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Influence of structural irregularities on seismic performance of RC frame buildings

Krishna Ghimire[1], Hemchandra Chaulagain[1,*]

[1] *School of Engineering, Faculty of Science and Technology, Pokhara University, Kaski, Nepal*

**Corresponding email: hchaulagain@gmail.com*

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Abstract

Irregular building structure is frequently constructed across the globe for fulfilling aesthetic as well as functional requirements. The structures with irregularities are the common building type in earthquake-prone country like Nepal. However, a post-earthquake reconnaissance survey reports revealed the high seismic vulnerability of the building with structural irregularities. In this context, the present study explores the influence of structural irregularities on performance of reinforced concrete (RC) frame structure. To this end, the structural irregularities are created in in the building structures. The geometrical irregularities are created by removing the bays in different floor levels. Likewise, the effect due to mass irregularities are studied by considering the swimming pool and game house at different floor levels. Furthermore, the stiffness irregularities are formulated by removing the building columns at different sections. All these irregularities are studied analytically in finite element program with 3-D structural models. The numerical analysis is done with non-linear static pushover and time history analysis. The results are analyzed in terms of fundamental time period, storey shear, storey displacement, drift and overturning moment. The results indicate that the level of irregularities significantly influenced the behavior of structures.

Keywords: *Nonlinear analysis; plastic hinge; storey drift; structural irregularity.*

1. Introduction

The behavior of a civil engineering structure during strong ground shaking depends on the level of irregularities in structures (Lee and Ko, 2007). It mainly occurs due to the irregular distribution in their strength, stiffness, mass and uneven plan configuration along the height of the structure and its combined effects. Past scenarios of the damage patterns of the building indicated that the seismic response of irregular building subjected to ground motion tends to be significantly stronger due to torsional effects. It arises from the non-uniform distribution of mass and stiffness of the structure. Torsion has been the cause of major damage to buildings subjected to strong shaking. It occurs under the action of earthquake forces when the centre of mass of the building does not coincide with the center of rigidity. The distance between them is called eccentricity. Lateral force multiplied with this eccentricity causes a torsional moment that must be resisted by the structure (Gautam and Chaulagain, 2016).

To perform well against seismic force, structure should be subjected to adequate lateral strength, simple and regular configuration, sufficient stiffness and ductility. Buildings with simple geometry and uniformly distributed mass and stiffness in plan and elevation are less vulnerable in comparison to the structure with irregular configuration (Kostinakis and Anthanatopoulou, 2020). In reality, a large number of building structures are in irregular in some sense. Some have been initially so designed and others have become so by accidently. The main vertical irregularities examined by the researchers are stiffness irregularity (soft-storey), mass irregularity, vertical geometric irregularity and in-plane discontinuity. Similarly, the horizontal irregularities are basically due to asymmetrical plan shapes, re-entrants' corners, diaphragm discontinuity and torsional irregularities (Varadharajan et al., 2012).

Nowadays, irregular structures are quite frequently built in Nepal. These constructions are popular in multi-storied building because of its both aesthetic architecture and functional use. Due to the irregular nature of the structure stress concentration and ductility demand is localized in the structure. On the other hand, regular structures have uniform distribution of mass and stiffness and resulting the improved level of performance. In this context, this study highlights the effect of irregularities by comparing the results with regular structure. The results are analyzed in terms of fundamental time period, storey shear, storey displacement, drift and overturning moment.

2. Classification of Irregularities

2.1 Mass Irregularity

In structural system, if there is a variation of more than 150% of mass between the adjacent story then it is considered as mass irregularity (see Fig.1). Researchers highlighted the effect of several irregularities such as strength, mass, discontinuity in capacity and restrained corner in their study (Sadashiva et al. 2009). Several building structures were damaged during Bhuj, Chili and Gorkha earthquake due to the mass irregularities. The higher amount of mass leads in the reduction of ductility of vertical load resisting elements and leads to the collapse of structures. The heavy mass on upper story leads the structure to the vulnerable condition than those at lower story level. From the analytical study of different regular and irregular building, it is noticed that a type, magnitude and location of irregularities had strong influence on collapse capacity of the structures. The buildings having stiffness, setback and strength irregularity at the bottom storey has less collapse capacity (Chaulagain et al., 2016). For mass irregular building, the maximum impact on collapse response was observed for the case when mass irregularity was present at the top story.

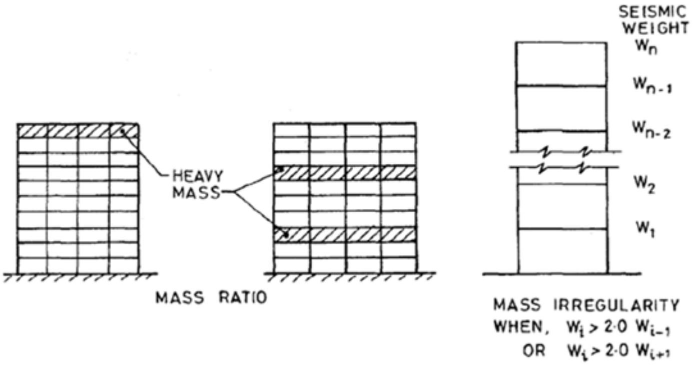


Figure 1: Representation of mass irregular structure.

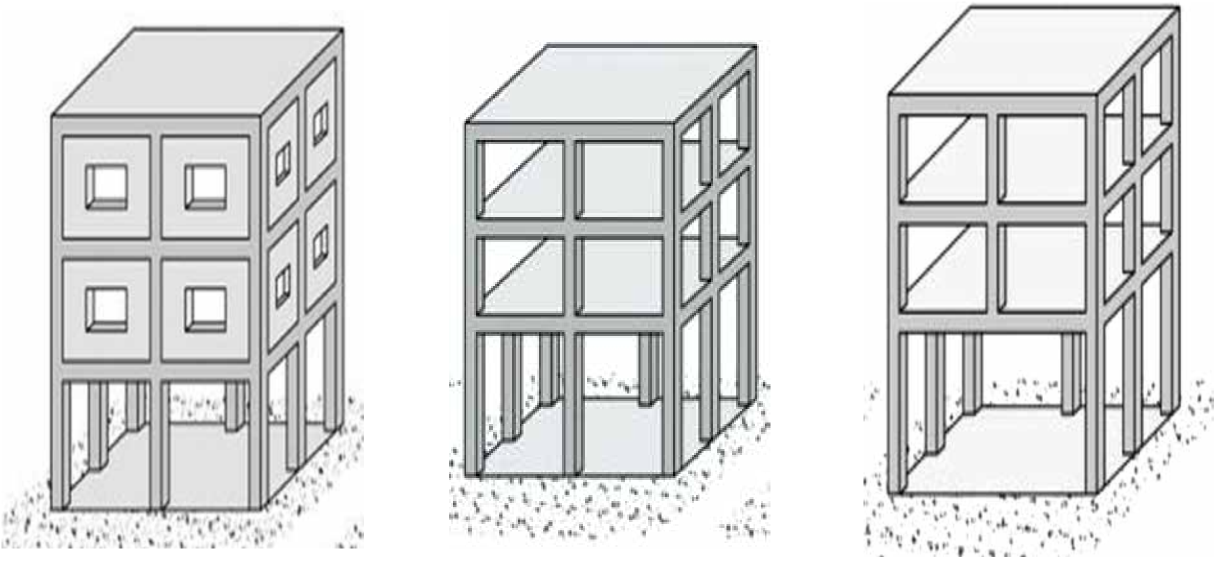
2.2 Stiffness Irregularity

In structural system, if the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average stiffness up to 3 storey then it is said to be soft story (Dya and Oretaa, 2015). During the earthquake in Chili, several number of buildings around the alto-Rio building were badly damaged but safe while the alto-Rio building got completely collapsed due to vertical irregularities in the stiffness (Rahman and Salik, 2016). The performance of the structure also depends on the lateral shear stiffness or flexural stiffness. The lateral shear stiffness of the story can be found by using following relation. The representation of stiffness irregularity is shown in Fig. 2.

