A Study on the Effects of the Superstructure Stiffness in the Seismic Base Isolated Structures

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Abstract - In this study, the improvement of the seismic behavior has been searched using the base isolation in the reinforced concrete school building, where the strengthening work was previously carried out. Firstly, the fixed supported structure model has been compared to the fundamental isolated models, in order to show the contribution of the seismic based isolation to the structural seismic behavior. Thus, the seismic behavioral differences of a seismic isolated structure and a fixed supported conventional structure and the contributions of the seismic isolation to the structural seismic behavior have been put forward. The dynamic analysis of the models with the same superstructural bearing system have been made for different soil characteristics and the effects of the soil characteristics of the seismic isolated structure have been detected, in order to show the effects of the different soil characteristics of an isolated structure. Finally, the superstructure models in the different stiffnesses have been used, in order to show the effects of the superstructural bearing system on the seismic base isolated structure. In the first model, it has been modeled by the placing of basic level isolation to the existing structure. In the second and third models, the concrete shear wall has been respectively put into the 5 story and 10 story building models at the rates 1 % and 2 %" of the floor area and the superstructural stiffness has been increased. The comparison of these three models has shown, at which rate the increase of superstructural stiffness contributes to the seismic behavior of the base isolated structure.

Index Terms - Base isolation, seismic, structural behavior, earthquake.

1 INTRODUCTION

The seismic base isolation is applied for the seismic behavioral improvement of the existing buildings, besides the new designed buildings. For the structures with base isolated design, the criteria "superstructural bearing system, superstructural storey number and sitting area" are as important as the design of the base isolation. For instance, the displacement values because of the seismic forces can be higher than acceptable levels by the increase in the construction height. Besides the increase in the construction height causes the overturning risk of the structure. Therefore, the base isolation is not enough for a high construction and needs using of additional dampers. The seismic movements in the base isolated structure are met by the rigid displacement of the structure due to the layer with low horizontal stiffness. Therefore, it is not necessary that the bearing elements in the base isolated structure are determined as ductile. But the effects of the superstructure stiffness on the seismic behavior of the structure must be known. There are many studies on the seismic behavior of the base isolated structures. Some of these studies are given in the following. Chopra [1] explained the seismic behavior of the base isolated structures.

Malangone and Ferraioli [2] proposed a modal method for the nonlinear analysis of the multi-storied structures with high damp and isolation system. Cimilli [3] examined generally the seismic isolation with elastomer based supports. Türkmen [4] detected the parameters for analytical modeling of an isolator using the test results of shake table for an isolator. Şener et all [5] searched the effect of base isolation on the control of displacements in the concrete prefabricated structures. Matsagar and Jangid [6] examined the isolator effects on the dynamic behaviors of multi-story and base isolated structures. Elma [7] examined the effects of the superstructure rigidity on the seismic behavior of the base isolated structure. Guerreiro and friends [8], searched the seismic passive protection systems in structural improvement. Thermou and Elnasnai [9] explained the seismic improvement and strengthening methods of the reinforced concrete structures. Ibrahim [10] examined recent advances in nonlinear passive vibration isolators. Tena-Colunga and Escamilla-Cruz [11] searched torsional amplifications in asymmetric base-isolated structures.

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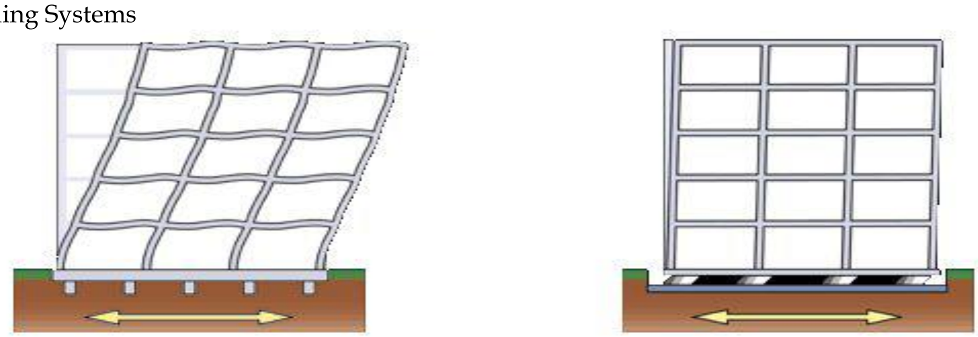
Pourzeynali and Zarif [12] researched multi-objective optimization of seismically isolated high-rise building structures using genetic algorithms. Providakis [13] performed the pushover analysis of the based isolated and steel-concrete composite structures near the fault line. Kilar and Koren [14] examined the seismic behavior of the base isolated, non-symmetrical and different isolated structures. Sivapalan and Duraisamy [15] researched the modelling of energy dissipation in structural devices and foundation soil during seismic loading. Islam et all [16] examined the Non-linear time domain analysis of base isolated multi-storeyed building under site specific bi-directional seismic loading. Islam et all [17] examined incorporation preference for rubber-steel bearing isolation in retrofitting existing multi storied building. Konstantinidis and Nikfar [18] researched seismic response of sliding equipment and contents in base-isolated buildings subjected to broadband ground motions. Wolff et all [19] searched effect of viscous damping devices on the response of seismically isolated structures. Sarlis et all [20] examined negative Stiffness Device for Seismic Protection of Structures. Afshar and Pour [21] researched on inertia nonlinearity in irregular plan isolated structures under seismic excitations.

In this study, the improvement of the seismic behavior has been searched using the base isolation in the reinforced concrete school building, where the strengthening work was previously carried out.
Firstly, the fixed supported structure model was compared with the basic level isolated models, in order to put forward the contribution of the seismic base isolation to the structural seismic behavior.
Thus, the seismic behavioral differences of a seismic isolated structure and a fixed supported conventional structure and the contributions of the seismic isolation to the structural seismic behavior have been put forward. The dynamic analysis of the models with the same superstructural bearing system has been performed for different soil characteristics and the effects of the soil characteristics of the seismic isolated structure have been detected, in order to show the effects of the different soil characteristics of an isolated structure. Finally, the superstructure models in the different stiffnesses have been used, in order to show the effects of the superstructural bearing system on the seismic base isolated structure. In the first model, the structure has been modeled, by the basic level isolation has been put into the existing structure. In the second and third models, the reinforced concrete shear walls have been respectively placed to 5 story and 10 story building models at the rates “1 % and 2 %” of the floor area” and the superstructural stiffness have been increased. The comparing of these three models, shows, at which rate the increase of superstructural stiffness contributed to the seismic behavior of the base isolated structure.

