The Seismic Response of Reinforced Concrete Structure with Viscous and Friction Damper

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ABSTRACT

Dampers are the energy dissipating devices which resist lateral loads and displacement in reinforced concrete structures. Viscous and Friction dampers dissipate partially the earthquake energy into heat which is transferred in return into the atmosphere. In order to check the effectiveness of viscous and friction damper in reducing earthquakes effects, time history and pushover analysis are conducted into reinforced concrete buildings of different stories levels (five, ten and twenty stories) with and without both type of dampers. In addition, the performance of viscous damper is compared to that of friction damper to find the variation between both types of dampers in dissipating earthquake energy. This comparison is performed by implementing friction dampers in the same places which viscous damper are implemented on and by achieving same analysis methods done for structural buildings with and without viscous dampers. Furthermore, for finding the optimum location of dampers in external structural frame, viscous and friction dampers are placed in three different locations in outer frames for each story level during time history and pushover analysis.

In other words, this study deals with studying the effectiveness of viscous and friction damper, comparing the performance of both types of dampers and finding the optimum locations of VD and FD in external frames. Viscous damper had the priority over Friction damper in improving the seismic response of structural building and the optimum location of dampers was the middle position of the outer frame.

Keywords: Viscous damper, Friction damper, Nonlinear analysis, Dissipating energy, Structural buildings

ÖZ

Sönümleyiciler betonarme binalardaki deprem yüklerini ve yer değiştirmeleri azaltmaktadır. Viskoz ve sürtünme sönümleyicileri deprem enerjisini kısmen sonunda atmosfere aktarılan ısıya dönüştürür. Bu çalışmada, viskoz ve sürtünme sönümleyicilerinin farklı kat yüksekliklerindeki (beş, on ve yirmi kat) betonarme binalardaki deprem etkilerini azaltmadaki etkinliğini kontrol etmek için zaman tanım alanında ve statik itme hesap yöntemleri kullanılmıştır. Viskoz ve sürtünme sönümleyiciye sahip çerçevelerle, sönümleyicisiz sistemler bu bağlamda karşılaştırılmıştır. Ayrıca, en ideal yeri bulmak için dış yapısal çerçevelerdeki sönümleyiciler üç farklı yere yerleştirilmiştir.

Başka bir deyişle, bu çalışma viskoz ve sürtünme sönümleyicilerinin etkinliğini incelemek, her iki tip sönümleyicinin performansını karşılaştırmak ve dış çerçevelerde viskoz ve sürtünme sönümleyicilerinin ideal yerlerini bulmakla ilgilidir. Viskoz sönümleyici, yapısal binanın sismik performansını iyileştirmede sürtünme sönümleyiciye göre daha etkilidir ve en ideal sönümleyici konumu dış çerçevenin orta pozisyonu olarak bulunmuştur.

Anahtar Kelimeler: Viskoz sönümleyici, Sürtünme sönümleyici, Doğrusal olmayan analiz, Enerji tüketmek, Yapısal binalar

DEDICATION

To My Family

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LIST OF SYMBOLS

C	Damping Coefficient
F	Damping Force
K	Matrix of Stiffness
M	Diagonal Matrix of Mass
Mw	Moment Magnitude Scale
R	Applied Load
S_1	Spectral Acceleration at a One Second Period
Sgn	Signum Function
Ss	Short-Period Spectral Acceleration
U	Displacement Function
Ú	Velocity Function
Ü	Acceleration Function
Ω''	Matrix of Eigen Values
ϕ	Matrix of Eigen Vectors

LIST OF ABBREVIATIONS

ABS	Active Brace System
AMD	Active Mass Damper
AEDS	Active Energy Dissipation System
ATCS	Active Tendon Control System
CP	Collapse Prevention
CSM	Capacity Spectrum Method
DCM	Displacement Coefficient Method
DL	Dead Load
FD	Friction Damper
FEMA	Federal Emergency Management Agency
IO	Immediate Occupancy
LL	Live Load
LS	Life Safety
PEER	Pacific Earthquake Engineering Research
PEDS	Passive Energy Dissipation System
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
SACS	Semi-Active Control System
STMD	Semi-Active Mass Damper
TBEC-2018	Turkish Building Earthquake Code-2018
THA	Time History Analysis
TMD	Tuned Mass Damper
TS-500	Turkish Standard 500

VD	Viscous Damper
VED	Viscoelastic Damper

Chapter 1

INTRODUCTION

1.1 General

Simply earthquake is defined as the process of shaking and vibration of the earth surface due to the underground agitation along a fault plane. Earthquake is well known by its catastrophic destruction which lead to casualties and deterioration of buildings with high significance for nations such as hospitals, schools and military bases etc. In addition, they cause economic disaster beside their effect on human lives. The horrific impact of earthquake on nature and human being had forced researchers and engineers to implement seismic response control devices. They are designed as energy dissipation devices. The most common used energy dissipation devices are viscous and friction dampers. Control system is categorized by different type such as passive, semi-active and active control system. Viscous damper along with Friction and viscoelastic dampers are considered as passive energy control system. The first full scale application of viscous and Friction damper was performed in Italy and New Zealand in the 1970s. In the 1980s, effective efforts were made to shift this industrial technology toward its application in the structural engineering field.

1.2 Previous Work Done

Viscous damper (VD) and Friction dampers (FD) were increasingly applied in the etinto early together with recent engineering structures due to their various advantages. According to De Domenico et al., (2019) the popularity of VD is gained because of its ability in improving earthquake performance by an important energy dissipation of ground motion. In addition, VD generates forces out of phase with displacements, and has high tendency to rise the damping ratio of a building with non-important modification of its original stiffness characteristics. In other word, repetitive trial-and-error design method which are mandatory to alternative devices type such as tuned mass damper and base isolator are not for VD.

Hejazi et al., (2009) have investigated the outcome of viscous damper in reducing the earthquake damage effect on three floors building. They concluded that using viscous dampers had decreased the structural response of the building by 80%. In addition, picking the right damping coefficient has an enormous effect on obtaining optimum design for which the effect of seismic load is diminished. Moreover, Prafull and Kumar (2018) had compared the outcomes attained from static and response spectrum analysis of square and rectangular structures of 15 stories including and not including viscous damper. They concluded that VD are able to reduce forces and displacements of buildings under earthquake loads. Furthermore, VD is capable of reducing shear in the buildings which will make the structure cost effective because this will lead to the decrease of column and beam sections. However, from their observation, the percentage reduction in displacement is more in rectangular buildings. Similarly, Landge and Joshi (2017) have performed a seismic assessment of reinforced concrete buildings of 8 stories without VD and including VD. Parameters which are studied are roof displacement, maximum acceleration, velocity, story shear and story drift. Eventually, the story shear, drift, maximum acceleration, velocity and displacement were higher in RC building without dampers comparing to building with dampers.

Economically, Miyamoto and Gilani (2015) affirmed that the use of earthquake conservation devices like VD produce a mixture of optimum engineering practice and

> reducing the costs of life-cycle. Viscous dampers are cost effective because the initial price of their deployment is neutralized by decreasing in price of other structural section like column-beam dimensions, requirement of minimum post-earthquake inspection and reducing of post-earthquake repairs or reconstruction.

Moreover, Dehgan and Soleymannejad (2015) have done a study which tried to study the outcome of viscous dampers on the behavior of ten and sixteen stories building. They concluded that viscous damper plays an efficient role in controlling and reducing maximum drift in the structure. Another study done by Lu et al., (2012) where the behaviors of viscous, steel and viscoelastic damper were compared by retrofitting an eight stories building in China. From the results obtained, viscous damper has better ability in controlling the displacement of the building during a moderate and major earthquake comparing to steel and viscoelastic damper. In addition, according to Cheng et al (2014) when viscous dampers are rationally arranged, the seismic response of the added-story structures is effectively reduced, and adding viscous dampers to building without seismic fortification is a good choice. Moreover, according to Kim, Choi and Min (2011), friction damper is considered one of the most important energy dissipating devices due to their ability of dissipating energy in case the structure building is under lateral deformation. In other word, earthquake loads acting on the structure are dramatically minimized because of the diversion of a major part of seismic energy. Paull et al (1996) have stated the economic and technical advantages of friction damper such as providing reduction in the initial price while constructing recent building and retrofitting an ancient one, ability of high energy dissipation, simplicity of their implementation in construction building and no need for FD repair after an earthquake.

Finally, to find the optimum location for viscous dampers inside the building, Mathew and Prabha (2014) have studied two square building of six and ten stories with and without viscous dampers. They found that placing viscous dampers at the external corner of all four sides of the building is more effective along the width of the building, but along the height of the building, placing VD all throughout the height was found to be effective.

1.3 Aim and Scope

As mentioned in previous section, the implementation of VD and FD in reinforced concrete structures has an effective role in improving their resistivity against earthquakes by dissipating their energy. For studying the effectiveness of VD and FD on minimizing damage effects of earthquakes on structural building, a comparison is performed between the seismic response of structures with and without viscous and friction dampers by using nonlinear static(Pushover) and dynamic(Time history) analysis. Moreover, the performance of structural buildings with VD in different positions will be compared to those with FD in same positions by using time history and pushover analysis to investigate the variation in efficiency between VD and FD and the optimum location of dampers in external frames for resisting earthquakes motions. In addition, both type of dampers was implemented in buildings with different stories level (5, 10 and 20 stories) to highlight the effect of increasing building height on dampers performance.

1.4 Thesis Outline

This study is basically consisted of five chapters. The first one contains general information about energy dissipating devices. In addition, it highlights a brief idea about previous work done on viscous and friction damper and the aim of this dissertation.

Chapter 2 discusses the composition and the mechanism of passive and active energy dissipation system. Furthermore, it contains explanations of nonlinear static and dynamic analysis.

Chapter 3 introduces the structural details of buildings used in the nonlinear static and dynamic analysis. Moreover, it contains information about the properties of viscous and friction dampers which are implemented in structural buildings. In addition, it describes the procedure of performing nonlinear static and dynamic analysis in this dissertation.

Chapter 4 presents the outcome resulted from time history and pushover analysis and a brief discussion about them. Finally, conclusion obtained from discussing the results is highlighted in chapter 5.

Chapter 2

LITERATURE REVIEW

2.1 General

There are three categories of energy dissipation systems which are passive, semi-active and active energy dissipation systems. Passive control system does not need an external power supply for functioning. However, active control system requires external supply for processing. In addition, an incorporation of both types of control system is called semi-active control system (SACS). This chapter will cover several types of passive energy dissipation systems (PEDS) such as Viscous Damper, Friction Damper and Viscoelastic Damper. In addition, it will cover some types of active energy dissipation system (AEDS) like Active Mass Damper, Active Tendon System and Active Brace System. Moreover, it will include explanation about nonlinear static analysis (Pushover) and nonlinear dynamic analysis (Time History).

2.2 Passive Energy Dissipation System

Passive energy control system improves energy dissipation in structural building by transforming kinetic energy into heat or by transferring of energy among vibration modes so it enhances stiffness, damping and strength of structural modal (Soong & Dargush, 1999). There is plenty example of PEDS such Viscous damper, Friction damper and Viscoelastic damper. The most useful and effective device among passive energy dissipation devices is Fluid Viscous Dampers (Lu et al, 2012).

2.2.1 Fluid Viscous Damper

Viscous damper became very popular in earthquake engineering after 1990. Before that date, they were broadly applied in many branches of US military. In 1990, succeeding the Cold War they pass into civil engineering applications. Between the year 1990 and 1993, after convenient testing, their implementation for seismic goals was authenticate. Their use become preferred for earthquake design and retrofitting due to VD capability in dissipating a portion of energy produced from the ground motion to the structural building which lead to the reduction of the deformation demand of building. In other word, VD could improve the structural behavior of recent and ancient buildings under seismic agitation in case they are rightly designed which improve the buildings safety. VD has been tested under earthquake loading, these tests prove that the hysteric behavior of VD is determined by a nonlinear fractional power law of the form:

$$f_d = c_d \mathrm{sgn}(v_d)|\, v_d|^{\alpha} \tag{2.1}$$

Where f_d is damper force, c_d is the damping coefficient, sgn the signum function, v_d is the velocity between damper extremities and α in velocity exponent. Most of the times α is varying between 0.15 and 1. In addition, nonlinear VD are capable to perform the identical response minimization in a structural building comparing to linear VD accompanying lower forces in dampers. Taking into consideration that the damper's cost relies on their top force, their implementation with a nonlinear performance will lead to an economic gain. For this reason, designers and producers take into consideration the general formulation for the dampers' force–velocity relation founded on the nonlinear fractional power law illustrated in Equation 2.1 (Pollini et al., 2017) .

The configuration of VD is composed of piston made from stainless steel with a bronze orifice head and an accumulator.

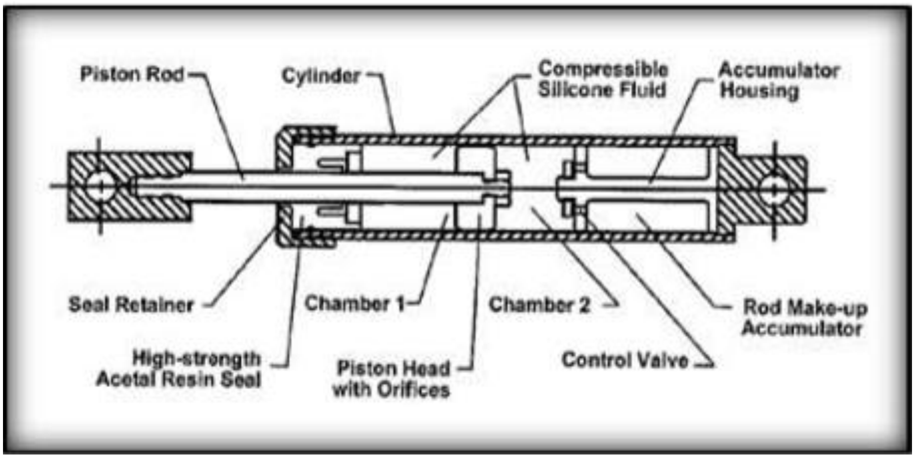


Figure 1: Detail of Viscous Damper (Sajjan & Biradar, 2016)

The Viscous Damper are passive energy dissipation apparatus which don’t depend on extraneous power supply comparing to active or semi-active systems which are controllable and need some amount of external supply for functioning. Active energy dissipation devices operate by sensor installed in the structure. However, semi-active energy dissipation system operates by a combination of active and passive control system.

VD are vigorous material, energy is conveyed by piston, then dissipated by silicon-based fluid flowing between the piston-cylinder arrangement. The damping force of VD is formulated by:

$$F = CV\alpha \tag{2.2}$$

Where F is the damping force, C is the damping coefficient, V is the velocity of piston and α is damping exponent.

VD operates by the flowing of silicon fluid across the orifice in the chamber shown in Figure 1. The silicon fluid is located in the chamber. The piston travels in the chamber filler by the silicon oil, the piston is made up by stainless steel. The silicone fluid is not flammable, inert and consistent for a long time period. The force resulted from the earthquake creates a variation in pressure between two chambers which stimulates the silicon fluid to moves through orifices through piston head. The flowing of silicone oil through the orifices will creates an inner energy which is transformed into heat which is dissipated through the atmosphere. By that way VD dissipate partially the earthquake energy into heat which is in return dissipated into the atmosphere. VD are able of functioning in a temperature which fluctuated of about -40°C to 60 °C. The devices are more applicable in designing and retrofitting of structures because of their simple ways of installation and they are adaptable and having a variety of sizes (Sajjan & Biradar, 2016).

There are many ways of installing VD in a structural system as shown in Figure 2. The most frequently implemented systems are the diagonal and chevron damper-brace systems. Damper displacement should be less than or equal to the drift of story at which the dampers are installed.

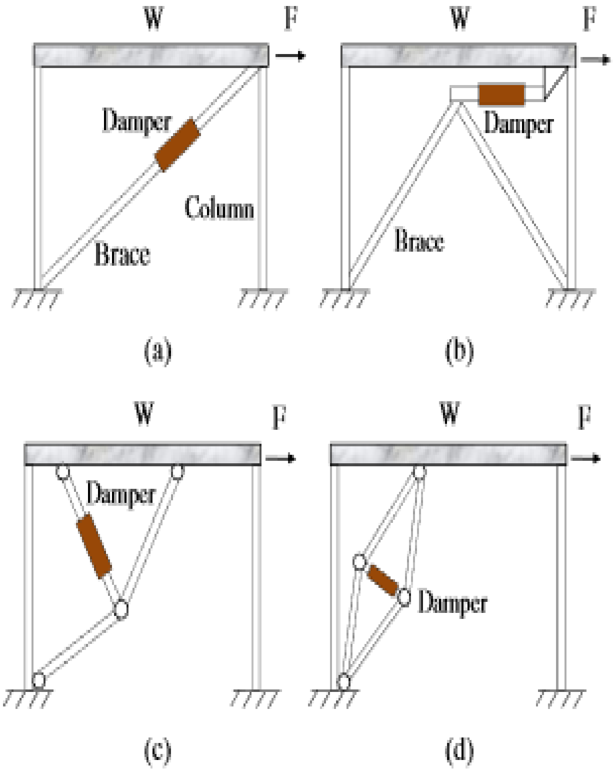


Figure 2: Illustration of dampers implementation ways: (a)diagonal; (b) chevron; (c) toggle; (d) scissor (Guo, Xu, Xu, & Di, 2014).

As shown in Figure 2 (c and d) are the toggle and scissor damper-brace systems where the hinged trusses are implemented for magnifying the influence of the structural drift on the displacement of damper and for rising the modest force of damper then transfer it into the structure frame. These magnifications will lead to a higher damping ratio comparing to the diagonal and chevron systems. However, due to their complexity in installing they are not widely implemented in practical situations (Guo et al., 2014). Mathematically, the idealized performance of damper-brace system is illustrated by the uncomplicated Maxwell model as shown in Figure 3.

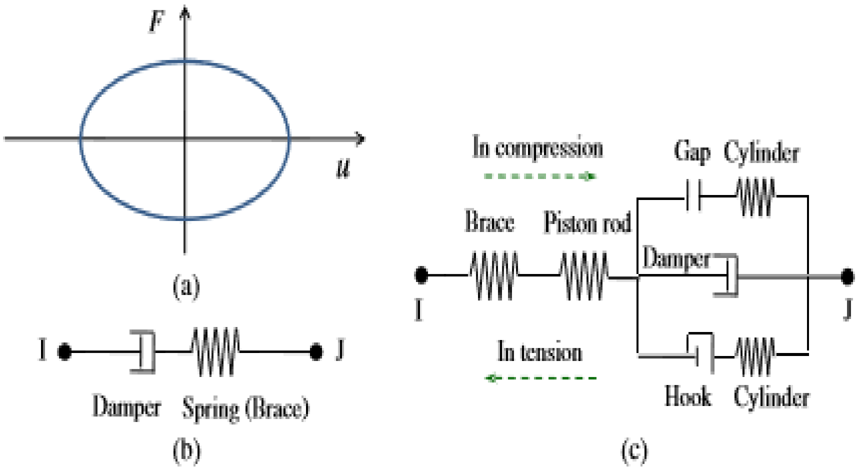


Figure 3: Idealized behavior and analytical models of VD: (a) idealized force-displacement relation; (b) Maxwell model for elastic analysis; (c) model for ultimate limit state analysis (Guo et al., 2014).

Referring to Figure 3(b) the damper-braced system is composed of a damper and spring where the last one is used as a stimulation of the brace. The system cannot figure out any stiffness in a normal status because the damper has an approximately zero stiffness and it is connected to the brace in series. However, this model is widely implemented while dealing with elastic analysis, but it is insufficient for the ultimate limit state analysis under scarce earthquakes. For this reason, a more inclusive model is established as illustrated in Figure 3(c) which consists of a hook and a gap element in parallel. This model has equivalent performance to the one showed in Figure 3(b). In that element, hook element stimulates the activation of piston rod, cylindrical wall and brace's stiffness in case the piston displacement attains the damper stroke under scarce earthquake (damper is in tension). In other situation gap element stimulates the activation of piston rod, cylinder and the brace's stiffness in case the piston retraction is equivalent to the stroke (damper in compression) (Guo et al., 2014).

2.2.2 Friction Damper

Friction Damper (FD) is permanent passive energy absorbing device where it doesn't need to be changed or substitute after several earthquakes. In order to dissipate an important amount of the earthquake's energy in the form of heat, FD employs the friction developed between movable solid interfaces. During severe seismic excitations, FD yield at the predetermined load providing dissipation of energy by friction phenomenon simultaneously it shifts the structural fundamental mode far from the earthquake resonant frequencies. In addition, to its invulnerability against thermal effects, it performs reliably with the stable hysteretic behavior (Damptech). As shown in Figure 4, FD is composed of various steel plates which rotates against each other in reversed directions. Shims with friction pad material creating friction with the steel plates.

Figure 4: Typical Friction (Landge & Joshi, 2017)

When the exterior forces exceed some limits, the damper's steel plate begin the rotation process with the conversion of the mechanical energy into heat in the friction layer between friction pad and steel plates. In addition, FD can be combined in many different ways, geometries and shapes (Damptech). Moreover, there are different models for installing FD as shown in Figure 6.

Figure 5: Different shapes and geometries of FD (Damptech)

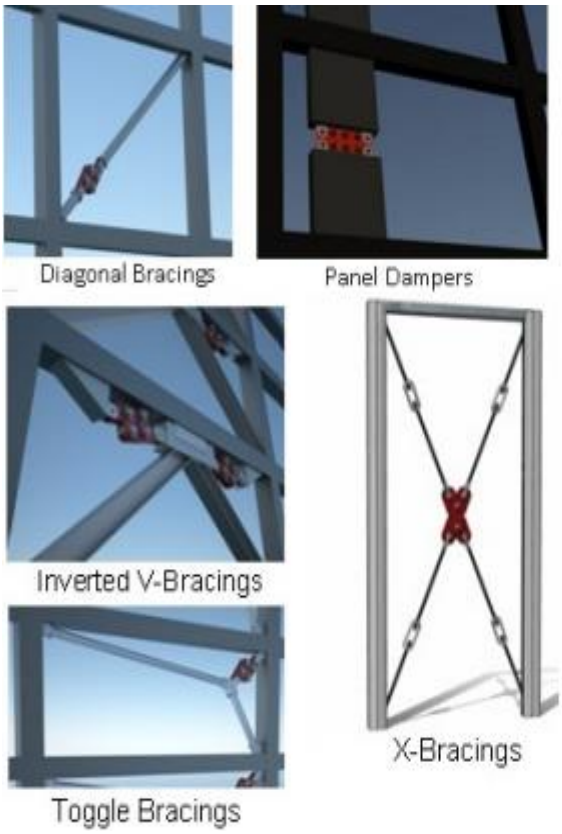


Figure 6: Different types of FD installation (Damptech)

2.2.3 Viscoelastic Damper

Viscoelastic dampers (VED) are used as energy dissipating systems to minimize the effect of wind and earthquake against tall building structures. Their successfulness was proved experimentally and analytically by many scientists over the last 25 years. VED are among the PEDS which were successfully installed in many high rise buildings in order to get down the motion amplitude and the acceleration happening because of earthquake forces. They decrease earthquake effects (building’s motion) by partially converting its mechanical energy into heat when they are installed properly. In addition, climate conditions and loading frequency are the decisive factors which have an impact on the performance of VED (Samali & Kwok, 1995).

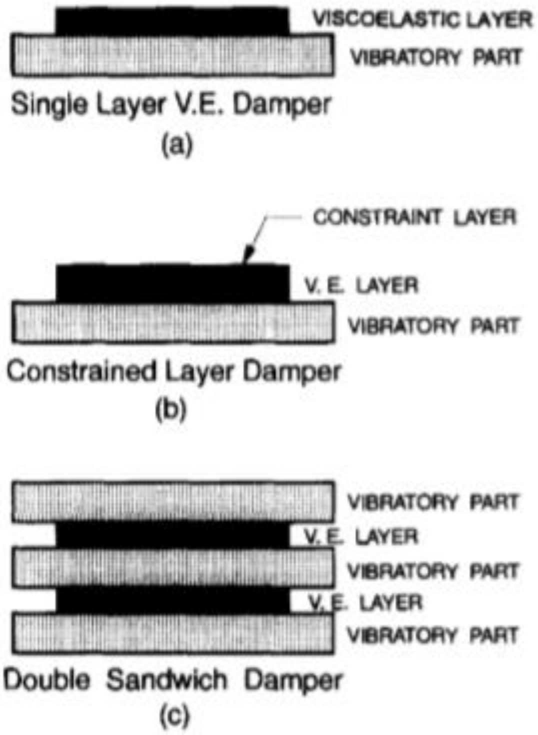


Figure 7: Various configuration of VED (Samali & Kwok, 1995)

As a damping tools, there are three different configurations of installing VED. The first is a straight employment of a viscoelastic layer to the vibrating member like plates and beams (Figure 7a). In that case damping is performed by extensional deformation of the viscoelastic layer. The following configuration is similar to the previous except of providing extra layer of a rigid material on top of the viscoelastic part where a constraint layer is formed so the viscoelastic material experience extensional and shear deformation. Last configuration which is most implemented one in structure field and it is considered a typical Viscoelastic Damper due to its suitability and effectiveness in damping out large amounts of earthquake energy. It consists of double viscoelastic layers connected between three parallel rigid surfaces as illustrated in Figure 7. A viscoelastic material's load-deformation curve in the form of a hysteresis loop is presented in Figure 8 and 9.

