CHAPTER 1

Introduction

1.1 Overview

For the last four decades, most buildings in Thailand have been constructed by using a traditional cast-in-place system. The system is very popular for constructing the reinforced concrete structures. However, the construction system needs more actual manpower to produce the concrete structures in each project, which is one of disadvantages in traditional construction system. During the year of 2011-2012, Thai government had declared the new minimum wage policy. As the result, the labor cost had quickly risen by more than 40% in some regions, reporting by Krungthep Thurakit, (2013). It heavily impacted on the construction industry. Due to the instant rise of minimum daily wage in Thailand as shown in Figure 1.1, it is one of the main reason, which many of developers, investors and contractors need to switch from the traditional system to an alternative system. The prefabricated application as shown in Figure 1.2 by using the precast concrete structure is one of the alternative way to replace the cast-in-place system. Although the precast concrete construction is still not familiar in Thailand, unlike, the US and several countries in Euro commonly used the prefabrication in the construction industry.

Although the prefabricated construction is a new technology in Thailand, the tradition system has been being continuously replaced by the prefabrication due to the reduction of construction time. Consequently, there was a word such as “Build it fast” for the new concept in new economical trend in Thai construction industry. For only less than last two decades, the prefabrication has played an important role in the modern world construction. The study of Ngoenchuklin (2014) reported that the precast construction has been dramatically growing in the last five years. Additionally, the precast construction offers several advantages such as better quality control and lower overall construction costs. For the use of precast concrete frame in Thailand, there were many types of the precast connection and their reinforcement details in joint region were difference. Almost all of the currently used connections developed from PCI manual (1973) and handbooks (1985), were designed specifically to support the gravity load with low seismic properties. Those details of the connections were redesigned and modified by engineers working on local concrete element producer company. Furthermore, almost all those connections were not appropriately tested or conducted under any simulated severe earthquake loading. There was no adequately studying and proven design recommendations. In additional, Donel's (1989) studied a behavior of precast concrete connection by applied both positive and negative moments to the test specimens. The PCI prototype connection was used for interconnecting in some test specimen. The test result shown that the low stiffness was observed in several of the PCI connection. For the reason, there have been many customers having the lack of confidence about their performance in seismic regions. That is the main reason for not widely use of the precast concrete buildings.

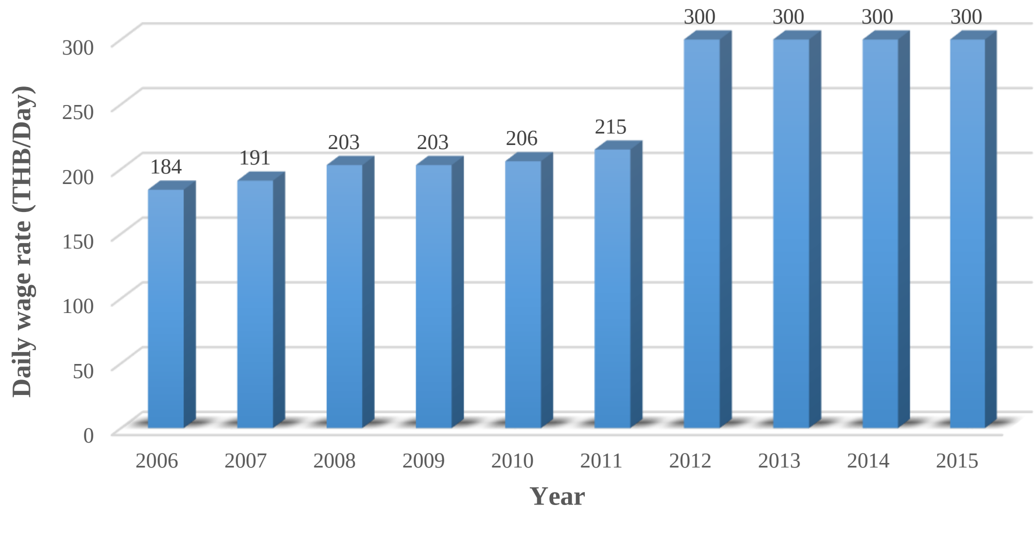

Figure 1.1 Thai minimum daily wage rate
(http://www.tradingeconomics.com/thailand/minimum-wages)

(a) Precast concrete elements for precast skeleton structure
(https://www.facebook.com/Precast-Khon-Kaen/)

(b) Installing process for multi-storey concrete building
(https://www.facebook.com/Precast-Khon-Kaen/)

