Seismic Response of Low-Rise Base Isolated Structures

E. Aydin, B. Ozturk & O.F. Kilinc
Department of Civil Engineering, Faculty of Engineering
Nigde University, Nigde, 51100, TURKEY

ABSTRACT:
Effects of base isolation on seismic response have been an important research area in recent years. In this study, the effects of added seismic base isolators on the structural response are investigated. Influences of seismic isolators added to a 4-storey reinforced concrete structure are ascertained. Stiffnesses of the isolators for three cases of low, moderate and high stiffness are changed; and their effects on structural response are studied. Time history analyses are performed by using Duzce (EW and NS) ground motion records which were recorded during the Marmara Earthquake in August 1999. Structural response parameters are defined as storey displacements, interstorey drifts, soft storey index which is defined as interstorey drift ratio, storey absolute accelerations, base shears and base flexural moments. The variation of first three periods of the structural models according to added seismic isolators are also analyzed. It is observed from the numerical analyses that the isolators make an important contribution to the structural response.

Keywords: Base isolation systems, Passive isolation, Earthquake resistant structural design

1. INTRODUCTION

There has been extensive research related to the application of base isolation systems (Soong and Constantinou 1994, Housner et al. 1997, Soong and Dargush 1997, Gavin and Aldemir 2001, Tezcan and Cimilli 2002, Aldemir and Aydin 2005). It is known that base isolation systems increase the natural period of structures due to their flexibility compared to structural systems without base isolation. Base isolation systems with sliding layers distribute earthquake energy by friction forces during the building motion. This type of systems gain importance for the control of earthquake induced vibrations and isolation of effects on buildings due to ground motions. In Figure 1.1, a base isolated system and its force-displacement relationships are shown.

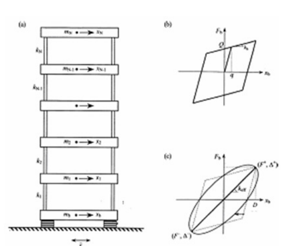


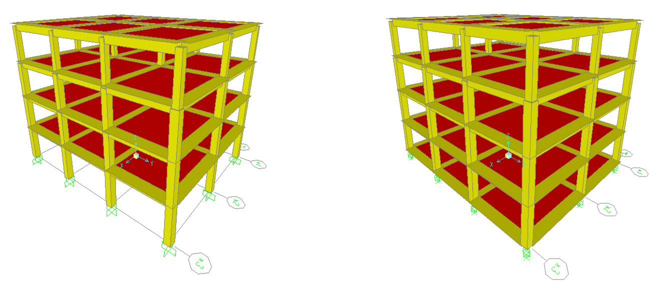
Figure 1.1 A base isolation model

An effective seismic isolation system is composed of rubber, steel impact absorbing pad layers and a lead core. These pad layers are placed in between the bottom side of columns and column foundations; and they absorb the energy transferred to the structure during the earthquake excitation. Accordingly; the building is exposed to smaller forces and moves in a controlled uniform manner, while storey accelerations and interstorey drift ratios decrease significantly. The structure makes almost the motion of a rigid body, when it is located on base isolation systems. Base isolation increases the period of a structure such that it becomes larger than both the period of a structure without base isolation and the effective period of ground motions.

In this study, the effects of added seismic base isolators on the structural response are investigated for a 4-storey structure using Duzce (EW and NS) ground motion records which were recorded during the Marmara Earthquake in August 1999. Meanwhile; stiffnesses of the isolators for low, moderate and high stiffness cases are changed; and their effects on structural response are studied. Time history analyses are performed and structural responses are defined as storey displacements, interstorey drifts, soft storey index which is defined as interstorey drift ratio, storey absolute accelerations, base shears and base moments. The variation of first three periods of the structural models according to added seismic isolators are analyzed. The numerical analyses revealed that isolators make an important contribution on the structural response of structural systems.

