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# Effect of building shape on the response to wind and earthquake

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**Abstract**: With the increase in the application of modern technologies in Civil Engineering, construction of high rise buildings is increasing very hastily. Such buildings are prone to lateral loads from wind or earthquake. Numerous approaches have been adopted to minimize the severe effects of lateral loads on the high rise buildings. Shape of building is one of such approaches. This paper presents a numerical study of the effect of building shape on the response to wind and earthquake. Three different shapes of buildings have been considered in the present study and a comparison between different shaped of buildings against the effect of lateral loads due to wind and earthquake has been presented. Computer aided analysis has been carried out to perform the relative comparison and focus the effect of the shape of building. The Bangladesh National Building Code (BNBC), 2006 has been considered in the analysis. The result depicts that the shape of building has noticeable effect in minimizing the drift of building.

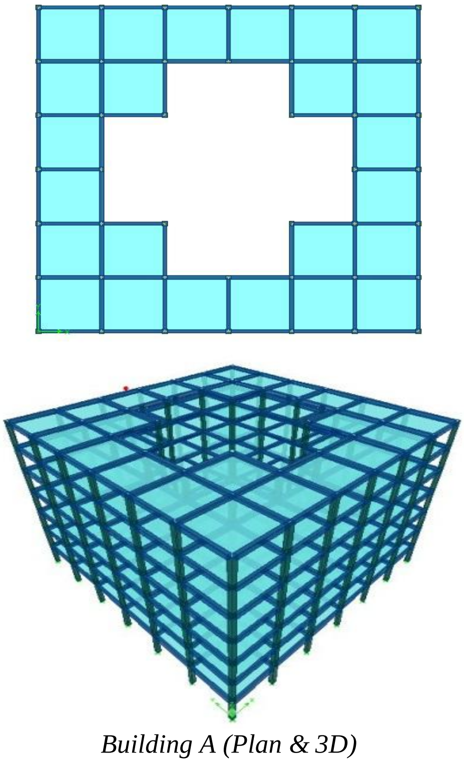
***Keywords****: Wind, Seismic load, Shape of building, Torsion, Multistoried Building*

## 1. Introduction:

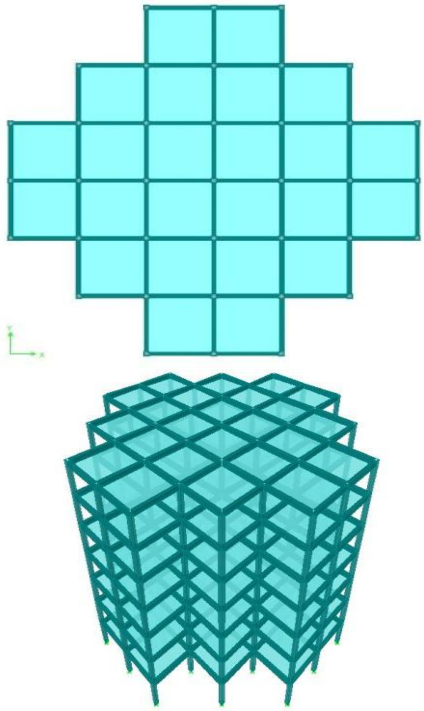
With the improvement of modern science and technology, a radical change in the building construction has been observed. Architectural views have been rehabilitated as well. The buildings of 1800s are architecturally simple and are of less stories compared to this century. In 1900s, a bit complex architectural parameter has been introduced and the structures become comparatively taller. The building of the current century partakes a variety of changes in architectural views, shapes, size & aesthetical views. Now, it has become a challenge for structural and geotechnical engineers to meet up the design need considering the variation in shapes, vertical irregularities, client's requirements, safety against natural calamities like wind and earthquake and economical facts. As the height of the building increases, the building is prone to severe action of earthquake and wind. Considerable materials and cost have to be invested to make the modern building safe which is disposed to earthquake and wind. Consequently, much attention has been paid to the research work to minimize the effect of earthquake and wind on the buildings which will reduce the cost of building construction. Consideration of the shape of building to minimize the drift/displacement of building has drawn attention to the researchers because it is such a technique that does not require any special treatment except the shape itself.

