APPLICATION OF SEISMIC ISOLATION SYSTEM FOR RETROFITTING OF AN EXISTING BUILDING IN BANGLADESH

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ABSTRACT

Some recent ground shaking indicates that Bangladesh is under risk of a lot of earthquake source in and around its territory. Seismic isolation is a creative and advanced technology for the protection of a variety of buildings that have the need of earthquake resistance beyond conventional solutions. Therefore, the main objective of this study is to know the performance of a seismically isolated structure and retrofit a structure with isolation system which will be resistant to a predicted earthquake and will be most cost effective. Firstly, a 6-story existing RC building located in the high seismic zone of Bangladesh has been taken as the target building for this study. 3D FEM modelling of the building was done with and without seismic isolators by using the software STERA 3D and dynamic nonlinear analysis was done against some earthquake data. The performance effect of both buildings was compared and the suitable property of the isolator was selected. To provide that suitable property, different arrangements with the different number of isolators were selected and the required structural design was made for those arrangement. Finally, cost comparison for different arrangements was made to find the lowest cost solution for seismic isolation. It was revealed that, although using the isolator increases overall displacement of the structure to a larger value, it reduces the relative story drift to a greater extent.

Keywords: Seismic isolation, Dynamic analysis, Retrofitting, Cost.

1. INTRODUCTION

Bangladesh lies in a highly seismic zone. It is believed that an earthquake of magnitude 8.0 occurring at either Chittagong hill tracts zone or Dauki fault will equally affect Dhaka very badly. Construction of too many low to medium rise buildings in a very densely populated area in Dhaka city has made this city a death trap in an event of earthquake. The Seismic isolation system is getting very popular in earthquake prone countries such as Japan, USA, New Zealand etc. However, in Bangladesh, the concept of the seismic isolation system is very new. In this study investigation was carried out to find the suitable procedure of the design of the isolation system for retrofitting of an existing structure.

2. METHODOLOGY OF THE STUDY

The step by step breakdown of the individual study is shown in Figure 1. The steps are explained clearly for better understanding of the method of the individual study in the master thesis.

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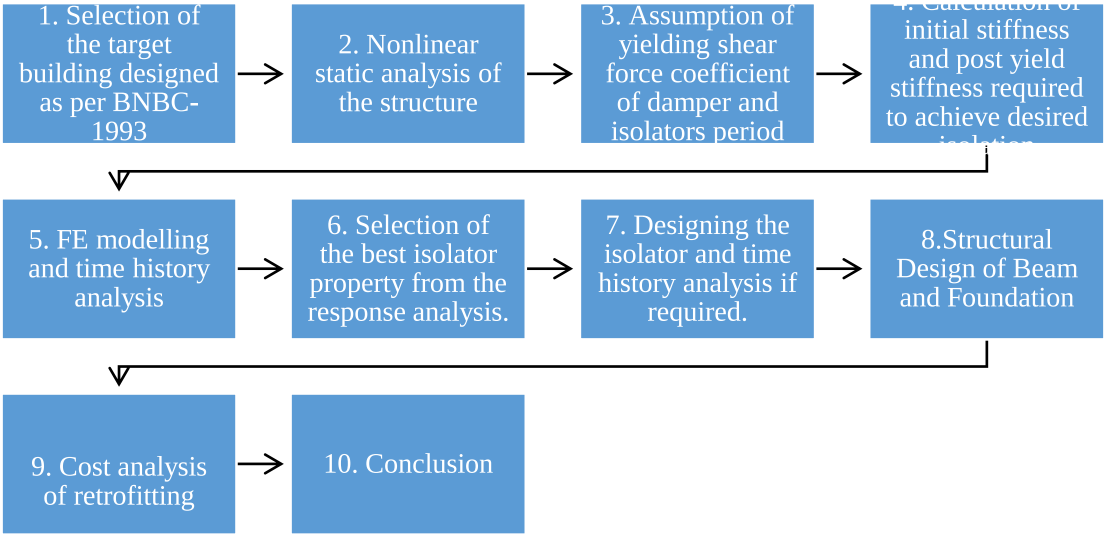

Figure 1. Methodology of the study.

