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Research Article

Investigation of Dynamic Behavior of Adjacent Tall Buildings Interconnected with Fluid Viscous Dampers Considering Soil-Structure Interaction

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Abstract
Tall buildings traditionally built may be inadequate to absorb the energy released during major earthquakes. Therefore, connecting two neighboring tall buildings with fluid viscous damping (FVD) devices could be an effective method of absorbing energy. In this study, two adjacent tall buildings placed on different soil types are connected with viscous damping devices under ground motion. The 12-storey Building A and the 12, 15, 18, 21 and 24 storey Buildings B are modeled as two-span frame system and connected to each other with fluid viscous damping devices. Three different soil types, identical to soft, medium-stiff and stiff soil types, have been identified. After that; the values of displacement, acceleration, and shear force obtained from fixed support case (no soil) are compared with the values obtained from three different soil types. Six different connection models are defined by changing location and number of the fluid viscous dampers. Soil model is created by using viscous boundary conditions. In the modeling and analysis, ANSYS R19.2 program was used. According to the results, fluid viscous dampers are very effective on the dynamic response of the buildings. Soil types are also effective on the response. Soft and medium stiff soils are critical floor types. Therefore, the effect of soil-structure interaction should be considered in the design of structural control systems. Besides, it is concluded that the most suitable connection type among the determined connection models is the viscous damping device connected to the top floor of the short building. No need to connect damping devices to all floors significantly reduced the cost of the structural control system.

Keywords: fluid viscous damper, structural control, structure-soil interaction, tall buildings, connected structures.

Sıvı Viskoz Sönümleyicilerle Birbirine Bağlanmış Komşu Yüksek Binaların Dinamik Davranışının Zemin-Yapı Etkileşimini Dikkate Alarak İncelenmesi

Öz
Geleneksel olarak inşa edilen yüksek binalar büyük depremler sırasında çıkan enerjiyi sönümlemede yetersiz kalabilir. Bu yüzden komşu iki yüksek binanın birbirine sıvı viskoz sönümleme cihazları ile bağlanması enerjiyi sönümlemede etkili bir yöntem olabilir. Bu çalışmada deprem etkisi altında ve farklı zemin türü üzerindeki iki yüksek bina birbirine viskoz sönümleyici cihazlar ile bağlanmıştır. 12 katlı A binası ile 12, 15, 18, 21 ve 24 katlı B binaları iki açıklıkı çerçeve sistem olarak modellenmiş ve birbirilerine sıvı sönümleyici sönümleyici cihaz ile bağlanmıştır. Gevşek, orta sıkı ve sıkı zemin türlerine denk üç farklı zemin türü belirlenmiştir. Sonrasında ankastre mesnet üzerinde elde edilen yer değiştirme, ivme, tepe ve taban kesme kuvvetleri değerleri üç farklı zemin türünde meydana gelen değerler ile karşılaştırılmıştır. Sıvı viskoz sönümleyicilerin yerleri ve sayısı değiştirilerek altı farklı bağlantı modeli belirlenmiştir. Viskoz sınır şartı kullanılarak zemin modeli oluşturulmuştur. Modellemeler ve analizler ANSYS R19.2 programıyla iki boyutlu olarak gerçekleştirilmiştir. Sonuçlar incelendiğinde bazı zemin türlerinde sıvı viskoz sönümleyici cihazlar yapının dinamik davranışında önemli iyileşmeler meydana getirmiştir. Ayrıca zemin türleri de sonuçlar üzerinde oldukça etkilidir. Gevşek ve orta sıkı zeminler kritik zemin türleridir. Bunun yanında belirlenen bağlantı modelleri arasında en uygun bağlantı şeklinin sadece en üst katına viskoz sönümleyici cihazın bağlanması olduğu sonucuna varılmıştır. Bütün katlara sönümleyici cihazların bağlanmasına gerek kalmaması yapısal kontrol sisteminin maliyetini önemli ölçüde azaltmıştır.

Anahtar Kelimeler: Sıvı viskoz sönümleyici, yapısal kontrol, yapı-zemin etkileşimi, yüksek yapılar, bağlı yapılar.

1. Introduction

Migration from rural to urban regions has increased due to the reasons including socio-economic, business life and life-quality, and so on, in the world. Engineers and managers have turned to high-rise housing in cities where the population is high and land opportunities are limited. However, it is very difficult to protect high-rise buildings against major earthquakes. Traditional tall building types may not provide the necessary performance to absorb energy that occurs in the event of a major earthquake and strong wind due to limited the quality of materials and element sizes. Therefore, additional damping systems are required to absorb large earthquake and strong wind oscillation energies in existing and new tall buildings. In recent years, efforts have been made by researchers for the applicability of the concept of energy damping in buildings. Researchers have developed and continue to develop structural control devices with many different energy damping principles. These damping devices can be grouped as active, semi-active and passive structural control devices. The effectiveness of these devices in absorbing earthquake energy has been proven by many researchers. Housner et al. (1996), Dyke et al. (1996), Housner et al. (1997), Soong and Spencer (2000), Spencer and Nagarajaiah (2003) gave comprehensive information about the development and future of structural control systems and summarized the studies. Active and semi-active structural control devices need an additional external power to operate. However, passive structural control devices do not need any external power to operate. Users who want to use this technology tend to prefer passive control devices considering the cost, stability and power requirement of active and semi-active structural control devices (Cimellaro & Lopez-Garcia, 2007). Active and semi-active structural control systems are difficult to apply to existing buildings. However, passive control devices such as fluid viscous damping devices devices are very easy to apply and model to existing buildings. Because of these reasons fluid viscous damping devices, a passive control device, are preferred in this study.

The idea of connecting the two buildings together to provide structural control was first expressed by Klein et al. (1972). They were suggested to connect two high-rise buildings in the USA close to their upper floors. Seto (1994) showed that connecting two flexible buildings together is a viable option for the protection of buildings. Considering the positive effect of this idea on the seismic behavior of the buildings and especially the cost effect, it has been the focus of attention for many researchers. Researches have been conducted by connecting two adjacent structures with various structural control devices to each other with different connection types. Gurley et al. (1994) and Sugino et al. (1999) investigated the effects of passive structural control devices for high and low-rise buildings. Combining low-medium buildings with passive devices was investigated by Luco and De Barros (1998). It was emphasized by all researchers that passive structural control devices gave effective results in terms of wind and seismic effects. Christenson et al. (1999) put forward that the idea of adjacent building accelerated from research concepts to real practice. Konoike, the Japanese construction company, is located in Osaka city and its headquarters consists of four buildings. One of these buildings has 12 floors and the other three buildings have 9 floors (Figure 1). In 1998, these four buildings were connected to each other with visco-elastic dampers and a passive control system was applied. The KI (Kajima Intelligent) complex was built in Tokyo, Japan as two 5-storey and 9-storey buildings (Figure 2). This complex is connected to the 5*th* floor with passive damping devices (Christenson, 2001). In 2001, Triton Square office complex in Tokyo were connected from the upper floors with an active damping system (Christenson et al., 2007). The complex consists of three buildings, 195 m, 175 m and 155 m tall. In order to protect from wind and earthquake, 195 m and 175 m tall buildings in the complex are coupled at a height of 160 m. 175 m and 155 m high buildings coupled at a height of 136 m (Christenson, 2001) (Figure 3).

