DETAIL SEISMIC PERFORMANCE EVALUATION OF A TWELVE (12) STORIED OFFICIAL BUILDING IN DHAKA AND SUITABLE RETROFITTING TECHNIQUE

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ABSTRACT

The main purpose of this study is the evaluation of the seismic performance of the existing RC building situated in Dhaka and constructed before the establishment of the National building code, 1993. Significance changes in seismic provisions have been brought in upcoming Bangladesh National Building Code (BNBC, 2017, draft). Therefore, it is necessary to evaluate seismic performance and the strengthening of old buildings to keep compatibility with the requirement of updated building code. This study compares the seismic evaluation results of building by the 2nd level screening method of Japan Building Disaster Prevention Association (JBDPA), 2001, and detail seismic evaluation method and suggests a suitable retrofit technique. To evaluate the seismic performance of the building by detail seismic evaluation method, non-linear static pushover analysis was performed according to ATC 40, 1996 / FEMA 273, 1997 /356, 2000 /440, 2005 and ASCE 41, 2013. The damage distribution and sequence of the collapse of the building were observed. It was found that detail seismic evaluation method provided most rational and practical results rather than 2nd level screening method of JBDPA, 2001 from the viewpoint of seismic evaluation of the building due to the target building was found to be weak-beam and high-rise building. Furthermore, the required strength for retrofit was easily estimated by this method. The new shear wall for retrofit proved to be effective in increasing the necessary seismic capacity of the building.

Keywords: Seismic evaluation, Detail seismic evaluation method, Non-linear analysis, Retrofit.

1. INTRODUCTION

Bangladesh, a country having more than 160 million people, has suffered from the number of natural calamities like earthquakes, fire hazards, floods, and cyclones in the recent past. Bangladesh is located in one of the most seismically active regions. There are three tectonic plates around this country named the Indian plate, the Eurasian plate, and the Burmese plate. Moreover, five major faults around this region are also the sources of the incident of earthquakes. The present generation of people of Bangladesh didn't witness any severe ground shaking. Due to the activity of the plate boundaries, active fault zones, and statistical data of previous earthquakes around Bangladesh, there is a possibility to occur a high magnitude of an earthquake. The first guideline for seismic design named BNBC was published in 1993. But due to lack of monitoring system and proper legal enforcement system, a large number of buildings have been constructed without considering the requirement of seismic provisions.

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Moreover, the buildings built before publishing BNBC 1993, did not follow the building code. Therefore, the majority of the buildings in Bangladesh are under the risk of devastating fate if a strong earthquake hits this area. At present, Bangladesh National Building Code is updated by the panel of experts and is in its final phase of getting approval. Significant changes in seismic code have been made in BNBC 2017 (Draft). It is, therefore, necessary to evaluate seismic performance and strengthening of old infrastructure to keep the compatibility with the requirement of updated building code.

2. THEORY AND METHODOLOGY

The selected building was evaluated by using both the Japanese Building Disaster Prevention Association (JBDPA), 2001 Standard for second level screening and detail seismic evaluation method which was proposed by Y. Nakajima, M. Seki, H. Suga, and R. Islam, 2020. In the procedure of 2nd level screening of JBDPA, 2001, the beams of the structure are considered as stiff elements. "The ductility capacity of columns and walls is estimated crudely for their failure modes (shear or flexure) and based on shear-to-flexural strength ratios. The combination of different ductility levels and shear resistances of vertical members were considered in estimating the earthquake resistance of a structure (Otani, 2000)". On the other hand, the proposed detail seismic evaluation method is based on both the Japanese and the American methods. The Japanese 2nd seismic evaluation method targets mainly weak-column buildings designed by the old Japanese building code so that it is insufficient to accurately estimate the weak-beam buildings. Therefore, the new detail seismic evaluation method is proposed to estimate the weak-beam buildings. It has an advantage of the harmonization with the American seismic evaluation method and of being able to indicate the seismic capacity of a building as a simple seismic index as the same as 2nd seismic evaluation method. This method includes nonlinear static pushover analysis. In the American seismic evaluation method, the performance level of each structural member on the process of pushover analysis is decided based on ATC40. The example of hinge mechanism and acceptance criteria is shown in the figures. Three acceptance criteria (ATC40, ASCE41): Immediate Occupancy (IO), Life Safety (LS), Collapse prevention (CP). For the proposed method, CP point is adopted as the performance limit displacement for the capacity of the structure.

