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Research paper



Seismic Analysis for Multi-Story Building Horizontally Damped Above Basement Level

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Abstract

Due to the urbanization multi-story building with underground story for parking space and storage are very common in practice. Now a day, seismic energy dissipating devices are being used for various types of structures and located in basements which are difficult to maintain. The main objective is to evaluate the effectiveness of horizontal dampers in the ground floor level of the multi-story building above basement. Among different types of dampers, visco-elastic [VE] dampers are used for this numerical study. Comparing with other types of passive energy dissipating devices, visco-elastic [VE] dampers are considered most suitable. For the better understanding of the effectiveness of horizontal dampers, stiff foundation system is considered thus soil-structure interaction is omitted. In this numerical study, seismic response of different hypothetical structures analyzed having different underground stories and horizontal dampers only in the ground level. Modeling and analysis of the structures and installation of the dampers are done by using finite element modeling software [ETABS]. Time history analysis was used to simulate the response of the structures. Sabah earthquake [05/June/2015] with the PGA of 0.126g was used for the time history analysis. Different dynamics parameters such as natural time period, displacement, base shear and inter-story drift were evaluated. Changes in the results among the structures demonstrated the efficiency of horizontal dampers. Optimum locations of the horizontal dampers were also revealed in this study in the basis of the analysis results.

Keywords: *Visco-elastic damper; horizontal damper; sabah earthquake; time history analysis*

1. Introduction

Due to the high increasing rate of population and some restrictions on construction in big cities, the basement floors are commonly exist in multi-story buildings. Today, a large number of residential and commercial buildings in the urban areas include one or several basement floors. The effects of basement floors having dampers on seismic behavior have not been studied very much. Failures of these types of buildings during earthquake show the importance of energy dissipating devices for these buildings. An attempt has been made to find the variation in natural period, story displacement, base shear and drift of structure by incorporating energy dissipating devices as compared between different models.
Recently, passive dampers are being used for the retrofitting of the existing structures and the design purpose for the new structures. Base isolation is being used as an effective way to mitigate earthquake damages. These isolators needed to satisfy the design requirements by laboratory tests. Performance of these isolators may be affected by over the time and seismic occurrence in the mean time also can affect their performance. Thus it is considered the important to check the performance of the isolators on a regular basis of several years or after the occurrence of an earthquake [1]. This system decouples the building from the foundation and costly also.
Today it is possible to use energy dissipating viscous dampers without isolating the structure. Although both two systems have the same objective in reducing earthquake damages but the techniques of implementation are different. Dampers can be used throughout the structure. Up to 30% or even more damping is possible by viscous dampers. These dampers can be used for new and existing structures [2].
For the building with several basements, viscous dampers can be placed perpendicularly along the height of the structures above basement level. So that it will be easy to install and maintain. These will add energy dissipation to the lateral system of the building.
In this research the effectiveness of horizontal dampers are studied for the buildings with several stories of basements. Among different types of dampers, visco- elastic dampers which are considered the most suitable energy device are used for this study.

2. Literature Review

Today in big cities building with underground stories are becoming very common. The lateral forces due to earthquake are not considered much during the design of these buildings. So, these basement structures are being designed by considering only gravity loads. Seismic effects on the basement members are required studying more [3]. Moreover, building systems type and configuration have much influence on dynamic behavior of a structure due to earthquake excitations [4]. Over the years, considerable achievement is done in improving seismic performance of the structures [5]. Although much unknown also remaining in this field to ensure the safety the structures.
Many advances became possible due to application of Finite Element Analysis [FEA]. Performances of real structures due to earthquake excitations are also being predicted. Although FEA is playing very important role in earthquake analysis but its limita-

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tions are also recognized. Thus a successful integration of analysis and design are needed.

Additional vibration stresses due to earthquake excitations are unwanted for the structures. By appropriate seismic design these should be eliminated or reduced as much as possible. Analysis of structures by installing different damping systems are increasing recently as the current trend of constructing high-rise buildings and tendency to make the structures safe against earthquake excitations [6].

Energy absorbing mechanical devices is being used to reduce earthquake effects and is generally located within the structure. Various research results showed using of mechanical energy absorbing devices are quite promising. During an earthquake phenomenon, these installed devices absorb energy and reduce the harmful effects to the structure. These devices generally do not support from the structure and can be removed anytime keeping the structure undamaged.

