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Research Article

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Effect of passive coupling on seismic interaction optimization of adjacent structures

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Abstract: During the past few years, several studies have been conducted in various fields of civil engineering in order to design structures that can withstand the forces and deformations that might occur during seismic events. However, more recently, building adjacent structures close to each other and more resistant to earthquakes, provided with coupling systems, has been an issue of major concern. The effects of some parameters, such as the characteristics of adjacent structures and those of the coupling system, on the choice of the separation distance, were investigated using a program that was developed using MATLAB. This article aims to present a study that is intended to determine the parameters characterizing the coupling system. Moreover, the influence of rigidity of the structure was also examined. For this, three examples were investigated: a flexible structure, a rigid structure, and a very rigid structure. The results obtained from the numerical study made it possible to show that knowing the characteristics, number, and arrangements of the coupling systems can be used to find the minimum separation distance between two adjacent buildings.

Keywords: Adjacent building, Coupling, Passive, Separation distance

1 Introduction

Over the past few years, seismic protection of adjacent buildings has been a topic of major interest for researchers throughout the world [1–4]. For such systems, the effects of seismic excitations can lead to negative interactions and collisions between adjoining buildings [1, 4–6], which can cause serious damage to these structures, even if they are well-designed and appropriately constructed.

The easiest and most effective way to limit risks and reduce the seismic pounding of adjacent buildings is to provide a sufficiently wide separation to avoid contact between them. Indeed, several studies have been conducted to determine that parameter [7–11].

Seismic pounding between adjacent buildings is a very complex phenomenon that could lead to the collapse of infill walls, plastic deformation and shear rupture of a column, local crushing and even possible destruction on the entire structure. It is important to know that adjacent structures with different ground levels are more vulnerable when subjected to seismic excitations due to additional shear forces acting on the columns. These forces would certainly lead to greater damage and therefore contribute to the instability of the buildings [12]. The phenomenon of seismic pounding between adjacent buildings is a quite complex issue that has been the subject of a number of studies around the world. The main concern of researchers was to understand the physical aspects of the pounding effect between adjacent structures in order to develop a rational basis that can help to mitigate the seismic risks.

Today, the greatest challenge facing civil engineers throughout the world is to design structures that are capable of withstanding the forces applied to them and therefore prevent the deformations induced by a seismic event. Researchers have found that pounding between two adjacent buildings can cause large-scale damage during strong earthquakes. Consequently, increasing the rigidity of structures using infill wall panels was one of several solutions that were proposed by several researchers working in this field. It was found that these wall panels can have a significant influence on the seismic behavior of structures during seismic excitations. Indeed, they can prevent and reduce the risk of pounding between adjacent structures [13]. However, the problem with infill wall panels is that it is difficult to predict and quantify the damage caused by the frame-infill wall interaction due to complications in modeling the interaction between these structures [4]. This leads us to ignore this solution that consists in modifying the dynamic behavior of adjacent structures during an earthquake.

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Furthermore, some researchers examined the effectiveness of coupling adjacent buildings (passive, active, and semi-active) [14–21].

In 1999, Xu *et al.* [12] investigated the performance of adjacent buildings connected by viscoelastic dampers against earthquakes; they also managed to determine the seismic response of buildings by the pseudo-excitation method. The same researchers demonstrated that coupling devices can reduce the seismic response of these buildings. To do this, they used the Kelvin–Voigt mathematical model which turned out to be unsuitable for modeling fluid viscous dampers. Later, another study was conducted by Zhang *et al.* [22] in 2000 using viscous fluid dampers to connect adjacent buildings. The Maxwell model was then utilized to represent these coupling systems, which are based on the principle of viscous fluid flows passing through specially shaped orifices. In this research, a comparison was made between the viscoelastic dampers that are based on the Kelvin–Voigt model, and the viscous fluid dampers that are based on the Maxwell model. Then, they showed that the two connection systems, the viscoelastic dampers and the viscous fluid dampers, all have the same efficiency. However, they did not study the impact of certain parameters, such as the optimal position of the dampers, torsional effects, and so on.

On the other hand, Jeng *et al.* [23] employed a spectral approach to evaluate the probability of seismic risk and pounding between two adjacent buildings, which were simulated by systems with multiple degrees of freedom (DOF). Their study revealed that the natural period of a building and the ratio of the periods of adjacent buildings are fundamental parameters that can significantly influence the pounding risk between adjacent buildings. Indeed, they proposed solutions where they assumed that the buildings are at the same elevations. Therefore, these solutions cannot be used for adjacent buildings with floor levels at different elevations. In 2003, Ying *et al.* [24] proposed the stochastic optimal coupling-control method for adjacent building structures, based on the stochastic dynamic programming principle and the stochastic average computation method. They coupled the structures by way of control devices that were subjected to random seismic excitations for the purpose of obtaining a reduced-order model for stochastic control analysis. Moreover, the numerical studies carried out indicated that it is quite possible to reduce the seismic response of adjacent buildings using the proposed stochastic optimal control coupling method. As some researchers studied only one particular case, several questions regarding the influence of the characteristics of adjacent structures still remain to be answered in order to draw adequate conclusions. Bhaskarar *et al.* [15] studied the case of two adjacent frame structures coupled with different types of dampers that were subjected to different seismic excitations. They suggested that dampers can be effective for reducing the responses of adjacent buildings to earthquakes; they also added that dampers can be quite effective in preventing the pounding phenomenon. The same authors finally concluded that using dampers with optimal parameters can make it possible to minimize the response of buildings to earthquakes.

