Design and Analysis of Reinforced Concrete Buildings with Base Isolator

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A*bstract*-In this paper Base Isolation System and Design of Fixed Base Reinforced concrete building is studied. The codes regulations for design of the seismic reinforced concrete building used here is provided in the 2018 Turkish Earthquake Building Codes. 2 building models are compared. The first model is fixed base 7-story hospital building. The base of the first model building is fixed, without isolators. The same model is then designed with Lead Rubber Isolators. The properties of these isolators are taken from the manufacturer, Dynamic Isolation System. Using past earthquake acceleration as an example, these building are subjected to horizontal earthquake force. The 2 buildings are then analyzed with the help of Structural Analysis Program Sap2000 version 19. In the analysis, Time History method of analysis is used and the results are compared using tables and graphs. After the comparison of the results, a solution and recommendations are prepared. Finally, the type of buildings and structures where isolators should be used are mentioned together with situations where they should not be used.

Keyword- Base Isolation System; earthquake regulations; forces; Seismic Excitation

I. INTRODUCTION

Base isolation involves decoupling the structure from the ground by use of material, which has very high vertical stiffness, but have very low horizontal stiffness, hence allowing the building to move easily in horizontal direction. This concept has become reality within the last 30 years. In design of buildings, engineer's main goal is to reduce interstory drift and floor acceleration. Large interstory drift during earthquake damages structural components of the structure while large floor acceleration damages sensitive materials in the building. Large interstory drift can be reduced by making the structure rigid. However this will lead to high floor acceleration. Floor acceleration can be reduced by making the structure flexible. But this results in large interstory drift. Base Isolation reduce both interstory drift and floor acceleration at the same time. In this system all the deformation are concentrated in the isolation system with the first dynamic mode of the structure orthogonal to higher modes. This gives the structure a fundamental frequency lower than the frequency of the fixed base counterpart and that of the ground motion. Base Isolated system increases the period of the structure thus making the building rigid at the same time. In this way the direction of earthquake forces are deflected through the Dynamics of the system and their effects are reduced.

II. CHARACTERISTICS OF THE BUILDING

Reinforced concrete building with seven story and total height of 21 meters is designed first without isolators (fixed base) and Time History method of analysis is carried out. The same model is again designed with isolators between the foundation and the ground (base isolation). Each story is 3 meters high. The architectural floor plan and 3D view of the model is given in figure 1 and 2 respectively. The building model stand on a land area of 40 m x 19 m. The general properties of the model are as follows:

The type of concrete used is C35, steel is S420. The column dimensions are 80x80 cm, beams 30x60 and the slab is 15 cm thick. The model is assumed to be located in first degree seismic zone of Turkey. It is assumed that the local soil class is ZD. In the base isolation system, 24 lead rubber isolators were placed under the columns between the foundation and ground floor. The properties of the isolators are shown in table 2. Several iterations were carried before determining its maximum displacement. They are capable of making 215 mm displacement in horizontal direction.

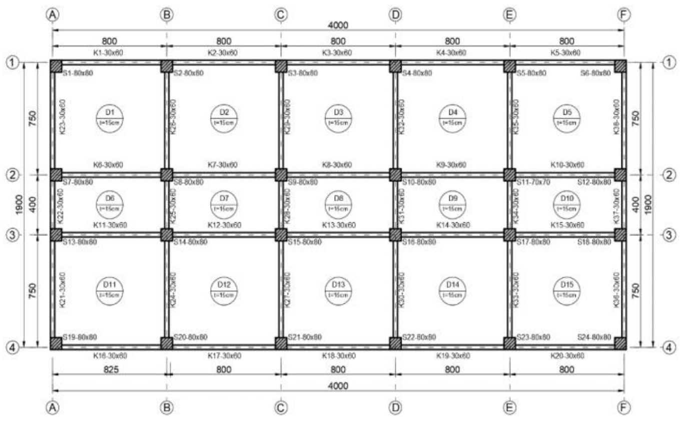

Fig. 1. Architectural floor plan of the building.

