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USING ORTHOGONAL PAIRS OF RODS ON CONCAVE BEDS (OPRCB) AS A BASE ISOLATION DEVICE – PART (II): APPLICATION TO LOW- AND MID-RISE BUILDINGS

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ABSTRACT

Application of a recently introduced isolating system, called Orthogonal Pairs of Rods on Curved Beds (OPRCB), to short- and mid-rise buildings, is presented in this paper. At first, the characteristics of the OPRCB isolators have been mentioned, and the set of differential equations of motion for isolated multistory buildings has been introduced, then some 3-, 6-, 10-, and 14 story regular buildings of shear type have been considered, once on fixed bases and once installed on the OPRCB isolators. In the next step, some 3-component accelerograms of both far- and near-field earthquakes with low to high frequency content, particularly those which have remarkable Peak Ground Displacement (PGD) values, have been selected, and normalized to three specific Peak Ground Acceleration (PGA) levels, and their stronger horizontal component simultaneous with their vertical component have been used for response analysis of considered buildings. Relative displacement and absolute acceleration response histories of isolated buildings have been calculated by using a program, developed by the authors in MATLAB environment by using the fourth order Runge-Kutta method, which can take into account the hysteretic behavior of isolators. After verifying the developed program by solving some previously solved referred problems, maximum relative displacement and absolute acceleration responses of considered isolated buildings for various earthquakes have been compared to those of corresponding fixed-base ones to show the efficiency of the OPRCB isolators.

Introduction

Several seismic isolation systems have been introduced and employed in many buildings in different parts of the world so far, however, still the use of isolation technique has not been acknowledged widely in all earthquake prone countries, mainly because of four reasons. First, the costs of isolation systems which is usually high; second, the required technology for manufacturing the isolator, which is not available yet for many non-developed and even

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developing countries; third, the weight of isolators which makes their transportation and installation costly and difficult; and fourth, the required relatively large free space between adjacent buildings due to the displacement amplification above isolators. One of the isolating systems, which has been considered more acceptable from cost, weight and technology aspects is based on the use of rolling rods. Studies on using this type of isolating system go back to early 90s. Lin and Hone (1993) have studied base isolation by free rolling rods under basement, and Lin and Chern (1995) have performed an experimental study on base isolation by free rolling rods. Jangid (1995 and 2000) has studied the seismic response of structures isolated by free rolling rods by both deterministic and stochastic approaches. The effectiveness of elliptical rolling rods for base isolation has been also investigated (Jangid and Londhe, 1998; Londhe and Jangid, 1999). Use of sloping surface roller bearing has been also studied (Lee et al., 2003; and Lee and Liang, 2003). Hanai and his colleagues (2004) have compared seismic performance of base-isolated house with various devices. Also Wu and Tsai and their colleagues (2004 and 2007) have conducted some tests on a scaled bridge model isolated by using rolling-type bearings. Dynamic behavior of nonlinear rolling isolation system has been also studied (Chung et al., 2008). Recently Lee and his colleagues (2008) have performed another study on a roller seismic isolation bearing for highway bridges. A brief review of all of these studies has been presented in a previous paper of the authors (Hosseini and Soroor 2010). In spite of several studies on the use of rollers as seismic isolators, they have not been used so far on concave bed for isolating multistory buildings. This paper discusses the use of Orthogonal Pairs of Rods on Concave Beds (OPRCB) as isolating system for low- to mid-rise regular buildings.