On the other hand, due to the fact that the seismic performance of buildings connected with friction dampers has not been sufficiently investigated, researchers such as Bhaskarar *et al.* [16] proposed two numerical models to calculate the response of adjacent buildings connected with friction dampers and then formalized the results of the suggested formulation. The results obtained suggested that friction dampers are effective at reducing the seismic response of adjacent buildings. It is important to note that the position of the dampers is critical for reducing the seismic response of buildings. Meanwhile, Basili *et al.* [21] carried out an investigation on the optimal passive control of adjacent structures connected by nonlinear hysteresis devices. They adopted the versatile Bouc–Wen model for nonlinear devices. In addition, the stochastic linearization technique was applied to solve the nonlinear equations of motion using a simplified solution. These findings explicitly confirmed the effectiveness of the dampers (the coupling system) used for attenuation of the seismic response of adjacent structures. In 2008, Seung *et al.* [26] proposed an optimal design method for nonlinear hysteresis dampers for the purpose of improving the seismic performance of two adjacent buildings. This approach uses a stochastic linearization method and a multiobjective genetic algorithm. They considered a numerical example of 10- and 20-story buildings coupled by magneto-rheological dampers to show that the proposed approach is economically efficient and gives good seismic performance. In 2009, Ye *et al.* [27] proposed a modified Kelvin model and compared it with other models. They used this model to study the behavior of a base-isolated building connected to adjacent structures. The same model was then validated through numerical comparisons with other models. In 2010, Bharti *et al.* [28] tried to assess the effectiveness of magneto-rheological dampers in the coupling of adjacent buildings; they also examined the influence of the position of these dampers on vibration control performance. Later, in 2011, Kim *et al.* [19] investigated the possibility of applying the hybrid control model using magneto-rheological dampers for semi-active control in order to reduce the seismic response of adjacent buildings. They suggested that this hybrid control model can be applied to control the vibrations of adjacent buildings exposed to high winds and other excitation forces. In 2012, Palacios *et al.* [18] proposed a strategy based on semi-active control and passive structural control. They indicated that this strategy can be adapted to a wide variety of multistructure systems; they also asserted that this approach is compatible with virtually any local feedback design methodology commonly used in building structures. Another method used to control system design, based on the active control of adjacent structures, was developed by Soon *et al.* [14]. In their numerical studies, they considered two adjacent buildings connected via active systems; using the linear quadratic regulator (LQR) algorithm, they showed that the proposed method is effective at reducing the seismic pounding risk of adjacent buildings. In Refs [14, 18, 19, 28], it was a matter of knowing whether the results remained unchanged when the authors investigated the effects of the characteristics of adjacent buildings on the separation distance between them. In 2014, Yang *et al.* [29] conducted a study on the influence of viscoelastic dampers on the responses of adjacent buildings accelerated in two horizontal directions by several seismic excitations.

Similarly, in 2014, Abbas *et al.* [5] made an attempt to assess damages that occur in adjacent buildings during seismic events; they assessed the effects of the separation distance between adjacent buildings and the elastic limit of these buildings on the performance indices, along with the associated structural damage. They found that the pounding risk between two adjacent structures increases as the distance between them declines. In 2017, Maria [9] suggested that the separation distance between adjacent structures depends on the elastic limit and the seismic risk level of the buildings under consideration. As part of the current work, our investigation will become interesting by examining the influence of coupling systems as well as the structural control in coupled buildings. It should be noted that a parametric study carried out by Shehata *et al.* [30] in 2019 showed that the eccentric hammering from one floor to another causes significant torsional movement, even in buildings with a symmetrical plan view. It is worth noting that pounding-induced torsional vibrations can dramatically affect the shear strength and ductility of the columns. These vibrations increase the requirements for shear strength and ductility of the columns along their perimeter. These columns are subjected to high displacement due to the rotational movement of the building. In addition, the torsional motion depends on the impact of the interaction zone and the impact of the eccentricity of forces produced by the centers of rigidity of colliding buildings.

It was found that when a structure is subjected to a severe earthquake, all constituent elements of the structure are subjected to large deformations. Then, if the elements do not have enough ductility, they will be severely damaged and the structure could collapse. It is worth recalling that ductility, otherwise known as the strain capacity, is often used in the field of seismic engineering; it is considered as one of the most critical parameters in evaluating the seismic performance of structures. The problem with adjacent structures is that if the separation distance is not sufficient, the ductility of these structures could be larger than that required by national and international regulations [13]. In 2019, Miari *et al.* [31] carried out a research review on the topic of pounding between adjacent buildings in order to better understand this phenomenon and to explain the contradictory results.

Based on previous research, we decided to do a parametric study to calculate an optimal separation distance instead of proposing some values [2, 3], to avoid hammering between adjacent structures. First, a MATLAB-based software program was developed using the fundamental equations of structural dynamics in the presence of control systems, and, second, to carry out an extensive parametric study to determine the influence of the characteristics of structures and coupling systems on the selection of the separation distance between adjacent structures as well as the elements connecting them.

2 Equation of Motion of Two Adjacent Buildings

This section aims to present the mathematical equations that allow calculating the dynamic response of two adjacent structures. To do this, the structures are assumed to be subjected to the same acceleration; the soil–structure interaction effect is neglected. In this case, two shear buildings were considered with NOA and NOB levels, such that NOA ≤ NOB. These two structures are coupled with Maxwell dampers of stiffness *Kd* and damping constant *Cd*, as illustrated in Figure 1.