Many researches were also carried out to mitigate the earthquake effect on the structures. Viti et al. [7] reduced the maximum acceleration of a structure by implementing damping devices to control seismic responses. A numerical study of a 7-story building was conducted by Ribakov et al. [8] by using dampers under different seismic excitations. Up to 70% reduction of peak displacement was obtained comparing with the un-damped structure. Madsen et al. [9] concentrated on the use of dampers for the tall buildings. The study was conducted by using Visco-elastic dampers placed within shear wall of the structure. The results were more effective for the lower stories of the structure. The effect of hysteretic-viscous dampers was analyzed on high-rise buildings by Hisano et al. [10]. Bhattacharya and Dutta [11] showed the significance of fundamental natural period in dynamic behavior of the low-rise buildings. The soil-structure interaction effect on different dynamic parameters such as base shear, moment and inter-story drift for the buildings with underground stories was studied by Saad et al. [12]. Pong et al. [13] did a study by using different building codes on seismic provisions and other design parameters.

Energy dissipating devices

Recently energy dissipation technology has modified usual seismic design. These are greatly improving the seismic performance of the structures and reducing structural seismic responses [14]. These energy absorbing devices may be active or passive in nature. Active controls do not found much application due to its high cost and large instrumentation set up. This system requires a power supply to operate hence undependable if the power supply disrupted during seismic events. Thus active dampers are preferable to wind induced loading on tall buildings rather than controlling the seismic effects.

On the other hand, passive control systems for example, base isolation, dampers, bracing systems etc, are found to be easy to install and cost effective as compared to first one. Among different types of passive dampers, metallic dampers, viscous dampers, visco-elastic dampers, and friction dampers are common in use. These systems are emerged as special devices which can be incorporated throughout a structure to absorb seismic induced energy. Use of passive dampers is now a day becoming cost effective solution for improve seismic performance of existing as well as new buildings. They reduce the seismic responses on the critical members of a structure. Thus demand of energy dissipation on main structural members is largely reduced and probability of structural damage also reduced. These absorbers can be replaced leaving the structure undamaged after the earthquakes as these do not carry any structural loads [15]. Thus structural and non- structural damages can be significantly reduced by using passive dampers which will reduce inelastic demand for structural members [16].

Again, on the basis of energy dissipation mechanism, dissipation devices can be categorized into two types; velocity dependent damper and displacement correlation damper [17]. Visco-elastic damper and viscous damper are velocity dependent damper. Metal damper and friction damper is displacement correlation damper [18].

2.1. Passive Energy Dissipation Devices

Kelly et al. [19] began the conceptual and experimental study to absorb seismic energy by using passive energy dissipating devices. Among different types of passive energy dissipation devices, base isolation are being used a lot in earthquake prone areas. The mechanism behind isolation is natural period of a structure got changed and it decouples the structure from ground. For this purpose, energy absorbing materials are inserted between the superstructure and substructure. As a result the amounts of transmitted seismic forces are reduced [20]. According to Di Sarno et al. [21], base isolation is quite useful but tough to carry out and expensive also.

Moreover, there are various types of passive dampers which are being used for high-rise building and commercially available. These can be produced with different properties and produce a wide variety of results. Visco-elastic dampers which are the most popular passive dampers can be used as an alternative of base isolation.

2.2. Visco-Elastic Dampers

Visco-elastic dampers are considered as the earliest passive dampers that successfully used in structures [22]. These are the most promising and have been used in many structures all over the world. These can absorb large amount of energy induced from both wind and earthquake. Many numerical and experimental studies reported reduction of seismic induced structural vibrations by installing visco-elastic dampers [23-25]. These dampers are consisting of visco-elastic materials which bonded with steel plates. Typical view of a visco-elastic damper is shown in Figure 1. Energy is dissipated by shear deformation of visco-elastic materials [26]. Generally, even small inter-deformations under dynamic loads can amplify damper displacement and dramatically improve the efficiency of viscous dampers [8, 27, 28]. From the previous studies, it is clear that visco-elastic dampers are treated as an ideal energy dissipating device because of the efficient energy dissipations, high reliability and cost effectiveness against dynamic loads. Therefore, visco-elastic dampers can be good alternatives to base isolation in new buildings or existing buildings [29].

