Responses of Building Base Isolated With High Damping Rubber Bearings

Nguyen Anh Dung, Quang Hung Nguyen

Abstract*: Seismic isolation is one of the most efficient techniques to protect structures against earthquakes. Rubber bearings are suitable for low-rise and medium-rise buildings due to its durability and easy fabrication. This paper presents the hori-zontal response of a six-storey base-isolated building using high damping rubber bearings (HDRB) under two ground motions of earthquakes as types I and II in JRA (2002) by finite element analysis. In this analysis, these bearings are mod-elled by the bilinear hysteretic model which is indicated in JRA and AASHTO. Comparison of horizontal response including base shear force and roof level acceleration between the two cases: base-isolated building and fixed-base building is carried out to evaluate the effectiveness of the use of HDRB on the protection of buildings from earthquakes. The numerical results show that the peak value of roof floor acceleration of the fixed-base building is two times higher than that of the base-isolated building, and the floor accelerations depend on the peak values of ground acceleration. In addition, the step-by-step design procedure for deter-mining the size of HDRBs used for buildings is also presented in this paper.

***Keywords*: High damping rubber bearings; seismic responses; earthquakes; buildings.**

I. INTRODUCTION

In the effort to mitigate hazards from destructive earthquakes, rubber bearings are widely adopted due to their efficiency. They can shift the natural period of structures so as to avoid the resonance with excitations. Besides, they can absorb energy by damping properties to improve the structures' damping performance. After the Kobe earthquake 1995, the applications using rubber bearings for structures were rapidly spread in Japan. High damping rubber (HDR) was developed for devices require high flexibility as well as energy dissipation capacity. Now, HDR is widely used in high damping rubber bearings (HDRB), but sometime also in dampers, due to its high flexibility and high damping capacity. Some special particles such as silica, carbon black, oils and so on are added during the vulcanization process of HDR material [1, 2], after that HDR has special characteristics that are quite different from other elastomeric base isolations. They are higher strength and higher damping capacity than the other rubber bearings. Rubber bearings are defined as HDRB when their equivalent viscos damping are larger than 10% [3]. Moreover, HDRB are very durable, their equivalent horizontal stiffness is reduced by about 10-25% after 100 years [4], it means that HDRB do not require maintenance. The purpose of this paper is to investigate the effectiveness of base-isolated building using HDRBs compared to the fixed-base building under ground motions of earth-quakes. Further, the effect of peak value and the time duration of ground accelera-tions on the horizontal response of the building is also investigated in this paper.

II. BASIC PRINCIPLES OF BASE ISOLATIONS

The basic principle of isolation system is that the structure's response is modified in order to make the ground below be capable of moving with transmitting minimal to the structure above. For this purpose, seismic isolations are usually inserted between the base of the structure and its foundation, these isolations are characterised by a high flexibility in large earthquakes. This This flexibility must be such as to move the fundamental response frequencies of the structure to values that are well below the range where the seismic motion of the soil is amplified. In this way, the soil motion is filtered, because most energy is withdrawn from the frequency range that characterises the vibration modes of the superstructure.

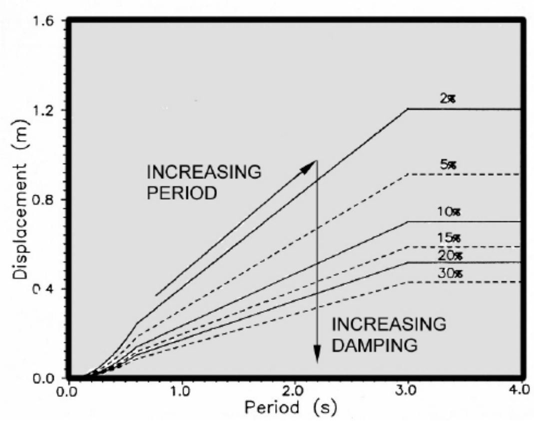

Fig. 1. Acceleration response spectrum are defined by EC8 [5] for ground acceleration 0,8g