2. DYNAMIC ANALYSES OF THE 4-STOREY STRUCTURAL MODEL WITH RUBBER BASE ISOLATION

In this study, the effects of seismic isolators on dynamic behaviour of a 4-storey reinforced concrete structure are investigated by using numerical analyses. The analyses are repeated both for the base isolated and the fixed supported cases considering the stiffness of the isolator being low, moderate or high. The structural model is shown in Figure 2.1.



(a) (b)

Figure 2.1 4-storey reinforced concrete model structure:
(a) the original structure with fixed support
(b) the base isolated structure

The 4-storey structure is initially modelled to be fixed supported at the base. Storey displacements, interstorey drifts, interstorey drift ratios, storey absolute accelerations, base shears and base moments are evaluated for this case. Afterwards; isolator types with low, moderate or high stiffness, which are shown in Table 2.1 (Karabork 2009), are placed at the foundation supports of the structure; and the analyses are repeated. Graphs of seismic behaviour values are tabulated and compared with the original structure without base isolation.

Table 2.1 Characteristic properties of rubber layers with high damping (Karabork 2009)

Stiffness	Vertical stiffness (kN/m)	Initial stiffness (kN/m)	Effective stiffness (kN/m)	Yield Force (kN)	Stiffness ratio	Mass(kg)
Low	1750.10^3	1.750	263	22,24	0,2	175,5
Moderate	1373.10^3	7.786	1.079	77,87	0,043	175,5
High	2746.10^3	12.454	1.863	124,54	0,055	175,5

Table 2.2 shows first three periods of both base isolated and the fixed supported structures. First mode period of the 4-storey original structure is 0.37 sec, while it goes up to 2,977 sec for the base isolated structure with low stiffness isolators. When the isolator is selected to be of moderate stiffness, the first

mode period of the structures increases to 1.49 sec such that it is half of the period compared to low stiffness isolator application. The period becomes 1.156 sec, when isolators with high stiffness are applied. In general, it is observed that periods of the base isolated structures are larger than the original structure; and the increase in stiffness of the base isolator decreases the period among the base-isolated structural models.

Table 2.2 Periods of the original structure and the base isolated structures

Period (s)				
4-Storey	Isolator stiffness	T_1	T_2	T_3
	Fixed support	0,370	0,348	0,325
	Low	2,977	2,974	2,704
	Moderate	1,491	1,485	1,351
	High	1,156	1,148	1,046

3. 4-STOREY MODEL BUILDING

A 4-storey reinforced concrete model building, having two bays of 7.5 m length for each in X direction and three bays of 5 m length for each in Y direction, is selected in order to characterize low storey structures. Concrete type of the structure is C25. Columns in the first 3 storeys are 50x50 cm, while in the 4th storey column dimensions reduce to 40x40 cm. Floor thickness is 15 cm. All beams are selected as T beams having dimensions of 25x50 cm. Storey height is 3 m. Modulus of elasticity for the material is 3.10^7 kN/m^2.

First of all, dynamic analyses are applied on the structure with fixed supports using the selected earthquake ground motions for time history analysis. Afterwards; isolators having different stiffness properties are located at the building foundation. In addition; beams and floors having the same properties as the upper storey structural elements are added to the entrance storey.

3.1. Base isolation with low stiffness rubber isolator

Storey displacements at each floor level in both X and Y directions are shown in Figure 3.1. It is observed that story displacements in base isolated structure are more than the ones in original structure. This is due to the fact that there is a large displacement at the foundation level in the base isolated structure, while upper storeys act almost as rigid bodies compared to the foundation. However; it may be misleading to compare the storey displacements in order to decide which case is better.

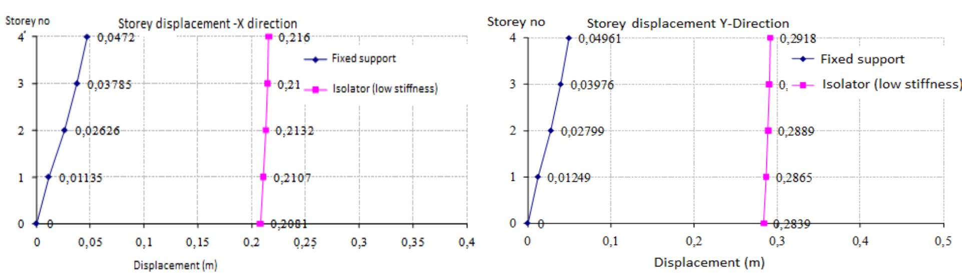


Figure 3.1 Storey displacements in both X and Y directions for both the original and the base isolated structures

Maximum interstorey displacements due to time history analyses of the 4-storey structure both in X and Y directions are shown in Figures 3.2. Interstorey displacements are the simplest parameters to define structural damage which are desired to be minimized.

