Analysis and Design of Reinforced Concrete Structures with Spring Base Isolation

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Abstract

In the study, analysis and design of four storey reinforced concrete building and it's isolations which is located in seismic zone 4.Then comparison of analysis results between fixed base condition and isolated condition of the building due to multi direction earthquake motions such as horizontal and vertical earthquake. Firstly, static analysis is used for fixed base condition due to gravity unfactored load to design the helical spring. Secondly spectrum analysis is only utilized for horizontal earthquake and time history analysis is used for both horizontal earthquake and vertical earthquake respectively. Finally, comparison of the analysis results such as forces, displacements, drifts, accelerations and shear at various levels of building are presented. The static period of fixed base is 0.4 sec. According to the base isolated concept, base isolated period is lengthened to 0.8 sec, 1 sec and 1.2sec for design earthquake level. The results which are especially compared to base isolated (1.2 sec) and fixed base building show that the displacements of base isolated is more than fixed base building but other seismic response such as acceleration of base isolated is significantly reduced compared to fixed base as well as base isolated building has capacity for reducing of member force of the structure with fixed base building.

1. INTRODUCTION

Myanmar lay in earthquake-prone region of the world and also most of the cities in the country are located in high seismic regions that the structures in this area would be subjected to environmental impact loads. If some of the building structures are built in high seismic regions, earthquake loading is considered the most significant and possibly the most destructive external load, particularly for low to medium rise buildings. Conventionally, seismic design of buildings is based on the concept of increasing the resistance capacity of the structures against earthquake by employing shear walls, braced frames or moment resisting frames. However, these methods of resistance often results in high floor accelerations for stiff buildings, or large inter-story drift for flexible building.

Modern buildings contain extremely sensitive and costly equipments that have become vital. In addition, hospitals, communications and emergency centers, police stations and fire stations must be operational when needed most, religious structures in our country in order to protect from damage, immediately after an earthquake. Therefore, special techniques are required to design building such that remain practically undamaged even in a serve earthquake. Two basic technologic are used to protect buildings from damaging earthquake effects. There are Base isolation Device and Seismic Damper.

Seismic isolation consist essentially the installation of mechanisms which decouples the buildings, and/or its content, from partially damaging earthquake induces ground or support motions. This decoupling is achieved by increasing the flexibility of the system, together with providing appropriate damping to resist the amplitude of the motion caused by the earthquake. The advantage of seismic isolation includes the ability to significantly reduce structural and non-structural damage, to enhance the safety of the building contents, and to reduce seismic design forces. This potential benefits are greatest for stiff structures fixed rigidly to the ground such as low and medium rise building, nuclear power plants, bridges etc.

Generally, horizontal inertia forces cause the most damage to a structure during an earthquake. Since the magnitude of the vertical ground acceleration components is usually less than the horizontal ground acceleration component, vertical seismic loads are not considered in the design of most structures. However, recent observation and analysis of earthquake ground motion have shown that the vertical motion in structure should be completely ignored. Researchers compiled records and photographs of damage and failures of building and bridges due to vertical motion. Damage from Kalamata, Greece (1986), Northridge, CA(1997), and Japan (1995) due to purely vertical effects is reported.

The vertical motion in the structure is crucial. The uplift from the vertical motion may cause loss of contact followed by impact, which is likely to lead higher mode response and large axial force on column. Existing building bearings included elastrometric bearings and lead rubber bearings among others are designed to only isolation in the horizontal plane. For instance, in some case, using only horizontal isolation may provide sufficient protection against an earthquake. However, in certain other cases, where vertical ground acceleration is significant, a multi-directional isolation system, which possibly employs helical spring may be required.