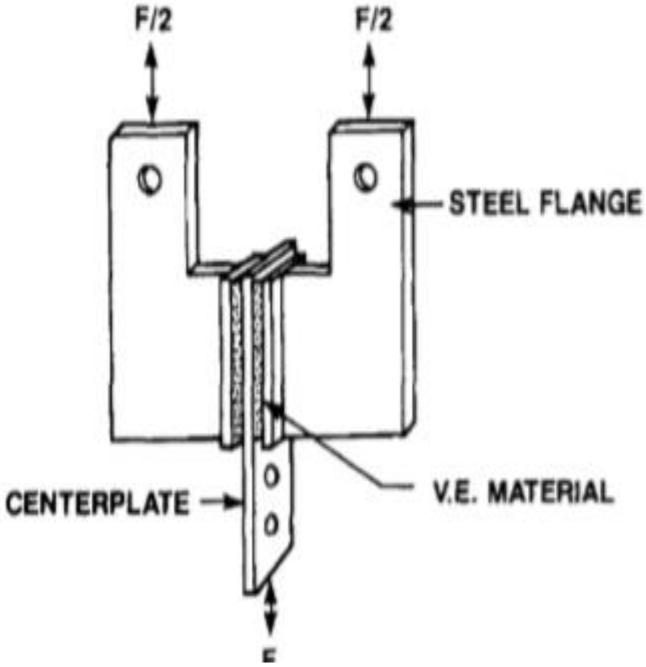


Figure 8: Typical VED (Samali & Kwok, 1995)

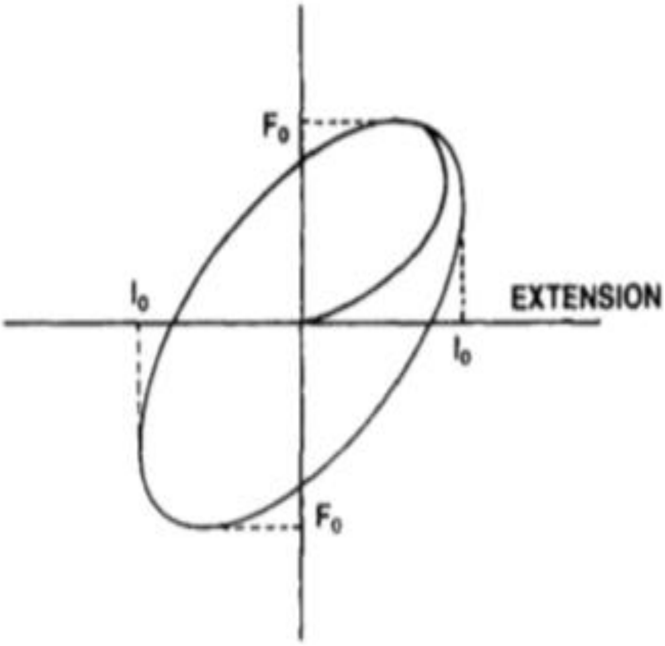


Figure 9: Typical hysteresis loop (Samali & Kwok, 1995)

2.3 Active Energy Dissipation System

Active energy dissipation systems (AEDS) are controllable system which acquires some amount of exterior supply for functioning. AEDS will function by sensor which is connected to structure and supply an analog signal into it. This signal is produced by the computer which follow a control algorithm that utilizes the measured responses of the structural building. SACS are energy dissipating instruments which are a composition of both active and passive control system.

2.3.1 Active Mass Damper

Tuned Mass Damper (TMD) is an energy dissipation device which can be easily installed to the structure and confine the primary structure's vibration. Originally TMD is PEDS, it has restricted performance because of the fixation of damper parameters, limited suppression of frequency range, inefficient reduction of non-stationary vibration, and a sensitivity problem due to detuning. The limited performance of passive TMD can be regulated by introducing the Semi-Active Tuned Mass Damper (STMD) and the Active Tuned Mass Damper (ATMD) or the Active Mass Damper (AMD) as energy dissipation devices. STMD and ATMD technologies depend on the control board and electronic circuit for sensing the motion of structure and stimulating the activation of the control force. However, STMD decrease the magnitude of earthquake vibrations by changing its natural frequency (by modifying either stiffness or damping properties) without producing a direct force. For that reason, STMD takes advantage over AMD in case the electrical power is unavailable because STMD is still able to supply current damping or stiffness to structure. The AMD suppress earthquake motion by applying a control force determined by utilizing a sensor signal and control algorithm which results an active vibration control. Since it uses sensors, actuators and a feedback control algorithm, the AMD is able of suppressing vibration caused by frequently varying external environment. Unfortunately, it may affect the stabilization of a main structure if structural parameter varied. For that reason, the authenticity of the control system should be insured before utilization (Yang, et al. 2017). The configuration of TMD is illustrated in Figure 10.

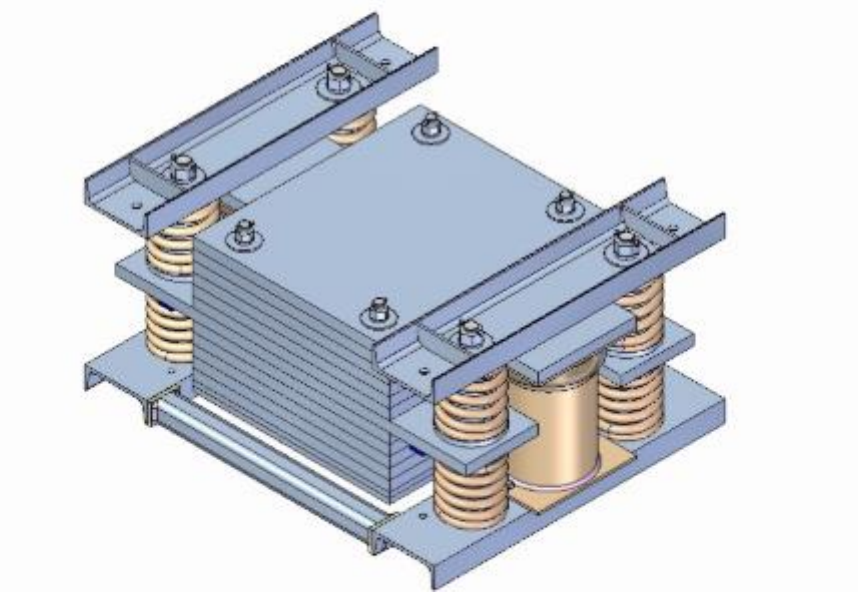


Figure 10: A vertical TMD (DEICON)

2.3.2 Active Tendon System

Active tendon control systems (ATCS) are effective structural control due to their ability of producing control forces for various sides corresponding to the responses calculated at structure’s side. They are composed of actuators, sensors, diagonal prestressed steel cables, pulleys, controller devices and sensors. In ATCS, the force on diagonal prestressed tendons linked to actuators located on the structure’s side are controlled which insure the sustainability of the damping of the earthquake’s vibration. Moreover, these energy dissipating control system with cable (tendon) is considered aesthetic when it is compared to diagonal braces (Nigdeli & Boduroğlu, 2013).

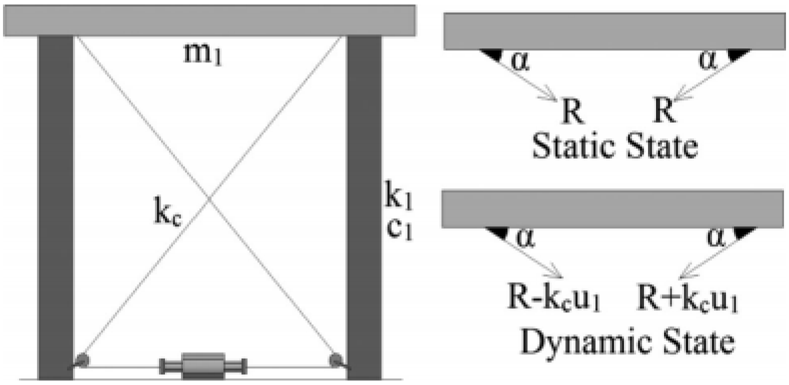


Figure 11: Active tendon control scheme (Nigdeli & Boduroğlu, 2013)

The model of ATCS which controls single degree of freedom structure and control forces in static and dynamic state is illustrated in Figure 11. In dynamic state when each tendon is under load of a prestressed force (R), tensile force is applied on one of the crosswise tendons, the other tendon is unloaded due to compressive force in case a tendon cannot carry compressive force. For that reason, control force’s absolute value should be less than the prestress force for guaranteeing the desired control force in accordance with the actuator displacement (Nigdeli & Boduroğlu, 2013). The configuration of ATCS in presented in Figure 12.

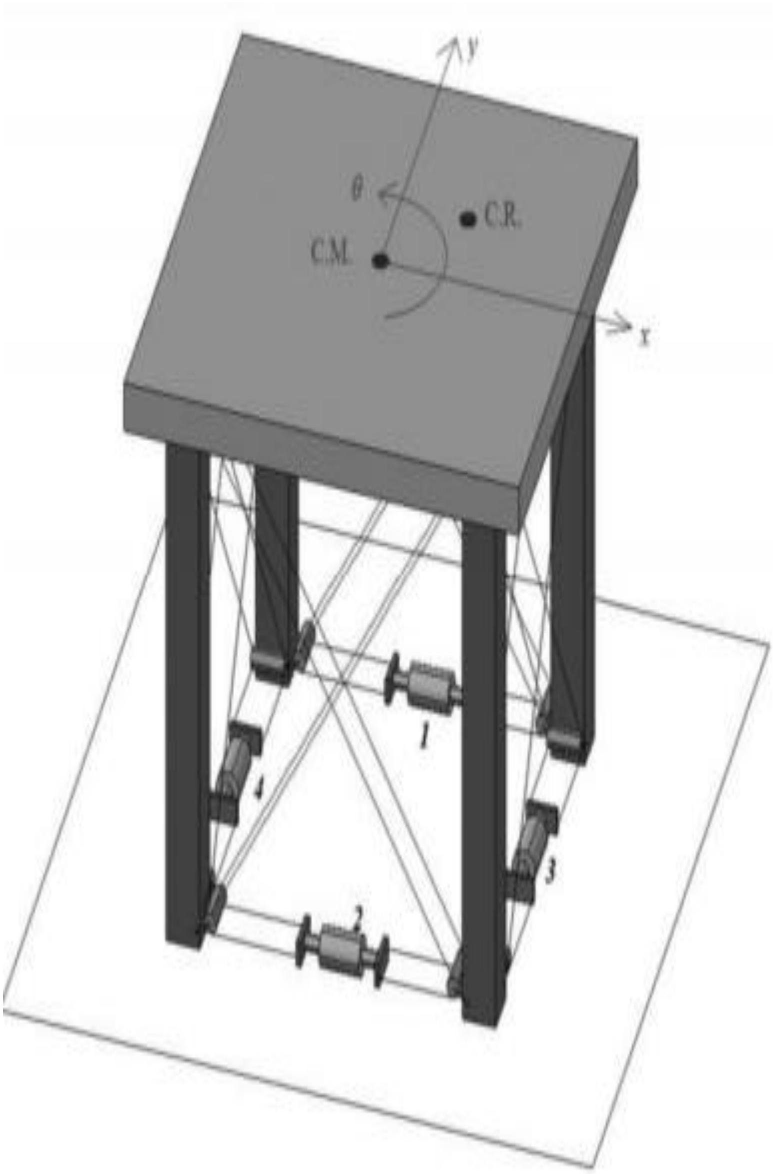


Figure 12: 3D view of ATCS single-story structure (Nigdeli & Boduroğlu, 2013)

2.3.3 Active Brace System

When the structural braces are used to develop an active control system by adding stimulator a new system is developed which is active brace system (ABS). ABS is divided into different bracing system like diagonal, K-braces and X-braces. They are used in conjunction with hydraulic actuators able of generating an important force control (Anwar, 2016).

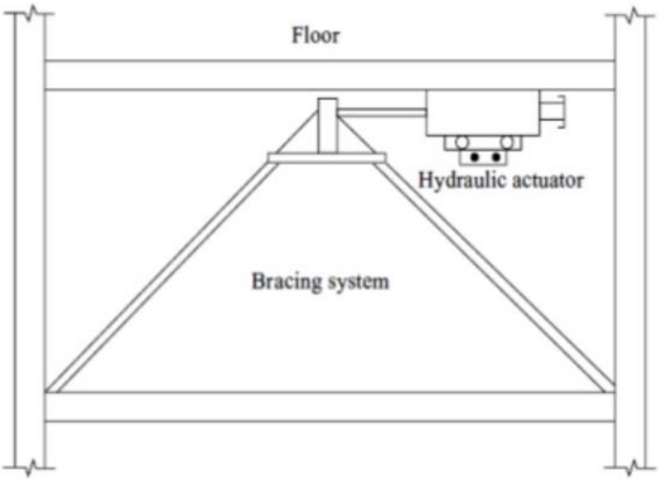


Figure 13: ABS with hydraulic actuator (Anwar, 2016)

2.4 Non-Linear Static and Dynamic Analysis

Performing seismic analysis of structure for the specification of seismic responses is a crucial matter. The analysis type is categorized as linear static/dynamic or nonlinear static/dynamic according to the external action and behavior of building. Linear static analysis is performed for regular building which has limited height and linear dynamic analysis is done by using response spectrum method. Nonlinear static analysis considers the inelastic behavior of structure where it is performed under permanent vertical loads and systematically increasing lateral loads to approximate damage pattern and deformation of structure. In addition, nonlinear dynamic analysis which is named time history is a significant technique in case the evaluated building response is nonlinear and it is performed to find out the seismic response of structure subjected to dynamic loading of representative earthquake.

2.4.1 Pushover Analysis

The main aim of using pushover analysis is to anticipate seismic force and deformation demands for evaluating the performance of both ancient and new structure. Information which are obtained by pushover analysis is not found from linear static/dynamic analysis procedures. It is an easy intermediate solution for anticipating force and deformation demands applied on structural buildings and their members by destructive earthquake.

Pushover analysis is an approximation analysis where the building or structure is subjected to monotonically rising horizontal forces with a constant distribution along the height until the attainment of target displacement. A series of sequential elastic and plastic analysis are performed to obtain an approximation of a force-displacement curve of the overall structure which is the main constituent of pushover analysis. First of all, two or three dimensional model including bilinear or trilinear load-deformation diagrams of all lateral force resisting elements is created where gravity loads were applied initially. After that, there’s application of predefined horizontal load pattern distributed along the building height. Horizontal loads are raised up to the yielding of some members. However, when horizontal load increase there will be a reduction of the stiffness of yielded members, so for accounting this problem the structural model is modified to match this reduction. After that the horizontal loads are once more increased up to the yielding of additional members. When structure becomes unsteady and control displacement at the structure’s summit reaches a certain level of deformation, the procedure stopped. At the end, the pushover curve is formed by plotting the roof displacement with base shear (Phyo & Khaing, 2014).

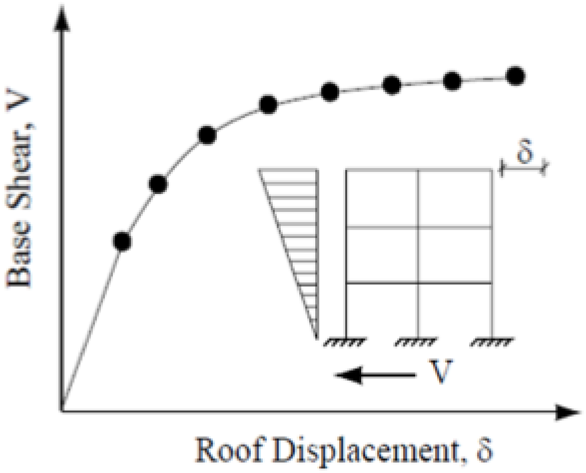


Figure 14: Pushover curve of a structural building (Phyo & Khaing, 2014)

Pushover analysis is achieved as force-controlled or displacement-controlled. In the first one, full load combination is worked on as specified by engineering codes but the accuracy of results is negatively affected due to the occurrence of some numerical problems due to a slight negative or positive lateral stiffness associated with target displacement due to the P-delta effects. However, the second procedure is applied when the magnitude of the applied load is unknown from the beginning. In order to estimate deformation demand and inelastic strength which need to be compared to the available capacities for performance check, deformations and internal forces calculated at target displacement are employed for estimation.

Moreover, pushover analysis can be performed by Displacement Coefficient Method (DCM) or Capacity Spectrum Method (CSM). CSM is used for many purposes like obtaining a quick evaluation of huge number of structures, verifying the design of a living structure to find out the damage states. It compares the capacity of the structural buildings by using pushover curve considering the demands on the structure. In addition, the main aim of DCM is calculating the target displacement which is the maximal displacement a building will experience during ground motion.

Furthermore, it has many advantages such as it can be applied equally for retrofitting an ancient structures and for designing a new ones and providing details on response characteristics which couldn’t be found from linear elastic static or linear elastic dynamics analysis. Some illustration of these response characteristics could be as follows:

1) Force demands in some brittle elements like axial loads demands in columns or force demands connections from beam to column, shear force demands in unreinforced masonry wall piers or reinforced concrete spandrel beams.
2) Approximation of deformation demands for members which do not deform elastically for dissipating the energy transmitted to the structure by earthquakes.
3) Specification of critical members where the deformation demands are anticipated to be higher than other members, they should be the focus of thorough detailing.
4) Highlighting modifications in dynamic characteristics of the inelastic limits due to strength disconnections in elevation or plan.
5) Estimation of interstory drifts which cause stiffness and strength discontinuities.
6) Checking the adequacy and completeness of load path including all members of the foundation and structural system.

In addition, pushover analysis is applicable for the evaluation at any performance level where there’s occurrence of inelastic deformations. Depending on the amount of damage suffered by the structure when pushover analysis is executed, the global structural response is categorized into five levels:

1) Operational level (O) where the structural and nonstructural damages are negligible, utilities are available, facilities can be used immediately after pushover analysis is performed and the losses of the replacement value is less than 5%.
2) Immediate Occupancy level (IO) where there are insignificant structural damages, slight nonstructural damage, building is secured for the occupancy. However, it is not functional and there are limited interruption of operations.
3) Life Safety level (LS), at this stage important structural damage, some fracture and considerable nonstructural damage may occur. Moreover, the losses are below 30%.
4) Collapse Prevention level (CP), it is characterized by occurrence of excessive damage in structural and nonstructural elements, important possibilities for injury without wide scale life loss, repair become not practical and the losses are greater than 30% (Phyo & Khaing, 2014).

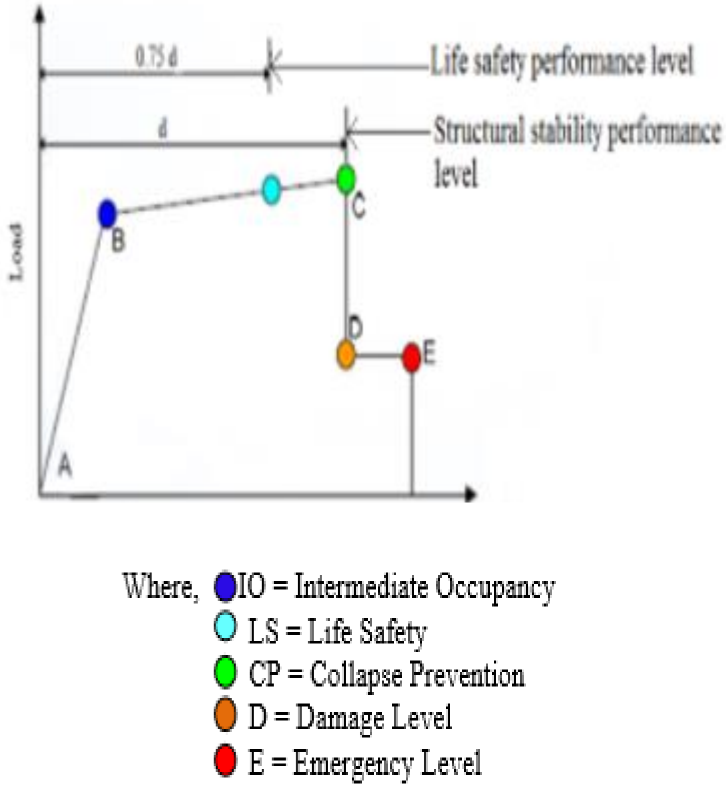


Figure 15: An example of performance level of a structure (Phyo & Khaing, 2014)

2.4.2 Time History Analysis

Non-linear dynamic analysis is named as time history analysis (THA). THA is crucial for seismic analysis of structure in case structural response of the structure in nonlinear. In order to perform this analysis type, realistic earthquake time history is needed for evaluating a structure. THA is performed to figure out the seismic response of a structure (base shear, displacement, etc..) which is under dynamic loading of realistic earthquake. THA is a gradually analysis of the dynamic response of a structure to a determined loading which fluctuate with time (Patil & Kumbhar, 2013).

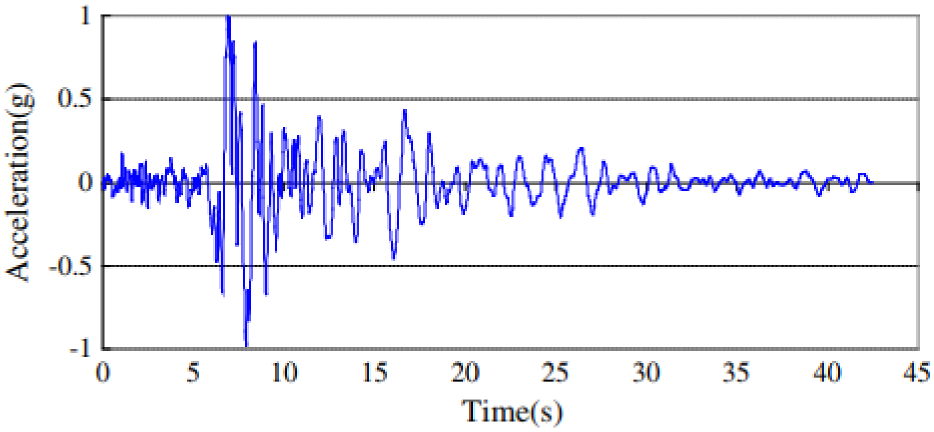


Figure 16: Example of time history analysis (Lu, Su, & Zhou, 2013)

Equation 2.3 is the equation of motion in its general form, it is essential for solving the systems for non-linear case.

$$\mathrm{M\ddot{u}\,(t) + \; C\acute{u}\,(t) + \; Ku\,(t) = \; r(t)} \tag{2.3}$$

Where M is the diagonal matrix of mass, C is the matrix of damping, K is the matrix of stiffness, R is the applied load, U is the displacement function, Ú is the velocity function and Ü is the acceleration function (Chopra & Anil, 2007).

The records of earthquakes are matched with structure building’s design spectrum; this is called scaling of ground motion. There are two ways earthquake records scaling, time domain scaling and scaling in frequency domain. In the first way scaling, earthquake records matching with response spectrum of design building occurs without any modification in the frequency of ground motion records. However, the acceleration of earthquake records is modified by adding wavelets. Frequency domain scaling depends on detecting the ratio of targeted response spectrum to time series response spectrum while making the Fourier stage constant. In case this method is used, the ground motion’s total energy will increase which result to numerous modification in the character of time series (Chopra & Anil, 2007).

