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Viscoelastic Damper Connected to Adjacent Structure with Seismic Isolation System

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ABSTRACT

Base isolation solutions are efficient alternatives for seismic protection of buildings and for enhancing resilient capacity. Currently, seismic isolation is primarily focused on the critical infrastructure of public health, transportation, education, and other essential sectors. The seismic response of a base-isolated structure with a storied configuration to various types of isolation systems, connected via viscoelastic dampers to an adjacent dissimilar base-isolated or fixed base structure, is investigated. The multi-storied structures are modelled as a shear-type structure with lateral degree of freedom at each floor, which are connected at different floor levels by viscoelastic dampers. The variation of top-floor absolute acceleration of both the buildings and bearing displacement under different real earthquake ground motions is computed to study the behavior and effectiveness of the resulting connected system. It is concluded that connecting two adjacent base-isolated buildings with viscoelastic dampers is beneficial in controlling large horizontal base displacements in base-isolated structures, thereby preventing isolator damage that can arise from large displacements or pounding with adjacent ground structures during earthquakes. The viscoelastic damper connection between adjacent structures is found to be most effective when the adjacent base-isolated and fixed base buildings are connected. Such a scheme is hence useful in upgrading the seismic performance of existing fixed-base structures adjacent to a base-isolated structure

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1. Introduction

The conventional earthquake-resistant design technique is based on the philosophies that structural safety must be assured in extreme earthquakes and that structural damage should be minimized or avoided in moderate earthquakes. To satisfy these design criteria, a structure needs to be designed with sufficient strength to withstand earthquake forces, adequate ductility to absorb earthquake energy, and appropriate stiffness to maintain structural integrity and serviceability. The dynamic response of a base-isolated structure, therefore, is considerably reduced when compared to its counterpart, the fixed-base structure, as documented in the literature available on base isolation [1-

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2]. Base isolation has been widely accepted as one of the most widely accepted seismic protection systems that should substantially dissociate a superstructure from its substructure resting on a shaking ground, thereby sustainably preserving entire structures against earthquake forces as well as inside non-structural integrities. Base isolation devices can operate very effectively against near-fault (NF) ground motions with large velocity pulses and permanent ground displacements. [3] The earthquake caused large acceleration values at stories in stiff buildings and caused large inter-story drift values in soft buildings. In the seismic rehabilitation of structures, instead of increasing the bearing capacity of the structure under lateral forces, the forces acting on it can be reduced. [4] In seismic isolation, the fundamental frequency is lowered and kept away from the predominant frequency range of most earthquake ground motions. Although with the decreasing frequency, floor accelerations are reduced, helping to limit the structure damages, the increased displacement at the isolation level calls for the necessity of maintaining an adequate separation gap distance to accommodate the large bearing displacement. The separation gap requirement in case of a base-isolated structure is therefore more than that of the fixed-base structure. In modern cities, however, due to a high value of land space, limited availability of land, and preference for centralized services, there is a tendency to construct buildings nearby without maintaining proper separation gaps. During an earthquake event, these buildings vibrate vigorously and may become a cause for severe damage because of mutual pounding. The 1985 Mexico City and 1989 Loma Prita earthquakes are typical examples of the large-scale damage caused by structural pounding. Given this, the building codes made stringent requirements for base-isolated structures, specifying accommodation of larger bearing displacements during maximum capable earthquakes and the need for supplemental damping devices. In overcoming this dilemma, the present study suggests the use of viscoelastic damper connections between the adjacent buildings.

The papers reported by Housner et al [5] and Soong and Spencer [6] provide a detailed review of earlier and recent studies made on structural control and supplemental energy dissipation devices and their applications to seismic protection. To avoid pounding damages, the concept of linking adjacent fixed-base buildings is introduced and verified analytically and experimentally by a number of researchers [7-8]. However, mitigation of pounding and›or /or impact damages in case of base isolated and adjacent structures through incorporation of damper links ages between them is untried yet. Therefore, it would be interesting to investigate the effectiveness of connecting the base-isolated building with the adjacent building as an alternative for the protection against possible destruction due to pounding because of an inadequate separation gap provided between the two, and improving the seismic performance of the existing fixed base buildings.

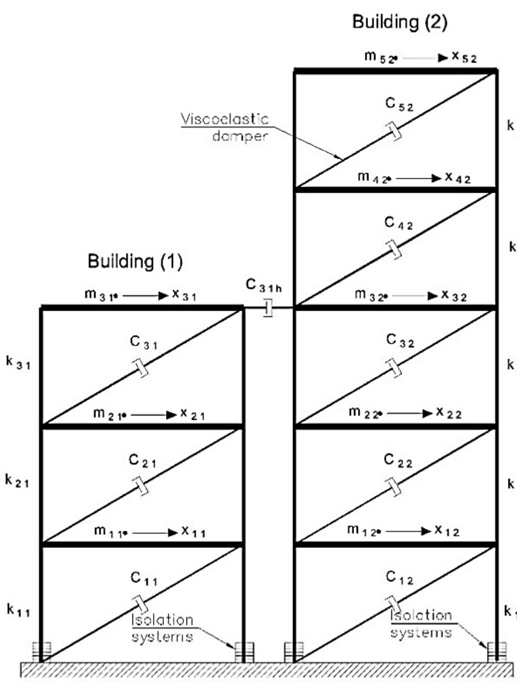
This paper investigates the advantages of connecting the base-isolated building to the adjacent base-isolated or fixed-base building using viscoelastic dampers. The main objectives of this study are to investigate the dynamic characteristics of a base-isolated building connected to the adjacent base-isolated or fixed-base building by discrete linear viscoelastic dampers and to propose this scheme for seismic retrofit of existing earthquake-prone fixed-base structures.