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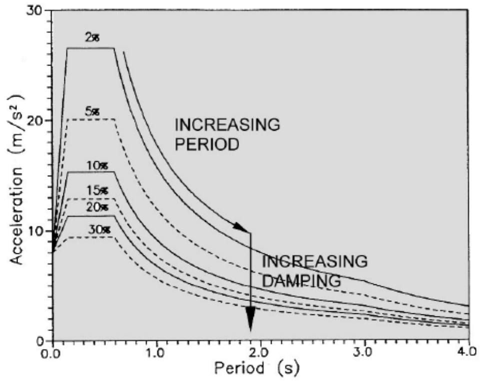


Fig. 2. Displacement response spectrum are defined by EC8 [5] for ground acceleration 0,8g

Theoretically, a structure can be isolated in both vertical directions and horizontal directions. However, the application of seismal isolator is often limited to the horizontal directions. The reasons are that seismic loads are largely less critical in the vertical direction, compared to the horizontal; also, possible rocking due to three-directional isolation must be avoided [3]. For large earthquakes, isolators must be characterised by a horizontal stiffness that is such as to move the fundamental response frequencies of the structure well below 1 Hz, (normally between 0.5 and 0.3 Hz) i.e. in the frequency range where the seismic motion of the soil is characterised by a low energy content. In this way, the structure mainly moves as a rigid body in the horizontal plane. If on the one hand isolators lead to a strong decrease in accelerations of structures, on the other hand, they obviously considerably increase its displacements. Therefore, in order to limit displacements to acceptable values, isolation systems must also contain dissipating elements, in addition to the filtering elements. They have to have a self-centring capacity, i.e. the isolation system can carry the structures back to its initial position aftet each peak of earthquake accelerations. This capacity can guarantee the structure safety in earthquake also.

The use HDRB has proven, even in recent earthquakes, to be a very efficient technique to protect structures from earthquakes. HDRB with their high flexibility and high damping capability can achieve two effects : (1) To shift the own period of the structures reducing in such a way the seismic response and (2) To disssipate energy reducing again the response and the displacement.

III. NUMERICAL ANALYSIS OF A BUILDING WITH HIGH DAMPING RUBBER BEARINGS

A. Prototype building for seismic analysis and high damping rubber bearings

The building considered for this analytical study is a six storey office building which is a reinforced concrete framed structure. The floor plan is 21.6m x 18m and total height of the building is 24.5m in Fig. 3. Each floor consists of a solid slab 100mm thick. Cross section of each column is 450x450mm. The distribution of the structural elements at each floor is symmetrical in both directions. The mass of the structure and the load carried by the building are assumed to be concentrated at the floor levels. Damping of superstructure is assumed to be 5% of critical damping in all the modes.

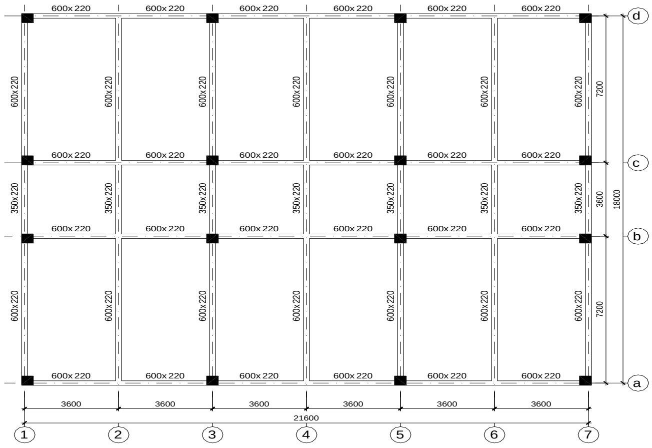
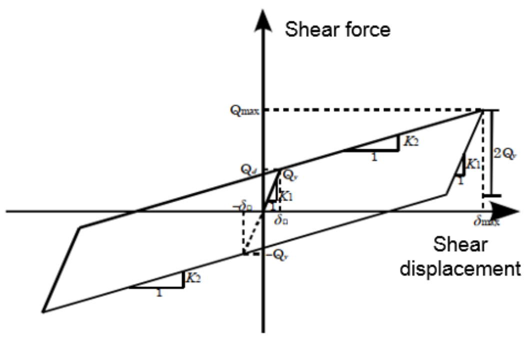


Fig. 3. The typical structure plan of the buidling for seimic analysis ; all dimensions are in mm.

