SHEAR WALL OF MULTI STORY WALL BEAM SYSTEM FOR TALL BUILDINGS

KYAW NAING WIN

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

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2017

This project report is dedicated to my parents and my family who raised me with all their hearts and taught me to live as an optimist and give endless support and encouragement to achieve one of my desires.

ACKNOWLEDGEMENT

This research work would not have been possible without the guidance of my brilliant supervisor as well as a motivator, **Associate Professor Dr. Abdul Kadir Bin Marsono** whom I deeply grateful for his encouragement, support, guidance and the valuable and incomparable teaching received in these years of study. A special thanks must go to my co-supervisor **Mohd. Zamri Bin Ramli** for his patience and knowledge in engineering and his kind hospitality. 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. Finally, thanks to all people for the chance to conduct part of this research at the Universiti Teknologi Malaysia.

Thank you…

ABSTRACT

Precast construction with wall beam system has gain many advantages in multi storey building construction. In addition, high rise building plays an important role not only in accommodation issue but also in safety issue of the lives during construction and living in that building. Therefore, most of the engineers explore the safer construction methods and economical solution for the construction of multi storeyed building. Moreover, wall beam system has a high resistance in the earthquake (lateral) load since the shear wall has been used as one of the main structural elements. Many research and testing has been done in shear wall analysis using various methods to determine the strength, the behaviour and failure mechanism of the shear wall. In this research work the dynamic properties and failure mechanism of scale-down shear wall with regular openings subjected to real seismic loads on shake table test are discussed. For this purpose, the experimental works are carried out in accordance with PGA (peak ground acceleration), natural frequency, mode of shapes, pushover testing and failure mechanism of the shear wall are evaluated and compared with the results from FEM software (ETABS). To sum up, wall beam system has many advantages in construction and it can be said that it is the most time effective construction method among the other construction methods especially if IBS is introduced. In addition, this type of structural system can withstand the lateral loads (earthquake) than any other types of the structure. Therefore, nowadays, this method has been accepted as one of the most appropriate methods in tall building construction system.

ABSTRAK

Pembinaan pratuang dengan sistem rasuk dinding telah mendapat keutamaan dalam pembinaan bangunan bertingkat. Di samping itu, bangunan bertingkat tinggi memainkan peranan penting bukan sahaja dalam isu penginapan tetapi juga dalam isu keselamatan kehidupan semasa pembinaan dan mendiami bangunan tersebut. Oleh itu, kebanyakan Jurutera meneroka kaedah-kaedah pembinaan yang lebih selamat dan penyelesaian yang menjimatkan bagi pembinaan bangunan bertingkat. Selain itu, sistem bangunan rasuk berdinding mempunyai rintangan yang tinggi beban sisi gempa bumi dan telah digunakan sebagai salah satu daripada unsur struktur utama. Banyak penyelidikan dan ujian telah dilakukan untuk dinding Ricih dengan menggunakan pelbagai kaedah untuk menentukan mekanisme kekuatan, tingkah laku dan kegagalan. Dalam kajian ini mekanisme dinamik dan kegagalan dinding ricih berskala kecil dengan bukaan berulang digegarkan pada meja seismic juga dibincangkan. Bagi tujuan ini, kerja-kerja eksperimen dijalankan mengikut PGA (puncak pecutan tanah), frekuensi semulajadi, cara bentuk, ujian sisihan dan mekanisme kegagalan dinding ricih dinilai dan dibandingkan dengan keputusan dari perisian FEM (ETABS). Secara ringkanya, sistem bangunan rasuk berdinding mempunyai banyak kelebihan dalam pembinaan dan ia boleh dikatakan menjimatkan masa pembinaan. Di samping itu, sistem struktur jenis ini boleh menahan beban sisian (gempa bumi) berbanding jenis lain-lain struktur. Oleh itu, kaedah ini boleh diterima pakai sebagai salah satu kaedah yang paling sesuai dalam membina sistem pembinaan pakai bangunan tinggi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Wall-Beam System

During the late 19th century, the tall buildings emerged as one of the national landmarks for the country but most of the people barely knew the effects of governing factors in constructing the tall buildings. At that time, the world population was growing steadily and most of the people thought that the requirements for the high rise accommodation is not very important than any other daily life needed things. Therefore, they tried to build tall buildings not only for landmark but also for showing how their engineering expertise and construction techniques has been innovated quickly. (Mir & Kyoung, 2007).