This study involves novel building bearing consist of helical spring to achieve a multi-directional seismic isolation system, which also provides controlled flexibility in the vertical direction. In the proposed configuration of the isolated building, the whole building system can be considered to be floating on the helical spring bearing. Helical springs, which have both vertical and shear stiffness, are designed to support vertical loads, including self-weight of the building, providing mechanism to accommodate moment in all directions. To protect the building from damage by earthquake in multi directions, helical spring are installed at the base of the building. The used helical spring isolation that is expected to provide an effective flexible seismic isolation that reduces the response of the system. From a numerical analysis study, how response of the building with proposed isolation system under multi-direction earthquakes is then presented followed by the conclusion.

2. AIM AND OBJECTIVES

[1] To reduce seismic response of the case study building.
[2] To introduce the helical spring base isolation system.
[3] To study the dynamic behavior of building supported on base isolator system.
[4] To compare results of seismic responses between fixed base building and base isolated building.

3. BUILDING CONFIGURATION OF CASE STUDY BUILDING

The case study building is a four story reinforced concrete building with an overall height of 40 ft. Each story height is 9 ft high. The building is rectangular in shape and is 52 ft long by 35 ft wide. Fig.1 is shown the plan and 3-D model of case study building is seen in figure2.

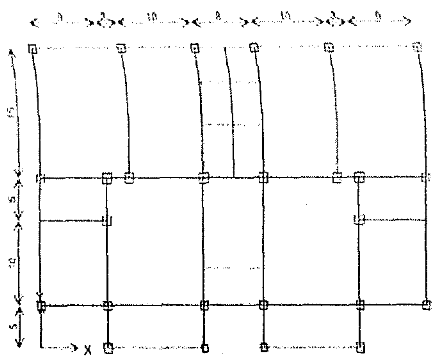

Figure 1: Plan View of Case Study Building

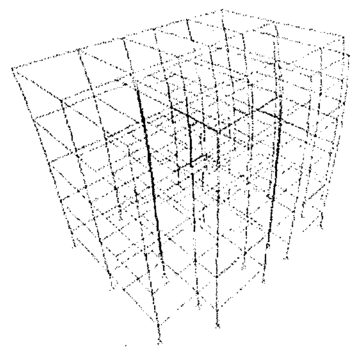

Figure 2: 3D View of Case Study Building

4. DESIGN CODE

The case study building was designed according to the load requirements in the UBC 97 and FEMA 451 NEHRP provision 2003. The design of structural components was carried out according to the provision of the American Concrete Institute (ACI) Building Code Requirement for Reinforced concrete, ACI 318-99.

5. LOADING

The self weigh of reinforced was assumed to be 150 plf , wall weight loading of 100 psf , partition weight loading of 50 psf , finished weight loading of 10 psf was considered. The roof load was to be 20 psf, 40 psf for floor areas and 100 psf for stair floor areas were applied to the case study building.

6. LOAD COMBINATION FOR CASE STUDY BUILDING

Q_{EX} or Q_{EY} (site specific)

$Q_E = \text{Max} \left(1\, Q_{EX} + 0.3\ Q_{EY}\ ,\ 0.3\ Q_{EX} + 1\, Q_{EY} \right)$

$E = Q_E \pm 0.2\ D$

$E = Q_E \pm 0.3\ D$

$U = 1.2\ D + 1.6\ L$

$U = 1.4\ D + 0.5L + 0.5\ Q_E$

$U = 0.7\ D - 0.5\ Q_E$

$U = 1.4\ D + 0.5\ L + Q_E$

$U = 0.7\ D - Q_E$

$U = 1.5\ D + 1.0\ L + Q_E \pm 0.3\ D$

$U = 0.8\ D - \left[Q_E \pm 0.3D \right]$

7. DESIGN PROCEDURE FOR HELICAL SPRING

The design procedures of helical spring are as follow.

1. The effective horizontal stiffness of the isolator is $K_{eff} = \dfrac{W}{g} \times \dfrac{(2\ )^2}{T_D^{\ 2}}$

2. The Design Displacement D_D is $D_D = \dfrac{g}{4\ ^2} \dfrac{S_{D1} T_D}{B_D}$

3. Selecting the material properties, including Young's modulus E and shear modulus G, from the manufacturer's test report.

