

Effect of Plan Irregularity on RC Buildings due to BNBC-2006 Earthquake Load

M.Z. Habib, M.A. Alam, S. Barua, M.M. Islam

Abstract— To dates irregular shape of building is being mostly designed by the architects; which offers more beauties. This irregularity may be plan or vertical. Plan or vertical irregularity makes structures vulnerable under seismic loading. Torsional irregularity, overturning moment can rise abruptly having irregularity in a structure. Hence, effect of irregularity is a very important issue to be considered during building design. Bangladesh National Building Code (BNBC) 2006 requires that practically all multi-storied buildings be analysed as three-dimensional systems. This is due to the irregularities in plan or elevation or in both. In the current study six buildings of different shape has been chosen and analysed by imposing seismic loads using finite element software (ETABS v 9.7.4). The shapes of the buildings are rectangular, square, Inverted L, T, U and L. Each of the building has G+6 number of storey and located at seismic zone-I of BNBC 2006. The current study discusses the performance evaluation of RC (Reinforced Concrete) Buildings with plan irregularity. Structural irregularities are important factors which decrease the seismic performance of the structures. The parameters whose effects are regulated such as: Lateral displacement, Storey Drift, Time period, Base Shear, Torsional Irregularity Ratio, Overturning Moment. Eventually it is revealed that, the rectangular shaped building undergo maximum lateral displacement as well as drift in both direction. No change in time period is observed due to change in building plan. Base shear and overturning moment is found maximum for T-shaped building. It has been studied that rectangular shaped building is torsionally irregular.

Index Terms— Plan Irregularity, Drift, Seismic Load, RC Building, Torsional Irregularity, Time period, Base shear

1 INTRODUCTION

Modern buildings are being widely designed as irregular structures. A building is said to be a regular when the building configurations are almost symmetrical about the axis and it is said to be the irregular when it lacks symmetry and discontinuity in geometry, mass or load resisting elements [1], [4] and [5]. Asymmetrical arrangements cause a large torsion force which makes the structure torsionally irregular [1]. The building configuration has been described in BNBC-2006 as regular or irregular in terms of the size and shape of the building, arrangement of structural the elements and mass. There are two types of irregularities such as: 1) Horizontal irregularities refers to asymmetrical plan shapes (L, T, U and F) or discontinuities in horizontal resisting elements such as re-entrant corners, large openings, cut outs and other changes like torsion, deformations and other stress concentrations, 2) Vertical irregularities referring to sudden change of strength, stiffness, geometry and mass of a structure in vertical direction. The behaviour of a building during an earthquake depends on several factors, stiffness, adequate lateral strength, ductility, simple and regular configurations [2] and [3].

Ashvin et al.[3] evaluated the performance of RC (Reinforced Concrete) Buildings with irregularity. They studied five

frames and their lateral storey-displacements, storey drifts and base shears have been computed to obtain the effects of irregularities on the frames. Their study as a whole makes an effort to evaluate the effect of vertical irregularity on RC buildings, in terms of dynamic characteristics and the influencing parameters which can regulate the effect on Story Displacement, Drifts of adjacent stories, Excessive Torsion, Base Shear, etc. Konakalla et al.[5], investigated the behavior of irregular building under dynamic loading using linear static analysis. In their analysis they studied lateral displacement due to seismic loads. In the result they found no change in the displacement due to the change in plan.

In the current study, six different shapes of building have been studied to outline the effect of plan irregularity. The location of the building is assumed to be in the seismic zone-I as specified in BNBC-2006[1]. The effect is outlined with the following parameters: Lateral Displacement, Storey Drift, Base Shear, Time Period, Torsional Irregularity Ratio and Overturning Moment.

2 IRREGULARITY

Based on the structural configuration, each structure shall be designed as a regular, or irregular structure as defined below:

Regular Structure: Regular structures have no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems.

Irregular Structures: Irregular structures have significant physical discontinuities in configuration or in their lateral force resisting systems. Irregular structures have either vertical irregularity or plan irregularity or both in their structural configurations.

a) **Vertical Irregularity:** Structures having one or more of the irregular features listed in the Table 1 shall be designed as having a vertical irregularity.