3. THE TARGET BUILDING PROPERTIES

3.1. Outline

The target building is a 6-story Ansar barrack building situated in Bangladesh. The building is constructed on a medium category soil which has a site class of SC according to the new revised building design code. Table 1 shows various information related to the target building basing on BNBC 1993.

Table 1. Details of the target building.

Floor Height	3050mm
Number of story	6
Seismic Zone	III
Type of structure	SMRF, R=12
Soil condition	S3: Medium
Zone factor, Z	0.25
Importance factor, I	1.0

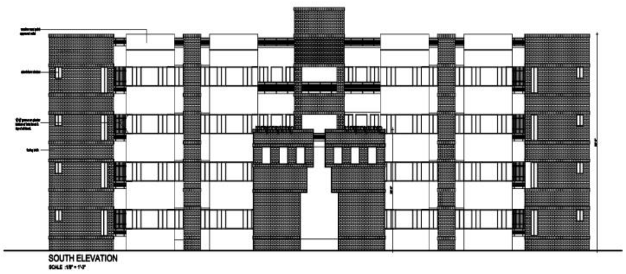

Figure 2. Front elevation of the target building.

3.2. Nonlinear static analysis of the target building

Pushover analysis was performed using STERA 3D in X direction. Target drift was considered up to 1/50 rad. The capacity curve of the frame model in X directions is shown in Figure 3. Maximum static base shear obtained from these plots are 9625 kN in X direction. In this study only X direction analysis has been considered.

The damage state of this building can also be seen from Figure 4 in which it can be seen that beams of bottom three stories got severely damaged and column of the bottom story got severely damaged. In STERA 3D when the ductility factor exceeds the value of 5 it shows red symbol at the end of beam and column. This red signs in Figure 4 are denoting the severe damage. Therefore, to overcome these damages the building was retrofitted by seismic isolation system in this study.

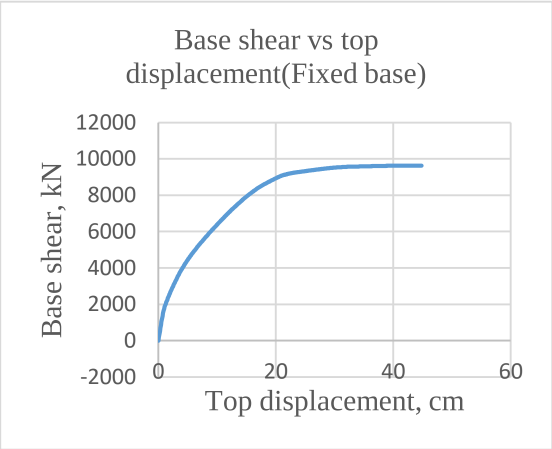

Figure 3. Base shear vs Top displacement from pushover analysis.

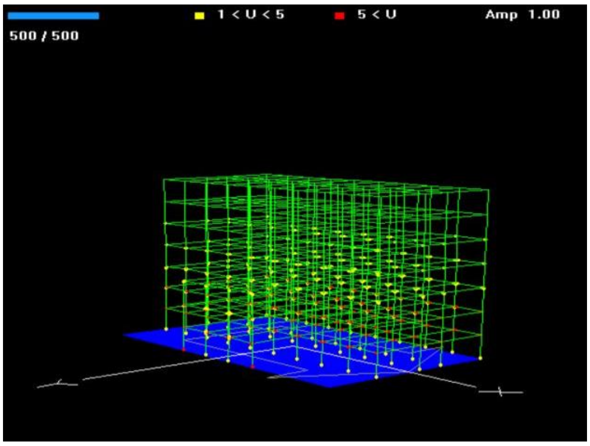

Figure 4. Damage state of building from pushover analysis.