2. Modelling of adjacent structures

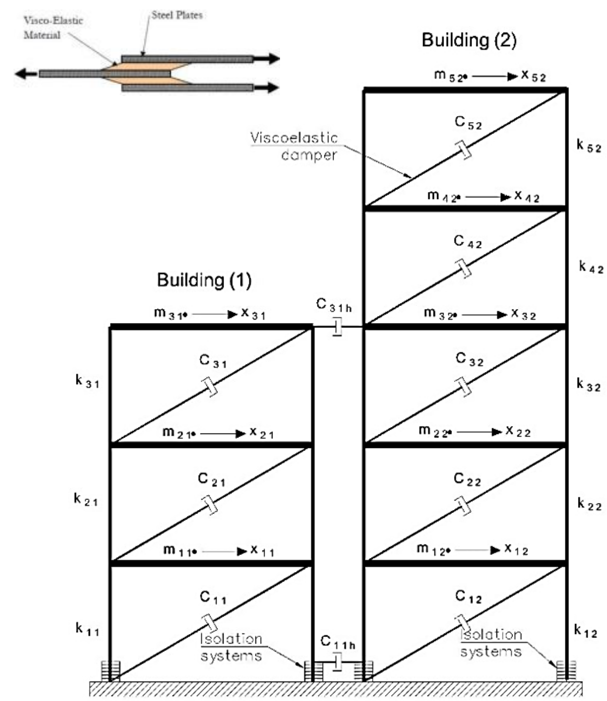
Fig. 1 shows the two structural models under consideration, depicting multi-degree-of-freedom shear models with rigid floors. Fig. 1(a) shows the I-story base isolated building connected through viscoelastic dampers at different floors to the adjacent story base isolated building. In Fig. 1(b), a similar viscoelastic damper connected system with the story base isolated buckling mounted on various isolation systems connected to the adjacent m-story fixed base building is shown, along with the schematic of a typical viscoelastic damper. The masses in these models are assumed to be lumped at each floor level, and the stiffness is provided by axially inextensible massless columns. Both the adjacent connected buildings are assumed to behave linearly elastically and receive the same earthquake ground motion horizontally. The soil structure interaction effects are not taken into consideration. For both buildings, the mass at all floor levels is kept constant while the stiffness is varied to achieve the desired fundamental periods under a fixed base condition. These adjacent buildings are connected at different floor levels by linear viscoelastic dampers to serve as an energy dissipation mechanism.

2.1. Damping devices

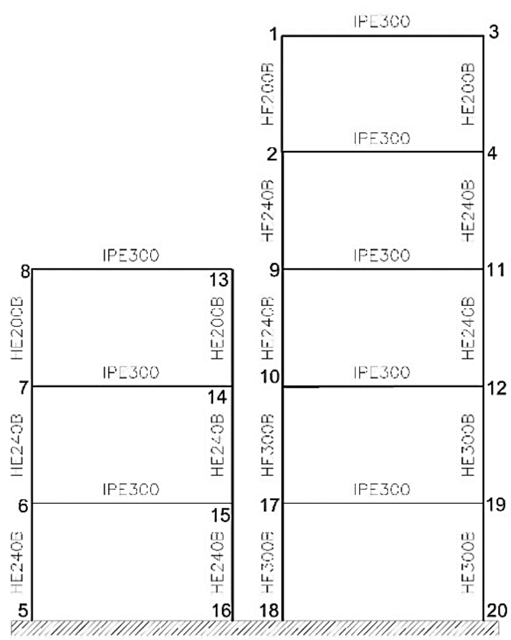
Energy dissipation devices are of different types and may be categorized depending on the type of material used to transform energy, such as: viscous, viscoelastic, friction, metallic yielding, and magnetic dampers. In viscous and viscoelastic dampers, the viscous›. A viscoelastic material, in the form of either liquid (silicone or oil) or solid (special rubbers or acrylics), is provided. Friction devices contain interface materials, such as steel-to-steel. copper with graphite-to-steel, or brake pad-to-steel. Metallic yielding devices most commonly use mild steel plates in different shapes and materials such as lead, shape memory alloys, etc. The magnetic damper functions on the principle of magnetism of fluid particles, as seen in the