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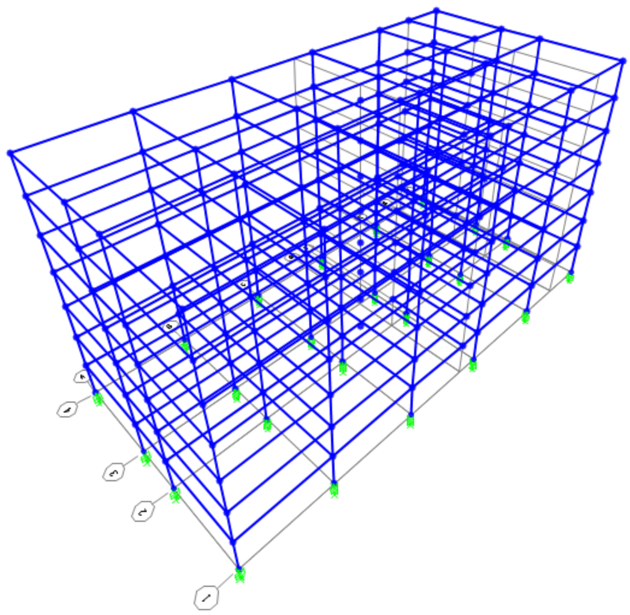

Fig. 2. Architectural 3D of the building.

III. EARTHQUAKE ACCELERATION RECORDS.

Earthquake acceleration records are shown in Table 1 and figure 3. Table 1 shows Earthquake Names, Epicentral Distance, velocities, the year of the earthquake and their magnitudes. Figure 3 shows spectra of the recorded accelerations.

Table 1. Earthquake records

No	Station	Year	Magnıtude (M)	Distance (R)	Vs30 (m/sn)
1	Imperial Valley	1979	6.53	10.45	231.23
2	Manjil	1990	7.37	63.96	348.69
3	Morgan Hill	1984	6.19	11.53	221.78
4	Landers	1992	7.28	68.66	328.09
5	Big Bear	1992	6.46	34.98	296.97
6	Hector Mine	1999	7.13	73.55	339.02
7	Chi-Chi	1999	6.20	21.62	258.89
8	Denali Alaska	1998	6.5	15.45	224.35
9	Ferndale City Hall	1982	7.5	10.55	242.65
10	Lenah Valley-6	1989	7.1	18.45	340.35
11	Amp chi	1998	6.5	25.56	300.45