4. Selecting the wire diameter (d), number of active coils (N_a), free length (L_o) compared length of helical (h_s), deflection (δ) and mean coil diameter (D_m) depending on axial load on each bearing.

5. The deflection (δ) for each helical spring is $\delta = \dfrac{8 P D_m^{\ 3} N_a}{G d^4}$

6. The vertical stiffness of helical spring is $K_v = \dfrac{G d^4}{8 D^3 N_a}$

7. The horizontal stiffness of helical spring is $K_H = \dfrac{10^4 d^4}{C_1 N_a D (0.204 h_s^2 + 0.265 D^2)}$

8. Total vertical stiffness for helical spring is $K_{V(total)} = K_1 + K_2 + K_3 + ...$

9. The required number of helical spring under each bearing is

$$\frac{\text{Number of helical load on each bearing}}{\text{Spring under each bearing}}$$

10.The total horizontal stiffness under each bearing is

$K_{H(total)} = K_H$ x Total number of helical spring each bearing

8. DESIGN CALCULATION FOR HELICAL SPRING BEARING

The detail design calculation of base isolations for various target period are omitted here and final design parameters are seen following table and also the design results systems are shown below along with their cross-sectional detail in figure 3.

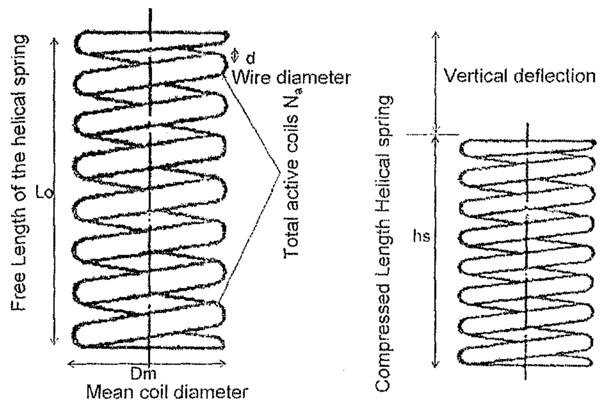

Figure 3: Cross- Section of Helical Spring Bearing System

Table 1: Design Parameters of Helical Spring for Various Target Period

Name	Symbols	Unit	Target Period		
	T_D	sec	0.8	1	1.2
Wire diameter	d	inches	1.5	1.5	1.5
Mean diameter	D	inches	4.5	4.5	4.5
Shear modulus of helical spring	G	Ksi	11598	11598	11598
Modulus of elasticity	E	Ksi	30023	30023	30023
Number of active coils	Na	nos	8	8	8

Number of total coils	Nt	nos	10	10	10
Vertical stiffness of each helical spring	K_V	Kip/ in	10.067	10.067	10.067
Free length of helical spring	Lo	inches	15.3	15.3	17.1
Maximum deflection of helical spring		inches	2.295	3.06	2.565
Compressed length of helical spring	h_s	inches	13.005	12.24	14.535
Horizontal stiffness of helical spring	K_H	Kip/ in	1.479	1.095	0.8112
Moment stiffness of helical spring	K_h	Kip-in	460.48	460.48	460.48
Horizontal stiffness of isolator group I	K_H	Kip/ in	5.918	4.37	3.271
Horizontal stiffness of isolator group II	K_H	Kip/ in	8.877	6.567	4.86
Horizontal stiffness of isolator group III	K_H	Kip/ in	11.836	8.756	6.49
Horizontal stiffness of isolator group IV	K_H	Kip/ in	14.796	10.945	8.11
Horizontal stiffness of isolator group V	K_H	Kip/ in	23.673	15.513	12.98

9. RESULTS FOR CASE STUDY BUILDING

9.1. Comparison Results from Response Spectrum Analysis

9.1.1. Story Acceleration Comparison

When the roof level acceleration for X direction in X direction earthquake of the base isolated building is observed 0.36g, the fixed base building has 0.71g. Therefore, the story acceleration at the roof of the isolated building is reduced to 49.23% of the fixed base building that is shown in figure 4.