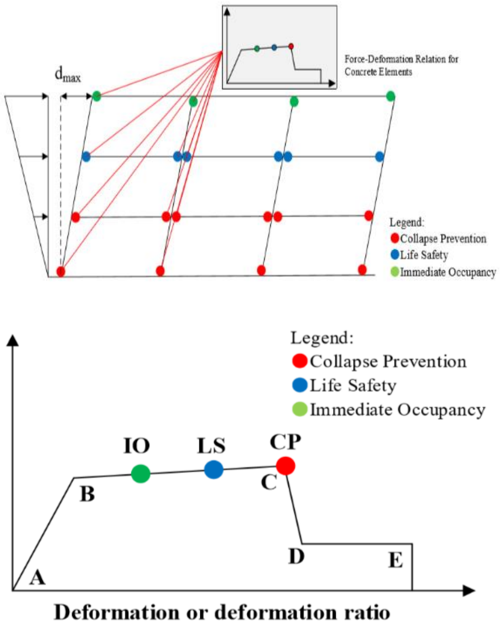

Figure 1. Nonlinear static analysis (Courtesy: Y. Nakajima, M. Seki, H. Suga, and R. Islam, 2020).

The procedure of determination of seismic index of structure (Is) is given below. The spectral acceleration vs. spectral displacement curve is shown in Figure 5. The seismic index ${}_{CP}I_S$ at CP point and ${}_{LP}I_S$ at LP point shall be calculated as following Eqs. (1) and (2).

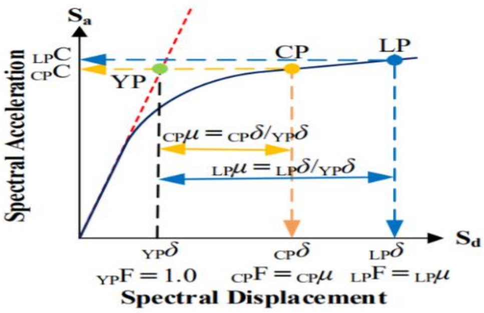

Figure 2. Evaluation of C index and F index by CP point and LP point (Courtesy: Y. Nakajima, M. Seki, H. Suga, and R. Islam, 2020).

$$ {}_{CP}I_s = {}_{CP}C \times {}_{CP}F = {}_{CP}C \times {}_{CP}\mu \quad (1) $$

$$ {}_{LP}I_s = {}_{LP}C \times {}_{LP}F = {}_{LP}C \times {}_{LP}\mu \quad (2) $$

where CP point: A point where the collapse prevention at some members in the structure occurred.

${}_{CP}C$: Strength index at CP point

$_{CP}F$: Ductility index at CP point

LP point: A point where the limited displacement defined in the seismic code occurred. Generally, the 0.02 story drift ratio is defined as criteria.

$_{LP}C$: Strength index at LP point

$_{LP}F$: Ductility index at LP point

$$I_s = Min({}_{CP}I_S, {}_{LP}I_S) \quad (3)$$

Table 1. Legend of each point in Figure 2.

Point	Yield	Collapse Prevention of member	Limited displacement of building
Notation	YP	CP	LP
Strength	$_{YP}C$	$_{CP}C$	$_{LP}C$
Deformation	$_{YP}\delta$	$_{CP}\delta$	$_{LP}\delta$

The judgement of seismic safety: The following equation will judge the seismic safety of the structure.

$$I_s = Min\left({}_{CP}I_S, {}_{CP}I_S\right) \geq I_{s0} \quad (4)$$

The procedure of determination of each story's Is is given below. After the judgement of the seismic safety of the building as a whole, the seismic index I_s of each story of the building can be easily estimated under consideration of CP point and yield point for each story. The following equation can represent the Is value for each story.

