# SEISMIC ANALYSIS FOR MULTI-STORY BUILDING HORIZONTALLY DAMPED ABOVE BASEMENT LEVEL

MOHAMMED ZIAUDDIN PATOWARY

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE 2017

***Alhamdulillah…***

*Thousand of gratitude to the Almighty Allah for the countless mercy and for giving me the courage and strength all this while…*

*To my beloved family…*

# ACKNOWLEDGMENT

Firstly, I convey my sincere thanks to the Almighty Creator, our Lord Allah (SWT) for making everything possible as there is no power or movement without His permission. Peace be upon Prophet Muhammad (SAW), the last messenger whose beautiful teachings of peace and prosperity shaped my psychology and life's philosophy.

I would like to express my heartfelt gratitude for my supervisor Associate Prof. Dr. Abdul Kadir Bin Marsono for his constant support and guidance throughout my study with patience and enthusiasm. His suggestions and comments up until the end of writing project were invaluable. I am greatly thankful to my co-supervisor Mohd. Zamri Bin Ramli for his tremendous support in my research. Big thanks go to my colleagues and friends from UTM who helped my difficulties during studying. From all these people, I learned a great deal.

## 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.

# ABSTRAK

Oleh kerana pembandaran bangunan berbilang tingkat dengan cerita bawah tanah untuk tempat letak kereta dan penyimpanan yang sangat biasa dalam amalan. Sekarang sehari, tenaga melesapkan seismik peranti yang digunakan untuk pelbagai jenis struktur dan terletak di bawah tanah yang sukar untuk mengekalkan. Objektif utama adalah untuk menilai keberkesanan peredam mendatar dalam peringkat tingkat bawah bangunan berbilang tingkat di atas tingkat bawah tanah. Antara jenis peredam, likat-kenyal (VE) peredam digunakan untuk kajian berangka ini. Dibandingkan dengan lain-lain jenis peranti dissipating tenaga pasif, likat-kenyal (VE) peredam dianggap paling sesuai. Untuk pemahaman yang lebih baik terhadap keberkesanan peredam mendatar, sistem asas sengit di anggap dengan itu tanah-struktur interaksi ditinggalkan. Dalam kajian berangka ini, tindak balas seismik struktur andaian yang berbeza dianalisis mempunyai cerita bawah tanah yang berbeza dan peredam mendatar sahaja di peringkat akar umbi. Pemodelan dan analisis struktur dan pemasangan Peredam dilakukan dengan menggunakan terhingga perisian pemodelan elemen (ETABS). Masa analisis sejarah telah digunakan untuk mensimulasikan sambutan struktur. gempa bumi Sabah (05 / Jun / 2015) dengan PGA of 0.126g telah digunakan untuk analisis sejarah masa. dinamik yang berbeza parameter seperti tempoh semula jadi masa, anjakan, asas ricih dan antara cerita drift telah dinilai. Perubahan dalam keputusan antara struktur menunjukkan kecekapan peredam mendatar. lokasi optimum peredam mendatar juga didedahkan dalam kajian ini dalam asas keputusan analisis.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| IBC | - | International Building Code |
| NEHRP | - | National Earthquake Hazards Reduction |
| ADAS | - | Added Damping And Stiffness |
| SMRF | - | Special Moment Resisting Frame |
| FEMA | - | Federal Emergency Management |
| RC | - | Reinforced Concrete |
| SBC | - | Slotted Bolted Connection |
| PED | - | Passive Energy Dissipation |
| VE | - | Viscoelastic |
| SDOF | - | Single Degree of Freedom |
| U.S. | - | United State of America |
| DBE | - | Design Basis Earthquake |
| MCE | - | Maximum Considered Earthquake |
| FDD | - | Friction Damper Device |
| EC | - | Euro code 8 |
| FE | - | Finite Element |
| 2D | - | 2 Dimensional |
| 3D | - | 3 Dimensional |
| RSA | - | Response Spectrum Analysis |
| THA | - | Time History Analysis |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| *m* | - | *Mass* |
| *c* | - | *Damping coefficient* |
| $\ddot{u}$ | - | *Structural acceleration* |
| $\dot{u}$ | - | *Structural velocity* |
| *u* | - | *Displacement* |
| ± | - | *Approximation* |
| *δ* | - | *Inter story drıft* |
| *b* | - | *Brace* |
| *d* | - | *Damper* |
| *f* | - | *Shear force/friction coefficient* |
| *N* | - | *Applied normal force* |
| *Δt* | - | *Time step* |
| *fy* | - | *Strength of reinforcement* |
| *E* | - | *Modulus of elasticity* |
| *G* | - | *Shear modulus* |
| *v* | - | *Poisson ratio* |
| *ye* | - | *Yield strength* |
| *Ue* | - | *Ultimate strength* |
| *p* | - | *Axial force* |
| *M* | - | *Bending moment* |
| *V* | - | *Shear force* |
| *A* | - | *Cross sectional area,* $m^2$ |
| *Fy* | - | *Yield strength, MPa* |

| | | |
|---|---|---|
| *fv* | - | *Maximum shear stress, MPa* |
| *fvt* | - | *Maximum torsional shear stress, MPa* |
| *g* | - | *Gravity = 9.81* $m/s^2$ |
| *K* | - | *Effective length factor* |
| $M_L$ | - | *Local magnitude (also often referred to as Richter magnitude scale)* |
| $M_O$ | - | *Seismic moment, N.m* |