Nevertheless, in present days, the demand for accommodation is rising sharply due to the dramatic increase population and urbanization. Therefore, the role of high rise building becomes famous and important. In addition, due to the growth of world population, people are now finding the places not only to provide accommodations but also to find the time saving construction methods and safety for the lives, living in that multi storey building. There are many methods in constructing multi storey building. Among them, wall beam system is one of the most effective and time saving methods in construction. (Chaitanya & Lute, 2013).

Wall beam system is defined as one of the construction methods using reinforced concrete wall (shear wall cast in-situ) and precast / pre-stressed slabs and beams, instead of using conventional columns as shown in Figures 1.1 and 1.2.

Figure 1.1 Construction of Multi Story Wall Beam System

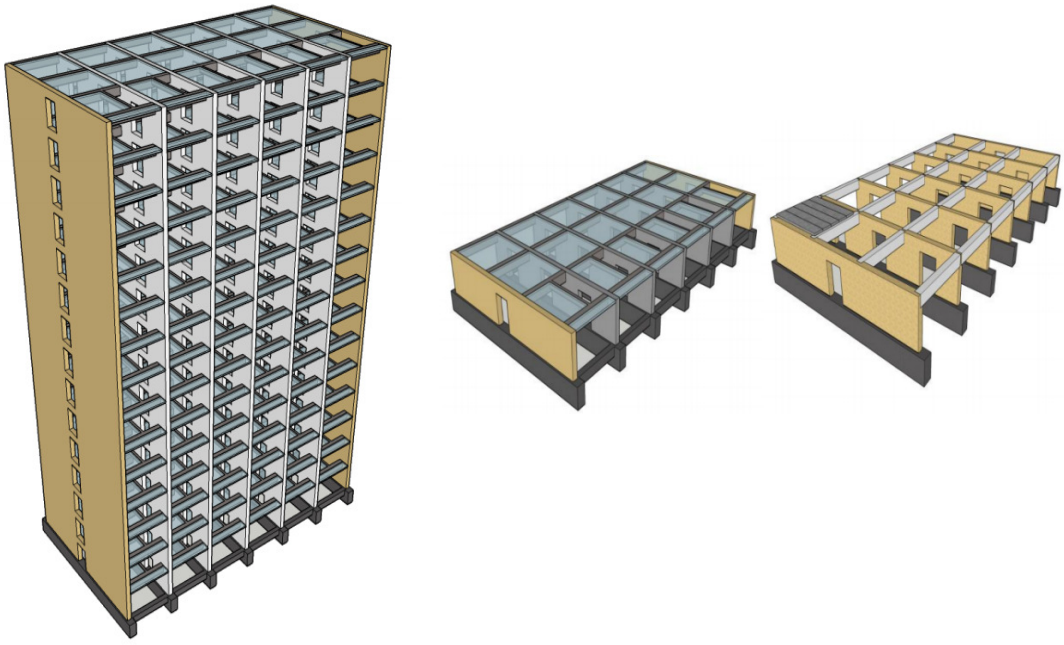

Figure 1.2 Multi Story Wall Beam System

In wall beam system, the shear wall will react as a vertical cantilever in multi storey building due to earthquake, wind (lateral load) and natural frequency of vibration. (Chaitanya & Lute, 2013) (Mir & Kyoung, 2007). In most cases, the shear wall is perforated for doors and windows in order to get the ease of access in the building. In this case, shear wall will suffer minor effects as a load bearing and act with a coupling beam action which is the condition that will happen when two or more shear walls are connected in the same plane by beams or slabs. In the case of perforated shear wall, "*the total stiffness of the system exceeds the sum of the individual wall stiffness because the connecting beam forces the walls to act as a single unit by constraining their individual cantilever actions*" (Mir & Kyoung, 2007).