It exists two modal analysis types for determining modal load case which are Ritz-vector and Eigen-vector analysis. When Ritz-vector method is applied, the natural free vibration modes aren’t the largest in terms of their superposition analysis when structure is under dynamic loads. The results of Ritz-vector analysis are more accurate than those of natural mode shapes because the spatial distribution of dynamic loading are considered in this method, but they are abandoned in free vibration modes. By using Eigen-vector method, the modal’s frequencies and the undamped free vibration modes can be determined which provide a reasonable view in respect to structure’s performance. Equation 2.4 provides the general eigenvalue equation (Chopra & Anil, 2007).

$$(\mathrm{K} - \Omega^2\mathrm{M})\phi = 0 \tag{2.4}$$

Where;

Ω^2: Matrix of eigenvalues

Φ: Matrix of Eigen vectors

Chapter 3

METHODOLOGY

3.1 General

This section portrays the features of structural buildings which are used in this study and the properties of Viscous and Friction Dampers implemented into them. In addition, it covers the various locations of dampers into structural frames with different number of stories (5, 10 and 20 stories). Furthermore, it contains explanation of the two types of nonlinear analysis used in the analysis which are Time History and Pushover Analysis used for the comparison of buildings performance with and without dampers and the comparison of buildings with VD and FD.

3.2 Analytical Model of Structural Buildings

3.2.1 Description of Structural Buildings

This study consists of 3 sets of structural buildings where the first is five stories building, the second is ten stories building and the third is twenty stories buildings. The design of these sets is identical, the only difference is their height. They are modeled by using ETABS 2017 software. Their zone is assumed to be Duzce area which is a province in northwestern Turkey on the coastline of the black sea with soil type Z_B. Structural buildings are designed according to TS-500 and they are designed to withstand static earthquake load by using TBEC-2018. The seismic coefficients used for designing of the building are presented in Table 1. The buildings are designed to withstand static earthquake loads for 10% of occurrence probability. However, while analyzing of buildings the static earthquake loads have the probability of 2%

occurrence, this procedure is called MCE (maximum considered earthquake) according to TBEC-2018.

Table 1: Seismic Coefficients of Duzce zone for probability of 10% of earthquake occurrence according to Turkey Ministry of Interior Disaster and Emergency Management Authority (AFAD)

S_S= 1.344	S_1 = 0.365	PGA = 0.552	PGV = 35.460

Table 2: Seismic Coefficient of Duzce zone for probability of 2% of earthquake occurrence according to Turkey Ministry of Interior Disaster and Emergency Management Authority (AFAD)

S_S= 2.380	S_1 = 0.645	PGA = 0.933	PGV = 60.469

Table 3: Description of Structural Buildings

Concrete characteristic compressive strength, f_{ck}	30 MPa
Columns dimension	50 × 50 cm
Beams dimension	45 × 30 cm
Slab Thickness	150 mm
Span number in X direction	6
Span number in Y direction	6
5 stories building height	15 m
10 stories building height	30 m
20 stories building height	60 m

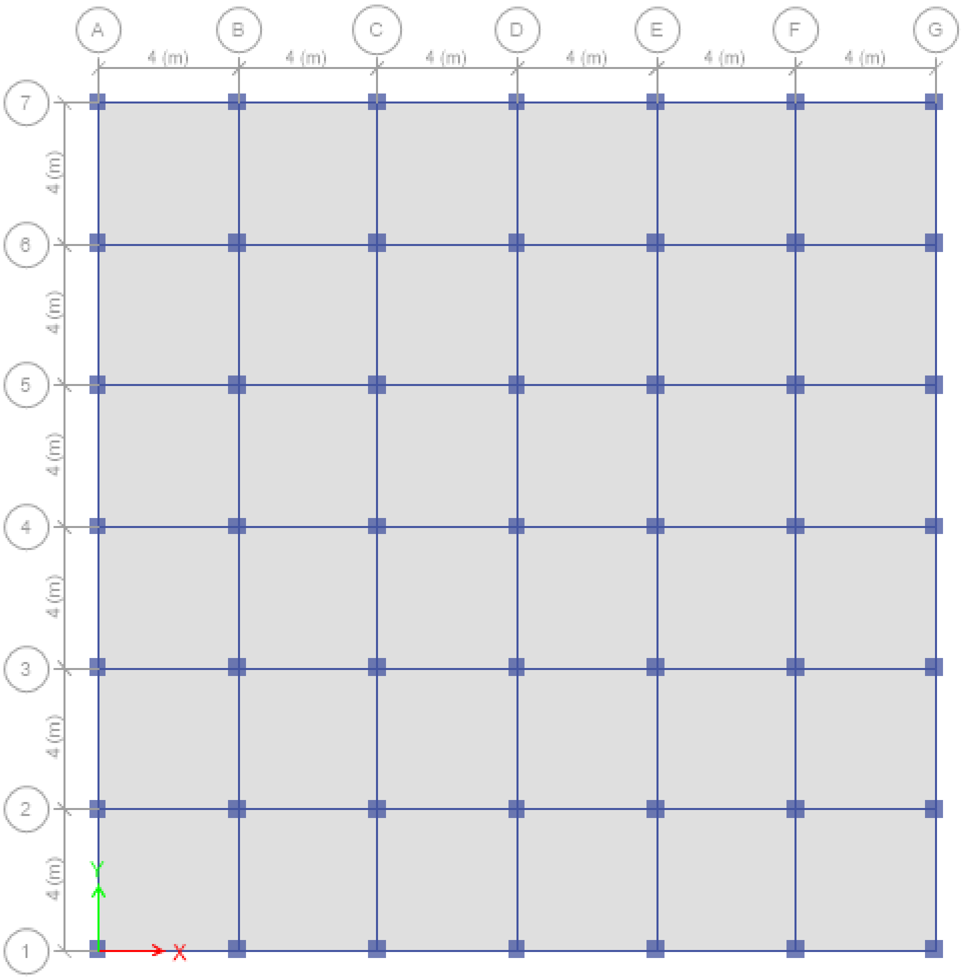


Figure 17: Plan view of structural buildings

Note that the plan view illustrated in Figure 17 is identical for all the structural building. In addition, a 3D view of five, ten and twenty stories is represented in Figure 18, 19 and 20.

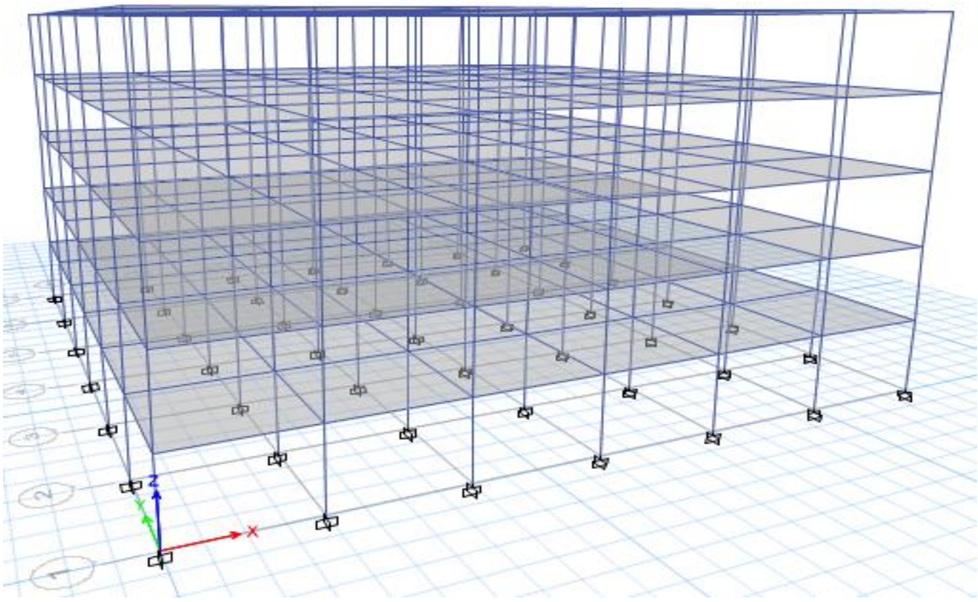


Figure 18: 3D view of five stories building without damper

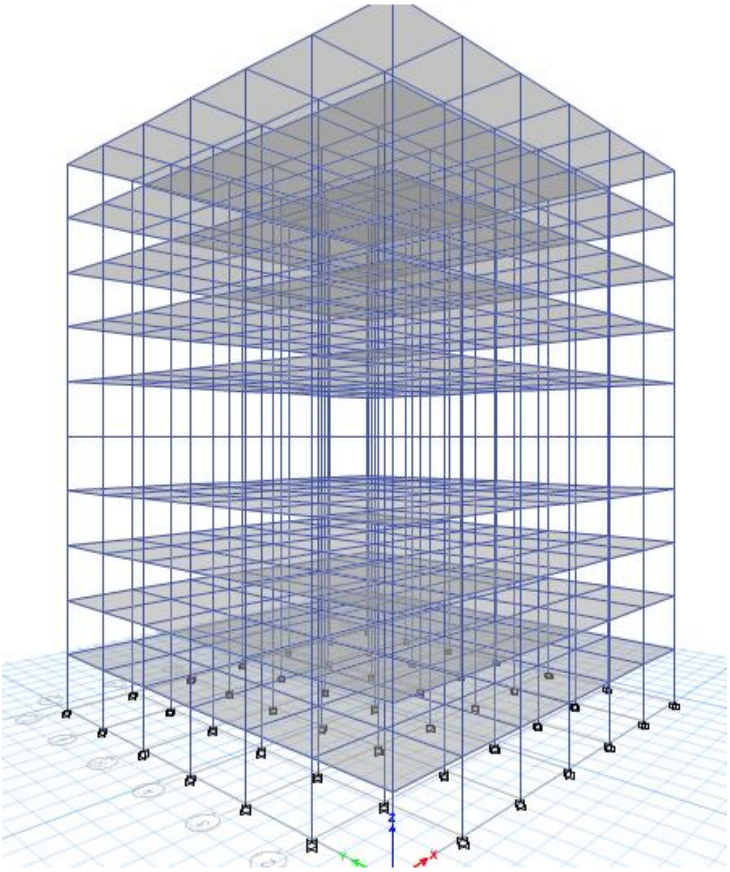


Figure 19: 3D view of ten stories building without damper

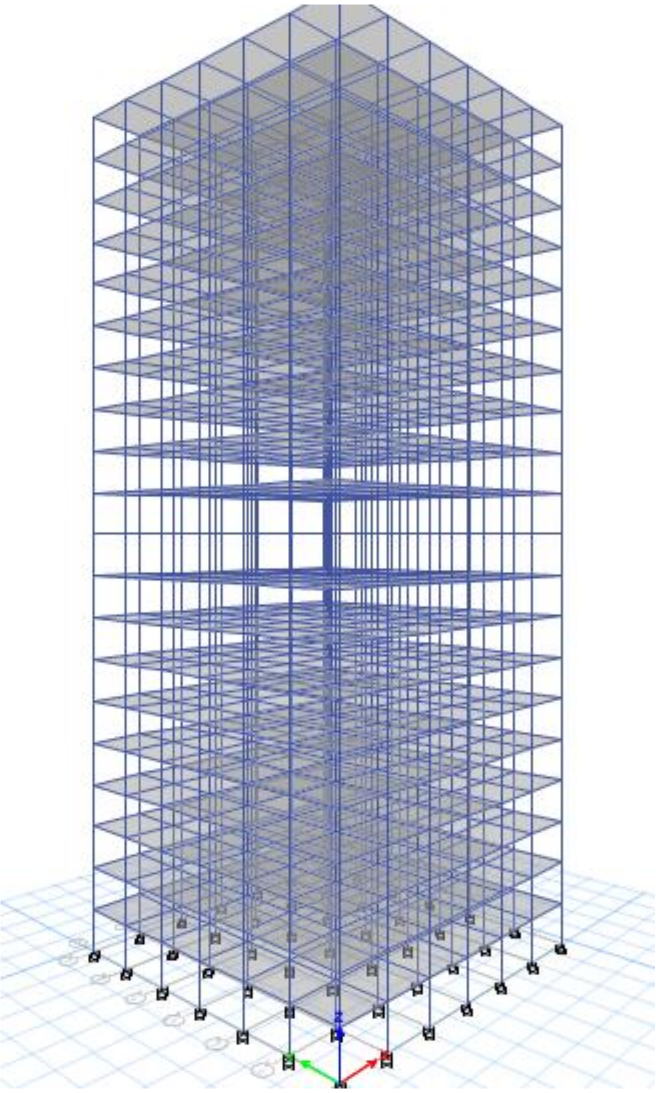


Figure 20: 3D view of twenty stories building without damper

3.2.2 Properties and locations of Viscous and Friction Damper

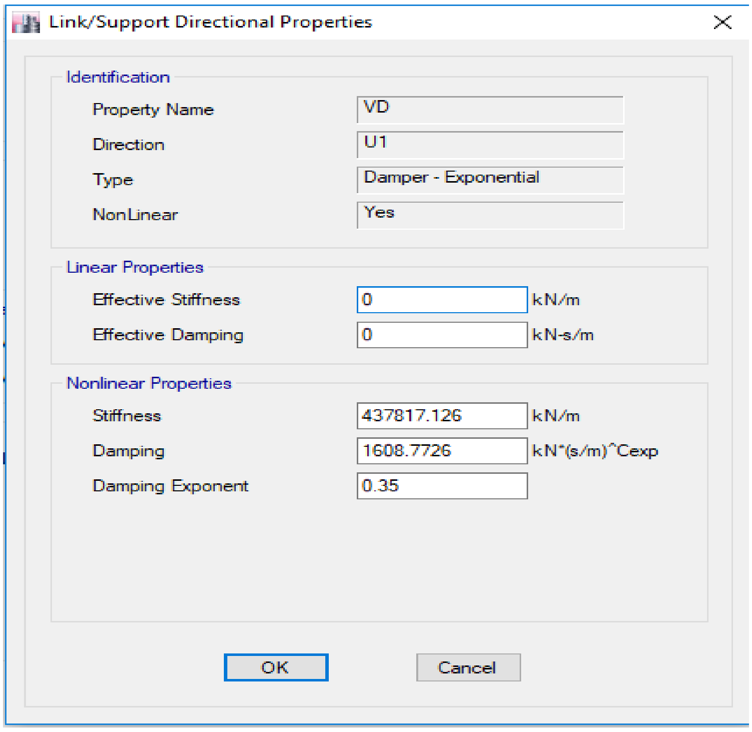
The properties of Viscous and Friction dampers were obtained from Taylor Device Company by its representative in Turkey which is Fuji Engineering Company. Viscous and Friction Damper are considered nonlinear. The properties of the Viscous and Friction dampers are given in Table 4 and Table 5, respectively. The decision of implementing these properties was taken according to drift ratio check which should be less than 0.02 for all stories according to TBEC 2018. The implementation of VD and FD in ETABS 2017 is given in Figure 21 and Figure 22, respectively. Dampers are implemented in ETABS software as a link element.

Table 4: Nonlinear properties of Viscous Damper.

Stiffness	437817.126 kN/m
Damping	1608.773 kN*$(\frac{s}{m})^{Cexp}$
Damping Exponent	0.35

Table 5: Nonlinear properties of Friction Damper

Initial Stiffness	437817.126 kN/m
Slipping Stiffness (Loading)	328362.845 kN/m
Slipping Stiffness (Unloading)	218908.563 kN/m
Precompression Displacement	-1.3 mm



Identification

Property Name: VD

Direction: U1

Type: Damper - Exponential

NonLinear: Yes

Linear Properties

Effective Stiffness: 0 kN/m

Effective Damping: 0 kN-s/m

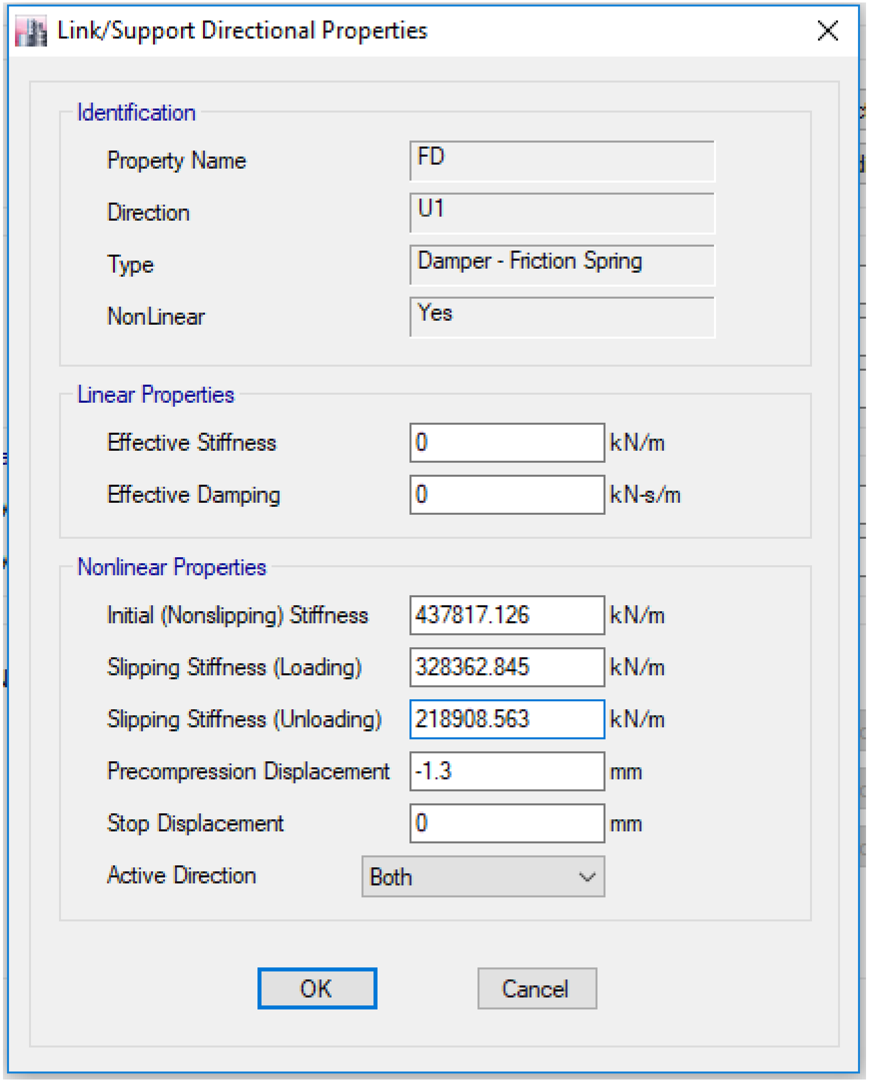
Nonlinear Properties

Stiffness: 437817.126 kN/m

Damping: 1608.7726 kN*(s/m)^Cexp

Damping Exponent: 0.35

Figure 21: Implementation of nonlinear properties of Viscous Damper on ETABS 2017



Identification

Property Name: FD

Direction: U1

Type: Damper - Friction Spring

NonLinear: Yes

Linear Properties

Effective Stiffness: 0 kN/m

Effective Damping: 0 kN-s/m

Nonlinear Properties

Initial (Nonslipping) Stiffness: 437817.126 kN/m

Slipping Stiffness (Loading): 328362.845 kN/m

Slipping Stiffness (Unloading): 218908.563 kN/m

Precompression Displacement: -1.3 mm

Stop Displacement: 0 mm

Active Direction: Both

Figure 22: Implementation of nonlinear properties of Friction Damper on ETABS 2017

Viscous and Friction dampers were distributed along the outer frame of structural buildings; eight dampers were located in each story in the form of diagonal bracing. In this study, three types of dampers distribution were implemented in each story. The first one consisted of dampers distribution in the corner of the outer frame, the second one consisted of dampers distribution in far middle of the outer frame and the third one included dampers distribution in outer middle of structural frame. Dampers distribution is illustrated in Figure 23, 24 and 25.

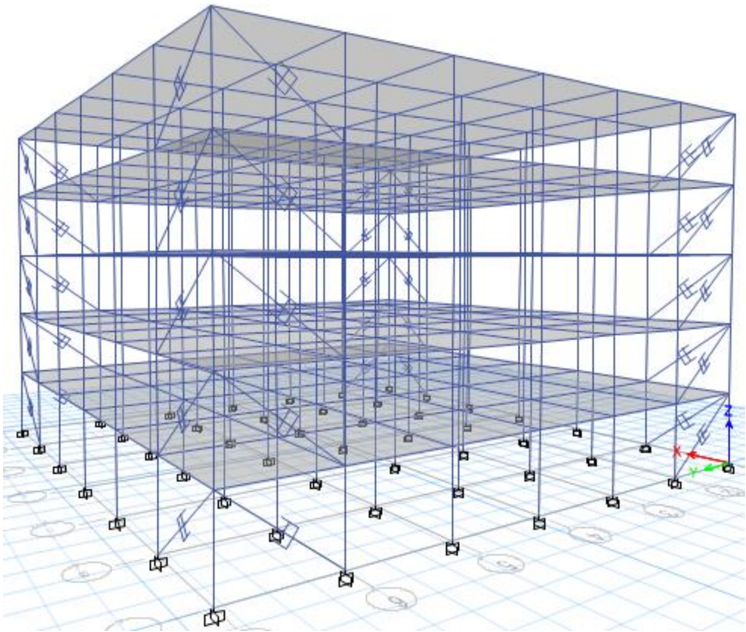


Figure 23: Dampers distribution in the corner of the outer frame

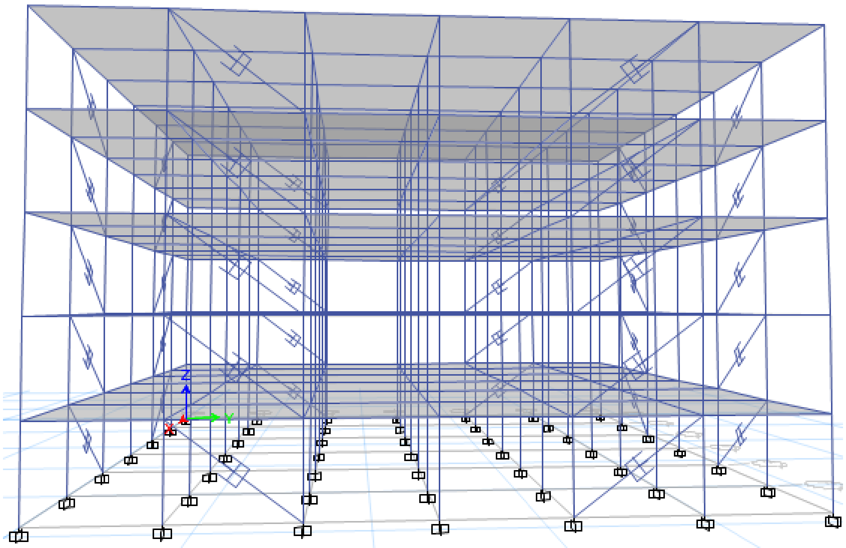


Figure 24: Dampers distribution in the far middle of the outer frame

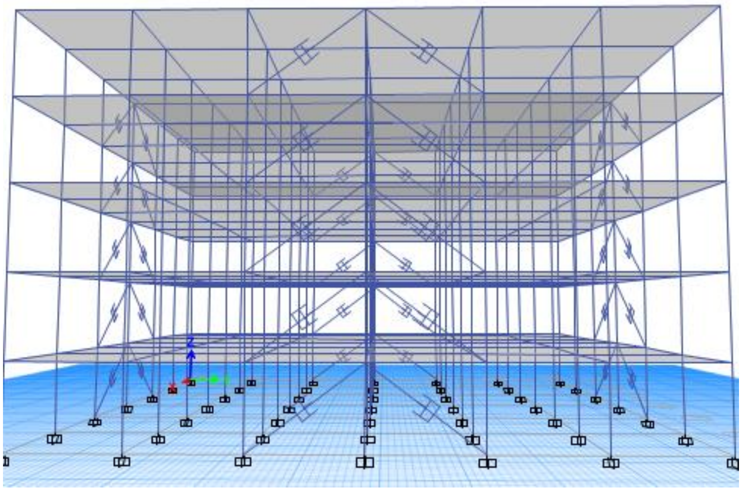


Figure 25: Dampers distribution in the middle of the outer frame

Note that Viscous and friction dampers are distributed in the same way in each structural building whether it is five, ten or twenty stories.

3.3 Non-linear Analysis Methods

3.3.1 Time History Analysis

Nonlinear THA was performed for determining the realistic nonlinear behavior of the structural buildings because it consists of applying real earthquake records to structural building. Structural models were exposed to actual ground movement records. Structures were exposed to different earthquakes which are Kocaeli, Duzce and Izmir earthquake. The earthquake records are taken from Pacific Earthquake Engineering Research Center (PEER Ground Motion Database). The feature of the three earthquake is illustrated in Table 6, 7 and 8.