Figure 1 Kajima Intelligent Building (Christenson, 2001)

Figure 2 Konoike Headquarter Buildings (Christenson, 2001)

Figure 3 Triton Square Office Tower (Bogdan et al., 2011)

Comprehensive evaluations of the connection of two multi-storey structures with non-linear passive devices were made by Cimellaro and Lopez-Garcia (2007). The device parameters were taken as constant and analyses were made with three suitable height possibilities for distribution according to the floors. Patel and Jangid (2008) investigated the damping characteristics and soil properties of dynamically different single degree of freedom adjacent structures connected with viscous dampers. At the end of the study, it was emphasized that soil-structure interaction changed the behavior and performance of the connected building system.

Uz and Hadi (2009) explained that the connection of adjacent building is important for improving the dynamic behavior of the buildings. Authors observed that viscous dampers, the top floor displacement, acceleration and shear force responses of two buildings connected in one direction are reduced. Patel and Jangid (2011) investigated the dynamic behavior of two structures connected with Maxwell type viscous dampers under earthquake effect. They concluded that viscous dampers are very effective in reducing the dynamic responses of adjacent structures under various earthquake effects. In addition, to minimize the cost of the dampers, it was recommended that all dampers are connected to appropriate locations instead of connecting them. Patel (2011) analysed the composite buildings connected with a similar dynamic structure viscous damper under four different real earthquake data. In the study, the damping coefficient of the viscous damper was kept constant. In the analyses, the effect of viscous dampers on the displacement, top floor absolute acceleration, base shear force and structural behavior was investigated. As a result, it was explained that when structures with similar dynamic properties are connected with viscous damper devices as specified in the study, the earthquake energy can be effectively absorbed and therefore no damping devices need to be connected to each floor. Farghaly (2014) examined the structural effects of two neighboring buildings on different soil types by connecting them with viscous dampers under earthquake effect. In the study, it was stated that viscous dampers are effective in seismic performance and the soft soil type is more critical than the stiff soil type. Shobhika (2015) investigated the effectiveness of friction dampers by comparing the seismic responses of two structures connected with friction damping devices in terms of displacement, velocity and acceleration under earthquake effect.

Engineers had to build high-rise buildings on very different soil types due to limited land opportunities. As it is known, the effects of soil types on the behavior of buildings are very high. In recent regulations, it has been made compulsory to consider the effect of soil-structure interaction. Unfortunately, the effect of soil-structure interaction was not considered in most of the studies investigating the structural behavior of connected structures.

In this study, dynamic behavior of buildings connected with linear fluid viscous dampers which are called passive structural control devices, under earthquake effect is investigated by considering the ground-structure interaction. Three different soil types have been identified, which are equivalent to soft, medium hard and hard soil types. In this study, the displacement, acceleration, top floor and base shear force obtained from soil types are compared with fixed support. The effects of fluid viscous dampers are investigated by connecting the buildings in six different ways. In addition, the effects of fluid viscous damper devices are investigated by dynamically modeling similar and non-similar structures.

2. Structural Modeling

All models and analyses are performed in 2D using ANSYS program working with finite element model.

2.1. Obtaining the Equation of Motion

For the equation of motion of two buildings connected with fluid viscous dampers, n-storey Building A and n+m storey Building B were considered (Figure 4). The mass, damping coefficient and shear stiffness values for the *i*th storey are $m_{i,A}$, $c_{i,A}$ and $k_{i,A}$ for Building A and $m_{i,B}$, $c_{i,B}$ and $k_{i,B}$ for Building B, respectively. The damping coefficient of the viscous damper in the *i*th floor is represented as c_{di}. The motion equation of the entire system is expressed in matrix form as follows:

$$\mathbf{M}\ddot{\mathbf{U}} + (\mathbf{C} + \mathbf{C_D})\dot{\mathbf{U}} + \mathbf{KU} = -\mathbf{MI}\ddot{\mathrm{u}}_{\mathbf{g}} \qquad (1)$$

where M, C *and* K *are the mass, damping and stiffness matrices of the adjacent buildings, respectively;* C_D *additional damping matrices consist of assembly of the fluid viscous dampers;* U *is the relative displacement;* I *is a unity matrix;* $\ddot{u}_g$ *is the earthquake acceleration.* The details of matrix are shown as follows:

$$M=\begin{bmatrix} M^A & 0 \\ 0 & M^B \end{bmatrix}$$

(2)

$$K=\begin{bmatrix} K^A & 0 \\ 0 & K^B \end{bmatrix}$$

(3)

$$C=\begin{bmatrix} C^A & 0 \\ 0 & C^B \end{bmatrix}$$

(4)

$$C_D=\begin{bmatrix} c_{d(n,m)} & 0_{(n,m)} & -c_{d(n,m)} \\ 0_{(n,m)} & 0_{(n,m)} & 0_{(n,m)} \\ -c_{d(n,m)} & 0_{(n,m)} & c_{d(n,m)} \end{bmatrix}$$

(5)

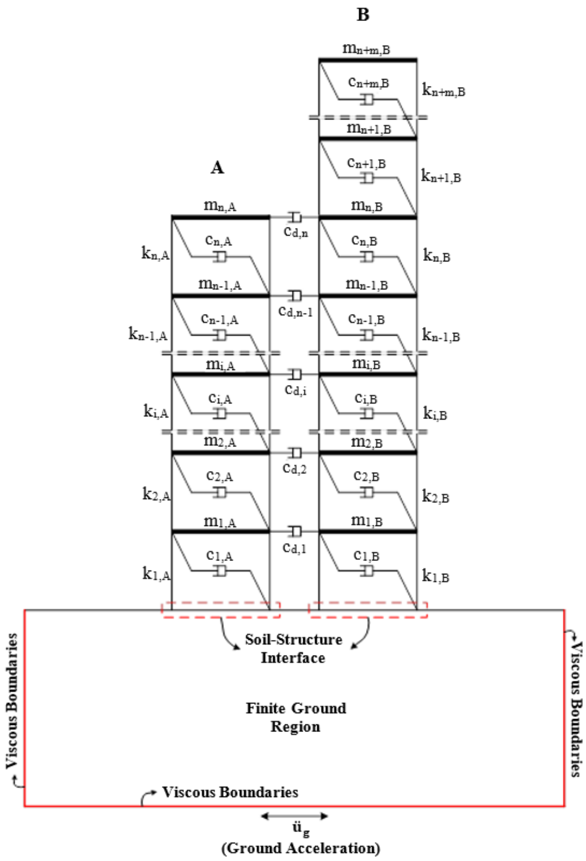


Figure 4 Schematic model of the soil-structure system of buildings connected with viscous dampers