As building heights increase, the importance of lateral force action rises at an accelerating rate. At a certain height, the lateral sway of the building becomes so great that considerations of stiffness, rather than strength of structural material, control the design. The degree of stiffness depends primarily on the type of structural system. Furthermore, the efficiency of a particular system is directly related to the quantity and quality of the materials used. Therefore, the optimization of the structure for certain spatial requirements should yield the maximum stiffness with least weight (W. Schueller, 1976).

The wall beam construction method has been founded in a past few decades and it has more advantages in comparison to any other construction methods in multi storey building construction. In in-situ, the construction time is very important and using precast system has less side effect on the labours. In addition, precast system speeds up the construction time and using less workmanship power, so that the construction accident will be reduced and the time consumed by accident will be reduced as well. Moreover, the wall beam system provides an economical solution compare to the frame structure in-fill wall system which is using as one of the conventional methods in construction field. (Chaitanya & Lute, 2013)

To sum up, wall beam system has many advantages in construction and it can be said that the most time effective construction method among various construction

methods. In addition, using shear wall and precast system accelerate the construction time and less side effect on the workmanship. Moreover, this type of structural system can withstand the lateral loads in under certain load combinations. Therefore, nowadays, this method has been accepted as one of the most appropriate methods in tall building construction system.

1.1.2 Seismic Analysis

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or non-building) structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are predominant. Commonly, a building has the potential to 'wave' back and forth during an earthquake (or even a severe wind storm). This is called the 'fundamental mode', and is the lowest frequency of building response. Most buildings, however, have higher mode shapes of response, which are uniquely activated during earthquakes. The first and second mode shapes tend to cause the most damage in most cases. (Reitherman, 1997)

The earliest provisions for seismic resistance were the requirement to design for "*a lateral force equal to a proportion of the building weight (applied at each floor level)*". This approach was adopted in the appendix of the 1927 Uniform Building Code (UBC), which was used on the west coast of the United States. It later became clear that the dynamic properties of the structure affected the loads generated during an earthquake. (ASCE 2000, FEMA-356)

Earthquake engineering has evolved a lot since the early days, and some of the more complex designs now use special earthquake protective elements either just in the foundation (base isolation) or distributed throughout the structure. Analysing these types of structures requires specialized explicit finite element computer code, which divides time into very small slices and models the actual physics. (Wilson and Clough, 1999).

1.2 Problem Statement

The higher the building, the greater the interference of lateral loads and slenderness (which is one of the main factors governing in tall building construction) to the structural system. So, the governing factors can be determined with the help of structural engineering software like ETABS, Multi Frame, STADD Pro, SAP2000 etc. Past few decades, some of the modelling and analysis works regarding with behaviour and stability of the shear wall, checking time history, push over test and shear wall test has been done for this type of structural system.

Nevertheless, a few works regarding with the joint analysis, joint displacement, similitude modelling and shake table testing has been done before. In this research work, the dynamic response and failure mechanism of scale-down shear wall with regular openings subjected to incremental seismic loads using shake table analysis are discussed. For this purpose, the experimental works are carried out, evaluate and compared with the results from FEM software (ETABS).

1.3 Aims and Objectives

In this research work, following facts are considered as major objectives regarding with the wall beam system in multi storey building.

I. To determine the dynamic modal properties of the shear wall element.
II. To obtain and determine the failure mechanism of shear wall using shake table test in the laboratory.
III. To evaluate the structural response up to 1.0g using shake table test.