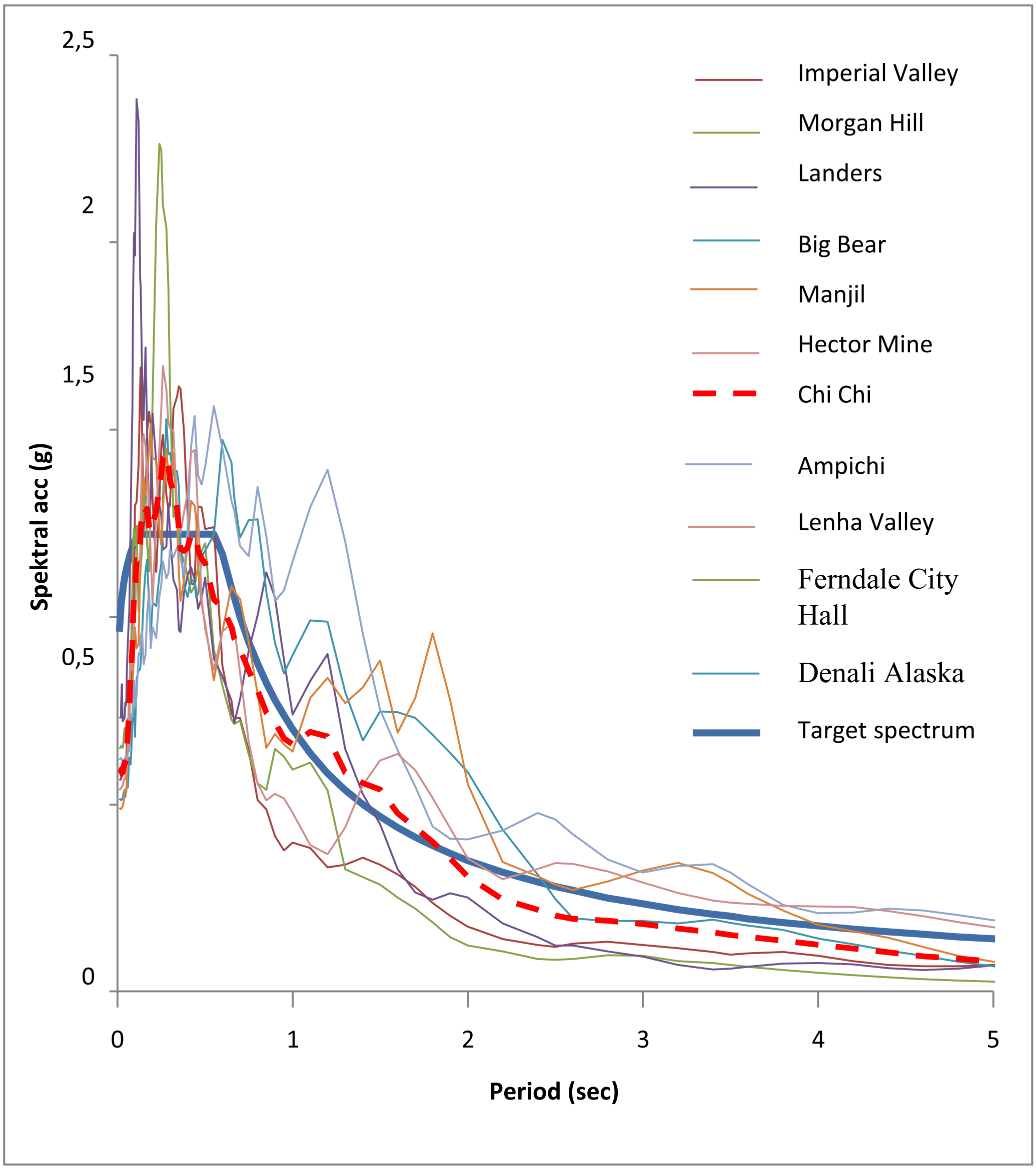

Fig. 3. Earthquake spectrum and target spectra of the earthquakes.

IV. LEAD RUBBER ISOLATOR

The type of isolator used in this paper is obtained from the manufacturer Dynamic Isolation System. The lead rubber isolator and its properties are given in Figure 4 and table 2 respectively.

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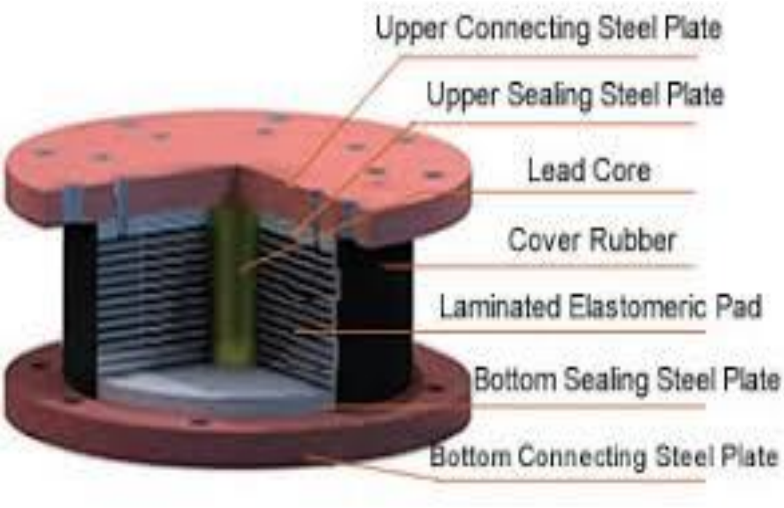

Fig. 4. Lead rubber isolator.