2 BASE ISOLATED SYSTEMS

The rigid motion in the superstructure is active at the first vibration mode in the isolated systems (Figure 1), [22] . As a result, the significant part of deformations are observed in the isolated system.
Although the Isolators in a base isolated system are very different, they can be classified in two groups:

- Elastomer Based Systems
- Sliding Systems



Fixed Supported Structure Seismic Isolated Structure

Fig. 1. The behaviors of the fixed supported and seismic isolated structures under earthquake motion

a) Elastomer Based Systems

A majority of the isolators is produced from elastomeric materials, i.e. from natural or synthetic rubber. Nowadays, the steel plates are used for safety transfer the vertical loads to the foundation on the elastomeric bearings. The thickness of these bearings occurs by the overlapping of the rubber plates between 8- 20 mm thickness and thin steel plates between 2-3 mm thickness. The vertical stiffness of elastomeric bearings is several hundred times more than horizontal stiffness.

The design of elastomeric bearings is directly related to choosing the bearing from right material and in an appropriate geometry. According to the bearing types, there are three application groups. They are below and in the following given ([23], [24]):
1. Low damped natural and synthetic rubber bearings
2. Lead core rubber bearings
3. High-damped natural rubber bearings

b) Sliding Isolated Systems

The sliding isolated systems are the oldest and simplest isolation systems. The main principle of the sliding isolation is to separate the foundation and superstructure by using the sliding isolation layer. The limited horizontal force transmission to the isolation section is possible by the low friction in sliding systems. The lower the friction coefficient is, the less force transmission is.
Fine sand, thin rubber or teflon can be used as sliding isolated layer. The Teflon-coated and stainless steel plates are most commonly used. Sliding isolated systems are below and in the following given: ([23], [24]).
1. Electiricite-de France system
2. EERC combined system
3. Flexible frictional base isolated system
4. Friction pendulum system.

2.1 Code requirements on the seismic isolation

The effect code "The International Building Code, 2009 Edition [25]" in the United States is valid for this study. IBC 2009 consists of the regulations for new structures and does not include the requirements of the existing buildings. Nevertheless, IBC 2009 requirements are generally applied to the strengthening of current structures against the seismic effects with seismic isolation.

The regulations on the seismic isolation don't put forward any isolation system. But the code conditions require that the isolation system must be stable in displacement, provide the adequate strength for the increasing displacement and not lose the properties under repeated reversible loads.
In this study, lead core rubber bearings are used as the kinds of isolators. In Figure 2, the parts of lead core rubber bearings are shown in the figure.

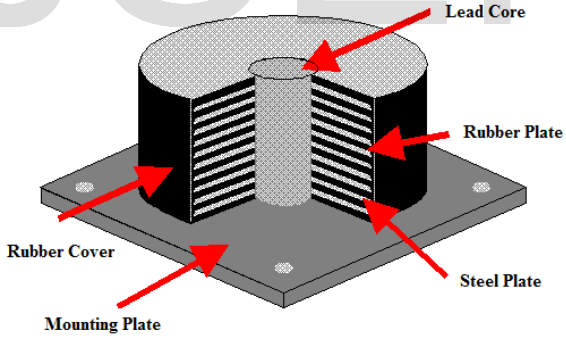


Fig. 2. Lead core rubber bearings parts

2.2 Mechanical properties of the lead core rubber bearings

The lead core rubber bearings are always modeled as bilinear elements and their characteristics depend on three parameters: K_1, K_2 and Q. The determination of elastic stiffness K1 is difficult and is obtained by empirical multiplying of K_2 with a certain coefficient. The characteristic strength Q is an intersection point of hysterical curve and force axis and determined depending on lead yield tension (10.3 MPa) and lead core area.

The effective stiffness of lead rubber bearing is obtained from K_{eff-} force-displacement graphic and the more displacement increases, the smaller its value gets.

$$K_{eff} = K_2 + \frac{Q}{D} \qquad D \geq D_y \tag{1}$$

D_y: Yield, displacement

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Natural frequency ω is calculated by the following formula.

$$\omega = \sqrt{K_{eff}\frac{g}{W}} = \sqrt{\omega_0^2 + \mu g / D} \qquad (2)$$

Where;

$$\mu = \frac{Q}{W}, \ \omega_0^2 = \sqrt{K_2 \frac{g}{W}} \text{ ' is.} \qquad (3)$$

And the effective period;

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\omega_0^2 + \mu \frac{g}{D}}} \text{ 'is.} \qquad (4)$$

For an effective damping $D \geq D_y$;

$$\beta_{eff} = \frac{\text{force - displaceme nt graph erea}}{2\pi K_{eff} D^2} \qquad (5)$$

The area of the force-displacement graph is calculated with 4Q ($D-D_y$).

$$D_y = \frac{F_y}{K_1} \qquad F_y = Q + K_2 D_y$$

$$D_y = \frac{Q}{(K_1 - K_2)} \qquad (6)$$

Effective damping value is transformed to the following expression using the above definitions.

$$\beta_{eff} = \frac{4Q(D - D_y)}{2\pi(K_2 D + Q)D} \qquad (7)$$

As a general rule, the effective damping rate takes the following form, freely from Dy, because elastic stiffness is 10 times more als K_1, K_2.

$$\beta_{eff} = \frac{4Q(D - Q/9K_2)}{2\pi(K_2 D + Q)D} \qquad (8)$$

2.3 Mathematical Models of the lead core rubber bearings

The used axial pressure in the columns of school building for the analytical application is about 1000 kN. The produced lead pin bearings by the firm "Dynamic Isolation Systems Inc." are three types. B-Type "lead-core bearings" have been selected, because the column loads is generally over 675 kN.

