Citation: Paul, I K., S. Nakai (2022), Seismic performance evaluation of typical residential RC buildings at different soil types with seismic zones in Bangladesh, Synopsis of IISEE-GRIPS Master's Thesis.

SEISMIC PERFORMANCE EVALUATION OF TYPICAL RESIDENTIAL RC BUILDINGS AT DIFFERENT SOIL TYPES WITH SEISMIC ZONES IN BANGLADESH

Indrajit Kumar Paul[1]
MEE21716

Supervisor: Shoichi NAKAI[2]

ABSTRACT

Soil site classes and seismic zones are the integral parts of building design. During the earthquake, the effect of local soil site conditions with zone coefficient plays an important role in building vulnerability. The Bangladesh National Building Code (BNBC-2020) recommends the guideline for design response spectrum to reduce the vulnerability during the seismic activity. The seismic performance level of the buildings was estimated by using the Capacity Spectrum Method (CSM) and compared with the results of nonlinear pushover analysis. Two maximum inter-story drift ratios of 0.5% (1/200) and 0.4% (1/250) are used to determine building performance levels and compare it with code limitation allowable story drift. The site classification is usually conducted using average shear wave velocity $\overline{V_S}$ if available. Otherwise, the value of $\overline{N}$ may be used for site classification. In this study, 160 boreholes locations were subjected to determined average N-SPT(N_{30}) values based on soil properties up to 30m of site profile as per BNBC-2020. It has been observed that the two model buildings having the limited drift angle of 1/200, are only operational in soil site classes SB and SC with a Peak Ground Acceleration (PGA) up to 0.12g. On the other hand, in both drift angles, these buildings in soil classes SB, SC, and SD with a higher PGA than 0.12g are not operational. This paper presents the maximum seismic performance level, for example, Operetional (OP), Immediate Occupancy (IO), Damage Control (DC), Life Safety (LS), and Collapse Prevention (PC), of the two model buildings located in the different site classes (SB, SC and SD) of four seismic zones. Therefore, the evaluation results of the building performance levels for the lower drift angle (1/250) are more resilient than the higher one (1/200).

Keywords: Drift angle, N-SPT (N_{30}), Response spectrum, Performance level, Site class.

1. INTRODUCTION

The severity of the earthquake depends on the local soil condition, such as the formation period of soil, soil properties, and the nearest active earthquake fault. During the seismic activity, local geology plays a significant role in controlling the surface effects of earthquake. In recent times Bangladesh does not experience any high-intensity earthquakes. Bangladesh is now going through the return period of the probabilistic Maximum Considered Earthquake (MCE) ground motion. Before 1993, Bangladesh had no building code of its own. At present, Bangladesh has its own building code. Depending on geological characteristics and the nearest seismic fault, Bangladesh Nation Building Code (BNBC-2020) has been divided into four seismic zones with different levels of ground motion. Each zone represents the

[1] Soil Mechanics & Foundation Engineering Division, Housing and Building Research Institute, Bangladesh.
[2] Professor Emeritus, Chiba Univ., and Visiting Research Fellow, Building Research Institute.

maximum consideration of peak ground acceleration (PGA) based on other soil site classes. Most of the buildings in our country are of RC frame structure with fill bricks masonry design by an equivalent static method, while western world or other advanced countries are using performance-based analysis. The design response spectrum is one of the main parameters to determine building performance. The effect of local soil conditions dominates the response spectrum. “Housing and Building Research Institute” (HBRI) has conducted sub-soil investigation work for the different infrastructure development projects of the Bangladesh Government. There are so much sub-soil investigation data of the whole country. Local private agencies have investigated general people's sub-soil so that they can estimate the expenses. In most cases, the soil test report is considered not accurate. Therefore, moderate-intensity earthquakes may severely damage our country, especially in the cities where multistoried RC masonry infill typical residential buildings with soft ground stories are commonly seen (Md. Arifujjaman, 2017). It is necessary to do the building performance evaluation of the multistory typical RC residential building based on the seismic zoning coefficient of different geological characteristics, depending on the places, soil conditions, and seismic zoning coefficient.

2. DATA

For this study, data from 160 boreholes with N-SPT values were collected from the existing soil test report of the Housing and Building Research Institute (HBRI). These borehole locations were selected in 160 sub-districts in Bangladesh. Measured N-SPT values were 0 to 50. Whenever the N-SPT values exceed 50 for 300mm penetration, it was treated as refusal and further N-SPT values were not measured for that depth as per BNBC-2020. However, measured N-SPT values were directly used here to determine the average N-SPT (N_{30}) up to the 30m depth.