$$\mathrm{Ki} = \sum_{j=1}^{nc} \frac{12\mathrm{EjIj}}{\mathrm{Lj}^3} + \sum_{m=1}^{nstrut} \frac{\mathrm{AmEm}}{\mathrm{Lm}} \cos^2\theta\mathrm{m} \quad \ldots (1)$$

Where,

Nc	total number of continuum columns in the ith story
Nstrut	the total number of struts in ith story
Ej,	modulus of elasticity of materials
Ij	moment of inertia of the member
Lj,	length of column
I	direction of interest
Em	elastic modulus
Am	axial area
Lm	Length
Θm	angle of inclination with respect to the horizontal axis of strut



(a) (b) (c)

Figure 2: Stiffness irregularity: (a) stiff and strong upper floors due to masonry infills, (b) the columns is one storey longer than those above and (c) soft storey caused by discontinuous column.

2.3 Vertical Geometric Irregularity

In the structural system, if the horizontal dimension of the lateral force-resisting system in any story varies by more than 130 percentage of adjacent story in both above and below level, then it is said to be vertical geometric irregularities (Amiri and Yakhchalian 2020, Sarkar et al 2010). This type of irregularity exists in elevation (see Fig. 3a)

2.4 *Horizontal Irregularity*

These types of irregularity exist if any element of the lateral load resisting system is not parallel to one of the orthogonal axes of the lateral load resisting system of the entire structure (see Figs. 3b and 4) (Raheem et al. 2018; Varadharajan 2014). Among the different horizontal irregularities, torsional irregularity is one and can be removed by increasing column sizes by bracing and adding the shear wall.

(a) (b)

Figure 3: a) Vertical geometric irregularity, b) horizontal irregularity.

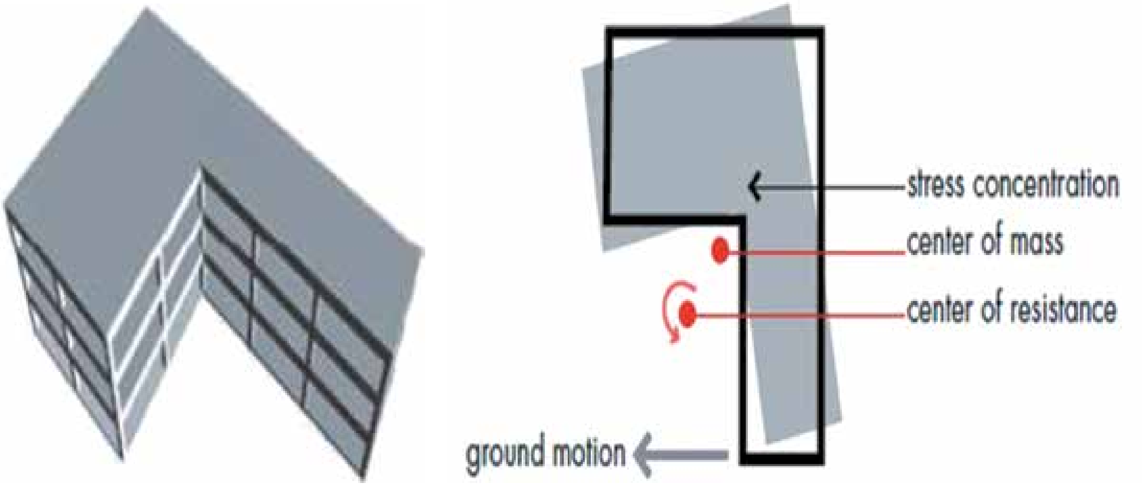


Figure 4: Condition of stress concentration in the structure

2.5 Irregularities Limits as per Various Codes

The irregularity limits for both horizontal and vertical irregularities based on Indian Standard Code IS 1893:2016 (Part 1), Eurocode (EC8:2004), Uniform Building Code (UBC 97), National Building Code of Canada (NBCC, 2005), International Building Code (IBC, 2003), Turkish Earthquake Code (TEC, 2007) and American Society of Civil Engineers (ASCE 7.05) standard can be summarized in the following Tables 1 and 2.

3. Structural Details and Modelling Approach

3.1 Description of the Buildings

In this study, one regular and eight irregular RC building structures are taken for analysis. Among eight irregular building; four of them have geometrical irregularities, two have stiffness irregularities and rest of two buildings have mass irregularities. The details of information have been collected from the drawing by consultants, municipality drawing and a field survey of existing buildings in Pokhara Metropolitan city. The typical building model used in the study is the real model. The different irregularities in this study are formulated by modifying the real regular structure.

Table 1: Irregularity limits prescribed by IS 1893:2016 (Part 1), EC8:2004, UBC 97, NBCC 2005

Type of irregularity	IS 1893:2016	EC8 2004	UBC 97	NBCC 2005
Horizontal				
a) Re-entrant corners	Ri ≤ 15% (Fig.2)	Ri ≤ 5%	Ri ≤ 15%	
b) Torsional irregularity	dmax ≤ 1.2 davg	rx > 3.33 eox ry > 3.33 eoy rx and ry > ls,	dmax ≤ 1.2 davg	dmax ≤ 1.7 davg
c) Diaphragm discontinuity	Oa > 50% Sd > 50%	rx2 > ls2 + eox 2 Ry 2 > ls 2 + eoy 2	Od > 50% Sd > 50%	
Vertical				
a) Mass	Mi < 2 Ma	Should not reduce abruptly	Mi < 1.5 Ma	Mi < 1.5 Ma
b) Stiffness	Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)	Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)	Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)	Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)
c) Soft-storey	Si < 0.7Si+1 or Si < 0.8 (Si+1 + Si+2 + Si+3)		Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)	Si < Si+1
d) Weak story	Si < 0.8Si+1		Si < 0.8Si+1	
e) Setback irregularity	SBi < 1.5 SBa	Rd < 0.3Tw < 0.1 Tw at any level	SBi < 1.3 SBa	SBi < 1.3 SBa