Design Pressure Load: 2265 kN (D_{CL})
Design displacement: 22.86 cm (D_D)
Little displacement limits: 7.62 cm (± 3.81)
Weight: 8.4939 kN
Height: 35.93 cm
Size of the plan: 74.93 cm
Thickness of single rubber layer (t): 7.62 mm
Total thickness of rubber sheet: 25.90 cm (0.762x34)
Lead core diameter: 12.07 cm
Lead yield strength: 10000 kN/m²
Shear module: 400 kN/m²

(K_1=10K_2 according to acceptance, the calculations will be made.)

The calculation of the required parameters in mathematical modeling:

1) $$K_2 = \frac{GA}{t_r} = \frac{400\pi(0.749)^2}{4(0.259)} = 680.5\ kN/m$$

2) $$S = \frac{\Phi}{4t} = \frac{74.9}{4(0.762)} = 24.57\,,\quad E_c = 6GS^2 = 6(400)(24.57)^2 = 1448840 kN/m^2$$

3) $$K_v = \frac{E_c A}{t_r} = \frac{1448840(0.441)}{0.259} = 2466940 kN/m$$

4) $$Q = f_y \times \text{Lead area} = \frac{10000(0.1207)^2\pi}{4} = 114.4\ kN$$

5) $$K_{eff} = K_2 + \frac{Q}{D} = 680.5 + \frac{114.4}{0.2286} = 1180.9\ kN/m$$

6) $$D_y = \frac{Q}{K_1 - K_2} = \frac{114.4}{9(680.5)} = 0.01868\ m$$

7) $$F_y = Q + K_2 D_y = 114.4 + 680.5(0.01868) = 127.1\ kN$$

8) The rate of stiffness after yield to the stiffness before yield; α=1/10=0.1

2.4 Minimum Requirements of Regulation IBC 2009

1) Seismic zone; Z= 0.4
2) Category of soil profile; S_B
3) Seismic Source Type A
4) Source proximity factors; Δ> 15 km; N_a=1, =1
5) Earthquake shake density; Z N_v=1(0.4)=0.4
6) MCE response coefficient; M_M=1.25
7) Seismic Coefficients; C_V=0.40, C_A=0.40 ve C_{VD}=0.40, C_{AD}=0.40
8) α= $M_M Z N_A$= 1.25(0.40)1= 0.50> 0.40; C_{AM}=1(α)= 1(0.5)= 0.50
   α′= $M_M Z N_V$= 1.25(0.40)1= 0.50> 0.40; C_{VM}=1(α)= 1(0.5)= 0.50
9) Structural system reduction factor; R_I= 2.0
10) Effective damping rate of the isolation system; β_{eff}= 0.15
11) Damping reduction factor; B=1.35
12) For preliminary design: it is estimated as T_D= 2.2 ve T_M= 2.7 s.
13) Efective Stiffness:
    Total weight of normal storeys: 4600 kN
    The weight of the roof floor : 3900 kN
    Storey weight at isolation level: 2700 kN
    Total weight of the building; W=4(4600)+3900+2700= 25000 kN

$$K_{D,min} = \frac{4\pi^2 W}{T_D^2 g} = \frac{4\pi^2(25000)}{2.2^2(9.81)} = 20787\ kN/m$$

$$K_{M,min} = \frac{4\pi^2 W}{T_M^2 g} = \frac{4\pi^2(25000)}{2.7^2(9.81)} = 13800\ kN/m$$

10 % deviation can be considered for maximum and minimum values of effective stiffness:

$K_{D,max}$= (1.10/0.90)x 20787= 25406 kN/m
$K_{M,max}$= (1.10/0.90)x 13800= 16870 kN/m

14) Minimum displacements:

$$D_D = \frac{gC_{VD}T_D}{4\pi^2 B_D} = \frac{9.81 \times 0.40 \times 2.2}{4\pi^2 \times 1.35} = 0.162\ m$$

$$D_M = \frac{gC_{VM}T_M}{4\pi^2 B_M} = \frac{9.81 \times 0.50 \times 2.7}{4\pi^2 \times 1.35} = 0.249\ m$$

15) Minimum Design Forces:

The minimum base shear force for the design of elements under the isolation system;

$V_b = K_{D,max} \times D_D = 25406 \times 0.162 = 4116\ kN$

$$V_S = \frac{K_{D,\max} \times D_D}{R_I} = \frac{25406 \times 0.162}{2} = 2058\,kN$$

3 THE DYNAMIC ANALYSIS WITH SAP2000 NONLINEAR PROGRAM

In the dynamic analysis of structures, the mode combination method (Response Spectrum Analysis) and the analysis in the time history method (Analysis in the time history method) have been used. IBC 2009 Acceleration Spectrums have been used for the calculation of the mode combination method. 1940 ELCENTRO earthquake record has been used for the analysis in the time history method. The earthquake record consists of 1210 datas in 0.01 second intervals.

In this study, the dynamic analyses of the fixed supported and isolated structure models in the time history method have been firstly made and the effect of the base isolation on the seismic behavior of the structure have been comparatively examined. The effects of the soil conditions on the seismic isolated structure have been examined making dynamic analyses by the mode combination method. The three dimensional model of the structure is given in fig. 3.

The effects of the superstructure stiffness on the isolated structure behavior for the design of isolated structure is important as well as the effects of the base isolation on the seismic behavior of the structure. Thus, the isolated structure model has been compared to the models with the shear walls at the rate %1 and %2 of floor area. The dynamic analyses of structure models with shear walls have been carried out as 5 and 10 story and the results have been compared to show the relationship between structure height and bearing system with shear walls.

The used lead-core elastomeric bearings in seismic isolation have been modeled as nonlinear link elements in program SAP2000 [26] and the element properties for the describing of these elements are shown in table 1.