Figure 1. Locations of the boreholes (▲) and two model buildings (★).

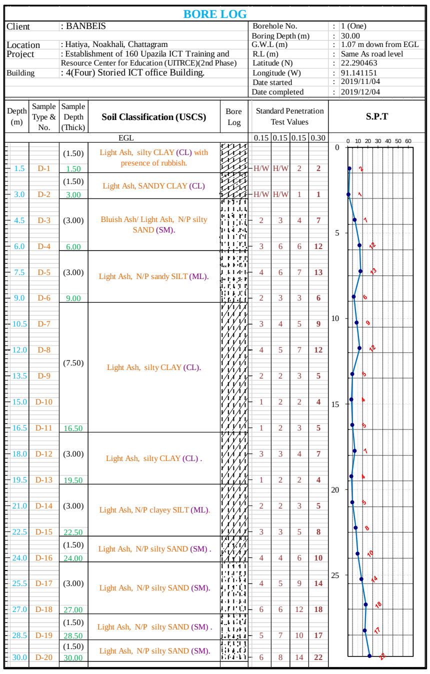


Figure 2. Typical bore log with SPT N values.

On the other hand, the target model buildings are 8-story and 5-story typical RC buildings situated at Dhaka and Narayanganj city in Bangladesh respectively. For the analysis of 8-story model building, the superimposed dead load and live load of each floor is considered as 13.85 kN/m^2, and for the 5-story building, it is considered as 11.73 kN/m^2. Floor area for 8-story is 167.84m^2 and 5-story 107.30 m^2. For the analysis, the target 2 buildings were modeled in STERA_3D (Ver.11.0), which has shown in the Figure 3 and 4.

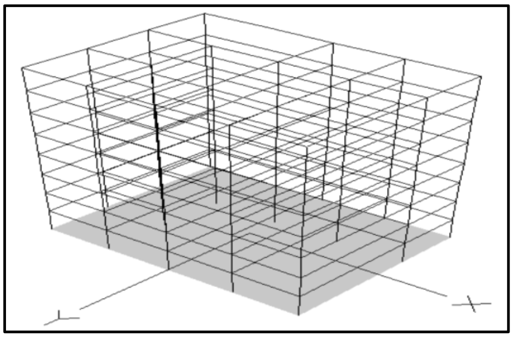


Figure 3. Three-dimensional view of entire structure (8-story model building).

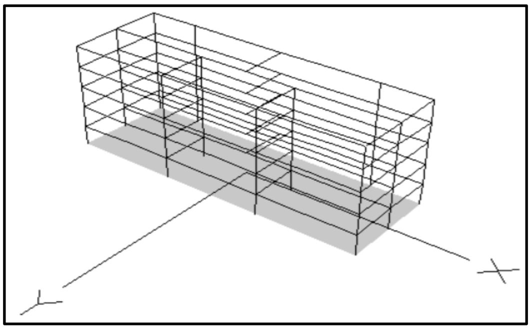


Figure 4. Three-dimensional view of entire structure (5-story model building).

3. METHODOLOGY

3.1. Site classification for the Study Area in (BNBC-2020)

The site classification has been done following the soil properties of the upper 30 meters of the site profile. Average soil properties will be determined as given in the following equations: $\bar{N} = \sum_{i=1}^{n} d_i \,/\, \sum_{i=1}^{n} \frac{d_i}{N_i}$ where, n= Number of soil layers in upper 30 m, d_i = Thickness of layer i, N_i = Field (uncorrected) standard penetration value for layer i. Average $\bar{N}$-SPT(N_{30}) not exceeding 100 blows/0.3m was directly measured in the field without corrections of the ith formation or layer. Most of the 160 locations can be classified as site class predominant by SD (96) and SC (61) type, apart from three locations which were found to be SB type. Average $\bar{N}$-SPT(N_{30}) values are within the range from 2 to 92. However, Figures 5 and 6 shows the N_{30} values and site classes, respectively.

Figure 5. Location point with (N_{30}) value.

Figure 6. Location point with site class.

3.2. Design response spectrum and pushover analysis procedure

BNBC-2020 has instructions regarding the demand spectrum of structurers for different soil categories. In addition, this demand spectrum also emphasizes peak ground acceleration. Figure 7 shows normalized design response spectrum in different site classes. In this study, all the plotted locations are in three different site classes (SB, SC and SD) with four seismic zone coefficients (0.12, 0.20, 0.28 and 0.36) for Acceleration Demand Response Spectrum (ADRS), where a 5% damping ratio is considered. Figure 8 shows ADRS for site class SC. The selected two model buildings are in Dhaka and Narayanganj cities.