# CHAPTER 1

# INTRODUCTION

## 1.1 General

The fundamental goals of any structural design are safety, serviceability and economy. Achieving these goals for design in seismic region is especially important and difficult to achieve. Uncertainty and unpredictability of when, where and how an earthquake event will strike a community increases the overall difficulty. In addition, lack of understanding and ability to estimate the performance of constructed facilities makes it difficult to achieve the above mentioned goals. In some cases, especially under strong earthquake excitations, these can cause the structural damage or even collapse of structure. For the structures that have high inherent or natural damping, the likelihood of damage will be decreased. However, for structures subjected to strong vibrations, the inherent damping in the structure is not sufficient to mitigate the structural response. In many situations, supplemental damping devices may be used to control the response of structure.

## 1.2 Background of the problem

Among the natural phenomenon that human kinds worried are about the earthquakes. Location and time of occurrence since earthquakes are unpredictable. During a major earthquake, a large amount of input energy due to earthquake is displacing the building. The performance of a structure during an earthquake depends on its energy absorption and dissipation capacities. The manner in which earthquake energy is consumed in a structure determines by the level of damage. The building codes recognize that it is economically not feasible to reconcile this energy within the elastic capacity of the structural systems.

The most feared effects of earthquake are collapse of structures especially tall building structures due to high displacement between stories. One of the key solutions with this explanation is the reduction of structural response by increasing the dissipation of input energy due to earthquake. In the other words, if the amount of energy getting into the structure can be controlled and a major portion of the energy can be dissipated mechanically independently of primary structure, the seismic response of the structure and damage control potential can be considerably mitigate. These objectives can be delivered by adopting new techniques of base isolation and energy dissipation devices in the structural system. That's why damper devices are the most popular instruments for increasing the dissipation of input energy.

The scale of designing in conventional building codes is to design structures to resist moderate earthquakes without significant damage and avoid collapse during major earthquakes. The primary emphasis is on life safety. The reliance for survival is placed on ductility to dissipate energy during inelastic deformations causing bending, twisting and cracking. Recent earthquakes have clearly demonstrated that conventional construction is unavoidable in technologically advanced countries, is not unaffected to destruction.

Finite Element Method (FFM) is a numerical method that can be used to solve different kinds of engineering problems in the stable, transient, linear or nonlinear cases (Bathe, 1996). Among finite element method software's, ETABS is known as one of the most practicable software in industry and university researches. It is used for dynamic analysis such as earthquake and water wave loading on structures.

## 1.3 Statement of the problem

In seismic structures retrofitting, one of the lateral force reduction caused by the earthquake is by the use of dampers. Damping increasing reduces structural response (acceleration, velocity and displacement). The retrofitting of dampers has become very popular in the recent years due to its ease of placements.

Since the motion of earthquakes is random at the point where vibration enter in the structural system, the principle of vibration isolation are being used to protect a building (i.e., it is decoupled from the horizontal components of the earthquake ground motion by rubber bearings between the building and its foundation).

The principle behind isolation is to change the natural period of the structure, substantially decouple a structure from the ground motion input and therefore reduce the resulting inertia force that the structure must resist. This is done by the insertion of energy absorbing material between the substructures and superstructures, which will reduce the amount of seismic forces transmitted to above system.

But, the method of structural isolation is very expensive and difficult to carry out (Di Sarno et al., 2005). Instead of using base isolation in the foundation, horizontal dampers can be an alternative solution, which are easy to install and maintain.

## 1.4 Objectives of the study

The objectives of this study can be listed as follows:

1. To model tall building using finite element modeling.
2. To evaluate seismic performance of typical tall building due to earthquake excitations.

3. Studying the seismic behavior tall building structure by horizontal damper using time history analysis.

## 1.5 Scope of the study

The scopes of study are:

a) Earthquake characteristics according to Eurocode 8.

b) Response of tall building structures to earthquakes through the numerical method of ETABS software.

c) Horizontal damper characteristics through the analysis of forty storey buildings.

d) Evaluation of response of tall building structures equipped by horizontal damper for the building with underground stories.

## 1.6 Organization of the Study

The preparing of the objectives and scopes of study are explained as below;

**Stage 1: Explaining of the project on the objectives and scopes of the study**

It is to verify the feasibility of the study outcomes and planning of methodology for efficient thesis of input and output.