It was predicted that, the calculation of ductility factor before and after the retrofitting work with isolation system would give the transition of ductility factor from 5 to a lesser value which is desired.

4. SEISMIC ISOLATOR PROPERTY FOR THE TARGET BUILDING

4.1. Prediction of maximum displacement

For an isolation system of lead rubber bearing, prediction of maximum displacement had been done through equivalent linearization method. In this study, medium category of soil was considered in the building zone. The isolation period has been taken as more than 1 sec and from the Japanese seismic design code the values of $S_a(cm/s^2) = 0.96g/T_{eq}$, $S_v(cm/s) = 0.96g/2\pi = 150$ and $Sd = 0.96gTeq/4\pi^2 = 23.8Teq$ were taken, which is close to the site condition of the target building. The curves for the prediction of maximum displacement of the isolation system, for various parameters of isolators were prepared and shown in Figure 5 and from these curves the decision for choosing the appropriate isolators parameters was taken.

4.2. Calculation of choosing different isolator parameter

In this target building lead rubber bearing will be placed under multiple columns which extends up to 6^{th} story and elastic sliding bearing will be placed under multiple columns of the porch portions columns which extends up to the 2^{nd} story. The steps of calculating the stiffness parameters are shown below:

Step 1: Assume target period, T_f of isolator.

Step 2: Assume yielding shear force coefficient of damper, $\boldsymbol{\alpha}_s$.

Step 3: Find rubber stiffness, k_1 and assume initial stiffness k_0.

Step 4: Find yield force of damper, Q_d.

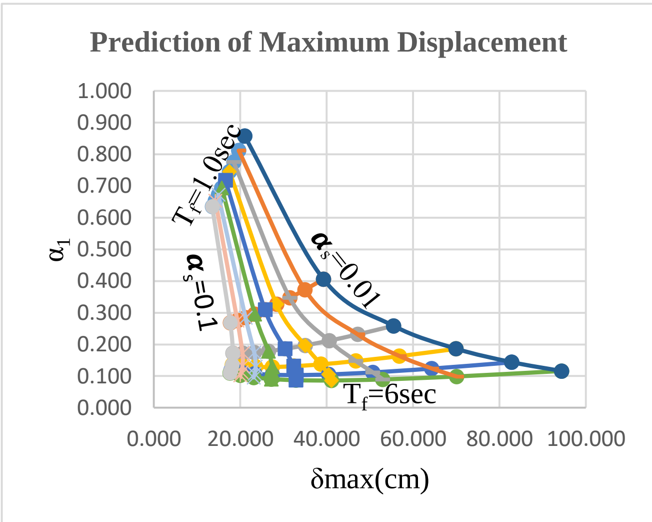

Figure 5. Prediction of isolation level maximum displacement.

5. TIME HISTORY RESPONSE ANALYSIS

5.1. Input earthquake ground motions

Three real earthquake and one artificial earthquake ground motion were used in this study. The ground motions were scaled up to a level mentioned in new BNBC draft as maximum considered earthquake (MCE) for the site of the target building. Ground motion records from Elcentro(N-S), Kobe(N-S), and Hachinohe(E-W) were considered in this study and these motions were scaled up to 0.36g as per the new BNBC requirement. One artificial ground motion data was generated according to acceleration response spectrum from the new BNBC draft for that target building's zone and soil. In this motion, acceleration response spectra of site class SC were used and the phase of Kobe earthquake motion was considered. Figure 6 shows the energy spectra of all the earthquake ground motion used here respectively.