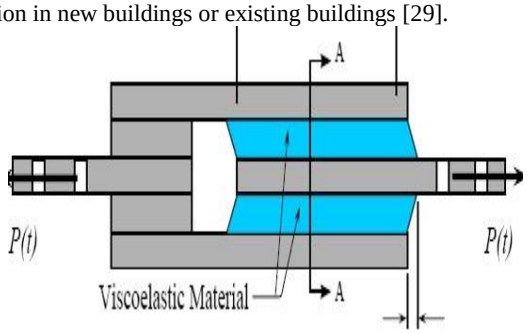


Fig. 1: Typical view of a visco-elastic damper

The investigation of the energy dissipating mechanism in the structures during earthquakes is important for upgrading existing structures and seismic resistant design. Thus research on energy dissipating mechanism is greater than ever. In this study, visco-elastic dampers are used as horizontal dampers considering the buildings with multiple underground stories and dampers are installed only above the basement level due to the ease of practical installation.

3. Methodology

Methods of modeling and applying the seismic load are important in order to understand the seismic behavior of the structures [30]. This study was carried out by using time history analysis using the finite element modeling software [ETABS software]. For the modeling purpose frame elements were used for columns and beams and shell element was used for slabs. Dampers were mod-

eled by using link property. 3D hypothetical models were used for the understanding the seismic behavior of horizontally damped building. As the main objective of this study is to investigate the effectiveness of horizontal dampers in the buildings with multiple basements, hence soil-structure interaction is not considered in the study.

3.1. Modal description

A hypothetical 40 story moment resisting residential building was designed without any basement with plan dimension 34 m by 28 m [31] as shown in Figure 2. The total height of the building was 120m and typical floor to floor height is 3 m. The building is modeled symmetrically to avoid torsion effects. Column size is kept similar for the whole building. Concrete unit weight is considered as 24.0 KN/m^3. The inherent damping of the frame is considered 5%. The frames have been modeled as rigid frames. All restrains that have been modeled are assumed to be fixed. Dead and live loads were assigned to the shell elements of the structure according to Eurocode 1 EN1991-1-1:2002. The compressible soil condition was not considered and the entire building was supported by fixed foundation.

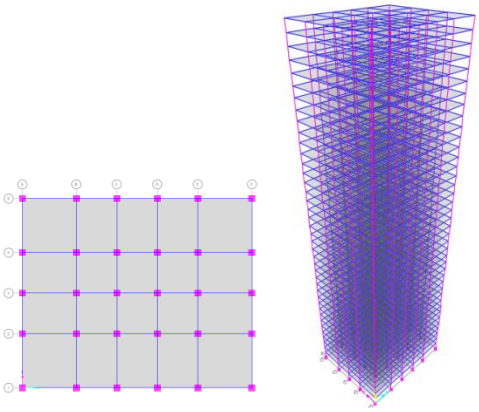


Fig. 2:Plan view and elevation of the hypothetical building

Again, four buildings were modeled having a different basements and horizontal dampers at the ground floor level as Cases are B, C, D and E. Case B, C, D and E had 5th, 10th, 15th and 20th level of dampers respectively as shown in Figure 3. These 4 buildings had similar 40 stories height.

