Response of multi-storey regular and irregular buildings of identical weight under static and dynamic loading in context of Bangladesh

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ABSTRACT

The aim of this paper is to assess the seismic vulnerability and response of regular and irregular shaped multi-storey building of identical weight in context of Bangladesh. Both static and dynamic (response spectrum) analysis has been performed to study the influence of shape of a building on its response to various loading. 15 storeyed regular (rectangular, C-shape and L-shape) shaped and irregular (combination of rectangular, C-shape and L-shape) shaped buildings have been modeled using program ETABS 9.6 for Dhaka (seismic zone 2), Bangladesh. Effect of wind and static load on different shaped structure along with dynamic response under BNBC response spectrum has been meticulously analyzed considering the mass of each shaped building is same. Comparative study on the maximum displacement of storey and center of mass of different shaped building due to static loading and dynamic response spectrum has been explored. If the total mass doesn’t vary too much, the response of any shape building is almost matching. But the end result shows, it’s the orthogonal dimensions that makes a structure vulnerable to its’ weak direction. Maintaining the total mass constant, it is possible to construct an irregular shaped building which might behave more like a rectangular building.

Keywords: Response spectrum analysis, Regular and irregular shaped multi-storey building, Maximum displacement, Center of mass displacement, Building mass.

1. Introduction

Bangladesh and the north eastern Indian states have long been one of the seismically active regions of the world, and have experienced numerous large earthquakes during the past 200 years. The geotechnical set-up of the country, which is located along two of the planet’s active plate boundaries, Indian plate and Burmese plate, suggests high probabilities of damaging future earthquakes and the possibility of rarer but extraordinary large earthquakes that may cause damage far from expectations. The occurrence of earthquakes with magnitude averaging around 5 in Richter scale is quite frequent especially in its eastern region. Although, Dhaka has not been experienced with any moderate to large earthquake in historical past, even then the earthquake of December 19, 2001 with magnitude of 4.5 and focal depth of 10 km located very close to Dhaka is certainly an indication of its earthquake source and vulnerability (The Daily Star, 2013). In addition, micro-seismicity data also supports the existence of at least four earthquake source points in and around Dhaka. The earthquake disaster risk index has placed...
Dhaka among the 20 most vulnerable cities in the world (The Daily Star, 2013). For this reason it is important to design structures appropriately to reduce damage of structure and life.

Among the factors configuration of a building is an important feature which has huge influence on the damage during the earthquake shaking (Islam et al. 2011, Islam et al. 2012, Islam and Islam 2014). The feature of the regularity and symmetry in the overall shape of the building both in plan and elevation enormously affects the response of the building under static and dynamic loading (BNBC 1993).

Considering all of these, this study aims to observe the impact of shape and configuration on earthquake response of a building located in Dhaka, Bangladesh. The shape of different model and corresponding dimensions are so selected to maintain uniform weight in each case. Difference in response for regular and irregular shaped building is observed.

2. Strategy

The response of a structure to earthquake-induced forces is dynamic phenomena (IAEE Manual, 1986). So a realistic assessment of the design forces can be obtained only through a dynamic analysis of the structure models. But it is time consuming and complicated because most of the buildings are designed for inelastic range with nonlinear response. Nonlinear response of same structure may differ for different ground motion (Bagheri et al. 2012, Finley and Cribs, 2004). So to get design forces one should have to repeat the analysis several times. For this reason dynamic approaches are not used for routine design. In this study equivalent static load method and dynamic response spectrum are considered to analyze 15 storeyed regular and irregular shaped building in ETABS program. All the models are so prepared to maintain almost equal self-weight. Corresponding response to different types of loadings are observed. Maximum storey displacement and displacement of center of mass are plotted against storey level for different shaped building.

3. Model Analysis

3.1 Equivalent Static Load Method

Equivalent Static Load method defines a series of forces acting on a building to represent the effect of earthquake ground motion. It assumes that the building responds in its fundamental mode, for which the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum.

3.2 Response Spectrum Analysis

This method requires the collection of seismic parameters (i.e. displacement, velocity, or acceleration), which are then reduced into a spectrum of seismic action versus time period. Detailed information from the structural model is coupled with the corresponding spectral values for each specific mode of vibration. The independent results are then combined using an appropriate technique to determine the response of the overall structure. The required response quantity of interest of the structure can be obtained in each mode of vibration using the maximum response. Response spectrum analysis consists of an elastic dynamic analysis of a structure shall be performed with a mathematical model using either site specific design spectra or normalized response spectra. For analysis purpose, the normalized response spectrum (Figure 1) for damping ratio 5% is used (BNBC, 1993).
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Figure 1: BNBC Response spectrum curve for 5% damping ratio

4. Details of Models

Size of columns, shear wall and beam are taken as per approximate design output for 15 storied buildings of rectangular, C, L and irregular shape. The structural dimensions of the members along with the total mass are kept uniform for all of the modeled buildings to keep their influence similar. The plan dimensions of the modeled buildings are shown in Figures 2 and 3. As may be seen from these figures, the span length varies both in X and Y direction of different shapes to maintain the total mass nearly constant (Figure 4). The storey plans are uniform in all shapes except the irregular one. Bottom storey height is 12 ft and typical storey height is 10 ft. Applied loads on modeled structures including dead load, live load, earthquake and wind load are according to BNBC 1993. Reasonable structural dimension details and material properties are presented in Table 1 and Table 2 respectively.

