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RESEARCH ARTICLE OPEN ACCESS

BASE ISOLATION OF MULTI-STORIED BUILDING USING LEAD RUBBER BEARING

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ABSTRACT

Earthquake resistance building design is the most important thing to ensure safety and minimize loss in recent years. Nowadays, many techniques are being used in earthquake resistance building design. Base-isolation is one of the best techniques used in earthquake resistant design building in economical. It reduces seismic energy transmitted to buildings, in highly seismic prone areas. Lead Rubber Bearings are the most widely used technology in seismic base isolation, because of its technical and economic effectiveness and reliability. In this research, a multi-storied building that is located in Dhaka city is performed at numerically design as a base isolation building where the lead rubber bearing is designed and used as isolator. The building is analyzed for El Centro earthquake data of 15, 20, and 25 second. For base isolated and non-isolated condition nonlinear time history analysis is done using SAP2000 18. By comparing displacement vs time, acceleration vs time graphs for base isolated and non-isolated condition, the displacement difference between top and bottom floor is almost close that indicates this building structural behavior better during lateral load.

I. INTRODUCTION

Isolation means separation or closing-off. Base isolation also called as seismic base isolation or base isolation technique is one of the best method of protecting a structure against lateral forces such as earthquake loads. Base isolation define as structural elements that should separate a superstructure from its substructure resting on a ground motion or shaking thus protecting the structure. when structures are built according to code specifications (BNBC), they are expected to be damaged during strong earthquakes, but to remain upright. This conventional approach to seismic design is not acceptable for critical structures like hospitals, fire stations, and telecommunications centers.

Base isolation is an anti-seismic design strategy that can reduce the effect of earthquake ground motion by separating the superstructure from the foundation. The structure can be dissociated from the horizontal components of the ground motion by intervening structural elements with low horizontal stiffness between the foundation and superstructure [1].

II. LITERATURE REVIEW

At first base isolation was registered as a patent in 1800's, with Lead Rubber Bearing (LRB) providing high flexibility and damping. The natural rubber has been used for base isolation since 1840's, through the process of material development synthetic rubber or poly-tetra-fluoro-ethylene (PTFE) which is developed by DuPont was used, and designed for 50 years or more [2].

Investigated a smart base-isolation system using Magneto-Rheological (MR) elastomers, which are a new class of smart materials whose elastic modulus or stiffness can be adjusted depending on the magnitude of applied magnetic field. The results suggest the feasibility of using MR elastomers as variable stiffness elements for enhancing the performance of conventional base-isolation systems [3].

The total restoring force model of isolation device, a slide-limited friction base isolation technology. They analyzed the influential factors such as friction coefficient, elastic stiffness and yield displacement of displacement-constraint device on base isolation system [4].

In university of Asia pacific; over last some years there have been some studies in nonlinear analysis but they are not performed practical on base isolation system of the structure.

III. OBJECTIVE

The main objective of this study is to perform to analysis base isolated building and non-base isolated building under El Centro Earthquake data for (15;20;25 sec) and to compare the results with corresponding results from SAP2000 18 using nonlinear dynamic analysis. Some other objectives can be summarized as:

1. Study of Seismic demands of regular R.C buildings using the linear response spectrum and Non-linear time history analysis;
2. To illustrate the effects of base isolators, on the response of the High-rise Symmetric Buildings;
3. Perform numerical study (by SAP2000 18) of the ten-storied building models subjected to scale El Centro earthquake (15; 20; 25Sec) ground motion and compare the results of numerical studies with and without base isolation, changing of time duration of the earthquakes.

IV. METHODOLOGY

IV.I DESIGN OF LEAD RUBBER BEARING

Structural control system, base isolation system is classified as passive control. Isolators are the major devices that are implemented in a structural system for the purpose of isolation. The typical isolators are classified [5].

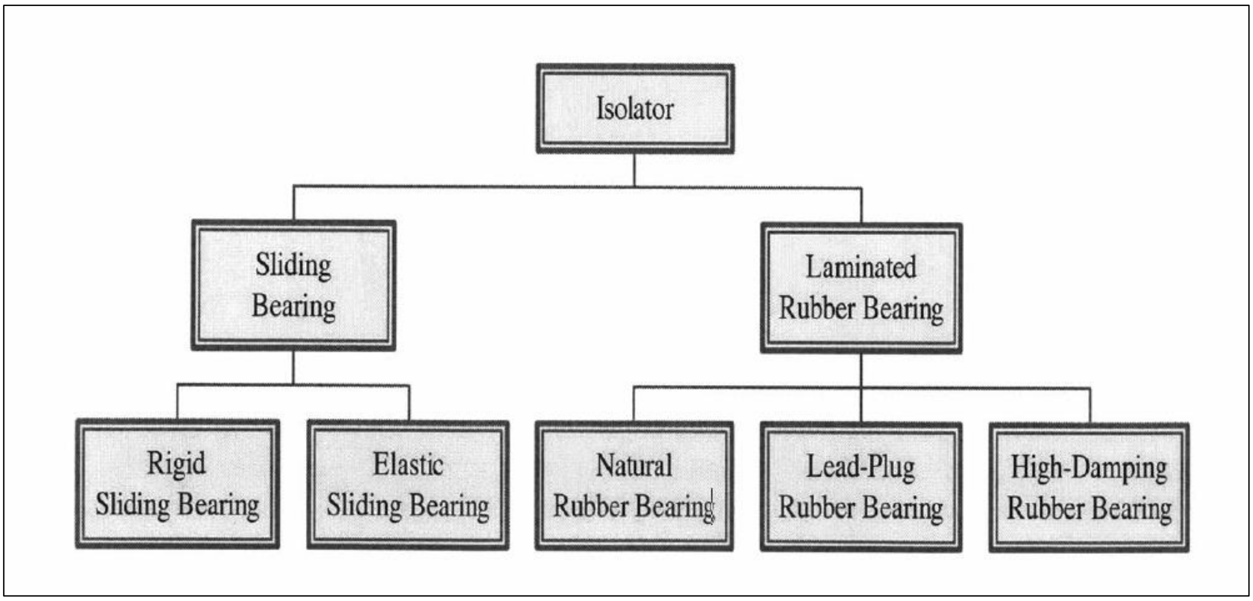


Figure 1: Types of isolator.
Source: Authors, (2020).

