Citation: Bidhan C. Dey, M. Seki (2021), Seismic evaluation considering infill wall and retrofit of a five storied RC building in Bangladesh, Synopsis of IISEE-GRIPS Master's Thesis.

SEISMIC EVALUATION CONSIDERING INFILL WALL AND RETROFIT OF A FIVE STORIED RC BUILDING IN BANGLADESH

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ABSTRACT

The recent revision of the Bangladesh national building code (BNBC) necessitates the buildings designed in the old code be assessed for their adequacy to satisfy seismic provisions of the revised BNBC. The existing evaluation manual in Bangladesh is based on the Japanese second-level evaluation method that considers the strong-beam weak-column failure. However, the buildings designed according to the previous code consider the strong-column weak-beam failure. Therefore, the proposed detailed seismic evaluation (DSE) method capable of capturing this effect and providing a simple index resembling the existing manual was tested in a low-rise building. Moreover, in design, ignoring the brick infill can alter the strength and deformation behavior of the columns and the story's capacities accordingly. This research aims to assess the variation of story-wise performance considering the infill wall for a low-rise building designed according to the previous code. Additionally, the low-cost strength-based ferrocement (FC) retrofit was tested as a performance improvement technique. The draft copy of the SATREPS manual was used as a basis for calculating wall capacity for both untreated and FC treated. This research found that the DSE method provides more realistic seismic performance capturing reasonable failure mechanisms initiated by plastic hinges in beams than the JBDPA second level evaluation. Moreover, the contribution of suitably configured solid masonry walls can improve both strength and deformation behavior and thus increase safety, leading to more economic evaluation. Additionally, the Out-of-plane capacity for walls was found to be larger than the in-plane capacity. FC retrofit method proved to be a convenient way to improve performance without intervening in the columns or RC walls. Therefore, it is expected to conduct further analysis under other considerations not estimated in the present research in the future.

Keywords: Detail seismic evaluation method, infill wall effect, ferrocement retrofit.

1. INTRODUCTION

Bangladesh is an earthquake-prone country and experienced several earthquakes of moderate magnitude. From continuous plate tectonics and previous records on the active fault zone, it is predicted that there is a high possibility for an earthquake of considerable magnitude in the near future. In the past earthquakes, the poorly designed and constructed infrastructures suffered the most. Moreover, the Bangladesh national building code (BNBC) has upgraded many sections in the 2020 revision, including seismic design provisions. This necessitates the evaluation of the existing buildings designed based on previous codes to assess whether the buildings' performance is acceptable. In Bangladesh, the reinforced concrete (RC) frames are infilled with brick masonry, which also contributes to the lateral strength of

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the stories. Therefore, it is necessary to consider the infill wall effect in the evaluation process, giving a more rational result.

2. METHODOLOGY

Currently, the existing manual for RC building's seismic evaluation is published under CNCRP (Capacity Development on Natural Disaster-Resistant Techniques of Construction and Retrofitting for Public Buildings) project. It is based on the second level evaluation from Japanese standards for seismic evaluation (JBDPA evaluation guideline, 2001), where strong-beam and weak-column are considered. However, the philosophy of the designed RC buildings following the BNBC is the strong-column and weak-beam concept. The recently proposed detailed seismic evaluation (DSE) method introduces evaluating the buildings based on nonlinear static pushover analysis that captures the failure sequence in a better way. In this method, the plastic hinges are assigned according to the ASCE 41-13, which is based on the experimental results. Additionally, considering the wall effect in the evaluation process makes the evaluation more rational, and performance improvement can lead to a more realistic assessment. Currently, no other studies in Bangladesh consider the combined effect of the frame and the infill masonry wall in the evaluation, using the DSE method. The current research focuses on studying the infill wall effect in the capacity enhancement of the seismically inadequate stories of RC buildings based on the SATREPS manual. Additionally, a low-cost retrofitting technique, i.e., ferrocement lamination, was tested to improve the seismically inadequate stories. By assessing the infill masonry walls' contribution, the more realistic behavior of different stories can be determined, and a retrofitting plan can be addressed and utilized more economically.