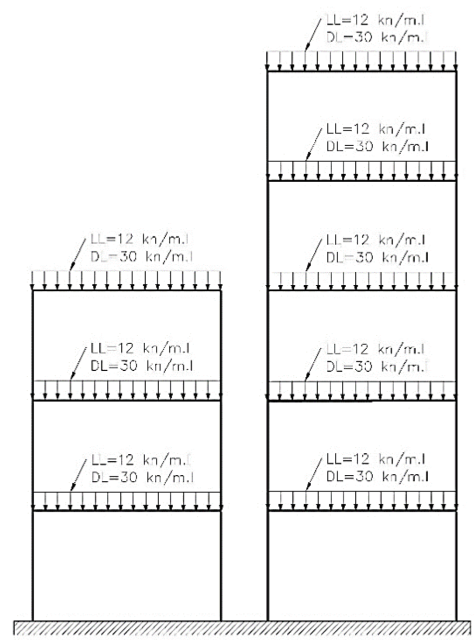
(a) Two base-isolated buildings



(b) Base-viscoelastic and Two base-isolated buildings



(c) Node number - frame sections



(d) Living and dead forces entering the frame

Fig 1. Mathematical model of viscoelastic damper connected adjacent buildings magnetorheological dampers. In the present study, the viscoelastic dampers are investigated for their usefulness in seismic response mitigation when used as connecting linkages between the two adjacent structures.

2.2. Viscoelastic damper

The viscoelastic solid materials are used as a means to dissipate energy in viscoelastic dampers [9- 10]. The viscoelastic materials generally used are copolymers or glassy substances. The energy is dissipated through shear deformation of the viscoelastic layers. Its behavior depends upon vibration frequency, strain levels, and temperature. However, the overall behavior of viscoelastic dampers can be represented by using a spring dashpot element acting in parallel. The typical viscoelastic damper consists of viscoelastic layers bonded with steel plates or solid thermoplastic rubber sheets sandwiched between steel plates; refer to Fig. 1(b). While in an active state, the relative motion between the central and outer plates gives rise to shear deformations in the viscoelastic fluid between these interfaces, and consequently, the energy is dissipated, leading to seismic response mitigation.

2.3. Damping force

The force generated in the viscoelastic damper comprises two components: elastic force and damping force. The elastic force is proportional to the relative displacement between the connected floors, whereas the damping force is essentially proportional to the relative velocity of the piston head concerning the damper casing. Hence, the damper force can be expressed as:

$$F_d = [K_d]\{Ub.U1.U2.\dots.Ul\}^T + [C_d]\{\dot{U}b.\dot{U}1.\dot{U}2.\dots.\dot{U}l\}^T \quad (1)$$

The vectors of relative displacement and velocity between the damper-connected floors of the adjacent buildings, and the over-dot denotes the derivative concerning time. Here, the stiffness elements of dampers placed along the height of the adjacent structures are:

$$[K_d] = \text{diag}\,[k_{db}, k_{d1}, k_{d2}, \dots, k_{dl}] \quad (2)$$

where k_{db} , k_{d1} , k_{d2}, … , k_{dl} are the damper stiffness coefficients at the different floor levels. In addition, the damper damping matrix for the array of dampers placed along the height of the adjacent structures is expressed as:

$$[C_d] = \text{diag}\,[c_{db}, c_{d1}, c_{d2}, \dots, c_{dl}] \quad (3)$$

where c_{db}, c_{d1}, c_{d2}, …, c_{dl} are the damper damping coefficients levels.

The total external damper stiffness and external damping added in the form of connection linkages between two adjacent buildings and are expressed respectively as a non-dimensional parameter

$$K_d = \frac{K_{db} + \sum K_{dj}}{\omega_e^2 \sum M_i} \qquad (I = 1,2 \text{ and } j = 1, L) \qquad (4)$$

$$\eta_d = \frac{C_{db} + \sum C_{dj}}{2\xi\omega_e^2 \sum M_i} \qquad (I = 1,2 \text{ and } j = 1, L) \qquad (5)$$

Where $M_i = m_{bi} + \sum_{j=1}^{l\ or\ m} m_{ji}$ is the total mass of the base isolated building; m_{ji} is the mass of 5^{th} floor of i^{th} building, ω_e is the equivalent isolation frequency considered as π rad/sec; ξ_e is the equivalent viscous damping ratio taken as 15% This implies that the total external damper damping and damper stiffness is expressed in proportion with properties of an equivalent linear viscous rubber isolation system having damping ratio of 15% and isolation time period of 2 sce.

3. Governing equations of motion

For the systems under consideration, the governing equations of motion are obtained by considering the equilibrium of forces at the location of each degree of freedom during seismic excitations. Two individual cases of governing equations of motion for such systems under earthquake excitation are given below.

3.1. Unconnected building systems

When the adjacent buildings are not connected with any link, they act independently, and for such unconnected base-isolated buildings, the following two sets of governing equations of motion can be obtained, which are of order L and m, the degrees of freedom for adjacent base-isolated Buildings 1 and 2, respectively, under earthquake excitation.

The isolation layer forces for three different types of isolation systems used in the present study, namely, high-damping rubber bearings (HDRB), lead-rubber bearings (LRB), and friction pendulum systems (FPS), are placed under the base isolated buildings. For a fixed base building, the corresponding isolation in the above governing equations of motion with appropriate modifications in the mass, stiffness, and damping matrices.