Table 6: Details of Duzce earthquake

Station Name	Duzce
Earthquake Name	Kocaeli
Magnitude	7.51 M_w
Damping ratio	0.05
Year	1999

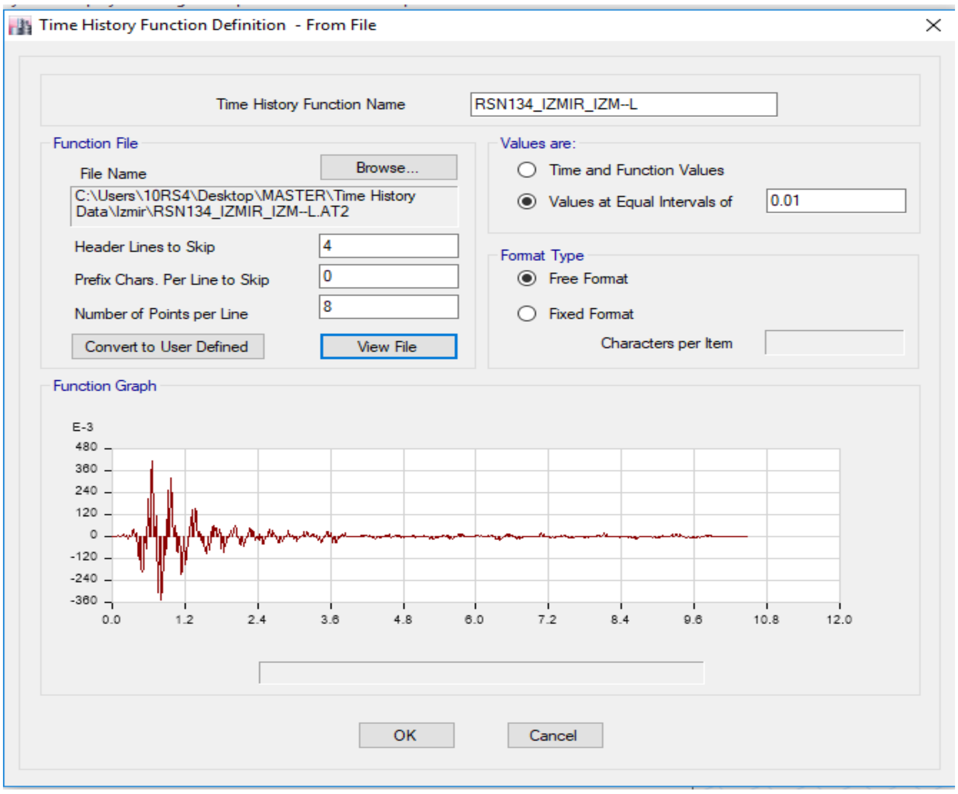
Table 7: Details of Istanbul earthquake

Station Name	Duzce
Earthquake Name	Duzce
Magnitude	7.14 M_w
Damping ratio	0.05
Year	1999

Table 8: Details of Izmir earthquake

Station Name	Izmir
Earthquake Name	Izmir
Magnitude	5.3 M_w
Damping ratio	0.05
Year	1977

The ground motion characteristics were entered into ETABS 2017 software, in other word the function of each earthquake record in X and Y directions was created by transferring their data from files downloaded from PEER to the software, (Figure 26).



Time History Function Definition - From File

Time History Function Name: RSN134_IZMIR_IZM--L

Function File

File Name: C:\Users\10RS4\Desktop\MASTER\Time History Data\Izmir\RSN134_IZMIR_IZM--L.AT2

Header Lines to Skip: 4

Prefix Chars. Per Line to Skip: 0

Number of Points per Line: 8

Values are:

○ Time and Function Values

● Values at Equal Intervals of: 0.01

Format Type

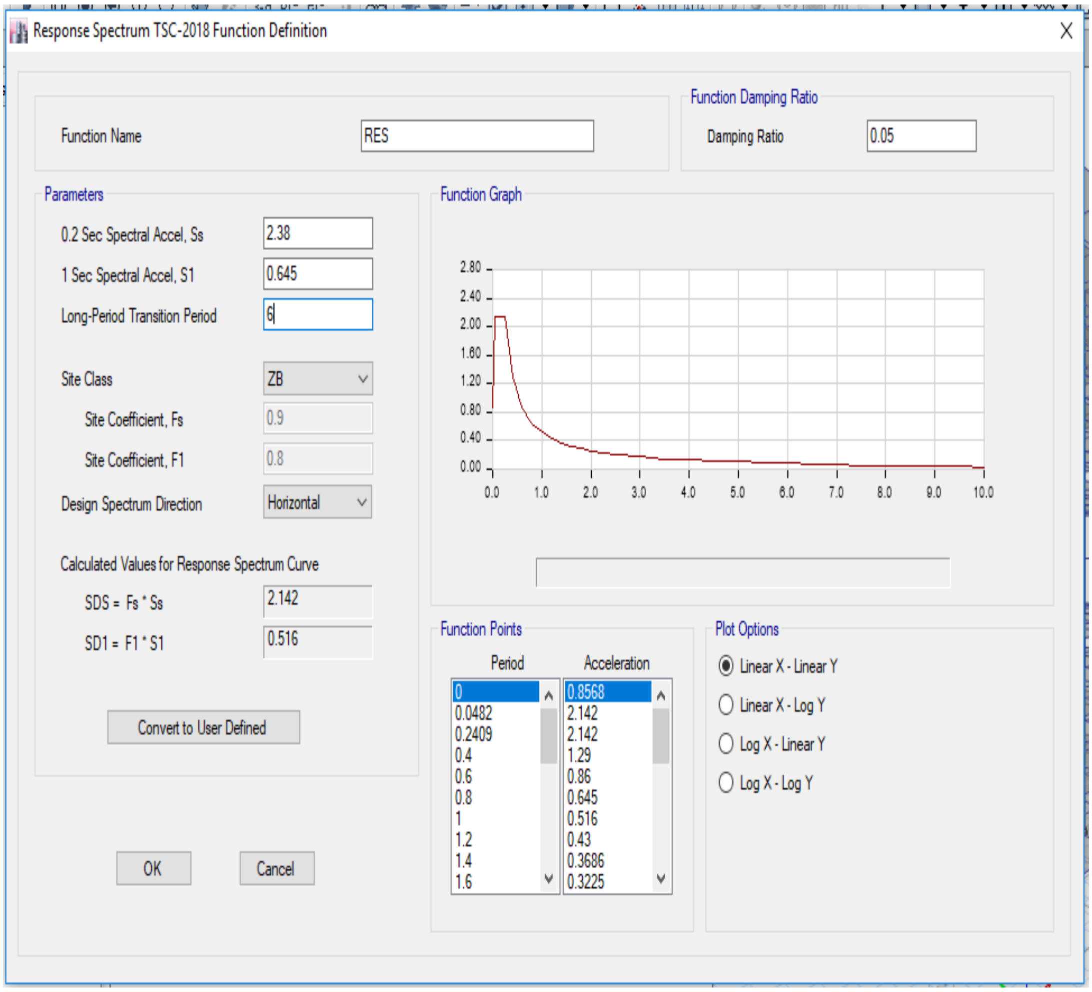
● Free Format

○ Fixed Format

Characters per Item:

Figure 26: Defining Izmir earthquake function in X direction

After that, the response spectrum function of structure building was defined according to TBEC-2018 as illustrated in Figure 27.



Response Spectrum TSC-2018 Function Definition

Function Name: RES

Function Damping Ratio
Damping Ratio: 0.05

Parameters
0.2 Sec Spectral Accel, Ss: 2.38
1 Sec Spectral Accel, S1: 0.645
Long-Period Transition Period: 6
Site Class: ZB
Site Coefficient, Fs: 0.9
Site Coefficient, F1: 0.8
Design Spectrum Direction: Horizontal

Calculated Values for Response Spectrum Curve
SDS = Fs * Ss: 2.142
SD1 = F1 * S1: 0.516

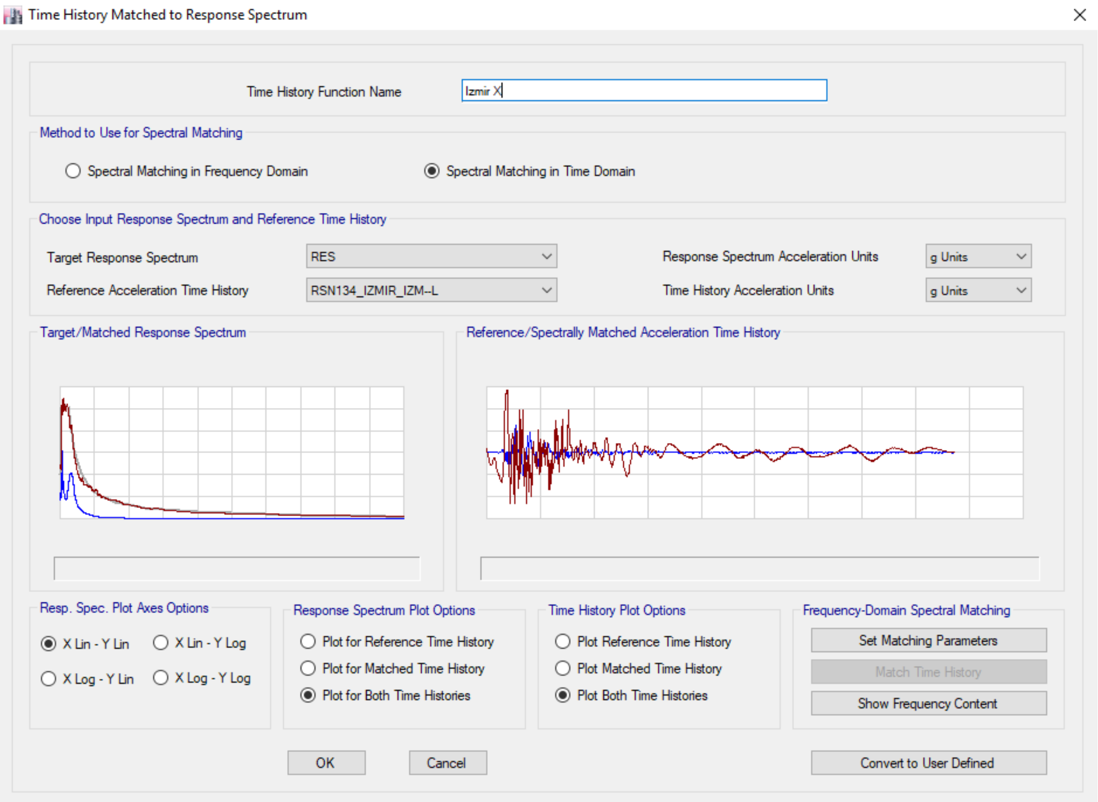
Function Points

Period	Acceleration
0	0.8568
0.0482	2.142
0.2409	2.142
0.4	1.29
0.6	0.86
0.8	0.645
1	0.516
1.2	0.43
1.4	0.3686
1.6	0.3225

Plot Options
● Linear X - Linear Y
○ Linear X - Log Y
○ Log X - Linear Y
○ Log X - Log Y

Figure 27: Defining the response spectrum of structural building according to TBEC-2018

Finally, earthquake functions and response spectrum of structures were matched together by using Time Domain method which will lead to the creation of new earthquake functions ready to be applied to the structural models as showed in Figure 28. In addition, modal load cases were defined according to Ritz-Vector analysis.


Time History Matched to Response Spectrum

Time History Function Name: Izmir X

Method to Use for Spectral Matching

○ Spectral Matching in Frequency Domain ● Spectral Matching in Time Domain

Choose Input Response Spectrum and Reference Time History

Target Response Spectrum: RES

Reference Acceleration Time History: RSN134_IZMIR_IZM--L

Response Spectrum Acceleration Units: g Units

Time History Acceleration Units: g Units

Resp. Spec. Plot Axes Options

● X Lin - Y Lin ○ X Lin - Y Log

○ X Log - Y Lin ○ X Log - Y Log

Response Spectrum Plot Options

○ Plot for Reference Time History

○ Plot for Matched Time History

● Plot for Both Time Histories

Time History Plot Options

○ Plot Reference Time History

○ Plot Matched Time History

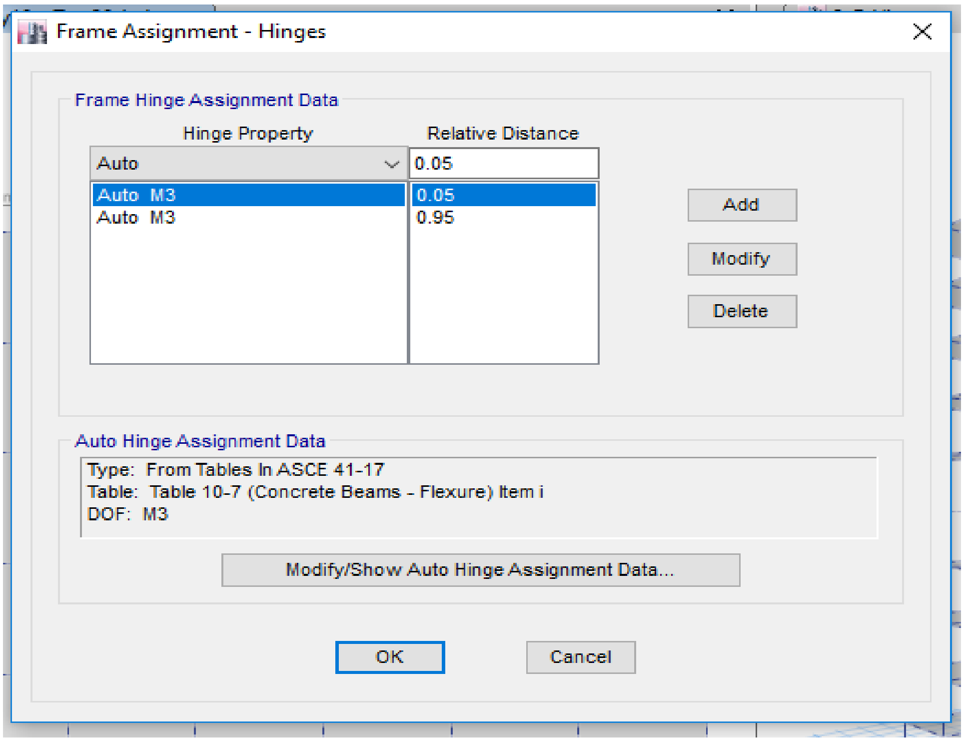
● Plot Both Time Histories

Figure 28: Matching response spectrum of structural model to the Izmir earthquake function in X direction

3.3.2 Pushover Analysis

This type of analysis is a nonlinear static analysis where the structural building is subjugated to a vertical load in addition to a progressively increasing horizontal loads till it reaches the collapse status. The static lateral loads are representing the earthquake forces so it is a kind of ground motion’s forces simulation. Pushover analysis consists of plotting base shear versus displacement. The plot’s purpose is to determine at the performance point the base shear along with displacement where the construction performance is checked out. Pushover Analysis was performed to check the number of hinges and their status at the performance point.

In this study, defining the combinations and the plastic hinges was performed in reference to FEMA 356 as illustrated in Figure 29. Combinations which are employed for the definition of vertical load applied to structural building in pushover analysis are 1.1DL + 1.1LL and 0.9DL. At the end, pushdown (vertical load) and pushX (lateral load) were defined as presented in Figure 30.



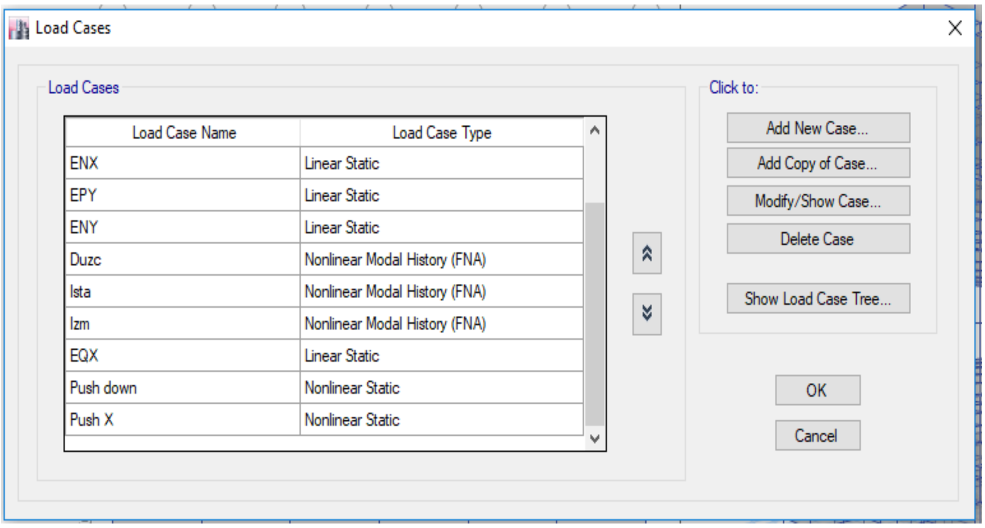
Frame Hinge Assignment Data

Hinge Property	Relative Distance
Auto	0.05
Auto M3	0.05
Auto M3	0.95

Auto Hinge Assignment Data

Type: From Tables In ASCE 41-17
Table: Table 10-7 (Concrete Beams - Flexure) Item i
DOF: M3

Figure 29: Defining beam hinges in ETABS 2017



Load Cases

Load Case Name	Load Case Type
ENX	Linear Static
EPY	Linear Static
ENY	Linear Static
Duzc	Nonlinear Modal History (FNA)
Ista	Nonlinear Modal History (FNA)
Izm	Nonlinear Modal History (FNA)
EQX	Linear Static
Push down	Nonlinear Static
Push X	Nonlinear Static

Figure 30: Vertical load definition (Push down) and lateral load definition (Push X) in the X direction in ETABS 2017

Chapter 4

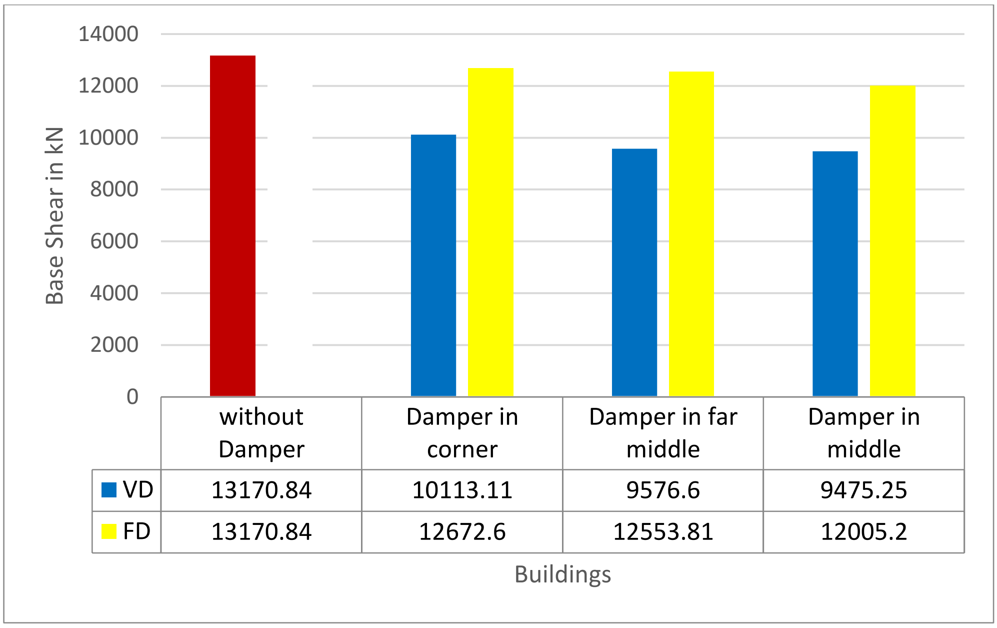
RESULTS AND DISCUSSIONS

4.1 General

In this section, the performance of buildings with viscous and friction dampers implemented in three different locations is compared in term of THA and pushover analysis. The section’s main aim is the determination of the damper type which has better performance for seismic response and the optimum location in outer structural frame where the damper has the best performance. This study is performed for buildings with five, ten and twenty stories in order to highlight the performance of each type of dampers with the increase of building height. Base shear, stories acceleration, roof displacement, kinetic-potential energy components and maximum inter-story drift were studied in THA. As stated before, in this study time history consisted of subjecting structural buildings with three different earthquakes records. Earthquake record which stimulates the maximum response of buildings in term of base shear, stories acceleration, roof displacement, kinetic-potential energy components and ultimate inter-story drift is employed in the analysis as stated by TBEC-2018. In pushover analysis, the number of hinges in different status (Immediate Occupancy, Life Safety and Collapse Prevention) is compared among different structural buildings at the performance point. ETABS 2017 Software was used for achieving the analysis.

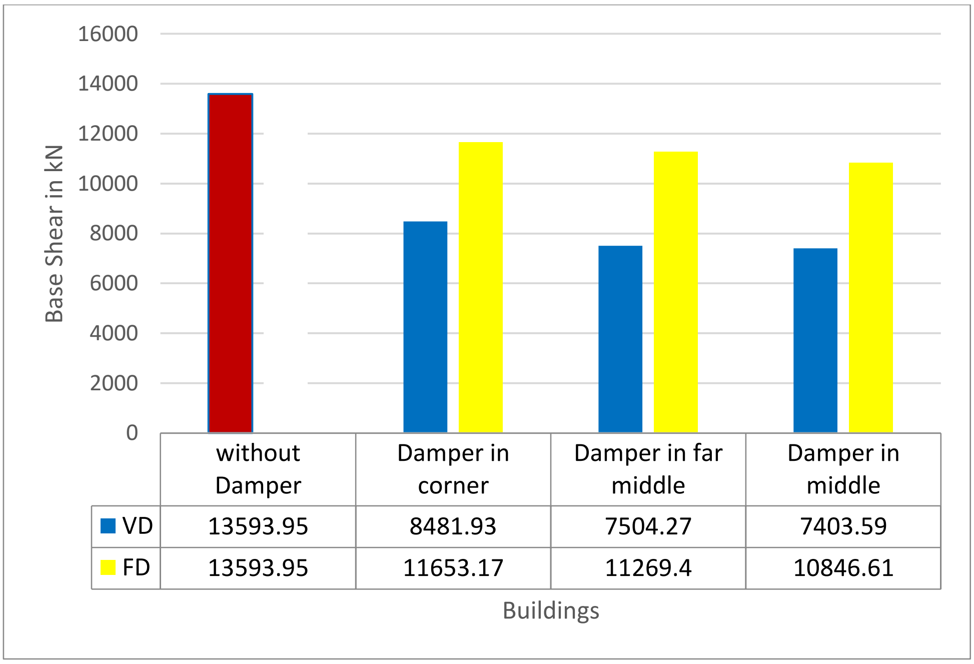
4.2 Time History Analysis

4.2.1 Base Shear



	without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	13170.84	10113.11	9576.6	9475.25
🟨 FD	13170.84	12672.6	12553.81	12005.2

Figure 31: Base Shear for five stories buildings in X direction



	without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	13593.95	8481.93	7504.27	7403.59
🟨 FD	13593.95	11653.17	11269.4	10846.61

Figure 32: Base Shear for five stories buildings in Y direction

In X direction, the base shear in building without damper was 13593.95 kN as illustrated in Figure 31. This value decreases obviously in buildings with VD to 8481.93 kN, 7504.27 kN and 7403.59 kN for VD placement in corner, far middle and middle positions respectively. In addition, it falls in buildings with FD to 11653.17 kN, 11269.40 kN and 10846.61 kN with damper placement in corner, far middle and middle position respectively. The amount of decrease of base shear in buildings with VD was higher than that of buildings with FD where base shear is minimized by 23, 27 and 28% for VD implementation in corner, far middle and middle position, respectively. However, it decreases to 3, 4 and 8% for FD implementation in corner, far middle and middle position, respectively. Buildings with Viscous dampers located in far middle and middle exhibited approximately same amount of base shear decrease which was higher than those with Viscous dampers located in corner position by 4 and 5%, respectively. However, for buildings with FD, the middle position exhibits better decrease in base shear than the far middle position by 1% only.

The same trend of variations was observed in Y direction as illustrated in Figure 32. Buildings with VD showed more decrease in base shear in the three different dampers position comparing to those with FD in the same positions (approximately the difference was ranged from 3000 to 4000 kN in each position). Moreover, far middle and middle dampers locations for buildings with VD exhibited better results than dampers position in the corner. In contrary for buildings with FD where the middle position shows better fall in base shear in comparison with far middle position.