2.1. Seismic evaluation without the masonry infill

The selected building is modeled and assessed using second-level evaluations of Japanese standards as mentioned in JBDPA (2001) and the DSE method proposed by Y. Nakajima, M. Seki, H. Suga, and R. Islam (2020). The basic difference between these two methods is considering the relative stiffness of the beam and column. In the Japanese 2nd level evaluation, the beams are considered more rigid compared to the column. This consideration ensures the hinge mechanism initiation in the column while no beam is affected at all. Additionally, for the story-wise evaluation of capacity, the lateral strength of the column is considered to be fully utilized. However, in pushover analysis based on the assignment of the plastic hinge, it may be initiated in either column or beam. It essentially captures both the strong-column weak-beam and vice versa based on the plastic hinge property. When assigning the plastic hinge section, three acceptance criteria are assumed, namely Immediate occupancy (IO), life safety (LS), and collapse prevention (CP) point. As per the DSE method, the two critical limits were considered to select a story's ultimate capacity are based on two points. One is LP points, and the other is the CP points. The LP points, i.e., the limiting points, are determined as per the limitation of drift by revised code provisions. CP limits are considered to be achieved when one or some member's plastic hinge crosses the predefined CP points. The pushover curve obtained thus is converted in the more representative ADRS format. The capacity of the building is then calculated using Eqs. (1) - (3)

$$ {}_{CP}I_S = {}_{CP}C \cdot {}_{CP}F = {}_{CP}C \cdot {}_{CP}\mu \tag{1} $$

$$ {}_{LP}I_S = {}_{LP}C \cdot {}_{LP}F = {}_{LP}C \cdot {}_{LP}\mu \tag{2} $$

$$ I_S = \min({}_{CP}I_S, {}_{LP}I_S) \tag{3} $$

Where, ${}_{CP}C$ and ${}_{LP}C$ are the strength indexes at the CP and LP points, respectively. ${}_{CP}F$ and ${}_{LP}F$ are the ductility indexes at the CP and LP points, respectively. The resulting capacity obtained thus is also compared with that found using the 2nd level evaluation of the JBDPA guideline (2001). However, both X and Y directions were found not to conform to the seismic demand while using the

DSE method in the selected building. Therefore, story-wise pushover analyses were performed, and the capacity of each story was assessed.

2.2. Seismic evaluation considering the infill masonry

To consider infill walls, two critical parameters, i.e., strength index and ductility index, since not provided in either the JBDPA standard or the proposed DSE method, the calculation procedure is adopted from the SATREPS manual. According to the manual, the equations were provided for evaluating strength and ductility index based on the experimental results. Four types of failure were categorized. Based on the test result, conservative ductility indexes were suggested for the different failure modes of walls in the SATREPS manual. To get the overall capacity of the stories, the result obtained thus are combined with those found earlier for the bare frame using the DSE method following the basic principle described in the JBDPA evaluation guideline.

3. DATA

The RC framed five-storied office building is selected for this research purpose. It contains brick masonry infilled RC frames that includes walls with opening also. The building does not have any RC walls. All vertical lateral-load-resisting elements are columns. The various essential properties, including geometrical and material-related properties, are shown in Table 1. The ground floor plan of the building is shown in Figure 1.

Table 1. Basic properties of the building geometry and its material

Geometrical, load and material related properties
Building name: 5 (five) storied administrative government building.
Number of story: 5 (five)
Framing: RC frame only (no RC shear wall)
Occupancy category: II
Importance factor: 1.00
Seismic zone: 3 (Z=0.28 in BNBC 2020)
Soil type: SC (BNBC 2020)
Concrete strength: 25 MPa
Steel yield strength: 414 MPa
Brick prism strength: 6 MPa
Total seismic weight: 27486 kN
Total area: 2295.20 m^2.