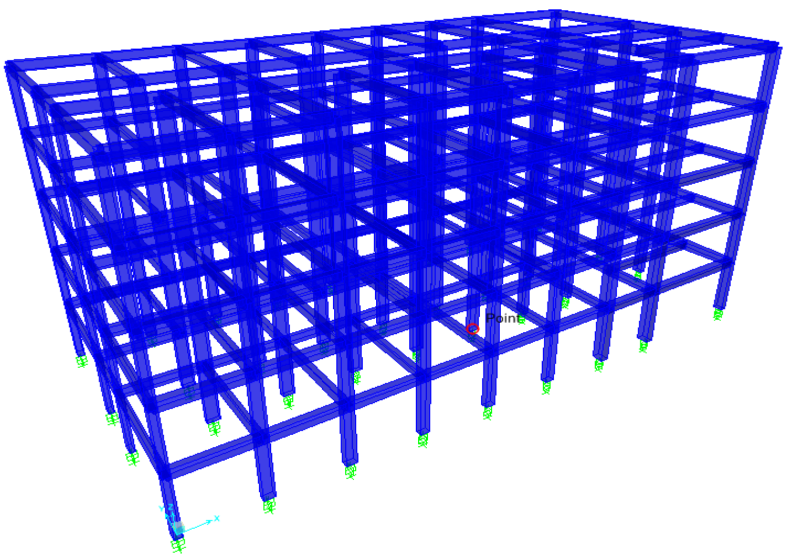

Fig. 3. Three-dimensional model of the school building in analytical application

Table 1. The properties of the modeled lead-core rubber isolators in program SAP2000

Rubber Isolator			
Mass: 0.849		Weight: 8.49 kN	
Directional	Properties		
		Linear	Nonlinear
U1 (Vertical)	Effective Stiffness (K_{eff})	2466940	-
U2, U3 (horizontal)	Stiffness	1180.9	680.8
	Effective Damping (βeff)	0.15	-
	Yield Strength (F_y)	-	127.1
	Post Yield Stifness Rate	-	0.1

3.1 Comparing of dynamic analysis of the fixed supported model and isolated model

The analysis-results of the fixed supported and isolated structures are given in table 2 and fig. 4.
According to the analysis-results, seismic isolated structure has possitive effects on the seismic behavior. Compared to fixed supported structure, the first mode period (T1) of isolated structure has increased from 0.86 to 2.15 with an arising of 2.5 times. Thus the acceleration values of the structure will be declined. While the displacement of superstructure with fixed supported model is 297 mm, the supper structure with isolated model has rigid mass movement and is exposed to a little displacement of 33 mm. It is observed that the isolated structure has a significant decrease in the values of base shear force and overturning moment.

Table 2. Dynamic analysis of the fixed supported model and isolation model

	Fixed Support	Isolated nonlinear analysis	Coefficient of Variation
Period (T_1)	0.86	2.15	2.5
Displacement of isolation layer (mm)	0	264	0.0
Total displacement (mm)	208	297	1.4
Displacement of superstructure (mm)	208	33	0.2
Base shear force (kN)	20100	3480	0.2
Moment (kN.m)	249390	39140	0.2

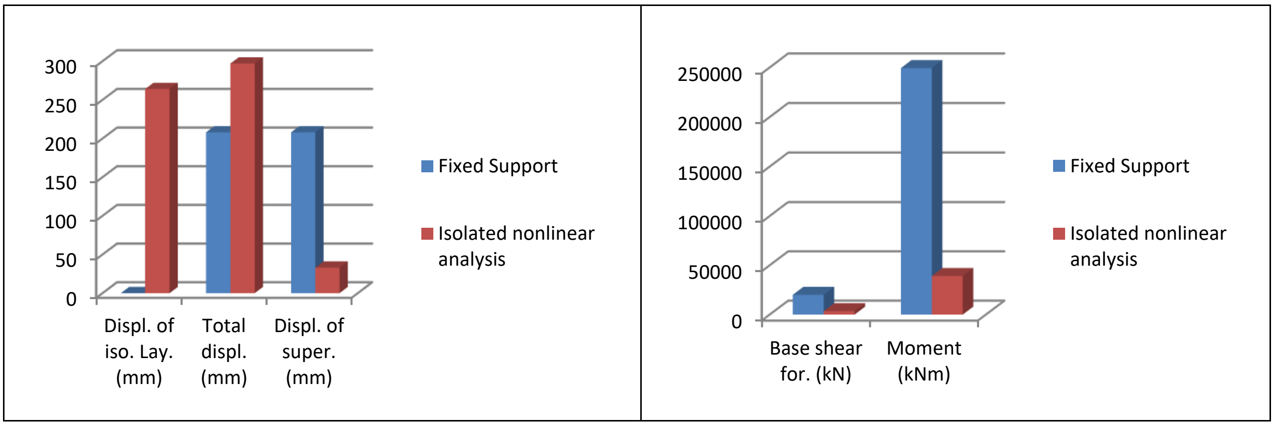

Fig. 4. Graphics of Dynamic analysis of the fixed supported model and isolation model

C-C axis frame of the school building for the analytical application is shown in fig. 5. School plan used in addition to the analytical work is also given in Appendix A. The displacement in the time history method of C-C axis frame is shown in the fig. 6. A majority of displacements in the isolated model has been seen in the isolation system and the superstructure has shown a close behavior to rigid mass movement. This shows the effectiveness of the isolation system.

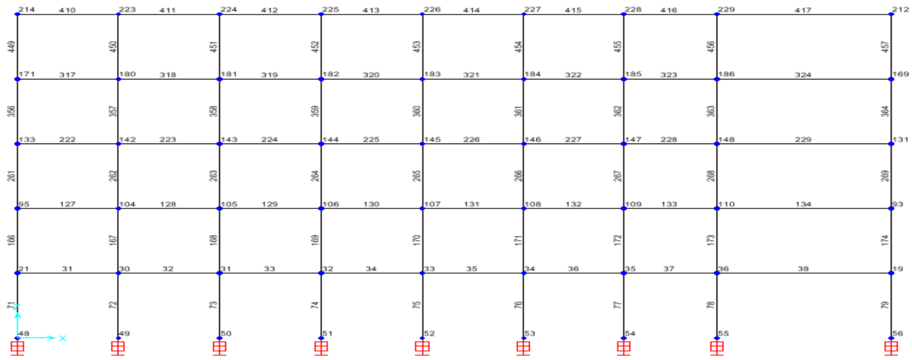

Fig. 5. C-C axis frame element and node point numbers in three-dimensional model of school building