**Stage 2: Literatures, collecting data and modeling of structures**

Initial study shall be done to understand the behavior of the tall building structure and best solution for retrofitting. Knowing the performance of the tall building structure subjected to earthquake loading if is essential to assume the structure behave according to literature findings. Obtaining the information of model before head and spearhead the modeling technique is part of the requirement in successful overall analysis.

**Stage 3: Verification of retrofitting devices and modeling**

The purpose of this stage is to identify appropriate and application of retrofitting devices, which are the horizontal dampers devices. In addition, the theoretical background of the frame equipped by damper devices is also included to verify the concept of work on the device. Material properties and analysis methods have been determined to obtain correct mode shapes. The structure with and without damper has been modeled by ETABS software to verify the response of structure with appropriate earthquake signals. In other words, the models are proposed with (damped) and without (un-damped) horizontal damper for comparison purposes.

**Stage 4: Vulnerability assessment of modeling and response analysis**

The response spectrums and Time histories analysis have been done to find responses of the two models.

**Stage 5: Discussion and conclusion**

Summary of the project according to the different analysis methods and comments on the further improvement to the study are to be enumerated.

## REFERENCES

ACI, Innovation Task Group 1 (2001). *Acceptance Criteria for Moment Frames Based on Structural Testing (ACI T1.1-01) and Commentary (ACI T1.1R-01).* American Concrete Institute, Farmington Hills, Michigan, USA.

Agrawal, J. N. Y. a A. K. (2002). *Semi-active Hybrid Control Systems for Nonlinear Buildings Against Near- field Earthquakes.* Engineering Structures **24**(3): 271-280.

Aiken, I.D. and Kelly, J.M. (1990). *Earthquake Simulator Testing and Analytical Studies of Two Energy-Absorbing Systems for Mutistory Structures.* Report No. UCB/EERC-90/03. University of California, Berkeley, CA, USA.

Amr. S. E. (2008). *Fundamentals of Earthquake Engineering.* (1st ed). Chichester, UK: Wiley.

Anil. K. C. (2002). *Dynamics of Structures, Theory and Applications to Earthquake Engineering.* (3rd ed). Upper Saddle River, N.J.: Prentice Hall, 2001.

An-Pei. W., and Yung-Hing. L. (2006). Vibration control of a tall building subjected to earthquake excitation. *Journal of Sound and Vibration.* 299(2007), pp. 757-773.

ASCE. (2000). Pre-standard and Commentary for the Seismic Rehabilitation of Buildings (FEMA-356) (Report No. FEMA 356). Reston, VA: *American Society of Civil Engineers prepared for the Federal Emergency Management Agency*.

ATC. (1985). Earthquake Damage Evaluation Data for California (ATC-13) (Report).

Redwood, CA: Applied Technology Council.

Avtar. S. P., and Cedric. M. (1982). Response of Friction Damped Braced Frames. Proceedings of the American Society of Civil Engineers, CASCE, Vol. 108, No. ST6.

Azlan. A., Tan Chee. W, Tan Beng. C. (2000). An Evaluation of High-Rise Building Performances Under Low Intensity Earthquake Effects. *The International Conference on Disaster Management: Lankawi.*

Azlan. A., Tan Chee. W. (2000). Response of High-Rise Buildings under Low Intensity Earthquake. *Japan-Turkey Workshop on Earthquake Engineering.*

Balendra. T., Lam. N. T. K., Perry. M. J., Lumantarna. E., Wilson. J. L. (2005). Simplified displacement demand prediction of tall asymmetric buildings subjected to long-distance earthquakes. *Engineering Structures,* 27 (2005), pp. 335-348.

Bath. K. J. (1996). *Finite element procedures*. Prentice-Hall, Englewood Cliffs, NJ.

Beedle, L. S., & Rice, D. B. (1995). Structural systems for tall buildings. Council on Tall Buildings and Urban Habitat (CTBUH) Committee 3.

Bozorgnia, Y. and Bertero, V. V. (Eds.) (2004). *Earthquake Engineering: From Engineering Seismology to Performance-Based Engineering*. Florida: CRC Press.

Building Seismic Safety Council, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Part 2 Commentary, FEMA 450, 2003, Washington, DC.

Carlos. Y. L., Chang. S. E., Avtar Pall, Ph.D., P.Eng, and Jason. J. C. Louie. S. E. (2003). *The use of Friction Dampers for Seismic Retrofit of the Monterey County Government Center.* San Francisco. C.A.

Chalhoub. M., and Kelly. J. (1990). Earthquake simulator testing of a combined sliding bearing and rubber bearing isolation system. Tech. rep., Report No. UCB/EERC-87/04, *Earthquake Engineering Research Center*, University of California, Berkely, CA.