1.4 Scope of the study

The three main cases of shear wall system which will be analysed and compared by experimental and numerical analysis based on loading system.

I. Scale-down 6 story shear wall with regular openings using alternate floor loading system.

II. Scale-down 12 story shear wall with regular openings using alternate floor loading system.

III. Scale-down 12 story shear wall with regular openings using inverted pendulum effect loading system.

1.5 Research Significance

According to previous research on structural engineering, many methods and evaluations are done regarding with the analysis, push over testing, shake table testing, similitude rule and time history analysis. Only few works has been done regarding with the dynamic properties and failure mechanism of scale-down shear wall with regular openings subjected to real seismic loads on shake table test. This could be a new approach to shear wall test using shake table and producing PGAs (peak ground accelerations) to know the failure state of the shear walls.

REFERENCES

A. Klenke, S.Pujol, A. Benavent-Climent and D. Escolano-Margarit (2012). Failure mechanism of reinforced concrete structural walls with and without confinement. *The 15th World Conference on Earthquake Engineering, Lisboa, Spain.* pp 1-9.

Aarthi Harini T and G. Senthil Kumar (2015). Behaviour of R.C shear wall with staggered openings under seismic loads. *International Journal for Research in Emerging Science and Technology*. Volume 2, Issue 3, March-2015. pp 91-96.

Abdul Kadir Bin Marsono, (2015). Monograph of tall building system - analysis and design, Universiti Teknologi Malaysia.

Anuj Chandiwala (2012). Earthquake analysis of building configuration with different position of shear wall, *International Journal of Emerging Technology and Advanced Engineering*. Volume 2, Issue 12, pp 347-353.

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.

Bindurani.P, A. Meher Prasad and Amlan K.Sengupta. (2013). Analysis of precast multi-storeyed building – a case study. *International Journal of Innovation Research in Science, Engineering and Technology*. Volume 2, (special issue 1) 294 - 302.

Bozorgnia Y., Bertero V., "Earthquake Engineering: From Engineering Seismology to Performance-Based Engineering", CRC Press, 2004.

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

Chaitanya, K.J.D. and Lute, V. (2013). Analysis of multi storey building with precast load bearing walls. *International Journal of Civil and Structural Engineering*. Volume 4, No (2), pp 147 – 157.

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.

Gummadi Amar (2014), Analysis of reinforced concrete coupled shear wall using finite element method, *International Journal of Education and Applied Research,* Volume 4, Issue 2, July – December 2014, pp. 24 – 30.

Hatem Tagel-Din and Kimiro Meguro (2015), Analysis of a small scale R.C building subjected to shaking table tests using applied element method. *Institute of Industrial Science, The University of Tokyo, Tokyo, Japan.12 WCEE 2000, Volume 0464,* pp. 1 – 8.

Iman Ghorbanirenani, Robert Tremblay, Pierre Leger and Martin Leclerc (2012), Shake table testing of slender R.C shear walls subjected to eastern north America seismic ground motions. *Journal of Structural Engineering @ ASCE / December 2012, 138 (12)*, pp. 1515 – 1529.

István Demeter, Tamás Nagy-György, Valeriu Stoian and Daniel Dan (2008). Quasi-Static Loading Strategy for Earthquake Simulation on Precast RC Shear Wall. *12th WSEAS International Conference on SYSTEMS, Heraklion, Greece*. pp 813-819.

J. C. D. Hoenderkamp (2011), The influence of single shear walls on the behaviour of coupled shear walls in high-rise structures, *Science Direct, The 12th Asia-Pacific Conference on Structural Engineering and Construction*, Proceeding Engineering 14 (2011), pp. 1816 – 1824.

J.Marcial Blondet, Juan F. Yep and James M. Kelly (1988), Shaking table evaluation of strong motion data processing techniques. *Proceedings of Ninth World Conference on Earthquake Engineering*. August 2-9, 1988, Tokyo-Kyoto, Japan (Vol. IV), pp. 11 – 16.