The aim of the present study is to compare the effect of building shape on the displacement characteristics of building. Heiza & Tayel [1] discussed about the comparative study of the effects of wind and earthquake loads on high-rise buildings. They analyzed almost 30 buildings to show the comparative effects of wind and earthquake as per the Egyptian code. It was found that wind has more effects in taller buildings. Seismic effects in shorter buildings are more than wind effects. Tani et al [2] represented the effect of plane shape and size of buildings on the input earthquake motions. He made a dynamic analysis for the presentation. Effects due to effective eccentricity were vastly discussed there. Banginwar et al. [3] showed the effect of plan configuration on the seismic behavior of the structure by response spectrum method. They took three types of shapes including regular, moderately irregular and strongly irregular for their research. They considered a number of properties such as proportions, slenderness ratios, etc.. They showed a decent overview of their research topic. Effect of differential areas, torsion developments due to shapes and differential displacements were the main issues of their work. Guevera et al. [4] has presented floor-plan shape influence on the response to earthquakes. They presented a further dynamic analysis on various shaped floor plans and the effect of earthquake on them. H-shape and L-shape were taken into considerations. Outcome of using seismic joints were also included to show the comparison more distinctly. Shape effects on the wind-induced response of high-rise buildings were discussed by Merrick & Bitsuamlak [5]. They discussed about the buildings with different floor-plan shapes such as square, circular, triangular, rectangular and elliptical shaped. They did comprehensive lab experiments for the research. Ravikumar et al.[6] deliberated about the effect of irregular configurations on seismic vulnerability RC buildings. They made their discussion more specific as they considered reinforced concrete buildings. They took a number of shapes with both horizontal & vertical irregularities for comparison. They made a vast discussion by doing dynamic analysis of their prospective samples. Though, a number of researches have been done on building shapes, this paper includes two more disparate shapes which have importance in practical consideration. The regular shaped with hollow space and the modified cross shapes have been considered in this research.

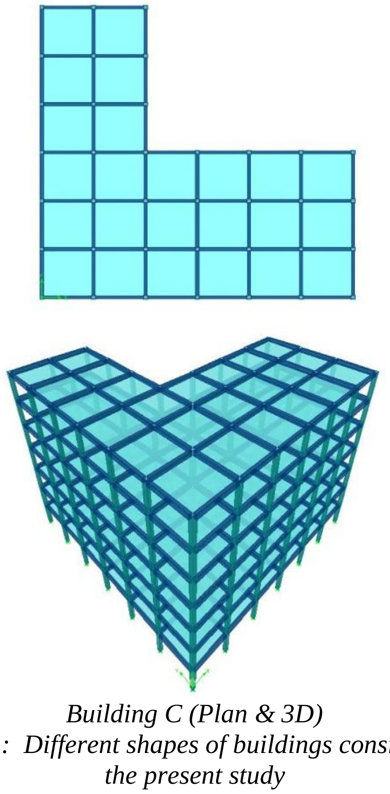
The aim includes showing the effect of eccentricity, irregularity and diaphragm discontinuity; making a comparison due to both wind and seismic force and showing the variation of point displacement and story drift. Considering different horizontal shapes, here a comparison has been made. Three different shaped buildings: Rectangular with hollow space, Modified cross shaped& L-shaped (see Fig. 1)have been considered. The hollow shaped building has symmetry with respect to both axes but there is a diaphragm discontinuity. We can consider this shape as a regular shape. These types of buildings are often seen in Bangladesh as residential halls in educational institutions and various public buildings. This is the prime reason to consider such shape of model. The reason for choosing model "B" is the architectural criteria often given by clients. Sometimes, it becomes a challenge for a structural designer to meet with all architectural basis. The modified cross type building has symmetry with respect to both axes but it is moderately irregular in shape. The L shaped building has been chosen for the same reason. The L-shaped building is asymmetrical to both axes. The models are of same plan area and same height. The material properties of the models are also same. Base shear, lateral displacement, eccentricity, story drift has been contemplated as the main comparison issues. A computer program has been used to analyze the buildings as per specifications detailed in BNBC2006 [10].The analysis result shows a decent result. The related results are reported in details in the following sections.



*Building A (Plan & 3D)*



*Building B (Plan & 3D)*



*Building C (Plan & 3D)*

***Figure 1**: Different shapes of buildings considered in the present study*

**2. Analysis Methodology:**

There are a number of provisions in BNBC [10] for analyzing wind and earthquake forces. For wind force analysis, they are:

a) **Surface area method:** This method is applicable for gable rigid frames, single story rigid frames and other types of framing systems. In this practice, design wind pressure is presumed to be applied normal to all exterior surfaces.

b) **Projected area method:** The projected area method is relevant to all buildings and structure without those specified for the previous method. It is assumed that the wind pressure is applied to the overall vertical projected area. For simplicity, it is assessed that the wind force is preceded as point loads on the nodal joints.

