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Seismic Base Isolation in Reinforced Concrete Structures

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Abstract: *Seismic hazards are a major concern in many populous regions of the world. Performance-based seismic design has brought about new technological advances and introduced an innovative approach to constructing seismic-resistant buildings. Base isolation systems are increasingly utilized methods of advanced seismic resistance, and the effects of these systems on the seismic responses of structures are studied in this paper. In order to verify the effect of base isolation system, two different structures are presented (symmetrical and non-symmetrical school buildings) in which the seismic responses of the 'fixed-base' and 'base-isolated' conditions have been compared using SAP2000 (a well-known computer program). The high damping rubber isolation system has been used and devices have been installed at the foundation level. Time history analysis has been performed on three earthquakes: El Centro, Loma and Coyote. Comparing the results of the base-isolated condition with those obtained from the fixed-base condition has shown that the base isolation system reduces the base shear force and story drifts, whilst also increasing the displacement.*

Keywords: *Base isolation, Rubber, Earthquake, Drift, Base shear*

1. Introduction

Earthquakes are one of nature's greatest hazards; throughout historic time they have caused significant loss of life and severe damage to property, especially to man-made structures. On the other hand, earthquakes provide architects and engineers with a number of important design criteria foreign to the normal design process. From well established procedures reviewed by many researchers, seismic isolation may be used to provide an effective solution for a wide range of seismic design problems.

The application of the base isolation techniques to protect structures against damage from earthquake attacks has been considered as one of the most effective approaches and has gained increasing acceptance during the last two decades. This is because base isolation limits the effects of the earthquake attack, a flexible base largely decoupling the structure from the ground motion, and the structural response accelerations are usually less than the ground acceleration [1].

Many comparative studies have revealed that the responses of the isolated structure are significantly smaller than the fixed base structure [2], [3], [4], [5], and [6]. Most of these studies compared the seismic demands (e.g. inter story drift, floor acceleration and base shear) for the two types of building structures, but only a limited number of studies investigated the responses of the isolated structure using high damping rubber (HDR) isolation with detailed procedures of the design of HDR. Skinner et al. [7] indicated that a base isolator with hysteretic force-displacement characteristics can provide the desired properties of isolator flexibility, high damping and force limitation under horizontal earthquake loads, together with high stiffness under smaller horizontal loads to limit wind-induced motions.

Kelly [8] gave a brief introduction to the response mechanisms of base isolated buildings through two degrees of freedom linear system. The effectiveness of the isolation system to mitigate the seismic response is through its ability to shift the fundamental frequency of the system out of the range of frequencies where the earthquake is strongest. Also, Skinner et al. [7] demonstrated that the most important feature of seismic isolation is that its increased flexibility increases the natural period of the structure. Because the period is increased beyond that of the earthquake, resonance is avoided and the seismic acceleration response is reduced.

Han et al. [9] studied the seismic risk analysis for an old non-ductile RC frame building before and after retrofit with base isolation with LRBs. They found that that the viscous damping, concrete compressive strength, steel yield stress and the beam–column joint parameter that defining the elastic range of the joint has the most impact on the structural seismic demand for the un-retrofitted building;

for the isolated buildings the temperature also have significant effects on the seismic demand. Base isolation was found to be effective in reducing seismic risk for higher damage levels.

Acar [1] studied the effect of HDR isolation on the seismic responses of different structures using IBC2000 and FEMA design codes and concluded that the site condition where earthquake data is recorded has a great influence on the design parameters of the structure. That is as the soil becomes softer, the response of the structure increases. Therefore the selected ground motion data must have been recorded on similar soil condition with the site where the structure is located.

In this paper, the effect of base isolation system on seismic responses of structures is studied. Two different structures are presented (regular and irregular 5-storey school buildings) in which the seismic responses of the fixed-base condition and HDR isolation condition have been compared using the well known computer program SAP2000 [10]. Time history analysis is performed using three earthquakes; El centro, Loma and Coyote.

2. Types of Base Isolators

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The successful seismic isolation of a particular structure depends on the appropriate choice of the base isolation devices. The basic features of an isolation system are identified as:

- An increased flexibility so that the natural period of the structure is increased sufficiently to shift the frequency of the structure out of the range of dominant frequency of earthquake.
- A capacity for dissipating earthquake energy for resisting excessive horizontal displacement at the base of the building.

It is also necessary to provide an adequate seismic gap (between the structure and the surrounding foundations) which can accommodate the isolator displacements.

Many different forms of practical base isolation systems have been developed to provide seismic protection for buildings, including laminated elastomeric rubber bearings, lead rubber bearings, high damping rubber bearing, and friction pendulum sliding bearing [11].

2.1. Laminated Rubber (Elastomeric) Bearing

Laminated rubber bearings are constructed of alternating rubber layers bonded to intermediate reinforcing plates that are typically steel as illustrated by the schematic of a deformed bearing shown in Fig1. The total thickness of rubber provides the low horizontal stiffness need to achieve the period shift whereas the spacing of the steel shim plates controls the vertical stiffness of the bearing for a given shear modulus and bonded rubber area [12].

