Design and Analysis of Reinforced Concrete Buildings with Base Isolator


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Abstract: *In this study, the behavior of the base isolation system and the classical fixed based building system were investigated. The rules taken into consideration during the design phase are taken from the 2018 Turkish Building Earthquake Code. The results of the building model which was designed in two different ways with base insulators and built-in supports, were compared. In the first model, 7-storey hospital building is designed and modeled as fixed base support. The same building is then designed with Lead Rubber Isolator. In the time-history analysis, the acceleration records of the earthquakes were performed. The results obtained from the analysis of time-history were compared in tables and graphs.*

Keywords: *Base Isolation System, earthquake regulations, forces, earthquake resistant design*

Taban İzolatörlü Betonarme Binaların Tasarımı ve Analizi

Öz: *Bu çalışmada, taban izolatör sistemi ve klasik ankastre mesnetli bina sisteminin davranışı incelenmiştir. Çalışmamızdaki bina tasarımında dikkate alınan kurallar 2018 Türk Deprem Yapı Yönetmeliğinden alınmıştır. Çalışmada, taban izolatörlü ve ankastre mesnetli olmak üzere iki farklı şekilde tasarlanan bina modeline ait sonuçlar karşılaştırılmıştır. İlk modelde, örnek olarak tasarlanan 7 katlı hastane binası ankastre mesnetli olarak modellenmiştir. Aynı model daha sonra kurşun kauçuk izolatör ile tasarlanmıştır. Daha önce meydana gelmiş depremlere ait deprem ivme kayıtları kullanılarak zaman tanım alanında analizler yapılmıştır. Zaman tanım alanında analizden elde edilen sonuçlar tablo ve grafiklerle karşılaştırılmıştır.*

Anahtar kelimeler: *Deprem izolasyonu, deprem yönetmeliği, depreme dayanıklı tasarım*

1. INTRODUCTION

In the earthquake prone areas, base isolation technique is one of the alternative methods for reducing losses. Base isolation involves decoupling the structure from the ground by use of a material, which has very high vertical stiffness but relatively low horizontal stiffness thus allowing the building to move easily in horizontal direction. This concept has become reality within the last 30 years.

A civil engineer's main goal in seismic design of buildings is to limit inter-story drift and floor acceleration. While a large floor acceleration may damage nonstructural components in the building, a large interstory drift during an earthquake causes damages in the structural components of the building. The interstory drift can be reduced by designing a more rigid structural system. However, this will lead to a high floor acceleration. Base isolation technique may reduce both interstory drift and floor acceleration at the same time. In this system, all the deformation is concentrated in the isolation system with the first dynamic mode of the structure. By this way, fundamental period of the building is shifted longer than the fixed base counterpart and that of the ground motion. At the same time, the direction of the earthquake forces are deflected through the dynamics of the system and their effects are reduced.

In the present paper, the seismic response of a base isolated and fixed base reinforced concrete building is investigated.

2. SEISMIC ISOLATION

Seismic isolation application is one of the important and new technological design methods developed by the structural engineers, aiming to reduce the earthquake forces that will affect the superstructure and thus protect the important structures such as hospitals, bridges, viaducts and energy structures that are required to be used immediately after an earthquake.

Base isolation method involves the principle of allowing the transfer of some part of the motion energy reaching the foundation of the structure with the ground shaking during the earthquake to the superstructure system. In general, this is done by means of advanced technology devices placed between the basic system of the structure and the superstructure. Although the theoretical knowledge of the method is quite old, the techniques related to its implementation are still in development stage. However, especially in recent years, applications for this type of construction method have gained momentum in the developed countries of the world. Though very few, some theoretical research and practical applications are also available in Turkey [1,2,3,4,5].

In summary, seismic isolation application technique and working principles are as follows: the structure is separated from the horizontal components of the earthquakes movement by placing an insulated high lateral rigidity isolator between the foundation and the superstructure. The base isolator unit having low horizontal stiffness, makes a large displacement in the horizontal direction and the earthquake energy is largely damped here. The superstructure moves in block form, however the displacement that occurs therein remains in the permissible limits.