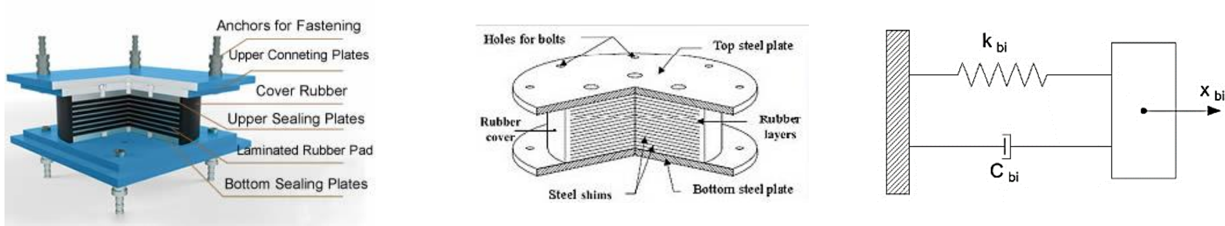
3.2. Connected building system

Owing to the introduction of viscoelastic dampers as connecting links at the superstructure of the two adjacent buildings, it converts to a connected isolated system with (1+m) lateral degrees of freedom.

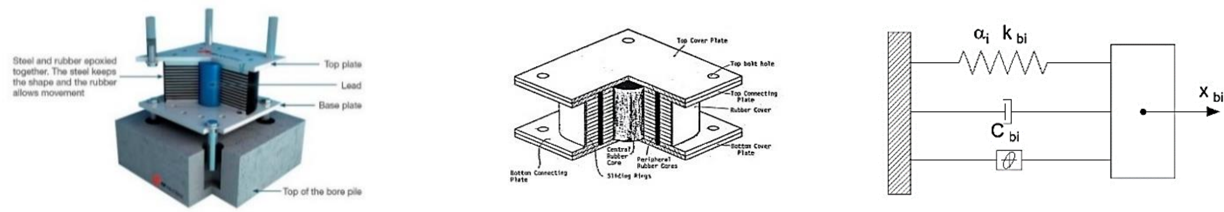
$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} + [F] = -[M]\{r\}(\ddot{x_g}) \qquad (6)$$

The unknown floor displacement, velocity, and acceleration vectors for the adjacent connected Buildings 1 and 2, respectively. In Eq. (6), the mass matrix. [M] for the combined system is obtained by.

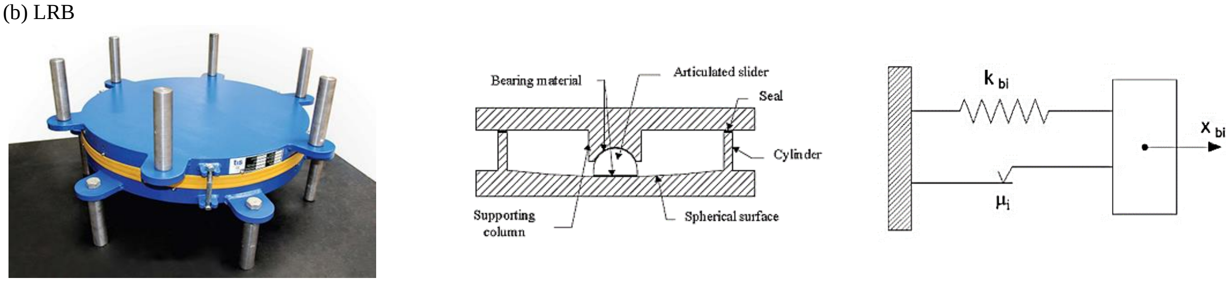
$$[M] = \begin{bmatrix} [M]_1 & [O]_1 \\ [O]_2 & [M]_2 \end{bmatrix} \qquad (7)$$



(a) HDRB



(b) LRB



(c) FPS

Fig 2. Schematic models of isolation systems (a) HDRB (b) LRB and (c) FPS

where $[M_1]$ and $[M_2]$ are the individual diagonal mass matrices for the adjacent Buildings 1 and 2, respectively; $[O_1]$ and $[O_2]$ are the null matrices of order (L* m) and (m * L) respectively. The stiffness matrix for the connected system is expressed as.

$$[M] = \begin{bmatrix} [M]_1 & [O]_1 \\ [O]_2 & [M]_2 \end{bmatrix} + \begin{bmatrix} [K]_d & -[K]_d & [O]_3 \\ -[K]_d & [K]_d & [O]_4 \\ [O]_5 & [O]_6 & [O]_7 \end{bmatrix} \tag{8}$$

where $[K_1]$ and $[K_2]$ are the stiffness matrices for the adjacent Buildings 1 and 2, respectively; and $[K_d]$ is as explained in eq (2).

$$[M] = \begin{bmatrix} [C]_1 & [O]_1 \\ [O]_2 & [C]_2 \end{bmatrix} + \begin{bmatrix} [C]_d & -[C]_d & [O]_3 \\ -[C]_d & [C]_d & [O]_4 \\ [O]_5 & [O]_6 & [O]_7 \end{bmatrix} \tag{9}$$

where $[C_1]$ and $[C_2]$ are the damping matrices for the adjacent Buildings 1 and 2, respectively; and $[C_d]$ is as explained in eq (3). The bearing force vector for com bind system is

$$\{F\} = \begin{Bmatrix} \{F_{b1}\} \\ \{F_{b2}\} \end{Bmatrix} \tag{10}$$

The isolation layer forces $\{F_{b1}\}$ and $\{F_{b2}\}$ for three different types of isolation systems used the present study such as high damping rubber bearings, lead rubber bearings and friction pendulum systems under the adjacent buildings are derived as follows.

