Faculty of Engineering

SEISMIC PERFORMANCE OF LOW-RISE PRECAST CONCRETE STRUCTURE WITH DIFFERENT TYPES OF BEAM-COLUMN CONNECTIONS USING NONLINEAR STATIC PUSHOVER ANALYSIS

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Final Year Project Report ☐
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LIM HUNG LING

This project is submitted in partial fulfilment of the requirements for the Master of Engineering
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"Dedicated to Amy and my beloved family..."

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ABSTRACT

Due to demand of speedy building construction and well controlled quality, precast concrete structure, being an Industrialized Building System, can replace the traditional construction method. However, the research on precast concrete structure in seismic zone is still requiring improvement. Hence, in this study, the types of beam-column connections are the main focus as the critical design parameter. Three three-storey two-dimensional precast concrete skeletal frames with three different types of beam-column connection, namely rigid, semi-rigid and pinned are modeled using structural analysis software, SAP2000V15. An earthquake excitation is simulated by applying a 10kN lateral force at a roof tip using the nonlinear static Pushover Analysis (based on FEMA356). The roof displacements of these frames versus increasing base shear are monitored and the resulting pushover curves are compared. A Seismic Demand Curve on probable earthquake in Malaysia is also constructed according to the code provision ACT-40. It is found that rigid frame can withstand the highest base shear and lowest storey drifts-joint displacement. However, a few of its beams and columns are badly damaged. The semi-rigid frame produces similar result to rigid frame with slight reduction in maximum base shear. The pinned frame can only withstand very low base shear with large storey drift-joint displacement. It collapses due to 'Soft Storey Mechanism' where its columns at the base floor severely damaged while beams and columns above the base floor remain unaffected. When comparing capacity-demand curves of these three frames, the structural capacities of rigid frame and semi-rigid frame are able to meet seismic demand without severe damage. However, the structural capacity of pinned frame meets the seismic demand with severe damages in structural members. As a conclusion, the rigid and semi-rigid connections are suitable to be used in precast concrete skeletal structures in Malaysia.

ABSTRAK

Oleh kerana permintaan atas pembinaan bangunan yang cepat dan kualiti yang dikawal dengan baik, struktur konkrit pratuang, iaitu sejenis Sistem Bangunan Perindustrian, boleh menggantikan kaedah pembinaan tradisional. Walau bagaimanapun, penyelidikan pada struktur konkrit pratuang dalam zon seismik masih memerlukan pembaikan. Oleh itu, dalam kajian ini, jenis sambungan rasuk- tiang adalah fokus utama sebagai parameter reka bentuk yang kritikal. Tiga dua dimensi konkrit pratuang bingkai rangka yang bertingkat tiga dengan tiga jenis sambungan rasuk- tiang berlainan, iaitu tegar, separa tegar dan disematkan telah dimodelkan dengan menggunakan perisian analisis struktur, SAP2000V15. Satu ujaan gempa bumi adalah disimulasi dengan menggunakan daya sisi 10kN di hujung bumbung menggunakan Analisis pushover statik yang tak linear (berdasarkan FEMA356). Anjakan bumbung ini bingkai berbanding peningkatan ricih asas dipantau dan graf pushover terhasil dibandingkan. Satu graf permintaan seismik dari gempa bumi kemungkinan di Malaysia juga dibina mengikut peruntukan kod ACT-40. Ia didapati bahawa kerangka tegar boleh menahan asas ricih tinggi dan simpangan tingkat atau anjakan sendi terendah. Walau bagaimanapun, beberapa rasuk dan tiang didapati telah rosak teruk. Rangka separa tegar memberi hasil analysis yang agak sama dengan kerangka tegar dengan sedikit penurunan dalam ricih asas maksimum. Rangka disematkan hanya boleh menahan ricih asas yang sangat rendah dengan simpangan tingkat atau anjakan sendi besar tingkat. Ia runtuh disebab oleh kejadian 'Mekanisme Tingkat Lembut' di mana tiang di tingkat terbawah telah rosak dengan teruk manakala rasuk dan tiang di tingkat atas berkekal tidak terjejas. Apabila membandingkan kapasiti keluk permintaan bagi ketiga-tiga bingkai, kapasiti struktur kerangka tegar dan bingkai separa tegar dapat memenuhi permintaan seismik tanpa kerosakan teruk. Walau bagaimanapun, keupayaan struktur rangka disematkan masih memenuhi permintaan seismik dengan kerosakan teruk pada anggota struktur. Kesimpulannya, sambungan tegar dan separa tegar adalah sesuai untuk digunakan dalam konkrit pratuang struktur rangka di Malaysia.