Specifications of OPRCB Isolators

Based on the analytical formulations, the experimental results and numerical calculations, presented in Part (I) of the study (Hosseini and Soroor, 2009) it can be said that the OPRCB isolators are suitable devices for seismic isolation of low- to mid-rise buildings, modeled as rigid blocks resting on isolators, and can reduce the earthquake induced forces drastically by reducing the total acceleration of the isolated system up to ten times comparing to the fixed-base system. This is basically because of the desired specifications of the OPRCB isolators, among which the following are more worth mentioning:

- The effective natural period of the isolated system can be easily controlled by the ratio of rollers' radius to concave bed's radius (r/R), and achieving a period of 2.5 second or more is possible with no difficulty.
- OPRCB isolators can have an energy dissipating capability whose amount depends on the rolling resistance between rollers and adjacent surfaces, which is itself a function of the hardness of surfaces, the radii of rollers and their concave bed, and the building weight.
- In spite of the nonlinear force – displacement behavior of the OPRCB isolators the natural period of SDOF system isolated by this device is basically constant (independent of the displacement amplitude), for a given value of r/R, and the rolling resistance gives a damping of the Coulomb type to the system.
- The maximum lateral displacement of the system under earthquake excitations can be kept limited to a few centimeters by using lower values of R, however, using low R values in some cases may cause the maximum acceleration transferred to the isolated system can not be reduced to the desired level.

These advantages of OPRCB isolators' performance on the one hand and their simplicity of production and installation, low cost, and relatively small dimensions and low weight, on the other, are very encouraging for proposing their practical usage in low- to mid-rise buildings. However, regarding that: 1) if the maximum lateral displacement of the system under earthquake excitations is desired to be limited to a few centimeters by using lower values of R, the maximum acceleration transferred to the isolated system may not be reduced to the desired level, and 2) since keeping the dimensions of the OPRCB isolators as low as possible, which is very important for practical advantages, may not be possible in case of some near-field earthquakes, in which the occurrence of a large amplitude long period pulse is likely and the maximum displacement which the isolator should facilitate may be very large, the authors decided to conduct more investigations on the performance of low- to mid-rise regular buildings isolated by OPRCB isolators, subjected to both far- and near-field earthquakes.

In the following sections of the paper at first derivation of the governing equations of motion for the multi-story buildings of shear type isolated by OPRCB isolators is presented, then the derived equations are arranged in the matrix format to be used in computer program developed in MATLAB environment for Time History Analysis (THA) of isolated buildings. In the next stage, the verified program has been used for time history analyses of several multi-story regular building models, having 3, 6, 10, and 14 stories, in both fixed-base and isolated states, subjected to the simultaneous horizontal and vertical components of several earthquake accelerograms. The accelerograms include both far field and near field earthquake records, with various frequency contents from low to high, and the calculated responses include the relative displacement at base floor level and the absolute acceleration of various stories.

Equations of Motion for Multi-Story Shear Type Buildings Isolated by OPRCB Devices

To derive the equations governing the motion of the non-torsional multi-story building of shear type, isolated by OPRCB devices, which moves independently in each of the two main horizontal directions, a schematic model of the building, which shows its movement in just one direction, is presented in Fig. 1.