9.1.2. Story Shear Comparison

The base shear value for fix base building is 261.49 kips and the base shear for 1.2 sec base isolated building with the helical spring system is 208.45 kips for X direction in X direction earthquake .It has been observed that the base shear for base isolated building is reduced to

20.28 % of the fixed base building, which is shown in figure.5.

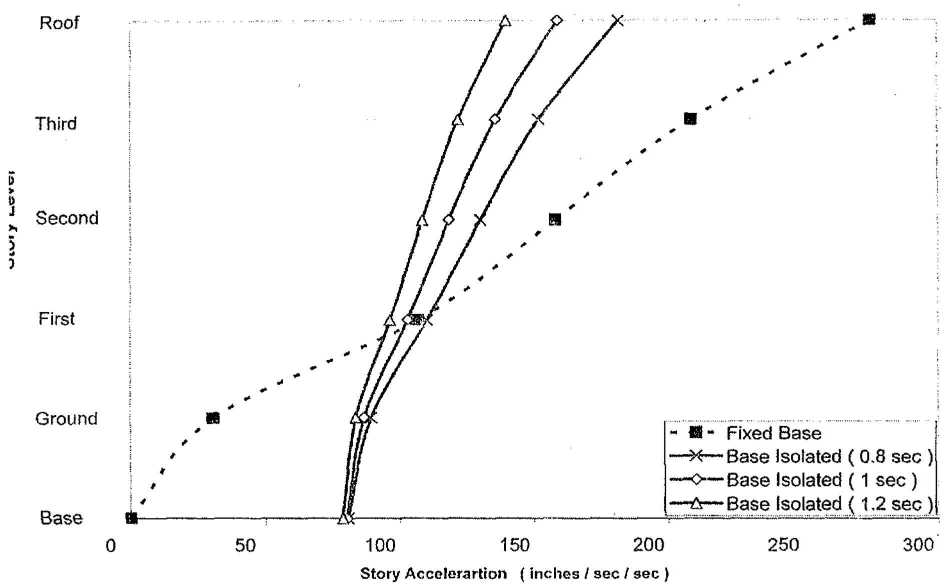

Figure 4 : COMPARISON OF STORY ACCELERATION ON FIXED BASE AND BASE ISOLATED

(0.8SEC, 1SEC AND 1.2SEC) FOR X DIRECTION DUE TO X DIRECTION EARTHQUAKE

9.1.3. Story Displacement Comparison

It has been observed that the displacement at roof of 1.2 sec base isolated building which is increased to 2.69 time for X direction of fixed base building due to X direction earthquake is greater compared to fixed base building as shown in fig.6.