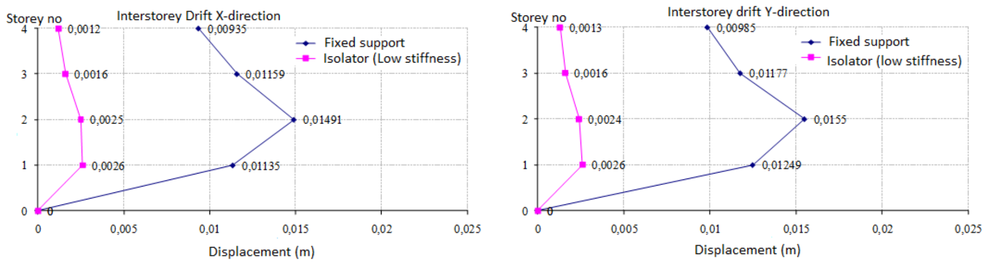


Figure 3.2 Interstorey displacements in both X and Y directions for both the original and the base isolated structures

Figure 3.3 shows maximum absolute accelerations, which are evaluated by time history analyses calculations, affecting at storey levels. Maximum absolute accelerations are indicators of inertia forces acting at storey levels due to ground motions which mean that the increase in absolute acceleration at storey levels will increase the earthquake force acting on that storey. From this perspective, reduction of absolute accelerations acting at storey levels by use of isolators is an important progress. According to the analyses made; absolute accelerations decrease significantly in both X and Y directions, when isolators are applied (Figure 3.3).

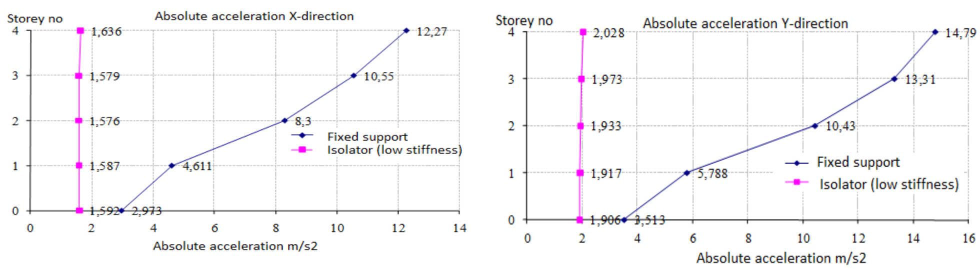


Figure 3.3 Absolute storey accelerations in both X and Y directions for both the original and the base isolated structures

At this stage of the study; relative displacement (R_i) ratios are investigated for both the original structure and the base isolated structure. Soft storey indexes (N_i) and ($1/N_i$) are defined as:

$$N_i = \frac{R_i}{R_{i+1}} \quad \text{and} \quad \frac{1}{N_i} = \frac{R_{i+1}}{R_i} \quad \text{where } i=1,\,2,\,3 \tag{3.1}$$

In Figure 3.4, N_i and $1/N_i$ values are shown in X direction for both the original structure and the base isolated structure.

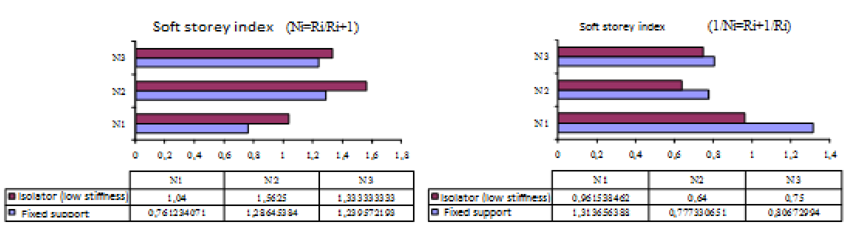


Figure 3.4 Soft storey index in X direction for both the original structure and the base isolated structure

In Figure 3.5, N_i and $1/N_i$ values are shown in Y direction for both the original structure and the base isolated structure.