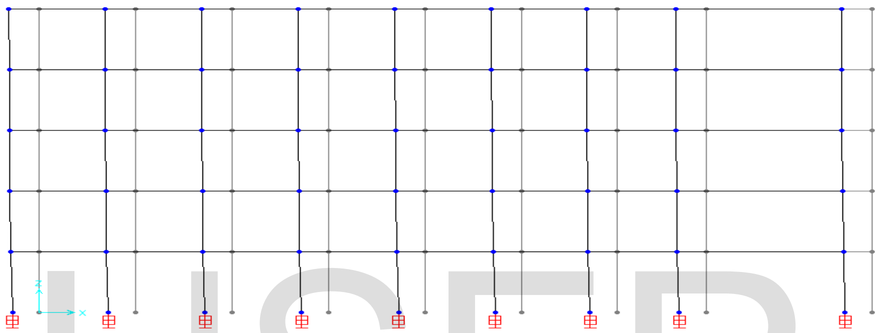

Fig. 6. Displacement after the time history-analysis of the C-C axis frame of the school building

The used isolation system in analytical application are lead core rubber bearings. This isolation system shows a nonlinear behavior under dynamic effects. The displacements and the internal force of the structure are compared in the table 3 and fig. 7, when the dynamic analysis has been made linear and nonlinear. Due to the nonlinear property of the isolation system, the displacement in the isolated system has decreased, if the dynamic analysis are linear carried out. The superstructure has moved away from rigid mass movement and the displacement of the superstructure has increased. Because the acceptance of linear behavior reduces the amount of consumed seismic energy by the displacement in the the isolation system. So that the seismic energy has been consumed by more displacements of the superstructure. According to these results it is clear that If the nonlinear property of isolation system does not take into consideration, the real behavior of isolation system disappears.

Table 3. The results of the linear and nonlinear analyses in the time history method of isolated models

	Isolated Linear Analysis	Isolated nonlinear analysis
Period (T_1)	2.15	2.15
Displacement of isolation layer (mm)	199	264
Total displacement (mm)	306	297
Displacement of the superstructure (mm)	107	33
Base shear force (KN)	8360	3480
Moment (KNm)	86700	39140

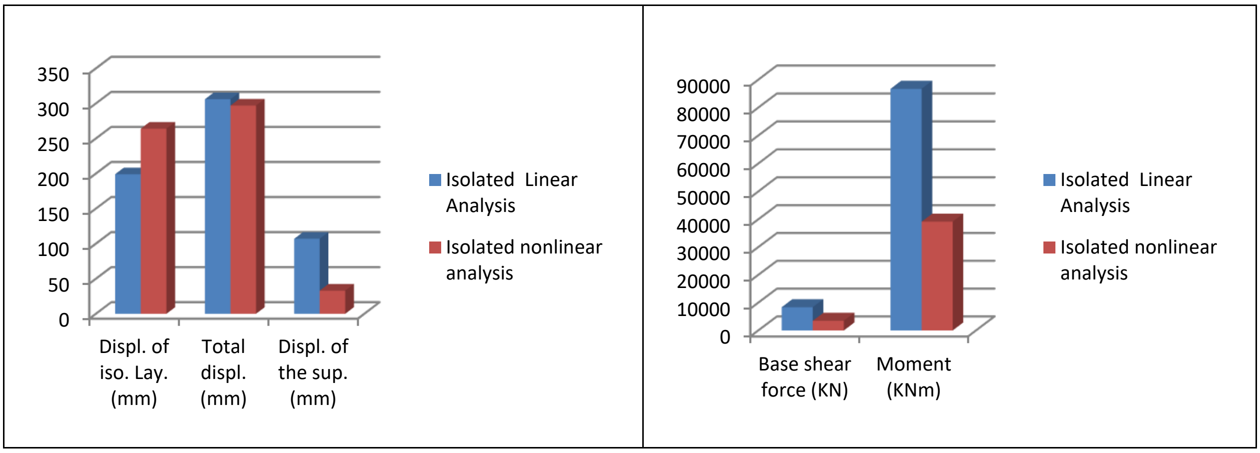

Fig. 7. Graphics of the linear and nonlinear analyses in the time history method of isolated models

3.2 The comparing of dynamic analyses about the soil effects of the fixed supported model and isolated model

By the use of 5 different soil profile types, which are defined at IBC 2009 and ranked from the soil with high bearing capacity to the soil with lower bearing capacity, the analysis of the fixed supported and isolated models for each profile type has been performed, in order to understand the effects of soil profiles on the isolated structure. The displacements and internal forces in the isolated structure increase with the decreasing of soil bearing capacity, such as in the table 4 and fig. 8. Furthermore, the decrease in soil bearing capacity prevents the rigid mass movement of the isolated structure. Thus, the decrease in soil bearing capacity reduces the effectiveness of the seismic isolation.

Table 4. The results of dynamic analysises of the fixed supported models and isolated models for the ranked profiles from soil with high bearing capacity to the soil with lower bearing capacity.

	Displacement of isolation layer D_{iso} (mm)	Total displacement D_{total} (mm)	Displacement of superstructure D_{up} (mm)	Base shear force (V)	Moment (M)
Fixed S_A	-	90	90	1042	12006
Isolated S_A	121	185	64	517	5100
Fixed S_B	-	113	113	1296	15005
Isolated S_B	152	231	79	646	6369
Fixed S_C	-	161	161	1811	21365
Isolated S_C	217	329	112	920	8989
Fixed S_D	-	180	180	2039	23951
Isolated S_D	244	370	126	1033	10107
Fixed S_E	-	219	219	2447	29193
Isolated S_E	365	555	190	1548	14990