The dynamic quantities of the ten storied educational building located at Dhaka Total participated mass of the whole structure (M) = 16329325 Kg (approximately), Mass of base floor (M_b) = 1043262 Kg (approximately) Fundamental period of the building T_f = 0.15 (sec) Because M_b is relatively small in comparison with the mass of the superstructure, so this building is treated a single degree of freedom system in dynamic response system.

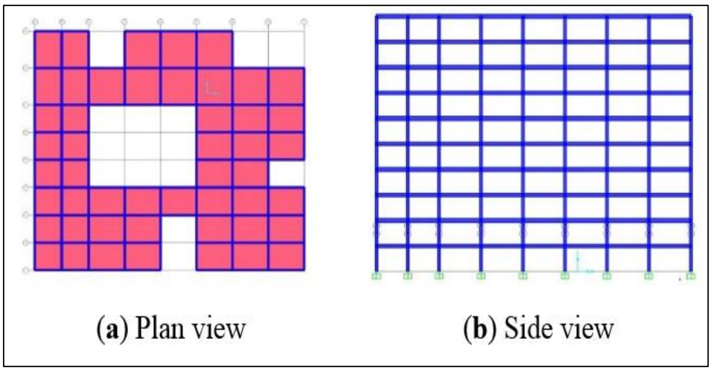


Figure 2: Plan and side view of isolated building.
Source: Authors, (2020).

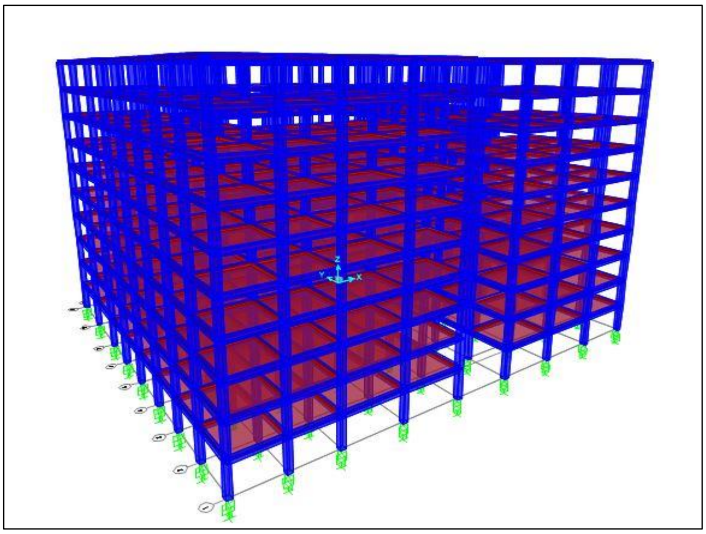


Figure 3: Base-Isolated Building Model.
Source: Authors, (2020).

Under isolation condition S_v = 0.6 (m/s). The system function are often associated with spectra velocity by$|U|_{max}$, finally, we will calculate for the displacement of isolators, U_b:

$$|U|_{max} = \frac{\Gamma\, S_v}{W_{eq}} = 2.19 \text{ x } 10\text{-}5\text{m} \quad (1)$$

$$U_b = \frac{K\,|U|_{max}}{K_b} = 0.087\text{m} \quad (2)$$

A typical design value of isolation layer is 0.3 (m) and therefore the value under the idea of Period T=0.3(sec) is on the brink of this target value which means that using this era can provide effective stiffness and optimal displacement for this building [6].

Lead-Rubber Isolators is usually more beneficial to start out designing isolation systems using lead rubber bearing isolators as a system then assign individual isolator properties. Therefore, we will use critical damping value 15% subject to verification and a rubber compound with a shear modulus of G=60 psi. The same target period of two.5 seconds maintaining or from [7]. For damping 15%; β_D= 1.35. Displacement at center of rigidity of isolation system at design basis earthquake (DBE); D or D_D [8];

$$D_D = \frac{(g/4\pi^2)S_{D1}T_D}{\beta_D} \quad (3)$$

$$D \text{ Or } D_D = 9.43 \text{ inch}$$

Behaving the entire isolation system as a unit, required stiffness form corresponding to this period is:

$$T_D = 2\pi\sqrt{\frac{W}{g \times K_{D,min}}} \quad (4)$$

$$K_{eff} \text{ or } K_H = 588.50 \text{ kip/inch}$$

Energy dissipated per cycle, $W_D = 2\pi\, K_{eff}\beta_{eff}D^2$=49322.05 kip-inch.

The area of the hysteresis loop of the isolator; D_y is relatively small size so ignoring:

$$W_D = 4Q_d(D\text{-}D_y) \quad (5)$$

$$Q_d = \frac{W_D}{4D} = 1307.59 \text{ kips}$$

Post-elastic stiffness; K_d and D_y; K_d = K_{eff} - $\frac{Q_d}{D}$ = 449.84 kip/inch.

$D_y = \frac{Q_d}{K_u - K_d}$ and $K_u = 10K_d$ then we get; $D_y = \frac{Q_d}{9K_d}$ =0.323 inch.

The total cross sectional area of the lead plug area needed for the entire isolation system is:

$$A_{pb}(\text{total}) = \frac{Q_d}{F_{y(pb)}} = 871.73 \text{ inch}^2 \quad (6)$$

For the sake of simplicity, we keep the diameter of all isolators the same at Φ=30 inch. Using 4.25 inch diameter lead cores in 65 of the 81 isolators provides a lead cross sectional area of slightly more than 922.11 square inches. Now we have to re-calculate Q_d based on this new area of lead:

$$Q_d = 922.11*1.5 = 1383.16 \text{ kips}$$

The stiffness provided by lead plugs and the stiffness provided by lead plugs are,

$$K_{pb} = \frac{Q_d}{D} = 146.68 \text{ kip-inch} \quad (7)$$

$$K_{rubber} = K_H - K_{pb} = 441.8 \text{ kip-inch} \quad (8)$$

Rubber cross sectional area and required thickness,

$$T_{rubber} = \frac{GA}{K_{rubber}} = 6.5 \text{ inch} \quad (9)$$

Therefore, assuming 1.25 inch thick top and bottom end plates and steel shims, our isolators will have a height of less than 9 inches. Selecting a shape factor of S=10; Number of layer:

$$t = \frac{\Phi}{4s} = t = \frac{30}{4*10} = 0.75 \text{ inch} \quad (10)$$

$$N = \frac{6.5}{0.75} = 8.67 \text{ say 9 layers} \quad (11)$$

IV.II SUPPORT PROPERTY DATA (ROTATIONAL INERTIA 1)

