EVALUATION OF THE SEISMIC PERFORMANCE OF AN EXISTING RC EDUCATIONAL COMPLEX IN THE CITY OF KHULNA

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ABSTRACT

So many mediums to high-rise buildings have suffered major damage from past major earthquakes in Nepal, China, Turkey, India, and other countries, including people's lives and safety. Because Bangladesh has not experienced a major earthquake in the last several centuries, a tremendous amount of energy has been stored and is ready to be released at any time. The current practice of seismic design is limited to demand estimation and analysis and thus cannot guarantee that the design structure meets the initial objectives. As a result, a performance-based approach should be initiated. Khulna is located in Bangladesh's seismic zone I, which indicates that the city has a moderate likelihood of experiencing earthquakes. While the likelihood of catastrophic vulnerability is low, urban areas are more vulnerable than rural areas due to their higher population density. This study emphasizes the importance of performing performance-based seismic design for RC buildings and investigates the seismic performance of an educational building located at the Khulna University of Engineering and Technology (KUET). The building was designed as per BNBC-2006, but the latest issued BNBC-2020 demands a complete new seismic evaluation complying latest code. Non-linear pushover analysis is carried out using ETABS v-16 software. The VBA program models plastic hinge properties of beams and columns using stress-strain models for concrete and steel according to BNBC-2020. The building's design base shear is compared to the requirement earthquake base shear. The global response of the structure is also examined for estimating the safety of the building under demand earthquake loading in terms of capacity curve, hinge placement, and ductility ratio.

Keywords: *Collapse prevention, Immediate occupancy, Performance based design, Pushover analysis.*

1. INTRODUCTION

Bangladesh's tectonic framework and adjacent locations imply that the country is well inside an active seismic zone. Even though a great deal of work has been made in recent years to precisely calculate the magnitude of an earthquake in many research institutes throughout the world, the growing need for additional research on the earthquake's impacts on theoretical and laboratory scales has been felt (Calvi, O'Reilly, & Andreotti, 2019).

Seismic-resistant structures can be designed in a variety of ways. Buildings can be designed with an elastic phase in mind to minimize the effects of an earthquake with a long return time (Calvi et al., 2019). The elastic design results in a major overdesign of the building parts because the probability of a high-intensity earthquake occurring throughout the lifetime of a building (in most cases 50 years) is only approximately 10%. The elastic technique is thus restricted to areas with low or moderate seismic activity. The alternative design method is based on non-linear ductile design concepts. It is possible to disperse energy during a seismic event by plastic deformation in a ductile structure that is flexible. As long as the displacement demand in the ductile components of the structure does not exceed the displacement capacity, the structure can withstand high-intensity earthquakes. Because the design seismic activities can be lowered depending on the ductility ratio, ductility allows for more cost-effective structures to be created (Chopra, 1995). It's common practice for building design in places with moderate to high seismicity to employ this strategy.

Some authors examined performance of several irregular structures on India's rocky soil (Ravikumar, Babu Narayan, Smith & Venkat Reddy, 2012). Another folk of authors studied the reaction of multistory reinforced concrete buildings in the setting of Bangladesh. Response spectrum evaluations had been performed on three normal and one irregular building models, but they did not address re-entrant corner irregularity (Kabir, Sen, Islam & Engineering, 2015). In another research authors conducted a seismic performance study on RC structures with plan irregularity. ETABS 9.7.1 and SAP 2000 v14.0.0 were used to examine several models on equivalent static, temporal history, and RSA. Each frame has the same breadth but not the same area or mass (Haque, Ray, Chakraborty, Elias & Alam, 2016). Further studies have investigated the seismic analysis of multistory reinforced concrete buildings with various layouts that included corners. There was a difference in the settling of the stories and the base shear of various sized buildings (Farhan, Bomisetty & Technology, 2019). Also others investigated the RSA of an ambiguous multistory structure in zone V in their work. A single irregular structure with around ten floors was photographed and analyzed with ETABS, STADPRO, and SAP2000. Several variables were thoroughly explored (Firoj & Singh, 2018).