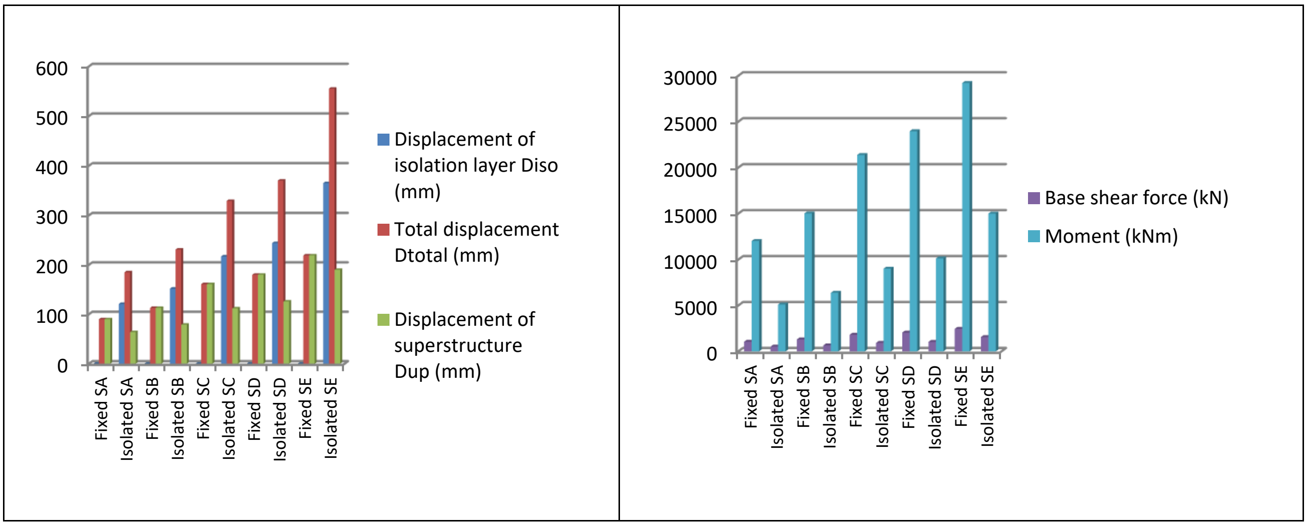

Fig. 8. Graphics of dynamic analyses of the fixed supported models and isolated models for the ranked profiles from soil with high bearing capacity to the soil with lower bearing capacity

3.3 The Comparing of seismic behaviors of isolated models with different superstructure-stiffnesses

The dynamic analyses of three different models "**5 story**, three models framed, concrete shear walls at the rate 1% and 2% of floor area" have been carried out in the time history method, in order to show the effects of the superstructure stiffness on the seismic behavior of base isolated structure. As the results of the dynamic analyses of these, three models are given in the table 5 and fig. 9. It has been seen, that the base isolated structure gets closer to the principle "desired superstructure rigid mass movement" upon the superstructure stiffness with the shear wall. While the observed displacement is 33 mm in mode without shear wall, it falls to 1/10 of this value in the model with shear wall. This situation shows that the rigid design of the superstructure provides the principle "expected superstructure rigid mass movement in the base isolated structure."

Table 5. The results of nonlinear dynamic analysis in the time history method of the isolated models

	Model without shear wall (5 story)	Model with shear wall at rate %1 (5 story)	Model with shear wall at rate %2 (5 story)
Period (T_1)	2.15	2.11	2.24
Displacement of isolation layer (mm)	264	260	272
Total displacement (mm)	297	263	274
Displacement of superstructure (mm)	33	3	2
Base shear force (KN)	3480	4259	4654
Overturning Moment (KN.m)	39140	32154	31540

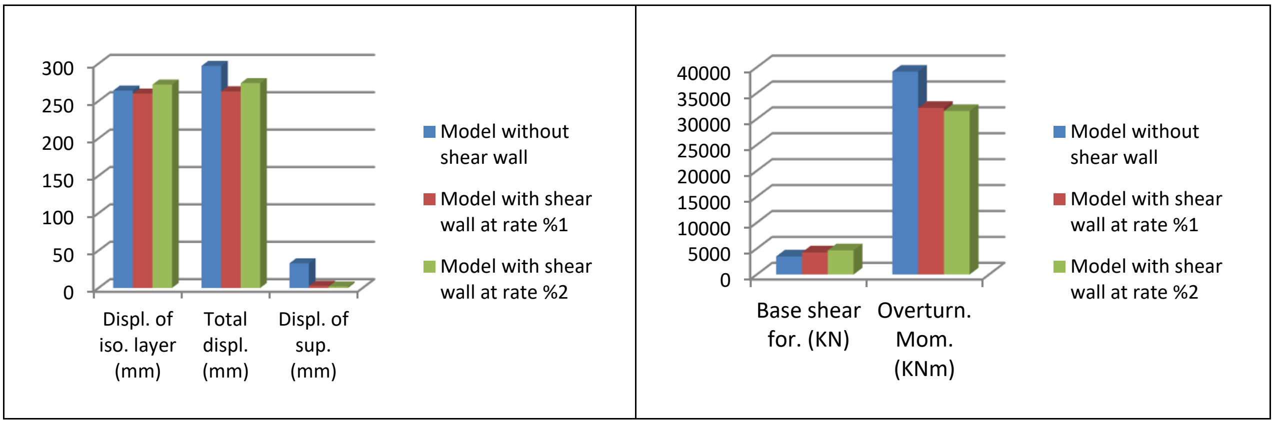

Fig. 9. Graphics of nonlinear dynamic analysis in the time history method of the isolated models

3.4 The seismic behaviors comparing of the isolated models with different superstructure stiffness and story number

The dynamic analyses have been carried out as "**5 story**, "**10 story** and with shear wall in turn at the rate 1% and 2% of floor area, in order to show its effects on the structure height behaivour in the seismic behavior of base isolated structure. The results of the dynamic analyses are given in the table 6. While the period of 5 story model is about 2 s, this period of 10 story model is over 3 s. Compared to the 10-story models, the amount of displacement at the isolation layer level has increased in 5 story model. Besides, the design values must be revised because of the distance from the expected period in the preliminary design. For the superstructure stiffness, the shear wall placing at the rate % 2 hasn't more important behavior contributions than the shear wall placing at the rate % 1 of the floor area in the 5 story building. But it appears that the placing at rate % 2 in 10 story model has more positive contribution to the rigid mass movement of the superstructure. While the shear wall placing at rate % 1 of floor area caused a displacement of 12 mm in superstructure, the shear wall placing at rate % 2 provides almost completely the rigid mass movement. Besides it has been seen that the shear wall placing at rate % 2 causes the less base shear forces. Because of the story increasing, the Overturning risk of the structure has reached to the limit values for 10-story buildings. Therefore, I f the structure height is over the 10 story, the additional dampers must be used in order to reduce the earthquake forces in the building. If the designed as base isolated structure requires a shear wall placing, then this shear wall placing must be applied in determined amount in the disaster regulation and in recommended amount for the fixed supported structures. It is detected that the superstructure has almost completely rigid mass movement. But the shear walls must be designed without ductility criteria and that they can safely carry the vertical loads (Table 6 and Fig. 10).