$$I_s = \frac{Q_i}{\sum_i^n W_i} \times F_i \times \varphi \quad (5)$$

where Q_i = Story Shear at level i

$\sum_i^n W_i$ = Part of the total seismic weight of the structure assigned to level i

$F_i = \frac{\delta_i}{\delta_{yi}} = \mu_i$ = ductility index at level i

φ = Story shear modification factor

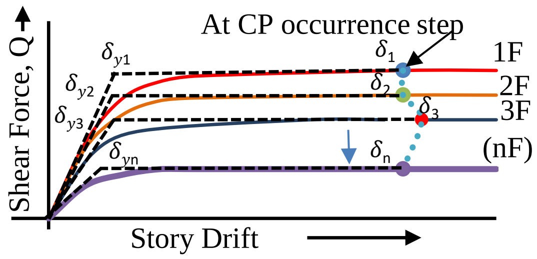

Figure 3. The calculation procedure of the seismic index I_s for each story of the building.

The calculation procedure of required shear strength for retrofit is given below. After the judgement of seismic safety of the structure, if the seismic capacity is insufficient, the retrofit plan shall be applied. The procedure of calculation of the required strength is described below. The outline of the procedure is presented in Figure 4.

<u>Steps:</u>

Step 1: $_RI_{S0}$: Newly defined based on structural type after retrofit

[Moment resisting type or Dual type]

Step 2: I_S = C x F: Current I_S index

Step 3: Assume $_RF$: F index after retrofit

$_RF$ < F

Step 4: $_R\Delta C$: Required shear coefficient

$_R\Delta C = {}_RIs_0/{}_RF$ - C

Step 5: $_R\Delta Q$: Required shear force

$_R\Delta Q = {}_R\Delta C$ x W

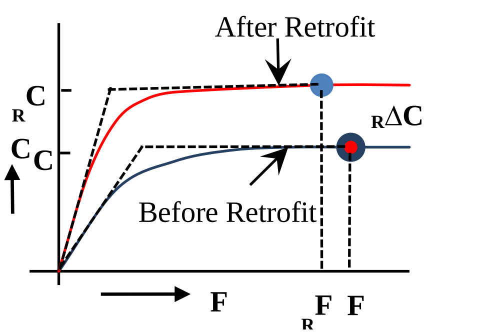

Figure 4. The calculation procedure of required strength for retrofit.

3. DATA

Twelve (12) Storied Government building is one of the first high rise buildings constructed by Public Works Department. The building was built more than fifty years ago and located in the seismic zone -II (as per BNBC 2017 draft). The building does not have an architectural and structural drawing. The detail investigations were done under the guidelines of "CNCRP" manuals. Finally, the as-built drawing of the structure was prepared. The various essential features of the target building are shown in Table 2. This building has three blocks, which are separated by an expansion gap. The typical floor beam layout plan is presented in Figure 1. The building has a 150 mm thick slab. The concrete core test was conducted to get the concrete compressive strength. In the time of the subsoil investigation, the soil type is found to be SC as per the BNBC 2017 draft. The first block of the building is selected for this research. There is a total of 06 (six) columns and 04 (four) shear walls.

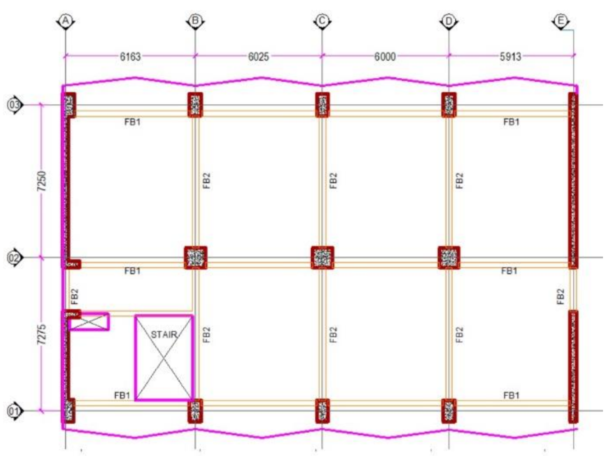

Figure 5. Typical floor plan.