Base isolation systems are divided into two main groups: rubber bearing and sliding bearing systems. The multilayer rubber-based base isolation systems are used all around the world. This system consists of steel plates as well as rubber elements and is generally in the form of layers. These systems are manufactured to provide the horizontal direction damping and vertical direction stiffness at the same time. Rubber materials have flexible behavior and great damping properties. Typical section of rubber bearing is shown in Figure 1.

The friction pendulum system is an improved friction seismic isolation technology to improve the seismic isolation resistance of structures. The friction pendulum isolator has a sliding material on the spherical surface made of non-corrosive steel. The part of the jointed slide contacting the spherical surface is covered by a low friction composite material. When the slide moves on the spherical surface, it increases the load being transported and provides a return force to the system. In this system, energy consumption is caused by the friction between the articulated sliding and the spherical surface. Typical view of sliding bearing is shown in Figure 2.

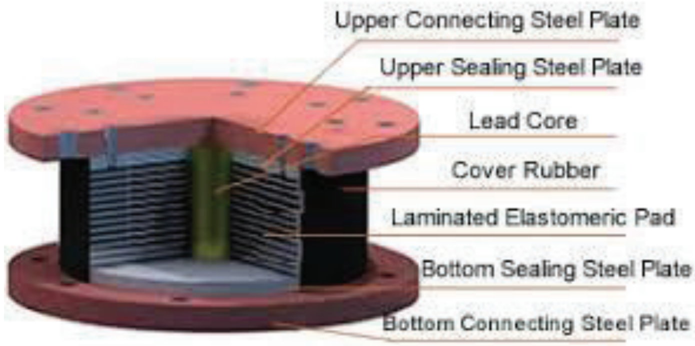


Figure 1. Rubber bearing [6]

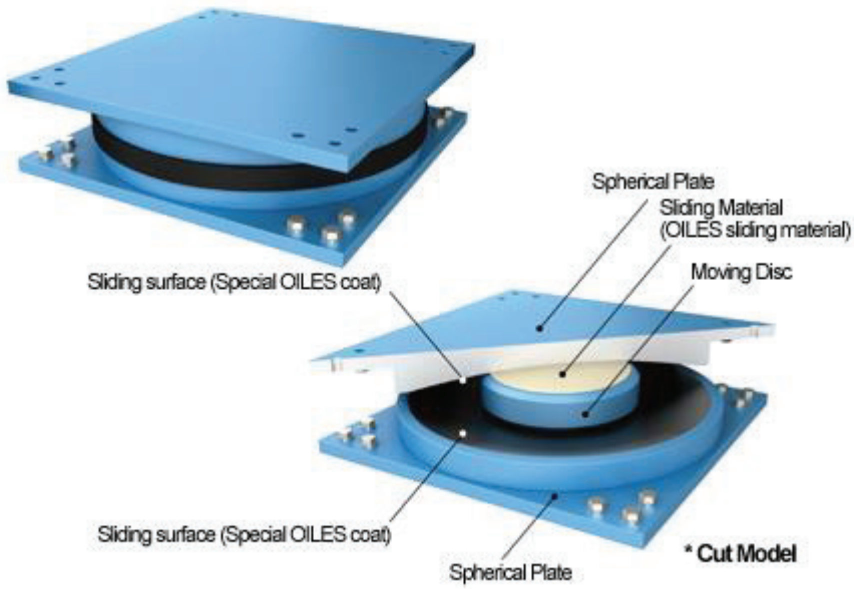


Figure 2. Sliding bearing [7]

Current study investigates the effect of buildings on earthquake behavior by using a rubber base isolator system.

3. CHARACTERISTICS OF THE BUILDING

In this study, the effects of base isolators on the behavior of a building were investigated. A reinforced concrete building with seven floors with a total height of 21 meters was first designed without isolators (fixed base) and time-history analysis was carried out. The same model was designed again with rubber isolators between the foundation and the ground (base isolation), where each floor was 3 meters high. The architectural floor plan and 3D view of the model is given in figures 3 and 4 respectively. The building model stands on an area of 40 m x 19 m. The general properties of the model are as follows:

- The type of used concrete 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.