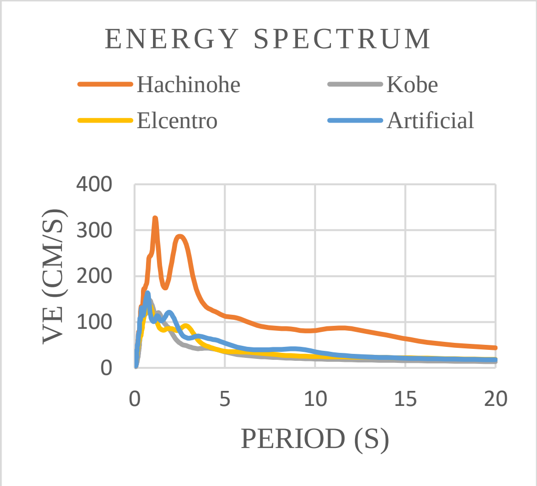

Figure 6. Energy spectra of all ground motions.

5.2. Results

From the time history results it can be seen that for the isolator time period T=4, both $\alpha_s = 0.02$ and $\alpha_s = 0.04$ gives very satisfactory result in terms of the response of the seismically isolated building with $\alpha_s = 0.02$ being slightly better. However, as calculated before, from the equivalent linear analysis, the displacement prediction curve in Figure 5 shows that $\alpha_s = 0.02$ gives large displacement compared to the $\alpha_s = 0.04$. Also if we analyze different time history analysis result comparisons, the relation between values of $\alpha_s = 0.02$ and $\alpha_s = 0.04$ are almost linear. Therefore, from here it is assumed that $\alpha_s = 0.03$ will give similar performance as compared to $\alpha_s = 0.02$ and $\alpha_s = 0.04$. In this case displacement can also be predicted to be less. Therefore, for this target building, retrofitting design of isolator will be on the basis of $\alpha_s = 0.03$ and T=4.

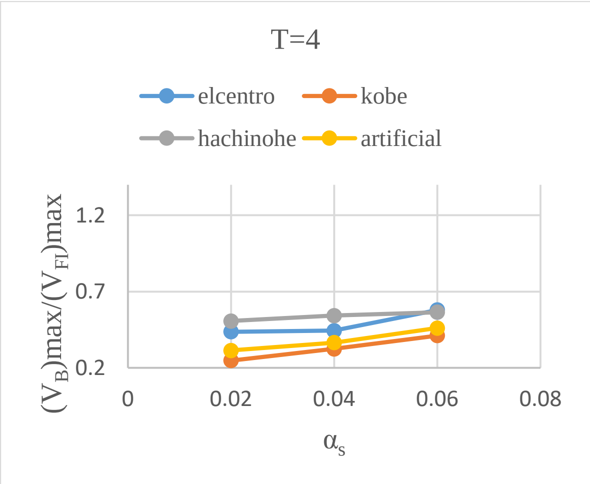

Figure 7. Comparison of base shear of isolation structure with fixed base structure T=4.

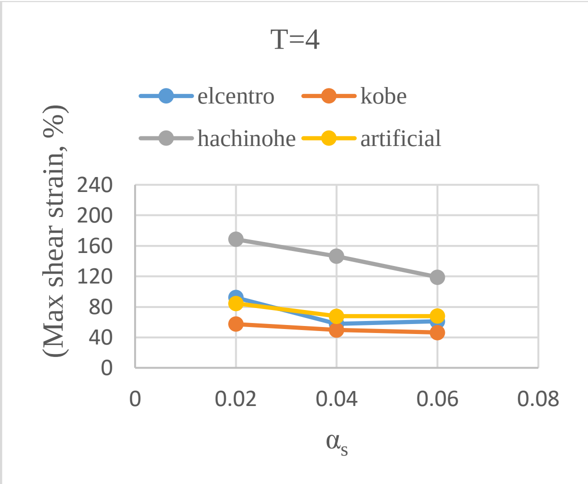

Figure 8. Comparison of shear strain level of isolator T=4.