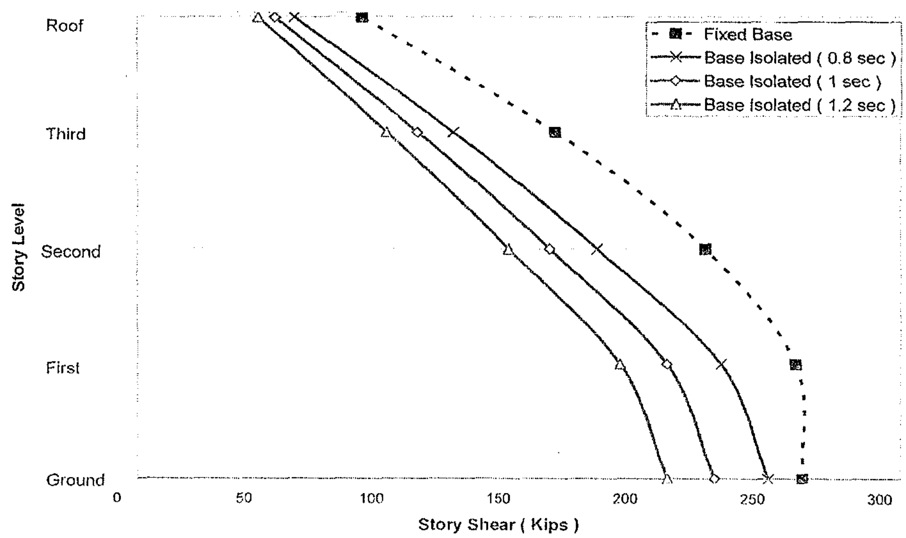

Figure 5: Comparison of Story Shear on Fixed Base and Base Isolated

(0.8 SEC , 1 SEC AND 1.2 SEC) FOR X DIRECTION DUE TO X DIRECTION EARTHQUAKE

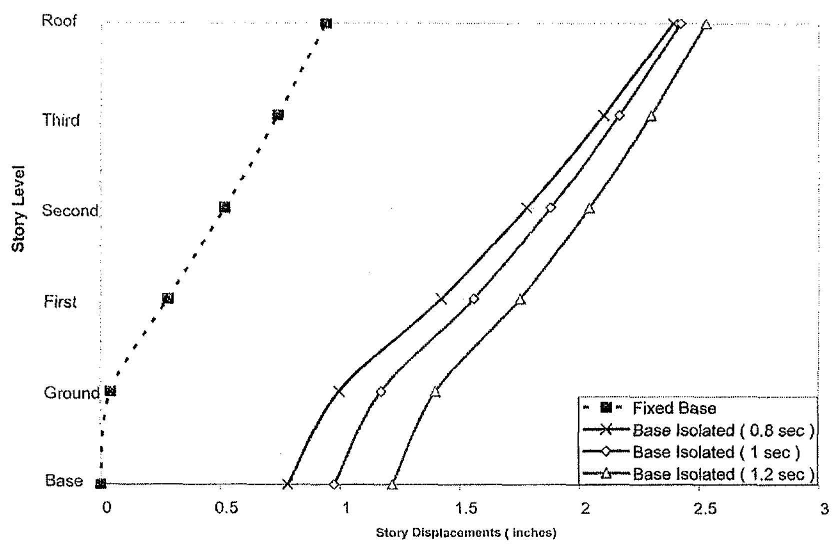

Figure 6 : Comparison of Story Displacement on Fixed Base and Base Isolated (0.8 sec , 1 sec and 1.2 sec) for X direction due to X direction Earthquake

9.1.4. Story Drift Comparison

The story drifts has been observed using response spectrum analysis that the story drift in base isolated building is higher than fixed base building. Fig.7. below show the story drift base isolated building with helical spring system compared with fixed base building due to X direction earthquake.

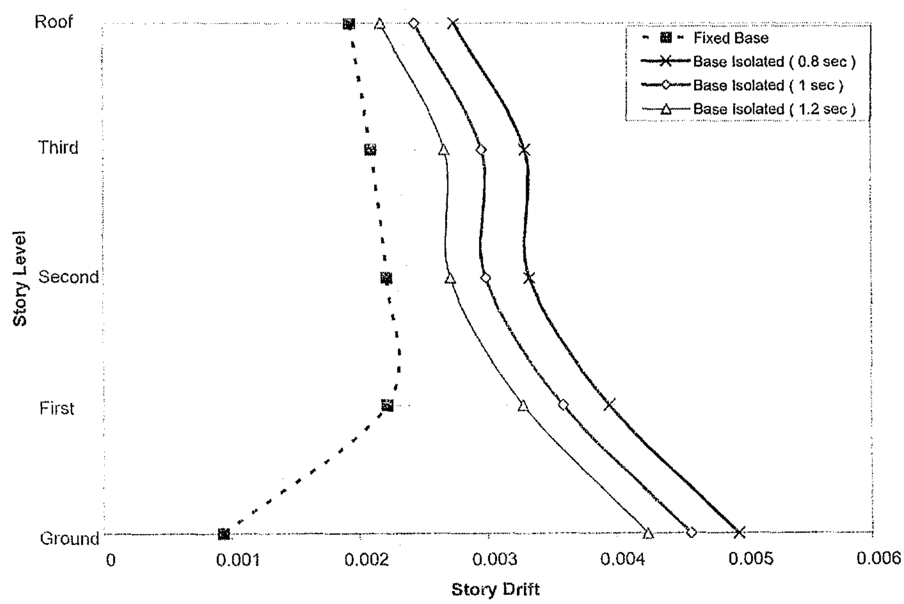

Figure 7 : Comparison of Story Drift on Fixed Base and Base Isolated (0.8sec, 1 sec and 1.2 sec) for X direction due to X direction Earthquake