Table 2. Important features of Target building.

Information
Name of the building: Twelve (12) Story Government Building
Number of stories: Twelve (12)
Structure and building type: Reinforced Concrete Office Building
Occupancy Categories: III
Importance factor: 1.25
Seismic Zone: 2 (Z=0.2, BNBC 2017 draft)
Soil Type: SC (BNBC 2017 draft)
Concrete Strength: 13.5 MPa
Steel: 275 MPa
Total seismic weight (Block 1): 51856 kN
Total area (Block 1): 4704.61 m^2

4. RESULTS AND DISCUSSION

The seismic demand of the target building is evaluated considering the different structure types. In X-direction, structural type is concrete moment resisting frame system and in Y-direction, structural type is dual frame system. Iso values are found to be 0.21 and 0.36 in X and Y -direction respectively.

Seismic evaluation of the building by using 2^{nd} level screening evaluation: Three blocks of the building are separated by an expansion gap (25 mm). Due to the poor expansion gap, the irregularity index is set as 0.95. The Time Index is set as 0.90 taking into consideration of deterioration of reinforcement. Figure 6 illustrates the comparison of the seismic evaluation of the target building for both directions. It is seen that the 1F to 9F requires retrofitting in the X-direction and 1F to 7F requires retrofitting in the Y-direction.

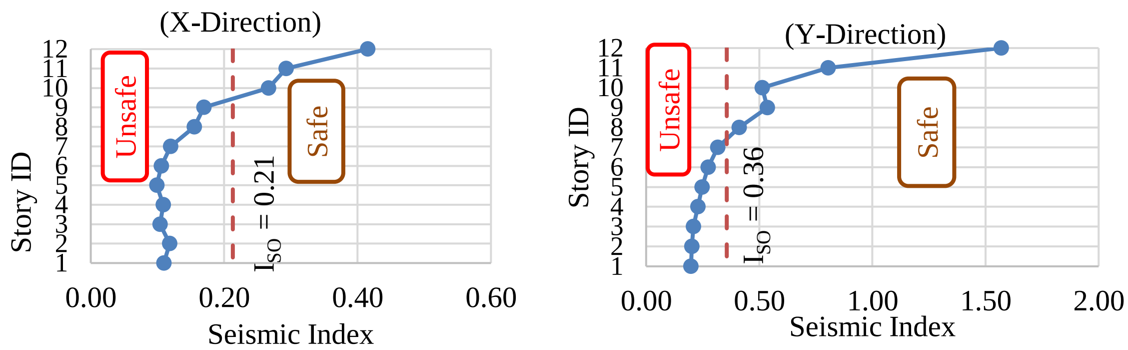

Figure 6. Evaluation by 2^{nd} level screening.

Seismic evaluation of the building by using detail seismic evaluation method:

X-direction: Figure 7 (Left) shows the result of the pushover analysis at the occurrence of first CP point and the final step, respectively. CP occurred at the end of the floor beam of 4F and 5F of Frame 2 in Step 7. At these connecting joints of beam and shear are vulnerable due to insufficient embedment length. After the first CP, many plastic hinges occurred to the surrounding beams, which finally led to the collapse. Figure 7 (Right) shows the result of the seismic evaluation. Since the building collapses before it reached LP, evaluation is not performed on LP. In this direction, the requirement of seismic demand, $I_{S0,}$ is 0.213, but the calculated seismic index of the structure is found to be 0.127, which is less than seismic demand. Therefore, it is judged that this building may not have adequate seismic capacity.