3.3. High-damping rubber bearing

The high-damping rubber bearing (HDRB) represents the commonly used elastomeric bearings. The basic components of HDRB are steel and rubber plates built in the alternate layers [11-12]. The dominant feature of HDRB is the parallel action of linear spring and damping as shown schematically in Fig. 2(a). The HDRB exhibits high damping capacity, horizontal flexibility, and high vertical stiffness. The damping constant of the system varies considerably with the strain level of the bearing (generally of the order of 15%). The system operates by decoupling the structure from the horizontal components of earthquake ground motion by interposing a layer of low horizontal stiffness between the structure and its foundation. The isolation effects in this type of system are produced not by absorbing the earthquake energy, but by deflecting through the system dynamics. Usually, there is a large difference in the damping of the structure and the isolation device, which makes the system non-classically damped.

The stiffness and damping of the HDRB are selected to provide the specific values of the two parameters characterizing the system namely the isolation time period (T_{bi}) and damping ratio (ξ_{bi}) defined as

$$T_{bi} = 2\pi\sqrt{\frac{M_i}{K_{bi}}} \qquad (i = 1 , 2) \qquad (11)$$

$$\xi_{bi} = \frac{C_{bi}}{2M_i\ \omega_{bi}} \qquad (i = 1 , 2) \qquad (12)$$

where $\omega_{bi} = \frac{2\pi}{T_{bi}}$ is the isolation frequency.

3.4. Lead-rubber bearing

The second category of elastomeric bearings is lead-rubber bearings [13]. Lead-plug rubber bearings were invented in New Zealand in 1975. The mechanism of lead-plug rubber bearings is very similar to that of low-damping natural rubber bearings. [14] This kind of frictional isolator has a sliding hinge part that slides on a spherical steel surface. The surface of the upper sliding part, which is in contact with the depression of the isolator during the time. [15] as shown schematically in Fig. 2(b). This system provides the combined features of vertical load support, horizontal flexibility, restoring force, and damping in a single unit. These bearings are similar to the HDRB, but a central lead core is used to provide an additional means of energy dissipation. The energy-absorbing capacity of the lead core reduces the lateral displacements of the isolator. The force-deformation. The behavior of the LRB is generally represented by nonlinear characteristics following a hysteretic nature. For the present study, Wen's model [16] is used to characterize the hysteretic behavior of the LRB.

where F_{yi} is the yield strength of the bearing; a_i anindex which represents the ratio of post to pre yielding stiffness; k_i the initial stiffness of the bearing: C_{bi} the viscous damping of the bearing; and Z_i is the non-dimensional hysteretic displacement component satisfying the following non-linear first order differential equation.

where q_i is the isolator yield displacement, dimension less parameters A, β , τ and are selected such that the predicted response from the model closely matches the experimentally obtained results. The parameter n is an integer constant, which controls smoothness of the transition from elastic to plastic response.

3.5. Friction pendulum system

One of the most popular and effective techniques for seismic isolation is the use of sliding isolation vices. The sliding systems exhibit an excellent performance under a variety of severe earthquake loading and are very effective in reducing large levels of the superstructure acceleration. These isolators are characterized by insensitivity to the frequency content of earthquake excitation because of the tendency of a sliding system to reduce and spread the earthquake energy over a wide range of frequencies. Another advantage of sliding isolation systems over conventional rubber bearings is the development of the frictional force at the base; it is proportional to the mass of the structure, and the center of mass and center of resistance of the sliding support coincide. Consequently, the torsional effects produced by the asymmetric building are diminished. The concept of sliding bearings is combined with the concept of a pendulum-type response, resulting in a conceptually interesting seismic isolation system known as a friction pendulum system (FPS) [17], as shown schematically in Fig. 2(c). In FPS, the isolation is achieved by means of an articulated slide on a spherical, concave chrome surface. The slide is faced with a bearing material which, when in contact with the polished chrome surface, results in a friction force, while the concave surface produces a restoring force. The resisting force provided by the FPS is:

$$F_{bi} = k_{bi}\ X_{bi} + F_{Xi} \qquad (I = 1 , 2) \qquad (13)$$

where k_{bi} is the bearing stiffness provided by virtue of inward gravity action at the concave surface: F_{Xi} is the frictional force at slide and polished chrome surface junction.

The system is characterized by isolation time period (T_{bi}) that depends upon radius of curvature of concave surface and friction coefficient (μ_i). The isolation stiffness k_{bi} is adjusted and the specified value of the isolation time period evaluated by the Eq. (11) is achieved.