Table 2. Lead rubber isolator properties

Isolator property		**Unit**
Isolator diameter, B	550	Mm
Diameter of lead core, B_L	150	mm
Stiffness modulus, G_v	0.7	N/mm^2
Thickness of each layer,rubber,t	10	mm
k1/k2	10	
Strength, FQ=	126000	N
Total height of rubber layers,T_r	150	mm
Vertical stiffness, k_v	629774.7	N/mm
Horizontal stiffness		
İnelastic stiffness, k_2	1026.254	N/mm
Elastic stiffness,k_1	10262.54	N/mm
Strength ,F_0	126000	N
Effective stiffness,k_e	1553.695	N/mm

V. COMPARISON OF ANALYSIS RESULTS

The results of the analysis are given first in tables and then figures. Periods, Floor displacements, relative story drifts, floor accelerations, shear forces and moments are given in tables 3 to tables 8.
Figures 5 to figures 10 shows the corresponding periods, floor displacements, relative story drift, floor accelerations, shear forces and moments respectively.

A. Periods

Table 3. Natural periods of base isolated and fixed base building

Mode	Fixed Base	Base Isolated
1	1.43	3.03
2	0.39	0.37
3	0.18	0.17

The figure in the next page shows how the periods change with modes in both isolated and fixed base building.

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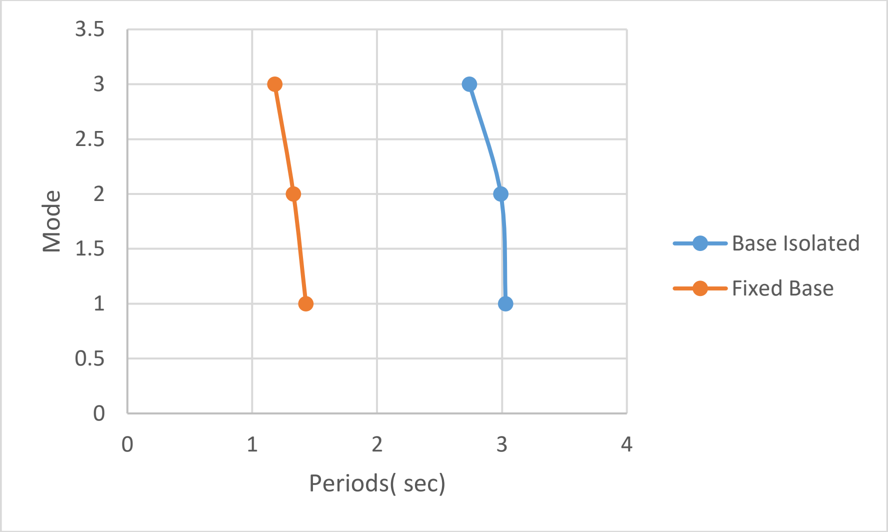

Fig. 5 Modes against periods of base isolated and fixed base building

B. Floor Displacements

Table 4. Floor displacements

Floor	Displacement of Fixed Base		Displacement of Base Isolated	
	x- direction (mm)	y-direction (mm)	x-direction (mm)	y direction (mm)
7	332	279	305	287
6	294	250	295	280
5	248	213	283	269
4	193	168	268	256
3	132	117	248	240
2	72	64	225	220
1	22	20	198	197
Base	0	0	166	169

C. *Relative Story Drift* Ratios

Table 5. Relative story drift Ratios

Floor	Relative Floor Displacements Ratios Fixed Base		Relative Floor Displacements Ratios Base Isolated	
	x-direction	y-direction	x-direction	y-direction
7	0.6529	0.5705	0.0540	0.0600
6	0.7969	0.6966	0.0684	0.0800
5	0.9330	0.8160	0.0867	0.1050
4	0.9034	0.8777	0.1065	0.1350
3	0.9675	0.8437	0.1269	0.1700
2	0.7786	0.6748	0.1479	0.2050
1	0.3403	0.2945	0.1699	0.2500

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D. *Floor Accelerations*

Table 6. Floor acceleration of base isolated and fixed base building

Floor	Floor Acceleration Fixed Base		Floor Acceleration Base Isolated	
	x direction *(m/s²)*	y direction *(m/s²)*	x direction *(m/s²)*	y direction *(m/s²)*
7	2.82436	2.907327	0.63460	0.72323
6	1.951138	2.007804	0.58770	0.62524
5	1.752025	1.863236	0.58594	0.61065
4	1.718847	1.803193	0.53075	0.54957
3	1.540011	1.699247	0.50048	0.54013
2	1.468527	1.50188	0.48225	0.50167
1	1.280447	1.152785	0.48186	0.48252
Base	0	0	0.47923	0.49073