Isolator is a cylinder with diameter Φ=30 inch with height, h= 9.0 inch. Then cross section area, a= 706.85 inch^2. Behaving the entire isolation system as a unit, the required stiffness corresponding to this period is; K_{eff} or K_H=588.50 kip/inch. I = $\frac{K_{eff}* h3}{12E}$ = $\frac{588.50*93}{12*14.51}$ = 49.042 inch4. Note that; young's modulus, E =0.01 ~ 0.1 Gpa. Assumed, E= 0.1 Gpa or 14.51 ksi.

$$D_y = \frac{Q_d}{9K_d} = 0.323 \text{ inch}$$

$$W = 0.241D2 – 0.0564D \quad (12)$$

[D ft]=0.00000296 kip
[M=0.00000136 kip.sec2/inch,] (17.5.3.5ASCE-4)

Using SAP2000 18, Define >Section Properties >Link/Support Properties >Add New Property;

IV.III SUPPORT PROPERTY DATA (DIRECTIONAL PROPERTIES; U1, U2, U3) AND NONLINEAR PROPERTIES

Effective stiffness = $\frac{A*E}{L}$ =1139.60 kip. Effective damping from the D_D =15 % [9].

Effective stiffness,K_{eff} or K_H=588.50 kip/inch. Effective damping from the D_D calculation =15 %, $D_y = \frac{Q_d}{9K_d}$ = 0.323 inch:

Stiffness = $\frac{\mu*w}{D_y}$ = 4681.11 kip/inch.

IV.IV GROUND MOTION DATA (EL CENTRO GROUND MOTION)

The ground motion data used in this work is a scaled version of the El Centro ground motion, which was the first major earthquake to be recorded by a strong-motion seismograph. It occurred in 1940, in the Imperial Valley in southeastern Southern California.

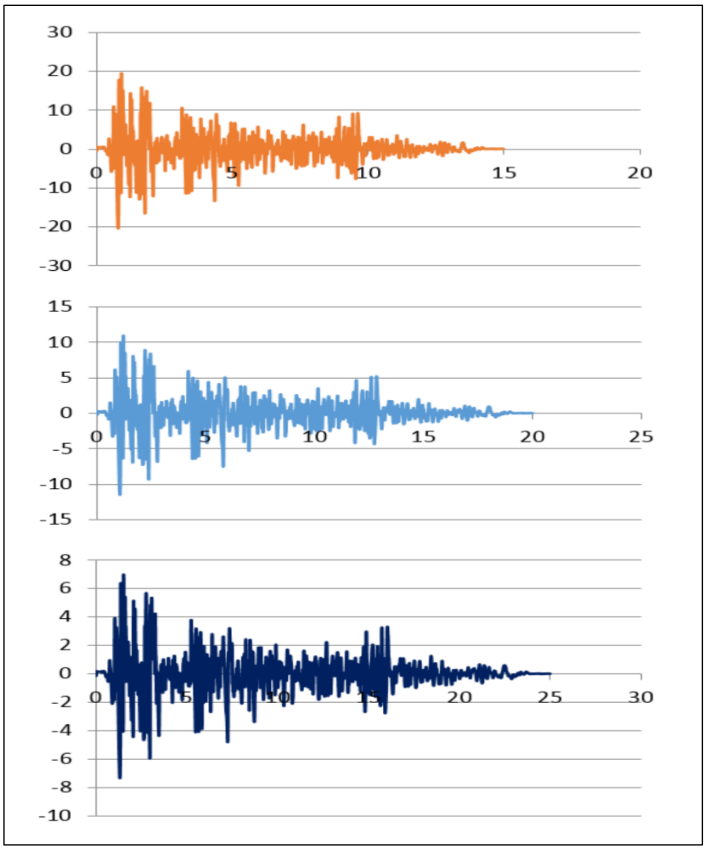


Figure 4: Acceleration vs. Time (Modified El Centro for 15, 20, 25 sec).
Source: Authors, (2020).

V. NUMERICAL ANALYSIS AND COMPARISON

SAP2000 18 nonlinear dynamic analysis is prepare and the comparison between bases isolated and not isolated building. Result for fixed supported building and base isolated building is described.

V.I NONLINEAR TIME HISTORY ANALYSIS

Time history function definition: Define > Function>Time history>Input file; Load case data: Define > Load case > Add new case > Time history.

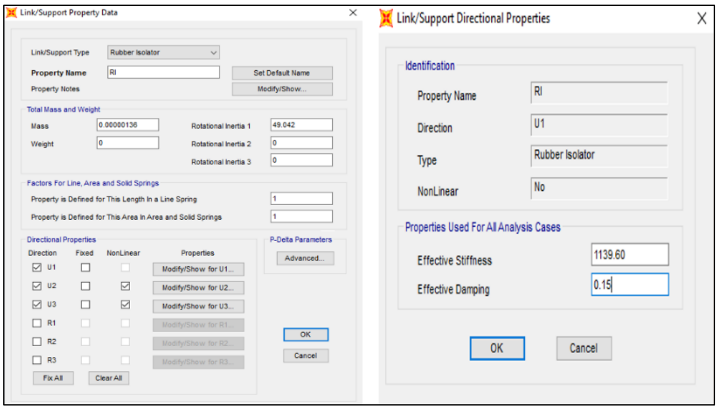


Figure 5: Link support properties.
Source: Authors, (2020).

Click the run for analysis. After analysis we get the displacement from. Display > Plot function > Displacement for time history at maximum time.