In this paper, the projected area method is used. In case of seismic analysis, the following methods are used.

i. **Equivalents static force method:** In this method of analysis, the seismic force is applied as nodal loads calculated by reflecting on the self-weight, soil profile and response modification factors of certain structures.

**ii. Dynamic analysis**

The dynamic analysis consists of the following methods.

i) **Response spectrum analysis**: In this method, a linear dynamic analysis is done by considering seismic ground motion.

ii) **Time history analysis**: In this method, a nonlinear dynamic analysis is done by considering seismic ground motion.

For seismic analysis, the equivalent static force method is used in this paper.

In Bangladesh, the Housing and Building Research Institute has divided Bangladesh into three zones based on the possibility of severe intensity of seismic ground motion. These are: Zone I, Zone II& Zone III. Zone III is the most severe zone among these zones.

Three different types of buildings named as A, B, C (Fig.1) is used. All these three buildings are of same areas axes. The specifications of model are given in Table 1:

***Table 1:*** *Specifications of model components*

| Model components | Specifications |
|---|---|
| Beam | 30x45(cm) in cross-section |
| Column | 40x40(cm) in cross-section |
| Slab | 12.5 cm in thickness |
| Floor Height | 3m |
| Total Height | 18 m |
| Plan area | 600 sq.m |

Dead load includes the self-weight of the building components. Live loads are taken from BNBC [10]. The selected city is Rajshahi. According to seismic zoning map of Bangladesh, Rajshahi is under zone I. The total load calculations have been done as per BNBC[10].The corresponding equations are as follows:

V = $= \frac{\text{ZIC}}{R} W$……………………(1)

where, $C = \frac{1.25S}{T^{2/3}}$……………………(2)

And T =C$t(hn)^{3/4}$…………………… (3)

***Table2:*** *Necessary coefficients for seismic load calculations*

| Parameters | Values |
|---|---|
| Base Shear, V | Calculated from equation (1) |
| Zone factor, Z | 0.075 |
| Structural importance , I | 1 |
| C | Calculated from equation (2) |
| Response modification factor, R | 8 |
| Structural Period, T | Calculated from equation (3) |
| Soil Profile, S | 1.5 |
| Building Coefficients. $C_t$ | 0.073 |

Required equations for wind pressure calculations are as follows:

$q_z = C_c.C_1.C_z.V_b^2$……………..…… (4)

$p_z = C_G.C_p.q_z$……….........……… (5)

**3. Effect of Shape:**

After analysis, a number of features have been observed. Though the areas are identical, there are variations in displacements. There are also inequalities in calculated base shear and story drift.

From Table 4, it is observed that the maximum displacements are in the "Building C". The minimum is in "Building A". From Figs. 2and 3, an explicit view of lateral displacements of the models can be shown. It is also observed from Figs. 2 and 3 that the dissimilarity in displacements among the models is less in the lower story while it is higher in the upper story. It should be noted that the differences of displacements are more in case of model A and B compared to model B and C.

Figs. 4 and 5 show an understandable variation of story- displacement and drifts (defined here as the difference of displacement divided by the story height). It is noted that the distinction of story drift is significant for lower stories while it is much low in top stories. In addition, the story drift is same for first two models (models A and B) along both directions while it is different for third model (model C). Table5 shows that the story drift due to seismic load is maximum for Building C. From Table 6, it is perceptible that the base shear is maximum in Building A. Table 7 shows the eccentricity of the models. Building A and B have no eccentricity while Building C has little eccentricity. Eccentricity is the differences between the ordinates of COM (center of mass) and COR (center of rigidity).Along x-direction, the eccentricity id is noted as $e_x$ while the same along y-direction is noted as $e_y$. Tables 8 and 9 show that the maximum displacements and maximum story drifts are observed for wind load. The displacements due to wind load are less than those due to seismic load