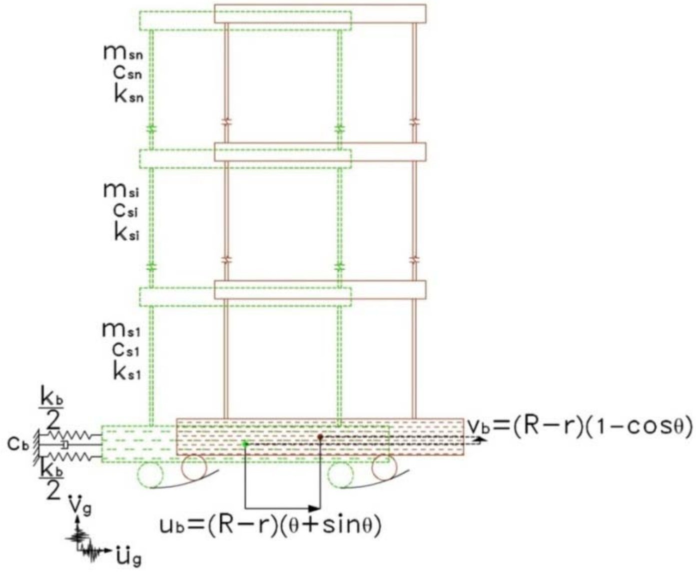
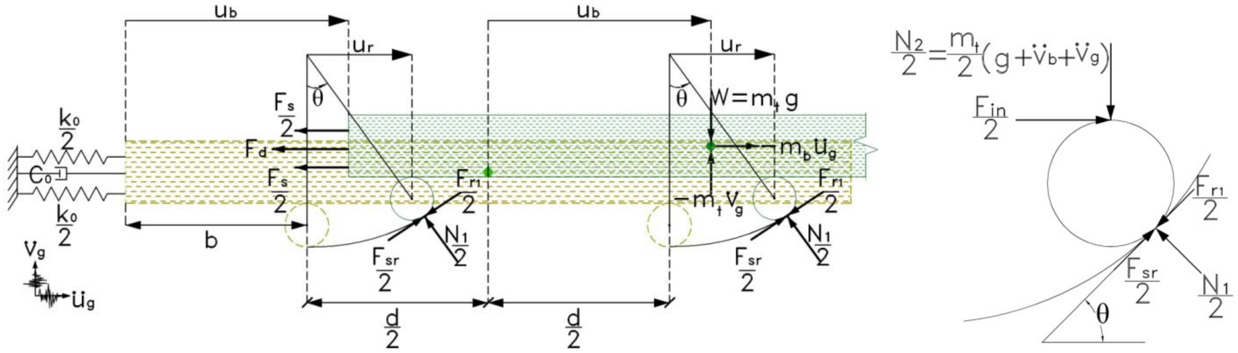


Figure 1. Schematic planar model of multistory shear type building on OPRCB isolators

In Fig. 1, k_b and c_b are respectively the total stiffness and damping coefficients of the springs and dampers which may be used at the base floor of the building, resting directly on the OPCBR isolators, m_{si}, c_{si}, and k_{si} are respectively the mass, damping coefficient, and stiffness coefficient of the i^{th} story, and u_b and v_b are respectively the horizontal and vertical components of the base, which are calculated by the simple formulas given in the Figure (Hosseini and Soroor, 2010). In those formulas R and r are respectively the radius of the concave beds and that of the rollers, and θ is the angle showing the location of rollers during the motion, with respect to their initial situation, as shown in Fig. 2.



(a) (b)

Figure 2. The forces engaged in: (a) the motion of the representative part of the base floor, carrying the representative column of the multi-story building, subjected to horizontal and vertical components of ground motion, and (b) the equilibrium of each of the rollers under half of column's load, for deriving the Lagrange equation of motion in the presence of rolling resistance

Considering the motion of the multi-story building in each main direction the same as the motion of a "representative column", carrying the weight associated with an average tributary area in various floors, to which a total mass of m_t is assigned, Fig. 2 shows a portion of the base level of the multi-story building on one pair of rollers of an OPRCB device, corresponding to the representative column. As shown in Fig. 2, of the total mass of the base floor a portion m_0 is assigned to the representative base part. In this figure k_0 and c_0 are respectively the stiffness and damping coefficients of the spring and damper corresponding to the representative column's base, resulting in spring force, F_s, and damping force, F_d, during the base motion, F_{sr} is the amount of sliding friction force required for preventing the rollers from slippage during their motion, F_{r1} is the rolling resistance force between the rollers and their beds, and N_1 is the reaction force normal to the contact surfaces between rollers and their beds.

As inspired by Fig. 2-a, it has been assumed that the two rollers act quite similarly in carrying the vertical load and other engaged forces, and the displacement of the line of action of the vertical load, $W = m_t g$, with respect to the centerline of the isolating device does not affect the equal distribution of loads between the two rollers. In fact, as long as the forces, whose values depend on the values of the normal forces between rollers and adjacent surfaces, have linear relationships with these forces, the aforementioned assumption does not impose any error in the corresponding equations. In this regard the only source of nonlinearity is the relationship between the value of rolling coefficient, μ_r, and the value of normal force, as shown in Fig. 2 of a previous paper of the authors relating to the fist part of the study (Hosseini and Soroor, 2010), however, this relationship is just slightly nonlinear, and therefore, the abovementioned assumption does not create any significant error, and assuming that each of the interacting forces between rollers and their bed and the mass above them is half of the total value of the total force for the two rollers is quite reasonable. On this basis, in Fig. 2-b, F_{in} can be considered as the total internal horizontal force acting between the rollers and the mass above them, and N_2 as the whole vertical force acting at the top of rollers pair during earthquake.