Design processes currently in use include demand estimation, seismic analysis, and design according to the code. This plan does not ensure that the designed building will satisfy the initial aims. Structural engineers need to employ performance-based design approaches (Fragiacomo, Dujic, & Sustersic, 2011). A preliminary assessment of the design is done to see if it fulfills the desired performance objectives, and if necessary, the design is reworked and reassessed until it does. Nonlinear static pushover analysis or nonlinear dynamic analysis can be used to assess or evaluate something. The structural engineering community has been employing nonlinear static procedure (NSP) or pushover analysis because of its simplicity. Pushover analysis is performed using the FEMA-356 and ATC 40 criteria for both the default and user-defined hinge parameters in both the default and user-defined hinge parameters (Tso & Moghadam, 2019).

Performance-based design is a broader design philosophy in which design goals are described in terms of accomplishing specified performance targets when the structure is subjected to specified levels of seismic danger (Nair, Hemalatha, & Muthupriya, 2017). The performance targets could be a maximum stress level, a load, a displacement, a limit state, or a target damage condition. Performance-based engineering entails moving away from reliance on empirical and experience-based conventions and toward a design and assessment process that is more firmly rooted in the realistic prediction of structural behavior under a realistic description of the spectrum of loading environment that the structure will face in the future. It enables the selection of a specific performance objective based on a variety of characteristics such as the owner's requirements, the structural utility, seismic risk, and potential economic losses (O'Reilly & Calvi, 2019).

By involving BNBC-2020 the present research examines a multi-story building employing response spectrum analysis as well as the non-linear pushover analysis. The process would be carried out by using ETABS v-16 that can help the existing building’s future outcomes. The mathematical outcome would enhance the information of properties of beams and columns for concrete and reinforcement according to BNBC-2020. Also, the estimated safety factors would be useful to understand different earthquake loading criteria with response analysis. Additionally, it was discovered that such systems, when it undergoes through various performance levels such as Immediate occupancy, Life-safety and collapse prevention.

2. METHODOLOGY

The Academic Building of Khulna University of Engineering and Technology which is an institutional building located in Khulna, was considered for the analysis. The existing plan of the building is given in Figure 1. The material property are given in the Table 1. also the loads as well as the section sizes are given in the Table 1&2 respectively.

