CHAPTER 1

INTRODUCTION

1.1 General

Many cities in South East Asia are considered as being located in a low to moderate seismic region. People who live in these cities are believed to be safe from earthquake. Recently, several occurrences of earthquake in South East Asia, especially the 2004 Sumatra earthquake in Andaman Sea with a magnitude of 9.3 on Richter Scale, caused severe shaking of many buildings in Thailand though the quake's epicenter was more than 800 kilometer away. For this reason, the earthquake has prompted a serious public concern on seismic safety and vulnerability of buildings.

Recently many provinces in the Northern and Western parts of Thailand, which are located on the active fault, have encountered several low to quite moderate earthquakes more often and at larger magnitude than ever. Furthermore, Bangkok, the capital of Thailand, is founded on a soft basin of marine clay with several ten-meter deep. This soil characteristic has a potential to amplify the seismic wave up to 3-4 times (Warnitchai, 2004). The soft ground condition is quite similar to that of Mexico City, which was destroyed by the 1985 Mexico earthquake with almost 10,000 deaths. For these reasons, Thai people are not absolutely safe from earthquake and can possibly have an earthquake disaster similar to those that occurred in high seismic regions.

Almost all of the buildings in Thailand were designed for gravity load and wind load but not for earthquake event so these buildings may not behave well in the aspect of ductile behavior for the seismic demand. Additionally, most of these assessed buildings reported by Cheejaroen(2004)and Chaimahawan et al(2006) lacked ductile reinforcement details: no stirrups were provided in the joint, stirrups in beam and column were usually widely spaced and the end hooks were non-seismic. Moreover, the column longitudinal bars were usually spliced immediately above the floor level. These buildings were therefore substandard with respect to modern seismic design code. These deficient details were resulted from reinforcement congestion within joint region, difficulty in construction and need for cost reduction. As a result of the lack of seismic details in each member, these RC beam-column buildings are generally weak against earthquake loads.

One of the most effective ways to prevent earthquake losses is to assess seismic performance and shear capacity of buildings frame. The assessment can be conducted by means of experimental program and numerical model. For more than several ten years, many experimental approaches have focused on both interior and exterior beam-column joint with standard and substandard reinforcing details. Both of the details may meet many important problems such as bond anchorage of longitudinal beam bar, ductile characteristic, lateral load resistance, brittle failure mode, joint dimension, amount of joint reinforcement and reinforcing congestion.

To prevent any of the problems, the experimental researches have been investigating and solving the mentioned deficiency point. While most of researches have dealt with the use of rectangular joint reinforcement, a few researches concerned with different arrangements of joint reinforcement details especially buildings located in low to moderate seismic risk zone. This is the reason why, this research is aimed to modify joint reinforcement detail for building designed without considering seismic details as modern seismic code.

Aside from the experimental assessment, numerical procedure is used for evaluating seismic performance of reinforced concrete building frames as well. Although experimental program assessment reflects real seismic behavior, it costs too much to produce specimen or to save time for construction. Some experimental programs cannot be conducted when the acquired tools are not sufficient enough. Moreover, with complexity of hysteresis behavior of beam-column joint, several factors involving seismic performance such as anchorage length, axial column load, concrete compressive strength, amount of joint reinforcement, ratio of longitudinal beam bar and sectional joint dimension have to be considered carefully. However, it is very difficult to cover all of the mentioned factors. Therefore, the numerical model is worth evaluating capacity of reinforced concrete buildings under seismic loadings. In this research, parametric study is conducted according to factors mentioned above.

1.2 Research significance

In general, a region of joint has to encounter an intensity of several forces, therefore, it is consider as critical member in lateral load path of reinforced concrete buildings frame when earthquake occurs. Problem of bond anchorage and shear failure within joint are raised dominantly since they may lead to building catastrophe whether transverse reinforcing detail of beam-column joints are standard with seismic consideration or substandard without seismic consideration. The international standard codes, ACI code and New Zealand Standard code, point out several important influences such as bond anchorage problem in terms of column depth and longitudinal bar diameter. The susceptibility of buildings with various column tributary areas, involving whether bonding or unbonding parameters to seismic behavior and type of failure, should be examined. For joint shear force, one of its significant roles is cited in the form of strut mechanism by concrete compressive strength and truss mechanism by joint transverse confinement.