Furthermore, referring to Fig. 2-a, it should be noted that the width size of OPRCB plates and their plan measures should be chosen in such a way that the distance b between the bed plate edge and the centerline of the adjacent roller in either side and either direction, and the distance d between the centerlines of the rollers' beds in both directions are large enough to let the $\mathrm{u_{b,max}}$ meet the conditions of $\mathrm{u_{b,max}} < b + \mathrm{u_r}$ and $\mathrm{u_{b,max}} < \mathrm{u_r} + \mathrm{d}/2$. These conditions are necessary to keep each of the middle and upper plates remaining on the two rollers all the time, on the one hand, and to make the line of action of the total column force (W= m_t g) remain between the two rollers' centerlines during the earthquake, on the other, otherwise the column base plate may tend to rotate with respect to one of the roller's centerline in case of extreme motion in either directions.

To use the idea of representative column, for derivation of equations which govern the motion of the multi-story building, under the simultaneous effects of horizontal and vertical ground excitations, the deformed shape of the representative column is shown in Fig. 3, where the stiffness, damping, and mass of the i^{th} story are shown respectively by k_i, c_i, and m_i, and its relative displacement by u_i.

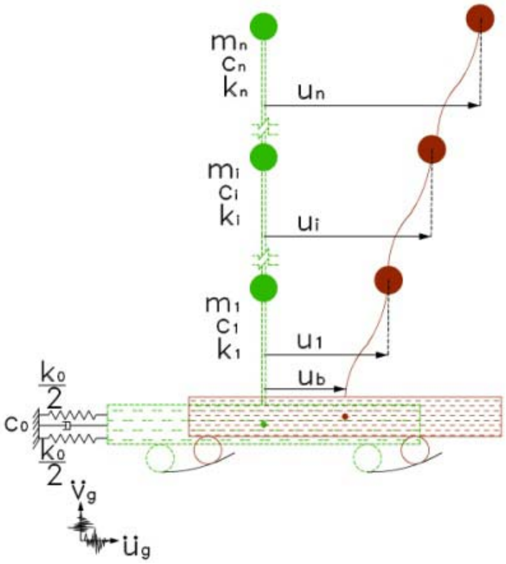


Figure 3. The building representative column for deriving the governing equations of motion

The motion of the system shown in Fig. 3 (considering the motion of only one pair of rollers in one main direction, as explained before) under the simultaneous effect of horizontal and vertical components of earthquake ground motion can be formulated by using Lagrange equation, as discussed hereinafter. Inclusion of springs' and damper's forces in these formulations makes it possible to compare the isolated buildings with non-isolated ones. To derive the equation of motion for this system by Lagrange formula, it is necessary to express the kinetic and potential energy as well as the variation of non-conservative forces in terms of the generalized coordinates of the system. Considering the nature of the OPRCB isolators the most appropriate generalized coordinate for the isolator's level is θ (see Fig. 2), and for other levels are the relative displacements of floors with respect to the base level (see Fig. 3). On this basis to write the system of differential equations in matrix format the mass, damping, and stiffness matrices, excluding the nonlinear terms related to the first generalized coordinate, θ, and its time derivatives, can be easily written. However, due to the existence of nonlinear terms in the first two ones of the set equations, governing the isolated system's motion, these equations can not be written in a format of $[\mathbf{M}]\{\ddot{\mathbf{U}}\} + [\mathbf{C}]\{\dot{\mathbf{U}}\} + [\mathbf{K}]\{\mathbf{U}\} = -[\mathbf{M}](\{\mathbf{r_h}\}\ddot{\mathbf{u}}_\mathbf{g} + \{\mathbf{r_v}\}\ddot{\mathbf{v}}_\mathbf{g})$ as for a linear MDOF system subjected to simultaneous effect of horizontal and vertical ground acceleration, in which $\{\mathbf{r_h}\}$ and $\{\mathbf{r_v}\}$ are the earthquake influence vectors for horizontal and vertical ground excitations, respectively. Nevertheless, by separating the linear and nonlinear parts in terms related to the first two generalized coordinates, and defining some auxiliary vectors, the set of equations can be written in matrix format as (Soroor 2009; Hosseini 2010):