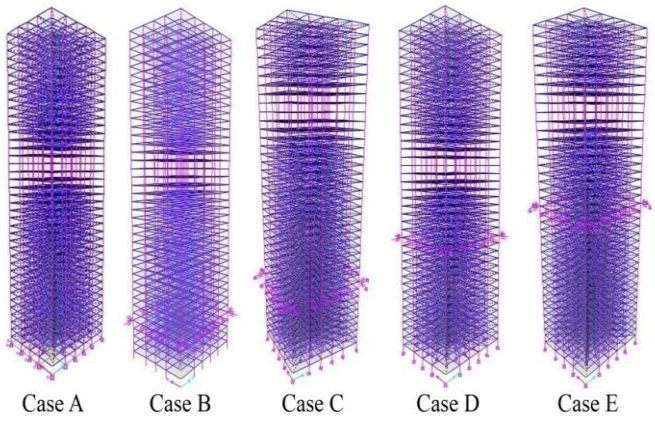


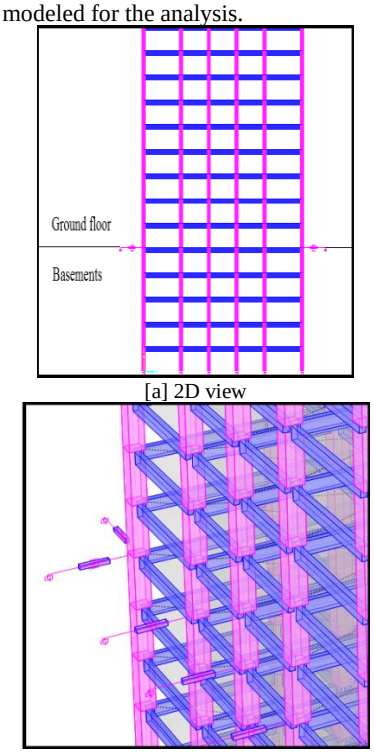
Fig. 3: Buildings with different cases

3.2. Installation of Dampers

Viscous Elastic Damper consists of steel plates and high damping elastic rubber, it could be configure into different forms according to the structure requirements. This kind of rubber can convert vibration energy to heat energy through shear deformation. From this reason, the viscous elastic dampers can effective control structural vibrations resulting from wind, earthquake, traffic and human activities.

Viscous damping can be implemented in many ways in a finite element analysis depending on the software. When damping is small, the damped natural frequency is almost the same as the undamped natural frequency. The Holmes consulting produces various visco elastic dampers having different damping properties. One of the dampers having the below properties are considered for this study: the stiffness, K of 20000 KN/m and the damping coefficient C of 10000 KNs/m [32].

Total 22 dampers are installed in each model having the above mentioned properties for each damper. Figure 4 shows the dampers that were modeled for the analysis.



[a] 2D view

[b] 3D view

Fig. 4[a]: 2D view and [b] 3D view of horizontal dampers modeling at ground floor level

3.3. Input of earthquake data

Sabah earthquake [05/June/2015] with the PGA of 0.126g was considered for this study. Only ground acceleration of X-direction is taken into account. The earthquake data was inputted as an electronic file having unit in mm/sec/sec. This type of data is common to use research purposes. In respect to that, the data is widely used in this study to analyze for the modeled structures under earthquake loading. 5% damping is considered for this study. Figure 5 shows acceleration of Sabah earthquake that was used in this study.

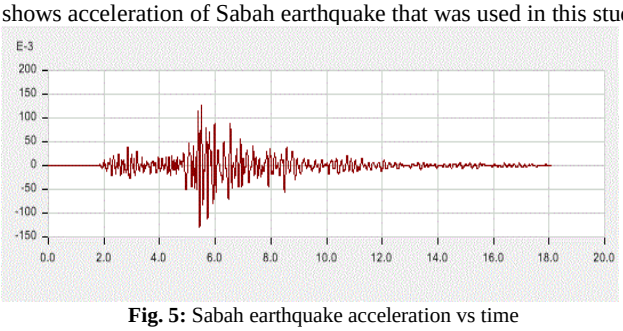


Fig. 5: Sabah earthquake acceleration vs time

3.4. Time history analysis in ETABS

Time-history analysis is most suitable analysis method for analyzing the structures under specific earthquake record [33]. For a specific earthquake data, structural behavior can be studied for every increment of time. This type of analysis can be used to study for any previously recorded ground motion [34]. The specific earthquake record is inputted at the base of the structure during the

analysis [35]. The dynamic behavior the structure can be computed for each moment of the earthquake incident.
In ETABS, there is a defining option for time history function. Using that option, time history functions can be created easily. In this research case, only one time history cases is defined by user – 0.126g in NS [north-south].
Among different types of Time history analysis, linear modal is used to define the load cases with respect to time history function. In addition, calculation and choosing the scale factors to get the earthquake effect on the structure is also important. For this study, the scale factor value of g is [9.81 m/sec^2] which is the unit of the acceleration. Another one important thing is to choose the number of output time steps and output time steps size. In this matter, Sabah earthquake signal is about 18 seconds and time step size is 0.005 second. Therefore, number of time steps divided by output time step size will give the detailed response of the structure in every 0.005 second. In mathematical expression, $\frac{18\ (\text{time taken by Sabah EQ})}{0.005(\text{Time step of Sabah EQ})} = 3600$ [for number of output time steps] and 0.005 for output time step size.