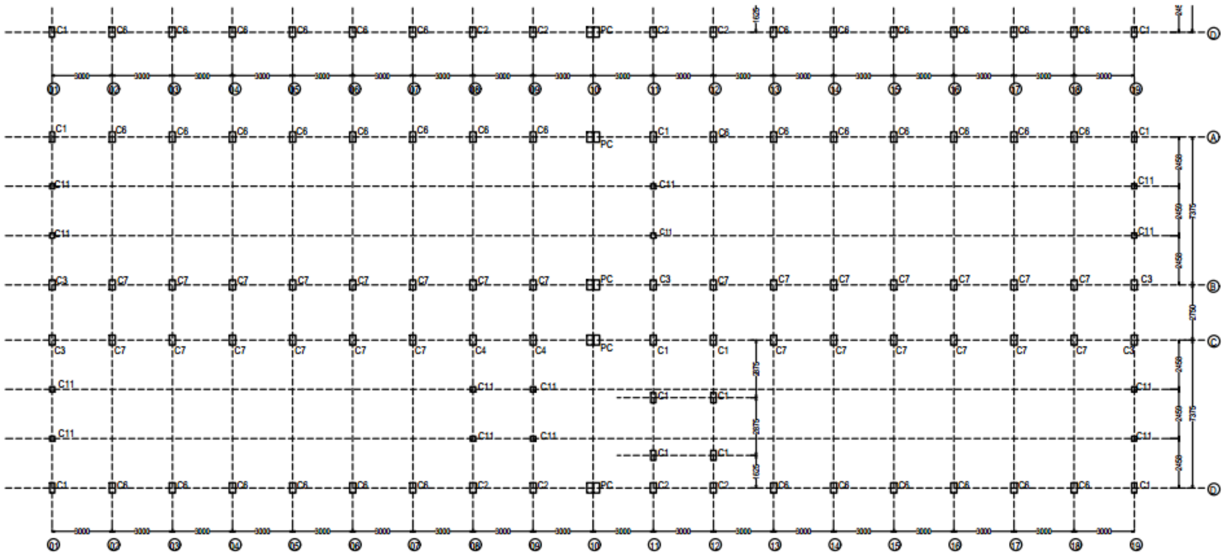

Figure 1: Structural layout of Academic Building

Table 1: Dead and live loads

Loads	**BNBC 2020**
Live load	Floor: 4.8 kN/m^2 (Occupancy type-B) Roof: 1 kN/m^2
Concrete unit weight	23.6 kN/m^3
Mechanical loadings	0.24 kN/m^2
Partition wall loads	0.72 kN/m^2

Table 2: Column section properties

Column names	**Column dimension**	**Bar Number**
Rectangular (C1)	500 mm x 250 mm	6-16 mm diameter
Rectangular (C2)	500 mm x 300 mm	8-16 mm diameter
Rectangular (C3)	500 mm x 300 mm	8-16 mm diameter
Rectangular (C4)	500 mm x 300 mm	4-22 mm diameter
PC (Pair column C5)	500 mm x 300 mm	4-22 mm diameter
Rectangular (C6)	500 mm x 300 mm	6-22 mm diameter
Rectangular (C7)	500 mm x 300 mm	8-22 mm diameter
Circular (C8)	450 mm diameter	6-16 mm diameter
Circular (C9)	450 mm diameter	6-20 mm diameter
Circular (C10)	450 mm diameter	6-16 mm diameter
Square (C11)	250 mm x 250 mm	6-20 mm diameter

Table 3: Beam section properties

Beam names	Beam dimension	Bar Number
B1	600 mm x 300 mm	2-22 mm diameter
B2	500 mm x 250 mm	2-16 mm diameter
B3	300 mm x 500 mm	4-16 mm diameter
B4	300 mm x 500 mm	4-16 mm diameter

2.1 Analysis Procedure

The Mathematical model was developed at ETABS-2016. The mesh size (A mesh partitions space into elements, cells or zones over which the equations can be solved, which then approximates the solution over the larger domain) was taken as 4ft to generate finite element analysis. As the Live load exceeds 4 kN/m^2 on the slab, 50% of the Live load was considered for mass source and all the load combinations according to BNBC-2020 was generated. After generating an equivalent static analysis, the spectral acceleration vs time period data (Figure 2) was inserted into the model, which was generated according to BNBC-2020 for Zone-I. The site location and classifications data shown in Table 3.

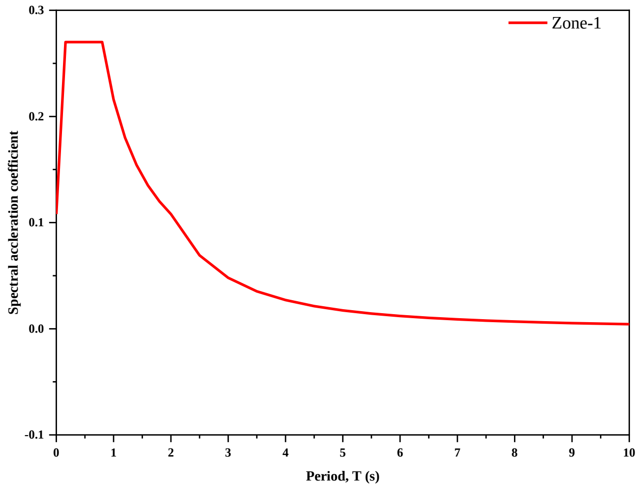

Figure 2: Spectral Acceleration Data

Table 3: Site Locations and Classifications

Code	ASCE 7-10
Location	KUET, Khulna, Bangladesh
Zone coefficient/ response acceleration parameters	Spectral response acceleration parameters: S_s=0.3, S_1= 0.12
Site class	Site class D, soft soil

After perceiving the response spectrum function, the analysis was run. As per code, to achieve 85% of static base shear, the scale factor was revised. Also, to achieve 90% of model mass participation, the mode number was also revised and the linear dynamic analysis was performed.