$$[M]\{\ddot{U}^*\} + \{I^*\} + [C]\{\dot{U}^*\} + \{D^*\} + [K]\{U^*\} + \{S^*\} = -[M]\left(\{r_h\}\ddot{u}_g + \{r_v\}\ddot{v}_g\right) + \{F_r\} \quad (1)$$

where the vector of modified generalized coordinates and its modified derivatives are:

$$\{U^*\} = \begin{Bmatrix} d_0^* \\ u_1 \\ u_2 \\ u_3 \\ \vdots \\ \vdots \\ u_n \end{Bmatrix} \qquad \{\dot{U}^*\} = \begin{Bmatrix} v_0^* \\ \dot{u}_1 \\ \dot{u}_2 \\ \dot{u}_3 \\ \vdots \\ \vdots \\ \dot{u}_n \end{Bmatrix} \qquad \{\ddot{U}^*\} = \begin{Bmatrix} a_0^* \\ \ddot{u}_1 \\ \ddot{u}_2 \\ \ddot{u}_3 \\ \vdots \\ \vdots \\ \ddot{u}_n \end{Bmatrix} \quad (2)$$

in which the modification is because of the first element in each vector, extracted from the nonlinear terms of the first governing differential equation, as:

$$d_0^* = (R-r)^2(1+\cos\theta)(\theta+\sin\theta) \qquad v_0^* = 4\,(R-r)^2\,\dot{\theta}\,\cos^4\frac{\theta}{2} \quad (3)$$

$$a_0^* = 4(R-r)^2\left(\ddot{\theta}\cos^4\frac{\theta}{2} - \dot{\theta}^2\cos^3\frac{\theta}{2}\sin\frac{\theta}{2}\right) \quad (4)$$

and the auxiliary vectors are:

$$\{M^*\} = \begin{Bmatrix} m_t(R-r)^2\left(\ddot{\theta}\,\sin^2\theta + \dot{\theta}^2\sin\theta\,\cos\theta + \frac{g\sin\theta}{R-r}\right) \\ 0 \\ 0 \\ \vdots \\ \vdots \\ 0 \end{Bmatrix} \quad (5)$$

$$\{D^*\} = \begin{Bmatrix} -2c_1(R-r)\cos^2\frac{\theta}{2}\dot{u}_1 \\ -2c_1(R-r)\dot{\theta}\cos^2\frac{\theta}{2} \\ 0 \\ 0 \\ \vdots \\ \vdots \\ 0 \end{Bmatrix} \{S^*\} = \begin{Bmatrix} -k_1(R-r)(1+\cos\theta)u_1 \\ -k_1(R-r)(\theta+\sin\theta) \\ 0 \\ 0 \\ \vdots \\ \vdots \\ 0 \end{Bmatrix} \{F_r\} = \begin{Bmatrix} -\mathrm{sign}(\dot{\theta})F_r\,R \\ 0 \\ 0 \\ 0 \\ \vdots \\ \vdots \\ 0 \end{Bmatrix} \quad (6)$$

and finally the earthquake influence vectors are:

$$\{\mathbf{r_h}\} = \begin{Bmatrix} (\mathbf{R}-\mathbf{r})(\mathbf{1}+\cos\theta) \\ \mathbf{1} \\ \mathbf{1} \\ \vdots \\ \vdots \\ \mathbf{1} \end{Bmatrix} \qquad \{\mathbf{r_v}\} = \begin{Bmatrix} (\mathbf{R}-\mathbf{r})\sin\theta \\ \mathbf{1} \\ \mathbf{1} \\ \vdots \\ \vdots \\ \mathbf{1} \end{Bmatrix} \tag{7}$$