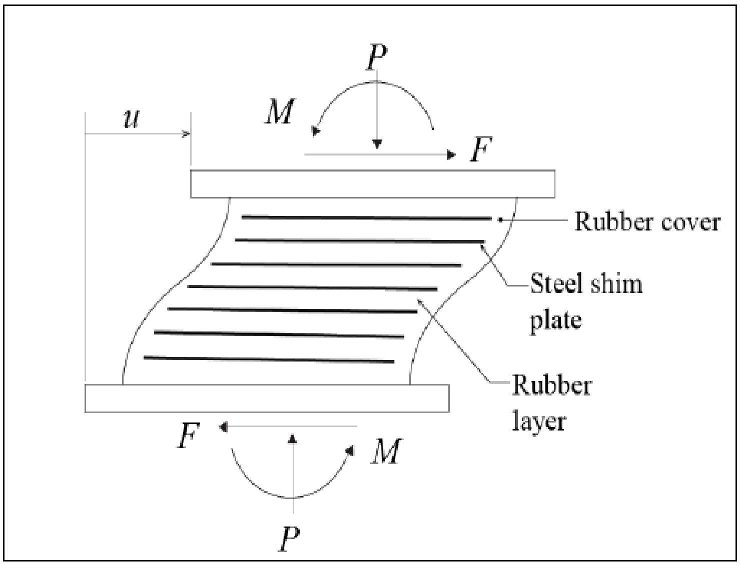

Fig1. *Schematic of a laminated rubber bearing in the laterally deformed configuration*

2.2. High Damping Rubber (HDR) Bearing

The energy dissipation in high-damping rubber bearings is achieved by special compounding of the elastomeric. Damping ratios will generally range between 8% and 20% of critical. The shear modulus of high-damping elastomeric generally ranges between 0.34 MPa and 1.40 MPa. The material is nonlinear at shear strains less than 20% and characterized by higher stiffness and damping, which minimizes the response under wind load and low-level seismic load. Over the range of 20-120% shear strain, the modulus is low and constant. At large shear strains, the modulus and energy dissipation increase. This increase in stiffness and damping at large strains can be exploited to produce a system that is stiff for small input, is fairly linear and flexible at design level input, and can limit displacements under unanticipated input levels that exceed design levels [12]. HDR bearing is shown in Fig2.

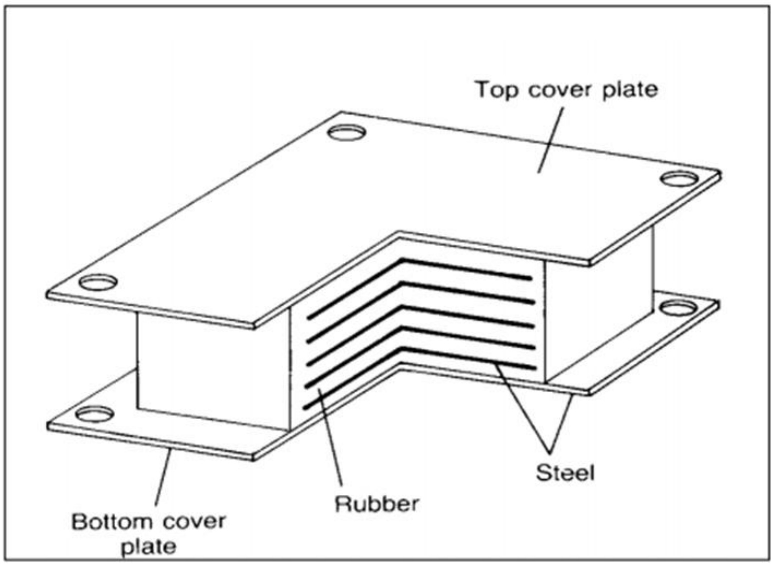

Fig2. *High damping rubber bearing [13]*

2.3. Lead Rubber Bearing (LRB)

Lead-plug bearings are generally constructed with low-damping elastomers and lead cores with diameters ranging 15% to 33% of the bonded diameter of the bearing as shown in Fig3. Laminated-rubber bearings are able to supply the required displacements for seismic isolation [12]. By combining them with a lead-plug insert which provides hysteretic energy dissipation, the damping required for a successful seismic isolation system can be incorporated in a single compact component.