TABLE CONTENT

CHAPTER 4: RESULTS AND DISCUSSION

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Precast concrete structure is well-known as a part of the Industrialized Building System (IBS). The building structure is constructed by using massive fabricated construction components. These construction components are fabricated in a factory by casting concrete using few reusable formworks. Then, they undergo curing stage under a controlled environment. When they are ready, they are transported to the construction site and erected as a structure (Glass, 2000).

Precast concrete has been used in the United State before the 19^{th} century. However, it is not widely spread around the world by then. After World War in Europe, it starts to gain popularity as people have to massively reconstruct buildings. During 1901 to 1940, many experiments were done. Since then, large number of commercial offices, hotels, apartments, car parks and factories have been built in Europe and North America (Glass, 2000).

There are several advantages of using precast concrete construction. Precast concrete products are high in quality and uniform standard as they are mass produced under a controlled environment in a manufacturing plant. Even though the precast components have difficulty in transporting due to heavy and large-sized, the speed of installation is more reliable compared to the cast in-situ concrete. All precast components are designed for simple connection to allow many components to be installed in a short time (Frank, 2002). However, there are some disadvantages of precast concrete construction in term of design and dimension flexibility and also other factors. Design and dimension flexibility may be limited as the manufacturers have fixed sizes and shapes of mould for producing precast components. Besides, the connections that are joining the precast components can be the weakness to the building stability. Hence, these connections are the one of critical design parameters (Mishra, 2011).

The design of joints for the beam-column connection is very vital for earthquake resistant of modern structural buildings such as reinforced concrete, steel, and precast concrete buildings. The importance of beam-column connection is recognized for the structural integrity as such beam-column connection is necessary to be capable to resist and sustain the loads transmitted from beams and columns with sufficient stiffness and strength. Moreover, different types of beam-column connection have various characteristics that may influence the behavior of a structure in terms of deflection or bending moment transferred especially in response to earthquake.

For example, normal reinforced concrete building has rigid beam-column connections as the building is casted monolithically. These rigid beam-column connections allow the building to be stiff to resist the low lateral force due to low magnitude earthquake and thus, the building will sway at very small displacement. However, when the building meets high magnitude earthquake, the building will sway more but due to stiffness of building, structural members will break as the bending moment exceeds the capacity of structural members.

1.2 Problem Statement

An earthquake is described as ground shaking caused by the sudden release of energy in the Earth's crust. This energy may be due to different sources, such as dislocations of the crust, volcanic eruptions, or even by man - made explosions or the collapse of underground cavities, such as mines or karsts. In early 19th century, many studies on predicting earthquake had been tried but been concluded as the earthquake was unpredictable. Later in 20th century, a few studies finally showed the earthquake is predictable. However, the accuracy of predicting time of occurrence, location of epicenter and magnitude still requires improvement. It is only accurate for predicting the earthquake that is soon to occur.

Importantly, earthquake is one of destructive natural disasters that causes building destruction and life lost. Higher the magnitude of earthquake can induce greater ground motion and more energy released. Greater energy released from earthquake is indicating greater destructive power of the earthquake. Kobe Earthquake in 1995 with magnitude 7.2 caused over 10,000 building damaged. A part of them were reinforced concrete buildings which faced shear failure of columns that caused entire structural failure (Figure 1.1). Furthermore, currently important issue to be concerned is that Malaysia has been affected by aftershock from Sumatra's earthquake for several times.