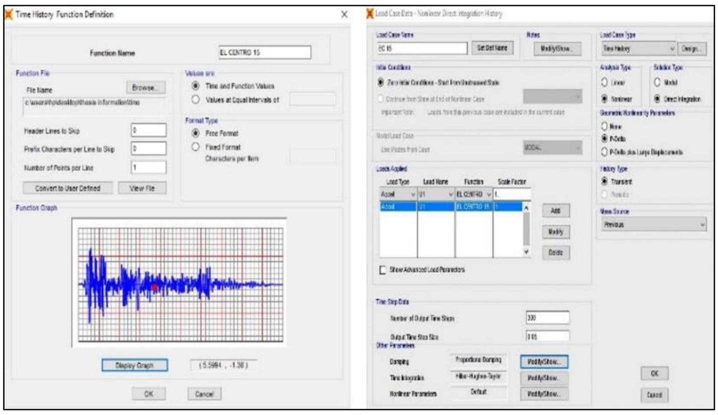
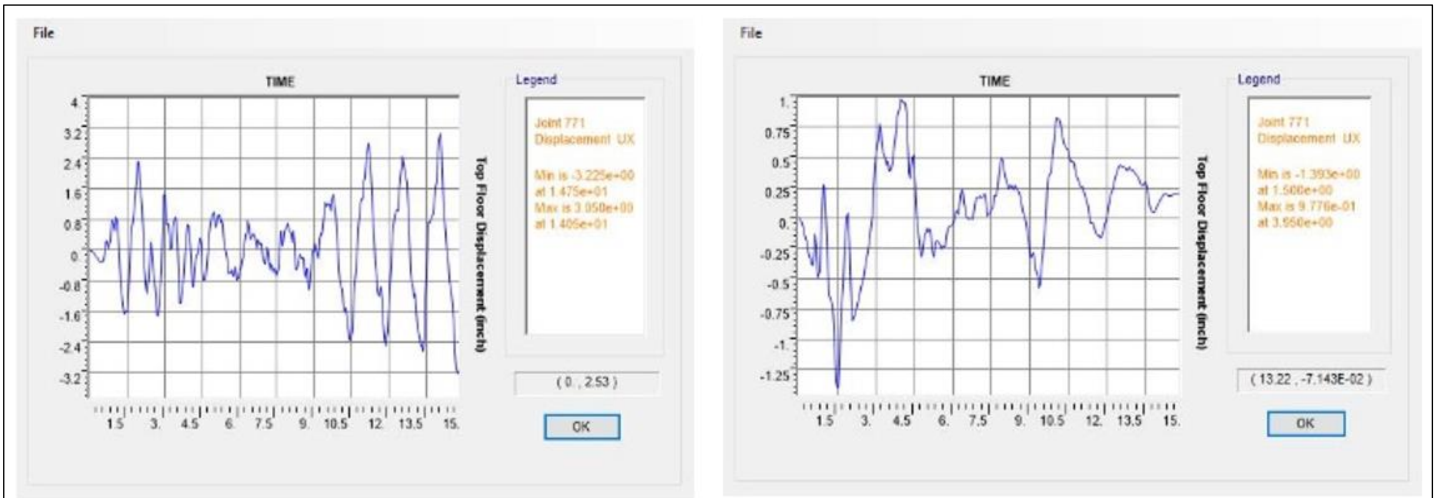


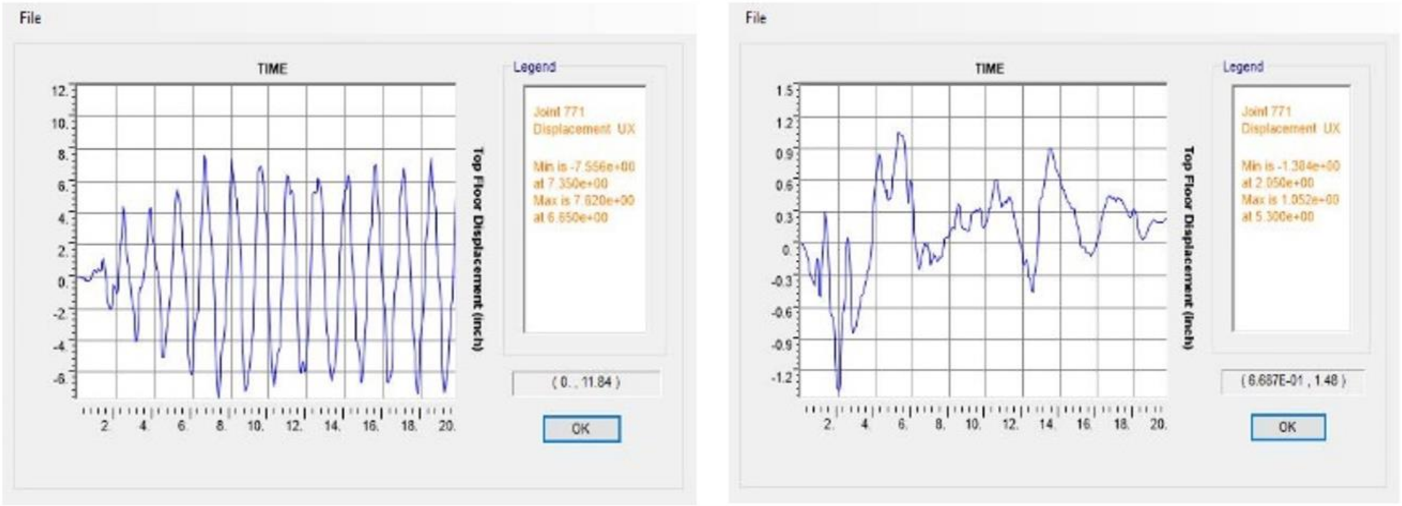
Figure 6: Time history function.
Source: Authors, (2020).

From SAP2000 18 analysis displacement vs. time; acceleration vs. time curves are found and comparison between top and bottom floor displacement vs. time; acceleration vs. time curves. The top floor displacement vs time curves with and without base isolation for 15, 20, 25 sec.