- Md. Zakaria Habib is currently working as a Lecturer at Department of Civil & Environmental Engineering in Uttara University, Bangladesh, PH-+8801718101165. E-mail: mzh.ce.97@gmail.com
- Md. Ashraf Alam is currently working as a Lecturer at Department of Civil & Environmental Engineering in Uttara University, Bangladesh, PH-+8801556383742. E-mail: ashraf.duet25@gmail.com
- Shisir Barua is currently working as a Lecturer at Department of Civil & Environmental Engineering in Uttara University, Bangladesh, PH-+8801913912586. E-mail: shisir.ce007@gmail.com
- Md. Mohaiminul Islam is currently working as a Lecturer at Department of Civil & Environmental Engineering in Uttara University, Bangladesh, PH-+8801673530974. E-mail: manikmsce14@gmail.com

Exceptions:

When no storey drift ratio under lateral force is greater than 1.3 times the storey drift ratio of the storey above, the structure may be deemed not to have irregularities of type I or II in the Table 2. For this case, the storey drifts may be calculated neglecting torsional effect and the storey drift ratio for the top two storey's need to be considered.

b) Plan Irregularity: Structures having one or more of the irregular features listed in the Table 1.2 shall be designated as having a plan irregularity.

Table 1: Vertical irregularity of Structures

Type	Definition	BNBC Section Ref.
I	Stiffness Irregularity (Soft Storey): A soft storey is one in which the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average of the stiffness of the three storeys above.	2.5.5.1
II	Mass Irregularity: Mass irregularity shall be considered to exist where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey. A roof which is lighter than the floor below need to be considered.	2.5.5.1
III	Vertical Geometric Irregularity: Vertical geometric irregularity shall be considered to exist where horizontal dimension of the lateral force resisting system in any storey is more than 130% of that in an adjacent storey, one-storey penthouses need to be considered.	2.5.5.1
IV	In-Plan Discontinuity in Vertical Lateral Force-Resisting Element: An in-plane offset of the lateral load resisting elements greater than the length those elements.	1.5.5
V	Discontinuity in Capacity (Weak Storey): A weak storey is one in which the the storey strength is less than 80% of that in the storey above. the total strength is the total strength of all seismic resisting elements sharing the storey shear for the direction under consideration.	1.5.4.3 1.3.5

Type	Definition	BNBC Section Ref.
I	Torsional Irregularity (to be considered when diaphragms are not flexible): Torsional irregularity shall be considered to exist when the maximum storey drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.2 times the average of the storey drifts of the two ends of the structure.	1.5.4.2, 2.5.6.5, 1.5.4.3, 1.7.2.9(d)
II	Reentrant Corners: Plan configurations of a structure and its lateral force resisting system contain reentrant corners, where both projections of the structure beyond a reentrant corner are greater than 1.5% of the plan dimension of the structure in the given direction.	1.7.2.9(d)
III	Diaphragm Discontinuity: Diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50% of the gross enclosed area of the diaphragm, or changes in effective diaphragm stiffness of more than 50% from one storey to the next.	1.7.2.9(d)
IV	Out-of-Plane Offsets: Discontinuities in a lateral force path, such as out-of-plane offsets of the vertical elements.	1.5.5 1.7.2.9(d)
V	Nonparallel Systems: The vertical lateral load resisting elements are not parallel to or symmetric about major orthogonal axes of the lateral force-resisting system.	1.5.4.2

3 SEISMIC LOADS

Seismic loading is one of the basic concepts of earthquake engineering which means application of an earthquake-generated agitation to a structure. It happens at contact surfaces of a structure either with the ground, or with adjacent structures.

- ✓ Seismic loading depends, primarily, on:
- ✓ Anticipated earthquake's parameters at the site - known as seismic hazard
- ✓ Geotechnical parameters of the site
- ✓ Structure's parameters
- ✓ Characteristics of the anticipated gravity waves.

Sometimes, seismic load exceeds ability of a structure to resist it without being broken, partially or completely Due to their mutual interaction; seismic loading and seismic performance of a structure are intimately related.

Table 2: Plan Irregularity of Structures

2.1 Seismic zone and zone coefficient

Seismic zone for a building site shall be determined based on the location of the site on the Seismic Zoning Map as in BNBC-2006. Each building or structure shall be assigned a Seismic Zone Coefficient, Z corresponding to the seismic zone of the site as set forth in Table 3.

Table 3: Seismic zone coefficient in Bangladesh

Seismic Zone	Zone Coefficient, Z
I	0.075
II	0.15
III	0.25

2.2 Design Earthquake Forces for Primary Framing Systems

The design earthquake lateral forces on the primary framing systems of every building or structure shall be calculated based on the provisions set forth in this section. The design seismic forces shall be assumed.