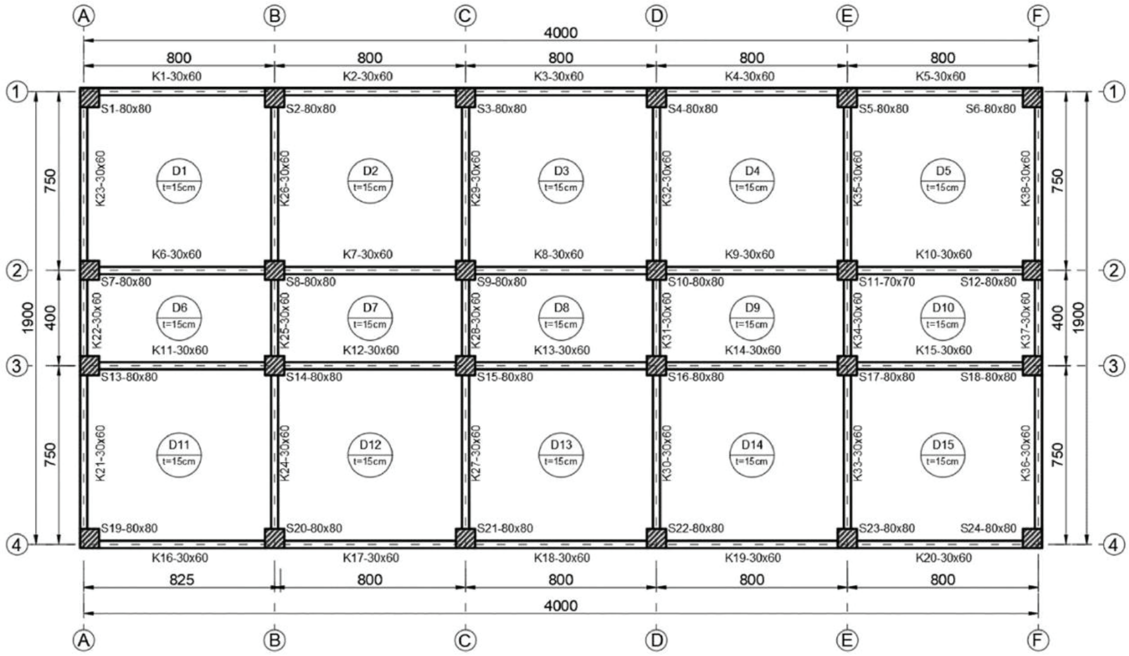


Figure 3. Floor plan of the building

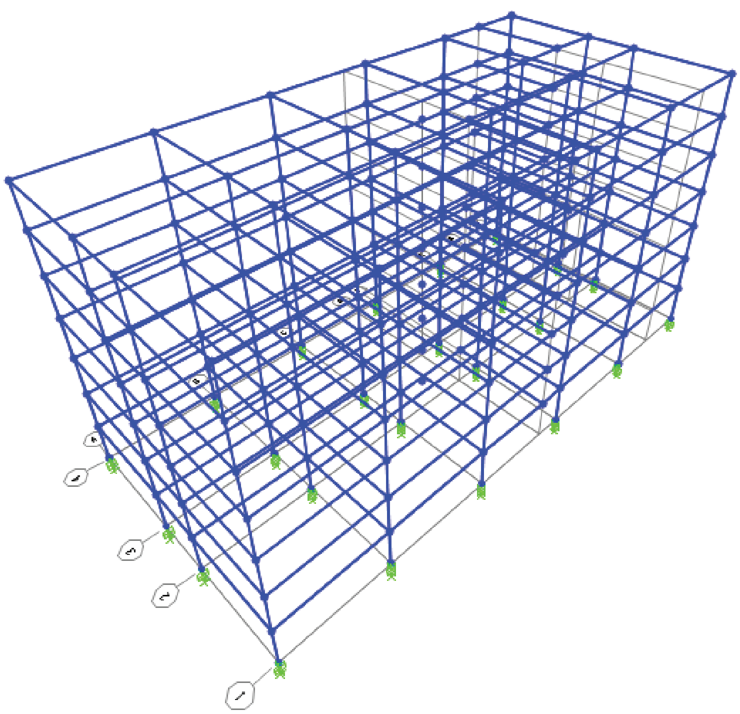


Figure 4. 3D Analysis model of the building

2. EARTHQUAKE ACCELERATION RECORDS

The earthquake acceleration records used in time-history analysis are shown in Table 1 and Figure 5. Table 1 shows the names of the earthquakes, epicentral distance, shear velocities of soil, the years of the earthquakes and their magnitudes. Figure 3 shows spectra of the recorded accelerations.