The equation of motion of structure A can be written as:

$$[M_A]\left\{\overline{X}_A(t)\right\} + [CA]\left\{\dot{X}_A(t)\right\} + [KA]\left\{X_A(t)\right\} = \{\delta_A\}\, x_0^{-g}(t) \tag{1}$$

That of structure B is written like:

$$[M_B]\left\{\overline{X}_B(t)\right\} + [CB]\left\{\dot{X}_B(t)\right\} + [KB]\left\{X_B(t)\right\} = \{\delta_B\}\, x_0^{-g}(t) \tag{2}$$

Combining Eqs (1) and (2), and adding the coupling system (passive, active, etc.) to find the equation of motion

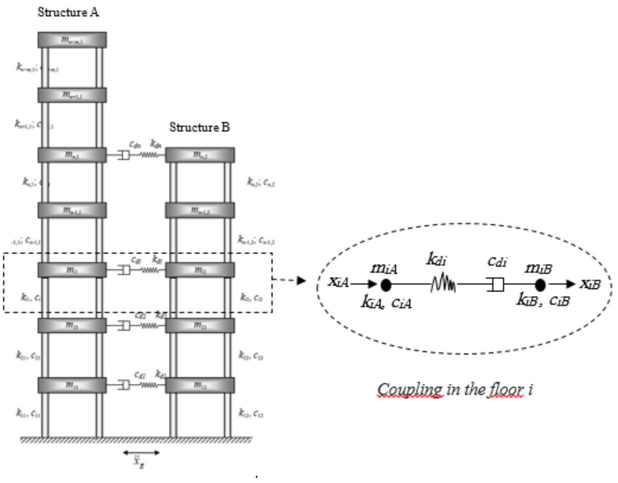


Figure 1: Model of two adjacent structures coupled with Maxwell dampers

of the two coupled adjacent structures, helps to obtain:

$$[M]\left\{\overline{X}(t)\right\} + ([C] + [Cd])\left\{\dot{X}(t)\right\} + ([K] + [Kd])\left\{X(t)\right\} = \{\delta\}\, x_0^{-g}(t) \tag{3}$$

where the matrices $[M]$, $[C]$, and $[K]$ of dimensions (NO × NO), such as NO = NOA + NOB, are, respectively, the mass, damping, and stiffness matrices of the system:

$$[M] = \begin{bmatrix} M_A & 0 \\ 0 & M_B \end{bmatrix} \tag{4}$$

$$[K] = \begin{bmatrix} KA & 0 \\ 0 & KB \end{bmatrix} \tag{5}$$

$$[C] = \begin{bmatrix} CA & 0 \\ 0 & CB \end{bmatrix} \tag{6}$$

$$[X(t)] = \begin{bmatrix} X_A(t) & X_B(t) \end{bmatrix}^T \tag{7}$$

It should be noted that the vector $\{\delta\}$ of dimension (NO × 1) represents the horizontal acceleration coefficient vector of soil for the two structures.

$\{\mathrm{X}(\mathrm{t})\}$ of dimension (NO × 1) represents the displacement vector of floors of the system $\left(x_{NO_A}^{tg} x_{NO_A-1}^{tg} \ldots\ x_i^{tg}\ \ldots\ x_2^{tg}\ x_1^{tg}\ ;\ x_{NO_B}^{tg} x_{NO_B-1}^{tg} \ldots\ x_i^{tg}\ \ldots\ x_2^{tg}\ x_1^{tg}\right)^{\mathrm{T}}$.

The mass matrix for $i = A,\ B$:

$$[M_i] = \begin{bmatrix} m_{NOi/i} & & \cdots & & 0 \\ & m_{NOi-1/i} & & & \\ \vdots & & \cdots & & \vdots \\ & & & m_{2/i} & \\ 0 & & \cdots & & m_{1/i} \end{bmatrix} \tag{8}$$

The stiffness matrix for $i = A$, B, and $j = 1, \ldots, \mathrm{NOA}$ if $i = \mathrm{NOA}$, and $j = 1, \ldots, \mathrm{NOB}$ if $i = \mathrm{NOB}$:

$$[Ki] = \tag{9}$$

$$\begin{bmatrix} k_{NOi/i} & -k_{NOi/i} & & & & & \\ -k_{NOi/i} & (k_{NOi/i} + k_{NOi/i-1}) & -k_{NOi/i-1} & & & & \\ & & \cdots & & & & \\ & & -k_{j/i} & (k_{j/i} + k_{j-1/i}) & -k_{j-1/i} & & \\ & & & & \cdots & & \\ & & & & -k_{3/i} & k_{3/i} + k_{2/i} & -k_{2/i} \\ & & & & & -k_{2/i} & k_{2/i} + k_{1/i} \end{bmatrix}$$

The damping matrix for $i = A$, B, and $j = 1, \ldots, \mathrm{NOA}$ if $i = \mathrm{NOA}$, and $j = 1, \ldots, \mathrm{NOB}$ if $i = \mathrm{NOB}$:

$$[Ci] = \tag{10}$$

$$\begin{bmatrix} c_{NOi/i} & -c_{NOi/i} & & & & & \\ -c_{NOi/i} & (c_{NOi/i} + c_{NOi/i-1}) & -c_{NOi/i-1} & & & & \\ & & \cdots & & & & \\ & & -c_{j/i} & (c_{j/i} + c_{j-1/i}) & -c_{j-1/i} & & \\ & & & & \cdots & & \\ & & & & -c_{3/i} & c_{3/i} + c_{2/i} & -c_{2/i} \\ & & & & & -c_{2/i} & c_{2/i} + c_{1/i} \end{bmatrix}$$

Matrices [Cd] and [Kd], of dimensions (NO × NO), are the damping and stiffness matrix, respectively, of the coupling dampers of the system.

The vector $\{\delta\}$ that allows passing from the external excitation to the considered DOF of the system is given as follows:

For $i = A, B$: $\{\delta\} = \begin{Bmatrix} \delta_A \\ \delta_B \end{Bmatrix}$, with

$$\{\delta_i\} = \begin{Bmatrix} -m_{NOi/i} \\ \vdots \\ -m_{j/i} \\ \vdots \\ -m_{1/i} \end{Bmatrix} \tag{11}$$

Matrix $[\gamma]$ whose dimension is (NO × NCD) is the localization matrix of the superstructure controllers, and NCD is the number of coupling controllers.