The total base shear can be calculated as follows:

$$V_b = \frac{ZIC}{R} W \tag{1}$$

Where,

Z = Seismic Zone coefficient

I = Structural Importance coefficient

W = Total Seismic dead load

C = Numerical coefficient given by the following relation :

3 STOREY DRIFT

Storey drift is the displacement of one relative to the level above or below due to the design lateral forces. Except otherwise permitted in BNBC Sec 1.3.4.2(a) calculated storey drift shall include both translational and torsional deflections and conform to the following requirements:

a) Storey drift, Δ, shall be limited as follows:

i) $\Delta \leq 0.04h / R \leq 0.0005h$ for $T < 0.7$ second.

ii) $\Delta \leq 0.03h / R \leq 0.0004h$ for $T \geq 0.7$ second.

iii) $\Delta \leq 0.0025h$ for unreinforced masonry structures.

where, h= height of the building or structure

b) The drift limits set out in (a) above may be exceeded where it can be demonstrated that greater drift can be tolerated by both structural and non-structural elements without affecting life safety.

4 TIME PERIOD

For all buildings the value of Time period, T may be approximated by the following formula :

$$T = C_t (h_n)^{3/4} \tag{2}$$

where, $C_t = 0.083$ for steel moment resisting frames

$= 0.073$ for reinforced concrete moment resisting frames

$= 0.049$ for all other structural systems

$h_n =$ Height in metres above the base to level n.

5 OVERTURNING MOMENT

Every structure shall be designed to resist the overturning effects by wind or earthquake forces as specified in BNBC re-

spectively. The overturning moment M_x at any storey level-x of a building shall be determined as:

$$M_x = F_n \left(h_n - h_x + \sum_{i=1}^n F_i \right) (h_i - h_x) \tag{3}$$

where,

$h_i, h_x, h_n =$ Height in meters at level-i, -x or -n respectively.

$F_i =$ Lateral force applied at level-i, $i=1$ to n.

$F_n =$ Concentrated lateral force applied at level-n in addition to F_n applicable for earthquake.

6 METHODOLOGY AND BUILDING STUDIED

6.1 Figures and Tables

It is obvious to address an area where the study is carried out. In the present study seismic zone-I of Bangladesh National Building Code-2006 is taken as study area. The soil profile of the study area is assumed to be S3 i.e a soil profile 21 meters or more in depth and containing more than 6 meters of soft to medium stiff clay but not more than 12 meters of soft clay.

Model is a technique by which anything can be described maintaining a proper scale. A three dimensional Finite Element analysis has been performed for this building based on as-built Layout Plan. The building consists of concrete beam-columns frame structure with edge supported slab. Beams and columns were modelled with appropriate frame elements. The slab was modelled with shell elements. Extended Three Dimensional Analysis of Building Structure (ETABS v 9.7.4) has been used as finite element modelling software. In any finite element analysis, applying appropriate boundary conditions are important. In the present project, the foundations included in the FE model have not been applied beneath the shallow footing. For simplicity fixed supports are used in all directions.

The present study has been carried out by a finite element analyses. First of all, the building models has been developed using the knowledge ETABS. Then analysis is carried out for different parameters. After the analyses some outputs have been taken and processed using MS Excel. The Study building are shown below [Fig. 1] with their lateral dimension ratio. Information of the building used in the study are summarized in Table 4. Three dimensional view of the selected shaped building are shown in Fig. 2.

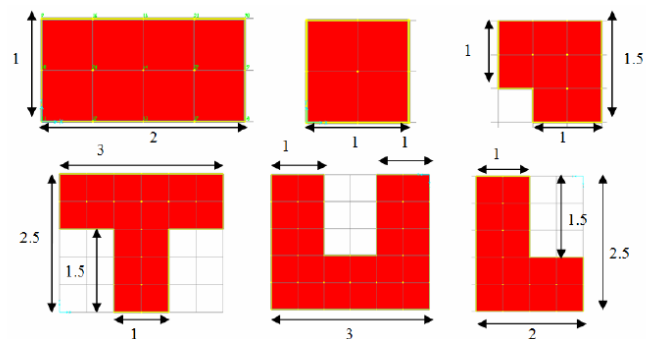


Fig. 1: Relation of geometric forms selected in first stage and its general dimensions standardizing in reference to the square plant.

