (NBC) 105:2020. Although many studies have been performed to quantify the effects of such irregularities internationally, design effect has not been analyzed in the context of Nepal and NBC 105:2020. Therefore, this study aims to present the variation in design demand for RC buildings in different irregularities scenarios. Three buildings models exhibiting irregularities in torsion, stiffness, and diaphragm are taken and analyzed in Finite Element platform SAP 2000 and compared with a regular building in terms of storey drift, internal forces, etc. The final design of the structural elements shows that the design demand in terms of section size and reinforcements can be significantly influenced by the presence of such irregularities.

Keywords: *Irregularities, Design demand, RC building, Storey drift*

Introduction

The construction of building with complex and irregular plans is a growing trend a fully regular structure is uncommon in real practice. The nature and principles of structural irregularities can vary greatly, and they are exceedingly difficult to characterize (Islam and Islam, 2014; Wood, 1992). Studies conducted on the effects of seismic actions on buildings have revealed that irregularly shaped buildings experience a greater amount of damage compared to buildings with regular shapes (Abdel Raheem et al., 2018; Haque et al., 2016). Therefore, irregular structures require a more thorough structural analysis to determine how they would behave after a powerful earthquake (Alavi and Rao, 2013).

Due to the architectural or functional requirements, errors and modifications during the construction phase, and changes in the building use throughout its service life, different type of structural irregularities are observed in buildings. In modern seismic design codes, structural irregularity is categorized into two types: plan irregularity and vertical irregularity. Vertical irregularity in a building can arise from various factors such as variations in stiffness of vertical elements, strength, mass, or dimensions, or due to an in-plane discontinuity in the lateral force resisting system. Numerous studies have been conducted to evaluating the effect of stiffness irregularities e.g. (Sadashiva et al., 2011; Satheesh et al., 2020). Stiffness irregularity can have a significant impact on the dynamic behavior of a building leading to changes in the natural period of vibration of the building, as well as its mode shape (Ventura and Schuster, 1996). According to Paulay and Priestley, (1992) stiffness irregularities can lead to a number of problems, including increased seismic demands on the structure, reduced ductility, and increased vulnerability to pounding. A study conducted by Satheesh et al., (2020) concluded that during the seismic loading overall stability and response of the buildings are highly influenced by the presence of stiffness irregularities.

The response of buildings during a seismic event is also significantly influenced by the configuration of the building's plan and irregularities. According to Banginwar et al., (2012), the way a structure is designed in terms of its plan configuration can have a considerable influence on how it responds to seismic activity, particularly in regards to lateral displacement, inter-storey drift, and storey shear force demands. As per seismic design codes, plan irregularity refers to structural irregularities caused by diaphragm discontinuities and torsional irregularities. According to NBC 105, If a diaphragm has a cutout or open area that is greater than 50% of its total enclosed area, or if there is a change of more than 50% in the effective stiffness of the diaphragm from one story to the next, then it is considered to have a diaphragm discontinuity irregularity. The presence of diaphragm discontinuity in a structure decreases its stiffness, leading to negative impact on the building's performance during dynamic loading (Bagawan and Patel, 2017). Positioning of slab openings in the buildings can change structural drift during dynamic loading. The storey having an opening at the center has less lateral displacement as compared to the opening at the periphery during dynamic loading (Manmathan,2017). The results of study conducted by Srisangeerthanan et al., (2018) showed that the presence of diaphragm discontinuity significantly increased the building's displacement demand and reduced its ductility.

However, in the case of torsional irregularities, there are various reasons for torsion to occur in buildings during earthquakes, but the most common is an unsymmetrical distribution of mass and stiffness throughout the building's height. D'Ambrisi et al., (2013) investigated the seismic behavior of 4-storey reinforced concrete framed buildings with irregularities under seismic loading. Their findings indicated that minor variations in eccentricity can result in significant changes in the seismic performance of the structure. Dimova and Alashki, (2003) stated that even if the symmetric building has minor accidental eccentricities, they can exhibit irregular behavior and hence by application of static torsional moments, the accidental torsional effects cannot be estimated accurately. Similarly, Gokdemir et al., (2013) concluded that torsional irregularity can cause failure of any structural system by forcing the entire structure to deflect beyond its lateral deflection limit. Study by Chopra and Goel, (2004) found that torsional irregularities can significantly increase the seismic response of structures and should be avoided to reduce the risk of damage to buildings during seismic events. Another study by Bhasker and Menon, (2020) found that torsional irregularities have a significant effect on seismic demand of RC frame structures. The study used a numerical model to analyze the behavior of a two-storey RC frame with various torsional irregularities. The results showed that torsional irregularities can lead to an increase in inter-storey drift to a maximum, as well as a decrease in the strength and stiffness of the structure. To address this issue, recent seismic codes have included a provision for considering accidental eccentricity during analysis and design, as a way to counteract these torsional effects.