2.2. Modeling of Buildings

The two buildings modeled in the study were named “A” and “B” for ease of expression. The concrete properties of all buildings modeled in the study are completely the same. In both buildings, the floor height is 3 m and the span between the two columns is 6 m. The height of Building A (H_A) is kept constant at 36 m (12-storey). The height of Building B (H_B) is determined so that the ratio of floor height of Building B to floor height of Building A (H_B / H_A) corresponds to 1; 1,25; 1,5; 1,75 and 2. The aim of this study is to investigate the effect of fluid building types, considering the effect of soil-structure interaction. All building model consists of 2-bay reinforced concrete frames and do not include shear buildings. Fluid viscous dampers on different adjacent five different examples have been identified. These examples are connected to 6 different cases. Example 1 has two parts. In Example 1(a), Building A is completely the same as Building B in terms of the dynamic characteristics. However, in Example 1(b), for Building B the stiffness of the columns is bigger than Building A. In this example, the purpose is to demonstrate the effectiveness of fluid viscous dampers in adjacent buildings of equal height in terms of dynamic characteristics. The Example 2 is one 12-storey Building A and one 15-storey Building B. Example 2; the aim is to demonstrate the effectiveness of the dampers in the same adjacent buildings in relation to the dynamic characteristics but with different buildings heights. All examples consist of two parts in conjunction with either the same stiffness or different stiffness. Dynamically similar analyses are defined by the index "(a)", dynamically different analyses are defined by the index "(b)". Detailed column and beam dimensions are given in Table 1.

Table 1 Column and Beam Dimensions (cm) of Buildings

	Building A		Building B	
	Beam	Column	Beam	Column
Example 1 (a)	30x60	50x50	30x60	50x50
Example 1 (b)	30x60	50x50	35x70	60x60
Example 2 (a)	30x60	50x50	30x60	50x50
Example 2 (b)	30x60	50x50	35x70	60x60
Example 3 (a)	30x60	50x50	30x60	50x50
Example 3 (b)	30x60	50x50	35x70	60x60
Example 4 (a)	30x60	50x50	30x60	50x50
Example 4 (b)	30x60	50x50	35x70	60x60
Example 5 (a)	30x60	50x50	30x60	50x50
Example 5 (b)	30x60	50x50	35x70	60x60

In order to control the seismic movement of two buildings under earthquake effect, the position and number of fluid viscous dampers are very important. For this reason, fluid viscous dampers are connected between the two buildings in 6 different ways. These connection types are named from Case 1 to Case 6. Connection types are shown in Figure 5 for Example 2. Case 1 is only connected with a fluid viscous damper (1 FVD) from the top floor of Building A. Case 2 is connected with a total of 2 fluid viscous dampers (2 FVD) from the top and middle floor of Building A. Other cases are shown in Figure 5.

2.3. Modeling of the soil

Relevant parameters are determined which can represent soft, medium stiff and stiff soil types. The width of the floor model is chosen as 210 m and its height as 90 m (Figure 6). Poisson ratio (υ), elasticity module (E) and unit volume weight (γ) of the soil type are given in Table 2. Viscous boundary conditions are applied to all ground boundaries. In order to obtain the viscous boundary condition, a speed-dependent spring element is defined at the ground boundary. The damping coefficient (C) of the spring element depends on the effective area

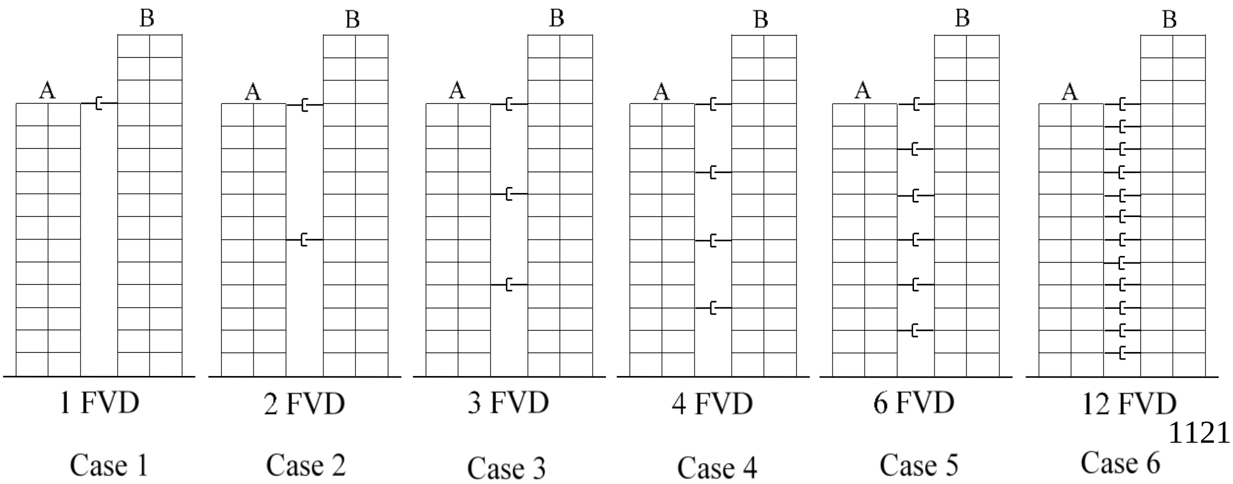


Figure 5 Distribution of FVDs in Adjacent Building

(A) of the finite element to which the spring element is attached (A), density (ρ) and wave velocity (V) (Equation 6).

$$C = A\rho V \quad (6)$$

Table 2 Properties of Soil Types

Soil Properties	Type I	Type II	Type III
E (Pa)	35	400	6000
υ	0,25	0,3	0,35
ρ (kN/m^3)	17	19	21
V_s (m/s)	90,75	284,56	1028,69
V_p (m/s)	157,18	532,35	2141,39