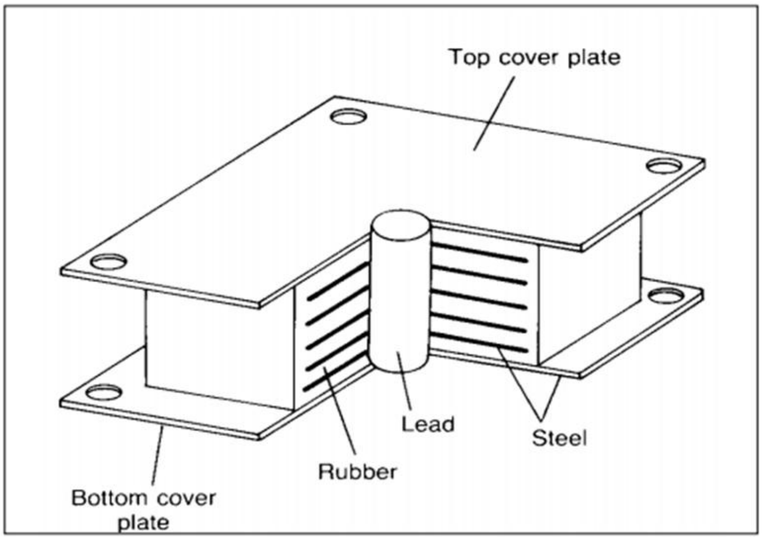

Fig3. *Lead Rubber Bearing [13]*

2.4. Friction Pendulum Sliding (FPS) Bearing

The concept of sliding bearings is also combined with the concept of a pendulum type response, obtaining a conceptually interesting seismic isolation system known as a friction pendulum system (FPS) [14] as shown in Fig. 4. In FPS, the isolation is achieved by means of an articulated slider on spherical, concave chrome surface.

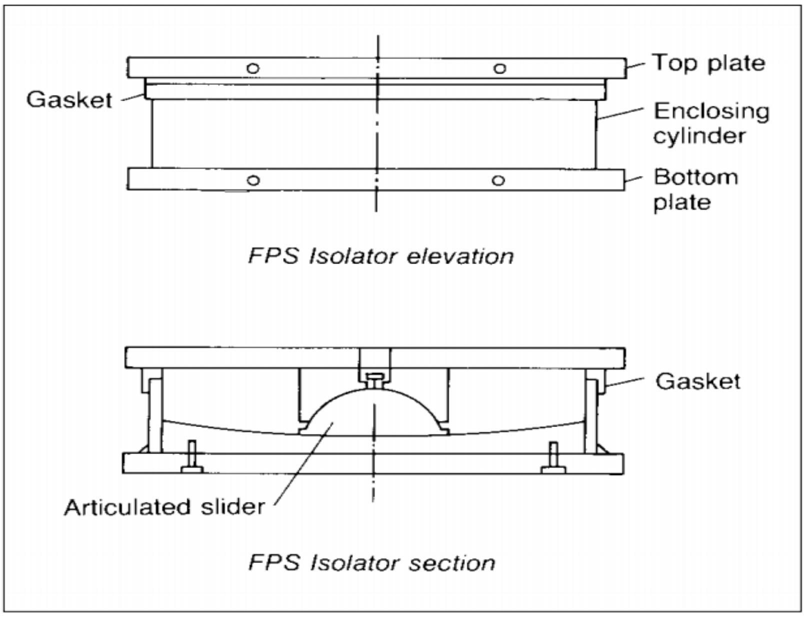

Fig4. *Friction pendulum system [13]*

3. DETAILS OF MODEL

In this research, the evaluation and comparison of seismic responses of base isolated structures with those of fixed base are performed. Two different structures are presented in this study, the first structure is regular and the second is irregular.

3.1. The Regular Structure

The symmetric structure consist of 5-storey reinforced concrete school building with regular plan. The school plan and elevation are shown in Fig. 5, Fig. 6 and Fig. 7. The slab thickness is 16 cm, the column section 55x55 cm and beam section is 30 x 70 cm.