Therefore, it is clear that effect of regularity in design demand is not negligible. Hence this study is aimed towards quantifying the design demand due to different irregularities with respect to the provision of Nepal Building Code, NBC 105:2020.

Methodology

Four different RC building models are considered in the study and one of them is a regular building, and the other three building models have been taken considering irregularities namely , torsion, stiffness, and diaphragm discontinuity. All these different representative buildings are numerically modelled in the finite element software SAP2000. Seismic forces are calculated for the different cases of irregularities as per NBC 105:2020 and numerical analysis is performed using linear static and response spectrum method. Finally, structural elements are designed following the requirement of IS 456:2000 and NBC 105:2020.

Buildings Description

T The building models considered in this study are of a reinforced concrete moment resisting frame structure, with a plan size of 15.291m x 9.601m and have five storeys. The study considers four different building models, including a regular building as the base (model 1), and three types of irregular buildings: torsional (model 2), stiffness (models 3), and diaphragm discontinuity buildings (model 4). The torsional irregularity model has a uniform height of 3m on each floor. The stiffness irregularity model has varying floor heights of 3m, 4m, 2.5m, 3m, and 2.5m for the first, second, third, fourth, and fifth floors, respectively. The diaphragm discontinuity model also has a uniform height of 3m for each floor.

For all building models, the thickness of the outer walls and partition walls is 229mm and 127mm, respectively, while the slab thickness is 125mm with concrete grade M20. The grade of concrete used for column and beam is M25, and initial size taken for numerical modelling for column is 350mm x 350mm, and that of beam is 250mm x 350mm. All building models are assumed to be situated in the soil type D as per NBC105:2020, and the peak ground acceleration considered for design is 0.35g. The importance factor used is 1. All building models are assumed to be fixed at the base. The dead load and live load are taken as per IS 875 (part I&II):1987. The building models for different irregularities scenario are shown in Figure 1 to 6.

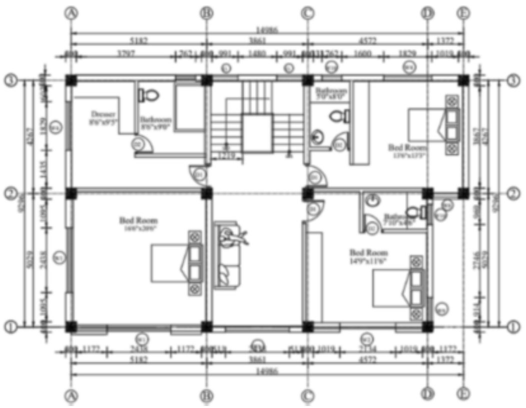

Figure 1: Plan of base model (model 1)

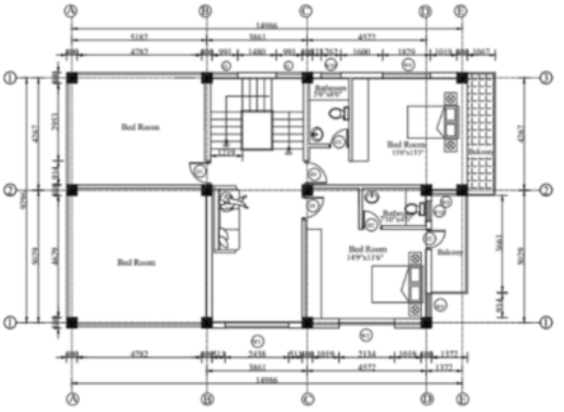

Figure 2: Plan of torsional irregularity model (model 2)