Based on the presented formulation, and solving the governing equations of motions, the seismic responses of a multi-story shear type building, isolated by OPRCB devices, subjected simultaneous effect of horizontal and vertical components of earthquake ground motion can be calculated, as presented in the next section.

Effectiveness of OPRCB Isolators in Seismic Response Reduction of Multi-Story Buildings

To study the effectiveness of OPRCB isolators in reducing the seismic response of shear type multi-story buildings of low to moderate height, simple models of 3-, 6-, 10-, and 14-story buildings, like the one shown in Fig. 1. Assuming an average floor mass of 1.0tonf per square meter, a value of 12 tons has been considered for the amount of mass assigned at each floor to the “representative column” of the building, and the stiffness values of stories have been considered in such a way that the fundamental period of the building gets a value around N/10 seconds (N being the number of stories) in each case. With regard to the buildings’ damping, although it is supported by the formulation of the problem to assign any desired value to the damping coefficient at each story, being either proportional or non-proportional to mass and/or stiffness values, for simplicity, the damping matrix has been assumed to be proportional to the stiffness matrix alone, in such a way that it leads to a modal damping ratio of 5% for the first mode of all buildings, in both isolated and non-isolated states.

To use the formulation, presented in the previous section for response analysis, a computer program has been developed in MATLAB environment to solve the set of nonlinear differential equations by fourth order Runge-Kutta method. To investigate the efficiency of the OPRCB isolators in response reduction of for various types of earthquake excitations, several multi-component records have been selected, with special attention to near field cases, which usually have extensive vertical PGA values, and also to earthquakes with initial large amplitude and long period pulse. The selected records relate to the following earthquakes, all picked from the PEER Strong Motion Database:

- Cape Mendocino (SHL090 record), Helena, Montana (B-FEB090_AT2 record) Oroville (D-DWR180 record) as relatively high frequency accelerograms
- Central Calif. (A-HCH181_AT2 and A-HCH271_AT2 records) and Humbolt Bay (FRN315_AQT2) as moderate frequency accelerograms
- Kobe, Japan (TAK00 and TAK090 record) and Kocaeli, Turkey (YPT060 record) as relatively low frequency accelerograms
- Imperial Valley (H-E06230 and H-QKP085 records) and Kocaeli, Turkey (YPT330 record) as near-fault accelerograms or those with strong large amplitude pulse.

To show the effectiveness of the OPRCB isolators in seismic response reduction maximum displacement and acceleration responses of the considered buildings in fixed-base and isolated states, subjected to samples of mid- and low-frequency and also near fault earthquakes, are compared in Tables 1 to 3, which shows the floors’ drifts and acceleration responses. More results of these types can be found in the main report of the study (Soroor 2009; Hosseini 2010).

Table 1. Maximum response values of all considered buildings, subjected to one of the used mid-frequency earthquakes