The mechanical properties of rubber bearings are the same as the HDRB in [6]. High vertical stiffness of these bearings is achieved through the laminated construction of the bearing using steel plates in Fig. 4. HDRB are placed between the end of the first column and the foundation slab. One rubber bearing is provided under each column.

Fig. 4. Cross section of high damping rubber bearings

In this study, these bearings are modelled by bilinear hysteretic model as shown in Fig. 5(a), this model is presented in some specifications [7, 8]. The bilinear model of the bearings can be represented using a structure of rheology model in Fig. 5(b).



(a)

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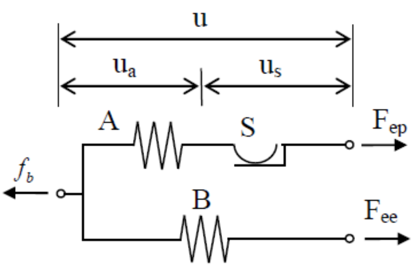

(b)

Fig. 5 : (a) Bilinear model for the bearings [7, 8], (b) a structure of rheology model

The bearing force can be determined as Eq. (1)

$$f_b = F_{ep} + F_{ee} \tag{1}$$

Spring A is linear as Eq. (2)

$$F_{ep} = K_a u_a \tag{2}$$

K_a is the stiffness of spring A.

Slider S will be activated and start to slide, if F_{ep} reaches to yield force Q_y.

$$\begin{cases} \dot{u}_s \neq 0 & if \quad |F_{ep}| = Q_y \\ \dot{u}_s = 0 & if \quad |F_{ep}| < Q_y \end{cases} \tag{3}$$

Q_y is yield force.

Elastic force F_{ee} in the second branch is defined as Eq. (4)

$$F_{ee} = K_b u \tag{4}$$

K_b is the stiffness of spring B, K_b represents the post yielding stiffness of the bearing.

The parameters K_a, K_b, and Q_y are determined from experimental data.

The post yielding stiffness of the bearing is the most important parameter. This value decides the first natural frequency of the base isolated building. The value of post yielding stiffness is kept such that the value of time period for the six-storey building is shifted from 0.6 sec. to 2.5 sec. The design steps for determining the size of bearing and total thickness of rubber are proposed to HDRB as below :

Step 1: To determine the ground acceleration a_g by Eq (5) and parameters of elastic.

$$a_g = \gamma_I a_{gR} \tag{5}$$

Where

a_{gR} is the ground acceleration peak on type A background;

γ_I is the importance coefficient of the building.

Step 2: Evaluation of the horizontal elastic acceleration spectrum at the period of 1 second S_1 by Eq (6)

$$T_C \le T \le T_D : S_1 = S_e(T) = a_g.S.\eta.2,5.\left[\frac{T_C}{T}\right] \tag{6}$$

Step 3: To determine the region coefficient F_v at the period of 1 (s)

Step 4: To calculate dynamic coefficients S_{M1} and S_{D1} by Eq (7) & (8)

$$S_{M1} = F_v S_1 \tag{7}$$

$$S_{D1} = \frac{2}{3} S_{M1} \tag{8}$$

Step 5: To apply the parameters of B_D or B_M based on the effective viscosity coefficient β_D.

Step 6: To select the period of the building at the horizontal displacement design value, T_d by Eq (9)

$$3T_f \le T_d \le 3(s) \tag{9}$$

T_f is the nature period of the above structure.