4. Solution of equations of motion

Classical modal superposition technique cannot be employed in the solution of equations because the system is not classically damped due to the difference in damping in the isolation system as compared to the damping in the superstructure of a base-isolated building, as well as the damper links. Therefore, for different earthquakes, the equations of motion are solved numerically using Newmark's method of step-by-step integration, adopting linear variation of acceleration over a small-time interval of Ar. The time interval for solving the equations of motion is taken as 0.02/20 sec (ie Δt 0.001 sec). At each time instant, the responses, namely the accelerations and displacements are obtained at each floor level of the two adjacent buildings.

5. Numerical study

The seismic response of two adjacent multi-storied buildings, connected using viscoelastic dampers, either

Table 1.
Mechanical specifications of isolators used in 3-story and 5-story structures

position	Load applied to the column W (ton)	Lead core yield strength Q (ton)	Yeld strenght Fy (kn)	stiffnes K0 (kn/m)	Effective stiffness Keff (kn/m)	Effective periodicity Teff (sec)	Effective damping ratio xeff ---	Effective damping Ceff (kn.s/m)
3-storey structure	37.80	1.89	22.27	2227.16	509.42	1.71	0.16	43.81
5-storey structure	63.00	3.15	37.12	3711.94	849.03	1.71	0.16	73.02

both or one of them supported on isolation devices, is investigated here. The multi-degree-of-freedom shear models of the adjacent buildings are used, with linear viscoelastic damping devices at different floor levels in Fig. 1. The earthquake selected for this study (1) Imperial Valley Earthquake occurred on October 15, 1979, equivalent to Mehr 23, 1358, at 23:16:54 UTC in the United States, Southern California region. The depth of this earthquake was 9.3 km, and its magnitude was 6.5 on the Mw scale, and its maximum intensity was declared on the Mercalli scale IX (Violent). Its PGA value is 0.28. (2) The Kobe earthquake or the Great Hanshin earthquake is an earthquake with a magnitude of 6.8 or a magnitude of 7.3 on the Richter scale, which shook and crushed the city of Kobe in Japan on January 17, 1995, at 5:46 a.m. for 20 seconds. Its PGA value is declared as 0.671. (3) The San Fernando earthquake occurred on February 9, 1971, at 06:00:41 AM local time (14:00:41 UTC) in the San Fernando area of the United States. The depth of the earthquake was 8.4 km. Its magnitude was reported as 6.6 on the Mw scale.

5.1. The shape coefficient of the spectrum of the ground plan

According to Standard 2800 of Iran, the shape coefficient of the spectrum of the plan used in this study, type III land, and the acceleration of the plan for the area with a very high-risk area is considered 0.35. In the Figure, the shape factor of the design spectrum for all types of soils in the zone of high risk and high void can be seen.

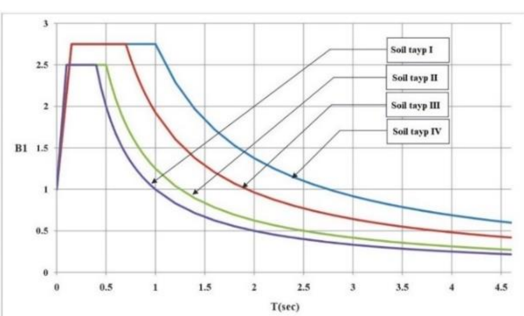


Fig 3. Shape coefficient of the design spectrum for all types of soils

5.2. Technical and mechanical specifications used in dampers and separators

A seismic isolation head and a viscoelastic damper were used to analyze 5-story and 3-story structures and observe the displacement in the structure based on 3 design earthquakes. The mechanical specifications and initial analytical results for use in the SAP2000 program are specified in the tables below. Considering the initial results and placing each of them in 3-story and 5-story structures, they were analyzed according to Figure 1.

Table 2.
Mechanical characteristics of viscoelastic dampers

Periodicity T	natural frequency ω	Elastic stiffness h	damping c
1.49	4.23	1.2	15%

Table 3.
Viscoelastic damper specifications separately in a 5-story diagonal structure

position	Stiffness of the structure ki	Damper stiffness k`i	damping c`i	Viscoelastic damper angle q
1st floor	79.41	35.47	10.07	30.25
2st floor	52.83	23.60	6.70	30.25
3st floor	21.36	9.54	2.71	30.25
4st floor	14.10	6.30	1.79	30.25
5st floor	6.73	3.01	0.85	30.25

Table 4.
Viscoelastic damper specifications separately in a 3-story diagonal structure

position	Stiffness of the structure ki	Damper stiffness k`i	damping c`i	Viscoelastic damper angle q
1st floor	45.38	20.27	5.75	30.25
2st floor	28.07	12.54	3.56	30.25
3st floor	45.82	20.47	5.81	30.25

Table 5.
Viscoelastic damper specifications separately in a 3-story horizontal structure

position	Stiffness of the structure	Damper stiffness	damping damping	Viscoelastic damper angle
	ki	k`i	c`i	q
1st floor	45.38	20.27	5.75	30.25
2st floor	28.07	12.54	3.56	30.25
3st floor	45.82	20.47	5.81	30.25

The following tables show the results of structural analysis in cases where a viscoelastic damper is used to connect two structures on the floor or as a metal member. Also, a seismic isolator is used in the structures at the same time, as shown in Figure 1. The amount of dead and live loads used in structural analysis is also specified in Figure 1.