Table 2: Irregularity limits prescribed by IBC 2003, Tec 2007 and ASCE – 7.05

Irregularity limits prescribed by IBC 2003, TEC 2007 And ASCE – 7.05			
Type of irregularity	**IBC 2003**	**TEC 2007**	**ASCE – 7.05**
Horizontal			
a) Re-entrant corners		Ri ≤ 20%	Ri ≤15%
b) Torsional irregularity		dmax ≤ 1.2 davg	dmax ≤ 1.2 davg dmax ≤ 1.4 davg
c) Diaphragm discontinuity		Oa > 33%	Oa > 50% S > 50%
Vertical			
a) Mass	Mi < 1.5 Ma		Mi < 1.5 Ma
b) Stiffness	Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)		Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)
c) Soft-storey	Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)	[ηki = (Δi / hi) avr / (Δi+1 / hi +1) avr > 2.0 or	Si < 0.7Si+1 Or Si < 0.8 (Si+1 + Si+2 + Si+3)
d) Weak story	Si < Si+1	[ηci = (Ae)i / < 0.80]	Si < 0.6Si+1 Or Si < 0.7 (Si+1 + Si+2 + Si+3)
e) Setback irregularity	SSBi < 1.3 SBa		SBi < 1.3 SBa

The structural information such as the size and detailing of RC elements (beam and column), inter-storey height, type of steel reinforcement and grade of concrete is same for all building models. The material properties of the building are considered to be same in all the buildings as; a) compressive strength of concrete fc=20Mpa, b) reinforcing steel yield strength fy=415 MPa, c) roof live load =1.5 kN/m^2 (nil for earthquake), d) roof and floor finish =1 kN/m^2, e) floor live load = 2 kN/m^2 (25% for earthquake). In this study, building models used in the analytical study are considered to have 7 bays with 4m width in X direction and 3 bays of 4m width in Y direction with 3m storey height.

The regular building is kept regular throughout the seven story whereas some bays are removed in different story in case of irregular building. In IRR1 type irregular building one bays in X- direction is removed in each story of the buildings. In IRR2 type irregular building two bays in X- direction is removed from each two story of the building respectively. In IRR3 building 3 bays in X- direction are removed from G+ three story of the buildings while in IRR4 type irregular building 4 bays in X- direction are removed from G+ four story of the buildings. For IRR5 building weight equal to water of swimming pool is kept at the top floor followed by game house weight at (G+3) building in IRR7 building to create mass irregularity. Similarly, in IRR6 and IRR8 column to create stiffness irregularity there is removal of parking column at two different section C-C and E-E respectively (see Fig. 5). The parameters used for design of regular and irregular building models is presented in Table 3.

Table 3: Parameters used for design of regular and irregular building models.

Description of building model			
Parameters	Data	Unit	Remarks
Size of column	450x450	mmxmm	
Size of beam	350x350	mmxmm	
Slab thickness	150	mm	
Specific weight of concrete	25	kN/m^3	
Modulus of elasticity (infill) E_m	5310	MPa	
Modulus of elasticity (concrete) E_c	25000	MPa	$E_c = 5000\sqrt{fck}$
Thickness of shear wall	250	mm	

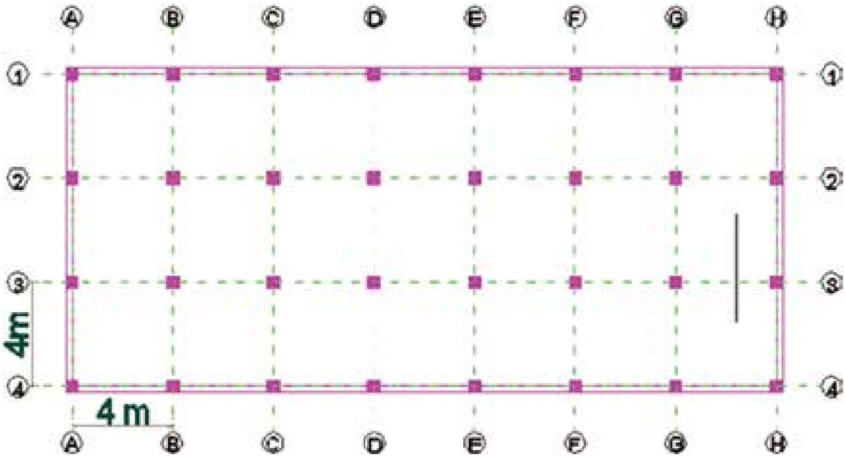


Figure 5: Plan of study building model.

3.2 Numerical Analysis

The numerical analysis in this study is performed through pushover analysis. A pushover analysis is performed by subjecting a structure to a monotonically increasing load until structure become unstable or predefined displacement reached. Under incrementally increasing loads various structural elements may yield sequentially. Consequently, at each event, the structure experiences a loss of stiffness. Pushover analysis generate static pushover curve which plots an applied lateral load against displacement. The value of the lateral force incrementally increases with the transition of structure in the nonlinear zone, plastic hinge is formed. When analyzing frame structure, material non-linearity is assigned to discrete hinge location where plastic rotation occurs according to the FEMA 356 (2000), ATC-40 (1996), or other set of code-based or user defined criteria.

Numerical analysis based on the bare frame building modelling with three dimensional models (see Fig. 7-10). Modelling of the structure is carried out by using finite element program SAP2000 (SAP 2000). Nonlinear behavior occurs within the frame elements at the location of plastic hinge (Nahavandi, 2015). Plastic hinges are the points on a structure where one expects cracking or yielding.

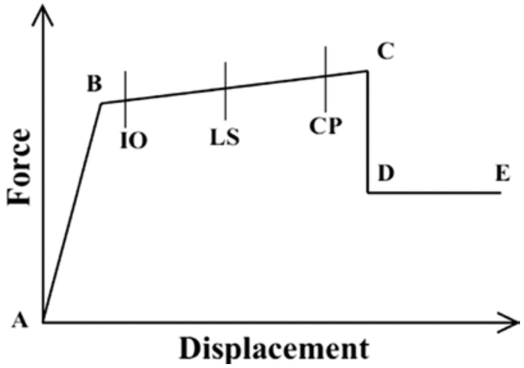


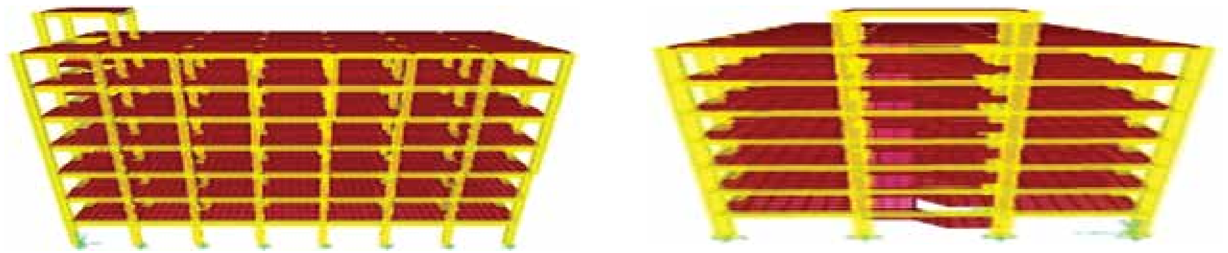
Figure 6: Force deformation curve with different performance level

A generic component behavior curve is represented in figure 6. The points marked on the curve is expressed by the software SAP 2000 as follows:

- Point A is the origin
- Point B represents yielding. No deformation occurs in the hinge up to point B, regardless of the deformation value specified for point B, the deformation (rotation) at point B will be subtracted from the deformations at points C, D, and E. Only the plastic deformation beyond point B will be exhibited by the hinge.
- Point C represents the ultimate capacity for pushover analysis. However, a positive slope from C to D may be specified for other purposes.
- Point D represents a residual strength for pushover analysis. However, a positive slope from C to D or D to E may be specified for other purposes.
- Point E represents total failure. Beyond point E on the horizontal axis, if it is not desired that the hinge to fail this way, a large value for the deformation at point D may be specified.