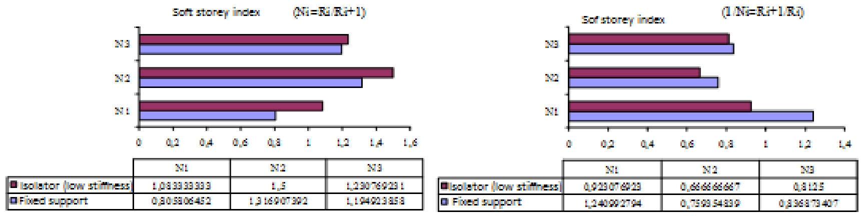


Figure 3.5 Soft storey index in Y direction for both the original structure and the base isolated structure

As shown in Figure 3.6; while in lower stories interstorey drift ratios (*R2/R1* and *R1/R2*) show a better performance for the base isolated structure, in upper stories the original structure shows a better performance regarding interstorey drift ratios (*R3/R2* and *R2/R3*) and (*R4/R3* and *R3/R4*).

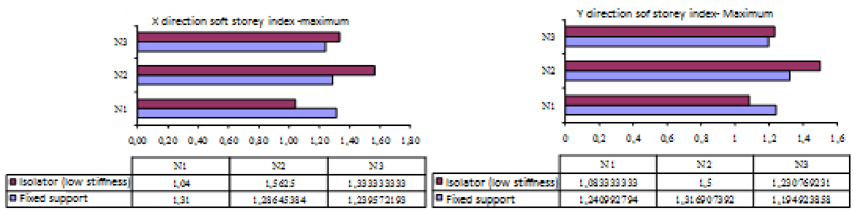


Figure 3.6 Maximum soft storey index in both X and Y directions
for both the original structure and the base isolated structure

Base shear forces and base flexural moments are investigated for both the original structure and the base isolated structure. Base shear forces and base flexural moments decreased significantly in both X and Y directions (Figure 3.7) for the base isolated structure.

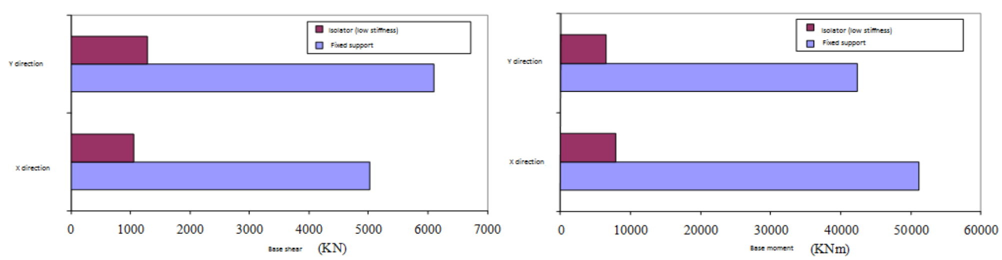


Figure 3.7 Base shear forces and base flexural moments
for both the original structure and the base isolated structure

3.2. Base isolation with moderate stiffness rubber isolator

In Figure 3.8, changes in displacements at storey levels at the 4-storey structural model are shown in both X and Y directions. It is observed that for the base isolated structure the storey displacements are larger compared to the original structure. This situation is due to the fact that the base isolated structure has a larger displacement at the foundation level, while the upper stories move almost in rigid motion compared to the foundation level.