Table 1. Selected earthquake records

No	Station	Year	Magnitude (M)	Distance (R)	V_{s30} (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

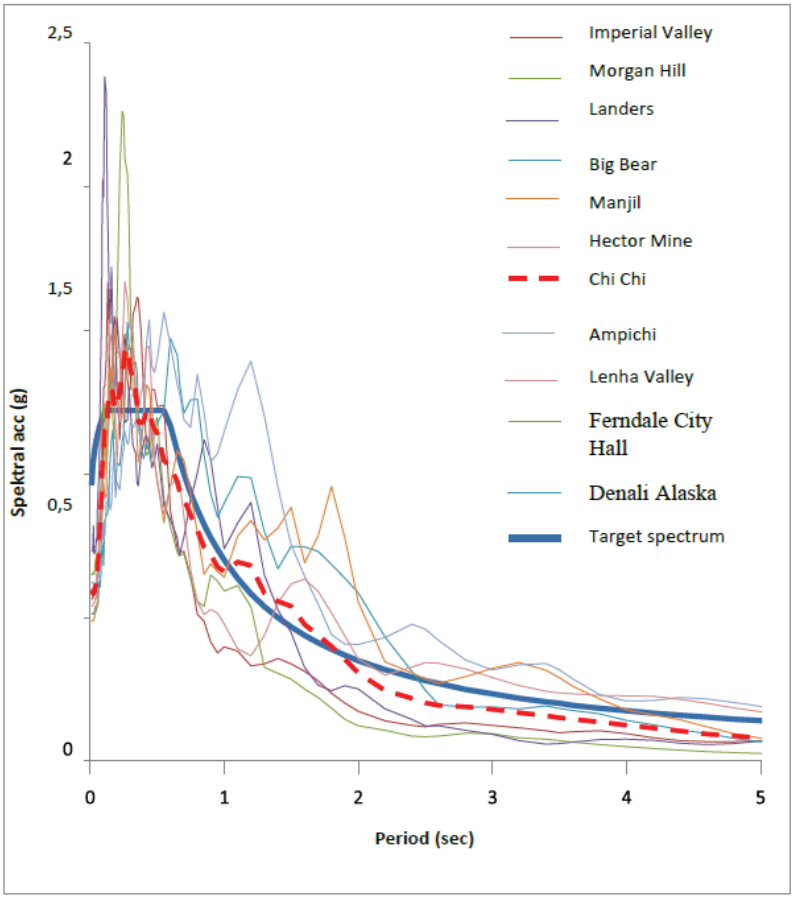


Figure 5. Earthquake spectrum and target spectra of the earthquakes

3. LEAD RUBBER ISOLATOR PROPERTIES

The type of the isolator used in this paper was obtained from the manufacturer Dynamic Isolation System [8]. The properties of the isolators are shown in Table 2. Several iterations were carried before determining the maximum displacement. They are capable of making 215 mm displacement in the horizontal direction.

Table 2. Lead rubber isolator properties

Lead Rubber Isolator	Value	
Isolator diameter, B	550	mm
Diameter of lead core, BL	150	mm
Stiffness modulus, Gv	0.7	N/mm^2
Thickness of each layer,rubber,t	10	mm
Strength, FQ=	126000	N
Total height of rubber layers,Tr	150	mm
Vertical stiffness, kv	629774.7	N/mm
İnelastic stiffness, k2	1026.254	N/mm
Elastic stiffness,k1	10262.54	N/mm
Strength ,FQ	126000	N
Effective stiffness,ke	1553.695	N/mm

4. COMPARISON OF ANALYSIS RESULTS

In the first phase, the building was designed as fixed supports and then as base isolator. The results of the analysis are given in tables and figures. Period, floor displacement, inter-story drift, floor acceleration values obtained from both analyzes were compared.

4.1 COMPARISON OF PERIODS

As a result of the analyses, it was seen that the periods of the base isolated building were longer than the fixed bearing building periods. In particular, the first period of the building was determined to be about 2 times higher (Fig. 6).