***Table3:*** *Table for the required coefficients for wind load calculations*

| **Parameters** | **Values** |
|---|---|
| Sustained wind pressure, $q_z$ | Calculated from equation (4) |
| Velocity to pressure conversion coefficients, $C_c$ | $47.2 \times 10^{-6}$ |
| Structural importance, $C_I$ | 1 |
| Combined height and exposure coefficients, $C_z$ | From BNBC2006 |
| Basic wind speed, $V_b$ | 155 km/h |
| Design wind pressure. Pz | Calculated from equation (5) |
| Gust coefficients, $C_G$ | From BNBC2006 |
| Pressure coefficients, $C_p$ | 1.41(BNBC2006) |

***Table 4:*** *Variations in maximum displacements due to Seismic load*

| Directions | Building A | Building B | Building C |
|---|---|---|---|
| | Maximum (mm) | Maximum (mm) | Maximum (mm) |
| Along X | 17.42 | 19.37 | 19.6 |
| Along Y | 17.42 | 19.37 | 19.71 |

***Table 5:*** *Maximum Story drift due to seismic load*

| Directions | Building A | Building B | Building C |
|---|---|---|---|
| | Drift | Drift | Drift |
| Along X | 0.001129 | 0.001261 | 0.001273 |
| Along Y | 0.001129 | 0.001261 | 0.001278 |

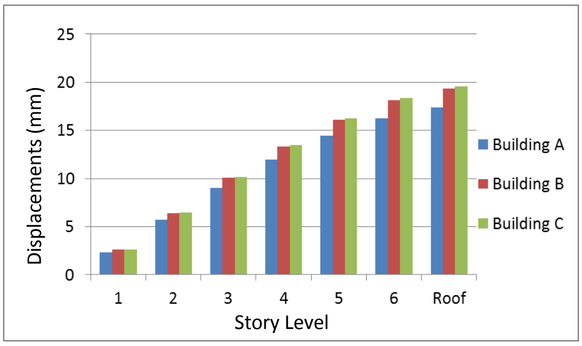



***Figure.2****: Variation of max displacements in each story level along x-axis due to earthquake*

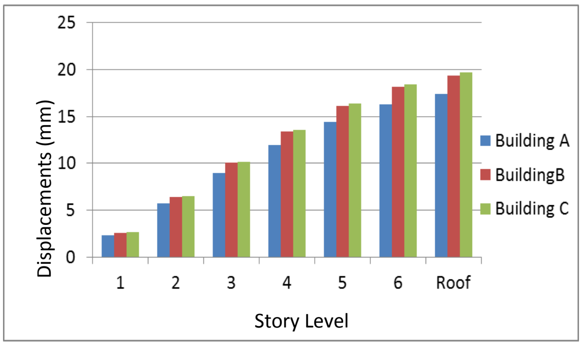



***Figure.3****: Variation of max displacements in each story level along y-axis due to earthquake*

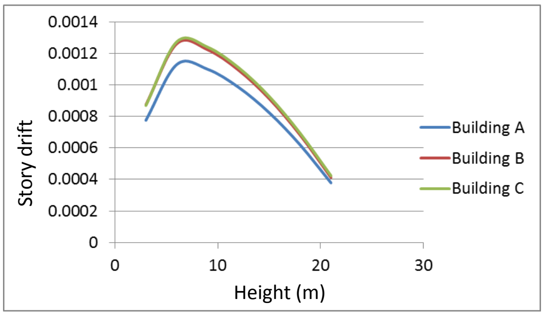



***Figure.4****: Variation of story drift due to earthquake as per height along x-direction*

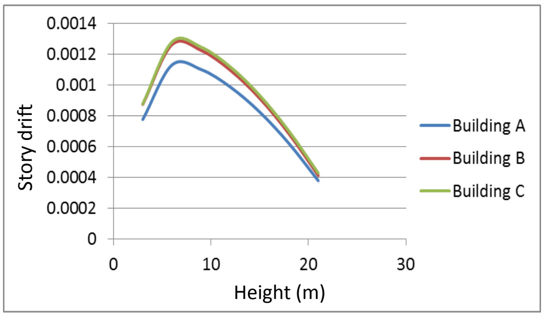



***Figure5****: Variation of story drift due to earthquake as per height along y-direction*

***Table 6:*** *Variation in base shear*

| Building A | Building B | Building C |
|---|---|---|
| Base shear(KN) | Base shear (KN) | Base shear (KN) |
| 825.1 | 757.4 | 757.4 |

***Table 7:*** *Variation in eccentricity*

| Direction | Building A | Building B | Building C |
|---|---|---|---|
| | Eccentricity | Eccentricity | Eccentricity |
| $e_x$ | 0.00 | 0 | 0.07 |
| $e_y$ | 0 | 0 | 0.51 |