Table 6. The results of nonlinear dynamic analysis in the time history method of isolated models and the models with different story units

	Shear wall placing at rate %1 and 5 story model	Shear wall placing at rate %2 and 5 story model	Shear wall placing at rate %1 and 10 story model	Shear wall placing at rate % 2 and 10 story model
Period (T_1)	2.11	2.24	3.01	3.13
Displacement of isolation layer (mm)	260	272	290	280
Total displacement (mm)	263	274	302	279
Displacement of superstructure (mm)	3	2	12	1

Base shear force (KN)	4259	4654	5816	4675
Overturning Moment (KN.m)	32154	31540	71203	9345

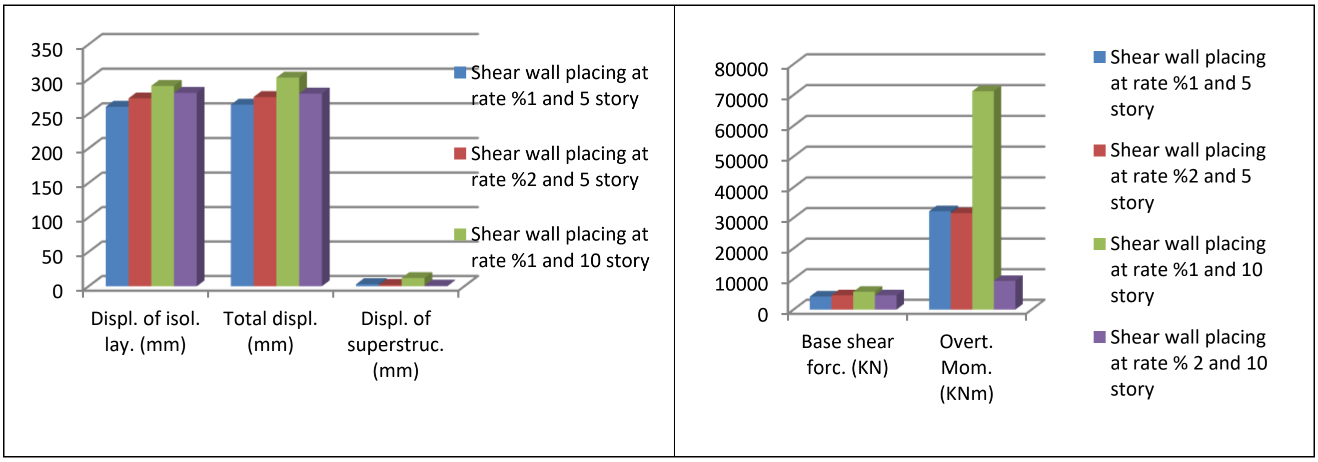

Fig. 10. Graphics of nonlinear dynamic analysis in the time history method of isolated models and the models with different story units

4 CONCLUSION

In this study, it has been searched the effects of the base isolation on the seismic behavior of structures. As the results of the analyses on the fixed supported and seismic isolated models, it has been seen that the seismic isolation has many positive effects on the seismic behaviours of the structures. Moreover, it has been searched the effects of the parameters such as superstructure stiffness and building height for the designed base isolated structures.
The elastomeric bearings with lead core have been used as isolation system. In the isolated structure model, the natural vibration period has been significantly increased to prevent the access of the vibration to structure, leaving from the main bearing system because of the isolation. Thus the spectral accelerations for the building have been significantly decreased.

The expected rigid mass movement of the isolated structure has been observed with the results of analyses. As the positive effects of the isolation, the relative displacements between stories and the exposed seismic forces of the structure have decreased. According to the comparing of the base shears for the isolated and fixed supported structures, the isolated structure has a less shear force at the rate 1/5. However, this positive effect decrease in the design phase, because the lessening factor R is accepted lower in the seismic isolation systems (R_{fixed}=8 and $R_{isolated}$=2). Furthermore it has been seen that the increasing of the superstructure stiffness has a positive contribution to seismic behavior of the isolated structure. In addition, the superstructure stiffness can be provided without the increasing of the structure- weight by using the steel diagonals. Also, it is estimated that the reinforced infill walls with Fiber Reinforced Polymer (FRP) can increase the superstructure stiffness and this must be experimental searched, because the shear forces in the superstructure and relatively storey displacements are low.
If high nonlinear materials have been selected as isolation system, the nonlinear dynamic analysis is required. Otherwise the effects of the isolation system on the structural dynamic behavior can not be fully reflected. The nonlinear properties of the isolation system may stimulate the higher modes of structure and this is an important issue for the seismic behavior of the isolated structure.

If the weakness of the foundation soil has negative effects on the isolated structures. The weaker the isolated structure soil is, the more it moves away from the rigid mass movement and more exposed to seismic forces. The range of the dominated vibration period for the soil enlarges because of the soil-weakness. The enlargement of the natural vibration period in the structure by the isolation system doesn’t cause the decreasing on the spectral accelerations as well as on the sturdy soils. Thus, the soil effect is an important issue to be taken into consideration in the design of isolated systems.

REFERENCES

[1] Chopra, A. K. “Dynamics of Structures”, Prentice Hall International Inc., New Jersey, USA. pp.683-702, 1995.