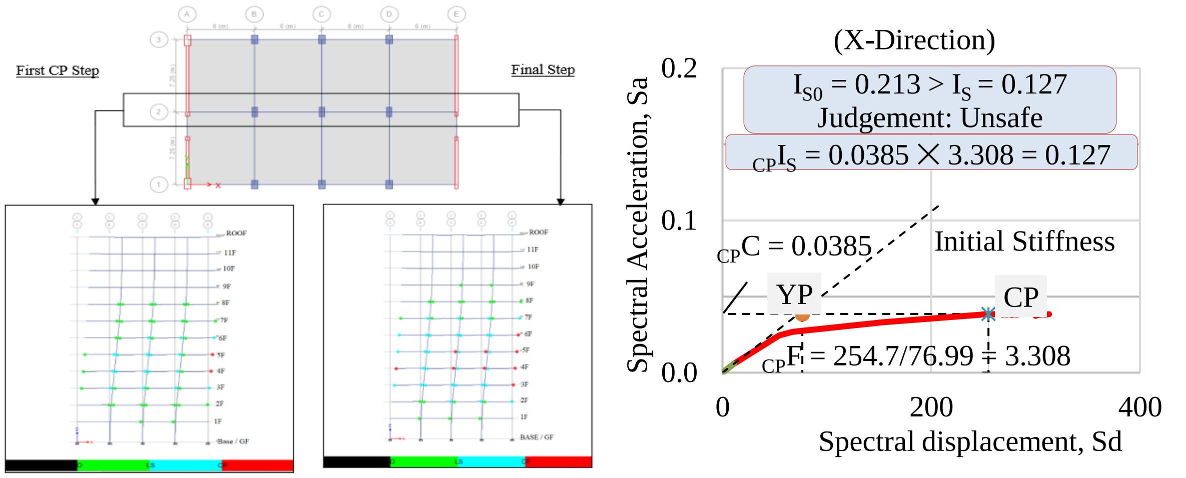

Figure 7. Evaluation by detail seismic evaluation (X-direction).

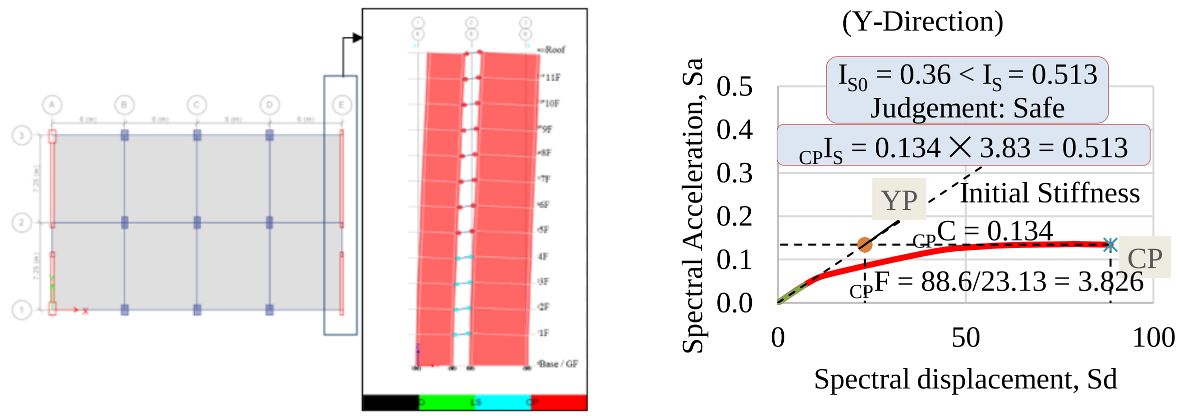

Figure 8. Evaluation by detail seismic evaluation (Y-direction).

Y-direction: Figure 8 (Left) shows the result of the pushover analysis at the occurrence of first CP point and final step. CP occurred at both ends of floor beams of 5F to Roof of frame-E in Step 15. Figure 8 (Right) shows the result of the seismic evaluation. Since the building collapses before it reached LP, evaluation is not performed on LP. In this direction, the requirement of seismic demand, $I_{S0,}$ is 0.36, but the calculated seismic index of the structure is found to be 0.513, which is larger than seismic demand. Besides, each story Is values are determined for both direction of the buildings and also compared with Iso values. The judgement is that the building needs retrofit technique in X-direction only.