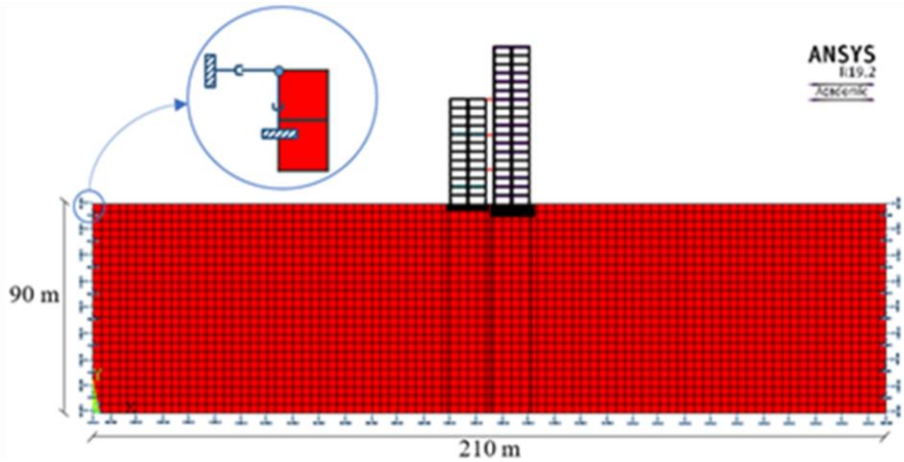


Figure 6 Soil Model

2.4. Modeling of fluid viscous damper

Linear fluid viscous damper behavior can be expressed by the following Equation 7.

$$F_T = CV^{cexp} + KD_K = F_D + F_E \quad (7)$$

where, the total force provided by the damper (F_T), *the damping coefficient* C, *is the spring constant* K. V *is the speed at the damper and* D_K *is the amount of displacement of the spring at the damper.* cexp *is the damping exponent.* The damping exponent should be between 0.5-2. For the device to be linear, cexp must be equal to 1. F_T's consists of two parts. The first is the damping force F_D, which is equal to CV^{cexp}. The second is F_E, which has a restoring force.

Fluid viscous dampers are modelled as COMBIN14 spring elements in ANSYS. cexp= 1, because fluid viscous damper will be evaluated linearly in this study. The damping coefficient of all fluid viscous dampers is determined as Cd = 10^6 N.s/m in this study.

2.5. Earthquake Acceleration Data

1999 Kocaeli earthquake is taken as the earthquake data. Acceleration data is taken from PEER Strong Montion Database (Yarimca-KOERI330) and occurred in the North Anatolian Fault Zone with the size of Mw 7.4 (Figure 7).

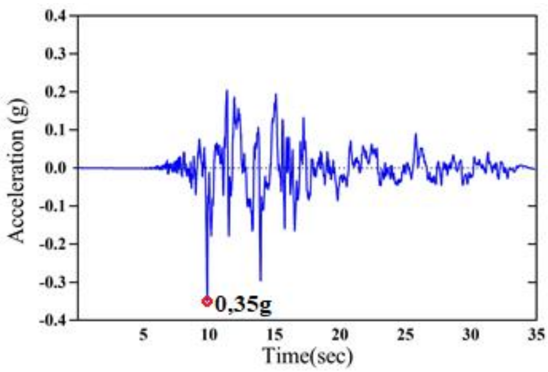


Figure 7 Kocaeli (Yarımca) earthquake acceleration (Anonymous, 2016)

3. Results

In this study, two multi-storey buildings connect with fluid viscous damping devices on 3 different floor types are compared in terms of displacement, acceleration, base and top floor shear force. The damping coefficient (Cd = 10^6 N.s/m) of the fluid viscous damping devices is taken as constant and 192 analyses are performed. Since the graphs of each analysis results cannot be presented in this article, the graphs that summarize the general situation are selected. In the rate graphs, the values of the buildings after connecting with fluid viscous dampers are obtained by proportioning the values of the buildings before connecting. The values of the two neighboring buildings before connecting were accepted as reference values. Displacement, acceleration and shear force reference values are defined as D_{ref}, A_{ref} and S_{ref}, respectively. The values that occur after the buildings are connected with fluid viscous dampers in six different ways are proportional to the reference value. In this way, the percentage of change in structural responses that occur in buildings can be determined. Therefore, values less than 1 in the rate graph mean that the relevant comparison value decreases, and values greater than 1 mean that the corresponding comparison value increases.

3.1. Comparison of buildings in terms of displacement

Example 1(a) analyses show that fluid viscous damping devices have no effect in both buildings and all cases. The rate graph of the displacement of Building A on different soil types is presented in Figure 8. However, in Example 1 (b) analysis, fluid

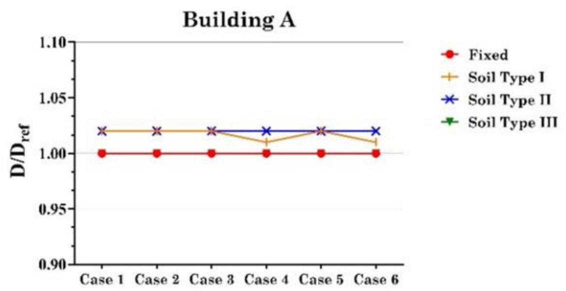


Figure 8 Top floor displacement rate graph of Building A in analysis of Example 1(a)

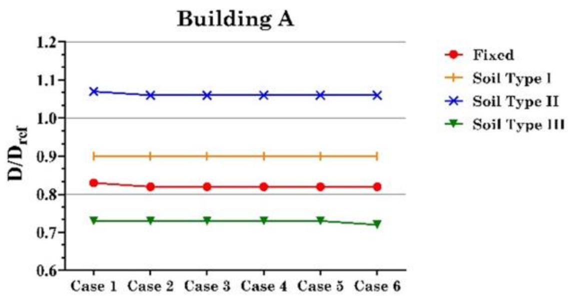


Figure 9 Top floor displacement rate graph of Building A in analysis of Example 1(b)

viscous damper devices were observed to be effective. When the displacement rate graph of Building A in Figure 9 is analyzed, the top floor displacements of Fixed, Soil Type I and Soil Type III decreased by approximately 18%, 10% and 28%, respectively, while it increased by 6% in Soil Type II. Significantly different results were observed between Fixed and Soil Types in terms of reducing top floor displacements by the effect of the fluid viscous damper device. However, when the displacement results obtained on the soil types are compared with fixed, there are very important differences. For Example 1 (b), in Soil Type I, Soil Type II and Soil Type III, respectively, 3.7, 3, 1.2 times higher results were observed in the top floor displacement compared to fixed.