Chopra A.K.(2000). "Dynamics of Structure: Theory and Applications to Earthquake Engineering. "Prentice Hall.

Connor, J. J. (2003). *Introduction to Structural Motion Control*. Pearson Education, Inc.

Constantinou, M. and Symans, M. (1992). *Experimental and Analytical Investigation of Seismic Response of Structures with Supplemental Fluid Viscous Dampers*. NCEER-92-0032, State University of New York at Buffalo, Buffalo, New York.

Constantinou M. C, Mokha A, Reinborn A. (1990) Teflon bearings in base isolation: modeling. *Journal of structural Engineering*, Vol.116 No.2, pp.445-474.

Dowdell, D.J. and Cherry, S. (1994) *Semi-Active Friction Dampers for Seismic Response Control of Structures*. Proc 5th US National Conf. On Earthquake Engng, Vol. 2, Chicago, IL, P. 819-828.

Filiatrault. A., and Cherry. S. (1987). Performance Evaluation of Friction Damped Braced Steel Frames under Earthquake Loads. *Earthquake Spectra.* Vol. 3, No. 1, pp. 57-78.

Garcia, D. L. and Soong, T. T. (2002). *Efficiency of A Simple Approach To Damper Allocation in MDOF Structures.* J. Struct. Cont., 9(1), 19-30.

Gaurav Rastogi, Khalid Moin and S.M Abbas (2015). Dimensional analysis and development of similitude rules for dynamic structural models. *International Journal of Emerging Technology and Advanced Engineering.* Volume 5, Issue

3, March 2015. pp 68-72.

Ghobarah, A. (2001). Performance-Based Design in Earthquake Engineering: State of Development. *Engineering Structures.* 23, 878-884.

Hanson RD and Soong TT. (2001). *Seismic Design with Supplemental Energy Dissipation Devices.* EERI Monograph No. 8, Oakland (CA): Earthquake Engineering Research Institute.

Imad. H., Mualla and Borislav. B. (2002). Performance of steel frames with a new friction damper device under earthquake excitation. *Engineering Structures.* 24, pp. 365-371.

Jacek Baranski, Piotr Berkowski (2015). Computer modelling of precast large-panel buildings with degraded horizontal joints. *Science Direct. Procedia Engineering 111 (2015)*, pp 89 – 96.

Lee, S.K., Park, J.H., Moon, B.W., Min, K.W., Lee, S.H, Kim, J.K. (2007).

*Design of a bracing-friction damper system for seismic retrofitting.* Smart Structures and Systems, Vol. 4, No. 5 (2008) 685-696.

Lopez Garcia. D. and Soong. T. T. (2002). Efficiency of a simple approach to damper allocation in MDOF structures. *Journal of Structural Control*, 9 (1), 19-30.

Marsono. A. (2009). *Tall building system: Analysis and Design.* Department of Structure and Materials. Faculty of Civil Engineering. UTM

Mir, M. Ali and Kyoung, S.M. (2007). Structural development in tall building: Current trends and future prospects. *Architectural Science Review*. Volume 50.3, pp 205 – 223.

Miyamoto, a R. D. H. (2004). *Structural Practices, Seismic Dampers: State of the Applications*. Structure Magazine: 16-18.

Moe. C. and Simon. F., Jacques. G. (2000). *Research and Application of Seismic Retrofit Technologies in Canada*. Hull, Quebec, Canada and Vancouver, British Columbia, Canada.

Mohsen. T and Farzaneh. H. (2002). Influence of earthquake source parameters and damping on elastic response spectra for Iranian earthquakes. *Engineering Structures.* 24(2002), pp. 933-943.

Moreschi, L. M., Singh, M. P. (2003). *Design of Yielding Metallic and Friction Dampers For Optimal Seismic Performance*. Earthq. Eng. Struct. Dyn., 32, 1291-1311.

Nayfeh, A. H. and Pai, P. F. (2004). *Linear and Nonlinear Structural Mechanics*. John Wiley & Sons.

NEHRP (2000). FEMA 356 / 357. Guidelines for the Seismic Rehabilitation of Buildings. Washington D. C.

Nims, D.K, Richter, P.J., Bachman, R.E. (1993) *The Use of Energy Dissipating Restraint for Seismic Hazrd Mitigation.* Earthquake Spectra, 9(3):467-89.

Nishant. K. R., Reddy. G.R., Ramanujam. S., Venkatraj. V., and Agrawal. P. (2009). Seismic Response Control Systems for Structures. *Defense Science Journal,* Vol. 59, No. 3, pp. 239-251.

Ou, J., Long, X., Li, Q. S. and Xiao, Y. Q. (2006). Vibration Control of Steel Jacket Offshore Platform Structures with Damping Isolation Systems. *Engineering Structures.*

Perry C. L., Fierro E. A., Sedarat H., Scholl R. E. (1993). *Seismic upgrade in San Francisco using energy dissipation devices*. Earthquake Spectra; 9(3):559–79.