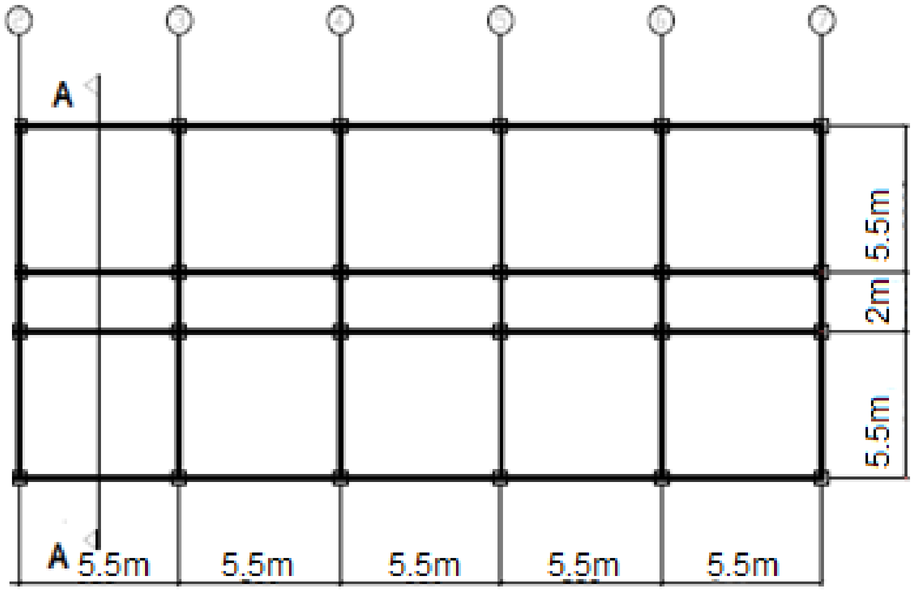

Fig5. *Plan view of the regular structure*

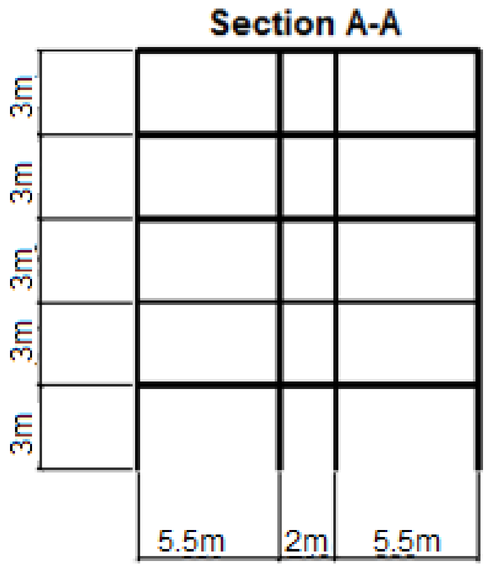

Fig6. *Sectional view of the regular structure*

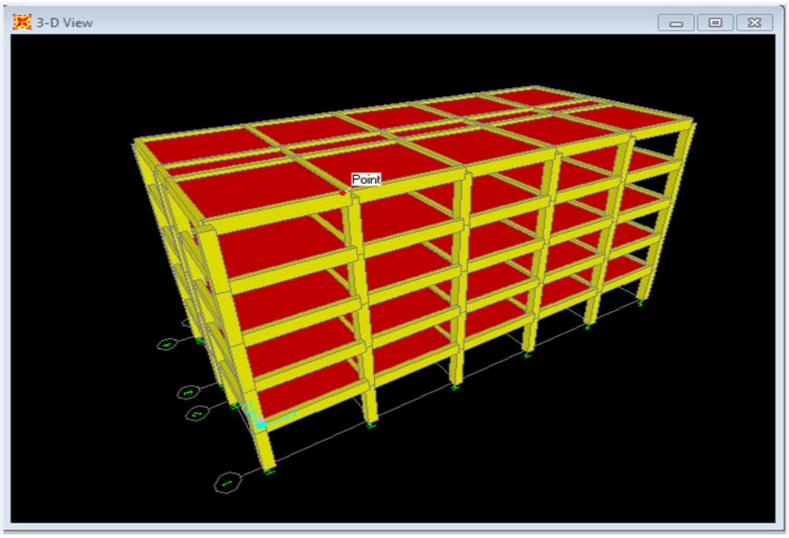

Fig7. *3D view of the symmetric building*

For isolating the structure, 24 units (HDR) are used. The basic structural data to be used for the design is as follows:

TD = 2.10 sec. (Target period for 'Design Level' earthquake)

TM = 2.50 sec. (Target period for 'Max. Capable Level' earthquake)

R = 1.00 (Seismic load reduction factor)

G = 550 kN/m^2 (shear modulus of HDR)

G = 700 kN/m^2 (small shear strain)

K = 2,000,000 kN/m^2 (Bulk modulus)

β = 15% (Damping ratio of isolator)

WT = 14068 kN (Total weight of the structure)

γmax = 150%

3.1.1. Lateral Stiffness of Base Isolators

By using the equation for ‘Design Level Earthquake’ [15]:

$$T_D = 2\pi\sqrt{\frac{W}{K_h g}} \tag{1}$$

$$2.1 = 2\pi\sqrt{\frac{14068}{K_{total}\times 9.81}} \rightarrow K_{total} = 11697\,kN/m$$

$K_h = \frac{11697}{24} = 487\,kN/m$ (for one bearing)

For ‘Maximum Capable Earthquake Level’:

$$2.5 = 2\pi\sqrt{\frac{14068}{K_{total}\times 9.81}} \rightarrow K_{total} = 6290\,kN/m$$

$K_M = \frac{6290}{24} = 262\,kN/m$ (for one bearing)

Where k_D and k_M are the minimum lateral stiffness of base isolation bearings corresponding to the ‘design earthquake’ and ‘maximum capable earthquake’, respectively.

3.1.2. Estimation of Lateral Displacements

From the equation [15]:

$$D_D = \left(\frac{g}{4\pi^2}\right)\frac{S_{D1}T_D}{B_D} \tag{2}$$

where:

BD = Numerical coefficient related to the effective damping of the isolation system at design displacement,

g = Acceleration of gravity

SD1 = Design 5% damped spectral acceleration at 1 sec. period

TD = Isolated period at design displacement

$$D_D = \left(\frac{9.81}{4\pi^2}\right)\frac{0.65\times 2.1}{1.38} = 0.24$$

$$D_M = \left(\frac{9.81}{4\pi^2}\right)\frac{0.65\times 2.5}{1.38} = 0.29$$

where DD and DM are the displacements of the isolation system corresponding to the ‘design earthquake’ and ‘max. capable earthquake’, respectively. The damping reduction factor B=1.38 is obtained from Equation $\frac{1}{B_D} = 0.25(1 - \ln\beta)$ [15].