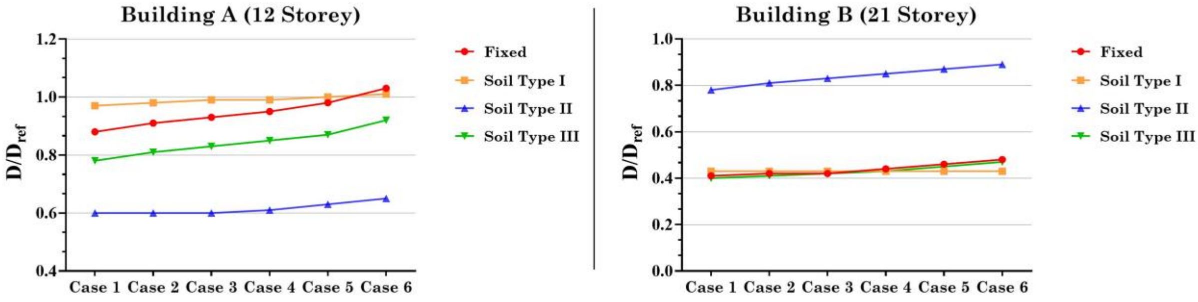
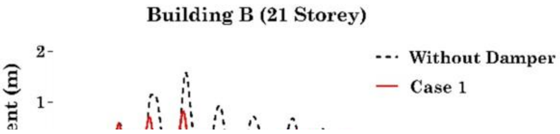


Figure 10 Top floor displacement rate graph of Example 4(a)'s analysis

The connection of tall buildings with fluid viscous damping devices is effective for all soil types in the analysis of type (a) and (b) of Example 3 and Example 4. The top floor displacement graph of Example 4 (a) is presented in Figure 10. In Building A, the top floor displacements of Fixed, Soil Type I, Soil Type II and Soil Type III decreased by approximately 12%, 3%, 40% and 22%, respectively. In Building B, the top floor displacements of Fixed, Soil Type I, Soil Type II and Soil Type III decreased by approximately 59%, 57%, 22% and 60%, respectively. It can be said that 24 storey Building B mostly benefited from this connection. Considering the two buildings together, fluid viscous damper devices for Case 1 (connection only at the top floor of the Building A) are the most effective.

The effect of fluid viscous damping devices on displacement can be seen more clearly on the Displacement-Time graph. In Figure 11, the top floor oscillation graph of Building B (on Soil Type I) in Example 4 (b) is presented. Fluid viscous damping devices show their effects not only in the peak displacement value of the building, but also in the oscillation of the building during the



earthquake effect.

Fluid viscous damper devices are effective in displacement reductions on other floors of the building. The floor displacement of Building B in Example 4 (b) on Soil Type III is shown in Figure 12.

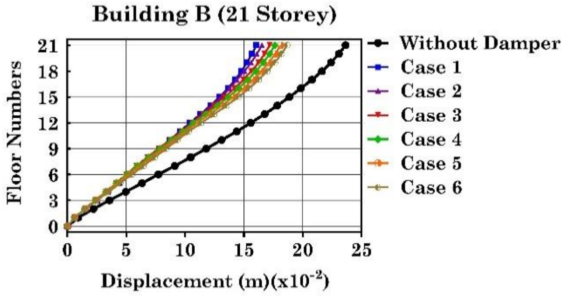


Figure 12 The floor displacement of Building B in Example 4 (b) on Soil Type III

In all analyses of Example 2 and Example 5, it is observed that the connection of tall buildings with fluid viscous damping devices causes different seismic responses depending on the soil type. So, these seismic responses contradict to each other. In Figure 13, the top floor displacement rate graph of Example 5 (a) is presented. Figure 13 shows that the top floor displacement of Building A in Soil Type II reduces by 38% while the top floor displacement of Building B increases by 22%. In Soil Type I, the top floor displacement Building A and B are seen the decline by nearly 10% and 47%, respectively. According to the displacement results of building A on the fixed support presented in Figure 13, it is not correct to

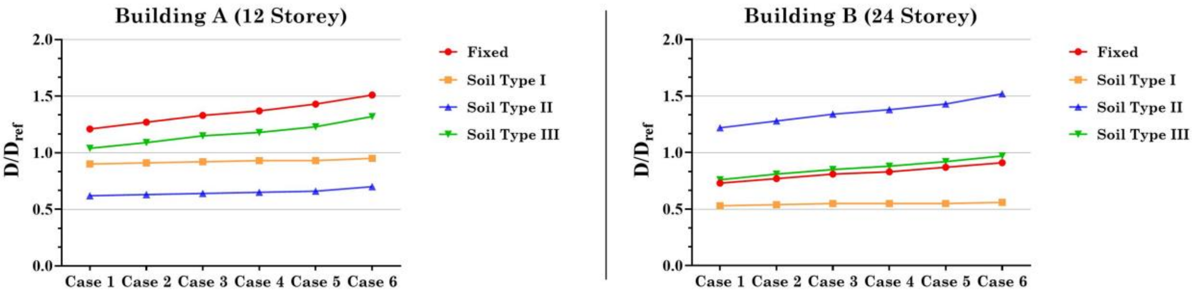


Figure 13 Top floor displacement rate graph of Example 5(a)'s analysis.

connect two buildings. Because, there were increases up to P in the top floor displacement of Building A. However, when connecting the same buildings with fluid viscous damper in Soil Type I, the top floor displacement decreases. In Case 1 connection type, top floor displacement of Buildings A and B decreased by approximately 10% and 47% respectively. Therefore, the connection of two buildings with fluid viscous damper in Soil Type I is an effective and desirable situation. Two different opposite results occurred in the same building models. These different results are due to the effect of soil types with different properties on buildings. Thus, it is necessary to consider the effect of soil-structure interaction in all analysis.

3.2. Comparison of buildings in terms of acceleration

In terms of acceleration, the connection of two buildings with fluid viscous damper has been very effective in some soil types. Just like the top floor displacements, the top floor acceleration value of the same model may decreased for one floor type and increase for the other floor type. When the results in Figure 14 are considered together for Building A (12 storey) and B (18 storey), it is seen that the connection of these two buildings is not appropriate. Because the top floor accelerations of Building A decreased in all soil types, but increased in building B. In Figure 15, the top floor acceleration values for both buildings decreased significantly. The peak acceleration value of Building A decreased by 36%, 39%, 44% and 34% respectively in Fixed, Soil Type I, Soil Type II and Soil Type III, respectively. Peak point acceleration value of building B decreased by 34%, 5%, 9% and 21% respectively in Fixed, Soil Type I, Soil Type II and Soil Type III, respectively. It can be said that the most effective form of connection is Case 2.

Figure 16 is a good example of why it is necessary to consider the effect of soil-structure interaction. The top floor acceleration decreased by 34% in both A and B (24 storey) buildings when connecting two structures on fixed support. In fixed, it is appropriate to connection buildings in Example 5 (b). However, considering the effect of soil-structure interaction, it seems that it is not appropriate to connect two buildings to each other with fluid viscous dampers in Soil Type I and Soil Type II. The necessity to consider the effect of soil-structure interaction is clearly seen.

The connection of tall buildings with fluid viscous damper devices was more beneficial for Building A (Building A is shorter than Building B) in terms of acceleration. When dynamically connecting similar buildings, the acceleration values did not change just like displacements. In general, fluid viscous dampers devices can be said to be effective in terms of acceleration.