4.3 COMPARISON OF FLOOR DISPLACEMETS

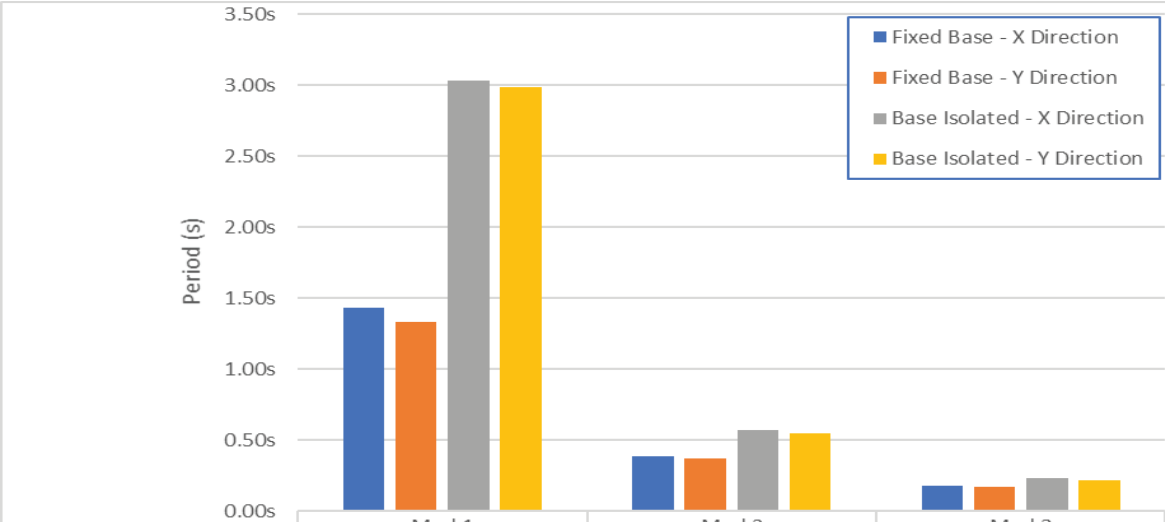
In the examined building, it was observed that the building with fixed bearing made less relative displacement than the isolated building in general. It is understood that the biggest displacements in the two buildings occur on the top floors, and the earthquake effect on these floors is great. It was determined that the biggest displacement in the isolated building was at the base level where the base isolator was placed (Fig. 7).

4.4 COMPARISON OF INTER-STORY DRIFT RATIO

When inter-story drift ratios are examined, these values are very low in the top floors of the base isolated building compared to the fixed base building. Therefore, the earthquake damage to the structural elements of the building with base isolation is expected to be minimal. Due to the inter-story drift ratios in the fixed base building, great damage may occur in the structural elements. The base isolation system has allowed the building to be rigid. As a result, inter-story drift ratios are very low in this building (Fig. 8).

4.5 COMPARISON OF FLOOR ACCELERATIONS

Reducing floor accelerations is important to prevent damage to items and valuable equipment inside the building. As seen from the results, the floor accelerations of the base isolated building are very low compared to the fixed supported building. In the building with base isolator, the acceleration value of the top floor was 4 times lower in the x and y direction than the fixed supported. Since the effects of earthquakes are accelerated in the building with base isolator, the damages in the equipment in the building can be prevented (Fig. 9).



	Mod 1	Mod 2	Mod 3
Fixed Base - X Direction	1.43s	0.39s	0.18s
Fixed Base - Y Direction	1.33s	0.37s	0.17s
Base Isolated - X Direction	3.03s	0.57s	0.23s
Base Isolated - Y Direction	2.99s	0.55s	0.22s