3.1.3. Estimation of Disc Dimensions

Thickness of the disc can be calculated by, $t_r = \frac{D_D}{\gamma_{max}} = \frac{0.24}{1.5} = 0.16m$, take tr=20 cm

Disc diameter, Φ is estimated by using the equation [12]:

$$K_h = \frac{GA}{t_r} \rightarrow A = \frac{K_h t_r}{G}$$

$$A = \frac{487\times 0.2}{550} = 0.177\,m^2 \rightarrow \phi = \sqrt{\frac{4A}{\pi}} = 0.475\,m \tag{3}$$

Take $\phi = 50cm$

3.1.4. Bearing Detail

For compressive stresses under vertical loads, the isolators undergo relatively smaller shear strain on older γ = 0.2 therefore G= 700 KN/m should be used. Shape factor, S, is selected as 8. The compression modulus, Ec, from the equation [12]

$$E_c = \left(\frac{1}{6GS^2} + \frac{1}{K}\right)^{-1} \quad (4)$$

Where:

Ec : Compression Modulus, S : Shape Factor (5< S < 30)

K : Bulk Modulus (1000MPa < K < 2500 MPa), G : Shear Modulus (0.5MPa < G < 2.5 MPa)

$$E_c = \left(\frac{6\times700\times8^2\times2000000}{6\times700\times8^2+2000000}\right) = 236953 kN/m^2$$

where the total vertical stiffness is determined from the equation [12]:

$$K_V = \frac{E_c A}{t_r} \quad (5)$$

$$K_V = \frac{236953\times24\times0.177}{0.2} = 5032881 kN/m$$

$$K_V = \frac{5032881}{24} = 209700 kN/m$$ (for one bearing)

From the equation $S = \frac{\phi}{4t_0} \rightarrow t_0 = \frac{500}{4\times8} \approx 16 mm$

$$n\times t_0 = 10\times16 = 160\,mm (n = 10 layers)$$

Consequently, the design of the bearing is completed as shown in Fig. 8. The end plates are 25mm thick, and the steel shims are 2mm each. The total height is:

$$h = (2\times25) + (10\times16) + (9\times2) = 228mm$$

Steel shims will have a diameter Φs = 490 mm, giving 5mm cover.

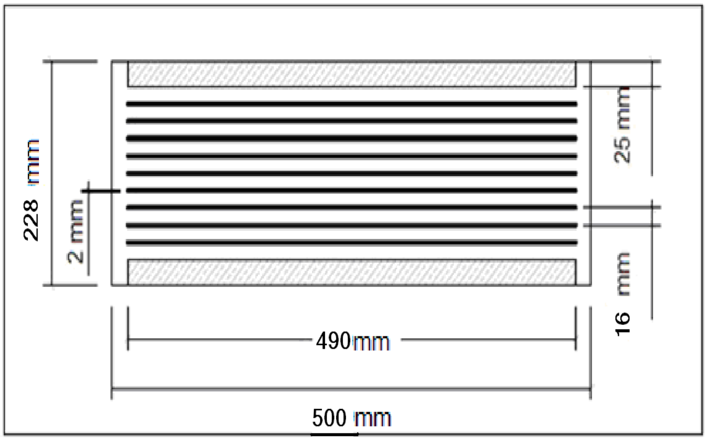

Fig8. *Detail design of isolator*

- Material and Structural Properties:

Weight per unit volume = 25 kN/m³

Modulus of elasticity, Ec = 24855500 kN/m²

Poisson's ratio = 0.20

Shear modulus = 10356490 kN/m²

Co-efficient of thermal Expansion = 9.9E-06

Gravity loads on the structure include the self-weight of beams, columns, slabs. The self-weight of beams and columns (frame members) and slabs (area sections) is automatically considered by the program itself.

3.2. The Irregular Structure

The non-symmetric structure is 5-storey reinforced concrete school building with irregular plan. The school plan and elevation are shown in Fig. 9, Fig. 10 and Fig. 11.

The slab thickness is 16 cm, the column section 55x55 cm and beam section is 30 x 70 cm.