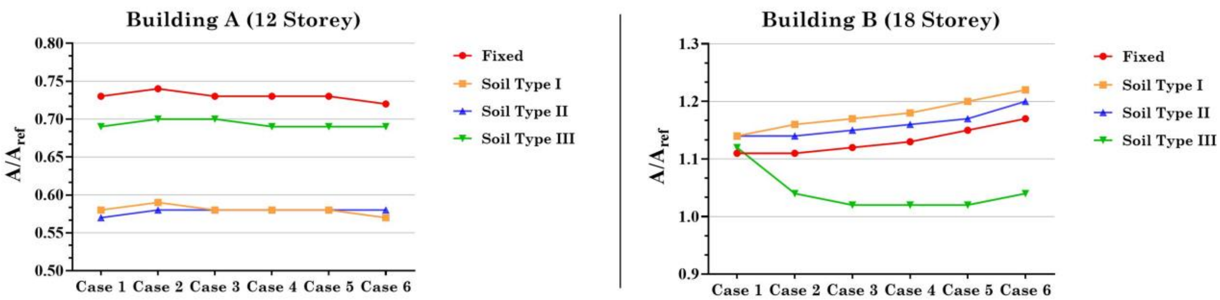


Figure 14 Top floor acceleration rate graph of Example 3(b)'s analysis

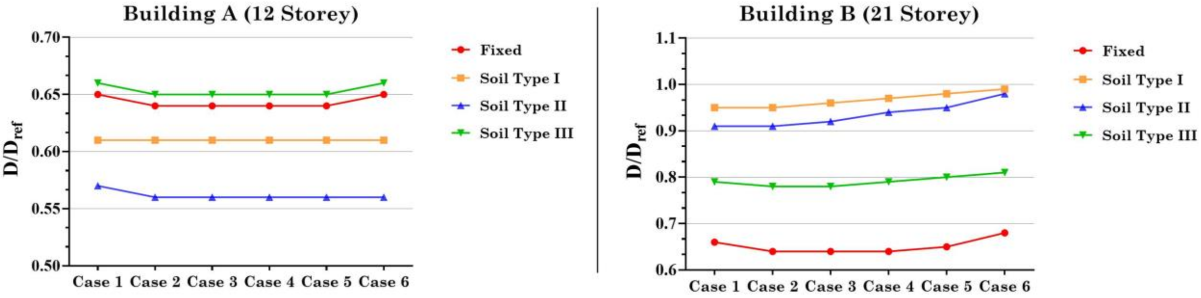


Figure 15 Top floor acceleration rate graph of Example 4 (a)'s analysis

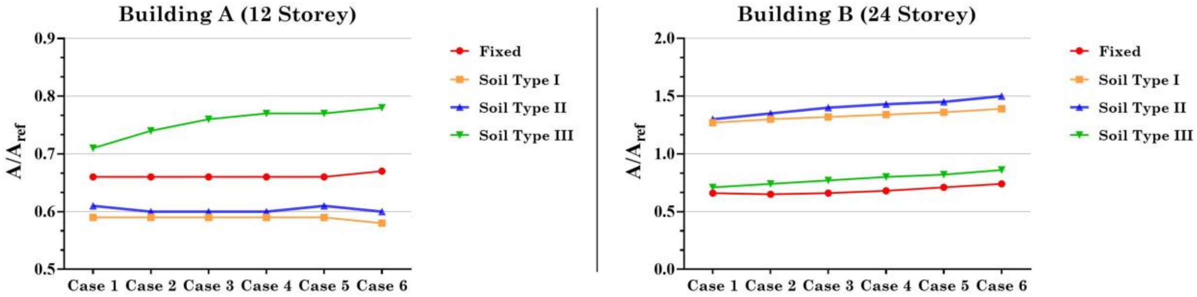


Figure 16 Top floor acceleration rate graph of Example 5 (b)'s analysis

3.3 Comparison of buildings in terms of base and top floor shear force

It is seen in Figure 17-20 that fluid viscous damper devices provide significant decreases in the base shear force and an increase in the top floor shear force. Significant reductions in all soil types are observed in the base shear force in most of the Example 3 and Example 4 analyses. In Figure 17 and Figure 18, the shear force graphs on the floors as a result of the analysis of Example 4 (a) are presented. In graphs, Case 1 appears to be more effective. In Figure 17, Case 1 (for Building A) shows fixed support, Soil Type I, Soil Type II and Soil Type III decreased by 24%, 17%, 44% and 24% respectively. The shear force graph of Building B is presented in Figure 18. Case 1 (for Building A) shows fixed support, Soil Type I, Soil Type II and Soil Type III decreased by 54%, 37%, 34% and 54% respectively.

Example 5(a) analysis of base shear force graphs A and B building is presented in Figure 19 and Figure 20. In general, in the analysis of Example 5 (a) (except Soil Type II), the base shear force increases for Building A, while it reduces for Building B. In Example 5 (a) analysis, Case 1 shows an increase of around 5%, while Building B decreases up to 35%.

When the top floor shear forces are examined, it is seen that the shear forces of the Building A increase significantly. This increase can be seen in Figure 17 and Figure 18. The top floor shear force graph of Example 4 (a) analysis is presented in Figure 17. The graph shows that for Case 1 (for Building A) fixed support, Soil Type I, Soil Type II and Soil Type III increased by 6.6, 4.4, 7.1 and 5 times, respectively. The top floor shear force graph of Example 5 (a) analysis is presented in Figure 18. The graph shows that for Case 1 (for Building A) fixed support, Soil Type I, Soil Type II and Soil

Type III increase by 9.7, 7.3, 7.1 and 7.2 times, respectively.