5.3. Analysis of the amount of floor displacement in case of using viscos-elastic damper in the base

In the Table 6, the amount of displacement of the floors of two buildings can be seen in two cases, one in which the viscoelastic damper was used at the highest level of the shortest floor (3rd floor) and one in the case in which, in addition to the use of the viscoelastic damper at the level of the third floor, it was also used at the level of the first floor (Figure 1-b).

According to the results of Table 6, it can be seen that the effect of the amount of displacement in node 16 is incremental, which is caused by the effects of the displacement of node 18 in the amount of about 20-30% compared to the design earthquake on it. In other nodes, this amount of displacement has been reduced to about 1-7% according to the design earthquake. This is even though both structures have a seismic isolator from the floor, and the closer the viscoelastic damper is to the floor, the lower its displacement.

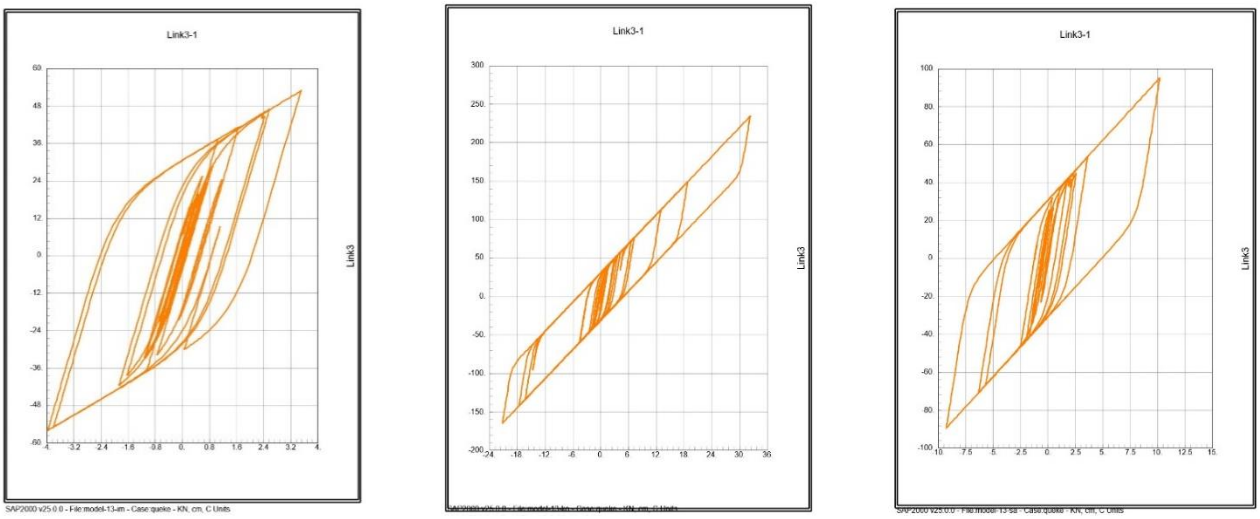
6. Conclusions

The amount of displacement and seismic response of adjacent buildings connected with viscoelastic dampers when both of the buildings are separated from the foundation was investigated in this study, and the following results were obtained.

- A considerable amount of reduction in earthquake displacement of the design is achieved by introducing viscoelastic damper joints in the floor surfaces of the buildings adjacent to the isolated foundation, which is useful to prevent the consequences of knocking. So that it balances the displacement of two structures.
- The effectiveness of viscoelastic dampers as connecting links is more important in the case of buildings with isolated foundations compared to two isolated buildings with adjacent connected foundations. It is very useful in retrofitting works in structures.

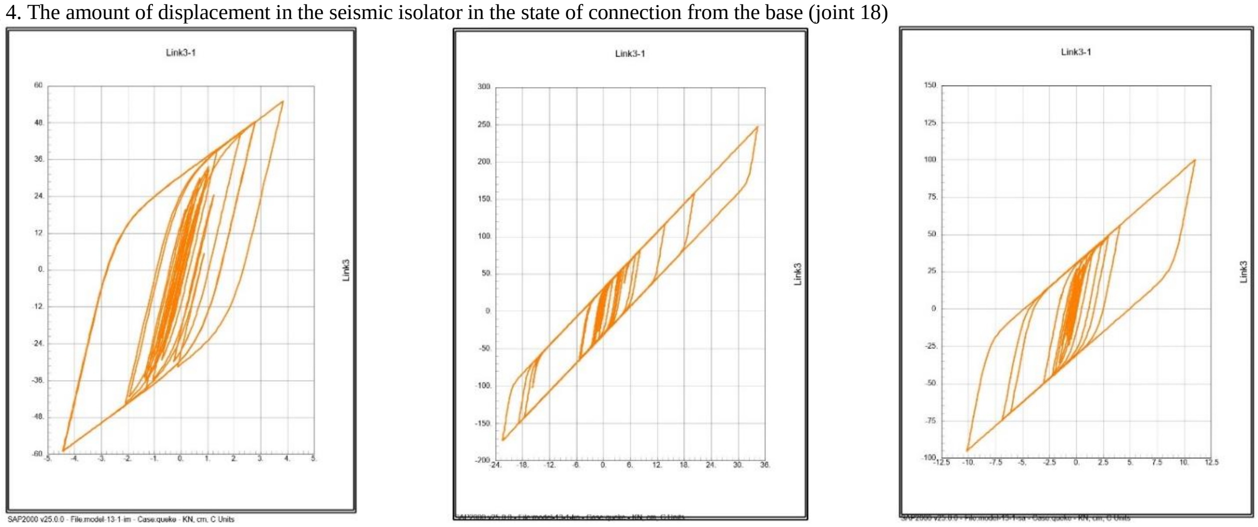
Table 6.
Table of displacement value of structural nodes according to design earthquake