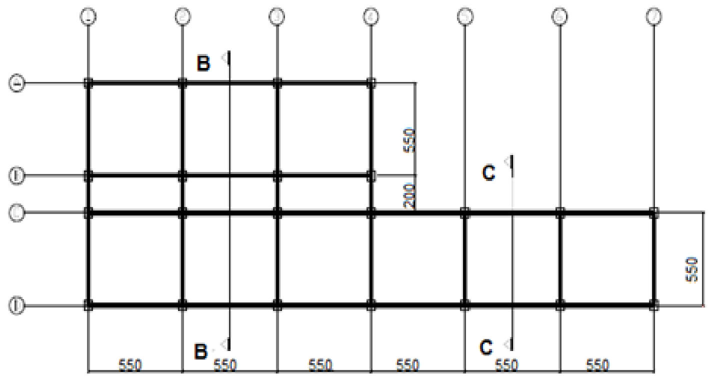

Fig9. *Plan view of the irregular structure*

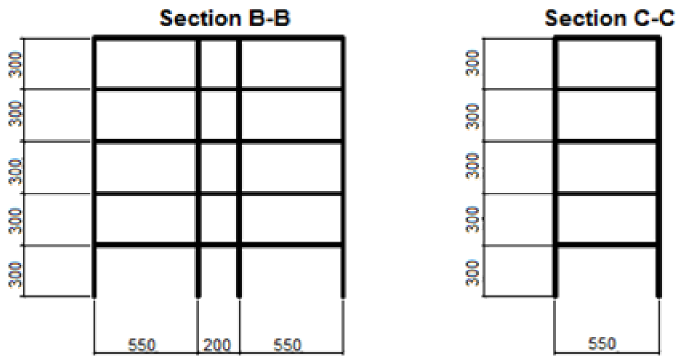

Fig10. *Sectional view of the irregular structure*

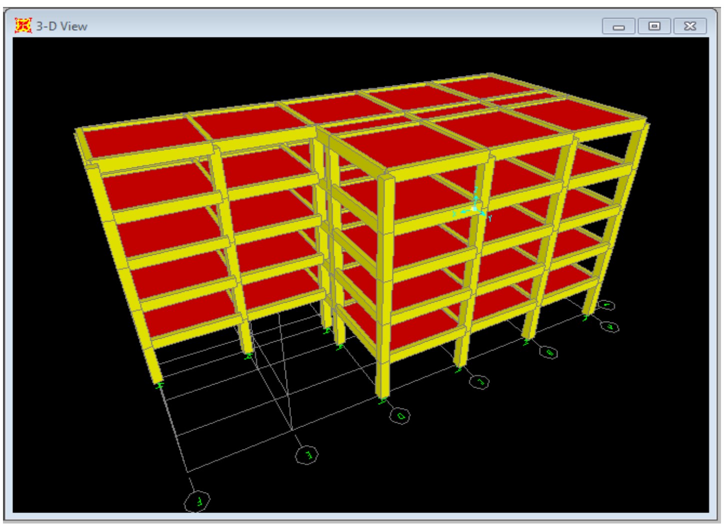

Fig11. *3D view of the non-symmetric building*

4. ANALYSIS AND RESULTS

Time history analysis is carried out to find seismic responses of structures using SAP 2000 software [10]. For time history analysis, three different earthquakes have been used El centro, Loma and Coyote.

4.1. The Symmetrical Building

4.1.1. Scaling of the Results

The symmetrical building is analyzed with time history analysis and the results of the analysis are scaled according to IBC2006 [16]. The parameters needed for the calculation of scaling factors are given below. The damping coefficient, B_D, is taken as 1.38 in the analysis. The fixed based period, T, and isolated period, T_D, of the building are given in Table 1.

Table1. *Fixed and isolated periods of the building*

T (sec.)	0.65
TD (sec.)	2.7

When IBC2006 is considered, the design displacement determined by time history analysis, $D_{analysis}$, must be greater than 90% of D_{TD}.

$$D_{TD} \geq D_D\left[1 + y\left(\frac{12e}{b^2 + d^2}\right)\right] \text{ (ASCE 7-05)} \quad (6)$$

Where:

d = Shortest plan dimension, b = Longest plan dimension

e = The actual eccentricity measured in plan between the center of mass of the structure and the center of stiffness of the isolation system, plus the accidental eccentricity taken as 5% of the longest plan dimension of the structure perpendicular to the direction of seismic loading under consideration.

On the other hand, the design base shear force on the structure above the isolation system must be greater than 60% of VS.

$$V_S = \frac{K_h D_D}{R} \text{ (ASCE 7-05)} \quad (7)$$

Otherwise, all response parameters, including component actions and deformations, must be adjusted proportionally upward. When the results of the analyses are examined, it is seen that the first scaling limit, D analysis> 90% of DTD, is more critical than the second one and results in greater scaling factors. Therefore, it is used in the scaling factor calculations. Table 2 shows the calculations of scaling factor.

Table 2. *Calculation of scaling factor for symmetric building*

SD1	DD (cm)	DTD (cm)	0,9*DTD (cm)	Danalysis (cm)	Scaling Factor
0.65	31.9	39.9	35.9	41	No need to scale

4.1.2. Results of the Analyses

The seismic responses of the fixed-base condition and base-isolated condition have been compared using the well known computer program SAP2000 [10]. The comparison about base shear force, base moment, drifts, time period and displacements.

Table 3 shows the time period of the symmetrical building for fixed-base and base-isolated conditions and for different mode shapes. The base shear, base moment and drift are shown in Table 4, and displacements for symmetrical building are shown in Table 5.