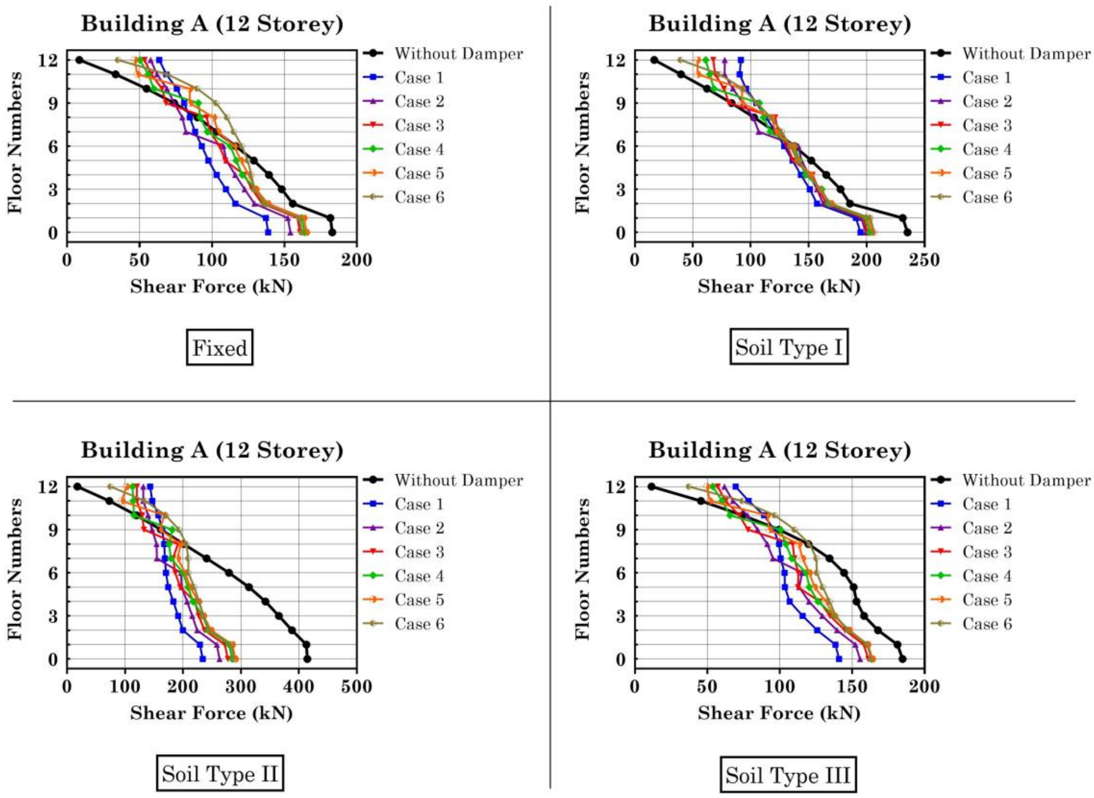


Figure 17 Shear force graph of Building A in analysis of Example 4(a)

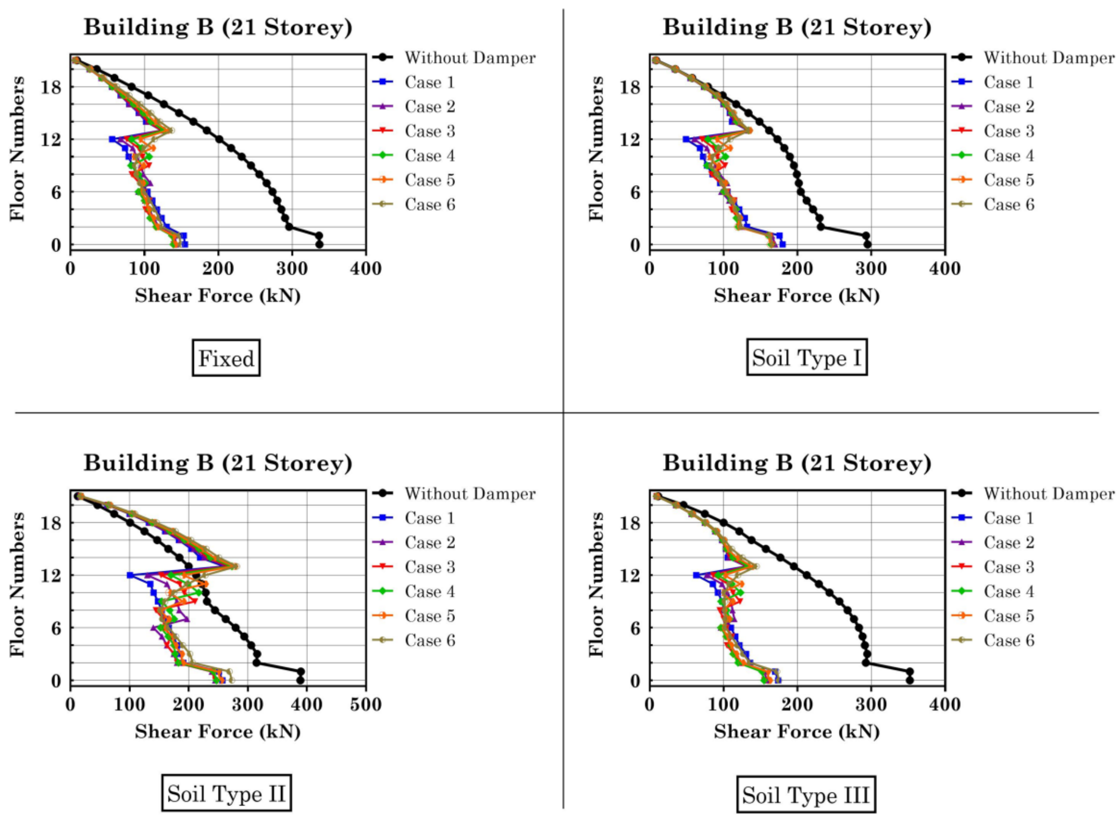


Figure 18 Shear force graph of Building B in analysis of Example 4(a)