The survivability of a structural building through an earthquake mainly depends on its earthquake response controlling parameters such as stiffness, strength and ductility. The higher the magnitude of the earthquake can cause the structural building swaying in large deformation or displacement. In the study of structural stability of precast concrete structures, the beam-column connection is the main element governing the structural behavior in responding to various loads such as earthquake. Different types of connections that are available for precast concrete structural building, namely pinned and rigid beam-column connections may provide various stiffness and ductility. The recent studies on precast concrete beam-column connections are mainly in experimental stage. Therefore, these researches are contributing to further exploration on studying the precast concrete structures in seismic zone. Thus, the type of beam-column connection and its design that allows the structure to be more sustainable in seismic zone will be determined. Different type of beam-column connection has different bending moment stiffness. The bending moment stiffness can control the amount of induced bending moment being transferred among structural members of a precast concrete skeletal frame. Consequently, it will affect the deflection behavior of structural members.

Large deformation of structural building in response to earthquake can be reduced by increasing the stiffness of its frames at the same it reduces ductility of frames. However, capacity of structural members is easily achieved to limit as less energy released from earthquake losing through small displacement. High ductility may allow the structural building swaying too much in displacement. However, the capacity of structural members is not easily achieved as most of energy from earthquake losing through large displacement.

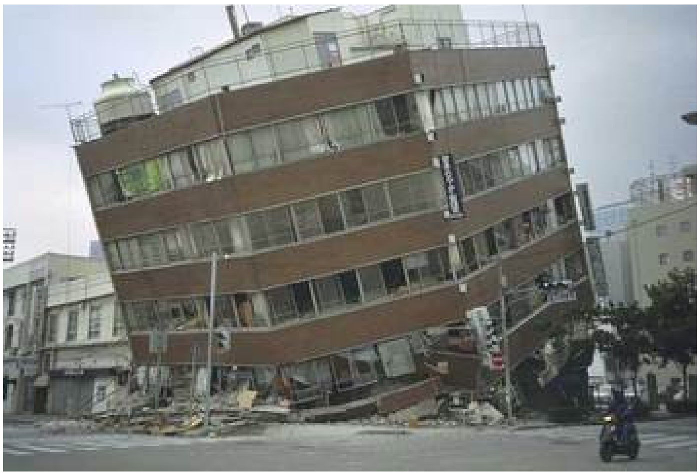

Figure 1.1: A collapsed building in Japan’s 1995 Kobe Earthquake

(Live Science, 2013)

1.3 Significance of Study

As recently increasing occurrence of earthquake in Sumatra, the west coast of Peninsula Malaysia begins to frequently feel the effects of earthquake such as tsunami and aftershock. It is notable that since past 30 years, Sabah, a state in Malaysia, has experienced several earthquakes with magnitude of 4.5 to 6.2. Hence, in future, Malaysia might be experiencing more frequent of low magnitude to medium magnitude of earthquakes. More buildings will be structurally damaged and more human lives will be lost due to earthquake.

Recently the Malaysia government has begun to promote the use of precast concrete in construction by targeting at least 30% of usage in a construction project and 70% in government buildings. As many believe that Malaysia is free from earthquake, precast concrete structures that have been built and will be built are designed without properly resisting the forces from low magnitude earthquake. A structure without proper prevention is prone to be damaged when the earthquake occurs.

As the safety of occupants of the structural building is an important concern in the structural design, the analysis of the precast building such as hospitals in earthquake situations must be conducted. It is to prevent important building from being badly damaged when the earthquake suddenly occurs in Malaysia. Hence, it is also to reduce loss of lives in the earthquake area as the precast concrete structures are able to sustain higher magnitude of earthquake.

The current Malaysia's building code has not considered earthquake in its code provision. The existing Malaysian buildings and future buildings need to have structural performance to be assessed for its ability to withstand an earthquake's aftershock.

Thus, this study can provide important insight which can be useful in future design of Malaysian buildings to reduce threat of earthquake. Furthermore, the life safety of building occupants can be ensured by using a structural design that is able to withstand earthquake.