Table3. *Time period for symmetrical building*

NUMBER	MODE SHAPE	TIME PERIOD (Sec.) FIXED BASE	TIME PERIOD (sec) HDR isolation
1	Mode	0.658218	3.569026
2	Mode	0.649716	3.234535

3	Mode	0.627309	3.210074
4	Mode	0.555953	1.104608
5	Mode	0.481895	0.716263
6	Mode	0.475950	0.693995
7	Mode	0.391598	0.497831
8	Mode	0.345471	0.414016
9	Mode	0.212128	0.367000
10	Mode	0.207803	0.338713
11	Mode	0.207291	0.332619
12	Mode	0.202469	0.328168

Table4. *Base shear, base moment and drift for symmetric building*

	Fixed base	HDR isolation
Base Shear in X Direction (kN)	13940	3557
Base Shear in Y Direction (kN)	14393	3506
Base Moment in X Direction (kN.m)	106042	21247
Base Moment in Y Direction (kN.m)	102504	21266
Max. Inter story Drift Ratio	0.003	0.0007

Table5. *Displacements for symmetrical building*

FLOORS	Displacement - FIXED BASE (m)	Displacement - HDR isolation (m)
1	0.019620	0.396366
2	0.042210	0.402285
3	0.062072	0.406728
4	0.077233	0.410260
5	0.086344	0.412882

4.2. The Non-Symmetrical Building

4.2.1. Scaling of the Results

The non-symmetrical building is analyzed with time history analysis and the results of the analysis are scaled according to IBC2006 [16]. The parameters needed for the calculation of scaling factors are given below. The damping coefficient, B_D, is taken as 1.38 in the analysis. The fixed based period, T, and isolated period, T_D, of the building are given in Table 6.

Table6. *Fixed and isolated periods of the building*

T (sec.)	0.42
TD1 (sec.)	2.2

When IBC2006 is considered, the design displacement determined by time history analysis, $D_{analysis}$, must be greater than 90% of D_{TD}. On the other hand, the design base shear force on the structure above the isolation system must be greater than 60% of V_S.

Otherwise, all response parameters, including component actions and deformations, must be adjusted proportionally upward. When the results of the analyses are examined, it is seen that the first scaling limit, $D_{analysis}$> 90% of D_{TD}, is more critical than the second one and results in greater scaling factors. Therefore, it is used in the scaling factor calculations. Table 7 shows the calculations of scaling factor.

Table7. *Calculation of scaling factor for non-symmetric building*

SD1	DD (cm)	DTD (cm)	0,9*DTD (cm)	Danalysis (cm)	Scaling Factor
0.65	26	32.5	29.2	23.7	1.23

4.2.2. Results of the Analyses

The seismic responses of the fixed-base condition and base-isolated condition have been compared using the well known computer program SAP2000 [10]. The comparison about base shear force, base moment, drifts, time period and displacements. The results of the analyses of non-symmetrical building are given in Table 8, Table 9 and Table 10.

Table8. *Time period for non-symmetrical building*

NUMBER	MODE SHAPE	TIME PERIOD (Sec.) FIXED BASE	TIME PERIOD(sec) HDR isolation
1	Mode	0.420381	2.284028
2	Mode	0.412645	2.239728
3	Mode	0.385632	2.001638
4	Mode	0.143878	0.223116
5	Mode	0.141336	0.199693
6	Mode	0.131892	0.183423
7	Mode	0.089393	0.112006
8	Mode	0.089094	0.101025
9	Mode	0.082799	0.100472
10	Mode	0.06956	0.09828
11	Mode	0.06936	0.093533
12	Mode	0.064346	0.086521

Table9. *Base shear, base moment and drift for non-symmetrical building*

	Fixed base	HDR isolation
Base Shear in X Direction (kN)	13203	3725
Base Shear in Y Direction (kN)	11840	3176
Base Moment in X Direction (kN.m)	89441	19103
Base Moment in Y Direction (kN.m)	103152	21748
Max. Inter story Drift Ratio	0.001	0.0005

Table10. *Displacements for non-symmetrical building*

FLOORS	Displacement - FIXED BASE (m)	Displacement - HDR isolation (m)
1	0.013386	0.349444
2	0.026169	0.353933
3	0.037012	0.35757
4	0.045247	0.360337
5	0.050230	0.362214

Comparing the base shear force in the base-isolated condition with those obtained from the fixed-base condition for symmetrical building has shown in Figure 12 and Figure 13.