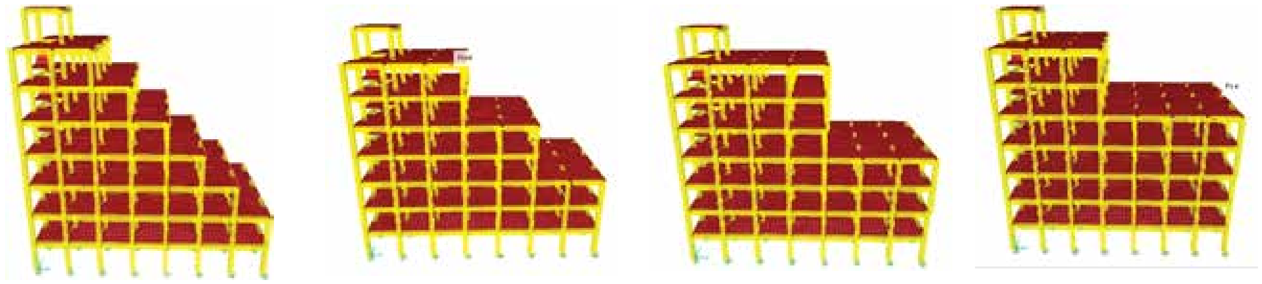
In the present study, the structures are modelled using default and user defined hinged properties. In the beam section, the moment curvature relation established which gives ultimate moment, yield moment, ultimate curvature and yield curvature and the values were normalized with respect to yield moment and yield curvature. The plastic hinge length is taken as half of the depth of beam (ATC-40, 1996). All the analysis is performed based on displacement-controlled procedure. The procedures adopted in this study can be summarized as:

- Application of 10% static lateral load induced due to earthquake at the CG of the building.
- Developing (M-θ) relationship for critical region of beam and column.
- Select control point to see the displacement.
- Apply full gravity load as a nonlinear static load pattern and gradually increasing lateral load, until the targeted displacement reached.
- Developing hinge formation sequences and the base shear vs roof displacement (pushover curve) table.



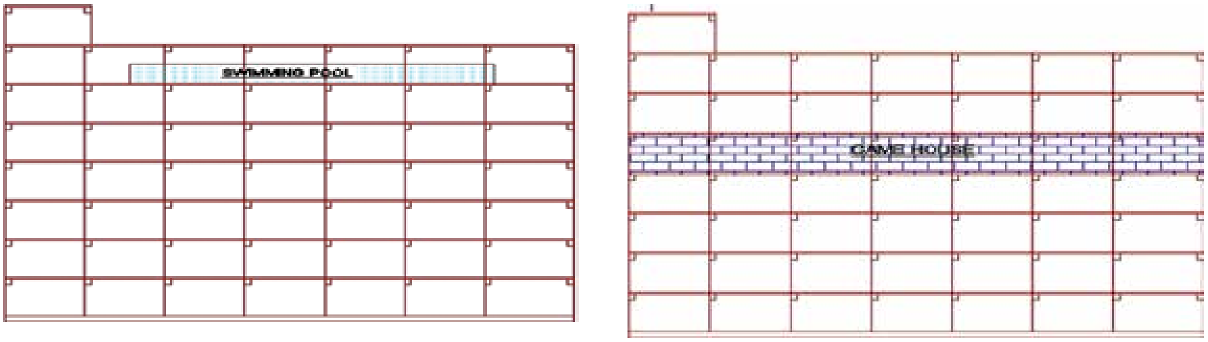
(a) **(b)**

Figure 7: REG Model with a) front elevation and b) side elevation



(a) **(b)** **(c)** **(d)**

Figure 8: Irregularities in the buildings a) IRR1 model (up to 2nd floor), b) IRR2 model (up to 3rd floor), c) IRR3 model (up to 4th floor) and d) IRR4 model (up to 5th floor)



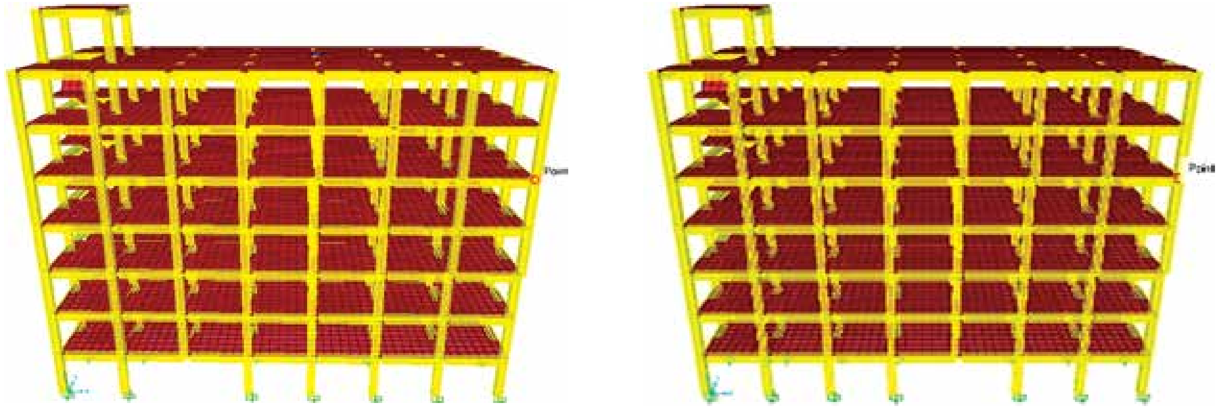
(a) **(b)**

Figure 9: Mass irregularities in the different floor level of building a) IRR5 model and b)IRR7 model

4. Analysis and Interpretation of Results

4.1 Pushover Curves

From the pushover analysis, it is noticed that regular buildings have immediate occupancy level before the performance point whereas irregular building reached life safety level before the performance point. In regular building, plastic hinges are evenly distributed from bottom to top storey level whereas in irregular building plastic hinges are formed in some of the beam only in the same storey level reaching the plastic limit earlier. The column of irregular building reached life safety and collapse prevention earlier than the regular building. From the pushover curve, it is clearly seen that irregular building has slightly higher base shear capacity.



(a) **(b)**

Figure 10: Building with floating column a) IRR6 model and b) IRR8 model

In regular building, the life safety level is reached from lower to higher storey in regular pattern whereas in irregular building (IRR1 and IRR2) the column of G+3 story reached life safety level. It is seen that when G+3 story column reached life safety level; G+1 and G+2 story is only in immediate occupancy level. Similarly, the results have shown that among the studied building types, regular building seem to have more capacity than any other steeped buildings. Regular building has higher stiffness compared to the buildings with floating columns. Irrespective of mass irregular building both of them have almost same capacity and have slightly less capacity than the regular building (see Fig. 11-12).