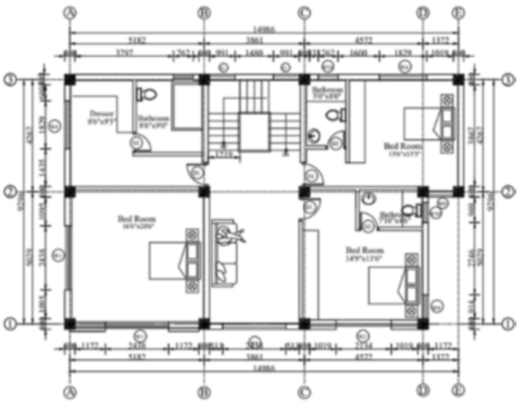

Figure 3: Plan of stiffness irregularity model (model 3)

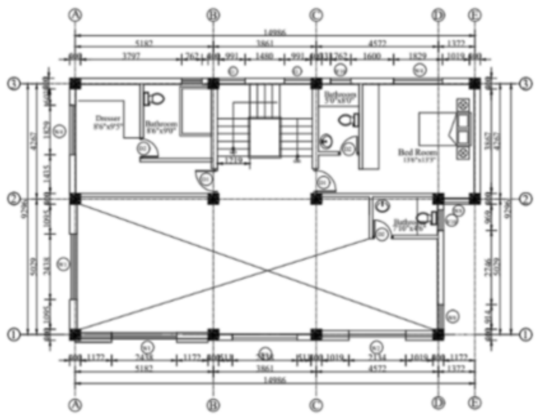

Figure 4: Plan of diaphragm discontinuity model (model 4)

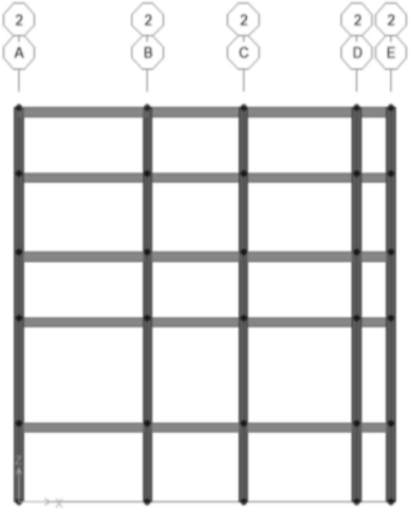

Figure 5: Section of stiffness irregularity building (model 3)

Figure 6: 3D view of base building (model 1)

Result and Discussions

1. Storey shear in kN

The analysis of story shear for all models is shown in Table 1. Although the base shear for each building model is almost similar, four buildings have varying storey shear force.

Floor level	Height (m)	Models			
		Base model	Torsional irregularity model	Stiffness irregularity model	Diaphragm discontinuity model
5	15	226.772	221.042	219.477	180.941
4	12	535.266	567.347	513.263	520.277
3	9	776.425	771.347	761.458	769.731
2	6	931.251	942.870	924.920	929.883
1	3	1003.834	1004.266	1009.553	1004.982

Table 1: Storey shear force in the buildings

2. Storey drift

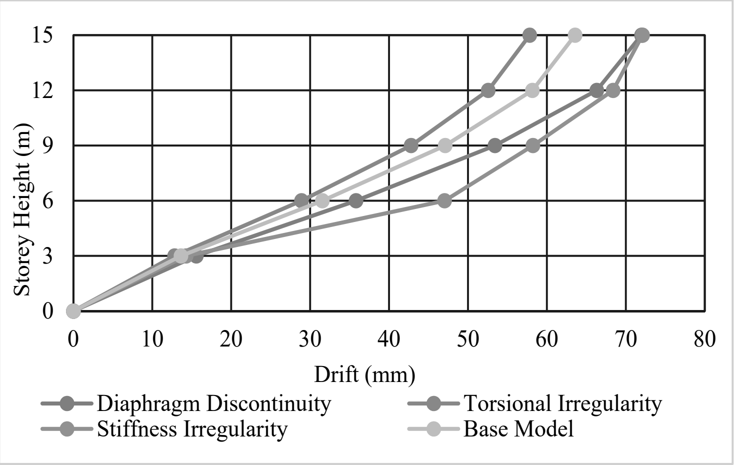

Figure 7: Storey drift due to X-direction earthquake

Figure 7 shows storey drift in the all models in the X- direction. It is observed that storey drift is higher in models which have diaphragm discontinuity and stiffness irregularities as compared to the regular model.