Eq. (3) can be written in the form of the following equation of state (Reteri and Megnounif, [32]):

$$\left\{\dot{Z}^t(t)\right\} = [A]\left\{Z^t(t)\right\} + \{E(t)\} \tag{12}$$

where $[A]$ is the characteristic matrix of the number of coupling controller systems; its dimension is (2NO × 2NO):

$$[A] = \begin{bmatrix} [0] & [I] \\ -[A_K] & -[A_C] \end{bmatrix} \tag{13}$$

$$[\mathrm{A_K}] = [\mathrm{M}]^{-1}\,[\mathrm{K}] \tag{14}$$

$$[\mathrm{A_C}] = [\mathrm{M}]^{-1}\,[\mathrm{C}] \tag{15}$$

$\{Z(t)\}$ is the state vector and $\{\dot{Z}(t)\}$ is the derivative of the state vector; its dimensions are (2NO × 1):

$$\{Z(t)\} = \begin{Bmatrix} \{X(t)\} \\ \{\dot{X}(t)\} \end{Bmatrix} \tag{16}$$

$$\{\dot{Z}(t)\} = \begin{Bmatrix} \{\dot{X}(t)\} \\ \{\overline{X}(t)\} \end{Bmatrix} \tag{17}$$

{E} is the external disturbance vector; its dimension is (2NO × 1):

$$\{\mathrm{E}(\mathrm{t})\} = \{\mathrm{C}\}\, \mathrm{x}_0^{\mathrm{g}}(\mathrm{t}) \tag{18}$$

{C} is the vector related to the acceleration of the structure base; its dimension is (2NO × 1):

$$\{C\} = \begin{Bmatrix} [0] \\ [M]^{-1} \quad \{\delta\} \end{Bmatrix} \tag{19}$$

3 Program Validation

Based on previous theoretical developments on the topic, the present work attempts to carry out a numerical simulation using MATLAB. A program was developed for the purpose of studying the dynamic behavior of adjacent structures (columns and beams) for any number of floors, structural characteristics, and coupling systems.

It is worth indicating that the issue can be treated with and without coupling. The validation of the program is performed by comparing the results obtained with those reported by Palacios *et al.* [17].

In this work, we calculated the separation distance by the absolute sum (ABS) of the maximum displacements with coupling:
The ABS:

$$D = x_{NOA/A} + x_{NOA/B} \tag{20}$$

where $x_{NOA/A}$ is the top floor displacement of structure A and $x_{NOA/B}$ is the displacement of floor NOA of structure B.

3.1 Program flowchart

In accordance with the previous mathematical development, a MATLAB-based program was established. The general flowchart considered is given as follows (Figure 2a). In order to validate the program for a numerical application, the dynamic loading used for the excitation of the two structures is the El-Centro 1940 earthquake with N–S components, as shown in Figure 2b.

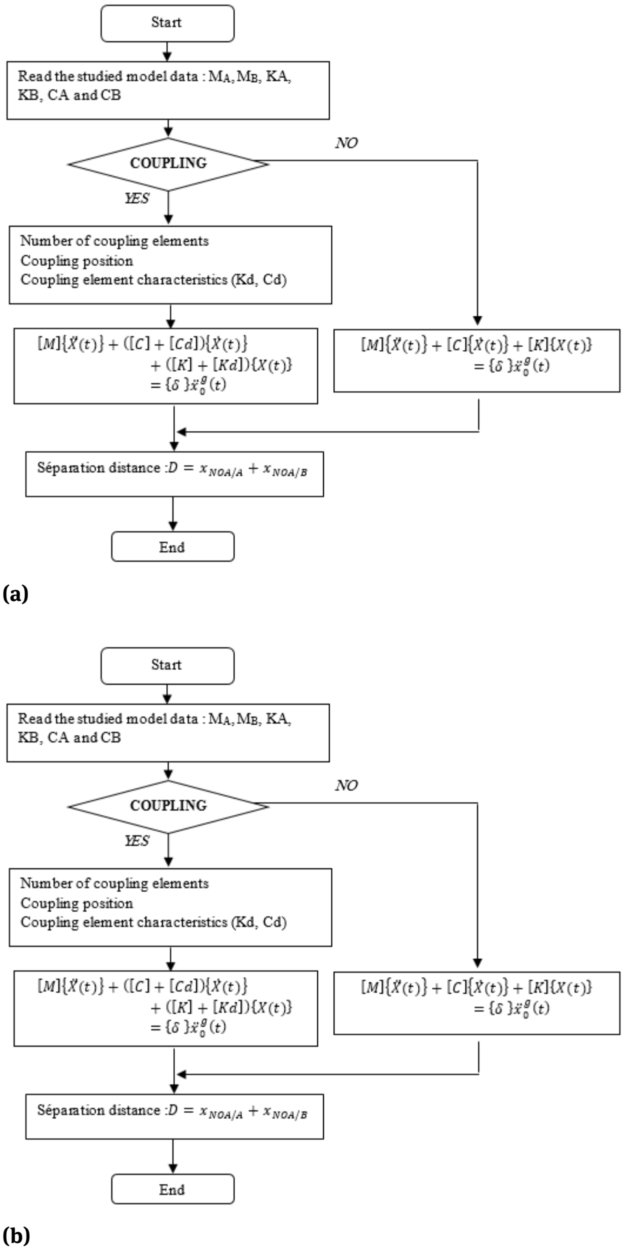


Figure 2: Flowchart of the simulation model and N–S components of El Centro earthquake (1940). (a) Flowchart of the simulation model and (b) N–S components of El Centro earthquake (1940)

The results obtained from our program, in the case with coupling, were compared with the results found by Palacios *et al.* [17].

The data of the model under study are presented in Table 1 [17].