9.2. Comparison Results from Time History Analysis

9.2.1. Horizontal Response of Case study Building due to Horizontal Earthquake

9.2.1.1. Comparison of story acceleration

The story acceleration from time history analysis for the case study building with 1.2 sec base isolation is reduced to 2.89 times at roof for X direction story acceleration of the original building due to X direction earthquake as seen in figure 8.

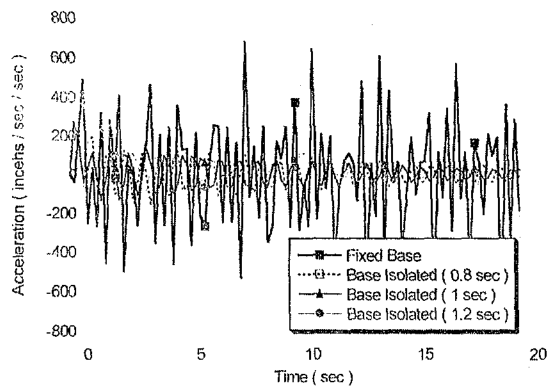

Figure 8 : Comparison of Story Acceleration in X direction at Roof Level of Case Study Building due to LACC Northridge X direction Earthquake

9.2.1.2. Comparison of story displacement

The results from time history analysis were compared between fixed base and base isolated building, the displacement values at various level of the base isolated building is greater than the fixed base building displacements because of contrary to reduction the accelerations along the height of the case study building as seen in fig.9.

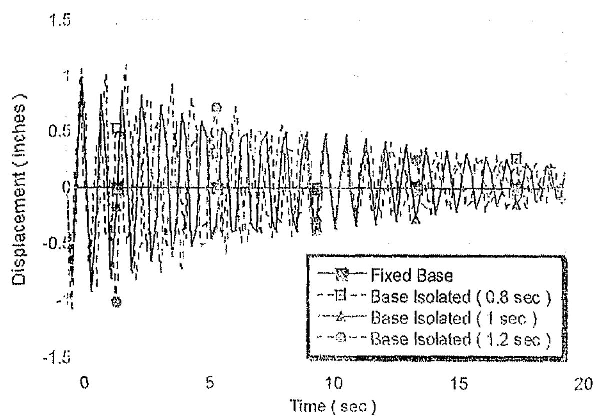

Figure 9 : Comparison of Story Displacement in X direction at Base Level of Building due to LACC Northridge X direction Earthquake

9.2.1.3. Comparison of base shear

The comparison of base shear between fixed base and base isolated building from time history analysis using LACC Northridge earthquake are illustrated in figure 10.

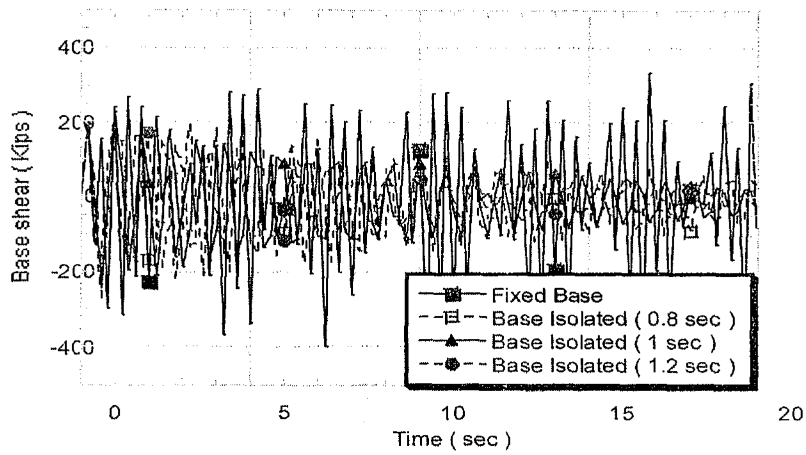

Figure10 : Comparison of Base Shear in X direction of Case Study Building due LACC Northridge X direction Earthquake