E. Shear forces

Table 7. Shear forces of base isolated and fixed base building

Floor	Shear Forces (KN) Fixed Base	Shear Forces (KN) Base Isolated
7	9800	4120
6	16191	5718
5	23916	7649
4	32266	9736
3	41434	12028
2	51343	14506
1	61540	17055

F. Bending Moments

Table 8. Bending moments of base isolated and fixed base building

Floor	Fixed Base Moment (kN-m)	Base Isolated Moment (kN)-m
7	8521	4288
6	27188	8955
5	53232	15466
4	84104	23184
3	117839	31618
2	152764	40349
1	188359	49248

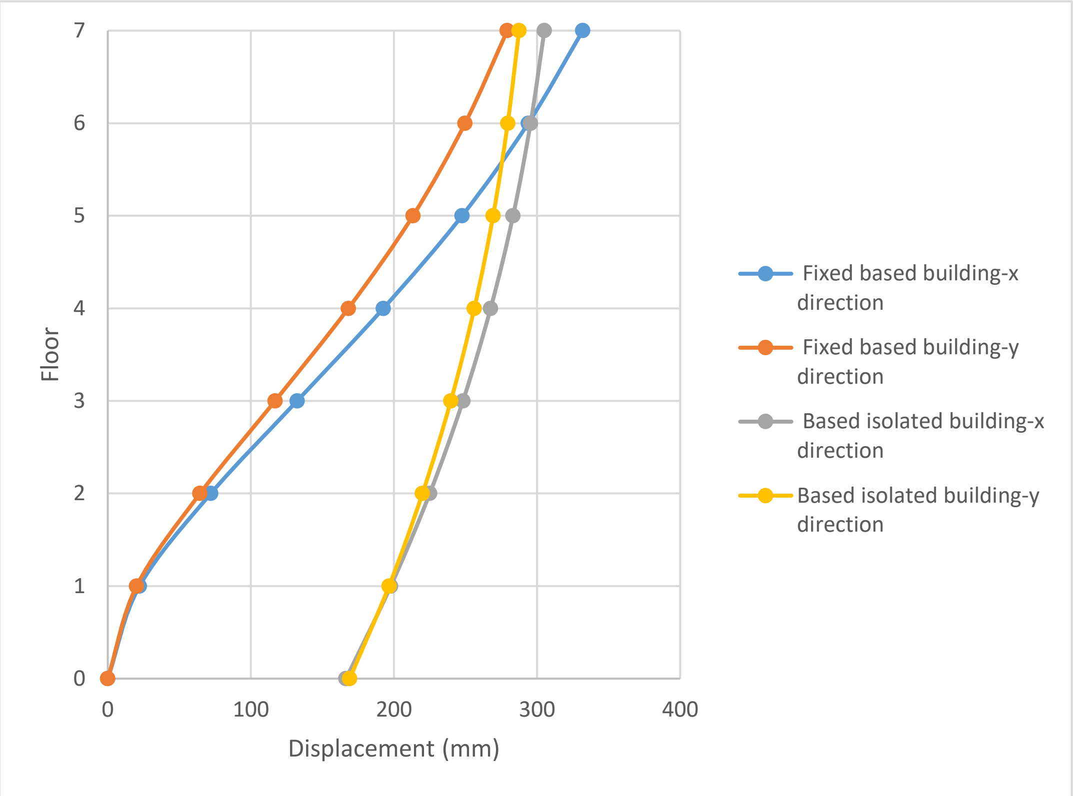

Fig. 6. Displacement (mm)