The characteristics of the coupling system are given as: $C_1^d = 0$, $C_2^d = 10^6$ N s/m, and $k_1^d = k_2^d = 0$.

Table 1: Data of the second case

Floor	Left building m_i (kg)	ki (N/m)	ci (N s/m)	Right building m_i (kg)	ki (N/m)	ci (N s/m)
1	1.29×10^6	4×10^9	10^5	1.29×10^6	2×10^9	10^5
2	1.29×10^6	4×10^9	10^5	1.29×10^6	2×10^9	10^5
3	1.29×10^6	4×10^9	10^5			

Table 2 gives the results found by our simulation and those of Ref. [17]:

Table 2: Maximum absolute interstory drifts (cm)

		Left building $y_1^{(l)}$ (cm)	$y_2^{(l)}$ (cm)	$y_3^{(l)}$ (cm)	Right building $y_1^{(r)}$ (cm)	$y_2^{(r)}$ (cm)
Free	By Palacios *et al.* [17]	2.71	2.13	1.17	3.16	1.95
	Simulation	2.67	2.09	1.17	3.20	1.99
	%	4	4	0	4	4
Passive	By Palacios *et al.* [17]	1.65	1.32	0.72	1.81	1.10
	Simulation	1.61	1.30	0.72	1.80	1.10
	%	4	2	0	1	0

The comparison of the results showed differences ranging from 0% to 4%, indicating very good agreement.

4 Parametric Study

For the purpose of studying the performance of adjacent buildings connected by passive dampers and determining the important characteristics relating to the selection of the best separation distance between adjacent structures, a parametric study was conducted in this article on four models, as shown in Figure 3, in order to show the influence of some specific parameters, such as the characteristics and position of the coupling systems, number of floors, and variation of stiffness from one building to another, in the two examples. The soil–structure interaction was neglected and was not taken into consideration in this study.

In both cases, and for the two examples of the parametric study regarding the three models, a number of iterations were performed for all values of the stiffness ratio (*Kd*/*KA*) of the damper between 0% and 100%. In addition, the damping value *Cd* was fixed at 0 in order to find an optimal stiffness value within the interval under study. These optimal values found for each model were used later. The same parametric study was repeated for the purpose of finding the most adequate damping value *Cd*. It should be noted that, throughout the entire parametric study, the two buildings were considered under the El-Centro seismic loading (Figure 2b). The results of the parametric study of the separation distance between buildings A and B are illustrated in Figures 4–7.

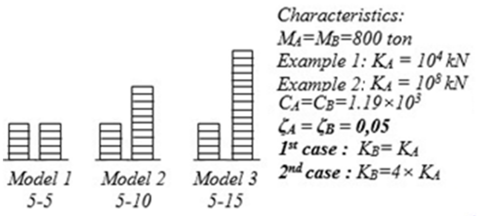


Figure 3: Models of the adjacent buildings under study

The figures on the left give the results obtained from the parametric study in order to determine the optimal value of K_d; those on the right give the results found with the parametric study in order to find the optimal value of *Cd*. Figures 4–7 allowed drawing the following conclusions:

The separation distance between buildings was calculated according to the stiffness values *Kd* of the damper. One can clearly observe that once that value is >60% of the stiffness of structure A, *Kd* no longer has any effect on the separation distance; this is true for most models. On the other hand, by increasing the stiffness value (*KA*) of the building, one can note that the influence of the ratio (*Kd*/*KA*) on this distance will cease when the value of *Kd* is equal to 80% of that of *KA*.

From Figures 4–7, we note that when the value of the ratio (*Kd*/*KA*) is varied between 60% and 80%, its influence on the separation distance was weak in some models, and in other models we noticed an increase in the separation distance.

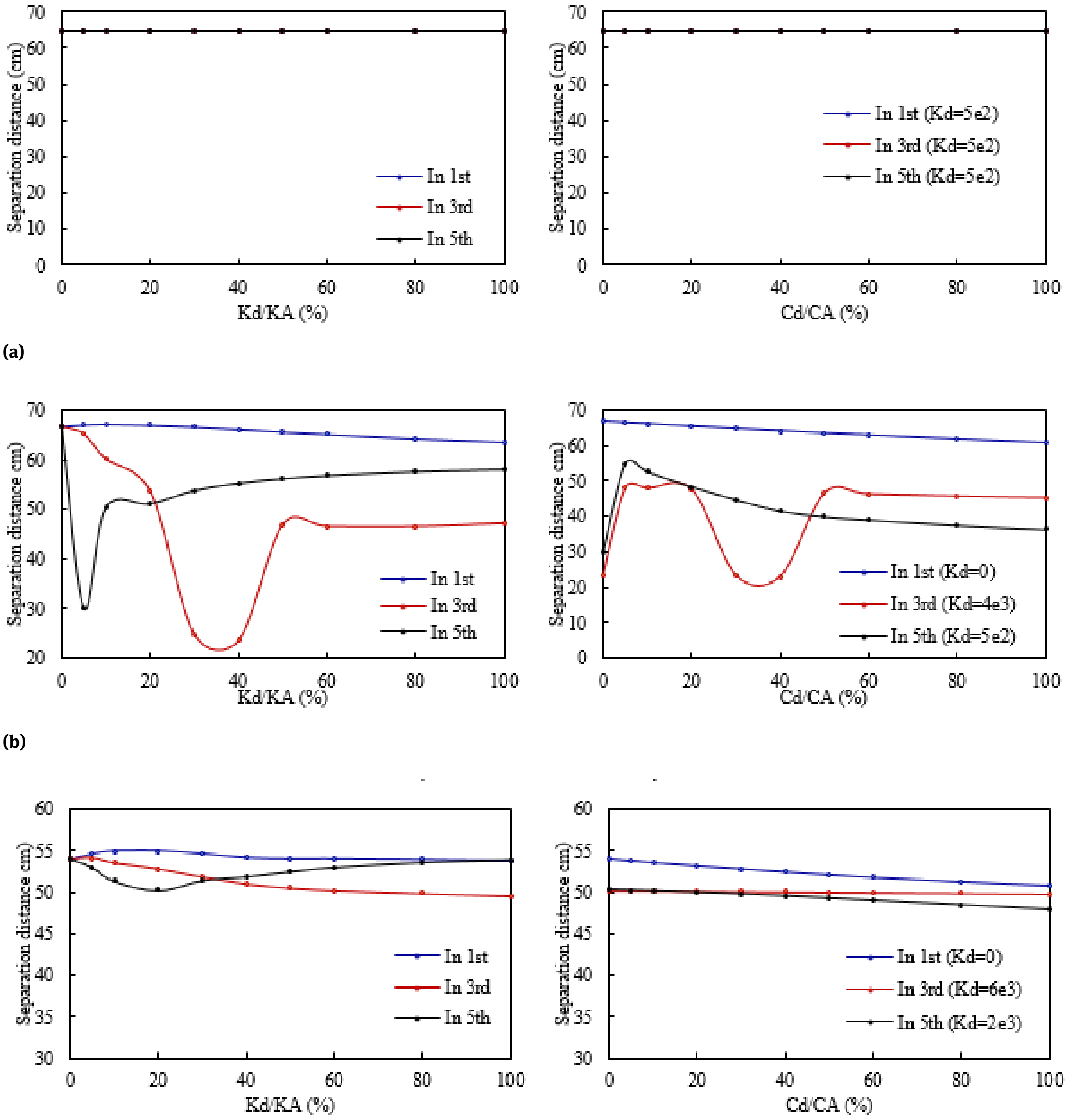
The results in Figures 4–7 (left) show the sensitivity of the change in the stiffness of the impact elements in the reduction of the separation distance (i.e., the reduction of the structural response). Contrary to the conclusion found in the literature [34], it was concluded that structural responses are not sensitive to changes in the stiffness of impact elements.