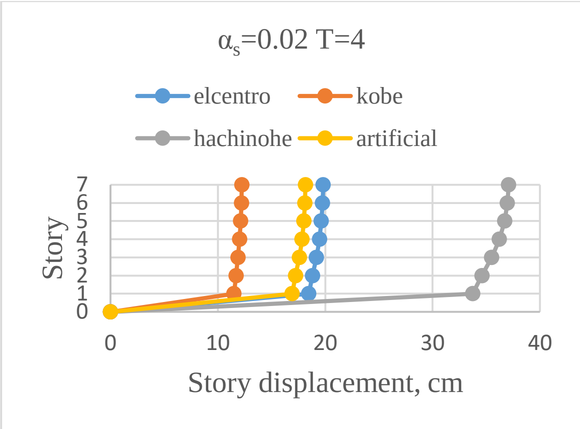

Figure 9. Comparison of story displacement for each earthquake.

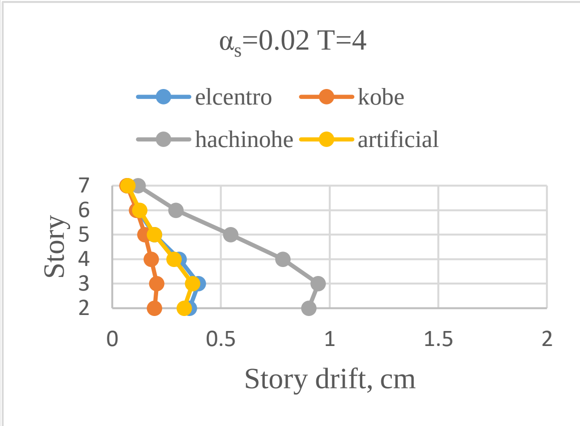

Figure 10. Comparison of story drift for each earthquake.

6. RETROFITTING USING THE ISOLATORS

The required yielding shear coefficient, α_s =0.03 and period of isolator T_f = 4 sec can be provided by altering the number of isolator under the building. In each arrangement, the number of isolator is different. From the analysis of cost, the optimum number of isolators was chosen. For the retrofitting of the structure, different arrangement will produce different amount of structural member and material and thus it will have an impact on the cost of retrofitting as a whole. The total building weight will be carried by the redesigned grade beam. The grade beam will transfer the load to the isolator and then the isolator will transfer the load to the redesigned foundation. Therefore, the number of isolator has an impact on the section of grade beam and foundation and as a whole impact on the total cost.

In arrangement 1, 8 lead rubber bearings and 2 elastic sliding bearings were used. The isolator's placement is shown in Figure 11. This figure also shows in solid line the new grade beams that should be constructed. Figure 12 shows the new foundation that should be constructed in solid line and the dotted line shows the existing foundation. In the new beam layout, the lead rubber bearings are shown in grid 1-4 and the elastic sliding bearings are shown in grid 5.

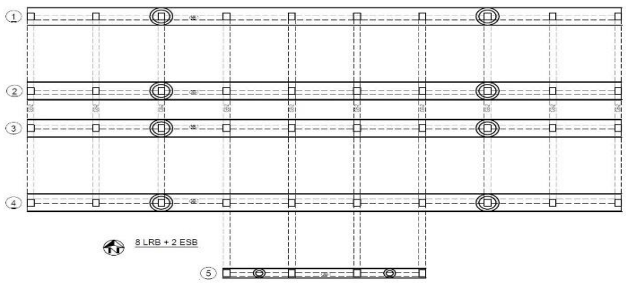

Figure 11. Arrangement 1 new grade beam layout.

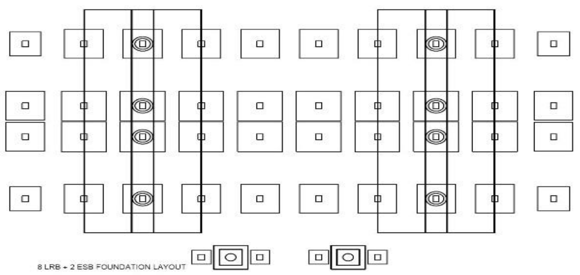

Figure 12. Arrangement 1 new foundation beam layout.