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.

Julian Carrillo, Giovanni Gonzalez and Luis Llano (2012). Evaluation of mass-rig systems for shaking table experiments. *DYNA, Volume 79, No. 176, Nov. / Dec. 2012*, pp. 1 – 12.

Koichi Yabuuchi, Hiroshi Morikawa, Atsushi Suzuki, Yoshio Kitada, Shinsuke Oguri and Katsuki Takiguchi (2004), Simulation analysis of shaking table test for R.C seismic shear wall in multi-axis loading tests, *13th World Conference on Earthquake Engineering, Vancouver, B.C, Canada*, Paper No. 2511, August 1-6, 2004, pp. 1 – 14.

Masato Sakurai, Hiroshi Kuramoto, Tomoya Matsui and Tomofusa Akita (2008). Seismic performance of RC shear walls with multi-openings. *The 14th World Conference on Earthquake Engineering, Beijing, China*. pp 1-8.

Mazen A. Musmar (2013), Analysis of shear wall with openings using solid65 element, *Jordan Journal of Civil Engineering*, Volume 7, No. 2, 2013. pp. 164 – 173.

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.

Mohamad Salleh Yassin & Ramil Abdullah (2015). Monograph of Reinforced Concrete Design to EUROCODE 2. Universiti Teknologi Malaysia.

O.Esmaili, S.Epackachi, M.Samadzad and S.R. Mirghaderi (2008). Study of structural RC wall system in a 56-story RC tall building. *The 14th World Conference on Earthquake Engineering*. October 12-17.

Pedro A. Hidalgo, Christian A. Ledezma and Rodrigo M. Jordan (2002). Seismic behaviour of squat reinforcement concrete shear walls. *Earthquake Engineering Research Institute*. Earthquake Spectra, Volumn 18, No.2, pp 287-308.

Pierino Lestuzzi and Hugo Bachmann (2007), Displacement ductility and energy assessment from shaking table tests on RC structural walls, *Science Direct, Engineering Structures 29 (2007)*, pp. 1708 – 1721.

Qiyun Zhu, Xilin Lu, Huanjun Jiang and Bin Zhao (2012). Shaking table test and numerical analysis on a shear wall high-rise structure with huge podium. *15 WCEE, LISBOA 2012*, pp. 1 – 8.

Ramu M, Prabhu Raja V and Thyla P.R (2015). Development of structural similitude and scaling laws for elastic models. *Published paper, Faculty of Mechanical Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India-641 004*. pp 67-69.

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.

Rogerio Bairrao and Carlos T Vaz (2013), Shaking table testing of civil engineering structures – the LNEC 3D simulator experience. *National Laboratory for Civil Engineering, Av, Brazil 101-1700-006 Lisboa, Portugal, 12 WCEE 2000,* Paper No. 2129, pp. 1 – 8.

S. B. Yuksel & E. Kalkan, Failure mechanism of shear-wall dominant multi-story buildings: High Performance Structures and Materials, *Department of Civil Engineering, Selcuk University, Turkey & California Geological Survey, Sacramento, CA, USA*. pp-337 - 345

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

Wei-Ting Lin, Yuan-Chieh Wu, An Cheng and Hui-Mi Hsu (2014). Seismic response and numerical verification for a 1/25 scaled-down reinforced concrete reactor building specimen. *Transactions of the Canadian Society for Mechanical Engineering.* Volume 39, No.3, 2015. pp 479-488.

Wilson, E. and Clough R., "Early Finite Element Research at Berkeley", *presented at the Fifth U.S. National Conference on Computational Mechanics*, Aug. 4-6, 1999.

Wolfgang Schueller (1976), Monograph of common high-rise building structures and their behaviour under load, Chapter 5 – the bearing wall structure, Syracuse, New York, November 1976. pp. 81 – 123.\