subjected to mid frequency record (α=1)									
Humbolt Bay (FRN315_AT2)									
PGA	max drift (m)				max diplacement in isolated base(m)	max absolute acceleration (g)			
	fixed base	story no.	isolated base	story no.		fixed base	story no.	isolated base	story no.
3-story									
0.15g	0.0033	1st	0.0007	3rd	0.0172	0.4457g	3rd	0.0972g	3rd
0.35g	0.0077	1st	0.001	1st	0.0544	1.0401g	3rd	0.1196g	3rd
0.7g	0.0155	1st	0.0021	1st	0.1376	2.0801g	3rd	0.2193g	3rd
6-story									
0.15g	0.0075	6th	0.0022	6th	0.0156	0.5125g	6th	0.1473g	6th
0.35g	0.0176	6th	0.0031	6th	0.0401	1.1959g	6th	0.2115g	6th
0.7g	0.0352	6th	0.0043	1st	0.1107	2.3919g	6th	0.2885g	6th
10-story									
0.15g	0.0083	10th	0.0069	10th	0.0151	0.3414g	10th	0.2827g	10th
0.35g	0.0195	10th	0.0082	10th	0.0284	0.7965g	10th	0.3382g	10th
0.7g	0.0389	10th	0.0098	10th	0.0769	1.5931g	10th	0.4066g	10th
14-story									
0.15g	0.0087	14th	0.0087	14th	0.0056	0.2583g	14th	0.2583g	14th
0.35g	0.0204	14th	0.0145	14th	0.0231	0.6028g	14th	0.4270g	14th
0.7g	0.0408	14th	0.0173	14th	0.0638	1.2056g	14th	0.5061g	14th

Table 2. Maximum response values of all considered buildings, subjected to one of the used low-frequency earthquakes

subjected to low frequency record (α=1)									
Kobe, Japan (TAK00)									
PGA	max drift (m)				max diplacement in isolated base(m)	max absolute acceleration (g)			
	fixed base	story no.	isolated base	story no.		fixed base	story no.	isolated base	story no.
3-story									
0.15g	0.0029	1st	0.0028	1st	0.2349	0.3480g	3rd	0.2786g	1st
0.35g	0.0067	1st	sliding	-	sliding	0.8119g	3rd	sliding	-
0.7g	0.0134	1st	sliding	-	sliding	1.6239g	3rd	sliding	-
6-story									
0.15g	0.0082	1st	0.004	1st	0.159	0.5367g	6th	0.227g	6th
0.35g	0.0191	1st	sliding	-	sliding	1.2524g	6th	sliding	-
0.7g	0.0382	1st	sliding	-	sliding	2.5048g	6th	sliding	-
10-story									
0.15g	0.0112	10th	0.0074	1st	0.1117	0.4552	10th	0.2686g	10th
0.35g	0.0262	10th	sliding	-	sliding	1.0622	10th	sliding	-
0.7g	0.0523	10th	sliding	-	sliding	2.1244	10th	sliding	-
14-story									
0.15g	0.0213	14th	0.0115	14th	0.0808	0.6160g	14th	0.3347g	14th
0.35g	0.0497	14th	0.0218	1st	0.2692	1.4373g	14th	0.5970g	14th
0.7g	0.0994	14th	sliding	-	sliding	2.8747g	14th	sliding	-

Table 3. Maximum response values of all considered buildings, subjected to one the used near-field earthquakes

subjected to near fieled record (α=1)									
Imperial Valley (H-QKP085)									
PGA	max drift (m)				max diplacement in isolated base(m)	max absolute acceleration (g)			
	fixed base	story no.	isolated base	story no.		fixed base	story no.	isolated base	story no.
3-story									
0.15g	0.0028	1st	0.0008	3rd	0.0422	0.337g	3rd	0.1057g	3rd
0.35g	0.0066	1st	0.0019	1st	0.1379	0.7862g	3rd	0.1918g	2nd
0.7g	0.0132	1st	0.0039	1st	0.31	1.5724g	3rd	0.4257g	2nd
6-story									
0.15g	0.0065	6th	0.0023	6th	0.0333	0.4401g	6th	0.1607g	6th
0.35g	0.0151	6th	0.0039	1st	0.1183	1.0268g	6th	0.2124g	1st
0.7g	0.0302	6th	0.008	1st	0.2797	2.0537g	6th	0.4347g	1st
10-story									
0.15g	0.0083	10th	0.0059	10th	0.0321	0.3411g	10th	0.2433g	10th
0.35g	0.0194	10th	0.0084	10th	0.0938	0.7960g	10th	0.3427g	10th
0.7g	0.0389	10th	0.0127	1st	0.2328	1.5920g	10th	0.4635g	10th
14-story									
0.15g	0.0091	14th	0.0084	14th	0.0133	0.2663g	14th	0.2460g	14th
0.35g	0.0213	14th	0.0127	14th	0.0734	0.6213g	14th	0.3757g	14th
0.7g	0.0427	14th	0.0159	1st	0.1868	1.2426g	14th	0.4482g	14th