Qu, W. L., Chen, Z. H., and Xu, Y. L. (2001). *Dynamic Analysis of Wind-excited Truss*

*Tower with Friction Dampers.* Computers and Structures 79 (2001) 2817-283, Pergamon, Elsevier Science Ltd, UK.

Robert Reitherman (1977). Historic Developments in the Evolution of Earthquake Engineering, *Adapted from the 1998 CUREE Calendar, Consortium of Universities for Research in Earthquake Engineering*, pp. 1 – 13.

Scawthorn, C. (1999). Earthquake Engineering. In: Chen, W. F. (Ed.) *Structural Engineering Handbook*. Boca Raton: CRC Press LLC.

Scholl. R. E. (1990). Improving the Earthquake Performance of Structures with Added Damping and Stiffness Elements. *Proceeding of Fourth U.S. National Conference on Earthquake Engineering.* Palm Spring California, 3, pp. 489-498.

Semih. S., Tezcan and Ozan. U. (2003). Reduction of earthquake response of plane frame buildings by viscoelastic dampers. *Engineering Structures.* 25(2003), pp. 1755-1761.

Soong. T. T., Dargush. G. F. (1997). Passive Energy Dissipation Systems in Structural Engineering. *John Willey & Sons Ltd.* ISBN. 0-471-96821-8.

Soong, T. T. and Spencer, B., F. Jr (2002). *Supplemental energy dissipation: state-of-the-art and state-of-the practice*. Engineering Structures 24 (2002) 243–259.

Stein, S. and Wysession, M. (2003). *An Introduction to Seismology, Earthquakes and Earth Structure*. Blackwell Publishing.

Suhardjo J., Spencer B.F., Sain M. K. (1990). *Feedback–feedforward control of structures under seismic excitation.* Struct Safety; 8:69– 89.

Teng, Y. L. X. a J.(2002). *Optimum Design of Active/Passive Control Devices for Tall Buildings Under Earthquake Excitations*. The Structural Design of Tall Buildings **11**(2): 109-127.

Tsai. C. S., Bo-Jen. C, Pong. W. S., Tsu-Cheng. C. (2004). Interactive Behavior of Structures with Multiple Friction Pendulum Isolation System and Unbounded Foundations. *Advances in structural engineering*, Vol. 7, No. 6, pp. 539-551.

Vamvatsikos D., Cornell C.A. (2002). Incremental Dynamic Analysis. Earthquake Engineering and Structural Dynamics, 31(3): pp. 491–514.

Viti. S., Cimellaro. G. P., and Reinhorn. A. M. (2006). Retrofit of a hospital through strength reduction and enhanced damping. *Smart Struct. Sys.* 2(4).

Wen-I. L., Imad. M., and Chin-Hsiung. L. (2004). Shaking-Table Test of a Friction-Damped Frame Structure. *Struct. Design Tall Spec. Build.* 13. pp. 45-54.

# SEISMIC ANALYSIS FOR MULTI-STORY BUILDING HORIZONTALLY DAMPED ABOVE BASEMENT LEVEL

MOHAMMED ZIAUDDIN PATOWARY[1], ABDUL KADIR MARSONO[2*] & MOHD ZAMRI RAMLI[2]

[1]*Postgraduate Student, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia*

[2]*Department of Structure and Material, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia*

*Corresponding author: akadir@utm.my

**Abstract:** Buildings in the city often have underground storage space for parking and building equipments. While seismic damper device devices usually are also placed here, making maintenance difficult. The main objective of this study was to evaluate the effectiveness of horizontal dampers at its position relative to at the bottom end of column basement. Among the various types of seismic dampers, type of viscous elastics was selected for this numerical study because of its simplicity. For better understanding of the study, a horizontal damper absorber is considered rigidly supported and is not affected by the act of soil and foundation of the building. In this numerical study, five prototype buildings have been analyzed by the different height position of its horizontal dampers. Modeling and analysis of the prototype buildings was done by using finite element software, ETABS. An earthquake time history analysis (05 / Jun / 2015) with the PGA of 0.126g of Sabah, Malaysia has been used to simulate the five building the prototype against seismic forces. Analysis produces dynamic characteristics such as natural period, displacement between floors, and its base shear displacement on the foundation. Comparison of the efficiency of the prototype shows the real values of horizontal damper installation vertical floor levels.

**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 limitations 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.

## 2.1 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).

## 2.2 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.

## 2.3 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).

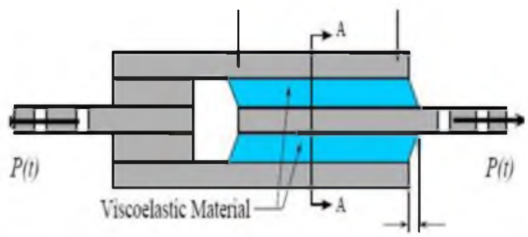



**Figure 1.** Typical view of a visco-elastic damper

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 modeled 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 (Case A) 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.