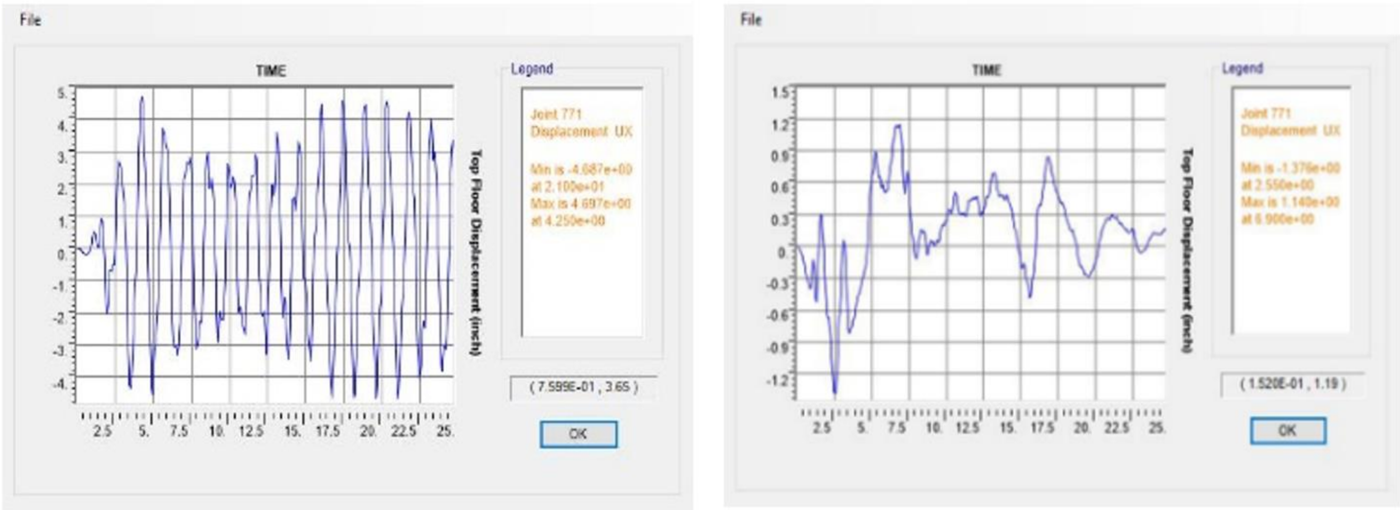
a). Without Isolator b). With Isolator

Figure 7: Top floor displacement vs time curve (15 sec).
Source: Authors, (2020).



a). Without Isolator b). With Isolator

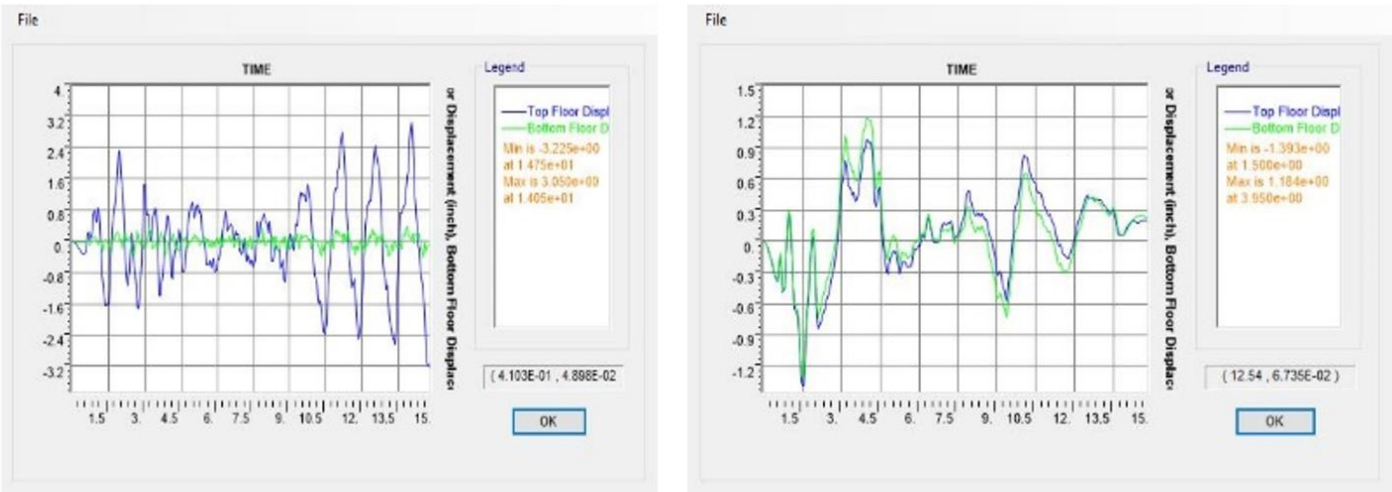
Figure 8: Top floor displacement vs time curve (20 sec).
Source: Authors, (2020).



a). Without Isolator b). With Isolator

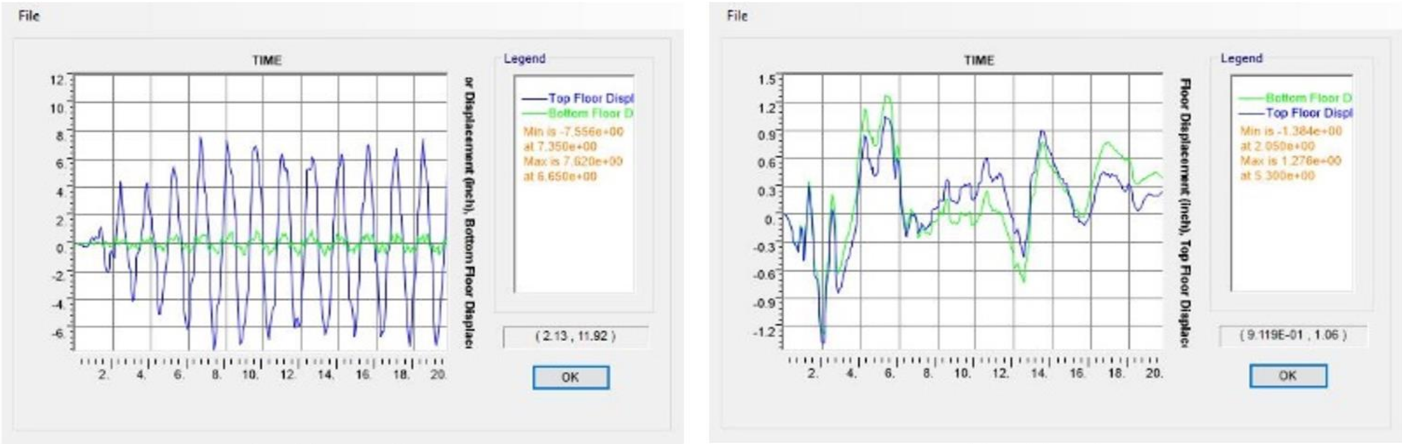
Figure 9: Top floor displacement vs time curve (25 sec).
Source: Authors, (2020).