After performing Response Spectrum Analysis, the dead load was converted to non-linear static load case, then the pushover load case was defined for both global X and Y direction. The control displacement limit for the analysis was taken as 50 mm and a maximum 100 number of states was taken. After that, the hinges were formed at all. The beams and columns at position of 10% length and the 90% of the length. Finally, the analysis was performed to observe the behaviour of the structure.

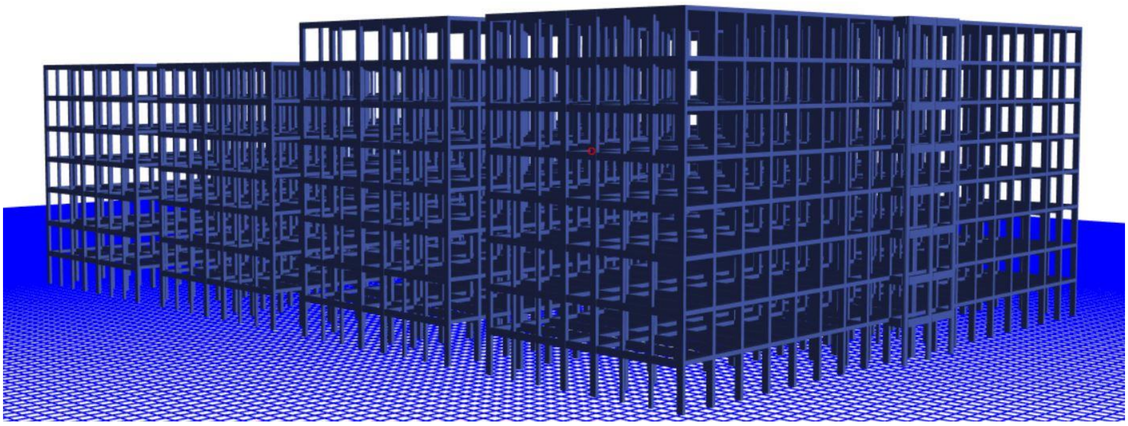

Figure 3: Analytical Model of Academic Building, KUET, Khulna

3. RESULTS AND DISCUSSION

3.1 Story Displacement

It was observed that the maximum displacement for the seismic analysis at global X-direction was found 27.053 mm and for global -Y direction 24.15 mm was found in (Fig-4. Also, the maximum base shear was found 2317.34 kN and 3331.56 kN for global -X and global -Y direction respectively.

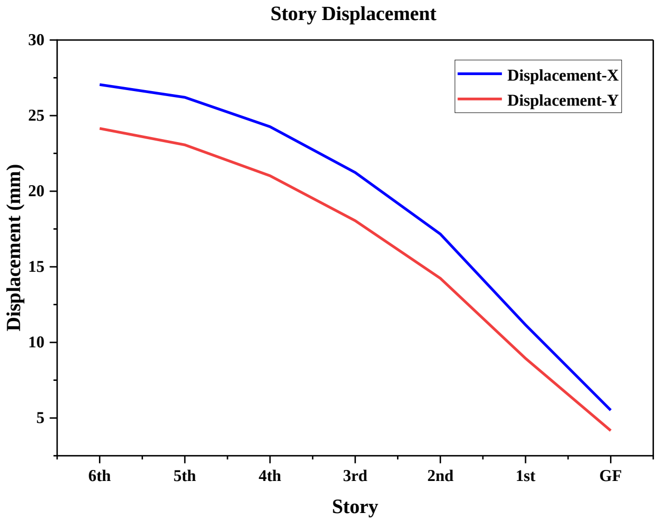

Figure 4: Story displacement at global –X and global –Y direction

3.2 Story Drift, Torsional irregularity, Stiffness irregularity

The story drift, torsional irregularity and stiffness was calculated for both the global –X and Global –Y direction. It was found that the mathematical model performed well and was able to keep the drift and drift ration under limit (Figure 5 & 6).