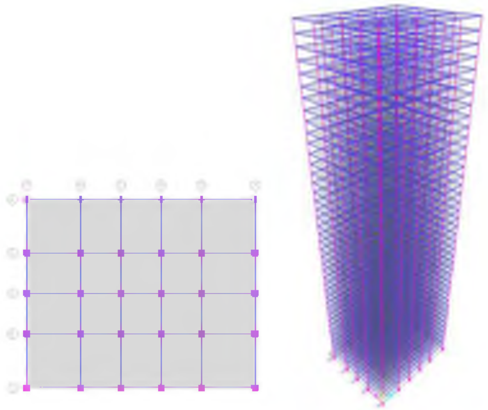


**Figure 2.** Plan view and elevation of the hypothetical building

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.

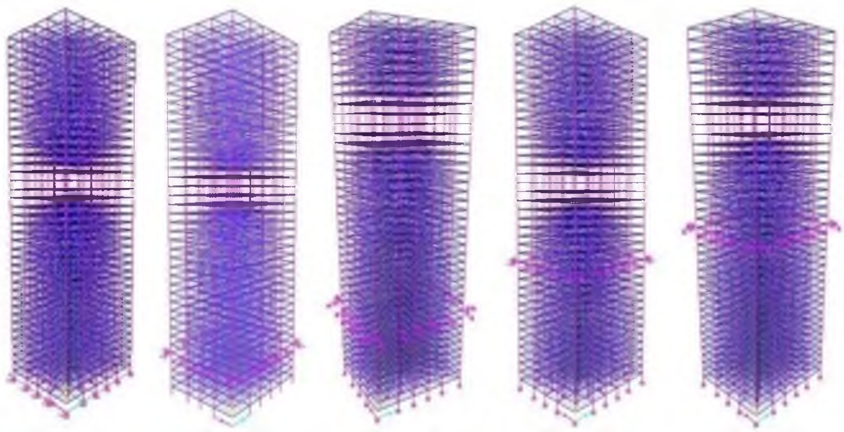


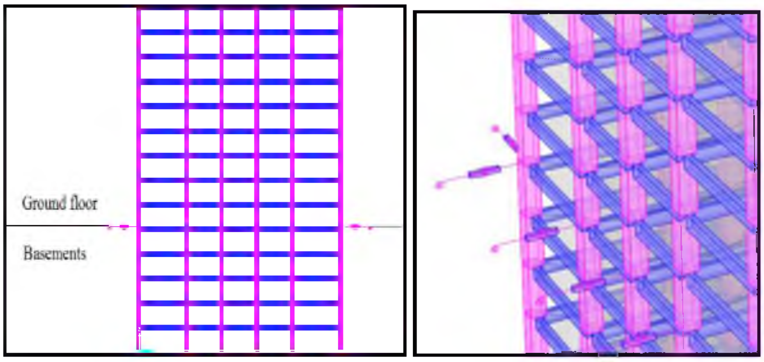

**Figure 3.** Buildings with different cases

### 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 un-damped 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 (31).

A total of 22 dampers were 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

**Figure 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.

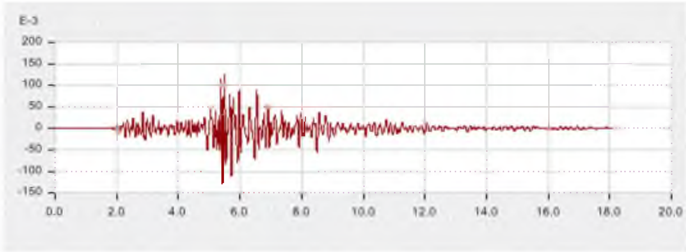



**Figure 5.** Sabah earthquake acceleration vs time

### 3.4 Time history analysis in ETABS

Time-history analysis is most suitable analysis method for analyzing the structures under specific earthquake record (32). 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 (33). The specific earthquake record is inputted at the base of the structure during the analysis (34). 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.