Comparison Top and Bottom Displacement vs. Time Curves for El Centro ground motion 15, 20, 25 sec.



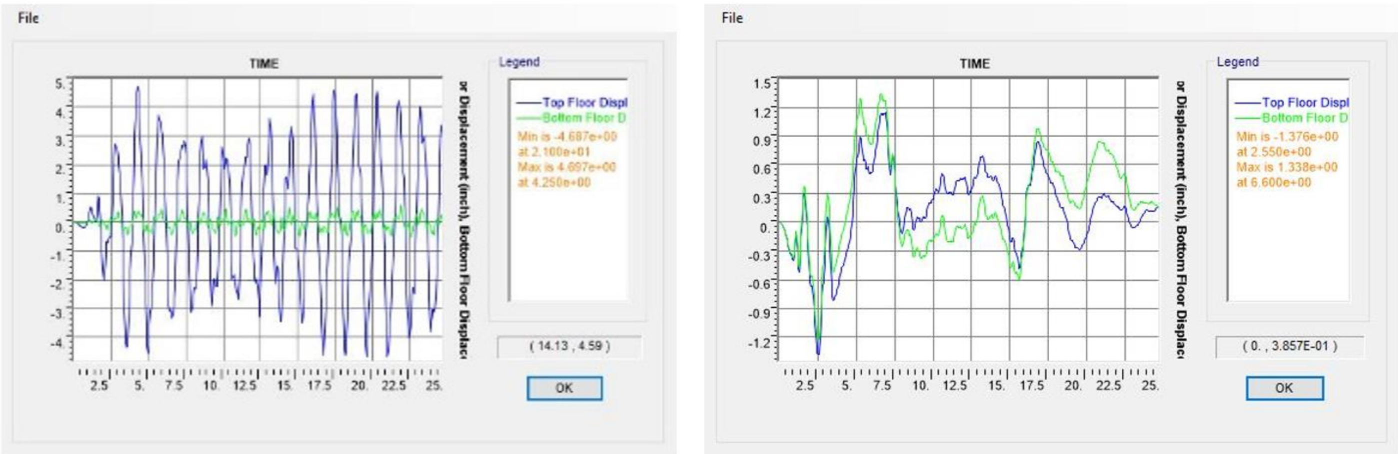
a). Without Isolator b). With Isolator

Figure 10: Top and bottom displacement vs time curve (15 sec).
Source: Authors, (2020).



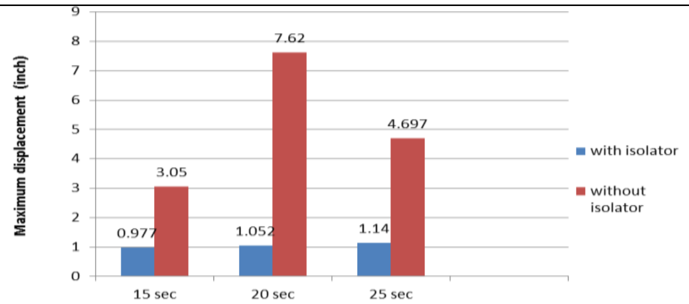
a). Without Isolator b). With Isolator

Figure 11: Top and bottom displacement vs time curve (20 sec).
Source: Authors, (2020).

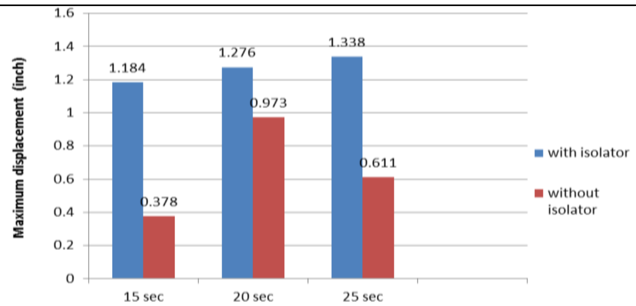


a). Without Isolator b). With Isolator

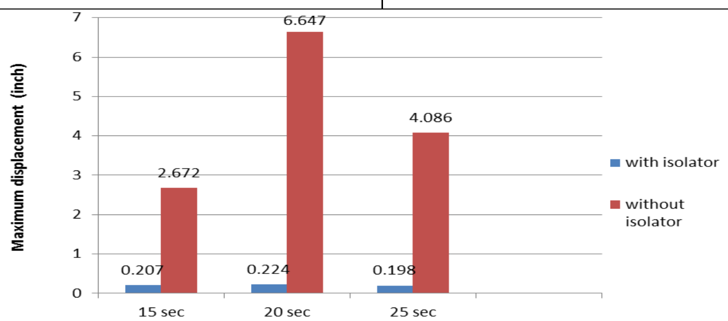
Figure 12: Top and bottom displacement vs time curve (25 sec).
Source: Authors, (2020).



a). Top floor displacement with and without isolator



b). Bottom floor displacement with and without isolator



c). Difference top and bottom floor

Figure 13: Displacement variation with and without isolator for different EL centro data.
Source: Authors, (2020).

Table 2: difference between top floor and base floor displacement of model for different El centro data.

time (sec)	with Base Isolation (inch)				without Base Isolation (inch)			
	Top Floor		Base Floor		Top Floor		Base Floor	
	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
15	0.98	1.39	1.19	1.32	3.05	3.23	0.38	0.41
20	1.05	1.39	1.28	1.28	7.62	7.56	0.97	0.87
25	1.14	1.38	1.34	1.22	4.69	4.69	0.61	0.52

Source: Authors, (2020).