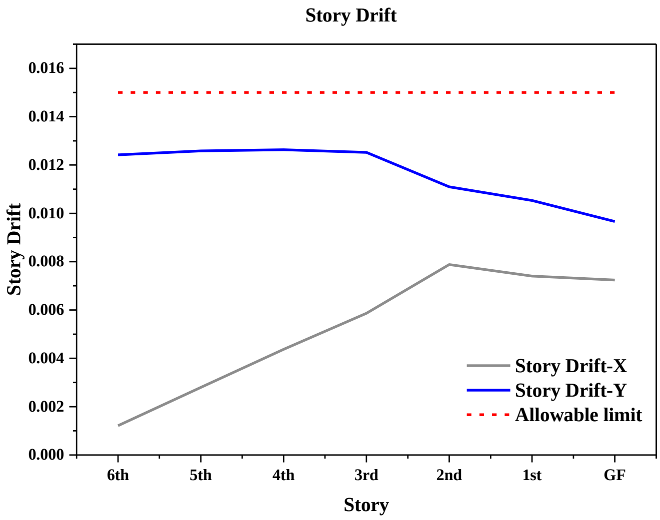

Figure 5: Story drift at global –X and global –Y direction

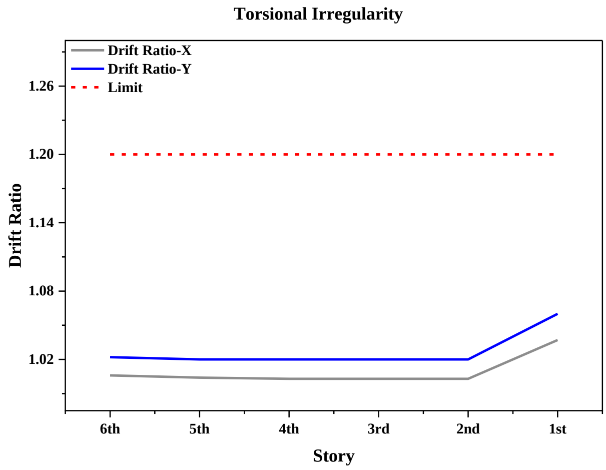

Figure 6: Torsional irregularity at global –X and global –Y direction

As a result, it can be said that in terms of drift and torsion no irregularity was found according to BNBC-2020. Also, in terms of stiffness no soft story effect was found as the structural system was able to keep the drift ratio over 80% (Figure 7).