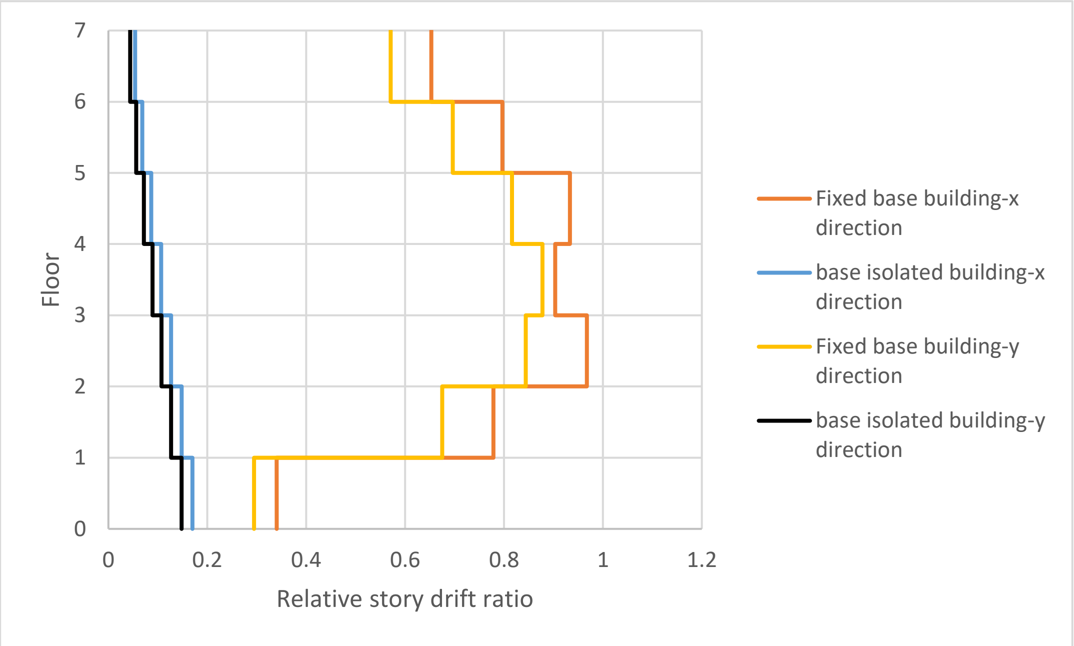

Fig. 7. Relative story drift ratios

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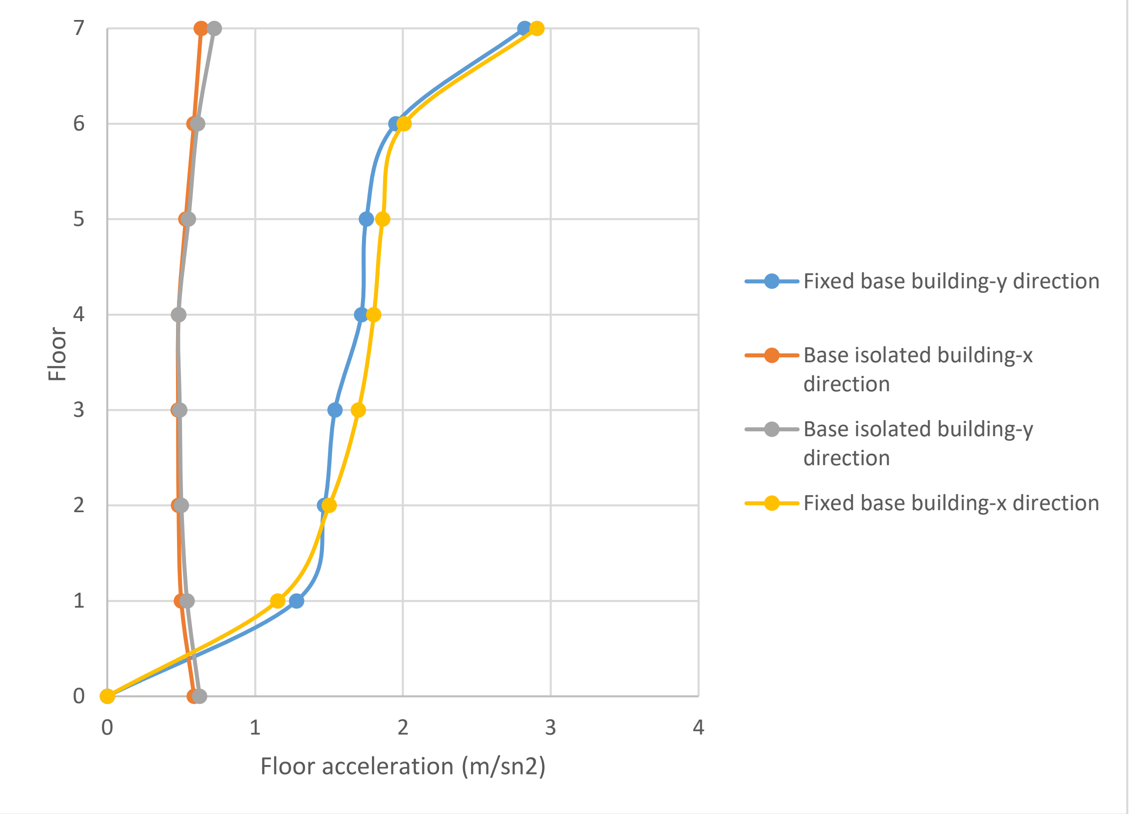