Table 3: modal participating mass ratios.

Output Case	Step Type	Period	Sum UX	Sum UY	Sum UZ
Text	Text	Sec	Unit less	Unit less	Unit less
MODAL	Mode	1.741249	0.85	0.006458	2.22E-08
MODAL	Mode	1.664218	0.87	0.71	0.000000421
MODAL	Mode	1.555428	0.89	0.89	4.213E-07
MODAL	Mode	0.548855	0.96	0.89	6.053E-07
MODAL	Mode	0.526091	0.96	0.95	0.000004552
MODAL	Mode	0.491833	0.96	0.96	0.000004559
MODAL	Mode	0.300586	0.98	0.96	0.000004752
MODAL	Mode	0.218247	0.98	0.96	0.000004774
MODAL	Mode	0.175874	0.99	0.96	0.000006694
MODAL	Mode	0.09474	0.99	0.96	0.000007226

Source: Authors, (2020).

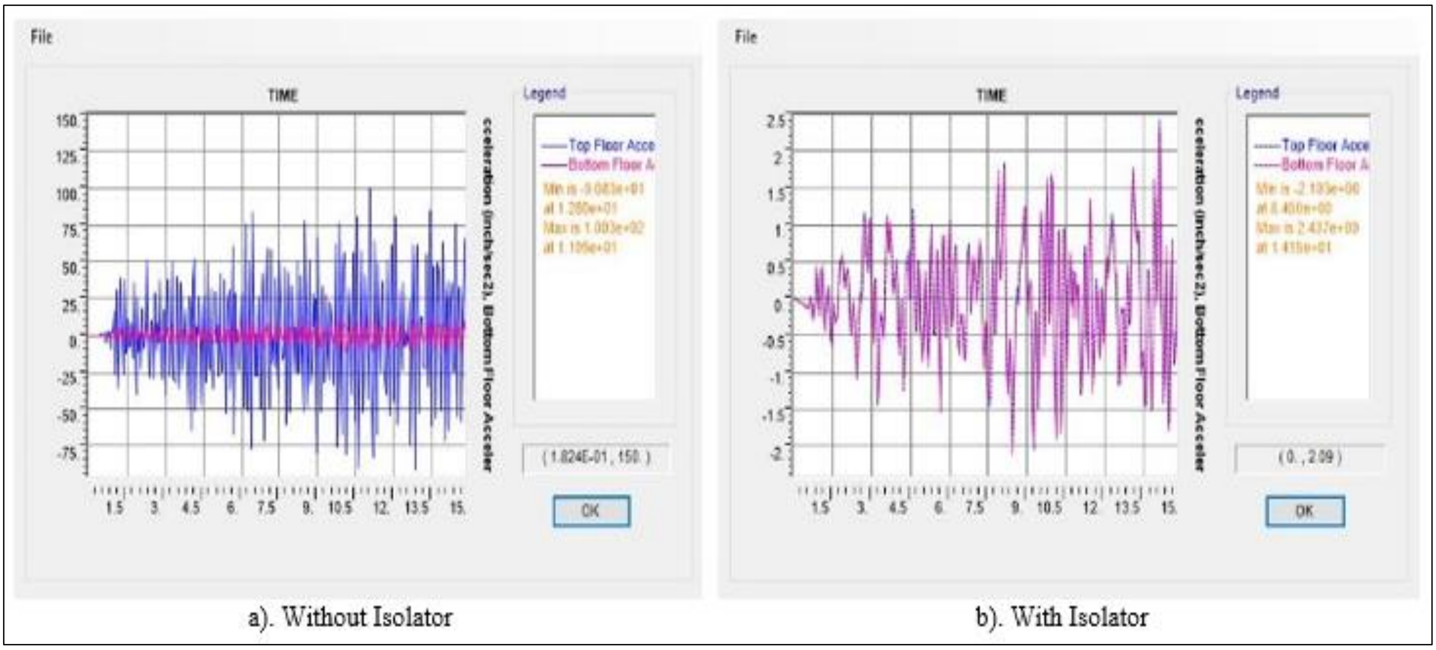


Figure 13: Top and bottom acceleration vs time curve (15 sec).
Source: Authors, (2020).