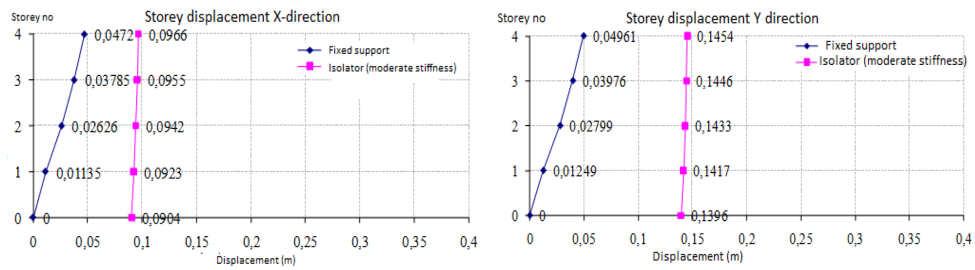


Figure 3.8 Storey displacements in both X and Y directions for both the original and the base isolated structures

Maximum interstorey displacements due to time history analyses of the 4-storey structure both in X and Y directions are shown in Figures 3.9. It is observed that interstorey displacements are significantly minimized compared to the original structure. In addition, their values are less than the values for the base isolated structure with low stiffness rubber isolator application.

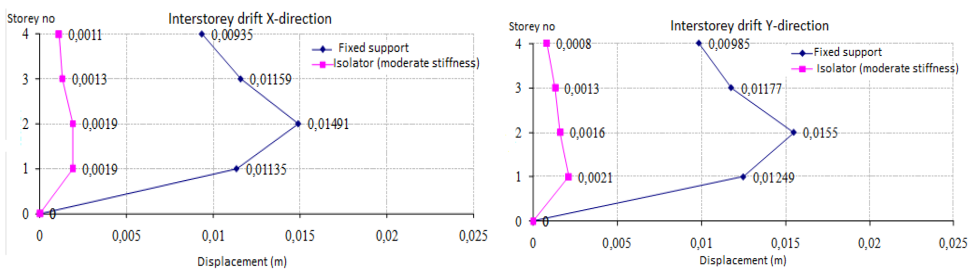


Figure 3.9 Interstorey displacements in both X and Y directions
for both the original and the base isolated structures

Figure 3.10 shows maximum absolute accelerations at storey levels which are evaluated by time history analyses calculations. It is observed that the increase in stiffness compared to the low stiffness rubber isolator causes an increase in acceleration values, even though it causes a decrease in displacements.

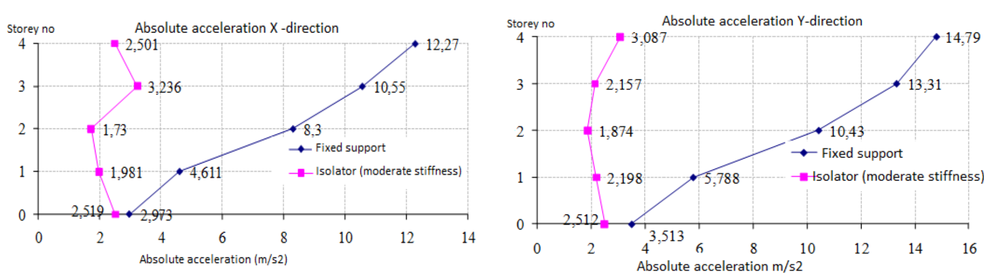


Figure 3.10 Absolute storey accelerations in both X and Y directions
for both the original and the base isolated structures

The graphs of soft storey indexes (N_i) and ($1/N_i$), which were previously defined in Equation 3.1, are shown in Figures 3.11 & 3.12 for the case of moderate stiffness rubber isolator. In Figure 3.11, N_i and $1/N_i$ values are shown in X direction for both the original structure and the base isolated structure.

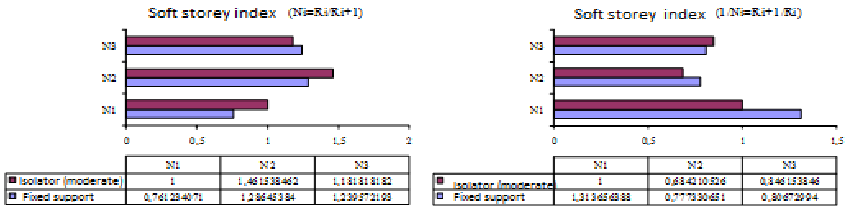


Figure 3.11 Soft storey index in X direction for both the original structure and the base isolated structure

In Figure 3.12, N_i and $1/N_i$ values are shown in Y direction for both the original structure and the base isolated structure.