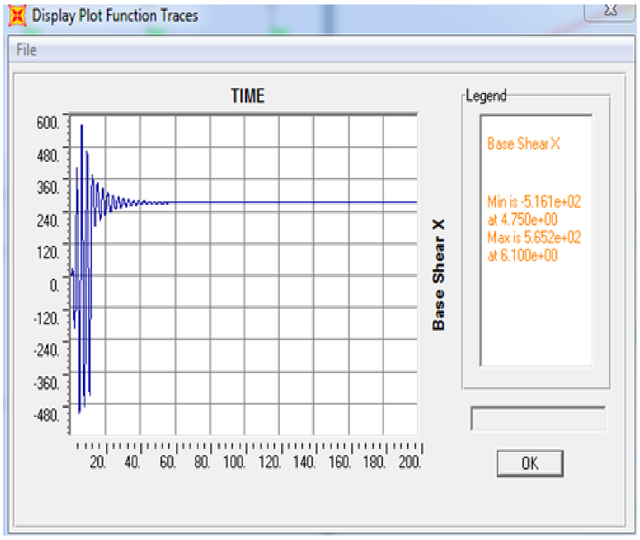

Fig12. *Base shear force in rubber isolation along x direction*

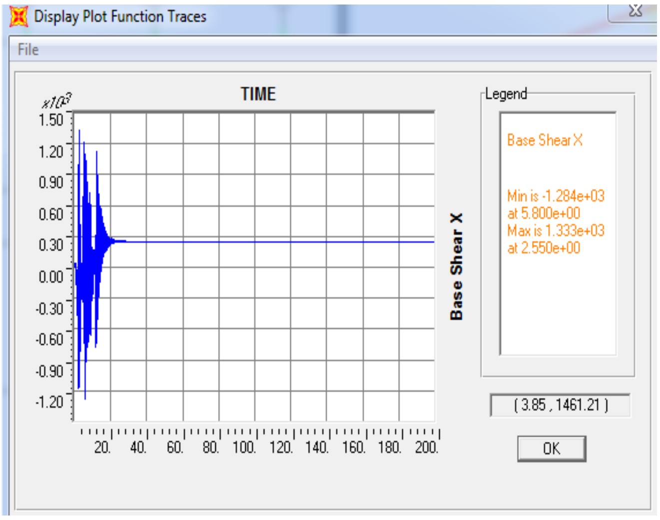

Fig13. *Base shear force in base -fixed along x direction*

5. Conclusion

- The results of the study shows that the response of the structure can be reduced by using base isolation.
- Comparing the results of the base-isolated condition with those obtained from the fixed-base condition has shown that the base isolation system reduces the base shear force and story drifts, whilst also increasing the displacement as the following:
  - The base shear in x-direction is equal to 3557 kN for the base-isolated condition while it is equal to 13940 kN in fixed-base condition for symmetric building.
  - The base shear in y-direction is equal to 3506 kN for the base-isolated condition while it is equal to 14393 kN in fixed-base condition for symmetric building.
  - The base moment in x-direction and y direction for the base-isolated condition is less than the moment for the fixed base condition.
  - The drift ratio is (0.0007) for the base-isolated condition while it is 0.003 for the fixed-base condition.

References

[1] Acar E. Comparison of design specifications for seismically isolated buildings. M.Sc thesis, Middle east technical university, Turkey 2006.

[2] Sayani Prayag J, Ryan Keri L. Comparative evaluation of base-isolated and fixed-base buildings using a comprehensive response index. J Struct Eng 2009;135(6):698–707.

[3] Erduran E, Dao ND, Ryan KL. Comparative response assessment of minimally compliant low-rise conventional and base-isolated steel frames. Earthquake Eng Struct Dyn 2011;40(10):1123–41.

[4] Karim KR, Yamazaki F. Effect of isolation on fragility curves of highway bridges based on simplified approach. Soil Dyn Earthquake Eng 2007;27(5):414–26.

[5] Zhang J, Huo Y. Evaluating effectiveness and optimum design of isolation devices for highway bridges using the fragility function method. Eng Struct 2009;31(8):1648–60.

[6] Huang YN, Whittaker AS, Luco N. Performance assessment of conventional and base-isolated nuclear power plants for earthquake and blast loadings. Buffalo, NY: MCEER-08-0019, Multidisciplinary Center for Earthquake Engineering Research; 2008.

[7] Skinner RI, Robinson WH, Mc Verry GH. An Introduction to Seismic Isolation, New York: John Wiley & Sons, Inc.; 1993, Chapter 1.

[8] Kelly JM. Base Isolation: Linear Theory and Design. Earthquake Spectra 1990; 6:223-244.

[9] Han R, Li Y, Lindt JVD (2014). Seismic risk of base isolated non-ductile reinforced concrete buildings considering uncertainties and mainshock–aftershock sequences. Structural Safety 2014; 50:39–56.

[10] CSI. SAP2000 Computer Software Technical Manual. Computers & Structures, Inc 2011. Available from http://www.csiberkeley.com/.

[11] Wiles JI. An overview of the technology and design of base isolated buildings in high seismic regions in the united states. M.Sc Thesis, Kansas State University, USA 2008.

[12] Naeim F, Kelly JM. Design of seismic isolated structures: from theory to Practice. New York : John Wiley; 1999.

[13] Kunde MC, Jangid RS. Seismic behavior of isolated bridges: A-state-of-the-art review. Electronic Journal of Structural Engineering 2003; 3(2): 140-169.

[14] Zayas VA, Low SS, Mahin SA. A simple pendulum technique for achieving seismic isolation. Earthquake Spectra 1990; 6: 317-333.

[15] ASCE.7-05. Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, USA 2005.

[16] IBC. International building code. International Code Council, Inc. USA 2006.

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