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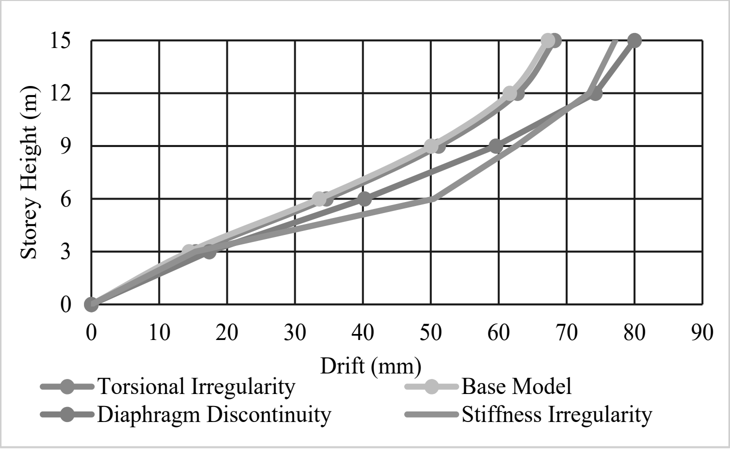

Figure 8: Storey drift due to Y-direction earthquake

Storey drift in the models in the Y-direction is shown in Figure 8. Models that have diaphragm discontinuity and stiffness irregularities exhibit higher storey drift compared to regular models, which in turn have the lowest storey drift among all models.

Internal force in structural elements

Figure 9 shows the maximum shear forces in beam in each of models. Models having torsional irregularity and diaphragm discontinuity having the higher maximum beam shear as compared to other models, whereas regular model have least.

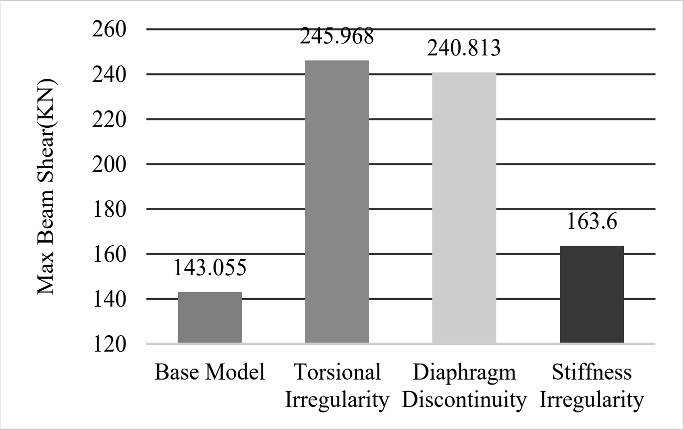

Figure 9: Maximum beam shear

Figure 10 displays the maximum column shear force observed in various models. Notably, the models with torsional irregularities and diaphragm discontinuities have exhibited higher maximum beam shear values when compared to the other models

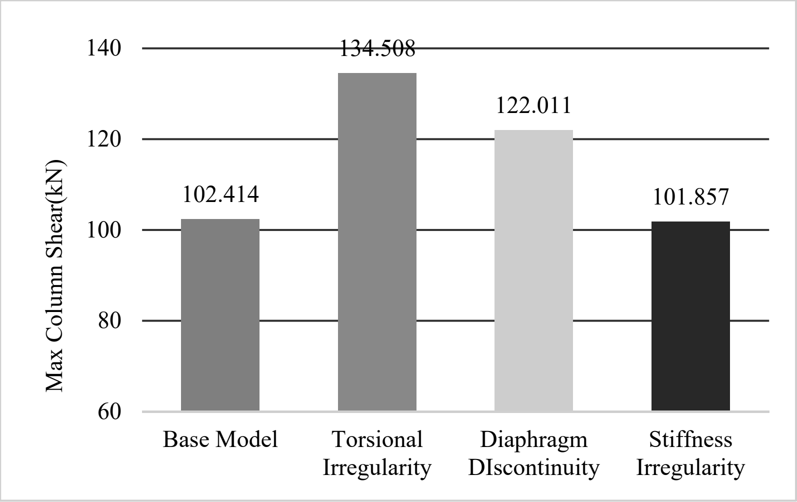

Figure 10: Maximum column shear

In Figure 11, the maximum beam moment for different models is displayed. The torsional irregularity model exhibited a greater maximum beam moment compared to the other models. On the other hand, regular model exhibited the least maximum beam moment.