[2] Malangone, P., Ferraioli, M. “A Modal Procedure for Seismic Analysis of Nonlinear Base Isolated Multy-story Structures.” *Earthquake Engineering and Structural Dynamics*, 27:397-412, 1998. DOI: 10.1002/(SICI)1096-9845(199804)27:4<397::AID-EQE736>3.0.CO;2-Y.

[3] Cimilli, S. “Seismic Isolation with Elastomeric Pads”, M.Sc. Thesis, University of Bosporus, 2001.

[4] Turkmen, F. “Comparative Study of Base Isolated Systems”, M.Sc. Thesis, Middle East Technical University, 2001.

[5] Sener, M., Arıoglu, E., Alper, T., Kelly, T. “Usage of Seismic Base Isolation to Reduce Ductility Demand from Prefabricated Concrete Structures”, Proceedings of 17th BIBM International Congress of the Precast Concrete Industry, İstanbul, 2002.

[6] Matsagar, V. A., Jangid, R.S. “Influence of isolator characteristics on the response of base-isolated buildings.” *Engineering Structures*, 26(12):175-185, 2004. DOI: 10.1016/j.engstruct. 2004.06.011.

[7] Elma, M. “The effects of the superstructure rigidity on the seismic behaviour of the base isolated structure”, M.Sc. Thesis, Selcuk University, Konya, Turkey, 2006.

[8] Guerreiro, L., Craveiro, A., Branco, M. “The use of passive seismic protection in structural rehabilitation.”, *Prog. Struct. Engineering Material*, 8:1-15, 2006. DOI: 10.1002/pse.219.

[9] Thermou, G. E., and A. S. Elnashai. "Seismic retrofit schemes for RC structures and local-global consequences." *Progress in Structural Engineering and Materials* 8.1: 1-15, 2006. DOI: 10.1002/pse.208.

[10] Ibrahim, R.A. “Recent advances in nonlinear passive vibration isolators”, *Journal of Sound and Vibration*, 314: 371–452, 2008. DOI:10.1016/j.jsv.2008.01.014.

[11] Tena-Colunga, A. and Escamilla-Cruz J. "Torsional amplifications in asymmetric base-isolated structures." *Engineering Structures*, 29(2), 237-247, 2007. Doi:10.1016/j.engstruct. 2006.03.036.

[12] Pourzeynali, S., Zarif, M. “Multi-objective optimization of seismically isolated high-rise building structures using genetic algorithms.” *Journal of Sound and Vibration,* 311: 1141–1160, 2008. DOI: 10.1016/j.jsv.2007.10.008.

[13] Providakis, C.P. “Pushover analysis of base-isolated steel-concrete composite structures under near-fault excitations.” *Soil Dynamics and Earthquake Engineering*, 28: 293-394, 2007. DOI: 10.1016/j.soildyn.2007.06.012.

[14] Kilar, V., Koren, D. “Seismic behaviour of asymetric base isolated structures with various distributions of Isolators.”,*Engineering Structures*, 31: 910-921, 2009. DOI: 10.1016/ j.engstruct. 2008.12.006.

[15] Sivapalan, G., Duraisamy, S. S. “Modeling of energy dissipationin structural devices and foundation soil during seismicloading.” *Soil Dynamics and Earthquake Engineering*, 31:1106–1122, 2011. DOI: 10.1016/j.soildyn.2011.02.006.

[16] Islam, A.B.M.S., Hussain, R. R., Jameel, M., Jumaat, M. Z. “Non-linear time domain analysis of base isolated multi-storeyed building under site specific bi-directional seismic loading.”, *Automation in Construction*., 22. 554-566, 2012. DOI: 10.1016/ j.autcon.2011.11.017.

[17] Islam, A.B.M.S., Jumaat, M.Z., Hussain, R.R., Hosen, A., Huda, N. (2015). “Incorporation preference for rubber-steel bearing isolation in retrofitting existing multi storied building.” *Computers and Concrete*, 16(4): 503-529, 2015. DOI: http://dx.doi.org/10.12989/ cac.2015.16.4.503.

[18] Konstantinidis, D., Nikfar, F. “Seismic response of sliding equipment and contents in base-isolated buildings subjected to broadband ground motions.” *Earthquake Engineering & Structural Dynamic*s, 44(6): 865–887, 2015. DOI: 10.1002/eqe.2490.

[19] Wolff, E. D., Ipek, C., Constantinou, M. C., Tapan, M. “Effect of viscous damping devices on the response of seismically isolated structures.” *Earthquake Engineering & Structural Dynamics*, 44(2):185–198, 2015. DOI: 10.1002/eqe.2464.

[20] Sarlis, A. A., Pasala, D. T. R., Michael C., Constantinou, M., Andrei M. Reinhorn, F., Satish Nagarajaiah, M., Taylor, Douglas P. “Negative Stiffness Device for Seismic Protection of Structures: Shake Table Testing of a Seismically Isolated Structure.” *J. Struct. Eng.*, 142(5): 04016005, 2016. DOI: 10.1061/(ASCE)ST.1943-541X.0001455.

[21] Afshar, M.A., Pour, S.A.“On inertia nonlinearity in irregular plan isolated structures under seismic excitations”, *Journal of Sound and Vibration*, 363: 495-516, 2016. http://dx.doi.org/ 10.1016/j.jsv.2015.11.015.

[22] D.I.S. “Seismic Isolation Catologue”. Dynamic Isolation Systems, Inc., Nevada, USA, 2007.

[23] Naeim, F., Kelly, J.M. “Design of Seismic Isolated Structures-From Theory to Practice”, John Willey and Sons, Inc. pp.47-58, 1999.

[24] Celep, Z., Kumbasar, N. “Earthquake Engineering Introduction and Earthquake Resistant Design”. Beta Distribution. Istanbul. pp.589-624, 2004.

[25] I.B.C. “International Building Code”, International Code Council (formerly BOCA, ICBO, and SBCCI), 2009.

[26] SAP2000N V.18.01. “SAP2000N Analysis Reference”, Computers and Structures Inc., Berkeley, California., USA, 2016.

APPENDIX A:

STATIC WORK PLAN OF THE SCHOOL BUILDING FOR THE ANALYTICAL APPLICATION

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