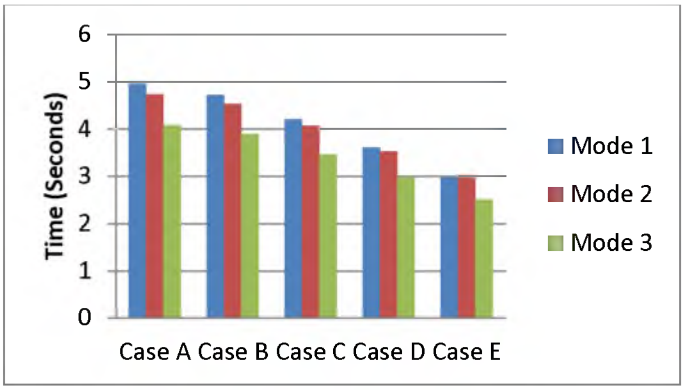



**Figure 6.** Natural periods for first 3 modes

## 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 |

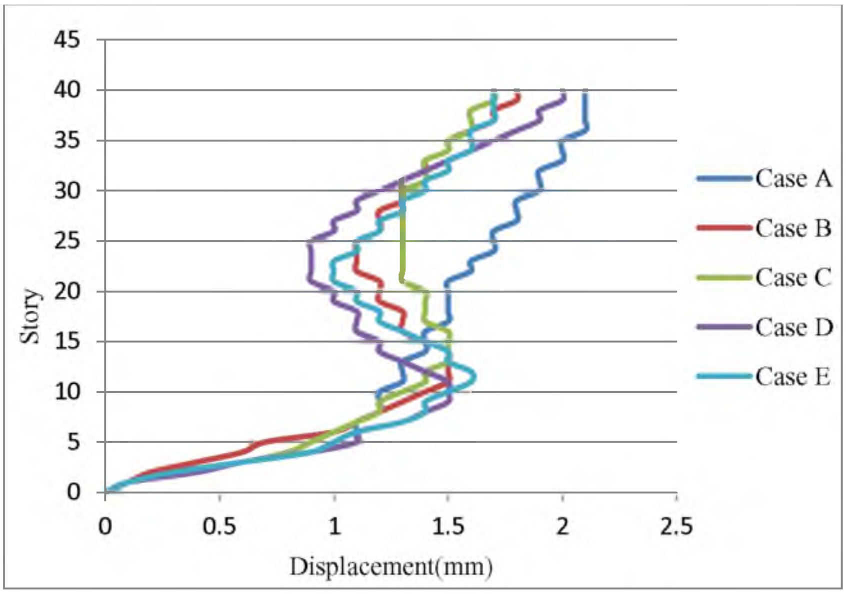



**Figure 7.** Story displacements for different cases

### 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 storey 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.

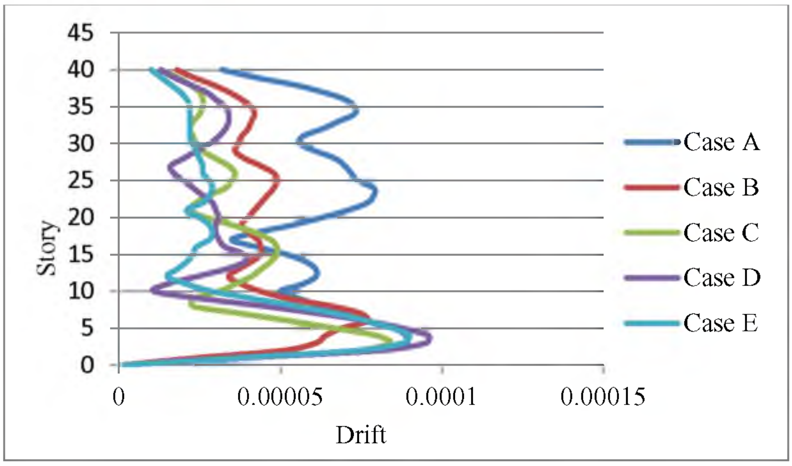



**Figure 8.** Inter-storey drifts of different cases

## 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:

(1) 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.

(2) 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.

(3) 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.

(4) 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.

## REFERENCES

1. Oliveto ND, Scalia G, Oliveto G. Time domain identification of hybrid base isolation systems using free vibration tests. Earthquake Engineering & Structural Dynamics. 2010;39(9):1015-38.

2. Haskell G, Lee D. Fluid viscous damping as an alternative to base isolation. ASME-PUBLICATIONS-PVP. 1996;330:35-40.

3. Lee D, Kim H, editors. Efficient seismic analysis of high-rise buildings considering the basements2001: NZSEE Conference.

4. Raheem SEA. Evaluation of Egyptian code provisions for seismic design of moment-resisting-frame multi-story buildings. International Journal of Advanced Structural Engineering. 2013;5(1):1-18.

5. Council NR. Preventing earthquake disasters: the grand challenge in earthquake engineering: a research agenda for the Network for Earthquake Engineering Simulation (NEES): National Academies Press; 2003.

6. Datta TK. Seismic analysis of structures: John Wiley & Sons; 2010.

7. Viti S, Cimellaro GP, Reinhorn AM. Retrofit of a hospital through strength reduction and enhanced damping. Smart Structures and Systems. 2006;2:339-55.

8. Ribakov Y, Reinhorn AM. Design of amplified structural damping using optimal considerations. Journal of Structural Engineering. 2003;129(10):1422-7.