Fig. 8 Floor acceleration (m/s^2)

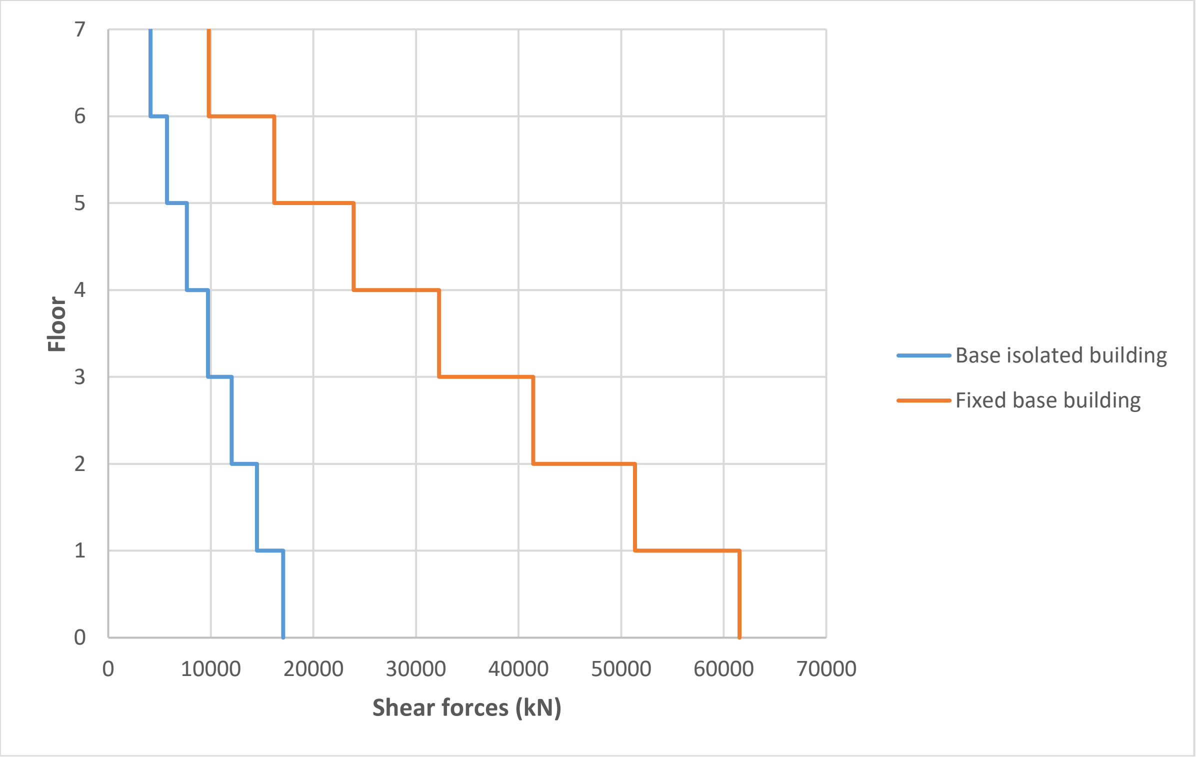

Fig. 9 Shear forces (KN)