Step 7: Evaluate the effective horizontal stiffness of the bearings, K_{eff} by Eq (10)

$$T_d = 2\pi\sqrt{\frac{W}{K_{d,\min} g}} \tag{10}$$

Where W is the total vertical force caused by the dead loads and live loads

$$\Rightarrow K_{eff} = \frac{W}{g}\left(\frac{2\pi}{T_d}\right)^2 \tag{11}$$

Step 8: To evaluate the design horizontal displacement of the bearings, D_D by Eq (12)

$$D_D = \left(\frac{1}{4\pi^2}\right)\frac{S_{D1}T_d}{B_D} \tag{12}$$

Step 9: To determine the total rubber thickness (t_r) by Eq (13)

$$\gamma = \frac{D_D}{t_r} \to t_r = \frac{D_D}{\gamma} \tag{13}$$

Where γ in the design displacement value following design standards

Step 10: To calculate the total cross-sectional area of the bearings, A by Eq (14)

$$A = \frac{K_{eff} t_r}{G} \tag{14}$$

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Where G is the shear modulus of HDRB

Step 11: To calculate the cross-sectional area of one bearing, A_i by Eq (15)

$$A_i = \frac{A}{n} \quad (15)$$

Where n is the numner of columns.

Step 12: To determine the design parameters of the bilinear model

HDRB in this analysis are the same bearings in [5], in where, the bilinear parameters C_1, C_2, and τ_{cr} are determined from the 1st cycle of sinusoidal loading tests and they are presented in Table 1.

Table 1. Parameters in Nguyen (2017) [6]

C_1 (MPa)	C_2 (MPa)	τ_{cr} (MPa)
17.29	1.136	1.215

These design parameters in Table 1 are converted into the above new design dimensions of HDRB by Eq (16)

$$\begin{cases} K_a = \dfrac{A_b}{h} C_1 \\ Q_y = A_b \tau_{cr} \\ K_b = \dfrac{A_b}{h} C_2 \end{cases} \quad (16)$$

Where A_b is cross-section area of the bearing, h is the total thickness of rubber. The bilinear parameters C_1, C_2, and τ_{cr} are in Table 1. The final design bilinear parameters are shown in Table 2.

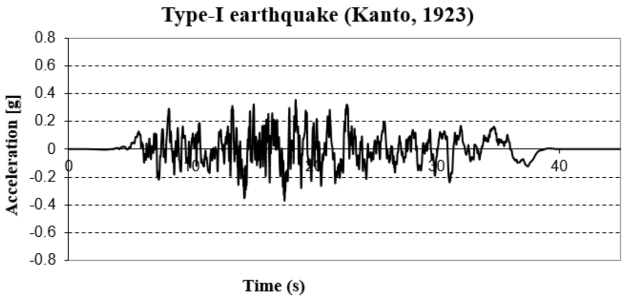
Table 2. Design bilinear parameters

K_1 (N/mm)	K_2 (N/mm)	Q_y (N)
21613	1420	48600

Finally, the dimension of bearing is 200x200mm, the total thickness of each bearing is 32mm, and details of design parameters of the bearings are given in Table 2.

B. Earthquake motions and the analysis method of building with HDRB

There are two ground acceleration histories used in the numerical analysis. These histories are presented in [8] an they are designed for level-2 type-I and type-II earthquakes by [8]. The type-I earthquake has large amlitude and long duration such as the Kanto earthquake. The type-II earthquake has strong acceleration and short duration such as the Kobe earthquake with low probability of occurrence.