These two locations are in seismic zone -2, whose zone coefficient is 0.20. The site classes of the model building's locations are SC and SD, and the soil site coefficients are 1.15 and 1.35 respectively.

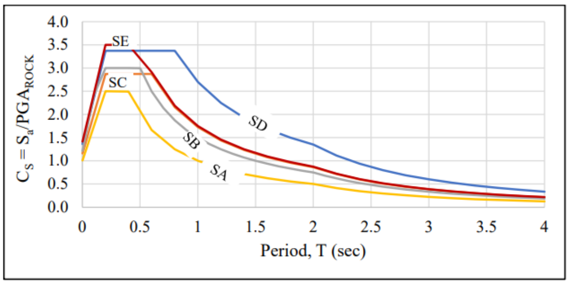


Figure 7. Normalized design acceleration response spectrum

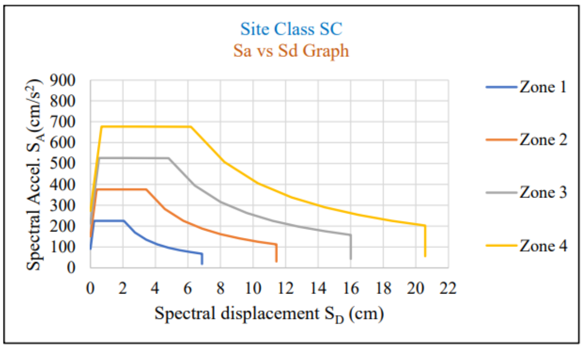


Figure 8. Acceleration Demand response spectrums for a 5% damping ratio in 4 seismic zone and site class SC

3.3 Capacity Spectrum method (CSM)

The Capacity Spectrum Method (CSM), a performance-based seismic analysis technique, is a common procedure for the assessment of building behavior due to ground motion. CSM is applied to assess building behavior depending on several soil site classes and surface geology conditions. In this procedure, the resistance capacity of a building to an earthquake which is described by the capacity curve represents the demand of an earthquake. An intersection point can be determined considering the ductility of the building. The equations required in this procedure are as follows: $S_a = \frac{2}{3}\frac{ZI}{R}C_S$, $S_d = \frac{S_a}{\omega^2} = S_a\left(\frac{2\pi}{T}\right)^2$.

3.4. Limit set of a structural model

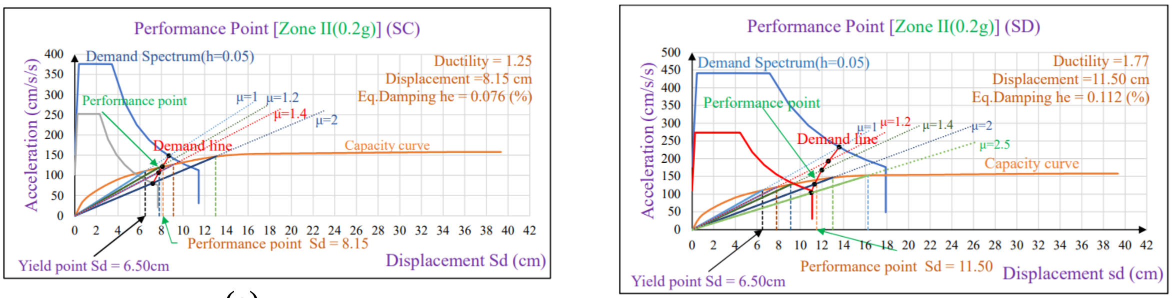
In order to better assess the structural performance of these structures under different ground motions, five performance levels were considered. The vertical gridlines on each graph at maximum inter story drift ratio of 0.005, 0.01, 0.015, 0.02 and 0.025 represent performance level of OP, IO, DC, LS and CP, respectively (Y.E. Ibrahim and M.M. El-Shami-2011). In this study, one more conservative drift ratio of 0.004 is considered to find the increasing performance level of these two model buildings.

3.5. Determination of performance point

To find the point where demand and capacity are equal, a point on the capacity spectrum needs to be selected as an initial estimate. Using the spectral acceleration and displacement defined by this point, reduction factors may be calculated to apply to the 5% elastic spectrum to account for the hysteretic energy dissipation or damping. The response spectral acceleration and displacement are reduced by the following equations: Equivalent damping ratio, $h_e = 0.25\left(1 - \frac{1}{\sqrt{\mu}}\right) + 0.05$, reduction factor of spectrum, $F_h = \frac{1.5}{1+10h_e}$, And ductility $\mu = \frac{m\delta_p}{\delta_y}$. Finally, the reduced demand spectrum is calculated using these S_a and $(S_d \times F_h)$ formulas.