It is seen in Tables 1 and 3 that in case of Humbolt Bay earthquake as one of the mid frequency and also Imperial Valley earthquake as one the near fault earthquakes the acceleration response has been decreased drastically because of isolation for all four buildings for all PGA levels. However, as Table 2 shows, in case of Kobe earthquake, as one of low frequency earthquakes, the isolating system has not worked well, because of sliding occurrence, for PGA levels of 0.35g and also 0.7g in case of 3-, 6-, and 10-story buildings, and for PGA level of 0.7g in case of 14-story building. This shortcoming can be resolved by adding the sliding friction between rollers and their beds. To show the results more concisely, the responses of each building subjected to all three earthquakes of each four categories, for both fixed-base and isolated states, have been presented together in one figure. Fig. 4 is a sample of these concise presentations, of which more results can be found in the main report of the study (Soroor 2009; Hosseini 2010).

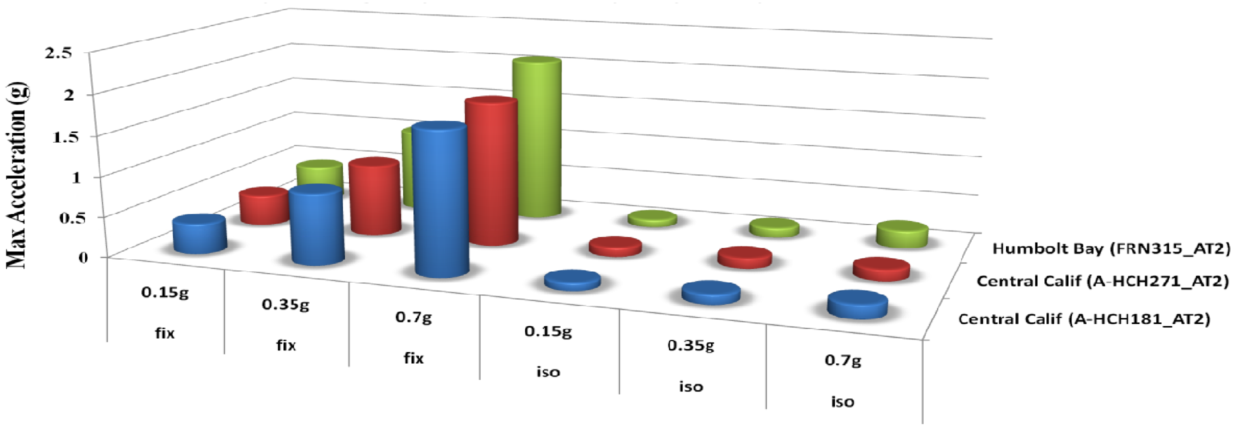


Figure 4. Maximum acceleration responses of 3-story building to mid frequency earthquakes in fixed-base and isolated states

Conclusions

Based on the numerical results obtained for low- and mid-rise buildings it can be concluded that:

- The OPRCB isolating system has high efficiency in case of high- and mid-, and most of low-frequency earthquakes, and earthquakes with strong large amplitude pulse, however, in case of some low-frequency earthquakes and earthquakes with vertical PGA of more than 1.0g the system may not perform satisfactorily.
- The maximum lateral displacement of isolated buildings at base level is mostly less than 40cm, which is in the range of other isolating systems such as LRB, HRB or FPS.
- To improve the performance of OPRCB isolating system for case of some low frequency earthquakes and earthquakes with very high vertical PGA more study is required.

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