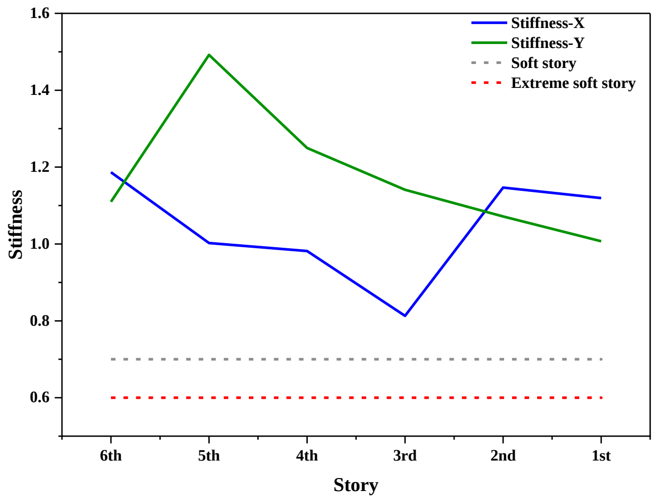

Figure 7: Stiffness at global –X and global –Y direction

3.3 Performance of the structure

After performing the pushover analysis, the performance of the structure was assessed for a controlled 50mm displacement. Figure 8 represents the various types of performance of a structure, from that we can define the performance level as Operation level (OA)-where buildings are expected to sustain no permanent damage and retain the original strength and stiffness; Immediate Occupancy (AB)-where minor cracks can occur in columns, shear-walls and interior walls; Life safety (BC)- Where failure of interior walls can be observed as well as the architectural and mechanical systems of a structure get damaged, as a result the structure crosses the economical limit to repair; Collapse Prevention (CD)-where the structure expected to avoid little residual strength and stiffness and reaches the collapse level.

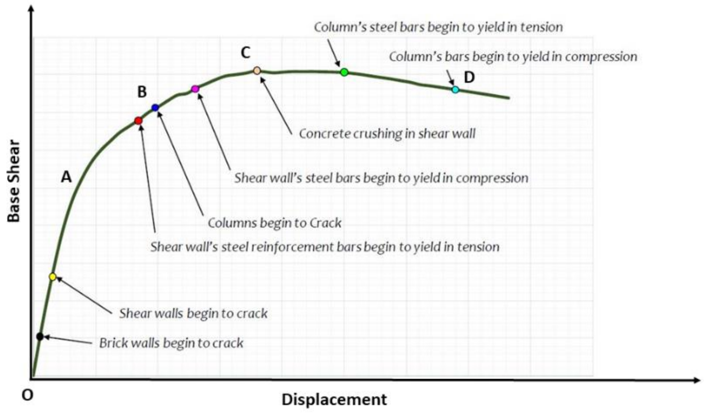

Figure 8: Various Performance Level for Structure.

Analyzing the capacity-demand curve of the structure with Figure 9 it can be said that the structure would be in Immediate Occupancy state for 50mm displacement, which is greater than the maximum allowable displacement.

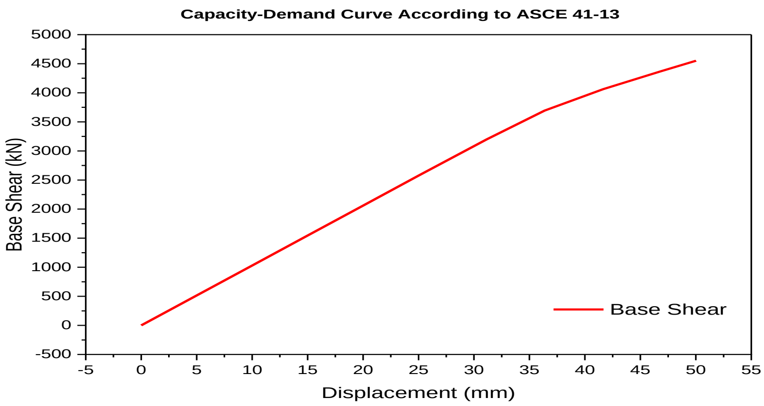

Figure 9: Demand capacity performance curve of the academic building KUET, Khulna.

3.4 Proof Check

The static analytical procedure was justified by calculating the base shear and time period manually for the structure. So, it can be said that the procedure was accurate.

4. CONCLUSIONS

Based on the findings, it is stated that performance-based design ideas offer a systematic design strategy for assessing the seismic capability of buildings intended for earthquake loading. Pushover analysis is used to validate the intended building's safe performance during a demand earthquake. The current building, which is in in seismic zone I, has demonstrated safe operation during a demand earthquake. The results of the safety ratio and base force at the Performance point (PP) show that the building was found to be safe, and so the capacity of the building can be reduced to some level to achieve economy in design. When compared to the default hinge model, the building model with user defined hinges is more ductile and has a lower base force at Performance point. As a result, it is critical to consider plastic hinge modeling for frame elements with user defined hinges for proper safety evaluation.

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