It can also be easily noted that the effect of the stiffness ratio (*Kd*/*KA*) is greater than that of the damping ratios (*Cd*/*CA*) of the coupling system.

The results in Figures 4–7 (right) of the damping rate (*Cd*/*CA*) show that the influence of the damping rate on the separation distance is negligible. These results confirm the conclusion in Ref. [3].

Regarding the position of the coupling system, it was revealed that it is generally more efficient when placed in the upper stories of the structure.

The curves plotted in Figures 4–7 clearly show the effect of introducing the coupling system between adjacent structures. The differences between the uncoupled and coupled curves can range from important to very important, depending on the cases under study. The stiffness of buildings and the position of dampers (coupling system), for Examples 1 and 2 in both cases 1 and 2, have a significant influence on the coupling efficiency. A simple comparison between the results obtained in the two cases showed that the second case gave smaller separation distance values, which leads us to conclude that the rigidity of the structure has a more positive impact with regard to the separation distance between adjacent buildings.



(a)

(b)

(c)

Figure 4: Separation distance of Example 1 (first case) as a function of ratios *Kd*/*KA* and *Cd*/*CA*. (a) Model 01: 5–5 stories, (b) Model 02: 5–10 stories, and (c) Model 03: 5–15 stories

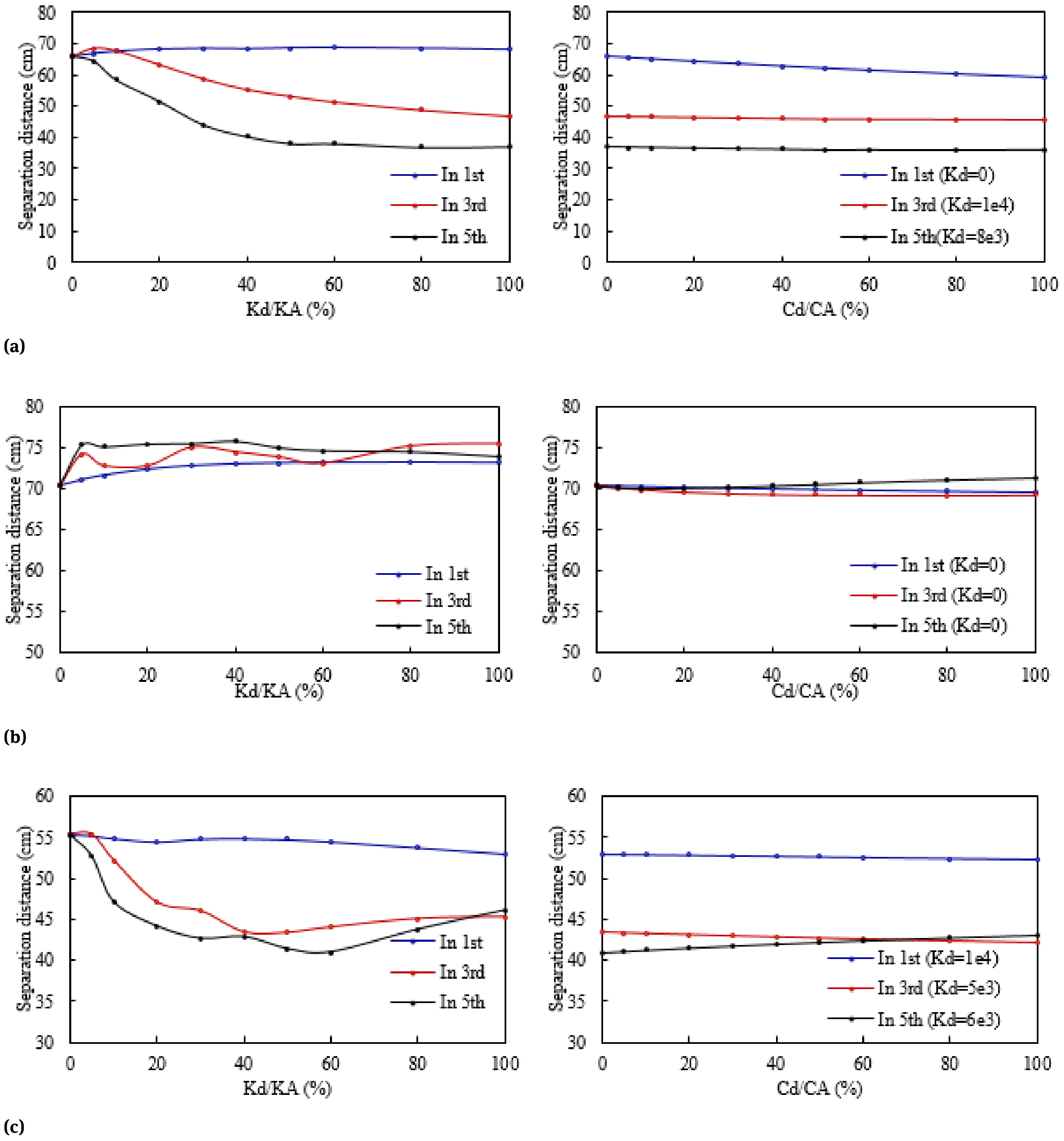


Figure 5: Separation distance of Example 1 (second case) as a function of ratios *Kd*/*KA* and *Cd*/*CA*. (a) Model 01: 5–5 stories, (b) Model 02: 5–10 stories, and (c) Model 03: 5–15 stories

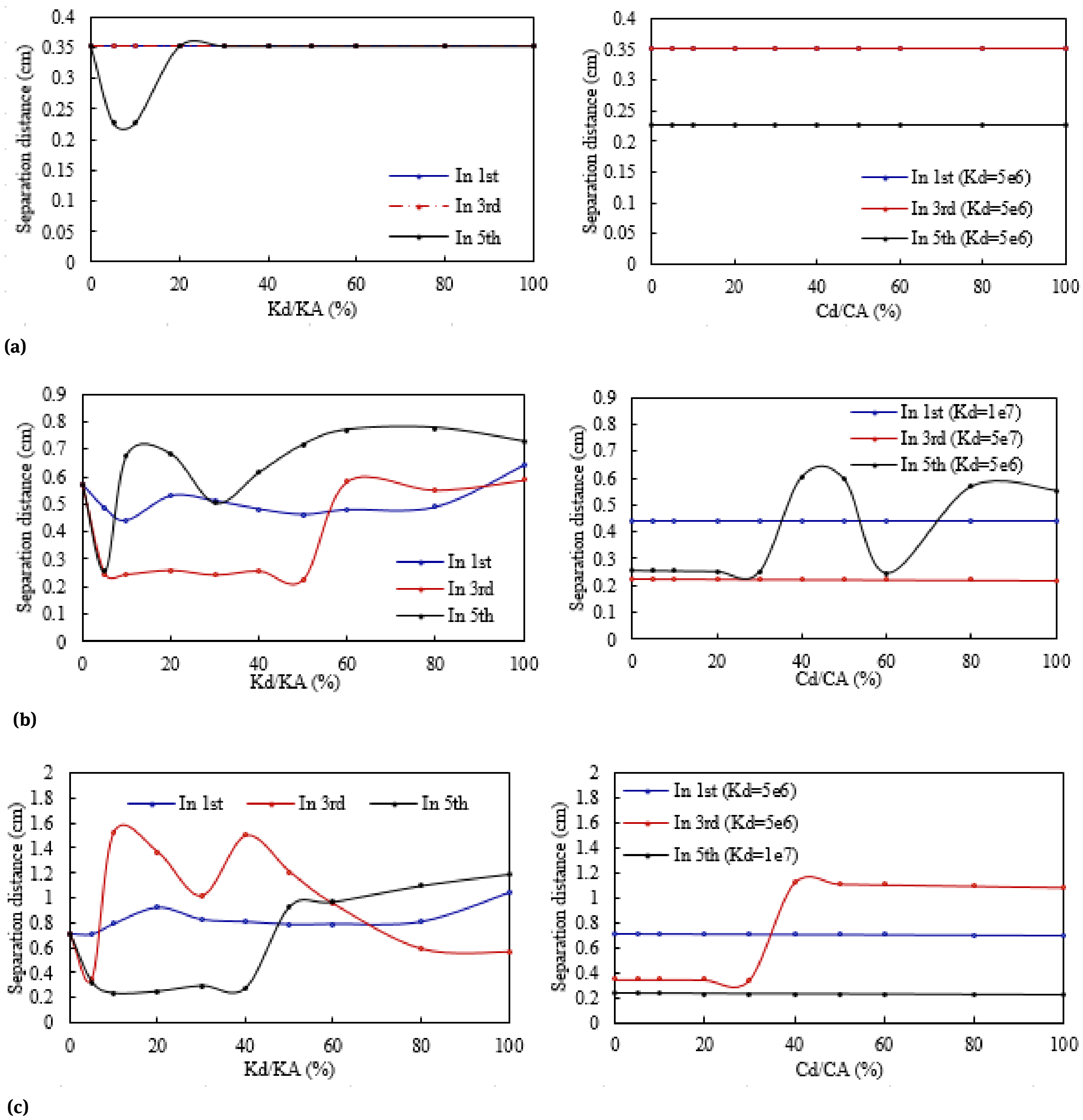
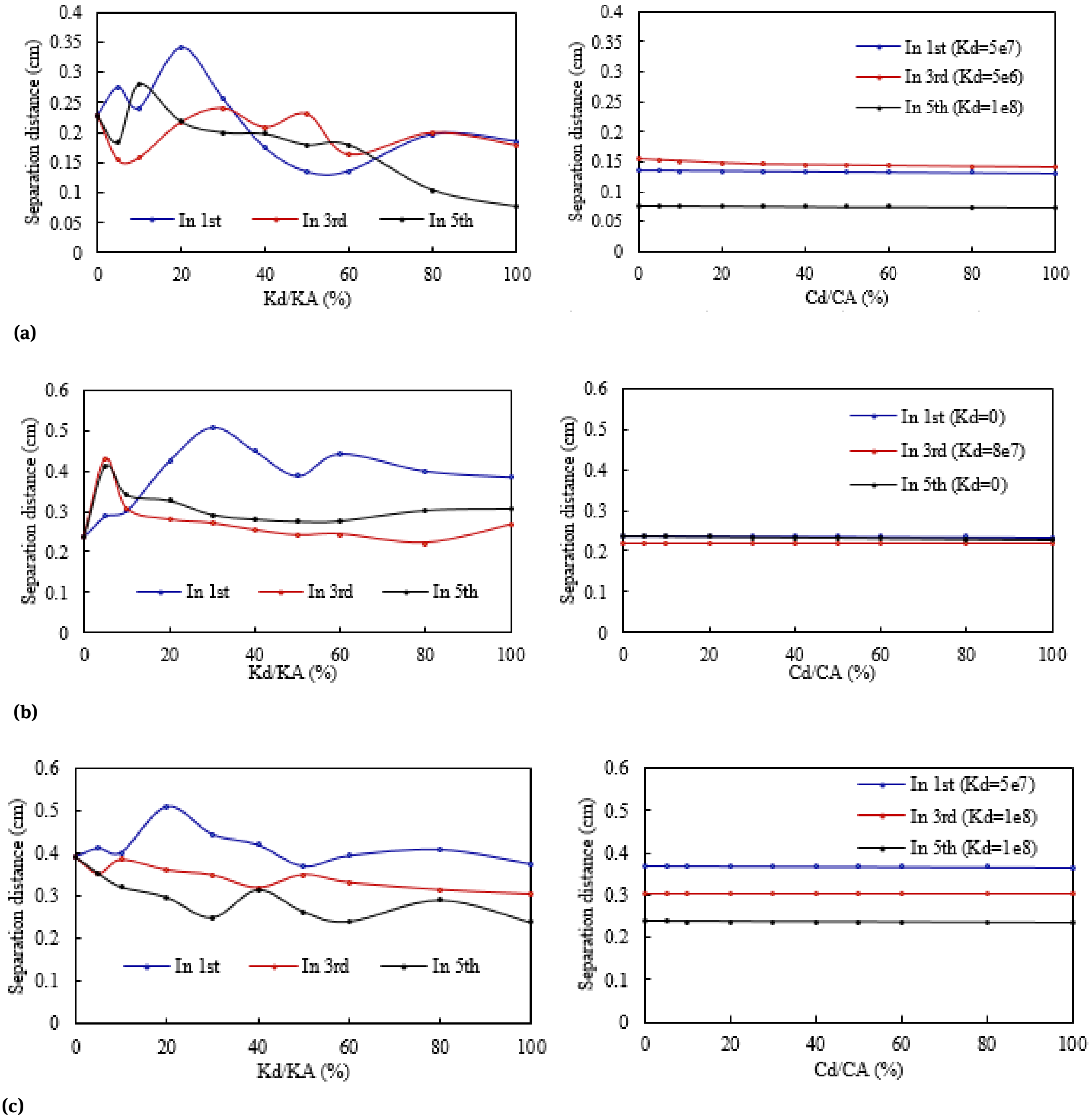