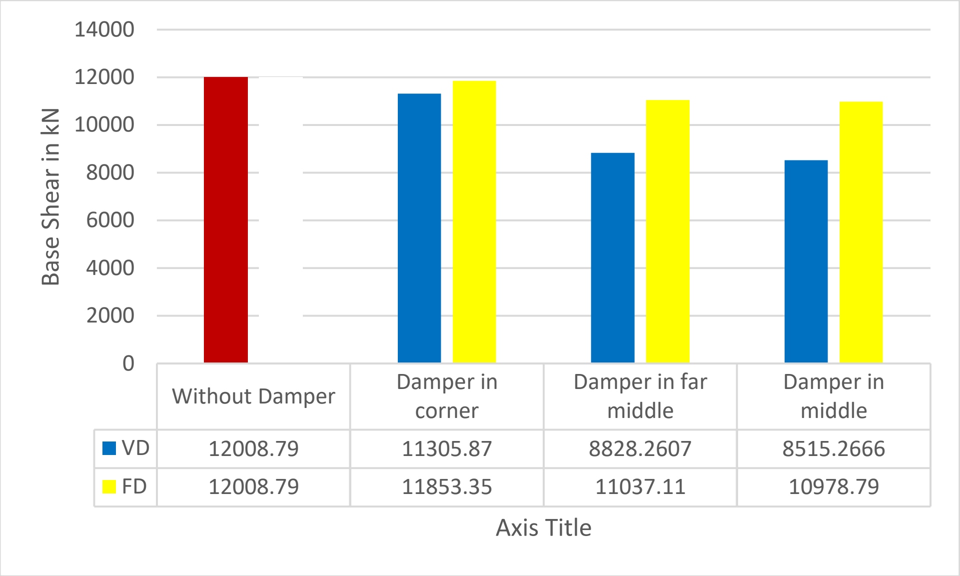


Figure 33: Base Shear of ten stories buildings in X direction

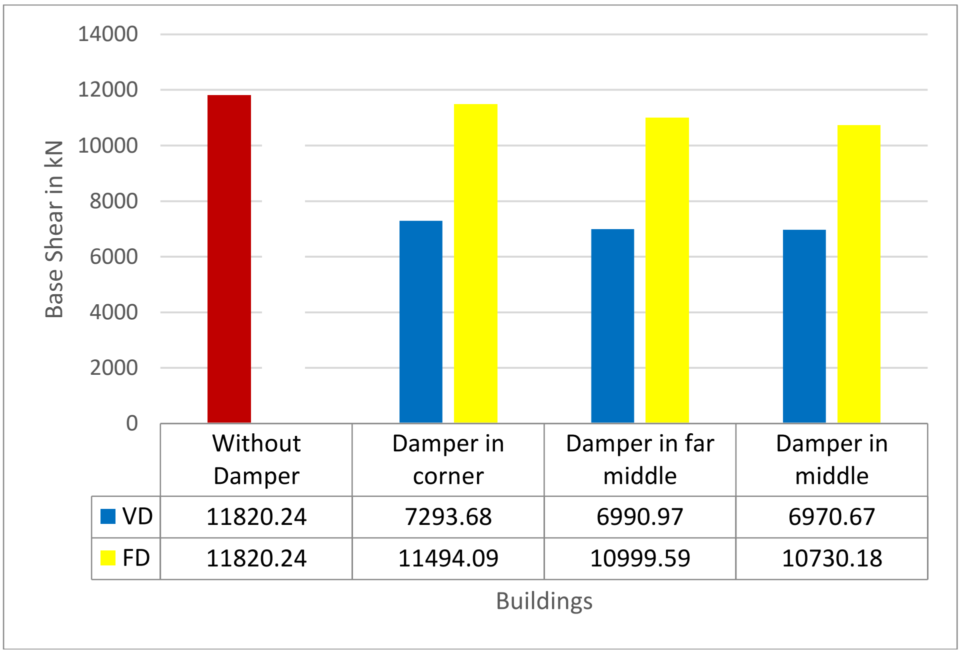
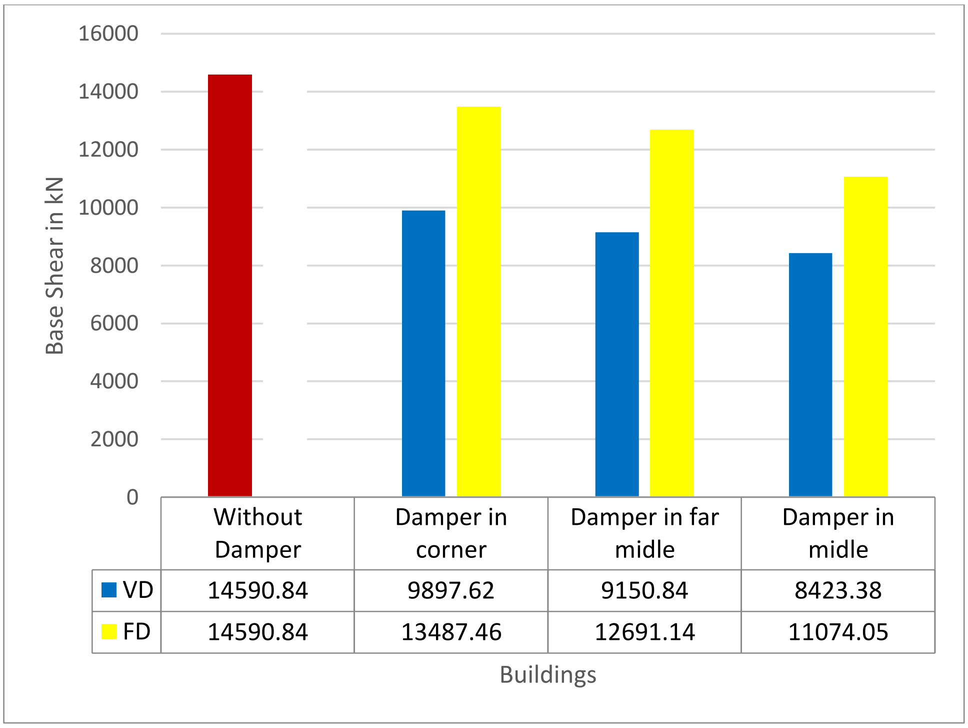


Figure 34: Base Shear in ten stories buildings in Y direction

For ten stories buildings as shown in Figure 33 and 34, the base shear in building without damper is 12008.79 kN and it falls to 10305.87 kN, 8828.26 kN and 8015.27 kN for VD locations in corner, far middle and middle respectively in X direction. It decreases from 11820.24 kN to 7293.68 kN, 6990.97 kN and 6970.67 kN for VD locations in corner, far middle and middle respectively in Y direction. For ten stories buildings with FD, base shear falls from 12008.79 kN in the one without damper to 11853.34 kN, 11037.10 kN and 10978.79 kN for FD positions in corner, far middle and middle respectively in X direction. In Y direction, base shear falls from 11820.24 kN in building without damper to 10494.09 kN, 9980.59 kN and 9730.18 kN for FD locations in corner, far middle and middle respectively. Similarly, to five stories buildings, the ones with VD perform higher decrease in base shear comparing to the ones with FD where the variation in base shear decrease in X direction was 1, 16 and 21% and 2, 33 and 32% in Y direction for dampers placement in corner, far middle and middle position. However, there is an obvious difference in base shear decrease between VD implemented in far middle and middle position in X directions where the last exhibits better performance. Contrary the ones in Y direction VD implemented in the two positions showed approximately same amount of base shear reduction.



	Without Damper	Damper in corner	Damper in far midle	Damper in midle
🟦 VD	14590.84	9897.62	9150.84	8423.38
🟨 FD	14590.84	13487.46	12691.14	11074.05

Figure 35: Base Shear of twenty stories buildings in X direction

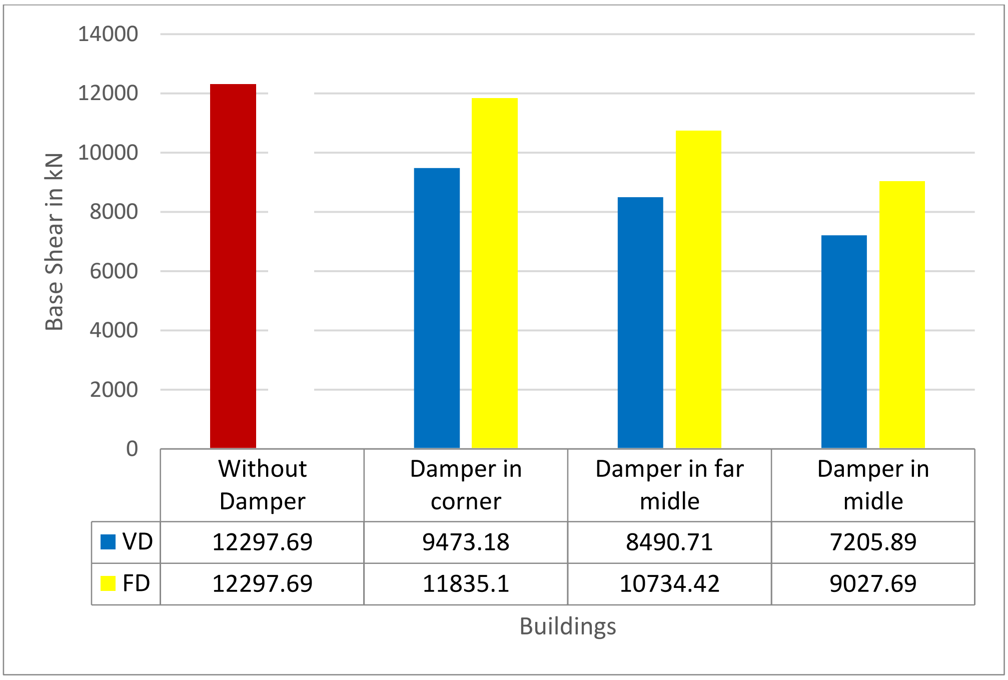


Figure 36: Base Shear of twenty stories buildings in Y direction

For twenty stories buildings, as presented in Figure 35 and 36, base shear is reduced from 14590.84 kN for building without damper to 9897.6185 kN, 9150.84kN and 8423.38 kN for buildings with VD in corner, far middle and middle locations respectively, to 13487.4606 KN, 12691.14 kN and 11074.05 kN for buildings with FD in corner, far middle and middle positions respectively in X direction. In addition, base shear is minimized from 12297.69 kN for building without damper to 9473.18 kN, 8490.71 kN and 7205.89 kN for buildings with VD in corner, far middle and middle locations respectively, to 11835.10 kN, 10734.42 kN and 9027.69 kN for buildings with FD in corner, far middle and middle positions respectively in Y direction. Identically to other sets of previous buildings, the minimization of base shear in buildings with VD was far superior than those with FD. However, the main difference in twenty stories buildings is that the amount of base shear reduction in buildings with VD and FD in middle position is obviously exceeding those with VD and FD in far middle position in both directions which make the middle position the best position in term of decreasing the base shear. The minimization of base shear when dampers are implied is because of their ability in dissipating earthquakes energy.

4.2.2 Stories Acceleration

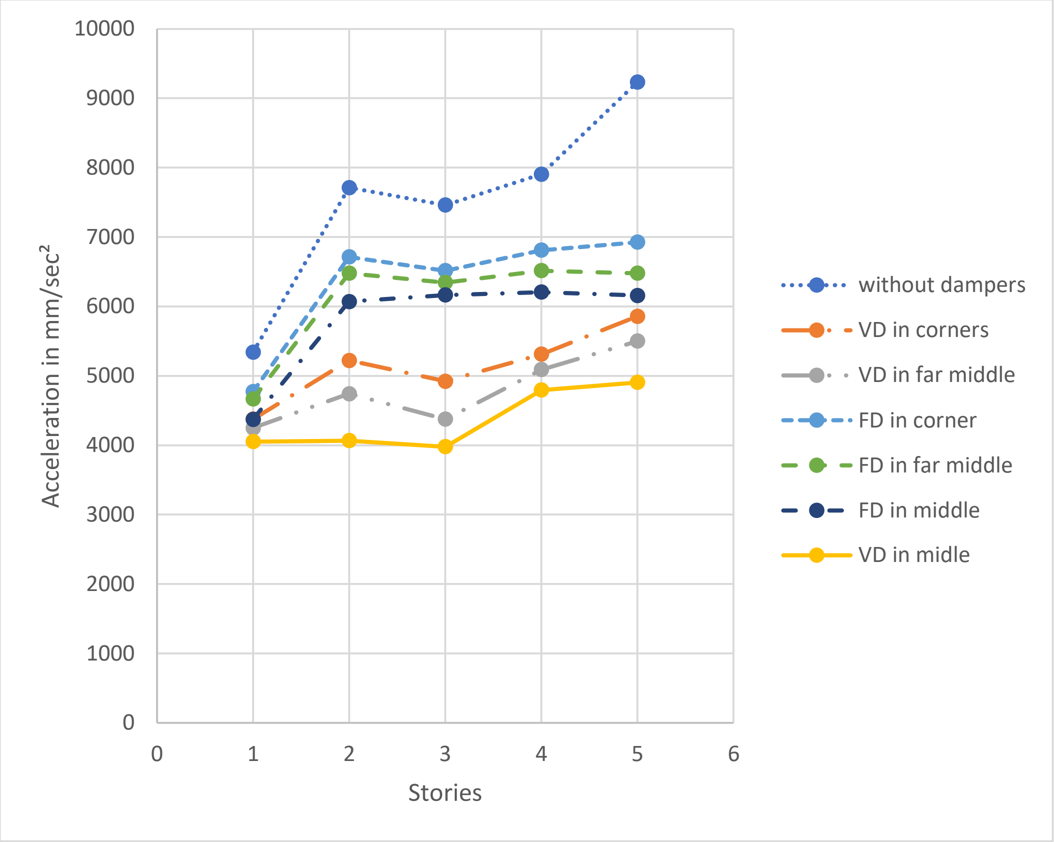


Figure 37: Stories Acceleration for five stories buildings in X direction

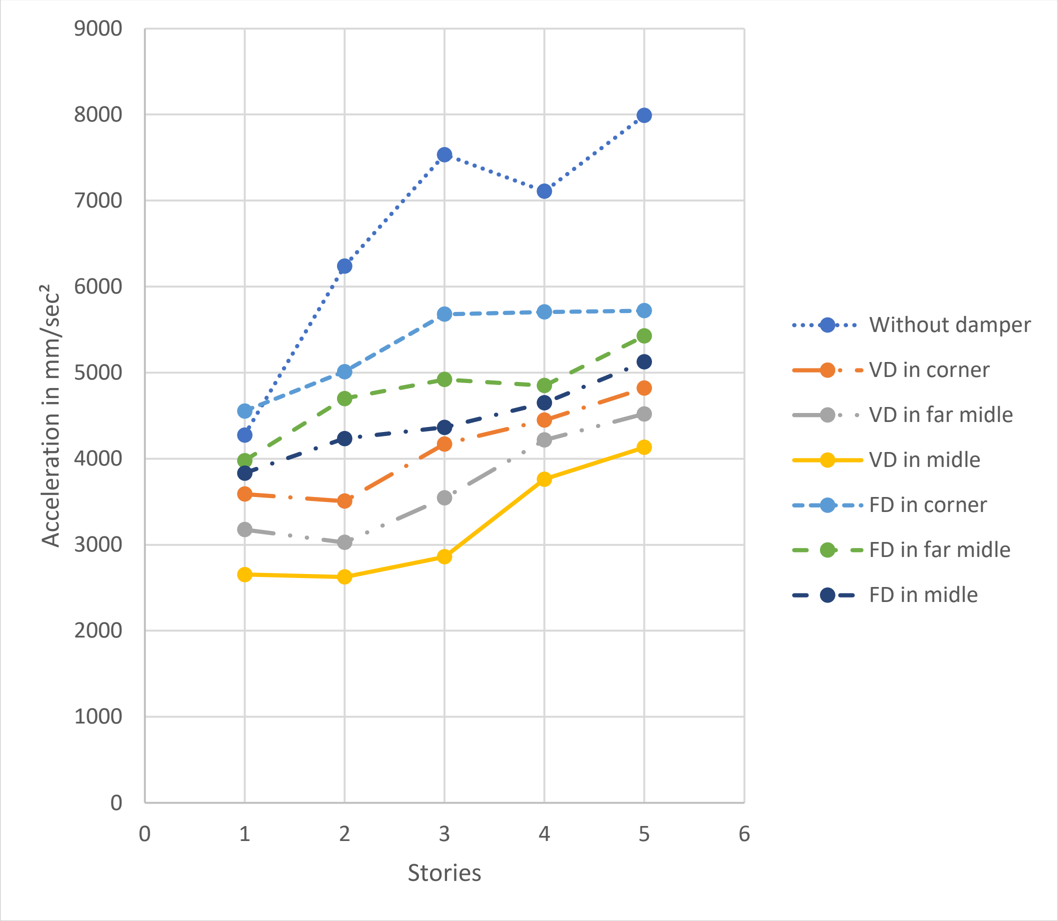


Figure 38: Stories Acceleration for five stories buildings in Y direction

For both directions as presented in Figure 37 and 38, the acceleration in building without damper was higher than those with VD and FD in all five stories except in the first floor in Y direction where the acceleration of building with FD in corner in the first floor is slightly higher than that without damper (the acceleration in the first floor of FD building in corner is 4553.63 mm/sec² and without damper is 4275.52 mm/sec²). It is noticeable that the acceleration in buildings with FD is higher than those with VD in both directions. Furthermore, building with VD in middle position exhibits better performance in reducing the acceleration comparing to buildings with VD in other two positions where the variation of acceleration fluctuates between 4051.27 mm/sec² in first floor to 4905.61 mm/sec² in the fifth floor in building with VD in middle position in X direction and from 2654.08 mm/sec² in first floor to 4132.87 mm/sec² in the fifth floor in Y direction. Similarly, for buildings with FD, dampers placed in middle position show better acceleration minimization comparing to the other two positions. In that position, acceleration fluctuates from 4371.55 mm/sec² in first floor to 6157.31 mm/sec² in fifth floor in X direction and from 3833.63 mm/sec² in first floor to 5124.88 mm/sec² in the fifth floor in Y direction.

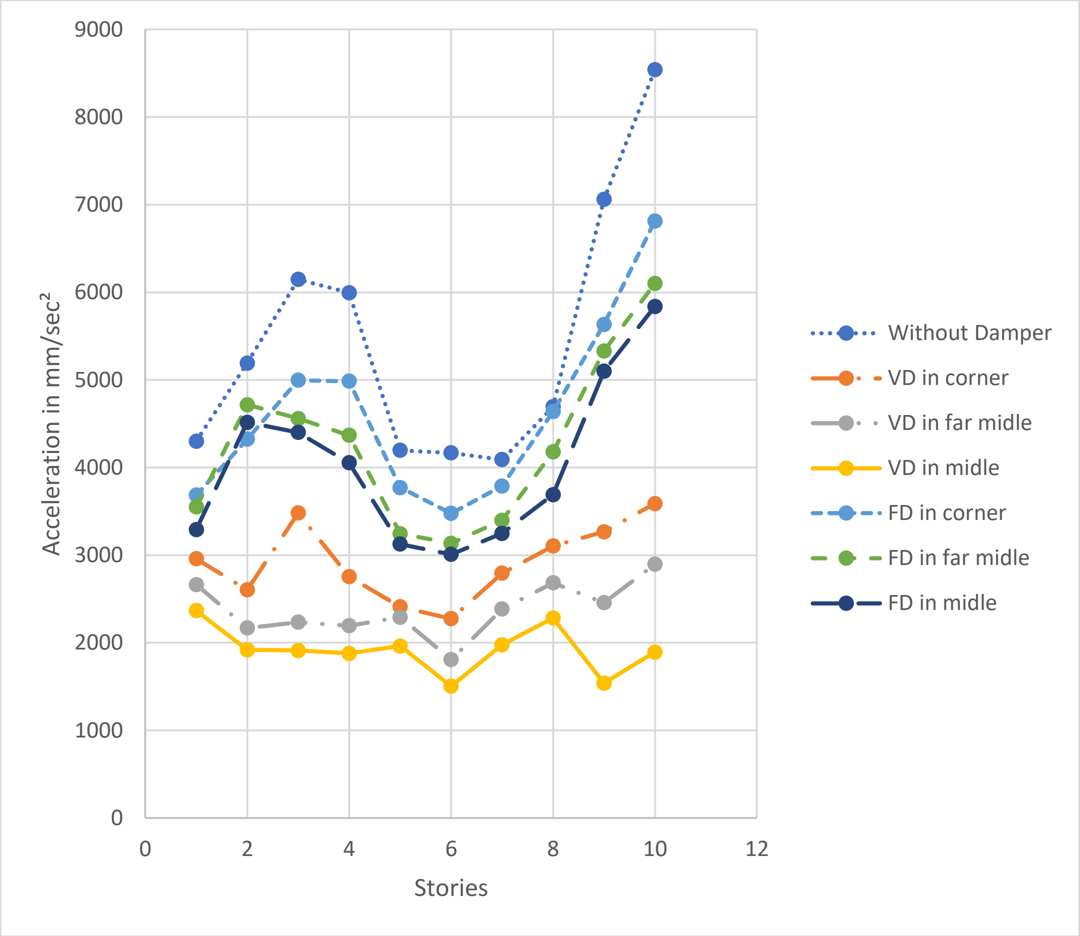


Figure 39: Stories Acceleration for ten stories buildings in X direction

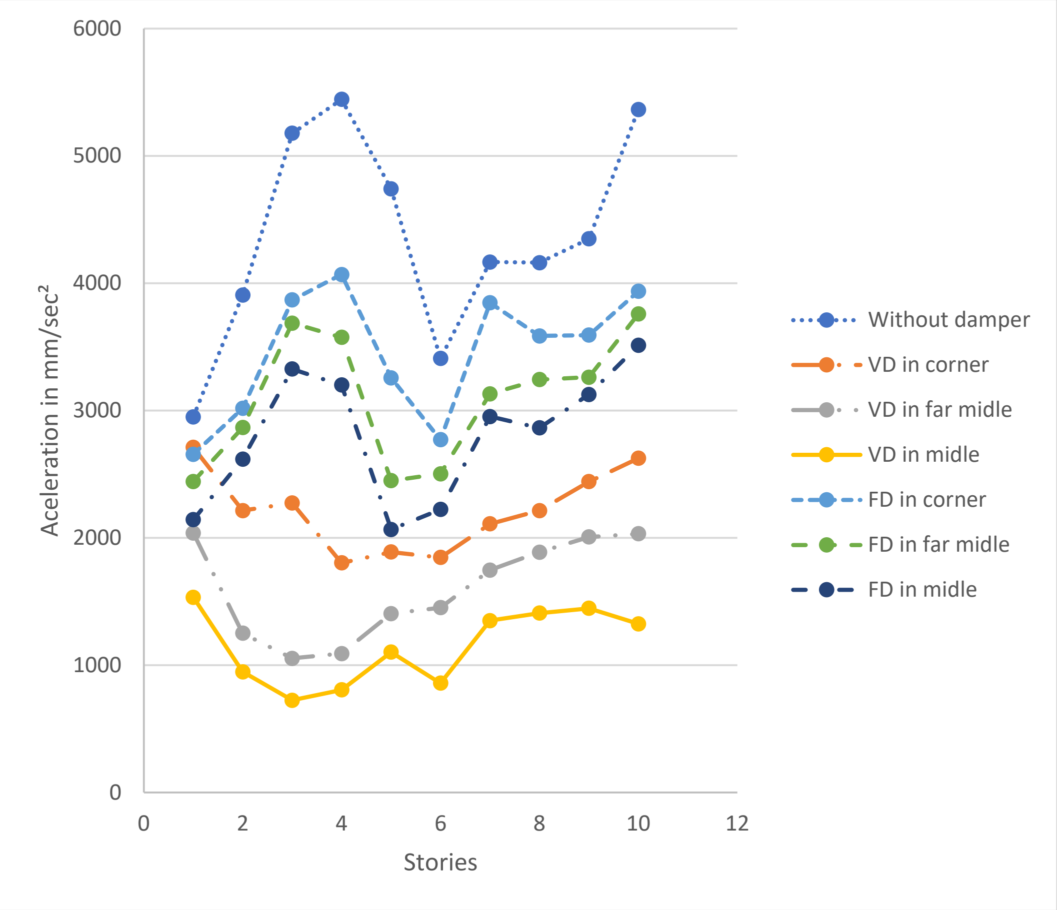


Figure 40: Stories Acceleration for ten stories buildings in Y direction

In both directions as shown in Figure 39 and 40, buildings with VD perform better reduction in acceleration comparing to those with FD specially when VD is placed in middle position. For buildings with FD, also the middle position of damper implementation achieves a slightly higher decrease in acceleration. However, in Y direction, buildings with FD exhibit more minimization in acceleration than building with VD in corner position only in the first story.