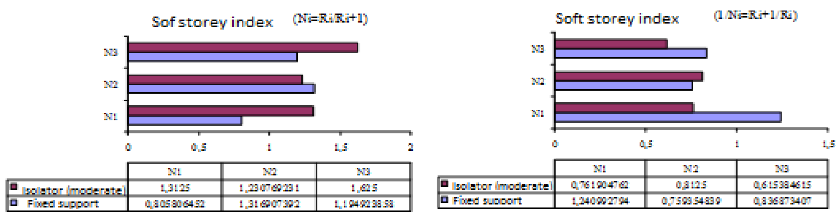
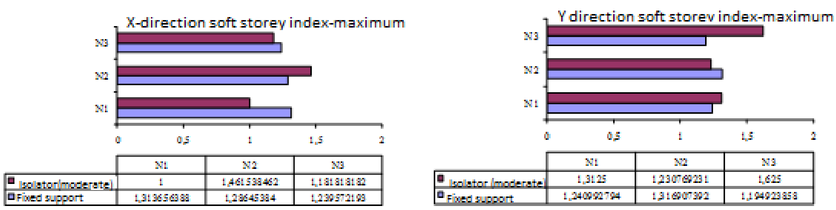


Figure 3.12 Soft storey index in Y direction for both the original structure and the base isolated structure

As shown in Figure 3.13(a); while *N1* and *N3* are smaller for the base isolated structure, *N2* is larger. It is important to note that these values are smaller than 2 as required by the earthquake codes. In addition; soft storey indexes in these graphs are close to 1 which is desired in design (UBC Code 1985).



(a) (b)

Figure 3.13 Maximum soft storey index in both X and Y directions
for both the original structure and the base isolated structure

Base shear forces and base flexural moments, which decreased significantly in both X and Y directions (Figure 3.14) upon application of moderate stiffness rubber isolators, are investigated for both the original structure and the base isolated structure.

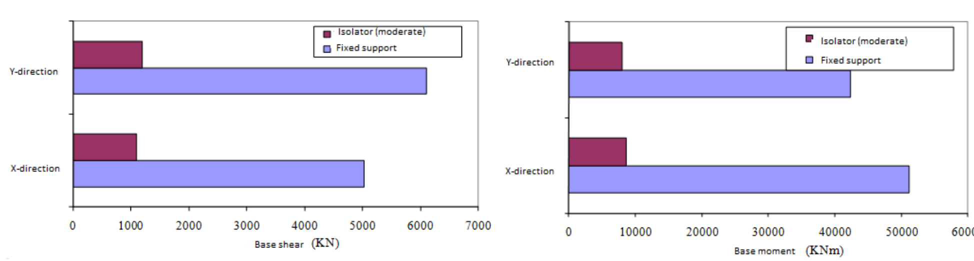


Figure 3.14 Base shear forces and base flexural moments
for both the original structure and the base isolated structure

It is observed that both base shear forces and base flexural moments are slightly larger compared to the low stiffness rubber isolator application.

3.3. Base isolation with high stiffness rubber isolator

In Figure 3.15, changes in displacements at storey levels at the 4-storey structural model are shown in both X and Y directions. It is observed that the storey displacements are even smaller than low and moderate stiffness rubber isolator applications for the base isolated structure.