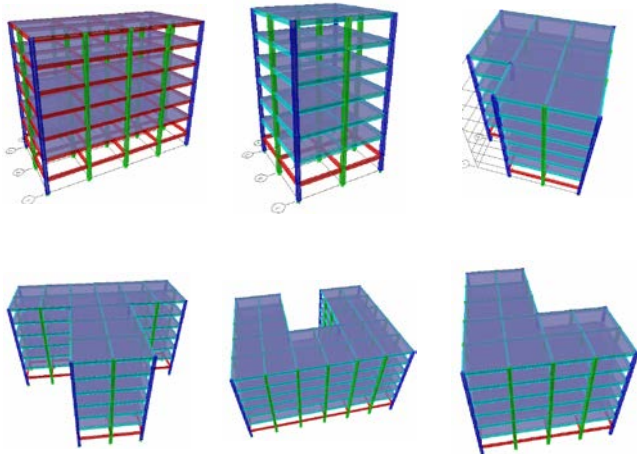


Fig. 2: Three dimensional view of study buildings

Table 4: Information of Building used in the study

Shape of the Buildings	Rectangular, Square, Inverted L, T, U and L Shaped.
Lateral Dimension of each bay	20 ft 0 inch
No. of Storey	G+6
Floor Height	10 ft 0 in
Foundation Bed Level	-8 ft 0 in
Concrete Strength, f'_c	5,000 psi
Yield Strength of Steel, f_y	72,000 psi
Corner Column Size	18 in X 18 in
Other Column Size	20 in X 20 in
Grade Beam Size	12 in X 18 in
Floor Beam Size	12 in X 20 in
Slab Thickness	6 in.
Live Loads	40 Psf
Floor Finish	25 psf
Partition Wall	450 plf (5 in Brick Wall)
Seismic Zone	Zone-I
Zone Co-efficient, Z	0.075
Moment Resisting Frame	IMRF
Response Modification Factor, R	8.0
Site Co-efficient, S_3	1.5

7 RESULTS

7.1 Lateral storey displacement

Lateral Storey displacement or sway is usually found when lateral load is applied to a structure. The lateral load may be seismic or wind load. In the current study seismic load is imposed on the structures. Fig. 3 represents the lateral maximum displacement for X and Y direction respectively. It is seen from the figures that sway in the X-direction for all types of buildings are seemed to be similar. However, Rectangular shape building undergoes a large sway in the Y-direction and others undergo almost similar level sway. From the sway point of view, it can be said that rectangular shape building has to undergo most effect perpendicular to its narrow side. Rectangular Shape building undergoes 74.5% more sway in the Y-Direction than X-Direction.

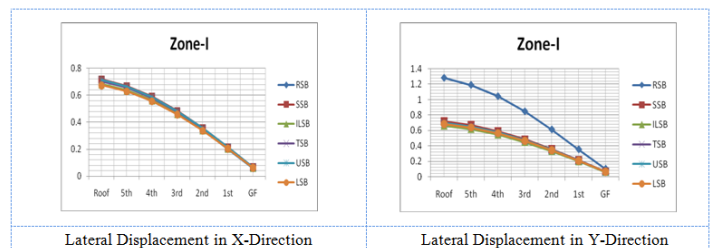


Fig. 3: Lateral Displacement

7.2 Storey drift

Storey drift is defined as the relative sway of frame to the adjacent floor. Storey drift should be limited to the prescribed value of BNBC-2006. Fig. 4 represents the storey drifts along different directions. Figures clearly demonstrates that, rectangular building undergo a huge large storey drift in Y-direction than any other shape building in any direction.

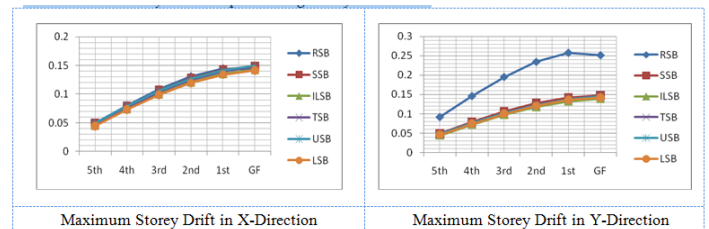


Fig.4: Maximum storey drift

7.3 Base shear

Base shear is the force which is acts in the base of any structure to overturn the building when earthquake load acts in a structure. Fig. 5 represents base shear value for different types of buildings when plan irregularity is exists. It is seen from the figure that, base shear varies by a large value due to the change of shape of building. U-shaped building undergo most base shear followed by TSB, LSB, RSB and SSB.