9. Madsen L. Improving the seismic response of structures by the use of dampers in shear walls. ME thesis, School of Civil Engineering, Queensland University of Technology, Brisbane, Australia. 2001.

10. Hisano K, Kuribayashi H, Saitou K, Nakano T, editors. The application example of the hybrid damping system combined the hysteretic damper with viscous damper to highrise building. Proc 5th Inter Conf on Motion and Vibration Control, Sydney, Australia; 2000.

11. Bhattacharya K, Dutta SC. Assessing lateral period of building frames incorporating soil-flexibility. Journal of sound and vibration. 2004;269(3):795-821.

12. Saad G, Saddik F, Najjar S, editors. Impact of soil structure interaction on the seismic design of reinforced concrete buildings with underground stories. Proceedings of the 15th World Conference on Earthquake Engineering; 2012.

13. Pong W, Gannon GA, Lee Z-H. A comparative study of seismic provisions between the international building code 2003 and Mexico's manual of civil works 1993. Advances in Structural Engineering. 2007;10(2):153-70.

14. Zhou FL. Seismic isolation of civil buildings in the People's Republic of China. Progress in Structural Engineering and Materials. 2001;3(3):268-76.

15. Council BSS. NEHRP guidelines for the seismic rehabilitation of buildings. FEMA-273, Federal Emergency Management Agency, Washington, DC. 1997.

16. Hameed A, Qazi A-u, Rasool AM. Seismic Performance of Low to Medium Rise Reinforced Concrete Buildings using Passive Energy Dissipation Devices. Pakistan Journal of Engineering and Applied Sciences. 2016.

17. Chen R, Xing G, editors. SEISMIC Analysis of high-rise buildings with composite metal damper. MATEC Web of Conferences; 2015: EDP Sciences.

18. Soong TT, Dargush GF. Passive energy dissipation systems in structural engineering: Wiley; 1997.

19. Kelly JM, Skinner R, Heine A. Mechanisms of energy absorption in special devices for use in earthquake resistant structures. Bulletin of NZ Society for Earthquake Engineering. 1972;5(3):63-88.

20. Di Sarno L, Elnashai A. Innovative strategies for seismic retrofitting of steel and composite structures. Progress in Structural Engineering and Materials. 2005;7(3):115-35.

21. Athanasiou A, Oliveto G, Takayama M, Morita K, editors. Problems in the identification of base isolation systems from earthquake records. Proceedings of the 15th annual conference companion on Genetic and evolutionary computation; 2013: ACM.

22. Mahmoodi P, Robertson L, Yontar M, Moy C, Feld L, editors. Performance of viscoelastic dampers in world trade center towers. Dynamics of Structures:; 1987: ASCE.

23. Zhang R-H, Soong T. Seismic design of viscoelastic dampers for structural applications. Journal of Structural Engineering. 1992;118(5):1375-92.

24. Chang K-C, Lin Y-Y. Seismic response of full-scale structure with added viscoelastic dampers. Journal of Structural Engineering. 2004;130(4):600-8.

25. Hwang J-S, Huang Y-N, Yi S-L, Ho S-Y. Design formulations for supplemental viscous dampers to building structures. Journal of structural engineering. 2008;134(1):22-31.

26. Rai NK, Reddy G, Ramanujam S, Venkatraj V, Agrawal P. Seismic response control systems for structures. Defence Science Journal. 2009;59(3):239.

27. Mcnamara RJ, Taylor DP. Fluid viscous dampers for high-rise buildings. The structural design of tall and special buildings. 2003;12(2):145-54.

28. Astaneh-Asl A. Seismic behavior and design of composite steel plate shear walls: Citeseer; 2002.

29. Symans MD, Constantinou MC. Semi-active control systems for seismic protection of structures: a state-of-the-art review. Engineering structures. 1999;21(6):469-87.

30. Chopra AK, Goel RK. A modal pushover analysis procedure to estimate seismic demands for unsymmetric-plan buildings. Earthquake engineering & structural dynamics. 2004;33(8):903-27.

31. Kazi R, Muley P, Barbude P. Comparative Analysis of a Multistorey Building with and without Damper. International Journal of Computer Applications, ISSN. 2014:0975-8887.

32. Mwafy A, Elnashai A. Static pushover versus dynamic collapse analysis of RC buildings. Engineering structures. 2001;23(5):407-24.

33. Bagheri B, Firoozabad ES, Yahyaei M, editors. Comparative study of the static and Dynamic Analysis of Multi-Storey Irregular building. Proceedings of World Academy of Science, Engineering and Technology; 2012: World Academy of Science, Engineering and Technology (WASET).

34. Kharade AS, Kapadiya SV, Belgaonkar SL. Earthquake analysis of tall sky-pod structures by considering the soil structure interaction effect. Elastic. 2013;46550(71425):123000.