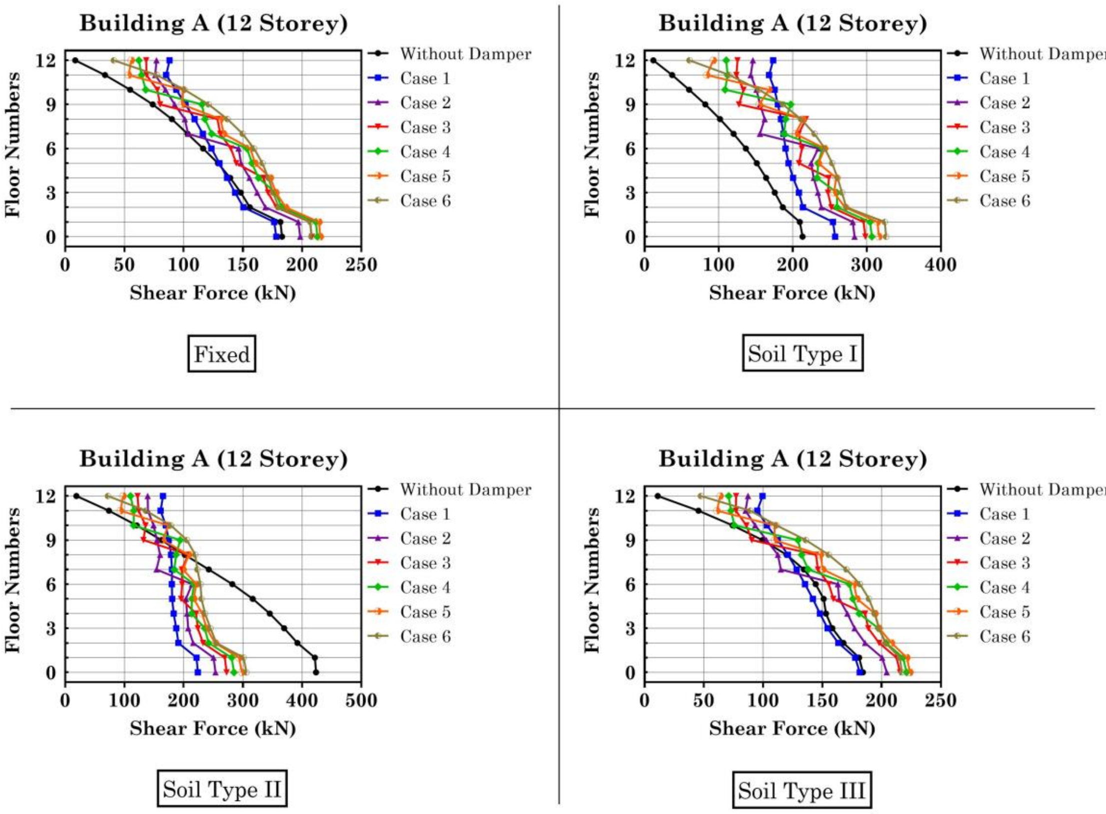


Figure 19 Shear force graph of Building A in analysis of Example 5(a)

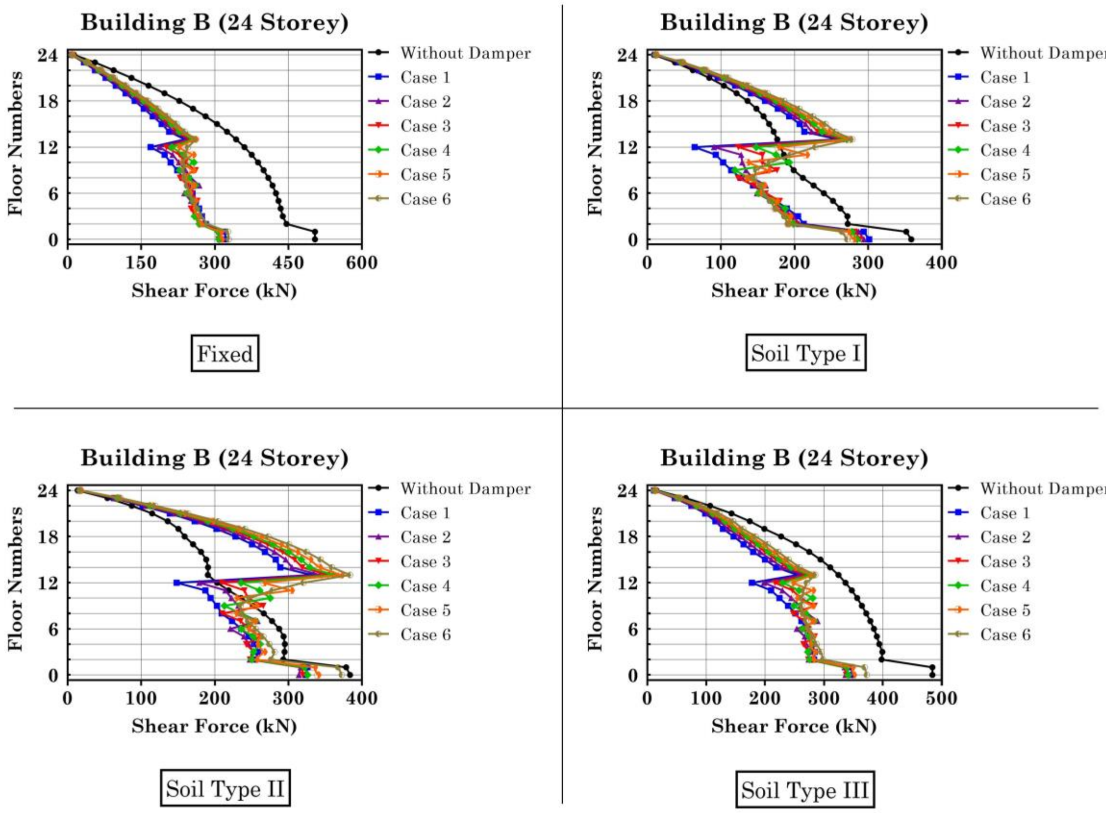


Figure 20 Shear force graph of Building B in analysis of Example 5(a)

4. Conclusion

In this study, the seismic response of two high-rise buildings connected with fluid viscous damping (FVD) devices on three different soil types under the influence of Kocaeli earthquake is investigated. Six different cases are identified in terms of location and number of fluid viscous damping devices. The height of Building A is kept constant 36 m (12 storeys). The heights of the B buildings are modeled as 36 m, 45 m, 54 m, 63 m and 72 m. Building 36 m is connected to buildings B, respectively. The results of the structural responses of the two neighboring buildings after connecting with fluid viscous damper devices were compared with the results of the structural responses of the buildings before they were connected. In addition the results from three different soil types are compared with fixed support. The comparison is in terms of top floor displacement, top floor acceleration value, base shear force, and top floor shear force. The damping coefficient (Cd = 10^6 N.s/m) of all fluid viscous damping devices in the study was taken as a constant.

The mechanical, geometric and dynamic properties of the soils affect the properties transferred to the superstructure. Similarly, the mechanical, geometric and dynamic properties of the superstructure also affect the properties reflected back to the ground from the superstructure. Soil properties can change the period and mode shapes of the building. The displacements of the structures built on soft floors at the peak point occur more. In medium stiff soils, the ground period can often coincide with the construction period depending on the height of the building. Therefore, considering the effect of soil-structure interaction, the results of the analyzes approach the actual results. According to the results of this study, loose and medium tight soils are critical soil types.

According to the results obtained from the models determined in this study, it is seen that fluid viscous damping devices provide a significant improvement in the seismic performance of the structure. Therefore, fluid viscous damping devices can be preferred for structural control. However, it is important to choose two buildings with correct dynamic properties and connection type in order to have this significant effect. Because fluid viscous damper devices are not effective in buildings with similar dynamic properties.

One of the most important results in the study is the necessity to consider the effect of soil-structure interaction. The results show that the system response consisting of fluid viscous damper connected buildings is also affected by the geotechnical properties of the soil. Considering the soil medium during the analysis, very different displacement, acceleration and shear force values are obtained. The results approach to fixed support values as the soil hardens. On the other hand, as the soil softns, the possibility of further amplification increases.

Another important result obtained from this study is that it is not necessary to connect fluid viscous damper devices to all floors. It can be seen from the graphs that it is not very effective to connect fluid viscous damper devices to all floors of the buildings, and even reduce the effectiveness of the damping device and affect seismic performance negatively. It can be said that the most effective form of connection determined in this study is Case 1. Case 1 is only connected with a fluid viscous damper (1 FVD) from the top floor of short building. This effect is thought to be caused by the first mode form of the building. No need to connect damping devices to all floors significantly reduced the cost of the structural control system.

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