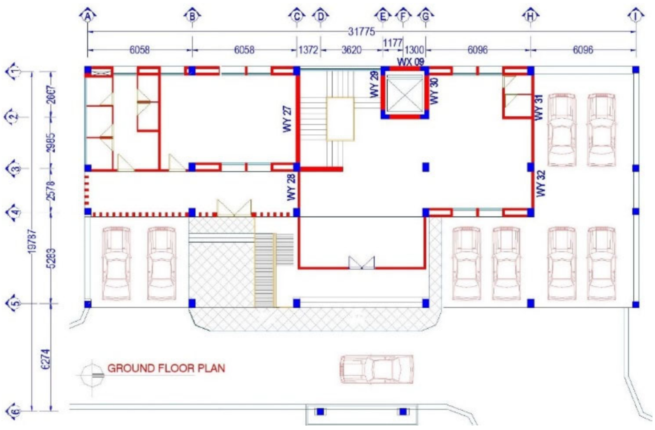
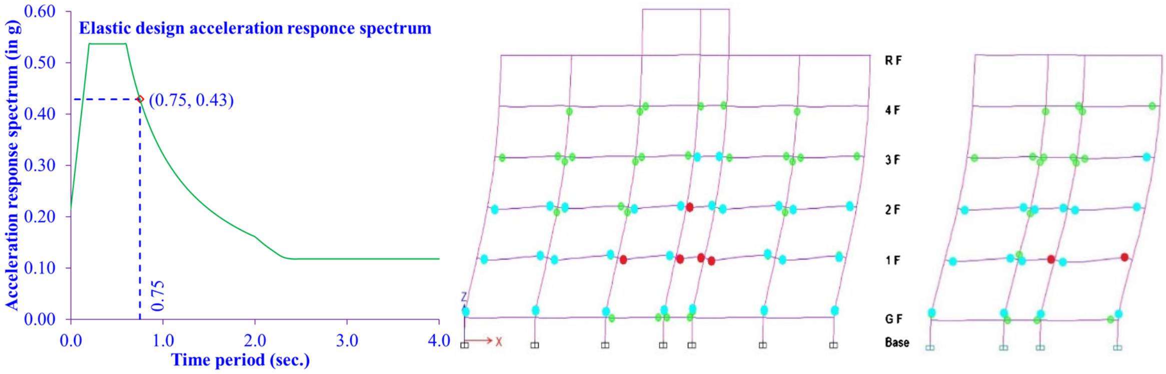


Figure 1. 1st floor plan showing the location and type of infill wall

4. RESULTS AND DISCUSSION

The seismic demand index was calculated from the revised BNBC and found 0.43, as shown in Figure 2(i). Pushover analysis was performed to obtain the governing limit between CP and LP points. For this building in each direction, CP points were found to be governing. Two sample elevation for both *X* direction and *Y* direction is shown in Figure 2(ii) and (iii). However, after the ADRS conversion and getting the I_S values using Eq. (3), it was found that the seismic index of the building was not satisfactory. Therefore, to identify the seismically deficient stories and the story-wise capacity, restrained pushover analysis was performed. in this analysis, stories lower than the concerned stories were kept translationally restrained in the corresponding direction while performing the pushover analysis.



(i) (ii) (iii)

Figure 2. (i) Seismic demand index as per revised BNBC (2020). Plastic hinge crosses the CP limit for different members in (ii) elevation 01 (*X* dir.) and (iii) in Elevation A (*Y* dir.)

From the story shear vs. story drift graph, the seismic capacity (I_S) of each story was determined. It was found that the lower two stories in *X* direction and the lowest stories in the *Y* direction have unsatisfactory seismic performance.

To compare, the bare-framed building was also evaluated using the second-level evaluation method of the JBDPA evaluation guideline.