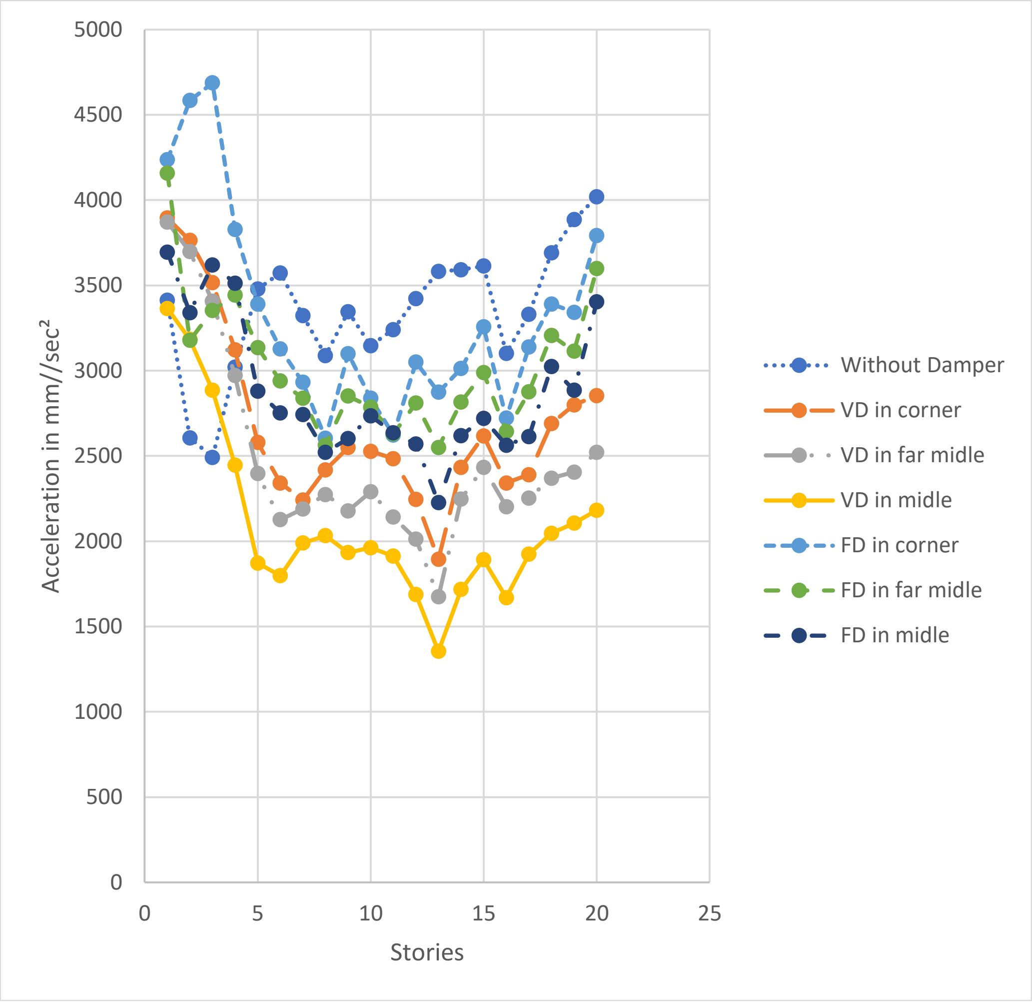


Figure 41: Stories Acceleration for twenty stories buildings in X direction

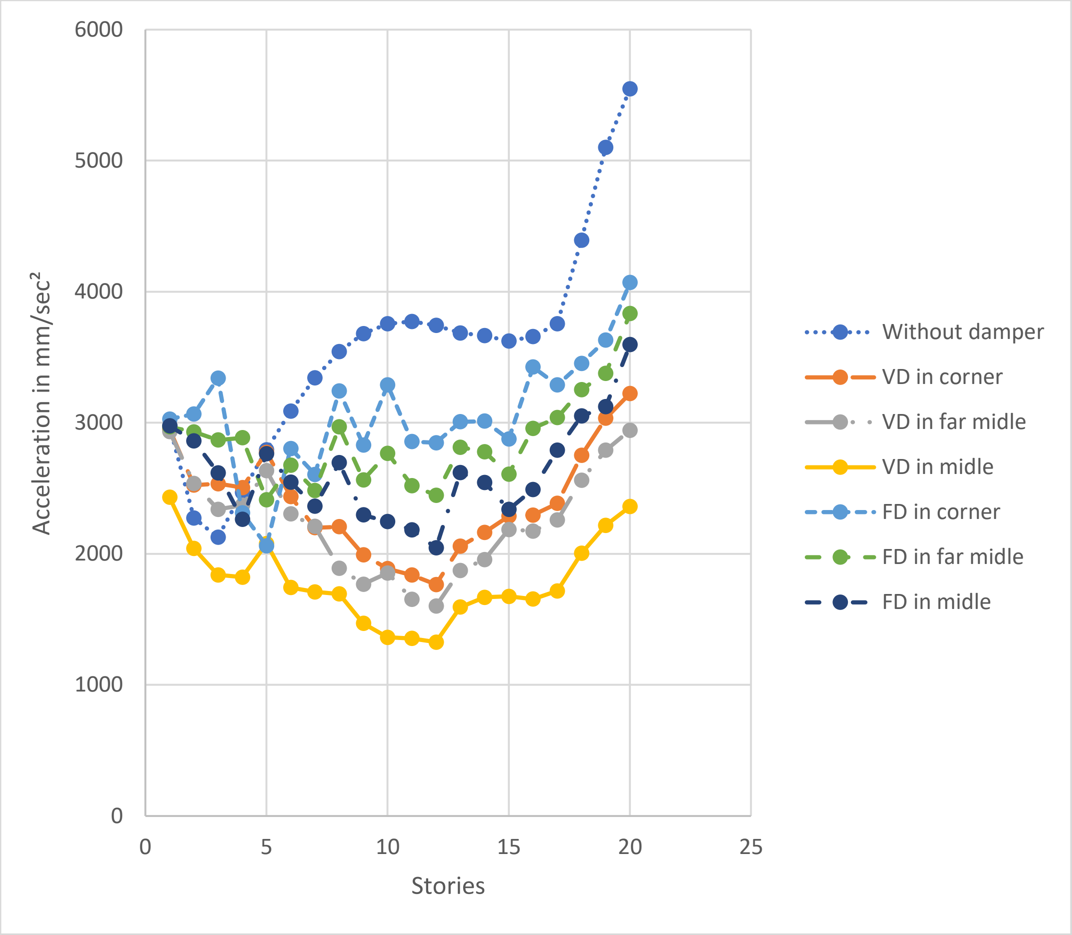
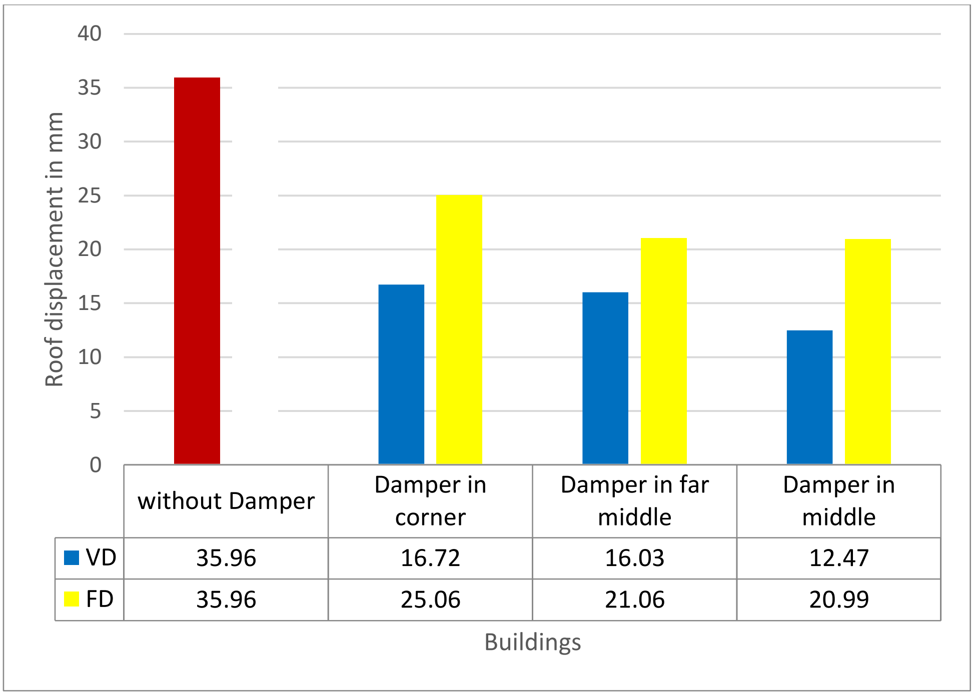


Figure 42: Stories Acceleration for twenty stories buildings in Y direction

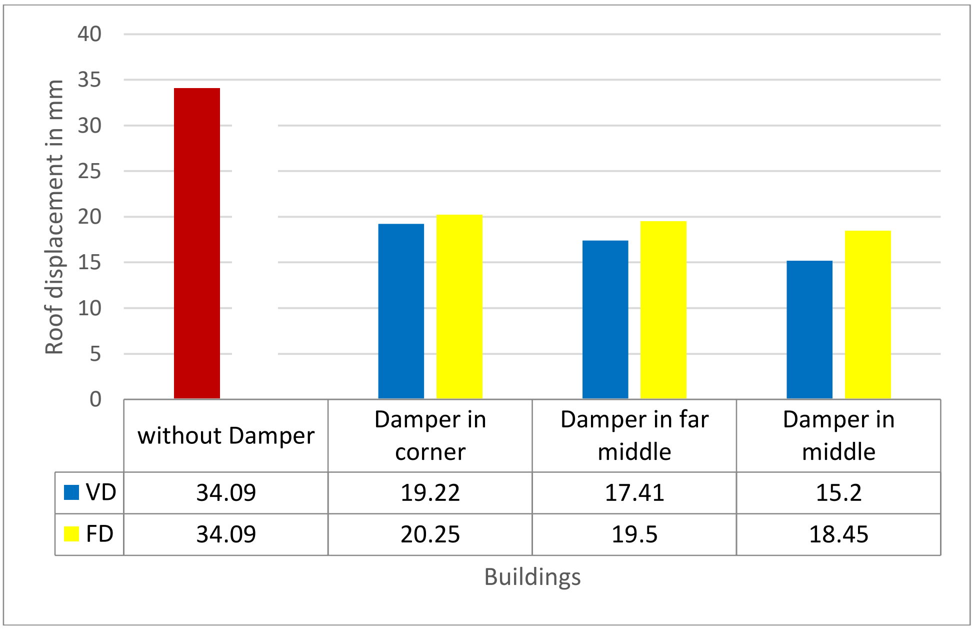
In X direction, according to Figure 41 building without dampers exhibits the least acceleration in the first three stories (3413.51 mm/sec², 2605.68 mm/sec² and 2491.56 mm/sec² in first, second and third story respectively). Later on, its acceleration become the highest comparing to buildings with VD and FD, especially at the fifth floor. Generally, the amount of acceleration minimization was higher in buildings with VD comparing to those with FD. It is noticeable that building with VD in middle position achieve the highest reduction in acceleration comparing to those with VD located in other positions. Similar variation is observed in Y direction as illustrated in Figure 42, but in the first five floors, except for building with VD in middle position, the variation of acceleration was excessive in a way that the behavior of buildings in term of acceleration reduction was not constant. The acceleration decreased in buildings with dampers due to the capability of VD and FD in squandering ground motion’s energy.

4.2.3 Roof Displacement



	without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	35.96	16.72	16.03	12.47
🟨 FD	35.96	25.06	21.06	20.99

Figure 43: Roof displacement for five stories buildings in X direction

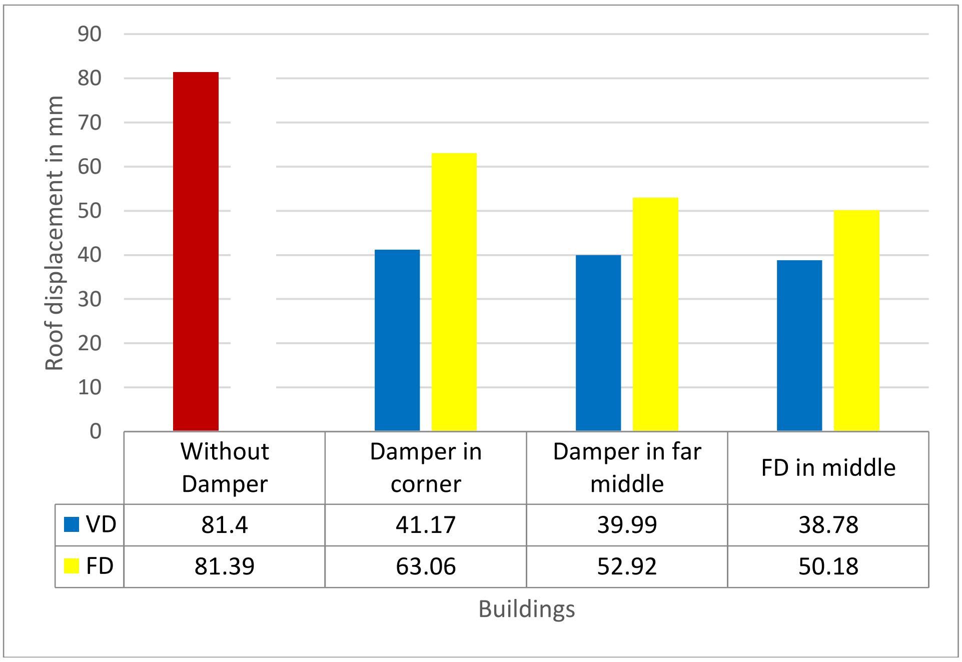


	without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	34.09	19.22	17.41	15.2
🟨 FD	34.09	20.25	19.5	18.45

Figure 44: Roof Displacement for five stories buildings in Y direction

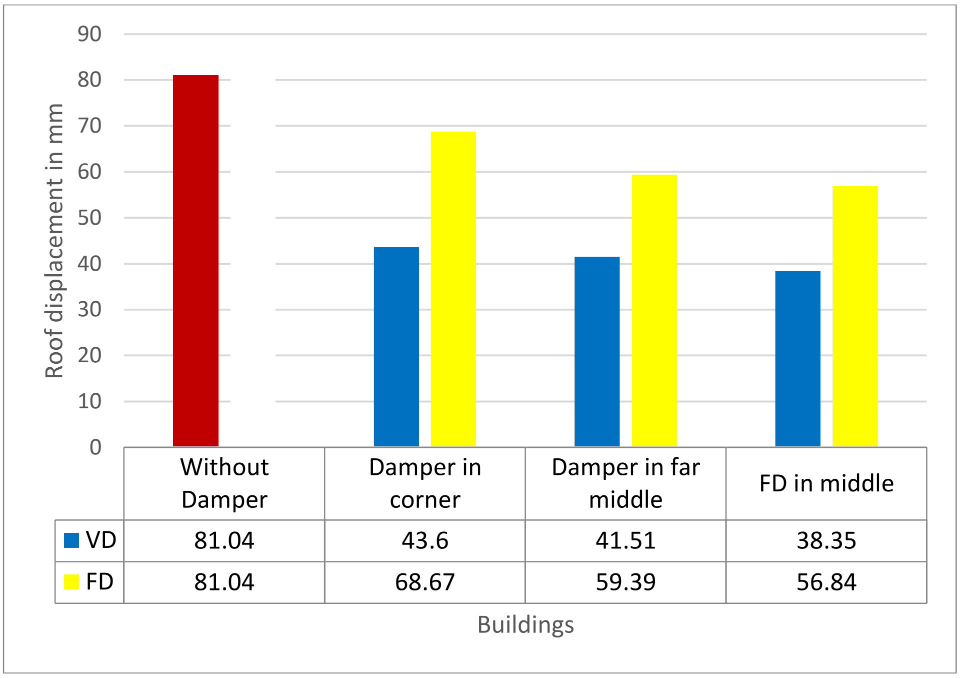
In X direction, building roof displacement without damper is 35.96 mm, this value falls to 16.72, 16.03 and 12.47 mm in buildings with VD in corner, far middle and middle positions respectively. Approximately, the roof displacement decrease to 50% in buildings with VD. However, this reduction in roof displacement was not similar for buildings with FD. The value of roof displacement decreases to 25.06, 21.06 and 20.99 mm in buildings with FD in corner, far middle and middle position respectively. Furthermore, the location of VD and FD does not affect the amount of roof displacement critically.

Similarly, in Y direction, buildings with VD exhibits higher minimization in roof displacement comparing to those with FD and the variation of dampers position did not significantly affect the decreased in roof displacement.



	Without Damper	Damper in corner	Damper in far middle	FD in middle
🟦 VD	81.4	41.17	39.99	38.78
🟨 FD	81.39	63.06	52.92	50.18

Figure 45: Roof Displacement of ten stories buildings in X direction

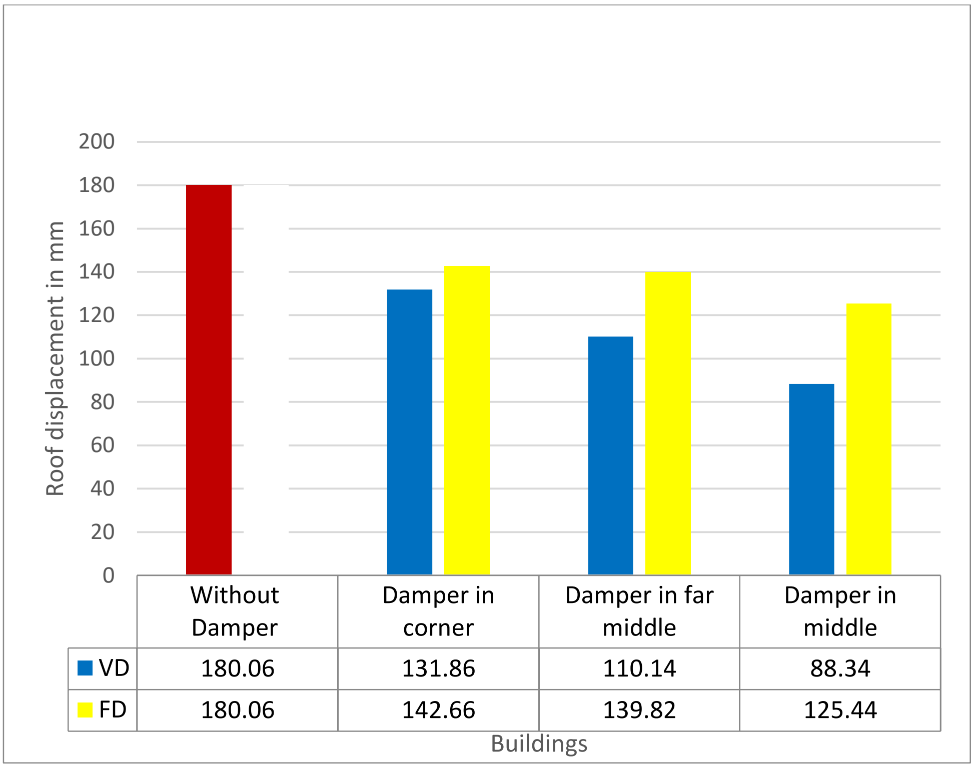


	Without Damper	Damper in corner	Damper in far middle	FD in middle
🟦 VD	81.04	43.6	41.51	38.35
🟨 FD	81.04	68.67	59.39	56.84

Figure 46: Roof Displacement of ten stories buildings in Y direction

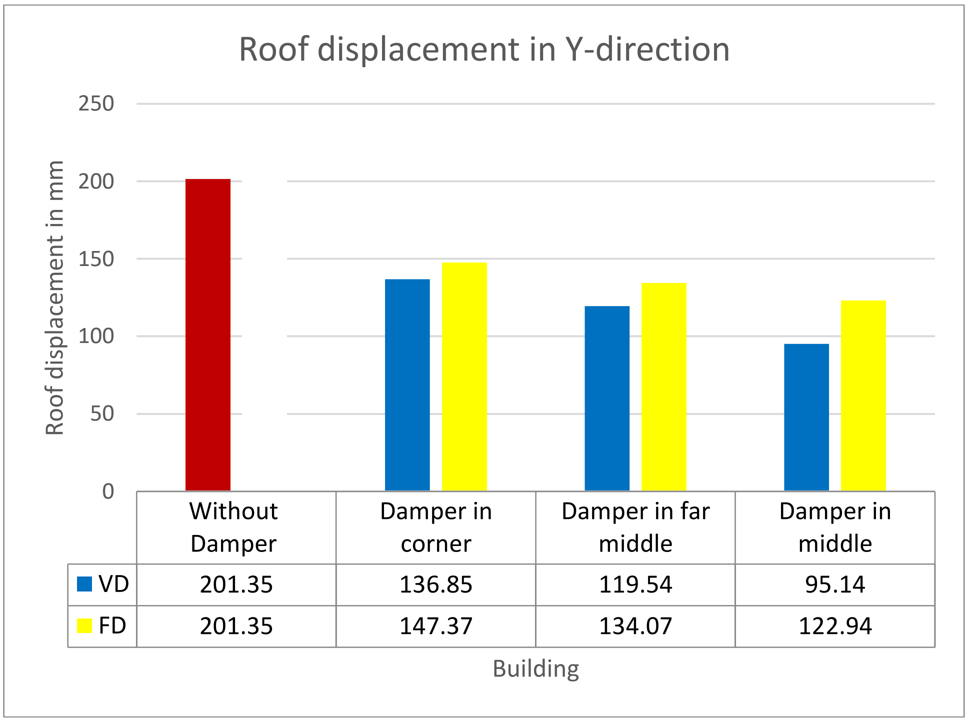
For ten stories buildings, roof displacement is minimized from 81.39 mm in building without damper to 41.17, 39.988 and 35.78 mm in buildings with VD in corner, far middle and middle positions, respectively and to 63.06, 52.92 and 50.18 mm in buildings with FD in corner, far middle and middle locations, respectively in X direction. It is noticeable that for ten stories buildings the performance of buildings with VD and FD in reducing the roof displacement became more different from each other where the percentage of roof displacement reduction in VD buildings became higher than those with FD comparing to the results of five stories buildings. In addition, VD in middle position exhibits clearly more minimization in roof displacement where it exceeds 50% comparing to building without damper.

The same conclusion can be drawn in Y direction, the difference in roof displacement reduction between buildings with VD and FD became higher comparing to those of five stories and the middle position of damper placement exhibits better performance in reducing roof displacement comparing to dampers installation in other position.



	Without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	180.06	131.86	110.14	88.34
🟨 FD	180.06	142.66	139.82	125.44

Figure 47: Roof Displacement for twenty stories buildings in X direction

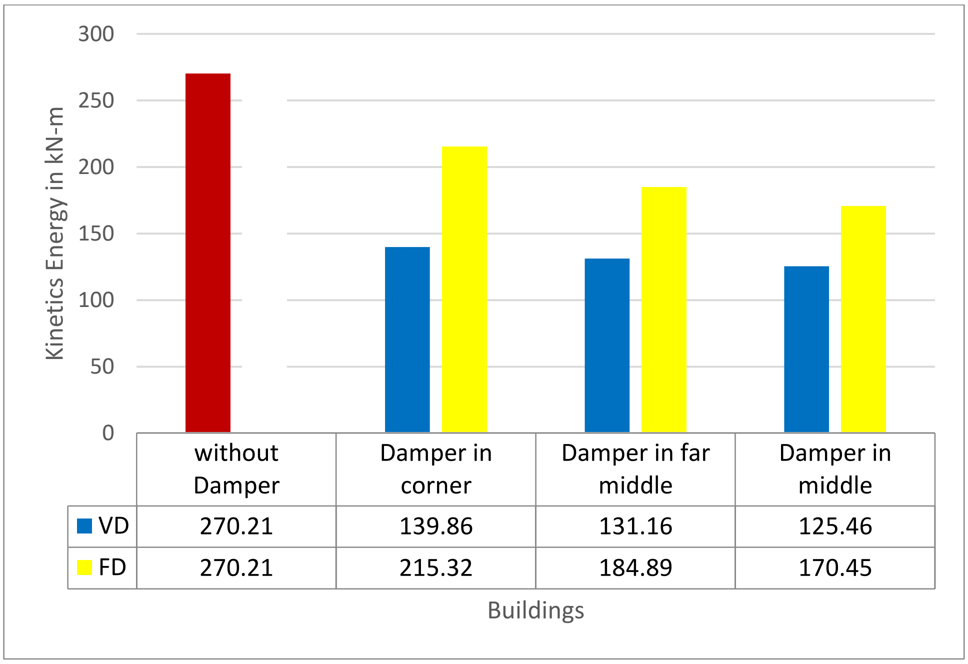


	Without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	201.35	136.85	119.54	95.14
🟨 FD	201.35	147.37	134.07	122.94

Figure 48: Roof Displacement for twenty stories buildings in Y direction

Similarly, to the sets of ten stories buildings, the minimization of roof displacement in buildings with VD is higher than those with FD. Moreover, buildings with VD and FD in middle position exhibits more reduction in roof displacement comparing to others in corner and far middle positions. For example, for both direction, roof displacement decrease more than 50% in buildings with VD in middle position comparing to the one without damper.