Table 1: Structural dimensions

<table>
<thead>
<tr>
<th>Structural Element</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
<td>24 in x 24 in (up to 5th floor)</td>
</tr>
<tr>
<td></td>
<td>18 in x 18 in (5th to 10th floor)</td>
</tr>
<tr>
<td></td>
<td>15 in x 15 in (10th to 15th floor)</td>
</tr>
<tr>
<td>Beam</td>
<td>15 in x 15 in (all floors)</td>
</tr>
<tr>
<td>Grade beam</td>
<td>12 in x 12 in (GF)</td>
</tr>
<tr>
<td>Slab thickness</td>
<td>6 in</td>
</tr>
<tr>
<td>Shear wall (SW) thickness</td>
<td>8 in</td>
</tr>
<tr>
<td>Span length</td>
<td>Variable (ft)</td>
</tr>
</tbody>
</table>

Table 2: Material properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Value used for modeling (unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength of concrete</td>
<td>4 ksi</td>
</tr>
<tr>
<td>Modulus of elasticity of concrete</td>
<td>3600 ksi</td>
</tr>
<tr>
<td>Shear modulus of concrete</td>
<td>1500 ksi</td>
</tr>
<tr>
<td>Poisson’s ratio of concrete</td>
<td>0.2</td>
</tr>
<tr>
<td>Yield stress of steel</td>
<td>60 ksi</td>
</tr>
</tbody>
</table>
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Figure 2: Plan of regular shaped buildings in feet (a) rectangular (b) C-shape (c) L-shape
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Figure 3: Plan of irregular shaped building in feet (a) GF to 4th Floor (b) 5th to 9th Floor Plan (c) 10th to 14th Floor

Figure 4: Mass comparison of different shape buildings

5. Analysis results and discussion

Graphical representation of maximum displacements of different stories due to static earthquake (EQ) and wind load (WIND) along with dynamic response spectrum (RS) in both directions are shown in Figure 5. Regarding the maximum displacement, wind load is predominant in all types of structures. Response spectrum analysis and static earthquake analysis shows slight variation. Displacement in static earthquake loading is somewhat higher than in response spectrum.

It is obvious that the maximum displacement increases with the storey height. Studying the diagram showed below, it is noted that deference of results in lower stories due to varying loads are insignificant for all shapes. But, with the increasing height, the difference becomes important.
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Figure 5: Storey displacement for varying loads (a) rectangular, (b) L-shape, (c) C- shape, (d) irregular

It is found that the C shape and L shape structure are most vulnerable in Y direction due to wind load and shows slightly higher displacement due to dynamic response spectrum analysis. Rectangular and irregular shaped building show very little variation in result. Towering of the buildings has made them more vulnerable against wind load rather than seismic loads.
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Figure 6: Storey displacement for varying shapes (a) EQX, (b) EQY, (c) WINDX, (d) WINDY, (e) RSX, (f) RSY

Figure 7: Maximum modal time period (mode 01)
For static dynamic earthquake loading, the variation in storey displacement is ignorable corresponding to its shape if the building dead weight is maintained same. Since the static earthquake load is related to the building dead weight, the responses are almost similar. So, it’s possible to make an irregular structure behave like any regular structure against seismic. But in case of dynamic response spectrum loading, irregular shape building shows somewhat higher displacement with relatively high fundamental time period (Figure 7). Wind load is the prime concern in a high rise building. Since the dimensions of rectangular and irregular shaped building is little greater than the others perpendicular to X direction, the effect of wind force in X direction is slightly higher. Conversely, the similar reaction is found in case of wind force in Y direction. In this case, the L and C shaped model showed higher response.

5.1 Conclusions

The end results of analysis can be compiled as follows,

1. Wind load is the prime concern in displacement of high-rise multi-storied building of any shape than static or dynamic earthquake loading.
2. Static and dynamic analysis shows insignificant variation in regards of displacement since it’s related with structures self-weight.
3. C- Shaped and L- Shaped multi-storey buildings are more prone to wind load depending on their dimensional variation in both direction. But it is possible to minimize the effect of loading if similar weight could be maintained to a regular rectangular building.
4. Rectangular and irregular shaped structure show almost similar displacement against wind load if the total mass is nearly constant.
5. Lower stories display minute variation but variation in maximum displacements significantly increases with the increase in height of different shaped building.
6. Maximum time period of irregular shaped is slightly more than others from modal analysis of structures.
7. Considering the all criteria, it can be concluded that C- shaped and L- shaped multi-storied buildings are more susceptible to static and dynamic seismic load and wind load compared to the rectangular and irregular shaped buildings. With a constant mass, rectangular and irregular shaped building acts alike.

6. References

5. IAEE Manual (1986), Structural Performance during Earthquake, IIT Kanpur, India.