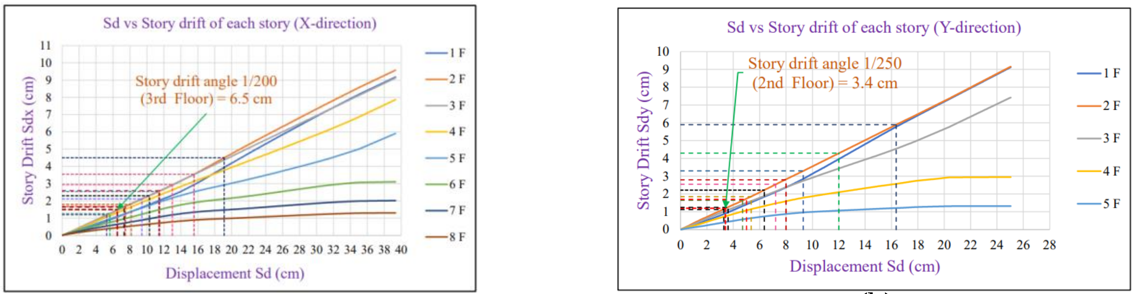
4. RESULTS AND DISCUSSION

In this study firstly the performance point was determined using capacity curve for each site class and four seismic zones as shown in Figure 9 (a) and (b). After getting the results of displacement response spectrum S_d and the story drift of each story *Sdx* and *Sdy* from pushover analysis using two drift angle 1/200 and 1/250, Figure 10 shows that for 8-story building 1st yieding point appears in the 3rd floor and the corresponding value of target yielding point displacement S_d 6.5cm and 5.3cm in the weaker Xdirection, inaddition 4.3cm and 3.4cm in the weaker Y-directions for 5-story building at 1st yielding act in the 2nd floor.



(a) (b)

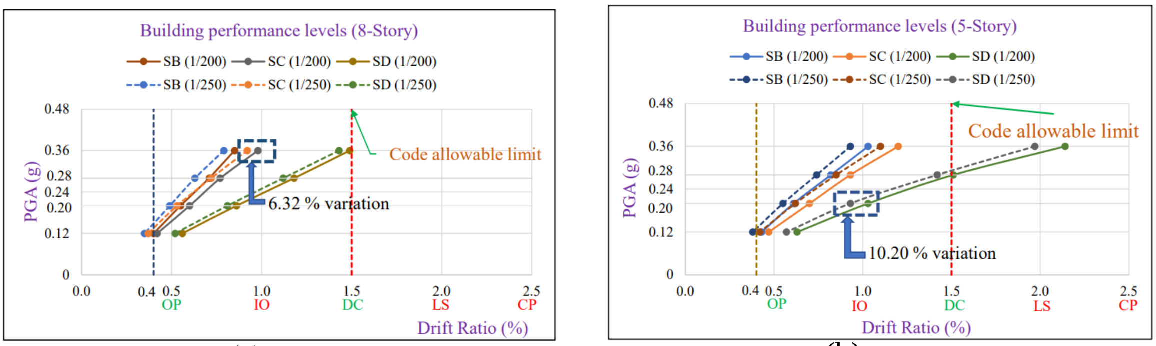
Figure 9. The performance point using capacity curve for soil class (a) SC (b) SD and zone-II (0.20g)



(a) (b)

Figure 10. Relative displacement of each story drift Sdx (a) (1/200) for 8-story and (b) 1/250 for 5-story.

According to the result obtained, Figure 11 shows, in the both story drift angle, the 8-story structures are not operational under all records for PGA higher than 0.12 g with soil classes SB, SC and SD; even PGA 0.12g with soil class SD is not operational either. The 8-story model building is operational only with soil classes SB and SC up to PGA 0.12g. Moreover, these 8-story building can be immediately occupied for all four PGA with soil classes SB and SC, but only soil class SD is immediately occupied for PGA 0.20g and 0.12g. For soil class SD with two seismic zones 0.28g and 0.36g, these 8-story building performance level is damage control level. However, the most important consideration is that these 8-story model buildings do not cross the code allowable story drift limitation. Furthermore, considering the conservative inter-story drift ratio, the 8-story model building performance level increased from 4.11 % to 13.33% individually, for all four PGA conditions with three soil classes.