To increase the strength and stiffness of the building in X-direction, the insertion of a new shear wall retrofit technique is adopted for the target building. With this option, the structural system type of the building in X-direction will change from the moment-resisting frame to dual system. The new seismic demand of the building in this direction is 0.36. The required strength of the building in X-direction are evaluated by considering $_{R}F$ value as 3.0. According to JBDPA, 2001, the ultimate strength of the inserted shear wall is found to be 4776.73 kN which is greater than the required strength 4710.51 kN.

Structural safety checking of the retrofitted structure by detail seismic evaluation:

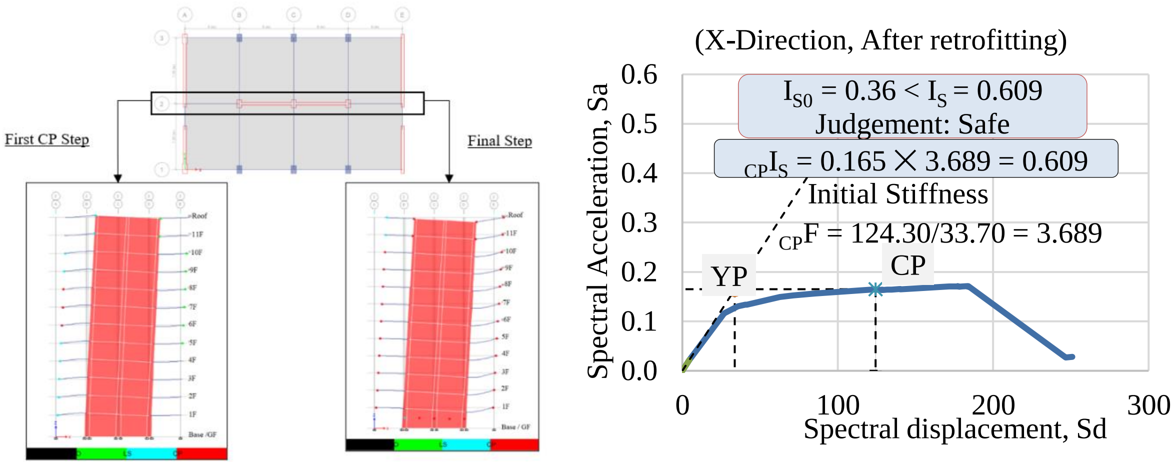

Figure 9. Evaluation by detail seismic evaluation (X-direction, after retrofitting).

X-direction: Figure 9 (Left) shows the result of the pushover analysis at the occurrence of first CP point and the final step. CP occurred at the end of the floor beam of 6F to 8F of frame-2 in Step 10. These connecting joints of beam and shear are vulnerable due to insufficient embedment length. After the first CP, many hinges occurred at the floor beams of the roof to 1F, and finally, shear wall failed to resist the load showing the CP on the ground floor, which subsequently led to the collapse of the building. Figure 9 (Right) shows the result of the seismic evaluation. Since the building collapses before it reached LP, evaluation is not performed on LP. In this direction, the requirement of seismic demand, $I_{S0,}$ is 0.36, but the calculated seismic index of the structure is found to be 0.609, which is larger than seismic demand. Therefore, it is judged that this building now has adequate seismic capacity after inserting the shear wall.

The key findings from this research are summarized below: The target building was recognized as weak-beam type building due to the formation of collapse prevention (CP) hinges at beams from the nonlinear pushover analysis. This building is also considered as a high-rise building. Consequently, the 2nd level screening method of the JBDPA, 2001 can provide an inaccurate result for the target building's seismic performance. The detail seismic evaluation method can evaluate the actual behaviors of the weak-beam buildings. Therefore, this method is a very effective and rational approach for seismic evaluation of the target building. With this new method, the seismic capacities of the target building for each direction were easily estimated by the ADRS format of the capacity curve of the building. The detail seismic evaluation method makes the calculation procedure of the required strength for retrofit easier. Retrofitting with new shear can be a practical solution since the goal of retrofitting was strength and ductility up-gradation. The detail seismic evaluation is a more rational and practical one to evaluate the seismic performance of the building and also for the retrofit plan.

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