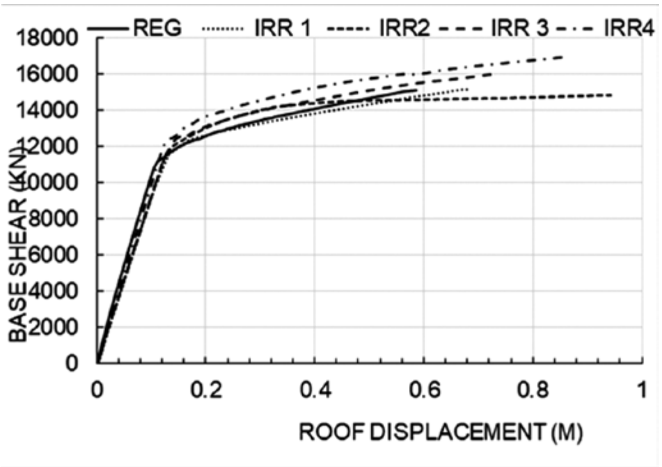
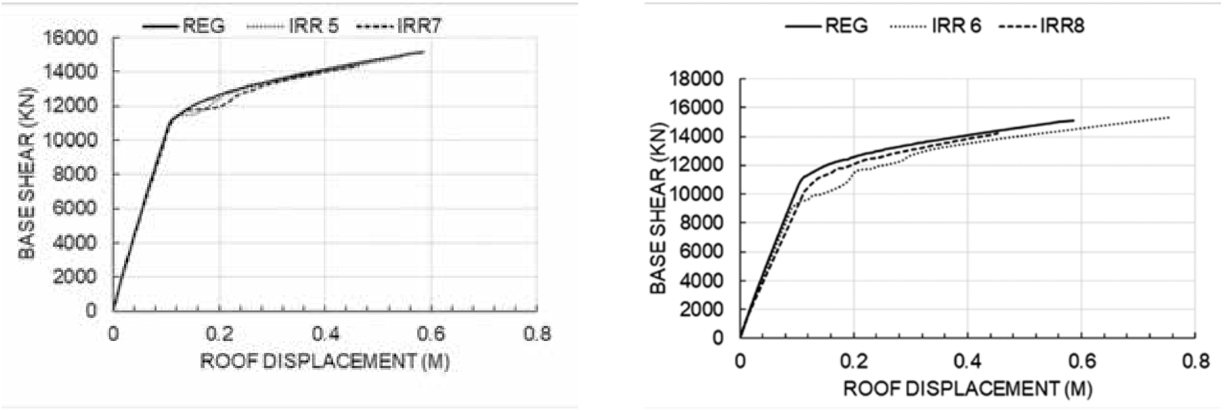


Figure 11: Comparison of base shear versus displacement of different regular and irregular building

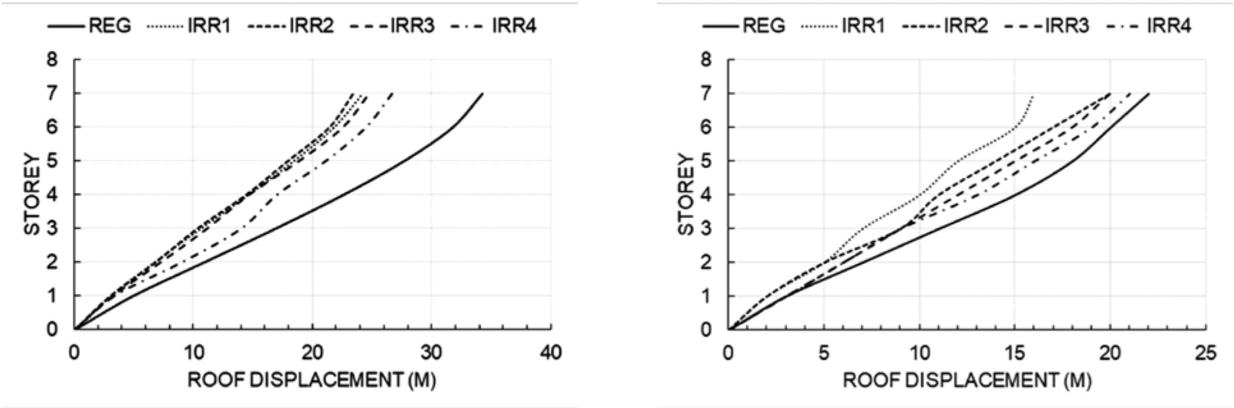
4.2 Displacements Due to Pushover Analysis

In figures 13, it is seen that the maximum displacement of regular building has more than that of the other irregular building. It is due to the higher mass up to top storey in regular building. The same condition is applied for the maximum top displacement in building model IRR3 and IRR4. These results justify that as the irregularity percentage increases in maximum displacement will decrease. However, due to torsional effects, the building model IRR1 has more displacement than IRR2 building model.



(a) **(b)**

Figure 12: Base shear versus displacement curve for: a) regular and b) irregular building structures



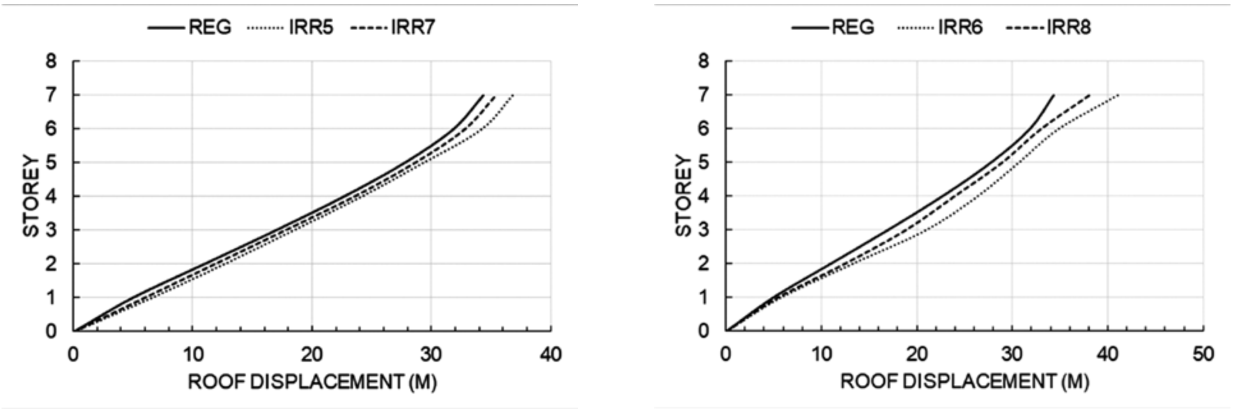
(a) **(b)**

Figure 13: Comparison of storey displacement (mm) of regular and geometric irregular building both in X and Y direction of loading, respectively.