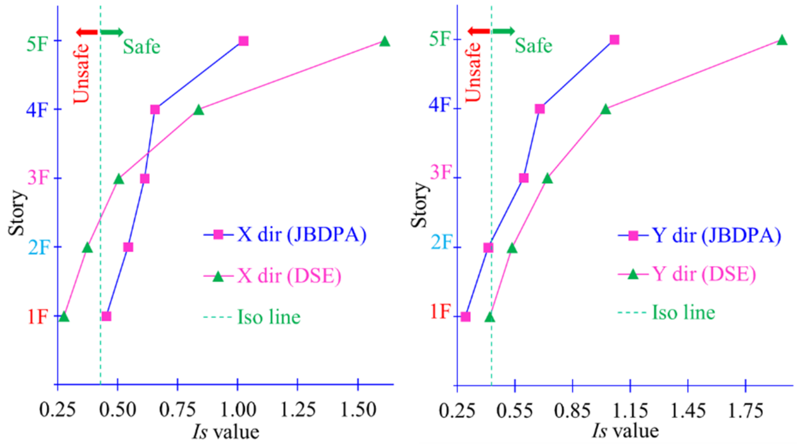
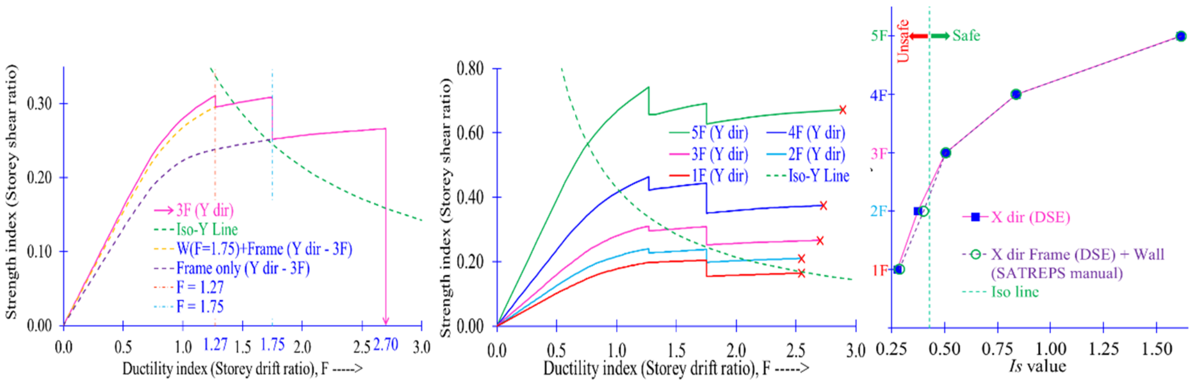


Figure 3. Comparison of the Story-wise capacity in X (left) and Y (right) direction using the DSE method and JBDPA second level evaluation.

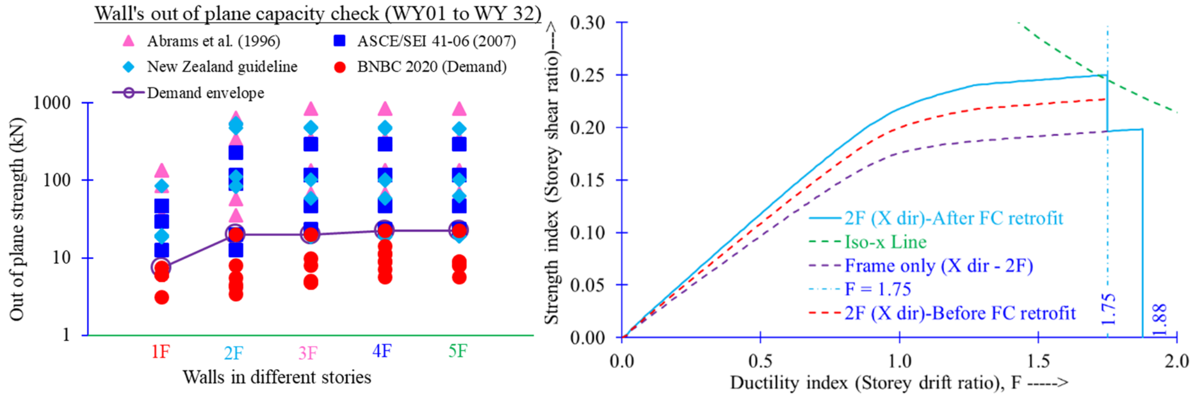


(i) (ii) (iii)

Figure 4. (i) C-F relation for 3F before and after considering the brick masonry wall, (ii)C-F relation of all stories (*Y* direction) considering the brick masonry wall and (iii) story-wise variation of I_S index (*X* direction).

However, the result for the bottom stories varies (Figure 3) from that found from the analysis using the DSE method. In the JBDPA method, the bottom-most two stories in *Y* direction and lowest story in *X* direction were found to have inadequate seismic performance.

A significant difference is found for the second story, where the evaluation result obtained is contradictory for these two methods for both directions. It essentially shows the conceptual difference between these two methods, i.e., the variation in assumption regarding the relative lateral stiffness of the frame element. In the JBDPA 2nd level evaluation method, all the columns are considered to be reached their full potential strength by forming hinge only in the column. Therefore, when using the result from this evaluation, judgment for buildings or stories could give drastic value changes and possibly be erroneous. On the contrary, since the DSE method considers the actual design philosophy, this evaluation method could be more economical for the low-rise buildings in Bangladesh.