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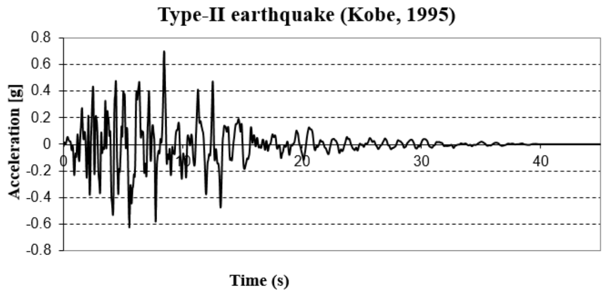

(b)

Fig. 6. Typical ground acceleration used in the numerical analysis: (a) type-I, (b) type-II

The time history analysis of the base isolated building is carried out using the computer program SAP2000 V14.2.2. A full three-dimensional representation of the structure is used in time history analysis of the base isolated buildings. The isolation system is modelled as a bilinear hysteretic element. There are some assumptions in the seismic analysis of the builiding :

• Only HDRB have non-linear behavior and the other superstructure is elastic.

• Each floor is infinitely rigid in its own plane and other frame substructures are connected at floor.

• There are three degrees of freedom at each floor, these degrees are attached to the centre of mass of each floor.

• There is not torsion resistance in the bearing and HDRB are rigid in the vertical direction.

• The stiffness of infilled walls is not considered, only the mass of the walls is mentioned in computation.

C. Seismic resposes

The comparison of seismic responses in Y-axis of the six storey fixed base building to that of base isolated building is given in Fig. 7&8 and Table 2. The continuos lines presente the responses of the fixed base building and the hide lines describe the responses of the isolated base building in these figures.

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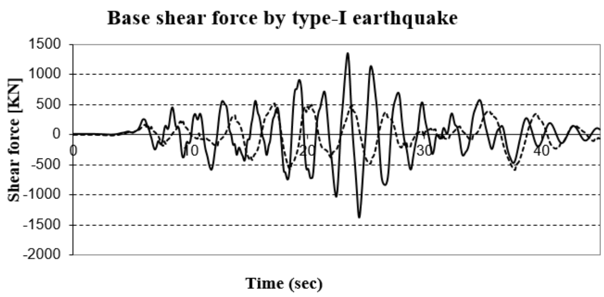
It is observed from Table 2 that there is a general much reduction in seismic responses for both earthquake motions. The maximum shear of the base isolated building is reduced to as much as 0.38 times and 0.42 times that of the fixed base building in type-I earthquake and type-II earthquake, respectively. For the remaining both ground motions, the maximum roof accelerations of the base fixed building are more than 2 times the accelerations of the base isolated building. This shows that this isolation system is very effective the buildings designed against earthquakes.

Although the acceleration peak of ground motion type-II is lager than that of type-I, the maximum base shear force induced by type-II is smaller than that induced type-I in Table 2. This means that the base shear force of the building depends on not only the strength of ground acceleration, but also the time duration of this acceletion. In addition, the roof acceleration peak induced by type-I is smaller than that induced type-II because the ground acceleration of type-I earthquake is smaller than that of type-II earthquake. It means that the roof acceleration depends much on the maximum ground acceleration.



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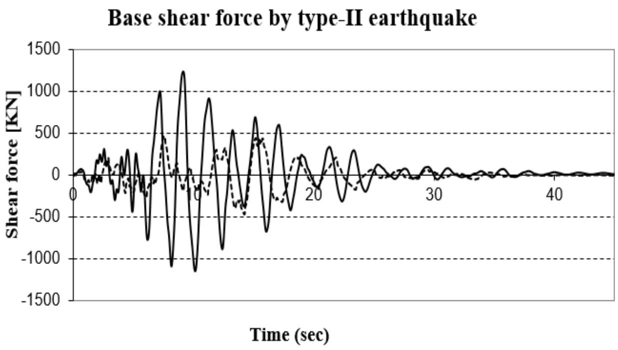
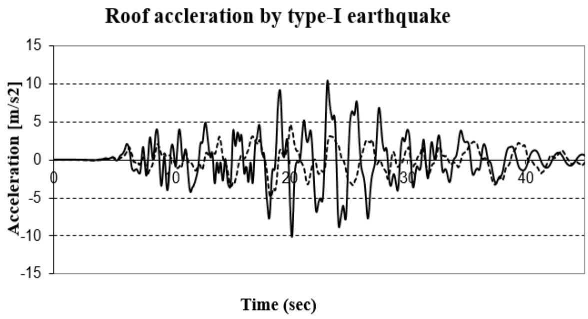