As presented in figure 14, IRR5 and IRR7 building models have top displacement of 36.8mm and 35.4 mm, respectively. The displacement of regular building has maximum as compared to the irregular one. It is due to the unequal distribution of mass (due to swimming pool and game house) in higher floor level in irregular building. Similarly, building model IRR6 and IRR8 have the top displacement of 41.02 mm and 38.08 mm respectively. The building model of IRR6 have higher maximum displacement value at roof compared to REG and IRR8 building model. It is due to the fact that building model IRR8 have floating column at middle of the building showing symmetric while building model IRR6 have the floating column are apart from middle and resulting the torsional moment and increases deflection.

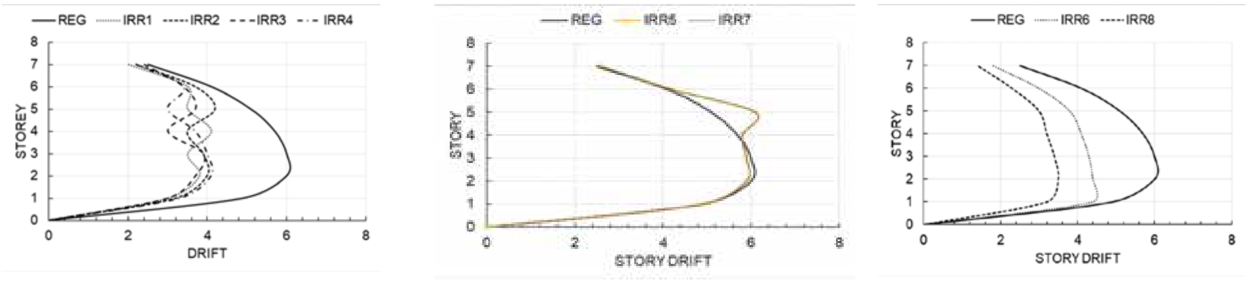
4.3 Comparison of Story and Story Drift of Structures

As indicated in figure 15, story drift at the location of the steps building is changing abruptly compared to the regular building. The change in story drift is noticed in the location of change of steps. The maximum story drift of irregular stepped building has lower value compared to regular building. The story drift of mass irregular building has almost same pattern. In case of floating column, the story drift of building model IRR 6 buildings is less than regular building and more than that of IRR8 buildings.



(a) (b)

Figure 14: Comparison of storey vs storey displacement in regular and irregular building model



(a) (b) (c)

Figure 15: Storey versus storey drift of irregular building models in push X.

4.4 Time History Analysis

The most accurate procedure for structure subjected to strong ground motion is the time-history analysis. The pushover analysis is less onerous than nonlinear dynamic analysis since it does not require the monitoring of cyclic inelastic response of structural member and it avoids the dependence on the input motion (Landi, et al., 2014). Pushover analysis ensure a reliable structural assessment or design subjected to seismic loading in simplest and fastest way (Chaulagain et al., 2014; Themelis, 2008). The earthquake time history data is important for dynamic analyses of the structures. In the context of Nepal, real accelerograms records are not available sufficient for time history analysis. Due to lack of actual time history data in Nepal, the dynamic time history analysis is performed with El Centro time history data (Fig. 16). The analysis is good to represent the realistic behavior of structure (King 1998).

From non-linear time history analysis, it is observed that the maximum top displacement of the regular building is 126.6 mm. The one step irregular building (IRR1) has displacement of 89.52 mm at the top while IRR2 have 94 mm and IRR3 have 95.98mm at the top, respectively. In this study, all the presented time-history results are peak-values. While comparing the result between the pushover and non-linear time history analysis the value of displacement of roof of the building given by non-linear time history is higher as compared to pushover analysis but the pattern of displacement of both the regular and geometric irregular building is same that is REG building had more displacement followed by IRR4, IRR3, and so on (see Fig. 17).

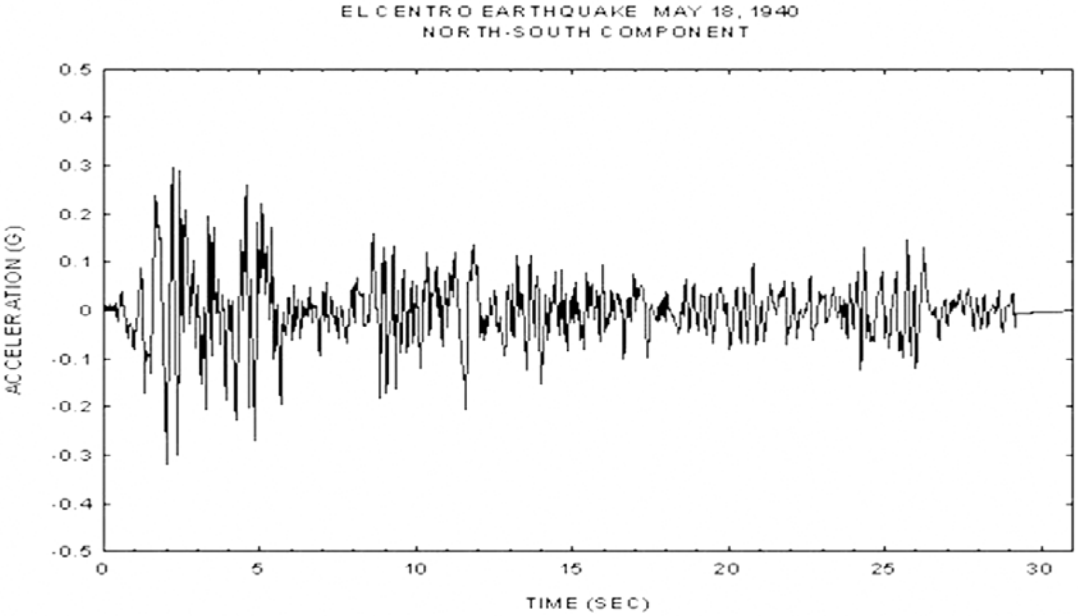


Figure 16: Time history data for El Centro Earthquake

From figure 18, it is seen that maximum displacement of the IRR5 at the top is more as compared to the regular and IRR5 building structure. The result shows that storey versus roof displacement curve has the same pattern but the value is more in time history analysis. The non-linear dynamic analysis shows the building model IRR6 have maximum displacement of 149.9 mm followed by IRR8 building with 130.8 mm. The pattern is same as that of pushover analysis. The value of displacement with time history analysis have higher as compared to non-linear pushover analysis. The building model IRR6 have higher deflection value. It is due to the removal of column for creating floating column. The removal of column for creating floating column is in unsymmetrical placed causing more torsion moment compared to IRR8 buildings.