9.2.2. Vertical Response of Case Study Building due to Vertical Earthquake

9.2.2.1. Comparison of vertical acceleration for story levels

The behaviors of the case study building were obtained by using ETABS software. Although the case study building has the behaviors over time, story acceleration was chosen for the case study in this section. Fig.11 illustrated the comparison of story acceleration at the roof level. It is shown that the story acceleration at the roof level for the base isolated (1.2 sec) is reduced to 4 times of the original building.

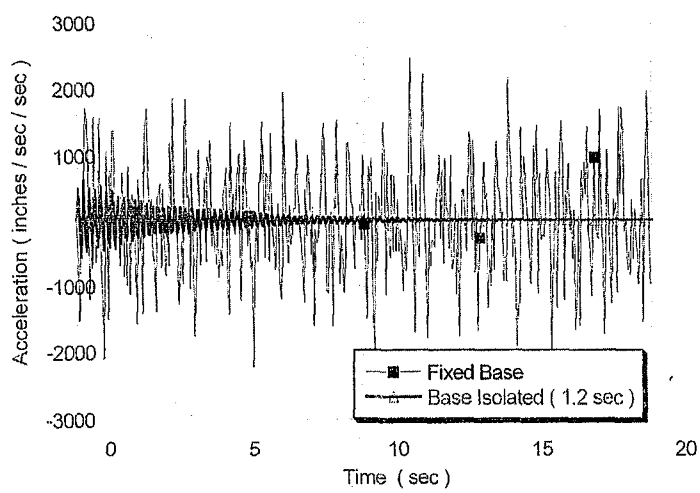

Figure11 : Comparison of the Vertical Acceleration at Roof Level due to Vertical Earthquake Motion

9.2.2.2. Comparison of vertical displacement for story levels

The comparison of the vertical displacements over time at story levels for the case study building with or with base isolation were obtained by utilizing ETABS software with Northridge vertical earthquake motion. It has been observed that maximum displacement at roof of the original building was 0.0996 inches and 0.538 inches for the base isolated building (1.2 sec). The comparison of the vertical displacement over time at roof level for the original and the base isolated building (1.2 sec) is seen in fig.12.

9.2.2.3. Comparison of axial force

The comparison of axial force on particular column point at ground level of case study building with or without base isolation are shown in fig.13.The result is shown that axial force of base isolated building is less compared with fixed base.

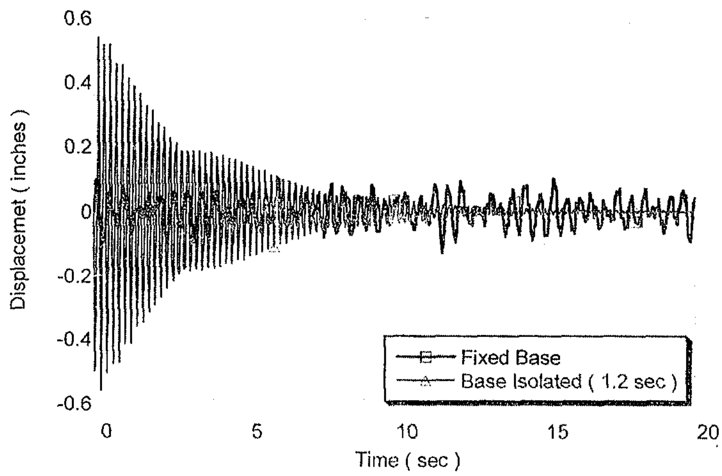

Figure12: Comparison of the Vertical Displacement at Roof Level due to Vertical Earthquake Motion