(c) Precast construction for residential building

(d) Precast construction for factory building

Figure 1.2 Precast concrete building in Thailand

(a) Precast beam element (b) Precast column element with steel socket

Figure 1.3 Precast concrete element

Because the Northern and Western regions of Thailand are located in the moderate seismic zones 2A-2B according to UBC design provision (1997) and the ministerial regulation for seismic building (2007), the connection detailing for gravity load is unable to maintain the overall stability of structure to undergo large inelastic deformations during ground motion. It is well known that the behavior of overall precast concrete structures is greatly influenced by the performance of its connections. There are two important factors, ductility and shear transferred, to reflect the structural response during earthquake loading. The first one is used to assess the deformationable of the structure beyond the ultimate capacity without a significant reduction in loading. The other one is a complex mechanism for developing carried load or load paths in precast structure system under reversible loading pattern. For the reason, only design procedure for precast connection under cyclic loading is unable to obviously define the seismic performance such as: strength, stiffness, energy dissipation and ductility. As shown in UBC1997 (1997) for considering seismic design, Section 1692.9.2, the precast structure is allowed for determining under only “undefined structural system”. Because the performance of the precast connection is significant difference depending on the characteristics in each connection details. Therefore, an experimental study has to be adopted for revealing their performance under equivalent earthquake loading. Also, an analysis study by using Finite element modeling was performed to understand the local response of the connection in critical region. Therefore, this study was aimed at the development of a precast concrete connection suitable for use in Thailand and for moderate earthquake capacity. The study proposed a T-section steel insert in beam embedded in the precast beam ends. It is the detail currently used by local precast concrete element producer in the Northern Thailand as shown in Figure 1.3.

1.2 Background of prefabrication system on seismic region in Thailand

In the last two decades, there were several major earthquakes striking on the Northern Thai region (Southern China, Lao, Myanmar and Thailand) such as Lao earthquake with M6.1 in 2007, Yunnan earthquake with 5.7 in 2009, Myanmar earthquake with M6.9 in 2011, and Chiang Rai earthquake with M6.3 in 2014. Theses major earthquakes destroyed many buildings and people living in the regions. Most collapsed concrete buildings during the last earthquake were destroyed at connection (beam-column joint) and column elements at the first story leading to the stiffness and strength degradation during the ground motion as shown in Figure 1.4 to Figure 1.5. It was because these structures were designed with elastic assumption without large displacement consideration. Furthermore, the current structural design criteria was based on the gravity load rather than laterally load generated during an earthquake.

Figure 1.4 Damage from the first soft story of concrete building

(a) Soft story collapse (b) Plastic hinge at the end regions of the column

Figure 1.5 Column failure of the residential building during Chiang Rai earthquake

Trends and developments in the use of precast concrete structure in Thailand, moment resisting frames and panel walls have been widely used for constructing the one-to-four story concrete structures as shown in Figure 1.6. Regard to the precast connection, the emulated cast-in-place method have been popularly adopted for jointing between the precast concrete elements by bolted and welded processes. For the last decade, there were several new precast concrete companies developing and distributing the precast productions to customers. The connection details in each company are difference, leading to the mechanical performance that is difference too. Figure 1.7 to Figure 1.9 show the jointing method for beam-column connection of the different precast companies. It can be seen that the concrete element are separated. Then, it are jointed by splicing of primary reinforcement using lapped bars, mechanical splices, and welded splices that are normally installed with emulated monolithic cast-in-place system in Thailand. ACI 318-99(1999), Chapter 21 have suggested the significant lengths of these splices. However, ACI 550.1R-01 (2001) according to ACI318-99 was not permitted for using these splices within a distance of two times the member depth from column face due to the location, where is the highest stress in the structural element. As shown in Figures 1.7 to Figure 1.9, there are the use of the splice method in current precast beam-column connection at the critical region.