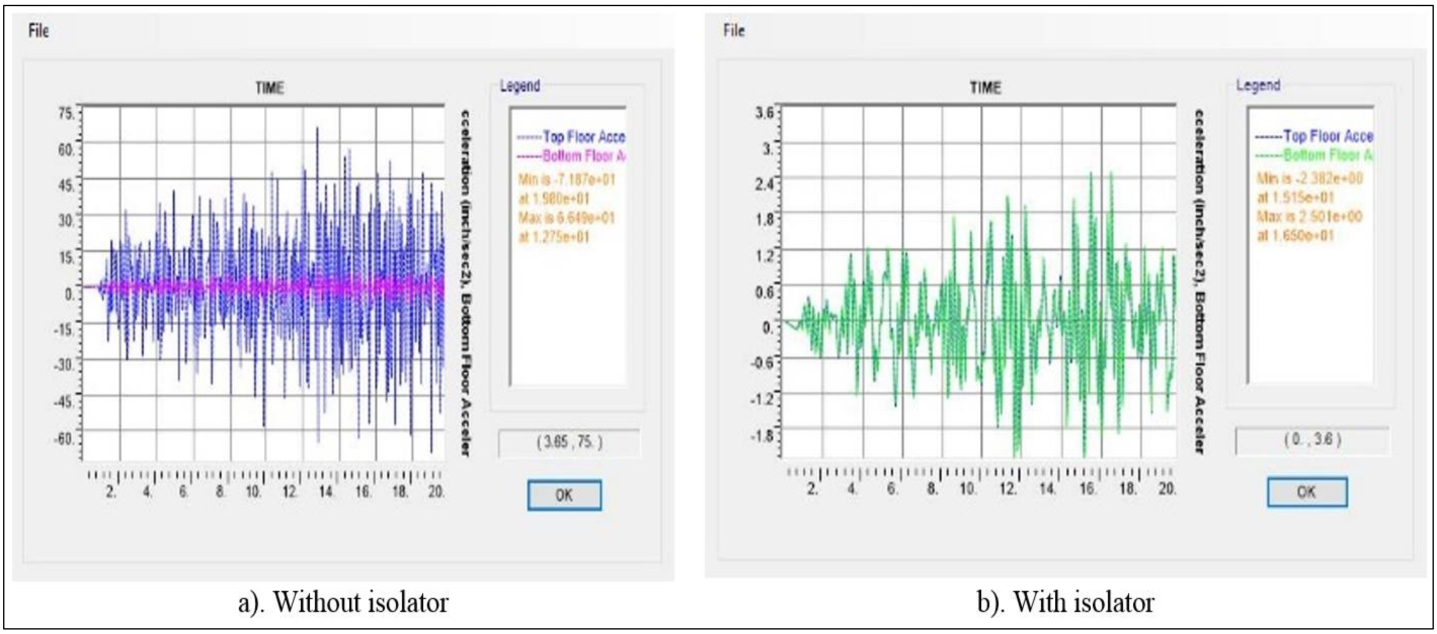
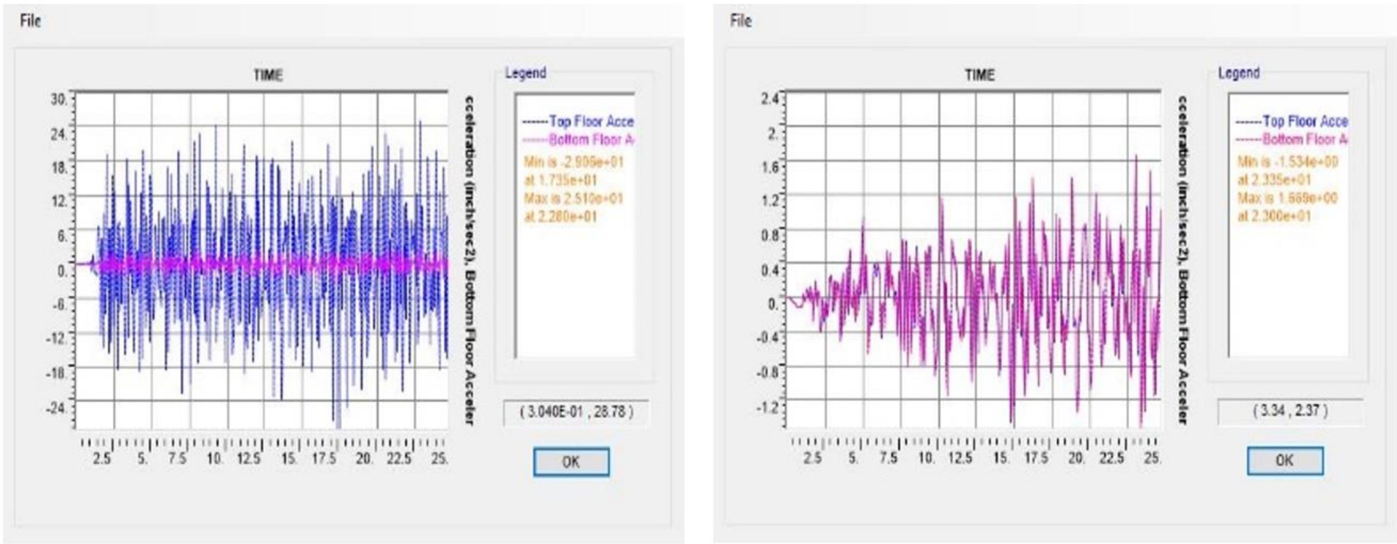


Figure 14: Top and bottom acceleration vs time curve (20 sec).
Source: Authors, (2020).



a). without isolator b). with isolator

Figure 15: Top and bottom acceleration vs time curve (25 sec).
Source: Authors, (2020).

VI. CONCLUSIONS

Numerical design of lead rubber bearing and applying lead rubbing bearing as a isolator of multi storied building in Dhaka. Development of working knowledge on SAP2000 18 and its application in the nonlinear dynamic analysis of multi storied building structures and it shows how a multi-storied building act as a base isolation building. The main comparison is among the displacements and accelerations found of the building in two condition (without base isolator and with base isolator) using SAP 2000 18 nonlinear dynamic analysis, the results show for base isolated building shows it can take more displacement than the building which is not base isolated. By comparing displacement vs time, acceleration vs time graphs for base isolated and non-isolated building, the displacement difference between top and bottom floor is almost close that indicates this building structural behavior better during earthquake load.

VII. SUGGESTIONS

Seismic isolation (SI) and the other anti-seismic (AS) systems have already been widely used in over 30 countries and their application is increasing more and more, for both new constructions and retrofits, for all kinds of structures and their materials. The features of the design rules used, as well as earthquake lessons, have plaid a key role for the success of the aforesaid technologies [10, 11]. The designers are allowed by the code to decrease the seismic forces acting on the superstructure when adopting this technology. Use this technology these things are require,

1. A reliable definition of the seismic input, i.e. by means of intensive use of Neo-deterministic seismic hazard assessment (NDSHA).
2. Careful selection, design, manufacturing, installation, protection and maintenance of the Seismic isolation (SI) devices during the entire life of the isolated structure;
3. Particular attention to be also paid to some further construction aspects (in particular, to the design, realization, protection and maintenance of the structural gaps and the safety related pipelines – e.g. the gas ones – again during the entire life of the isolated structure).

VIII. AUTHOR'S CONTRIBUTION

Conceptualization: Al Amin, Mufedul Islam.
Methodology: Al Amin, Mufedul Islam and Md. Jobaer Ahamed.
Investigation: Al Amin, Mufedul Islam and Md. Jobaer Ahamed.
Discussion of results: Al Amin, Mufedul Islam.
Writing – Original Draft: Al Amin.
Writing – Review and Editing: Al Amin, Mufedul Islam.
Resources: Mufedul Islam.
Supervision: Al Amin, Mufedul Islam and Md. Jobaer Ahamed.
Approval of the final text: Al Amin, Mufedul Islam and Md. Jobaer Ahamed.

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