CHAPTER 1

INTRODUCTION

1.1 Problem statement

Many catastrophic failures of building in 1978 Japan, 1980 Algeria, 1980 Italy, 1981 Greece, 1985 Mexico, 1999 Taiwan, and 1999 and 2002 Turkey earthquakes have shown the vulnerability of reinforced concrete frames built before modern seismic design codes were adopted, or built without seismic considerations even when such codes were in place (Fig. 1.1). The 1995 Hygo-ken Nanbu Earthquake in Kobe results for example in heavy damage to about 3,900 reinforced concrete structures, with about 330 structures in total collapses. In 1999, about 115,000 buildings collapsed or were heavily damaged and 17,439 people were killed and 43,953 injured in the Izmit Earthquake in Turkey. Economical and social sectors were severely hit as a result of the vast extent of damage caused by earthquakes. For example, in the Chi-Chi Earthquake in Taiwan, the estimated loss was in the order of 20-30 billion US dollars. On the other hand, most of the reinforced concrete structures built recently and designed according to modern seismic design codes did not suffer significant damage. Today, it can be said that the modern seismic design standards have been adopted in many regions around the world. However, there are still a great number of existing buildings that were not designed for earthquakes. These buildings are considered substandard with respect to modern seismic design codes. Many of them are still currently in service. The need to retrofit these buildings to comply with the modern seismic design standard is also an important activity in structural engineering.

Many researches have been conducted to propose an evaluation methodology to identify critical components of non-seismically designed buildings. The results will be used to prioritize buildings for seismic rehabilitation and strengthening. An evaluation of existing buildings by Kunnath S.K. et al., (1995) and Aycardi L.E. et al., (1994) found that in zones of low seismicity, such as in the eastern and central parts of the United States are not designed for earthquakes. In particular, buildings constructed before 1970 are likely to have non-ductile reinforcement details (Fig. 1.2) owing to older seismic design codes that did not incorporate capacity design concept (Hakuto S. et al, 2000). Many seismic deficiencies can be identified for these old buildings. They include, but are not limited to, low amount of confining reinforcement in column and beams, lap splices of column reinforcement just above floor level, little or no transverse reinforcement in the joint panels, discontinuous beam bottom reinforcement with short embedment length. These seismic deficiencies are typical details in lightly reinforced concrete structure considered to be under-designed against earthquakes.

In additional, recent seismic studies conducted by Warnitchai P. (2004) indicated that damaging earthquakes can occur in South East Asia countries such as Thailand, Singapore and Malaysia. For example, in 2004, the 9.3 Richter earthquakes at Sumatra islands of Indonesia caused the large tsunami that attacked the Andaman beach of Thailand. It killed over 5,000 people and more than 2,800 disappeared. As the most recent example, the 7.8 Richter Earthquake in Sichaun 2008 caused violent shaking of many buildings in Bangkok though the epicenter was about 2,000 kilometer away. Since Bangkok, the capital city of Thailand, is founded on a soft basin of marine clay with several ten-meter deep, the soil characteristic has a potential to amplify the seismic wave up to 3-4 times. 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 this reason, the earthquakes have raised public concern towards seismic safety of existing buildings since almost all RC buildings in Thailand were designed without seismic considerations. Evaluation of existing reinforced concrete buildings reveals seismic deficiencies (Chaimahawan and Pimanmas, 2006). It is found that almost all buildings do not have ductile reinforcement detail, especially the lack of adequate transverse reinforcements in beam, column and beam-column joint and non-seismic detail of hook anchorage. According to the investigation, the joint shear failure is identified to be one of the most critical failures of RC frame that can lead to the catastrophic collapse of buildings. Therefore preparation for seismic retrofit of beam-column joint in existing buildings is highly needed.

Fig. 1.1 Failure of beam-column joint may lead to catastrophic collapse of the entire building.

The performance of beam-column joints has long been recognized as a significant factor that affects the overall behavior of reinforced concrete framed structures subjected to large lateral loads. There have been many catastrophic failures reported in the past earthquakes, in particular in Turkey and Taiwan earthquakes in 1999, which have been attributed to beam-column joint failure. The poor design practice of beam-column joints is compounded by the high demand imposed by the adjoining flexural members (beams and columns) in the event of mobilizing their inelastic capacities to dissipate seismic energy. Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements. The common failure modes in beam-column joint are joint shear failure and anchorage failure of beam longitudinal bars (Park, R. et al, 1975; Supaviriyakit T., et al, 2007). In order to mitigate seismic hazards in existing structures, evaluation for seismic rating and appropriate retrofit method for beam-column joint is required. Seismic assessment is the first step within the retrofit strategy aiming to reduce the seismic risk (combination of hazard and vulnerability). A good understanding of the weak point of a structure under seismic loading could allow to complement and to design the most appropriate retrofit solution to reduce the seismic vulnerability of existing buildings.