4.2.4 Kinetic-Potential Energy Component



	without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	270.21	139.86	131.16	125.46
🟨 FD	270.21	215.32	184.89	170.45

Figure 49: Kinetic Energy Component for five stories buildings

Kinetic energy generated from earthquakes is responsible for the displacement of the structural buildings and potential energy generated from earthquake is responsible for elastic deflection of structural members. The maximum kinetic energy produced by the three earthquakes records in five stories building without damper is 270.21 kN-m. This value falls to 139.86, 131.16 and 125.46 kN-m in buildings with VD installed in corner, far middle and middle position, respectively. It is obvious that when VD is placed in middle position, the amount of kinetics energy dissipation become the highest where it is more than 50% comparing to the one without damper. However, the rate of kinetics energy dissipation was far less in buildings with FD where kinetics energy decreases from 270.21 kN-m in building without damper to 215.32, 184.89 and 170.45 kN-m for FD placement in corner, far middle and middle locations, respectively. In addition, for buildings with FD, the middle position exhibits higher kinetics energy dissipation comparing to FD placement in other position.

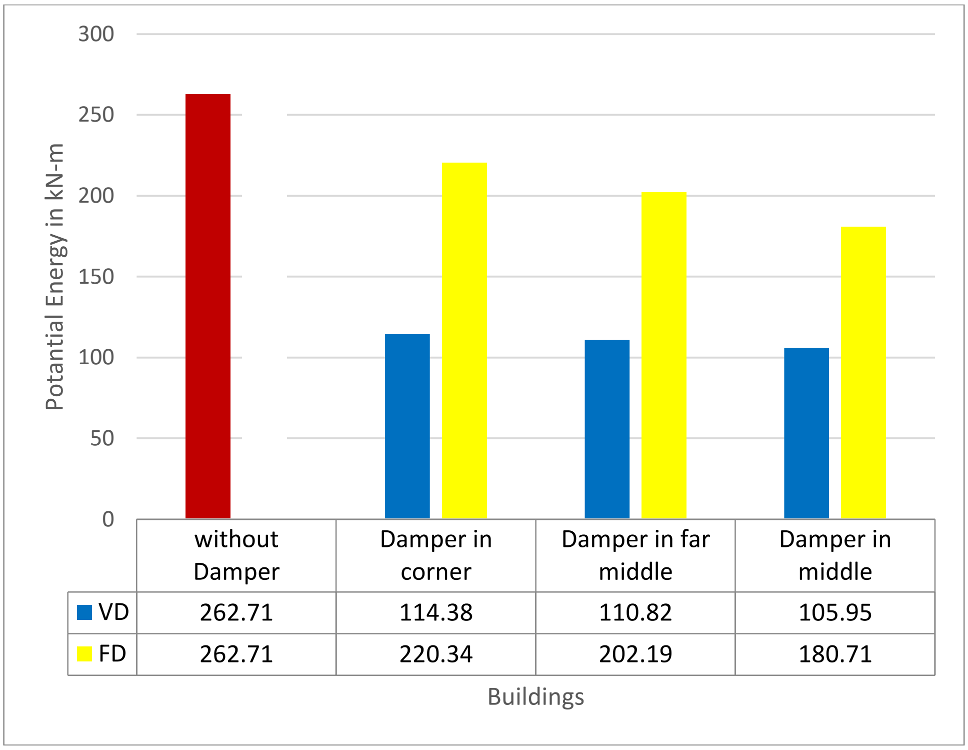


Figure 50: Potential Energy component for five stories buildings

The maximum potential energy produced by the three earthquakes records in five stories building without damper is 262.71 kN-m. Potential energy dissipation rate was higher in buildings with VD where it decreases to 114.38, 110.82 and 105.95 kN-m for VD installment in corner, far middle and middle position, respectively. However, for buildings with FD, it falls to 220.34, 202.19 and 180.71 kN-m for FD installment in corner, far middle and middle locations, respectively. For buildings with VD, the difference of potential energy dissipation rate between VD installment in different position is not critical as those with FD where the middle position of FD installment achieves higher rate of potential energy dissipation.

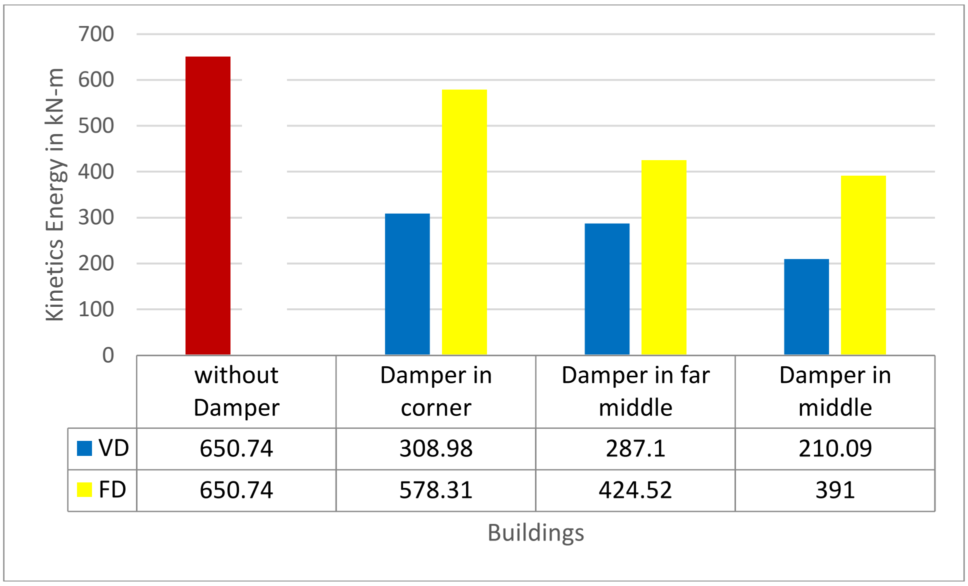


Figure 51: Kinetics Energy components for ten stories buildings

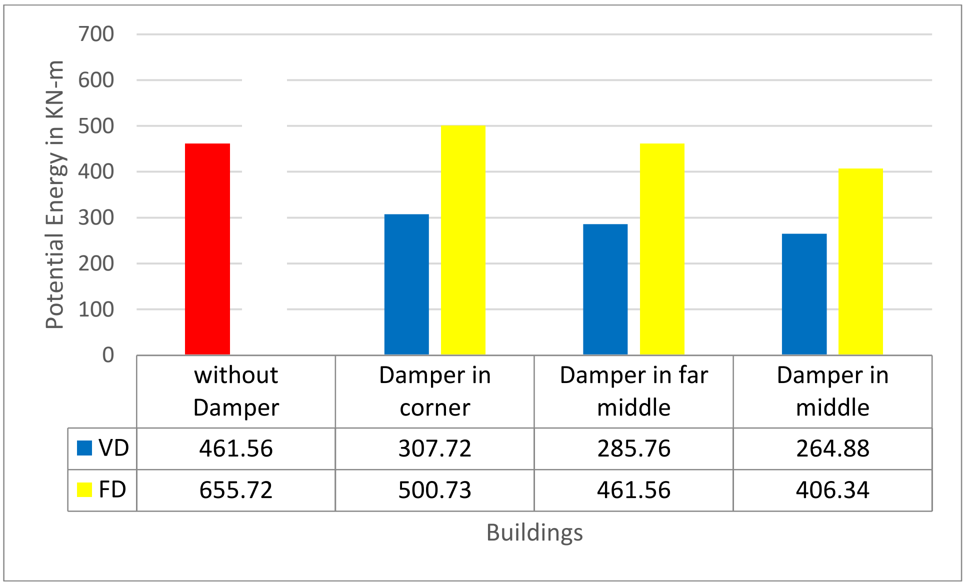


Figure 52: Potential Energy components for ten stories buildings

Similarly, to five stories buildings, the rate of kinetics and potential energy dissipation in buildings with VD is far higher than those with FD. Moreover, the placement of VD and FD in middle position exhibits best performance in term of dissipating both kinetic and potential energy. For instance, kinetics and potential energy falls for more than two third of their original values (in building without damper) when VD is installed in middle position where the first one decreases from 650.74 kN-m to 210.0897 kN-m and the second one decreases from 655.72 kN-m to 264.88 kN-m.

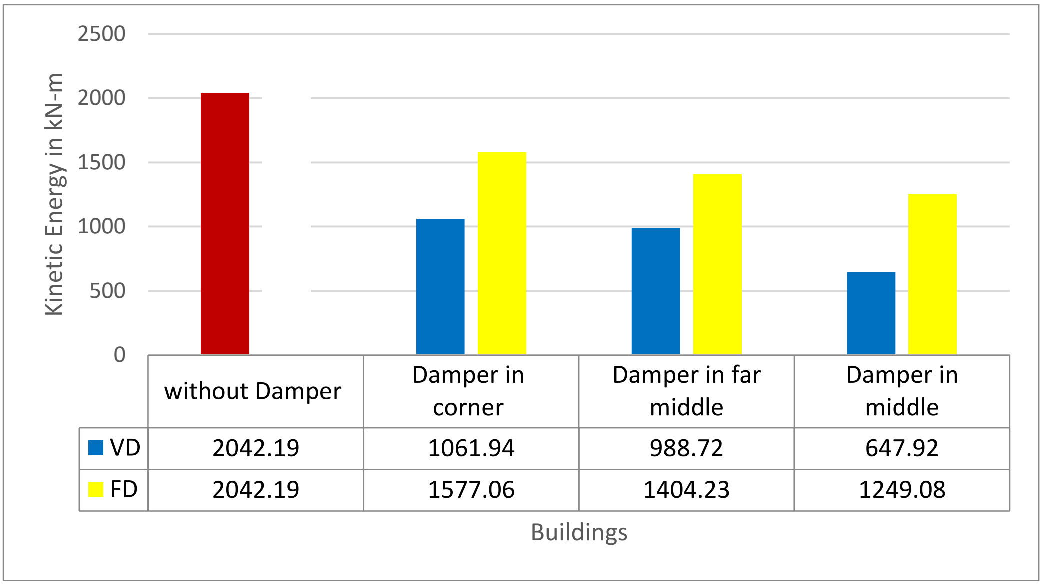


Figure 53: Kinetics Energy components for twenty stories buildings

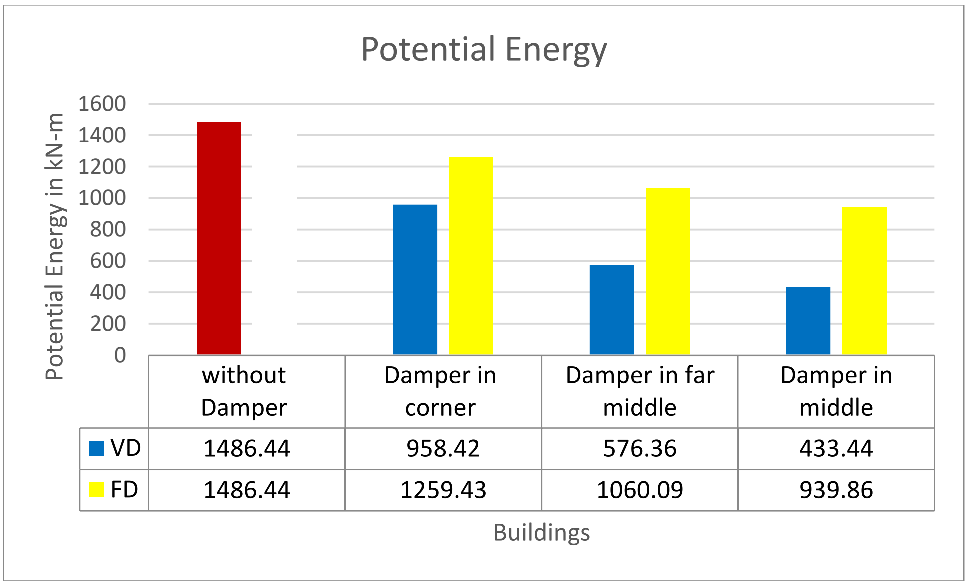
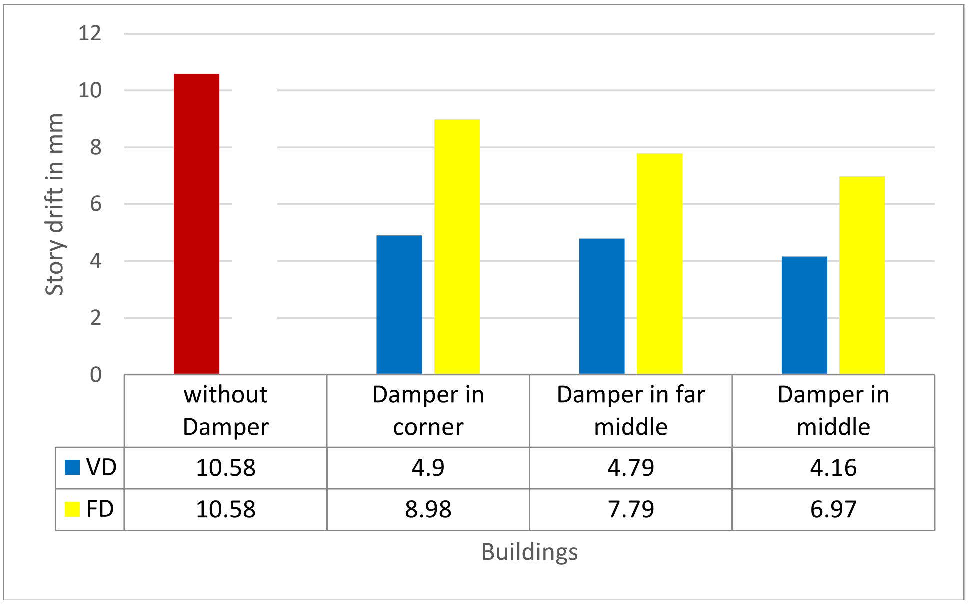


Figure 54: Potential Energy components for twenty stories buildings

Identically to the behavior of ten stories buildings in dissipating kinetics and potential energies. Buildings with VD exhibits dramatically higher rate of kinetics and potential energy dissipation comparing to those with FD. Moreover, middle position of VD and

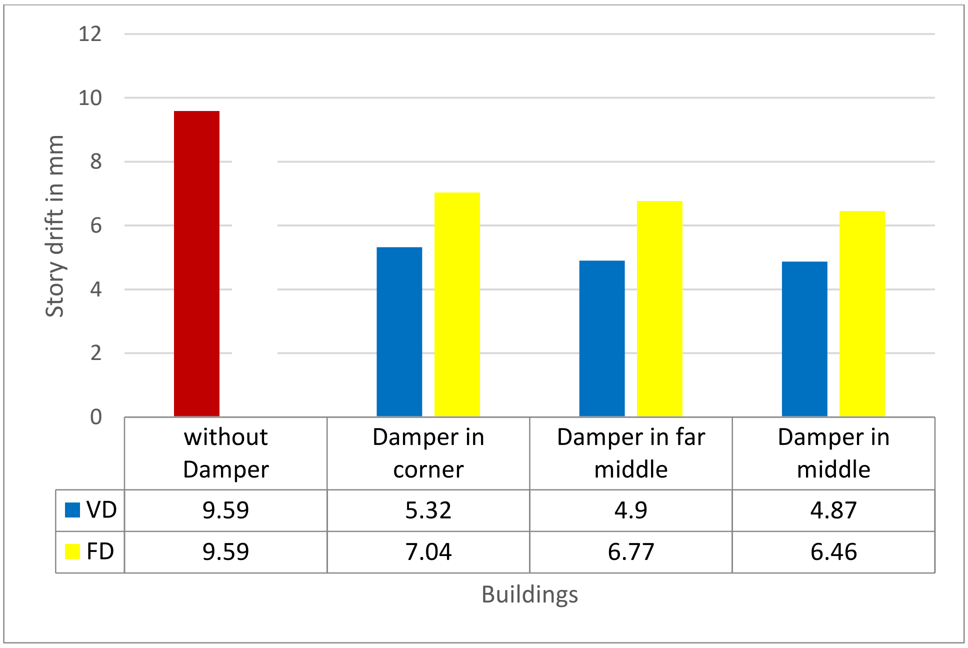
FD leads to higher percentage in dissipating kinetics and potential energy comparing to same type of damper implemented in other positions.

4.2.5 Maximum Inter-Story Drift



	without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	10.58	4.9	4.79	4.16
🟨 FD	10.58	8.98	7.79	6.97

Figure 55: Maximum Inter-story drift for five stories buildings in X direction



	without Damper	Damper in corner	Damper in far middle	Damper in middle
🟦 VD	9.59	5.32	4.9	4.87
🟨 FD	9.59	7.04	6.77	6.46

Figure 56: Maximum Inter-story drift for five stories buildings in Y direction

In X direction, maximum inter-story drift decrease from 10.58 mm in building without damper to 4.90, 4.79 and 4.16 mm in buildings with VD in corner, far middle and middle position, respectively. In addition, it falls to 8.98, 7.79 and 6.97 mm in buildings with FD in corner, far middle and middle position, respectively. In Y direction, maximum inter-story drift decrease from 9.585 mm in building without damper to 5.32, 4.90 and 4.87 mm in buildings with VD in corner, far middle and middle position, respectively. In addition, it falls to 7.04, 6.77 and 6.46 mm in buildings with FD in corner, far middle and middle position, respectively. Maximum inter-story drift is reduced more in buildings with VD comparing to those with FD.

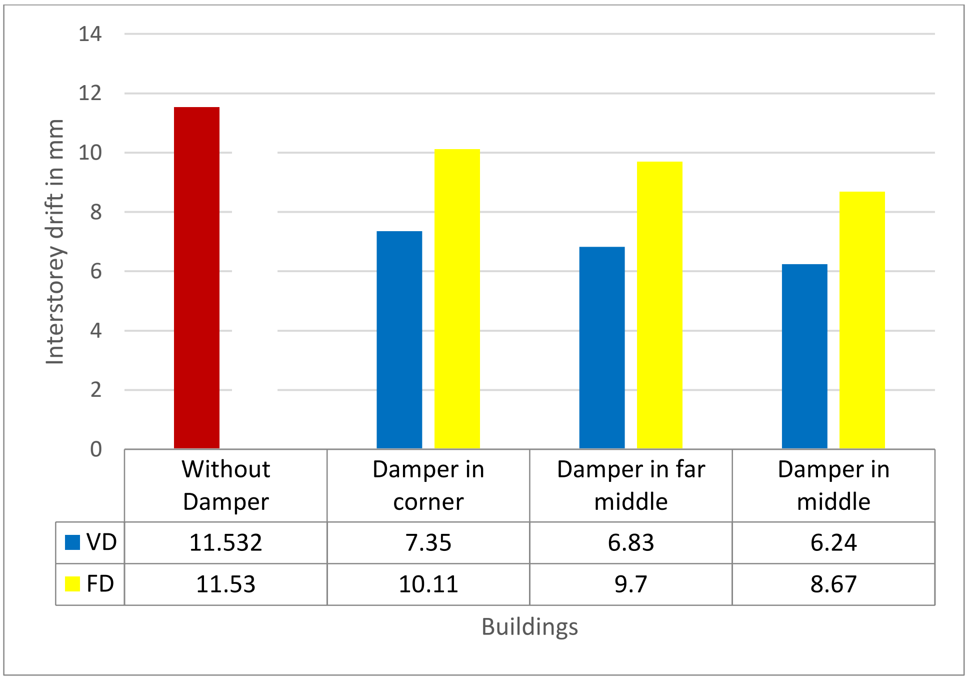


Figure 57: Maximum Inter-story drift for ten stories buildings in X direction

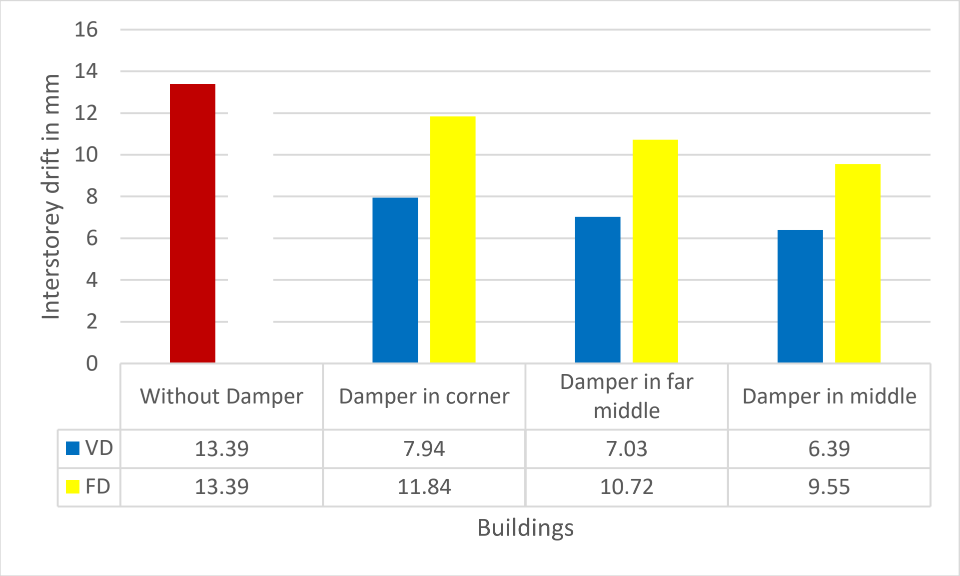


Figure 58: Maximum Inter-story drift for ten stories buildings in Y direction

According to Figure 56 and 57, similarly for five stories buildings the amount of maximum inter-story drift reduction in buildings with VD is higher than that in buildings with FD. In addition, middle position of VD and FD in buildings exhibits slightly better performance in minimizing maximum inter-story drift.