4. Results and Findings

A parametric study is done to evaluate the effectiveness of horizontal dampers in the structure due to earthquake excitation. The design parameters such as fundamental period, story displacement, top story displacement, base shear and inter-story drift are studied that were obtained from the analysis results. The results are showing the changes of different parameters for different analyzed cases.

4.1. Natural Time Period

The natural period is most important dynamic parameter to understand the behavior of a structure. Generally first few fundamental periods of any structure determine the dynamic behavior of that structure. The analyses were resulting a fundamental time periods at the first mode of Case A, B, C, D and E as 4.945sec, 4.721sec, 4.205sec, 3.613sec and 2.991sec respectively. . Maximum time period is observed for Case A which is about 40% more than case E. Figure 6 shows first 3 fundamental periods for different modeled buildings. With reference to figure there is huge change in time period for different cases. When the structures were modeled using dampers, time periods were decreased. The natural periods were decreasing as the numbers of basements were increasing indicating the ductile action. Thus it is clear that the natural period of structures decreased due to horizontal dampers effect. There was about 5%-40% of decrement in natural time period from first mode. According to the results, the time periods of mode shapes of damped structures were less than un-damped structure, it was due to increase in stiffness of damped structures.

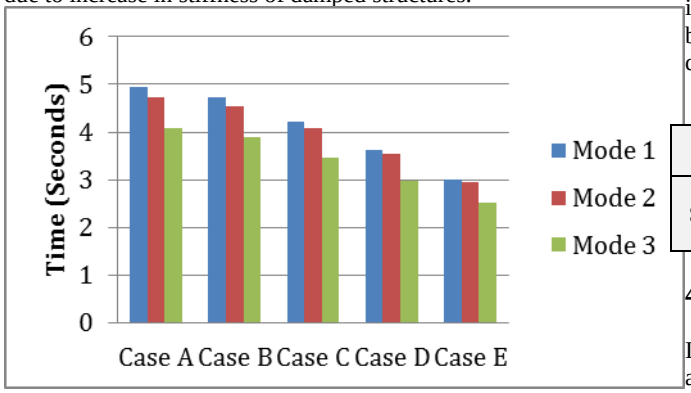


Fig. 6: Natural periods for first 3 modes

4.2. Story Displacement

Story displacements for all structures due to Earthquake are shown in Figure 7. With reference to the figure, a lot of difference is observed in the displacements profile of different structures. Maximum top story displacement was observed for Case A. In Case A, story displacement is seen to increase linearly along the story height comparing the others. But for the other cases more displacements were observed before reaching to the mid height although final displacements were less than Case A.
Maximum displacements for top floor of each building are shown in Table 1. It is evident that the maximum displacement is for the building modeled without damper. There were 14%, 19%, 5% and 19% decrease in top story displacement for Case B, Case C, Case D and Case E respectively. Thus horizontal dampers have been proved to be useful method for studying the structures with several basements.
Storey displacement profiles were also found almost similar for all the structures using dampers except the un-damped one. It is clear from the above results that, displacement of top story as well as vibration amplitude of structure is reduced by adding damper devices.

Table 1: Top Story displacements for different cases

Top story displacements[mm]	Case A	Case B	Case C	Case D	Case E
	2.1	1.8	1.7	2	1.7