(a) Precast concrete construction for factory building

(b) Precast concrete construction for residential building

(c) Precast concrete construction for multi-story residential building

Figure 1.6 Prefabricated construction in the Northern Thai region

(a) Beam-to-column connection with sliding plate

(b) Sliding plate

Figure 1.7 Sliding plate beam-to-column hidden connection

Figure 1.8 Jointing between precast concrete elements by welded splices

Figure 1.9 Jointing between precast concrete elements by welded steel plates

There are several studies reporting the damage and failure pattern of the precast concrete structure after major earthquakes. Park(2002) reported an observation of the precast connection failure as shown in Figures 1.10 (a-b) due to brittle (non-ductile) behavior of poor connection details, causing the poor detailing of components and poor design concept. During Spitak earthquake on 1988 December, many buildings were destroyed resulting to the deaths in the earthquake exceeding 25,000 people estimated by The Soviet government. The precast concrete building was one of the collapsed-buildings in the earthquake event. For the example case reported by King, Khalturin, and Tucker (2013), 9-story precast concrete structure was assembled from several precast concrete elements to be moment resisting frames. The precast elements were jointed in place by welding process in the critical maximum stress. As a result, an inelastic deformation or plastic hinge was unable to develop in the structural system, leading to dramatically collapse of the precast building during the earthquake ground motion as shown in Figure 1.10(c). There was another multi story precast building collapsed during the Spitak earthquake. Figure 1.10(d) shows the damage to 5-story communication building. The structural type was a precast-concrete-frame composite structure. The flooring system was a hollow-core precast plank which was inadequate connection between them to tie the floors together, leading to poor diaphragm action. From the reason, the middle slab portions of the building were collapsed while the ends remained standing, resulting in high number of death. Figure 1.10(e) shows the brittle failure of welded bars, commonly observed at the connection between the precast column elements.

(a) Tangshan, China, 1976 (Park, 2002)

(b) Leninakan, Armenia, 1988 (Park, 2002)

(c) Damage to 9-story precast concrete frame-panel apartment building in Leninakan
(http://www.hellerjohnsen.com/Spitak,%20Armenia%2012-7-88.pdf)

(d) Damage to Communications Building, Spitak, Armenia
(http://www.johnmartin.com/earthquakes/eqshow/647011_09.htm)

(e) Brittle failure of welded bar at the precast connection
(http://www.hellerjohnsen.com/Spitak,%20Armenia%2012-7-88.pdf)

Figure 1.10 Damage to precast concrete building caused by major earthquakes

From the previous experience of collapsed precast building in seismic area, most observations of the precast failures are mainly due to the brittle behavior of the poor connection details of the precast elements. In New Zealand during 1980s, the reason resulted in the precast concrete production in the structural frame and wall was shunned for many years (Park, 2002). It was similar to precast construction in Thailand. The major problem of precast concrete structure has been increased by using incorrect details, which are rather than intrinsic limits of the structural performance during earthquakes. Because there have been inadequately a few engineering researches and design recommendations which observed the seismic performance of the precast connection details used for construction in Thailand. Hence, there is a lack of confidence from the customers living on the seismic region. From the reasons, the study is aimed to observe the structural response of current precast concrete production during ground motion. It is developed and proposed the precast concrete connections modified from a currently precast detail. Moreover, the observation also reports the P-delta effect due to a largely lateral displacement while serves the earthquake event.

1.3 Objectives of the study

Despite the increase in number of prefabricated concrete structures the residential market, many customers have no clear confidence in their performance. This is especially true in regions of moderate seismic risk in Thailand. However, there have not been experimental work for conducting a seismic performance under any earthquake loading. For the reason, the study program was aimed to investigate and improve the seismic performance of precast connection, T-section steel insert, that has been widely used and distributed for residential buildings in Northern region of Thailand.

The objectives of the study are illustrated below:

- To develop an innovative precast connection using T-section steel insert for a moderate seismicity area.
- To clarify factors affecting seismic performance of precast concrete connection using T section steel insert.
- To criticize the current design concept for the better seismic performance of the precast connection using the T section steel insert.

1.4 Scope and limitation of the Study

This study involves experimental works and nonlinear analyses of the monolithic and precast concrete interior beam-column subassemblages under reversed cyclic loading. The research work was proposed with the following scopes:

- An experimental and analytical investigations was performed considering RC and precast interior beam-column joints.
- Experimental works were designed for clarifying seismic performance of precast concrete samples. Comparisons were made for identifying seismic design parameters and structure behavior under cyclic loading.
- Numerical models were developed by nonlinear analyses and validated with the experimental results. Parametric study on reinforcement detailing were performed.

1.5 Organization of the dissertation

The report of the study is divided into 2 parts; part A: experimental study and part B: analytical study, composing of seven chapters. First, the introductory chapter describes background and objectives of the study. Chapter 2 briefs information about the dynamic response of the precast connection and previous researches associating with experiment study and non-linear numerical study under seismic action. For a reinforcement detail of both monolithic and precast specimens, it is presented in the chapter 3. The techniques of testing process and installing instrument are also included. Chapter 4 and Chapter 5 report the investigating results from experimental study and the seismic properties of all precast specimens against the monolithic specimen. Chapter 6 presented a numerical results developed from fiber based finite element model. To simulate a seismic response of the concrete specimens subjected to the equivalent earthquake loading, the models are verified against the test results. Chapter 7 summarizes the study and presents conclusion along with further research in this area.