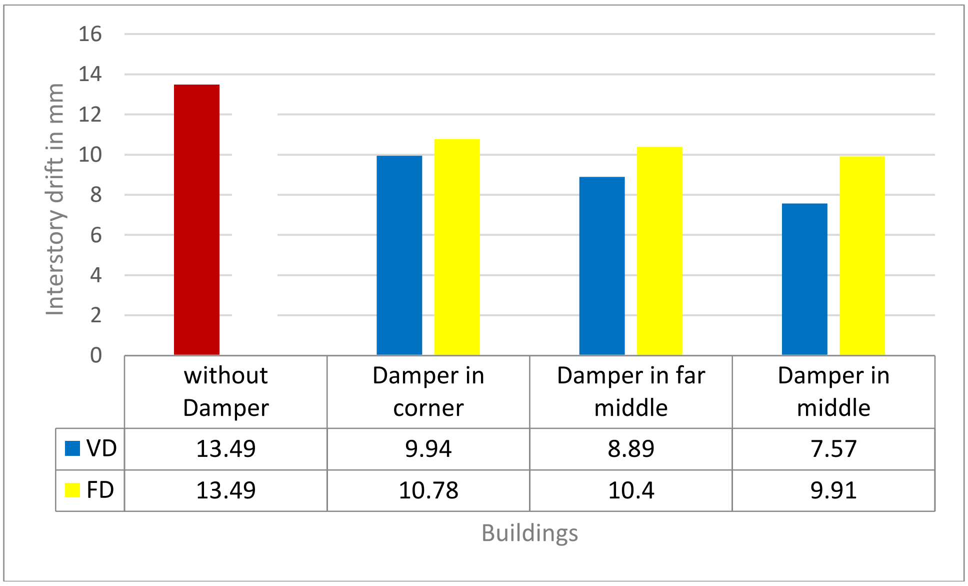


Figure 59: Maximum Inter-story drift for twenty stories buildings in X direction

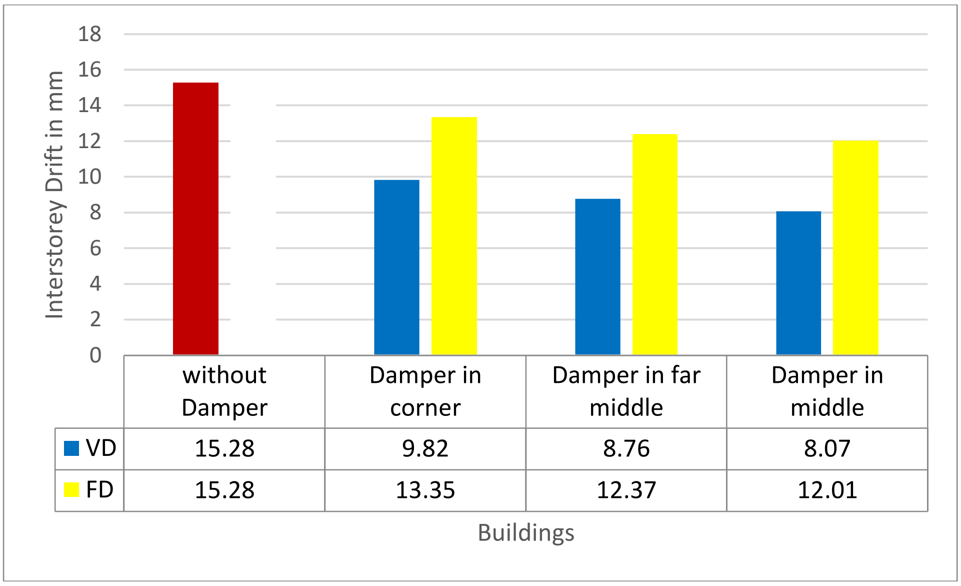


Figure 60: Maximum Inter-story drift for twenty stories buildings in Y direction

Referring to Figure 58 and 58, the behavior of VD and FD in decreasing inter-story drift is in its highest level in the middle position. Furthermore, the difference in minimizing maximum inter-story from its original status in building without damper is crucial between buildings with VD and those with FD.

4.3 Pushover Analysis

4.3.1 Capacity Curve

Due to the symmetricity of structural buildings (6 span in X and Y direction), pushover analysis was achieved only in X direction.

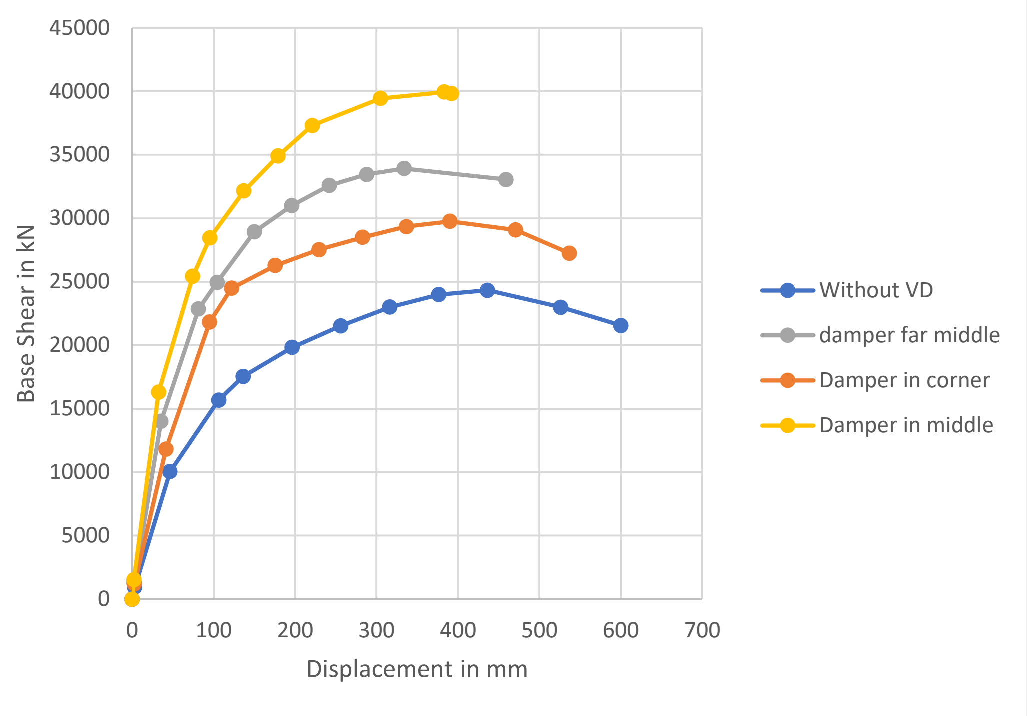


Figure 61: Capacity Curves for five stories buildings with and without VD

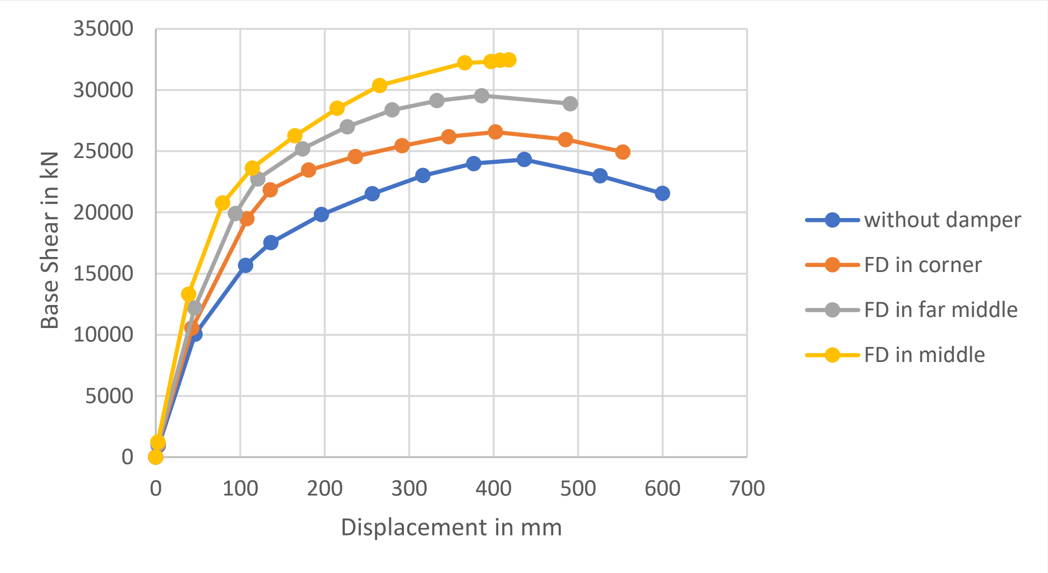


Figure 62: Capacity Curves for five stories buildings with and without FD

Table 9: Displacement at performance point obtained for five stories buildings

Types of buildings	Performance point (mm)	Base Shear (KN)	A-IO	IO-LS	LS-CP	>CP
Without damper	231.40	20217.35	999	89	65	177

VD in corner	150	25382.1	1266	42	13	9
VD in far middle	110.36	25455.6	1294	24	7	5
VD in middle	72.33	25615.6	1320	10	0	0
FD in corner	105.3	19476.4	1270	39	2	19
FD in far middle	90	19897.1	1288	21	8	13
FD in middle	64.89	20156.6	1329	4	0	7

According to Figure 61, when VD are implemented to five stories buildings, it is noticeable that the area under the elastic region of capacity curve increased which indicates that the initial stiffness increased. Similarly, as shown in Figure 62, installing of FD leads to the increase of the area under the elastic region of capacity curve which indicates an improvement of the initial stiffness. However, the improvement of initial stiffness was higher in case of VD implementation comparing to that of FD.

The number of collapse prevention hinges (>CP) falls dramatically from 177 to 9, 5 and 0 hinges in buildings with VD in corner, far middle and middle positions, respectively. In addition, it decreases to 19, 13 and 7 hinges with FD in corner, far middle and middle position, respectively. It is noticeable that buildings with VD perform better in term of minimizing the number of collapse prevention hinges. Furthermore, when dampers (viscous and friction) are placed in the middle location, the building performance become better than placing them in the other two positions.

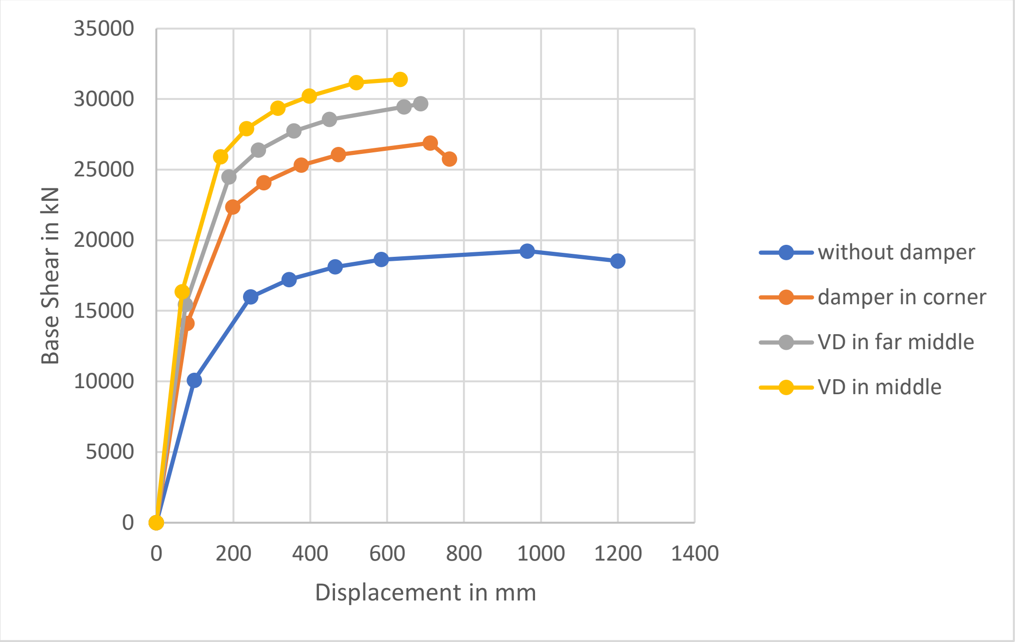


Figure 63: Capacity Curves for ten stories buildings with and without VD

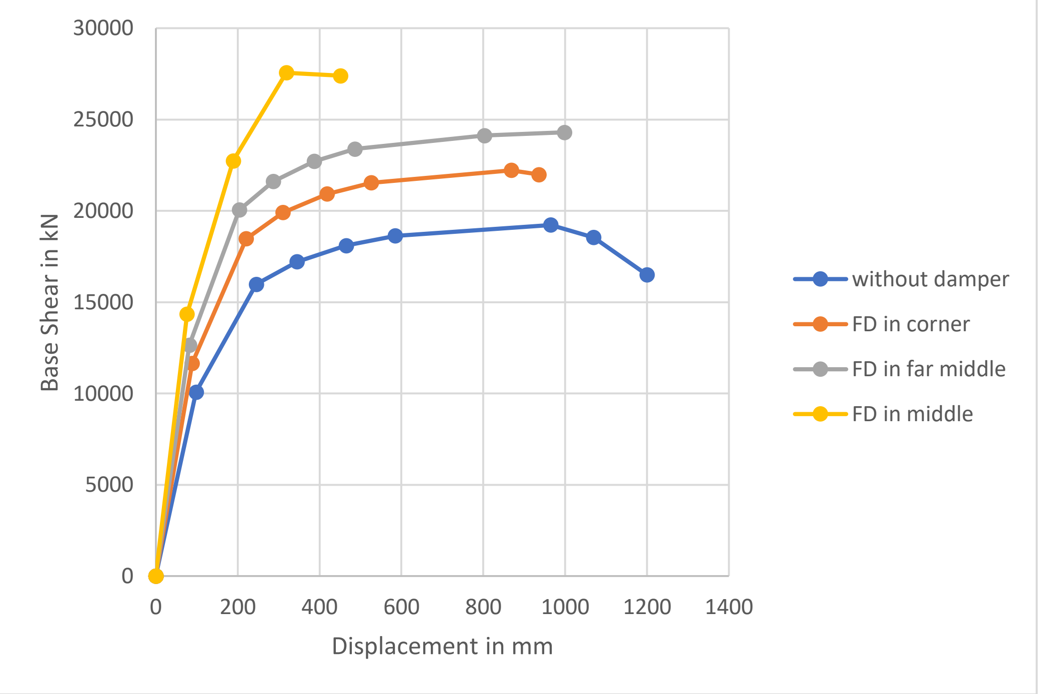


Figure 64: Capacity Curves for ten stories buildings with and without FD

Table 10: Displacement at performance point obtained for five stories buildings

Types of buildings	Performance point (mm)	Base Shear (KN)	A-IO	IO-LS	LS-CP	>CP
Without damper	450	17902.34	2439	150	4	67
VD in corner	240.82	23071	2616	36	7	7
VD in far middle	211.56	25163	2625	28	2	5
VD in middle	146.70	25700.58	2647	0	0	1
FD in corner	270.1	19306	2569	56	11	24
FD in far middle	204.60	20050.85	2572	57	16	15
FD in middle	153.93	21938.39	5281	23	10	6

According to Figure 63, when VD are implemented to five stories buildings, it is noticeable that the area under the elastic region of capacity curve increased which indicates that the initial stiffness increased. Similarly, as shown in Figure 64, installing of FD leads to the increase of the area under the elastic region of capacity curve which indicates an improvement of the initial stiffness. However, the improvement of initial stiffness was higher in case of VD implementation comparing to that of FD.

Inserting VD and FD has efficiently decreased the number of hinges which are between Immediate occupancy and life safety, life safety and collapse prevention and those which are above collapse prevention status. However, buildings with VD experienced higher decrease in number of hinges in these ranges. For example, the number of hinges above collapse prevention status in building with VD in corner position is 7, but it is 24 in building with FD in the same position. In addition, implementing VD and FD in middle position exhibits better results in term of building performance. For instance, the number of hinges in (>CP) for building with VD in middle location is 1, but it is 5 when VD in placed in far middle position of outer frame.

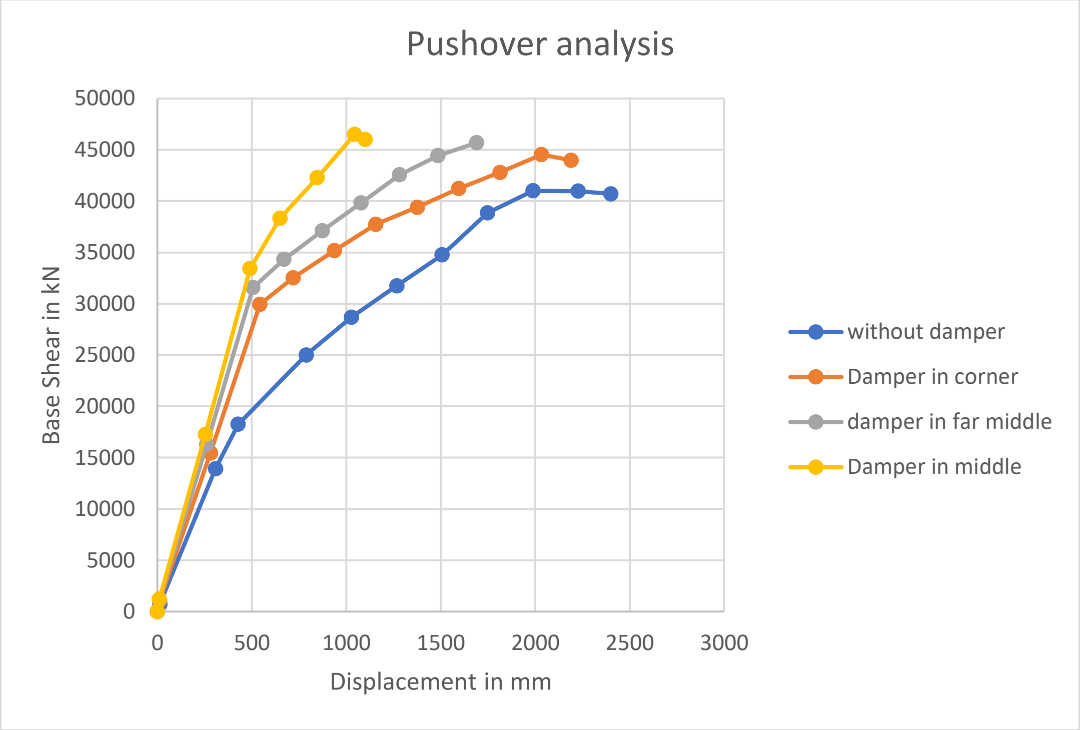


Figure 65: Capacity Curves for twenty stories buildings with and without VD

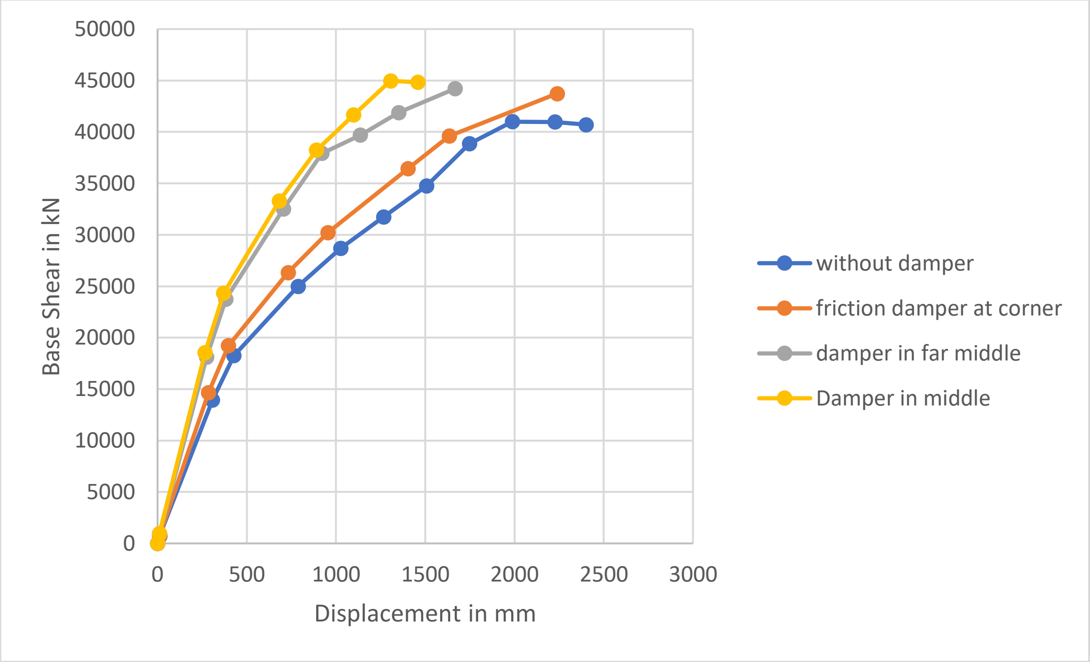


Figure 66: Capacity Curves for twenty stories buildings with and without FD

Table 11: Displacement at performance point obtained for twenty stories buildings

Types of buildings	Performance point (mm)	Base Shear (KN)	A-IO	IO-LS	LS-CP	>CP
Without damper	688.23	24658.41	4580	598	24	118
VD in corner	533.49	29742.72	5306	2	8	4
VD in far middle	492.18	31275.43	5313	5	0	2
VD in middle	449.52	32014.64	5320	0	0	0
FD in corner	588.14	23755.26	5184	99	13	24
FD in far middle	502	28425.98	5217	78	7	18
FD in middle	483.21	30101.15	5251	56	11	12

According to Figure 65, when VD are implemented to five stories buildings, it is noticeable that the area under the elastic region of capacity curve increased which indicates that the initial stiffness increased. Similarly, as shown in Figure 66, installing of FD leads to the increase of the area under the elastic region of capacity curve which indicates an improvement of the initial stiffness. However, the improvement of initial stiffness was higher in case of VD implementation comparing to that of FD.

Similarly, to ten stories buildings, adding viscous or friction dampers has improved the performance of buildings where number of hinges in several statuses (IO-LS, LS-CP and >CP) where minimized dramatically comparing to building without dampers. Furthermore, buildings with VD experiences better performance in term of decreasing the number of hinges in several statuses comparing to those with FD. Moreover, when dampers are implemented in middle location, the performance of building become better comparing to other situations where dampers are placed in the other positions (corner and far middle of outer frame).

Chapter 5

CONCLUSION AND RECOMMENDATION FOR FUTURE STUDIES

5.1 Conclusion

This dissertation highlights the seismic response of buildings without damper and buildings with VD and FD implemented in three different positions in the external frame in order to compare their effectiveness in dissipation ground motion energy and to find the optimum location of damper implementation. In addition, this dissertation takes into consideration the variation of buildings height where buildings of five, ten and twenty stories were taken into consideration during the analysis. From the results of time history and pushover analysis, the following conclusions can be drawn:

1) Implementing viscous and friction dampers has significantly decreased the base shear when buildings were subjected to earthquake records due to their ability in dissipating earthquake energy. However, viscous dampers prove their superiority in minimizing base shear comparing to friction dampers in buildings with different heights. In addition, implementing dampers in middle position of outer frame leads to better minimization of base shear comparing to their implementations in other positions.
2) For all sets of stories, acceleration was minimized in buildings with VD and FD. Buildings with VD exhibited better performance in reducing acceleration specially when VD is located at middle position of outer frame.

3) For roof displacement, adding dampers played a crucial role in reducing it. For five stories buildings, the performance of buildings with VD and FD in decreasing the acceleration was approximately the same. However, with the increase in buildings height, the ability of VD in minimizing the roof displacement was significantly higher than that of FD. Furthermore, both types of dampers exhibited their optimum performance in reducing roof displacement in the middle position of outer frame.
4) Adding VD and FD had leads to the dissipation of kinetics and potential energy of earthquakes which leads to the minimization of structural buildings displacement and the deflection of structure member in elastic status. However, energy dissipation was higher in buildings with VD. The highest increase in energy dissipation occurred when dampers were located in middle position of outer frames.
5) Maximum inter-story drift is minimized because of VD and FD implementation. Viscous Dampers has higher ability in reducing maximum inter-story drift than Friction Dampers specially when it is placed in the middle position of outer frames.
6) From the pushover curves, it was noticed that introducing VD and FD improves the performance of structural buildings by reducing the number of collapse hinges. In addition, the base shear which is the ability of building to resist lateral loads had increased when both types of dampers were implemented in structural buildings. It is noticeable, that performance of buildings with VD in term of reducing collapse hinges was predominant to those with FD specially when VD were implemented in middle position of outer frames.

Both types of dampers have risen the ability of structural buildings in resisting earthquake motion by dissipating earthquakes energy. However, nonlinear static and dynamic analysis shows that VD has the superiority over FD in reducing base shear, stories acceleration, roof displacement, kinetics and potential energy of ground motion, maximum inter-story drift and number of collapse plastic hinges. In other words, VD is more efficient than FD in improving the resistance of structural buildings against earthquakes by dissipating their energies. However, FD are still implemented into structural building in some cases because their repair is simpler than that of VD, where the whole damper doesn’t need to be shipped back to the factory after earthquake occurrence. Moreover, the building’s resistance of earthquakes is at its highest level when dampers are placed in middle position of outer frames.

5.2 Recommendation for Future Studies

This study investigates the role of VD and FD in reducing the effect of ground motion and optimum location of dampers in external frames. However, for future studies, the following aspect can be investigated:

1) Implementation of other types of PEDS like Viscoelastic damper and Tuned Mass damper instead of viscous and friction dampers to study their effectiveness in decreasing earthquake damages and comparing it to that of VD and FD.
2) Installing AEDS such as AMD, Active Tendon System and ABS instead of PEDS for comparing the performance of both types of dissipation system in reducing earthquake damages.
3) Placing viscous and friction dampers in the internal frame of structural buildings to investigate their ability in dissipating earthquake’s energy and comparing it to those which are located in external frame.

4) Performing the same study on irregular buildings to check the capability of VD and FD in minimizing the damages of earthquake in those types of buildings.

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APPENDIX

Appendix A: Duzce Location

Figure 67: Duzce Location in Northwestern Turkey (AFAD)