Similar to this arrangement, 3 more different arrangements were tried for designing the isolators for the building and among 4 arrangements , 1 arrangement was chosen as most economical.

7. COST ANALYSIS

The total cost of retrofitting includes new structural member cost and isolator cost. From Figure 13 it can be seen that isolator arrangement 1 which includes 8 lead rubber bearing and 2 elastic sliding bearing requires the least overall cost although the cost for new RC construction is high. This has happened because the cost of isolator is significantly higher compared to the RC cost. Arrangement 4 would have been more traditional in terms of placement of isolator, but as lesser number of isolator was tried in arrangement 1, the overall cost has been reduced to about almost 25% from arrangement 4. Figure 14 shows the stress and strain of isolator for different ground motions are well within the capacity envelope.

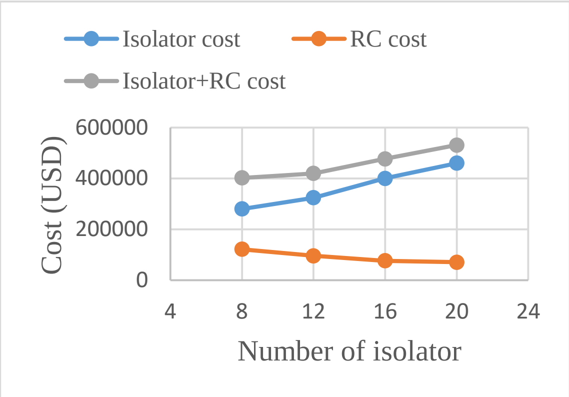

Figure 13. Cost analysis for different number of isolator.

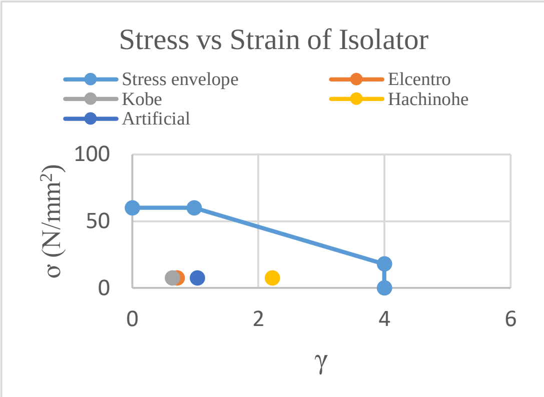

Figure 14. Check of Stress-strain of isolator in the envelope diagram.

8. CONCLUSIONS

The followings points can be categorized as the output of this study.
a) If the soil capacity is high and the building weight is low, the seismic isolation system in which one column supports multiple column weight can be used for retrofitting of very important structures.
b) Considering an arrangement in which less number of isolators were used lead to an overall 25% saving on RC and isolator cost.
c) After the inclusion of isolators, base shear of the seismically isolated building has been reduced to less than 50% of the base shear of the fixed base structure.
d) The maximum acceleration at the top of the seismically isolated building has been reduced to less than 40% of the maximum input acceleration of the structure at the base.
e) The maximum story drift in each story has been reduced to 20% of the drift in case of a fixed base structure.
From this study it can be concluded that after putting the isolators the section size and reinforcement quantity of structural members can be reduced which will have a good performance against an earthquake and also reduce the overall cost in case of new building construction also.

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REFERENCES

Jamshidi, A.K., Sivakumar, M., Pun, L., Boci, G.,2003, University of Toronto.
JSSI, Seismic Isolation Structure - from concept to design and construction -, Ohmsha, 2010.
Minewaki, S. et al., AIJ Annual Convention, Architectural Institute of Japan, pp.377-378 (in Japanese).
The Japan Society of Seismic Isolation, 2013, Ohmsha.
Wang, Yen-Po, Fundamentals of Seismic Base Isolation.
Yang, Y.B., Chang, K.C. and Yau, J.D., 2003, Earthquake Engineering Handbook.