(b)

Fig. 7. Base shear force at Joint 10 (axis C-3 in Fig. 3) by (a) type-I earthquake (b) type-II earthquake



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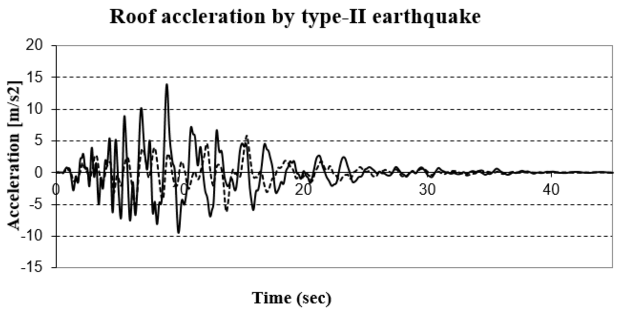

(b)

Fig. 8. Roof accleration by (a) Kanto earthquake (b) Kobe earthquake

Table 2: Effectiveness of base isolation with HDRB in Y-axis

Earthquakes	Base Shear at Joint 10 (KN)		Roof acceleration peak (m/s/s)	
	Fixed base	Base isolated	Fixed base	Base isolated
Type-I (Kanto, 1923)	1374.16	582.57	10.39	4.91
Type-II (Kobe, 1995)	1229.04	470.83	13.91	6.18

IV. CONCLUSIONS

A seismic analysis of the six-storey building is carried out to investigate the effective-ness of the use of HDRBs to protect buildings from earthquakes. This paper also proposes a design procedure to determine the size of HDRBs. This procedure can support to engineers to design base-isolated buildings using HDRBs. The peak values of roof floor acceleration of the fixed-base building are 2.14 times and 2.25 times higher than those of the base-isolated building under earthquakes type-I and type-II, respectively. Moreover, the base shear forces of the fixed-base building are 2.36 times and 2.61 times higher than the forces of the base-isolated building under the earthquakes type-I and type-II, respectively. The base shear forces of the base-isolated building depend on not only the peak values of ground accelera-tion, but also the time duration of ground acceleration of earthquakes. These results show that using HDRBs in buildings can improve the seismic capability of the struc-ture against earthquakes.

REFERENCES

1. Kelly, J.M, (1997). *Earthquake resistant design with rubber*. 2nd edition, Springer-Verlag Berlin Heidelberg, New York.
2. Yoshida, J., Abe, M., Fujino, Y, (2004). Constitutive model of high-damping rubber materials. Journal of engineering mechanics, 130(2), pp 129-141.

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3. Marioni, A, (1998). The use of high damping rubber bearings for the protection of the structures from the seismic risk. Jornadas portugesas de engenharia de estruturas, Lisbon, Portugal.
4. Gu, H., Itoh, Y, (2006). Ageing effects on high damping bridge rubber bearing. Proceeding of the 6th asia-pacific structural engineering and construction conference, Kuala Lumpur, Malaysia.
5. EC8 (2004). Eurocode 8: Design of structures for earthquake resistance Part 1: General rules, seismic actions and rules for buildings (EN 1998-1:2004). European Committee for Standardization.
6. Nguyen Anh Dung (2017). “Effect of modeling on seismic response prediction of a pier with high damping rubber bearings under earthquakes”. The 10th national Conference on Mecahnics, Hanoi, 8-9/12/2017, pp 191-197. (In vietnamese).
7. American association of state highways and transportation officials-AASHTO (2010). 3rd Edition. Washington DC: Guide Specification for Seismic Isolation Design.
8. Japan road association-JRA (2002). Specifications for highway bridges. Part V: seismic design. Tokyo: Maruzen.

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