The studied earthquake		**Imperial Valley 1979**	**Kobe 1995**	**San Fernando 1971**
Isolation system 3-story Building 1 5-story Building 2		Bearing displacement (cm)	Bearing displacement (cm)	Bearing displacement (cm)
Unconnected	point 3	5.89	43.39	14.40
	point 20	1.28	23.02	6.40
	point 13	4.80	38.88	12.67
	point 16	2.48	25.51	7.84
	point 9	4.82	38.90	12.68
	point 18	3.66	34.11	10.84
Connected	point 3	5.98	42.77	14.26
	point 20	1.24	21.62	5.95
	point 13	4.87	38.32	12.53
	point 16	3.52	31.96	10.16
	point 9	4.86	38.09	12.46
	point 18	3.55	32.28	10.26
Percentage reduction of node displacement in connection mode from the base	point 3	-1.56%	1.46%	1.02%
	point 20	3.74%	6.46%	7.62%
	point 13	-1.41%	1.47%	1.07%
	point 16	-29.66%	-20.18%	-22.85%
	point 9	-0.81%	2.14%	1.75%
	point 18	3.10%	5.66%	5.61%



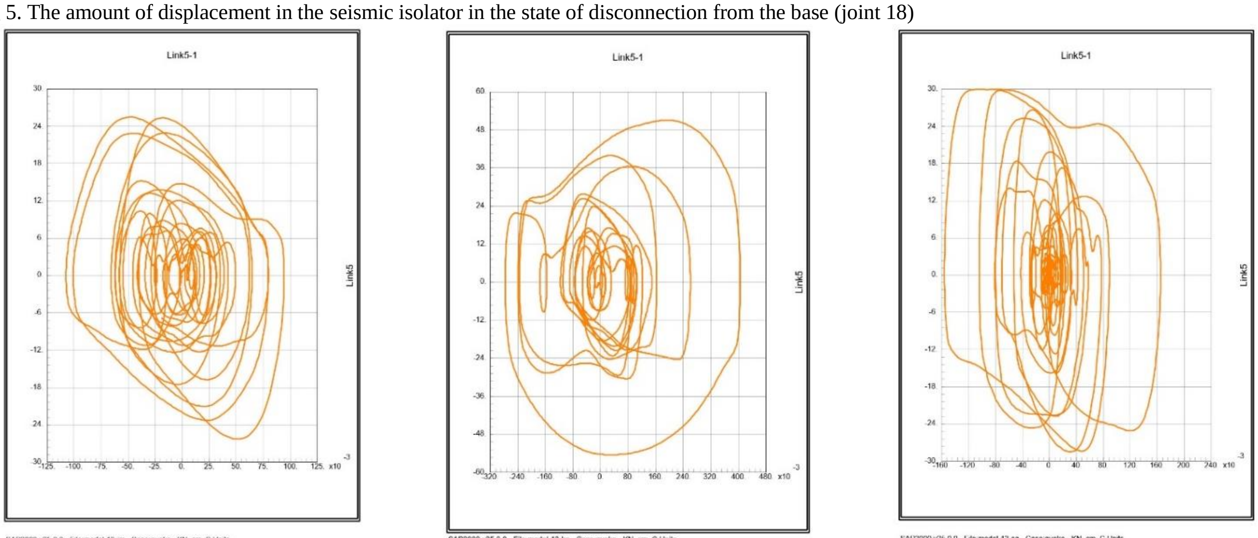
(a) Earthquake Imperial Valley 1979 (b) Earthquake Kobe 1995 (c) Earthquake San Fernando 1971

Fig 4. The amount of displacement in the seismic isolator in the state of connection from the base (joint 18)



(a) Earthquake Imperial Valley 1979 (b) Earthquake Kobe 1995 (c) Earthquake San Fernando 1971

Fig 5. The amount of displacement in the seismic isolator in the state of disconnection from the base (joint 18)



(a) Earthquake Imperial Valley 1979 (b) Earthquake Kobe 1995 (c) Earthquake San Fernando 1971

Fig 6. The amount of force in the viscoelastic damper in the connection state from the base

- The escape position of the viscoelastic damper is very useful and effective for optimizing the design during an earthquake. So that by absorbing high force during vibration, it causes more stability of the structure and also reduces the dimensions of the components of the structure.

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