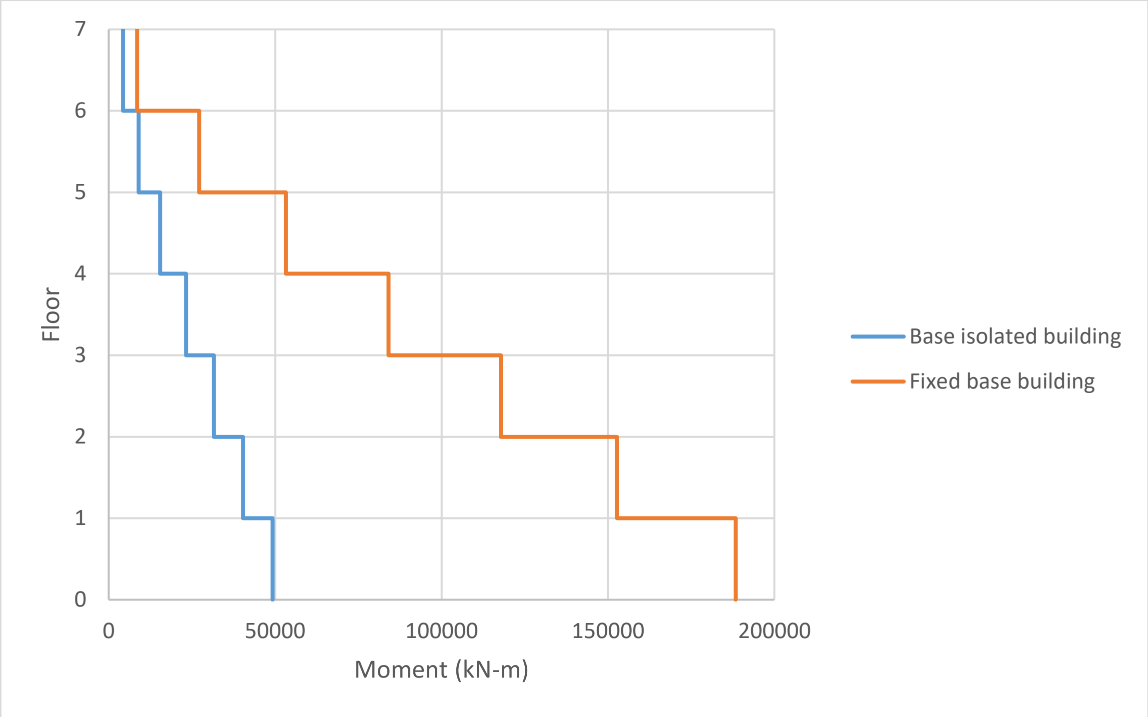

Fig. 10 Bending moment (KN-m)

VI. CONCLUSION AND RECOMMENDATIONS

In light with the analysis carried out in the paper it is observed that Base Isolated building behaves independently from its foundation. The building moves together as one rigid body as compared to fixed based building.

The periods of isolated buildings are long and therefore frequency of the vibration of the floors are reduced. Fixed base buildings are subjected to higher floor vibration because of their short periods.

The floor displacements of base isolated building are generally more than displacements of fixed base building but interstory drifts are small compared to fixed base building. Therefore, the structural elements of the base isolated building are not harmed by seismic forces.

The floor accelerations of base isolated building are low because the effect of seismic force is reduced by isolators' movements by changing the direction of seismic forces. This is important because sensitive materials in the building will not be harmed if the floor acceleration is low.

Internal forces developed in the structural elements are significantly reduced in base isolated buildings compared to high internal forces in fixed base buildings. Shear forces and bending moments are lower for base isolated buildings than its fixed base counterparts.

Based on these results, it is concluded that isolators should be used for important buildings constructed in earthquake prone regions. Fire fighter stations, communication buildings, airports, bridges, police headquarters, historical buildings, hospitals and buildings that contain important material and machines are some of the structures where base isolation system should be applied.

Base isolated buildings are approximately 5% more expensive than fixed base buildings. However, considering that it will not collapse during earthquake this expense is worth.

Base isolation system should not be applied on soft soil areas. Increasing the periods of the building will make it approach the already long period of soft ground, making isolators useless. Very tall and multistory structures and buildings whose column are subjected to high-tension forces are not appropriate for Base isolation system.

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