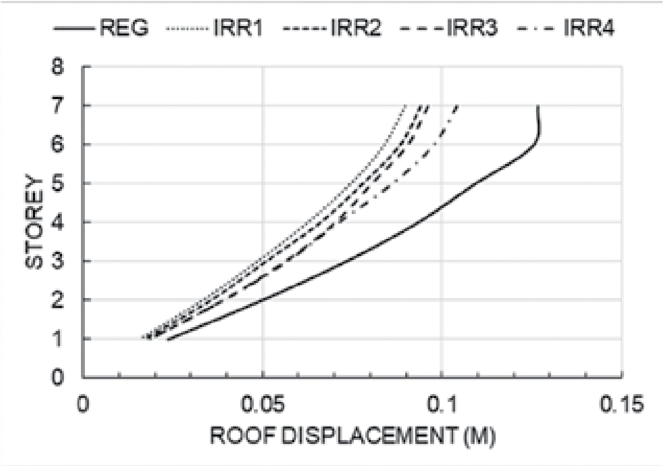
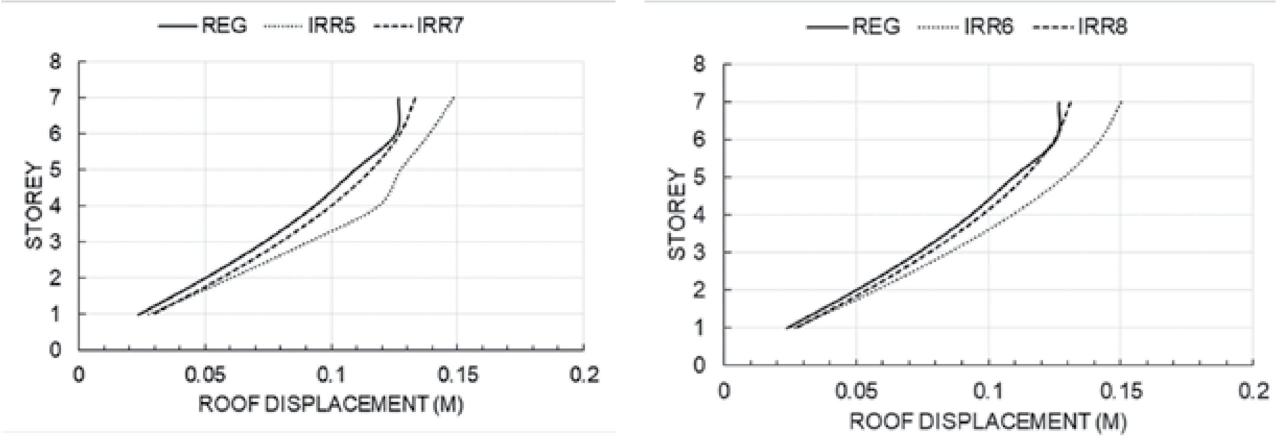


Figure 17: Story versus displacement curve from non-linear time history analysis

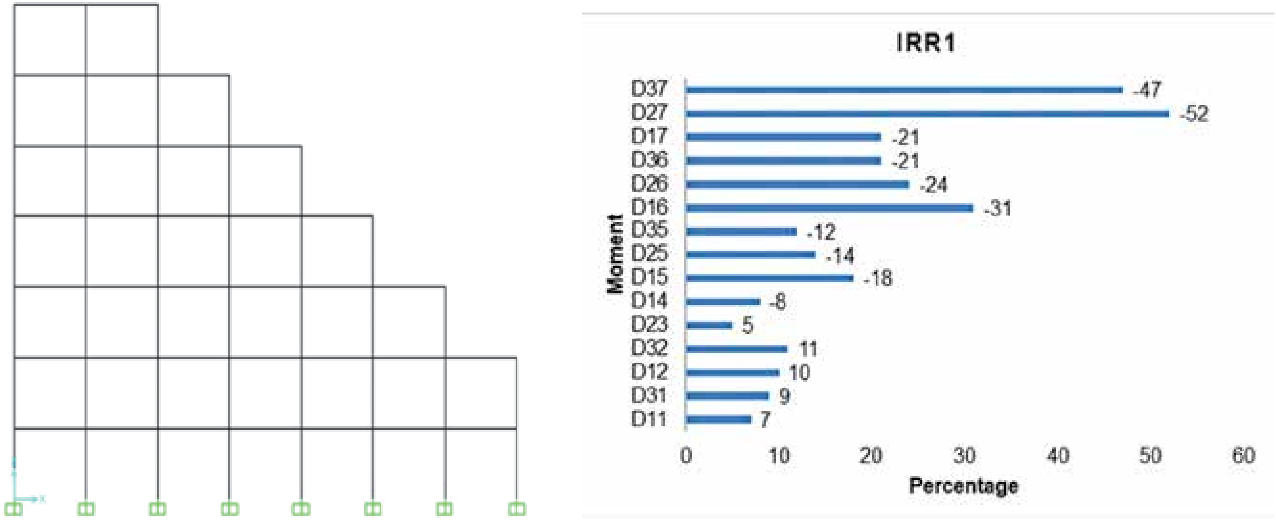


(a) **(b)**

Figure 18: Story versus displacement curve of regular and irregular building model using non-linear analysis.

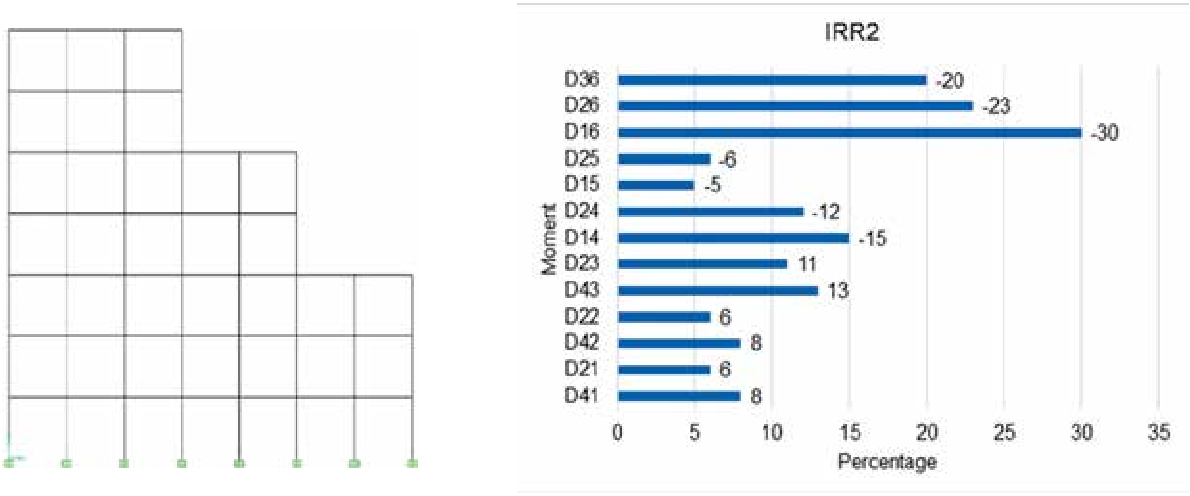
4.5 Comparison of Moment of Regular and Geometric Irregular Building

At section DD, the moment of regular building model is greater than IRR1 building upto the 2nd story and slightly higher at 3rd story level. But, after the 3rd storey level the moment of IRR1 building is about 52% higher than regular building model. This variation is due to the higher level of irregularity in IRR1 building model. Similarly, IRR2 building model has about 13% less moment at lower storey as compared to regular building (Figs. 19-22).