(i) (ii)

Figure 5. (i) Out-of-plane demand and capacity for the walls in *Y* direction. (ii) Improvement in C-F relation after retrofit. Illustration shown for 2F-*X* dir.

From the range of the values of the seismic index, it is observed that it varies in a wide range for evaluation results using the DSE method compared to the JBDPA 2nd level evaluation method. It indicates the DSE method is relatively more sensitive than the 2nd level evaluation method as per JBDPA.

It is observed that the consideration of walls can show a more realistic behavior by improving the deformation behavior providing sufficient strength at lesser ductility (Figure 4). Therefore, consideration of this property should give a more economical result. Thus it also shows the higher margin of safety for the non-structural elements by reducing the lateral drift of a story.

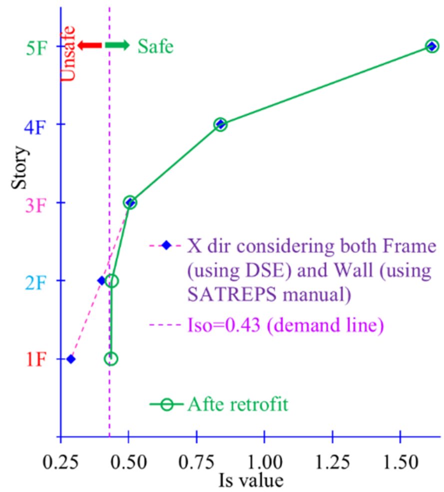


Figure 6. Comparison of Story-wise seismic index value before and after retrofit.

The building contains various sizes of walls with different thicknesses. All are checked using three different equations for out-of-plane capacity and compared to the limit design value recommended in BNBC 2020. Thus, the adequacy of out-of-plane failure is tested, and it is observed that all the walls considered as structural walls are safe against out-of-plane failure. From Figure 5(i), it is observed that, the demand is significantly low compared to the capacity calculated using different equations in most cases. Therefore, for this type of buildings and wall configuration, out-of-plane failure may not govern.

However, the installing connection between the surrounding frame element and the FC layer during retrofitting would provide an additional safety margin. It is observed that the inclusion of walls in the evaluation process could increase the seismic capacity of the story. Therefore, an additional number of masonry walls will increase the strength of the building. However, the ductility range of the wall is very small compared to the frames of the stories. Therefore, considerable strength is required from the masonry wall to achieve the additional strength needed in the lower ductility (Figure 5 (ii)).

The retrofitting calculation shows that FC retrofitting can be very effective and straightforward in improving seismic index (Figure 6) since this method primarily involves non-structural elements, e.g., masonry wall and reduces interference with the structural element, e.g., beam, column, etc.

5. CONCLUSIONS

From the results of this research, it can be concluded that the DSE method for seismic evaluation of building can assess the seismic performance and capture the failure initiation process effectively for the strong-beam weak-column cases comparing to JBDPA second level evaluation. Since the story's capacity is based on the two sets of limiting criteria, i.e., CP points and LP points found from the pushover analysis, this is more advantageous because it additionally provides identification of structurally vulnerable members. Moreover, since it is more sensitive with a wide variation range of I_S value than the JBDPA second level evaluation method, this can lead to a more accurate evaluation and thus economic retrofit accordingly for the low-rise RC buildings of Bangladesh.

Again, from the results of the story's capacity, when the infill wall effect is considered, it is found that the lateral load capacity can be increased, and the deformation behavior can be improved. Therefore, a proper layout plan of these masonry walls can increase the story's capacity and make the non-structural members safer.

The out-of-plane failure is found not to be governing for this selected typical low-rise buildings composed of brick masonry walls.

Finally, the ferrocement retrofit method was tested on the building for retrofitting purposes and found to effectively improve the lateral load capacity of the seismically deficient stories without intervening with the primary structural member e.g. vertical lateral load resisting frame elements.

ACKNOWLEDGEMENTS

This research was conducted as the individual study of the training course "Seismology, Earthquake Engineering and Tsunami Disaster Mitigation" by IISEE/BRI, JICA, and GRIPS. I would like to express my sincere gratitude to my supervisor Dr. Matsutaro Seki, Advisor Dr. T. Kashima for his valuable support and guidance that helped me to accomplish my research successfully.

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