Figure 6. Comparison of periods of building

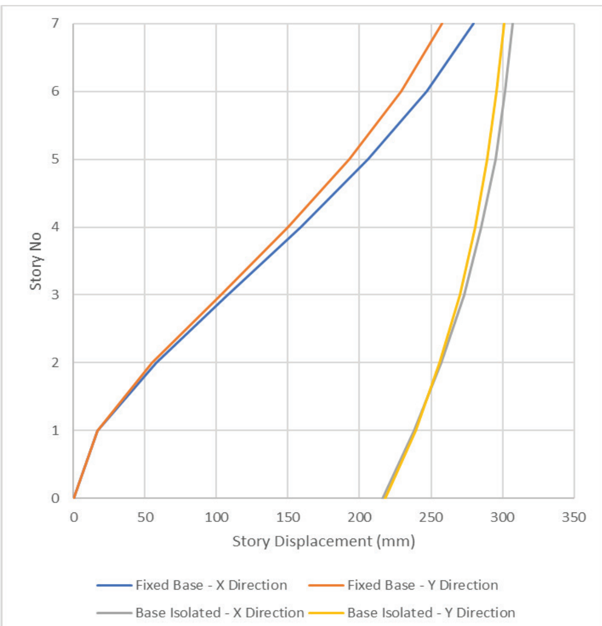


Figure 7. Comparison of floor displacements

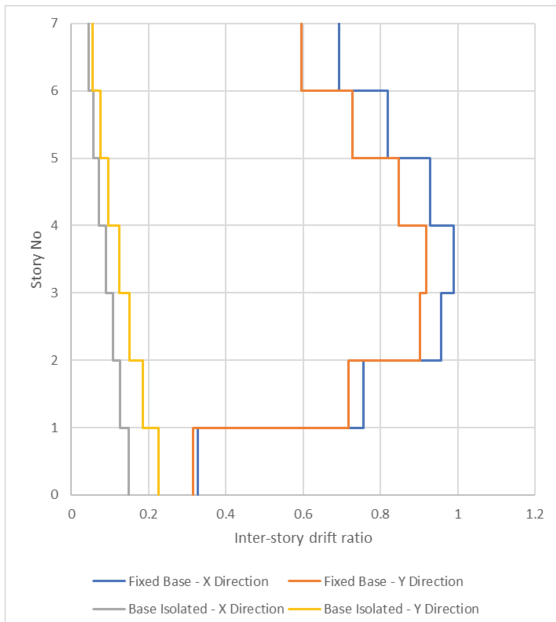


Figure 8. Comparison of inter-story drift ratio

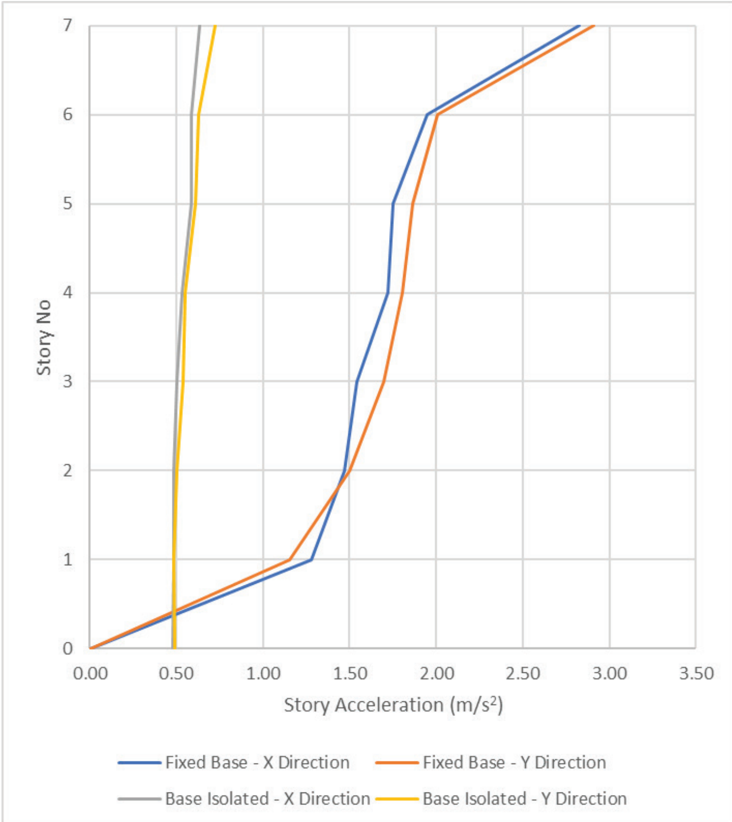


Figure 9. Comparison of story acceleration

4. CONCLUSION

In light of the analyses 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 different from the fixed based building.

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

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

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

Based on these results, it is concluded that the isolators should be used in the construction of important buildings such as fire fighter stations, communication buildings, airports, bridges, police headquarters, historical buildings, hospitals and buildings that contain important material and machines, which are located in earthquake prone regions.

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