(a) (b)

Figure 11. (a) and (b), Performance levels of the buildings with two different angles (1/200) and (1/250).

Figure 11(a) also shows the percentage variation between the two-drift angle. For example, for SC soil, let $X_1 = 0.98$(1/200) SD, and PGA) and $X_2 = 0.92$(1/250) and substitute into formula $= \frac{|0.98-0.92|}{[(0.98+0.92)/2]} \times 100 = 6.32\%$.

Similarly, in Figure 11 (b), the 5-story building is not operational when the story drift angle is 1/200 with soil classes SB, SC and is higher than 0.12g. Even when PGA is 0.12g with soil class SD, it is not operational. The 5-story model building is operational only under ground motions with PGA up to 0.12 g including soil classes SB and SC. Only in case story drift angle is 1/250, PGA is 0.12g with soil class SB, it is operational. For story drift angle 1/200, the 5-story building can be immediately occupied by two 0.20 and 0.28 PGA with soil classes SB and SC, but only soil class SD immediately occupied PGA 0.12g. It has been observed that due to the lower drift angle, the soil class SB zone 0.36g, the performance level has changed from DC to IO. Furthermore, considering the conservative inter-story drift ratio, the 5-story model building performance level increased from 5.44 % to 12.35% individually, for all four PGA conditions with three soil classes.

5. CONCLUSIONS

The analysis showed that with the maximum inter-story drift angle of 1/200, the 8-story and 5-story model buildings are only operational with soil classes SB and SC with PGA up to 0.12 g ground motion. This operation means that negligible damage to nonstructural components of the building is expected even after the earthquake. On the other hand, in both drift angles of 1/200 and 1/250, these buildings in soil classes SB, SC, and SD with a PGA higher than 0.12g are not operational. In addition, that 8-story building can be immediately occupied for all four PGA with soil classes SB and SC, but only soil class SD is immediately occupied for PGA 0.20g and 0.12g. For soil class SD with two seismic zones 0.28g and 0.36g, these 8-story building performance level is damage control level. Consequently, that 5-story building can be immediately occupied for two PGA 0.20g and 0.28g with soil class SB and SC, however with soil class SD only immediately occupied for PGA 0.12g. Considering the lower drift angle (1/250), the performance level of these two model buildings will increase from 4.11% to 13.33% for 8-story and 5.44% to 12.35% for 5-story by different soil site classes. In this research, it has been observed that when the ground motion in our country is moderate or high intensity, this type of RC building will be safe in the location which falls in the seismic zone 1 (0.12g) with soil classes SB and SC.

Finally, the result shows that 60 percent in the study area is soil class SD (Alluvial silt / Alluvial silt and clay) predominated. Therefore, the evaluation results of the building performance levels for the lower drift angle (1/250) are more resilient than the higher one (1/200). So, this study recommended yield point drift angle of 1/250 from the static non-linear pushover analysis of the SDOF system, especially in our country's context.

ACKNOWLEDGEMENTS

I express my sincere gratitude to my thesis supervisor, Dr. Shoichi Nakai, and my adviser, Dr. Eng. Hiroto Nakagawa, for their supervision assistance, helpful discussions, and valuable ideas throughout my master's studies. I also acknowledge Dr. Taiki Saito's continuous advice on using Stera_3D modeling and pushover analysis. I like to convey my deep gratitude to the individual study period of the training course on "Seismology, Earthquake Engineering, and Tsunami Disaster Mitigation" by the Building Research Institute (BRI) Japan, JICA, and GRIPS.

REFERENCES

ASCE., 2000, American Society of Civil Engineers, FEMA 356.
BNBC 2020, "Bangladesh National Building Code".
FEMA. (2004), FEMA 389, Washington, D.C.
Ibrahim, Y.E., and El-Shami, M.M., 2011, IES Journal Part A: Civil and Struct. Eng., 4(4), 213-223.
Mohd Assyarul Bin Saadum (MEE20710), 2021, IISEE Synopsis, 1-6.
Mahmoud Helal SaadEldin Elawady, 2017.
Md. Arifujjaman (MEE16712), 2017.
Mohammad Tariqul Islam (MEE16714), 2017,
P. Anbazhagan et al., Pure Appl. Geophys. 170 (2013), 299-318.
Q. Xue, C.-W. Wu, C.-C, Chen, K.-C. Chen., Engineering Structures, 2008. 30(6), 1535-1547.
Saito T., STERA_3D Ver. 11.0 "Technical Manual" & FEM-I, IISEE Lecture Note-2021-2022.