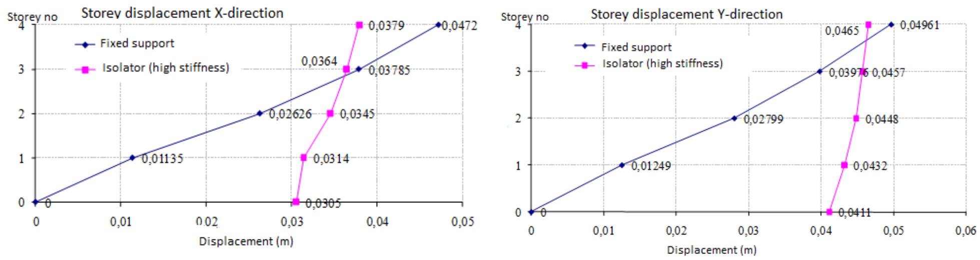


Figure 3.15 Storey displacements in both X and Y directions for both the original and the base isolated structures

Maximum interstorey displacements due to time history analyses of the 4-storey structure both in X and Y directions are shown in Figure 3.16. It is observed that interstorey displacements are even more minimized compared to the values for the base isolated structure with low and moderate stiffness rubber isolator applications.

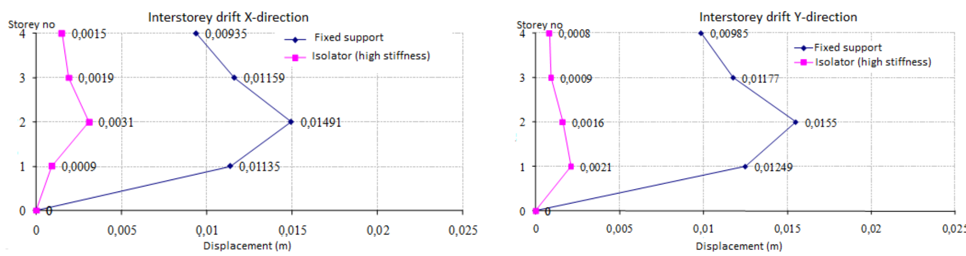


Figure 3.16 Interstorey displacements in both X and Y directions
for both the original and the base isolated structures

Figure 3.17 shows maximum absolute accelerations at storey levels which are evaluated by time history analyses calculations. It is observed that acceleration values are smaller than the values for the original structure.

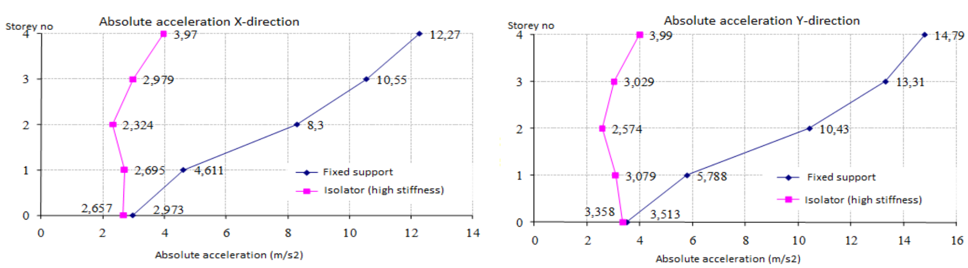


Figure 3.17 Absolute storey accelerations in both X and Y directions
for both the original and the base isolated structures

The graphs of soft storey indexes (N_i) and ($1/N_i$), which were previously defined in Equation 3.1, are shown in Figures 3.18 & 3.19 for the case of high stiffness rubber isolator. In Figure 3.18, N_i and $1/N_i$ values are shown in X direction for both the original structure and the base isolated structure.

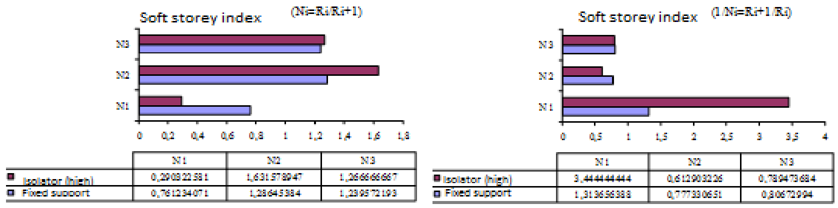


Figure 3.18 Soft storey index in X direction for both the original structure and the base isolated structure

In Figure 3.19, N_i and $1/N_i$ values are shown in Y direction for both the original structure and the base isolated structure.