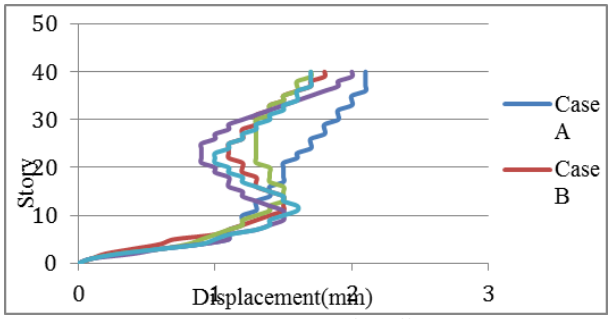


Fig. 7: Story displacements for different cases

4.3. Base Shear

Base shear is the maximum lateral force at the base due to earthquake excitations. The values of base shear for different cases are as shown in Table 2. It is seen that as the flexibility of the structures decreases the value of base shear increases, since base shear is dependent on the primary factor, natural period. With the decrease in flexibility of the structure, the natural period of the building decreases and base shear increases. These values also associate with structural configurations. As building configurations also changed due to dampers, so these lead to higher base shear. It is expected that base shear would be low. Among the analysis results, Case A showed less base shear which was un-damped one. From the analysis, it is clear that base shear increased gradually as the level of basements is increasing. Here, Case C showed tremendous increase in base shear. From the results of base shear, Case B can be considered the suitable one against base shear among the damped structures.

Table 2: Base shear for different cases

Kind of Response		Case A	Case B	Case C	Case D	Case E
Base Shear [kN]	Max	287.7	322.9	529.14	509.88	497.7
	Min	-341.45	-305	-530.26	-552.22	-467.6

4.4. Inter Story Drift

Inter-story drift is one of the important response parameters that are widely used in determining the seismic behavior of the structure. Comparison of drift for different cases is shown in Figure 8. From the graph it is observed that the drift increases from bottom storey to 4th storey. Almost for all cases, maximum values were found in 4th story level and then rapid decrease up to around 10th story level. Again, for Case A drift was found to be much higher comparing with other cases. On an average Case A showed around

50% higher drift in the upper stories comparing with other cases. So Case A shows poor performance in terms of drift compared to other cases. Study results indicate reduction of inter-story drift significantly due to effect of dampers.

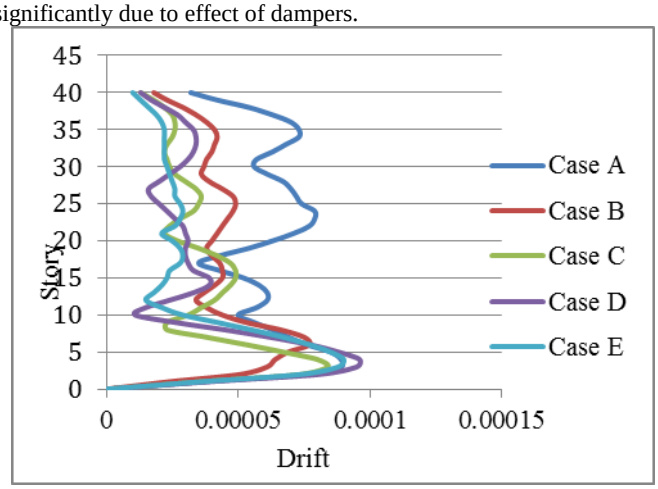


Fig. 8: Inter-story drifts of different cases

5. Conclusion

Present paper investigates the effect of horizontal dampers on the structural behavior of a building with multiple basements during an earthquake. A parametric study with time history analysis is done. Variation in dynamic properties such as natural time period, roof displacement, base shear and inter-story drift are observed. Based on observation of the results, the following main conclusion can be drawn:

Fundamental natural periods of the un-damped building was more than the corresponding values of the damped buildings. Dampers decreased flexibility of the structures as a result fundamental natural periods decreased and the structures became stiffer.

Dampers reduced seismic response of the structures thus less top story displacement found for the damped buildings. The displacement profiles of the damped structures along the story height were found also different, relatively much displacement observed at the one third heights of the damped buildings.

Higher base shear found for the all damped cases due to increase in stiffness. In terms of base shear, Case B showed less among the damped structures.

Horizontal dampers dramatically changed inter-story drift of the structures which will make the structures safe against earthquake excitations.

The analysis results show that, horizontal damper devices are perfectly able to reduce the structural response as well as oscillation of structures. In summary, horizontal dampers can contribute significantly towards minimization of earthquake damages for multi-story buildings having basements. Analysis results predict there is a relation between the horizontal dampers and their location along the height of the building. In this study, dampers at the one eighth height of the structure showed the most pleasant result.

This study indicates horizontal dampers can be possible as an alternative to base isolation. Maintaining of horizontal dampers is much easier than base isolation in terms of cost and ease of installation.

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