Figure 6: Separation distance of Example 2 (first case) as a function of ratios Kd/KA and Cd/CA. (a) Model 01: 5–5 stories, (b) Model 02: 5–10 stories, and (c) Model 03: 5–15 stories



(a)

(b)

(c)

Figure 7: Separation distance of Example 2 (second case) as a function of ratios *Kd*/*KA* and *Cd*/*CA*. (a) Model 01: 5–5 stories, (b) Model 02: 5–10 stories, and (c) Model 03: 5–15 stories

5 Conclusions

The urban land scarcity and the need to build more homes have pushed decision-makers to build taller and higher-density buildings. Many housing structures are currently built next to each other, forming a set of adjacent buildings. These structures are usually separated by a gap that civil engineers are trying to minimize as much as possible in order to save space. The present research aimed to investigate several parameters characterizing the buildings in order to find a way in which they can relate with the coupling system used, in order to determine the smallest separation distance. For this purpose, a MATLAB-based program, which was founded on a mathematical formulation, was developed. Several studies were conducted for the purpose of better understanding the impact of control systems on the seismic joint. The most important conclusions that could be drawn from this study are as follows:

- When the coupling parameters, such as stiffness and damping, are varied, the stiffness has a greater influence on the separation distance than damping. In this case, the optimum stiffness value *Kd* is 60% of the stiffness of the shorter and softer structure of the two adjacent structures.
- Increasing the stiffness of the structure has a direct impact on the separation distance between structures and, consequently, on the choice of the position of the coupling system, which in turn has an effect on the joint. In the case of a single damper, it is much more interesting to place it at the top than at the bottom of the building.
- The position of the coupling system depends on the height of the structure. The numerical results obtained suggest that it is possible to have a tall building adjacent to a short one without increasing the separation distance. In this case, the separation distance can be decreased even more.
- Increasing the stiffness of one structure with respect to another may result in using smaller seismic joints. Additional numerical studies could be carried out to better understand and control the seismic joint systems. In this case, if one considers adding control systems to the coupling devices, then the distance between buildings can be even smaller.

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