The codes propose conservative procedures for determining joint transverse reinforcement whereas the joint reinforcement is assumed to equilibrate a series of compression field, sub-strut. The sub-strut is derived from bond stress of longitudinal bar which passes the joint core as long as the bond anchorage is available within the joint. However, a correct portion between strut mechanism and truss mechanism is not evidently known. Therefore, stress and strain of joint reinforcement have to be investigated. Furthermore, the building frames located on higher seismic risk zone should possess more ductile behavior. The joint of building frames is recommended to use transverse reinforcement in accordance with modern seismic provision. However, every joint cannot achieve ductile behavior, this research proposes new joint reinforcement details. They are expected to increase ductility and to avoid brittle failure at joint core instead of using joint transverse reinforcement which may not avoid brittle failure. For deep scrutinize, the structure with new joint reinforcement detail has to be observed a localized crack pattern and inspected stress-strain development under cyclic loadings.

Moreover, the standard codes demonstrate importance on types of transverse joint reinforcement. One example is that ACI code provides a minimum volumetric amount of spiral confinements less than that of rectangular ones because the spiral can give more effective than the rectangular. For other confinements, it is wonder whether they will more effective than discrete confinements- both rectangular and spiral ones. One sample, continuous confinement is set to be applied within joint core. This research studies the hysteresis behavior of structure and the stress-strain of joint confinement.

1.3 Objectives

The research on the RC beam-column frame has the following major objectives:

- To comparatively study the hysteresis behavior of the interior reinforced concrete beam-column frames with two different joints designed: one concerned and another unconcerned seismic event
- To investigate crack development and failure characteristics of the interior reinforced concrete beam-column frames with the modified joint reinforcements and to compare those with substandard joints.
- To clarify how the problem of bond deterioration within beam-column joint affects both joint and adjoining members, such as beam and column.
- To thoroughly investigate the relation of various anchorage bond, pull-out bond and stress-strain development of longitudinal beam bars passing through joint under cyclic displacement loadings.
- To scrutinize the bond and stress development of longitudinal bars in the modified beam-column connection and compare them with the existing substandard connections.
- To investigate the effect of amount of rectangular joint reinforcements on seismic performance of building frames under earthquake loadings.
- To compare the influences between substantial rectangular joint reinforcements and joint dimension on cyclic behavior of substandard interior beam-column connection of building frames
- To determine new reinforcing details within interior beam-column joint, which are feasible for reinforced concrete building frames in low to moderate seismic risk zone.
- To examine effectively seismic performance of beam-column joint which is confined with various types of confinement, i.e. spiral, rectangular, and plate hoops
- To develop the rational model of interior beam-column joint for predicting the lateral load capacity and failure mode.
- To study factors affecting seismic performance of interior beam-column joint, i.e. axial column load, bond anchorage, column depth, column width, amount of joint reinforcement and ratio of longitudinal reinforcing bar.
- To serve as a guideline for civil engineers to implement the design method of interior beam-column joint under moderate seismic load.

1.4 Scope of research

This research is divided into 2 parts. The first part of the research focuses on the experiment of the five modified substandard interior beam-column joints which are typical mid-rise reinforced concrete buildings in Thailand. The typical two-dimensional specimen is regarded as the representative of the existing building frame. These specimens are tested by reversed cyclic displacement loadings. The size and reinforcing details of the specimens are half-scale of the actual structure. Only joint reinforcement details are modified to improve some aspects of seismic performances of buildings located on low to moderate seismic zone. The modified reinforcing details within joint involve the use of horizontal transverse joint reinforcements, joint spiral confinement, joint continuous confinement, unbonding beam bar and diagonal arrangement of beam bar. Additionally, three experimental results of Cheejaroen's specimens(2004) and one experimental result of Norachan's specimen (2005) are used for the comparative analysis in each important point such as i) effect of the reinforcing bar anchorage within joint core, ii) joint performance with different joint details, iii) role of the amount of horizontal joint reinforcement and iv) effect of joint discrete and continuous confinement. For comparative discussions, they are reported in several aspects, i.e. global observation of cracks pattern on each component including the failure mechanism, the hysteresis loops of column shear force and relative drift ratios, the relation between shape deformation and relative drift ratio in any zone, and the stress-strain history of reinforcing bar.

The other part, the author proposes a numerical model as a tool to evaluate the seismic performances such as failure mode and peak lateral load capacity. The model consists of beam, column and beam-column joint of the interior reinforced concrete building frame. The model is analyzed with two-dimensional nonlinear plane stress. The capacity of joint model is derived from the integration of beam's strength, column's strength and joint's strength. Moreover, splitting crack and bond deterioration mechanism are taken into account in the model. The model is verified with the experimental results of both author's specimen and other's specimen. In addition, the model is used for parametric study in each influential factor on cyclic performances, i.e. i) effect of axial column load ratio, ii) effect of the column depth to the beam bar diameter (h_c/d_b) ratio and the column width (b_c), iii) effect of concrete strength and column width and iv) effect of the top to bottom reinforcement ratio and the high yield strength to normal yield strength.