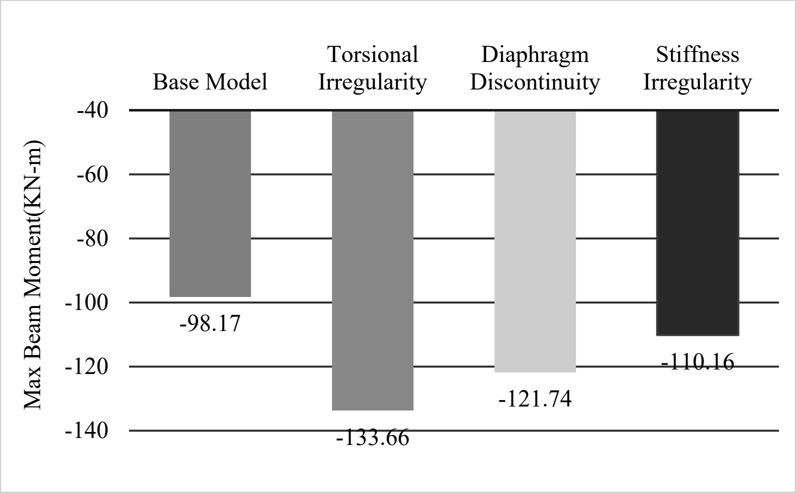

Figure 11: Maximum beam moment

Figure 12 displays the maximum column moment of various building models, where buildings with stiffness irregularities demonstrate a higher maximum column moment compared to other buildings. Conversely, regular buildings show the least maximum column moment.

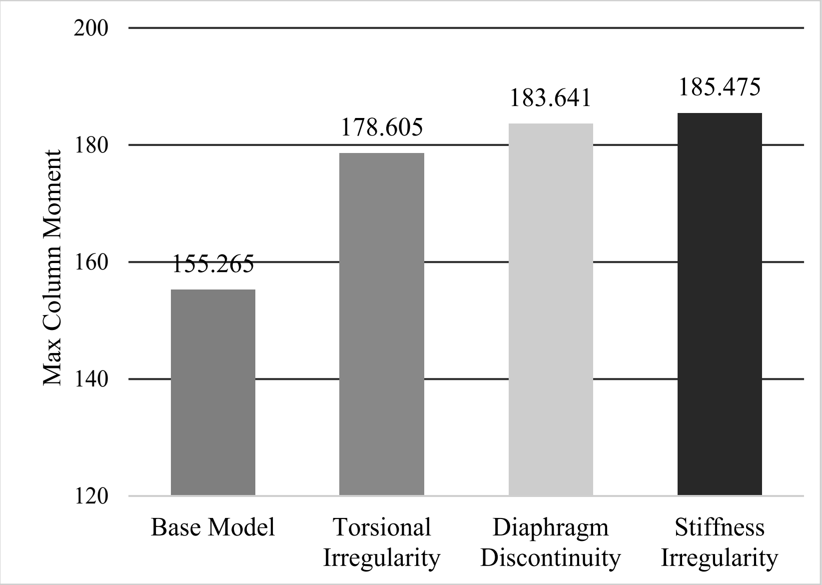

Figure 12: Maximum column moment

3. Design of structural elements

All model buildings are designed based on limit states of strength. Base models with standard cross-sections for beams (250mm x 350mm) and columns (350mm x 350mm) fulfilled the design criteria, while those with irregularities tend to fail due to excessive shear and bending moment. Torsional irregularities caused corner beams to fail. For columns, irregular models demand more longitudinal reinforcement than what is practically permissible, which is 4 %. In cases of stiffness irregularities, higher floor heights required higher amount of longitudinal reinforcement. Ultimately, defining larger cross-sections for beams (300mm x 400mm) and columns (400mm x 400mm) made irregular models to satisfy the design stage.

Conclusion and Recommendation

Following conclusions have been made based on the study of models that displayed both regular and irregular scenarios:

- Buildings with irregularities have higher inter-storey drift, with diaphragm discontinuity resulting in the highest storey drift.
- The existence of irregularities on buildings lead to a rise in the internal forces acting on the structural member.
- As the height of a storey increases, there is a corresponding increase in the amount of longitudinal reinforcement required for the column.
- Structural members located at the corners of buildings with torsional irregularities are more susceptible to failure.
- In comparison to regular buildings, the cross section demand is higher in buildings that have irregularities.

The above conclusions are made based on a study of one particular building type of similar height with some changes to give different irregularities. The results can differ for different building scenarios. Further studies with varying building storey are recommended to quantify the effect in size demand of structural elements due to common irregularities in the buildings.

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