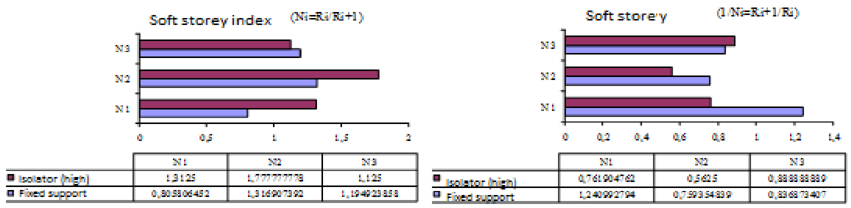
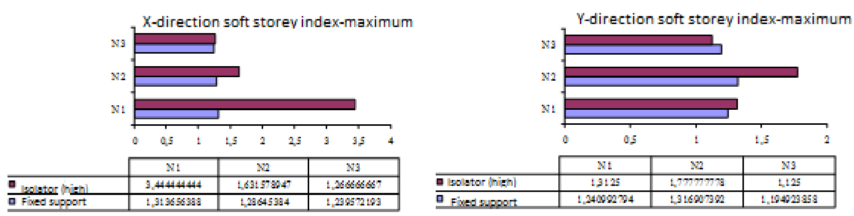


Figure 3.19 Soft storey index in Y direction for both the original structure and the base isolated structure

As shown in Figure 3.20(a); all *N1, N2* and *N3* values are larger for the base isolated structure compared to the original structure in X direction, while in Figure 3.20(b) *N1* and *N2* values are larger in Y direction.



(a) (b)

Figure 3.20 Maximum soft storey index in both X and Y directions
for both the original structure and the base isolated structure

Base shear forces and base flexural moments are investigated for both the original structure and the base isolated structure. Base shear forces and base flexural moments decreased significantly in both X and Y directions (Figures 3.21) upon application of high stiffness rubber isolators.

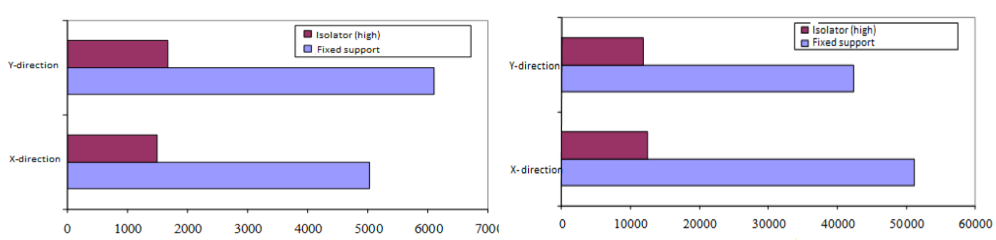


Figure 3.21 Base shear forces and base flexural moments
for both the original structure and the base isolated structure

Meanwhile; it is observed that both base shear forces and base flexural moments are slightly larger than low and moderate stiffness rubber isolator applications.

4. RESULTS

In this study; effect of high damping isolators on seismic behaviour of a 4 storey reinforced concrete building is investigated. Meanwhile; the effect of change in stiffness of rubber isolators is examined on seismic behaviours of structures. Duzce (EW and NS) ground motion records which were recorded during the Marmara Earthquake in August 1999 are used for time history analyses using SAP 2000 structural analysis program (2000). It is observed that application of rubber isolators have a significant effect on structural behaviours.

Results of the analyses show that application of rubber isolators significantly increase periods of the original structure, while the increase in rubber isolator reduce the period increase in the structure. It is observed that application of low stiffness rubber isolators provides a better structural behaviour compared to application of moderate or high stiffness rubber isolators on the structure. In addition; seismic behaviors of both the original and the base isolated structures are discussed according to the interstorey drift ratios.

Base isolated structures show a better performance regarding the interstorey drifts compared to the original structure, since interstorey drifts reduce significantly. In addition, the absolute storey accelerations decrease, when rubber isolators are applied; and the increase in stiffness of rubber isolators increases the absolute storey accelerations. Both base shear forces and base flexural moments decrease upon the application of rubber isolators, while the increase in stiffness of rubber isolators increases them simultaneously.

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