***Table 8:*** *Variations in maximum displacements due to wind load*

| Directions | Building A | Building B | Building C |
|---|---|---|---|
| | Maximum (mm) | Maximum (mm) | Maximum (mm) |
| Along X | 9.30 | 10.62 | 14.78 |
| Along Y | 9.30 | 10.62 | 13.6 |

***Table 9:*** *Maximum story drift due to wind load*

| Directions | Building A | Building B | Building C |
|---|---|---|---|
| | Drift | Drift | Drift |
| Along X | 0.000695 | 0.00798 | 0.001109 |
| Along Y | 0.000695 | 0.00798 | 0.001018 |

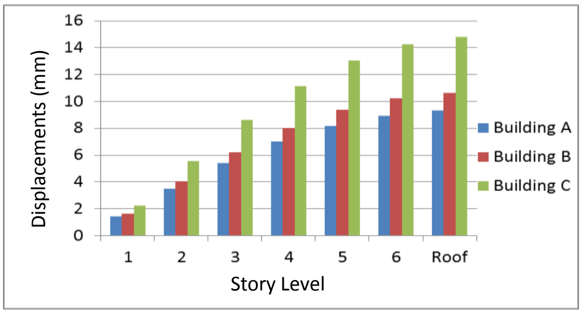



***Figure6:*** *Variation of max displacements in each story level along x-axis due to wind*

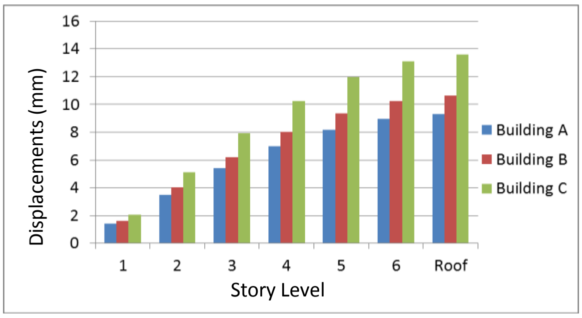



***Figure 7****: Variation of max displacements in each story level along x-axis due to wind*

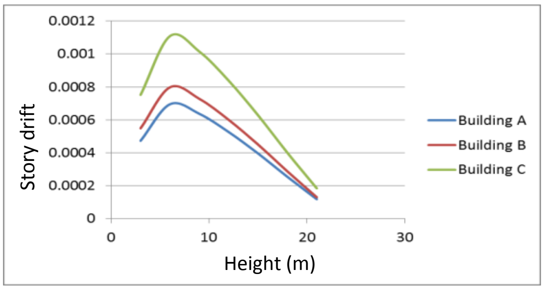



***Figure8****: Variation of story drifts due to wind as per Height along X Direction*

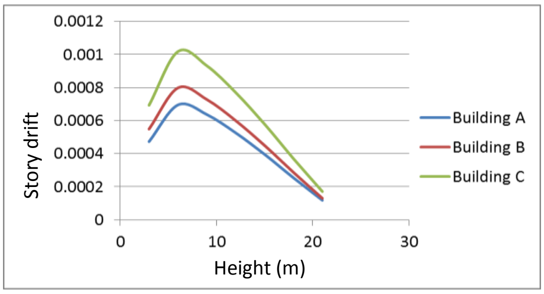



***Figure9****: Variation of story drifts due to wind as per Height along Y Direction*

## 4. Conclusions:

A numerical investigation is carried out to evaluate the effect of shape of building on the drift and displacement due to wind and earthquake loads. A number of conclusions can be made from the present study.

(i) The maximum displacement due to earthquake is observed in the C type building shape and it is noted along y-direction. This is because the distribution of seismic force depends on the relative stiffness of the lateral frames.

(ii) The maximum displacement due to wind is also observed in the C type shape of building and it is noted along x-direction. This is because the distribution of wind pressure depends on the exposed area. The weakest node for seismic load is not weak for wind load. This is because the node has more stiffness against wind pressure.

(iii) Maximum story drift for earthquake is along y-direction while it is along x-direction for wind load. Maximum story drift is noted for "Building C".

(iv) Substantial differences are perceived for both cases comprising lateral displacements due to wind load than the seismic load. Though the inclusive worst condition is for earthquake forces.

(v) The "Building A" is the safest model considering all conditions

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