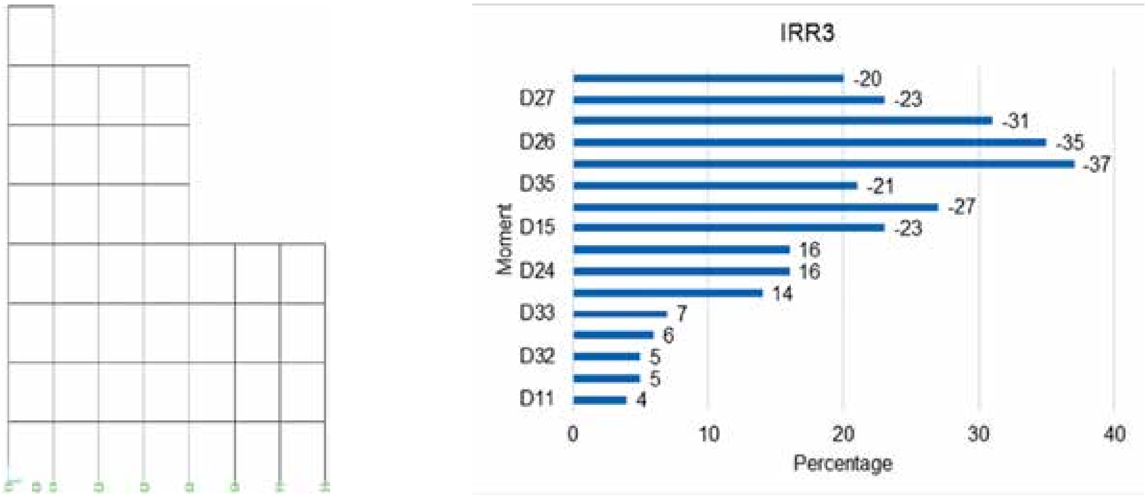
(a) **(b)**

Figure 19: Plan and percentage increased or decreased of moment IRR1 with respect to regular building.



(a) **(b)**

Figure 20: Plan and percentage increased or decreased of moment IRR2 with respect to regular building.

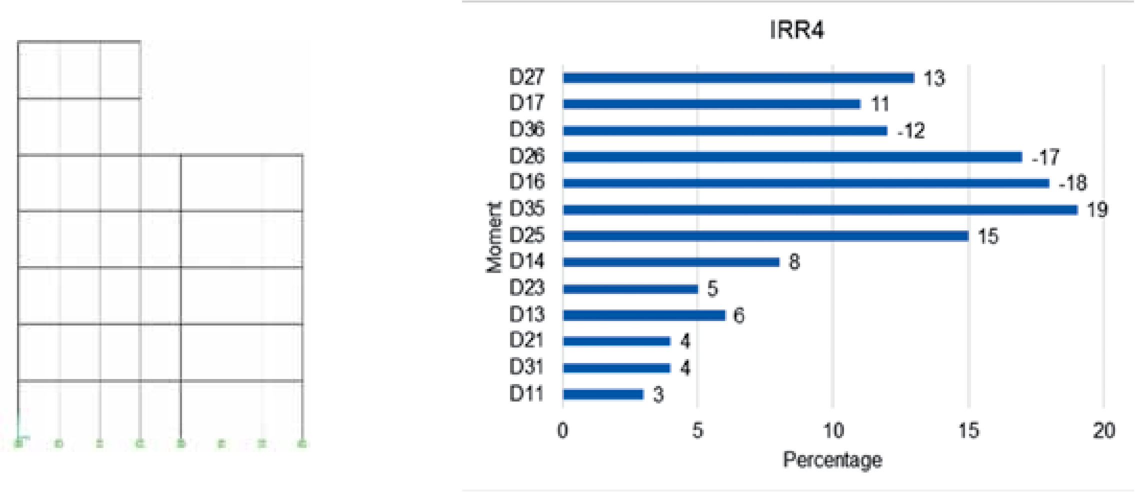


(a) **(b)**

Figure 21: Plan and percentage increased or decreased of moment IRR3 with respect to regular building.

4.6 Torsion Effect on Irregular Building Structures

The torsion in the building structure during earthquake is generated due to the unsymmetrical distribution of mass and stiffness along the height of building (Gokdemir et al., 2013; Cai and Pan, 2007; Neelavathi et al., 2017). In recent years, codes have given special provision to counter these effects by introducing accidental eccentricity which has to be considered during analysis and design. The torsional factor of studied building structure is presented in Table 4. From table, it is observed that regular building has almost same torsion factor in all the storey level. On the contrary, the high level of irregularity is clearly seen in the form of torsion appeared in the building models IRR1, IRR2, IRR3 and IRR4. The torsional effect is not observed in the structure with swimming pool (IRR5) and Game hose (IRR7).



(a) (b)

Figure 22: Plan and percentage increased or decreased of moment IRR4 with respect to regular building. (Note: D11, D32, D42 likely D represents the value of moment at section DD (see figure 5) second place numerical value represents the place of moment taken as per plan of the building and third place numerical value represents story levels. Here, the negative value represents that irregular building have more moment than regular building in percentages).

Table 4: Torsion factor of studied building structures

Storey	REG	IRR1	IRR2	IRR3	IRR4	IRR5	IRR6	IRR7	IRR8
1	0.559	0.669	0.519	0.575	0.531	0.629	0.566	0.627	0.544
2	0.558	0.564	0.524	0.572	0.526	0.629	0.566	0.626	0.543
3	0.557	0.683	0.714	0.565	0.776	0.629	0.565	0.627	0.542
4	0.554	0.765	0.732	0.748	0.785	0.632	0.563	0.630	0.538
5	0.552	0.826	0.820	0.756	0.790	0.635	0.561	0.633	0.538
6	0.552	0.871	0.826	0.757	0.794	0.635	0.564	0.646	0.541
7	0.553	0.874	0.829	0.758	0.796	0.633	0.568	0.631	0.547

Note: Torsion factor =Deflection Umax / (Deflection U1max +Deflection U2max)

5. Conclusions

This study highlights the effect of structural irregularities on seismic response of reinforced concrete building structures in Nepal. The geometrical irregularities are created by removing the bays in different floor levels and mass irregularities are studied by considering the swimming pool and game house at different floor levels. The results are analyzed analytically in terms of storey shear, storey displacement, drift and overturning moment. The effect of different irregularities is highlighted by comparing the results with regular structure. The main conclusions of the study can be summarized as:

- Based on the formation of plastic hinges, the columns of an irregular building reached life safety and collapse prevention level earlier than a regular building. The storey wise distribution of plastic hinges in beam and columns are distributed evenly in regular building model.

- The results indicated that the maximum top displacement of the regular building is 126.6 mm. Building model IRR1 have top displacement of 89.52 mm while IRR2 have 94 mm and IRR3 have 95.98mm at the top respectively. It reflects that higher the structural irregularities lower the storey displacement and vice versa. The displacement of regular building is more than the irregular building. It mainly depends on the amount of reduction of mass and stiffness in irregular structure.
- It can be observed that the moment of regular building model is greater than IRR1 building up to the 2nd story level. After 3rd storey level, the IRR1 building has about 52% higher moment than regular model. The regular building model generates the higher moment in lower stories. As the result of torsional effects, irregular building models induced higher moment in top stories.

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Conflict of Interests

Not declared by authors.

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