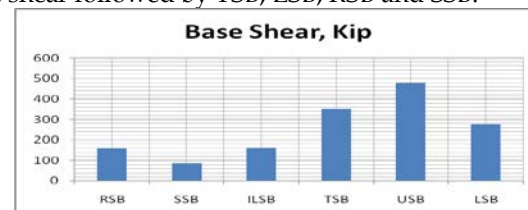


Fig. 5: Base Shear Value for different shape buildings

7.4 Time period

Time period of any building expresses that how long the building will take to collapse whiles the ground acceleration exceeds its tolerable limit. Fig. 6 represents the comparison of computed time period by ETABS and time period from BNBC. It is seen that time period recommendation in BNBC is 40% higher than the actual one found in ETABS analysis irrespective the shape of Building.

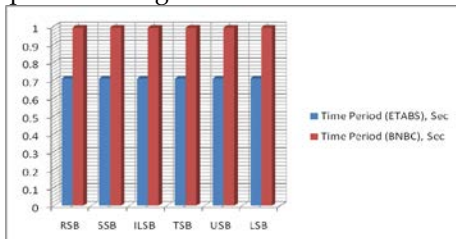


Fig. 6: Time Period ETABS vs Time Period BNBC

7.5 Torsional Irregularity

Bangladesh National Building Code recommends that no one building can have the ratio of average drift to minimum drift in any direction more than 1.2. If so then those building will have to be taken for special treatment to withstand torsional forces. Fig. 7 represents the comparison of torsional irregularity factor. It has found from the analysis that Rectangular shape building is vulnerable to torsional irregularity. Other shapes are found within the prescribed value by BNBC code.

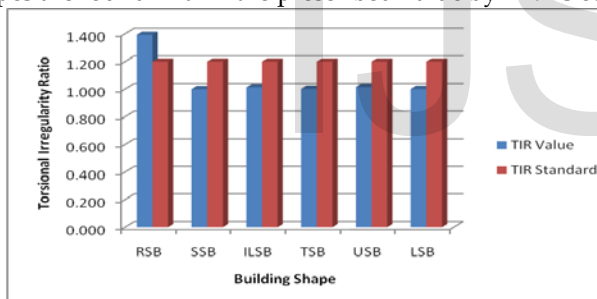


Fig. 7: Torsional Irregularity Ratio (TIR) Comparison

7.6 Overturning moment

Overturning is a phenomenon that occurs tilting of the structure when lateral load is imposed in the building. Fig. 8 represents the overturning moment of different shape buildings. Figure shows that maximum overturning moment will produce if the shape of building is like a T followed by U, L, IL, R and S.

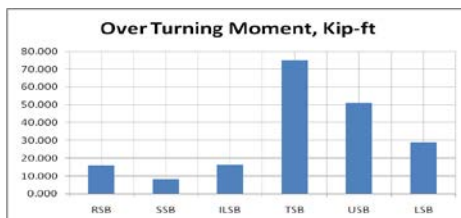


Fig. 8: Overturning moment of different shapes

8 CONCLUSION

The following conclusions can be made from this study:

- I. Lateral displacement of all shaped structure is found very close to each other in each direction. However, 74.5% increased lateral displacement is found in rectangular shaped building in Y-direction;
- II. Findings for storey drift is similar as in the case of lateral displacement because drift is totally depends on lateral displacement. A 74.5% higher value of drift is computed for rectangular building in Y-direction;
- III. Base shear varies by a large value due to the change of shape of building. U-shaped building undergo most base shear followed by TSB, LSB, RSB and SSB. the computed base shear values are 159, 85,36, 162.12, 353.54, 478.72 in Kips and 277.73 for RSB, SSB, ILSB, TSB, USB and LSB respectively.
- IV. It is seen that time period recommendation in BNBC is 40% higher than the actual one found in ETABS analysis irrespective the shape of Building.
- V. It has found from the analysis that Rectangular shape building is vulnerable to torsional irregularity (TIR=1.39). Other shapes are found within the prescribed value by BNBC code.
- VI. Maximum overturning moment is produced for T-shaped building followed by U, L, IL, R and S.

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