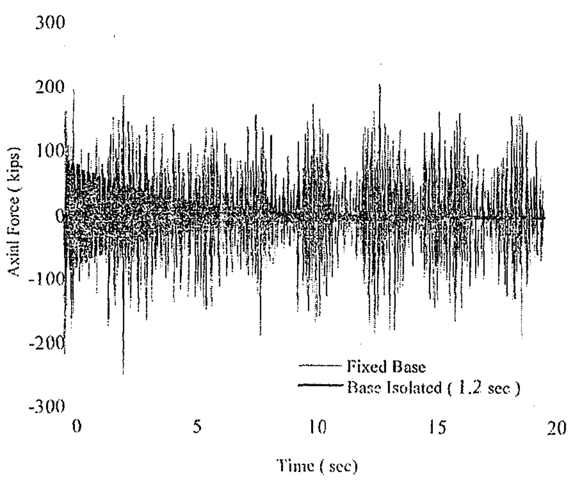

Figure13: COMPARISON OF AXIAL FORCE AT GROUND LEVEL DUE TO VERTICAL EARTHQUAKE MOTION

Seismic isolations are used as bearing for modern building to protect from damaging under earthquake. Seismic isolations have various type and most of the isolators are design to resist the horizontal loads. In this study, helical spring systems are used as bearing system in order to better protection for the case study building subjected to multi directional ground motion. Helical springs are attached at the base of the building without base slab which is located in zone 4. . For the helical isolation design, the response spectrum analysis of a fixed base building was carried out firstly. The fundamental time period was 0.4 sec. This result is an input for deciding the target fundamental period of a base isolated building, which is approximately about three times of fixed base fundamental time period. In this research, the fundamental period of base isolated building with helical spring bearing was lengthened to 0.8 sec, 1 sec and 1.2 sec. The response spectrum analysis and time history analysis of the base isolated building were carried out after the design of spring base isolator and models them into ETAB 9. When the case study building has been carried out with ETABS software using response spectrum analysis and time history analysis, both the building and isolator are considered in elastic condition.

The response of acceleration at roof level of 1.2 sec isolated building for X direction due to X direction earthquake has been greatly reduced up to 1.97 times of fixed base building from response analysis and 2.89 times of fixed base building from time history analysis. The more the period is lengthened, the lesser the story acceleration along the height of the case study building comparing to with fixed base building using dynamic analysis. The base shear value for fixed base building from response analysis was as low as 261.49 Kips, while for 1.2 sec base isolated building with spring system was 208.45 Kips for X direction in X direction earthquake. Therefore, the base shear for base isolated building is approximately 1.25 times lower compared to fixed base building.

The base shear value for fixed base from time history analysis is more than 1.78 times of 1.2 sec base isolated building. Therefore, the base shear value of base isolated building is less compared to fixed base building when the isolated building period is increased for dynamic analysis. The story drift for base isolated building with spring from response analysis was more compared to fixed base building. The response of displacement of base isolated building using both response spectrum and time history analysis was greater than fixed fixed base building. So, the response of displacement due to provided flexibility is effectively controlled by the addition of energy devices. From the analysis data it can be concluded that base isolated building has much more favorable behavior compared to fixed base building.

In vertical response results due to vertical earthquake motion, the vertical acceleration at roof level of base isolated (1.2 sec) is much smaller compared to fixed base building. Although the vertical displacement above the ground level of base isolated building (1.2 sec) is grated than fixed base building within in first 12 sec, the displacement of fixed base building is more compared to base isolated building after about 12 sec. The member forces of the base isolated is reduced compared to fixed base building and member size of the base isolated is decreased. The total cross-section area of base isolated is reduced to 5.8 % of fixed base building. The mass center may be changed after installing base isolator. Base isolated building has much more favorable behavior compared to fixed base building.

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