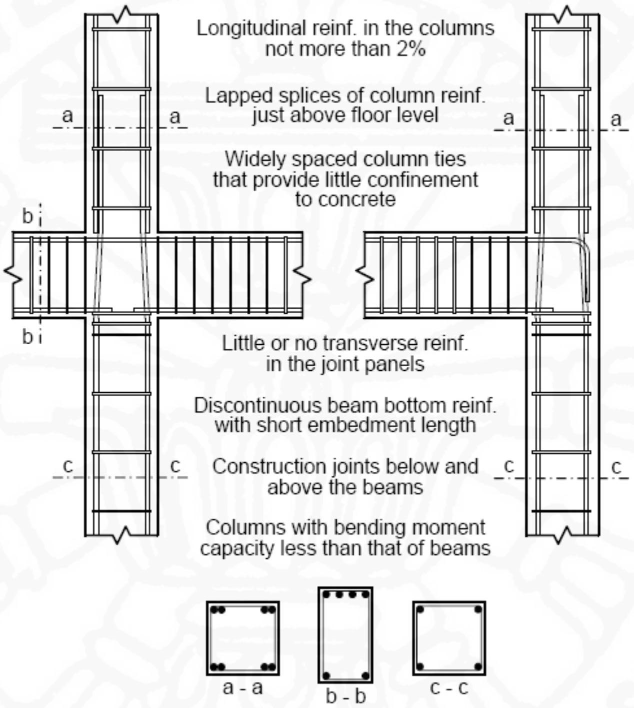

Fig. 1.2 Typical details in under-designed reinforced concrete structures.

There are many objectives in retrofit design, for example increasing lateral stiffness to limit the structural deformation under seismic forces, or adding shear strength or reducing flexural strength to increase deformation capacity of brittle members and/or improving ductility of the existing structures. Over the past 20 years, significant advancements have been made in the research and development of innovative materials and technologies for improving the seismic performance of existing structures through rehabilitation processes. The selection of an appropriate rehabilitation technique based on the structural condition and its deficiencies is the most important step in the whole rehabilitation process. Seismic rehabilitation of existing structures is still a fairly new and challenging activity for many practitioners. And since no two structures are exactly the same, it adds challenge to the rehabilitation process. Therefore, the selection of rehabilitation techniques is a complex process, and is governed by technical as well as economic and social aspect considerations.

Several retrofitting methods for beam-column joints have been proposed. Concrete jacketing of beam-column joint is one of the common techniques (Alcocer and Jirsa, 1993). This technique did provide increased joint strength, shifted the failure to their beams, and increased overall lateral strength and energy dissipation. However, this method increases the member sizes and produces protruding parts of jacketing in floor space which is may be architectural undesirable.

Strengthening joint shear resistance by using steel plates, rods, and jackets has been tested by Beres et al. (1992) and Ghobarah et al. (1997). The steel jacketing has proved successful in upgrading the shear strength of the joint. However, the corrosion potential and the need to fireproof the added steel elements posed a challenge to widespread application of the procedure.

The use of fiber-reinforced polymer (FRP) materials for increasing joint shear strength has been investigated by several researchers (Gergely, I. et al., 2000; Ghobarah, A., 2002; Clyde C, et al., 2002). FRP composites have the advantages of fast and easy application, high strength to weight ratio and corrosion resistance. Externally bonded glass or carbon composite materials (GFRP or CFRP) are attached to the faces of the joint by using epoxy resin. Significant improvements in joint strength and ductility have been achieved.

In this thesis, a joint retrofitting technique called “planar joint expansion” is proposed. In this method, the beam is encouraged to fail by beam flexural failure and the joint shear is to be avoided. The beam-column joint is two-dimensionally enlarged by cast in-situ concrete. The in-situ cast joint expansion can be independently installed in transverse and longitudinal directions (Fig. 1.3). The method is comparatively easy in application. No slab perforation is required. Since conventional materials are used, the method is cost-effective. In terms of architectural concern, the planar joint expansion can be hidden in infill walls or non-structural walls with less than 5% coverage area. Unlike concrete jacketing, there are no protruding parts of joint expansion, hence the full floor space is available, making the method architecturally acceptable. Besides using cast in-situ concrete as planar joint expansion, it may be possible to use steel angles to perform similar functions.

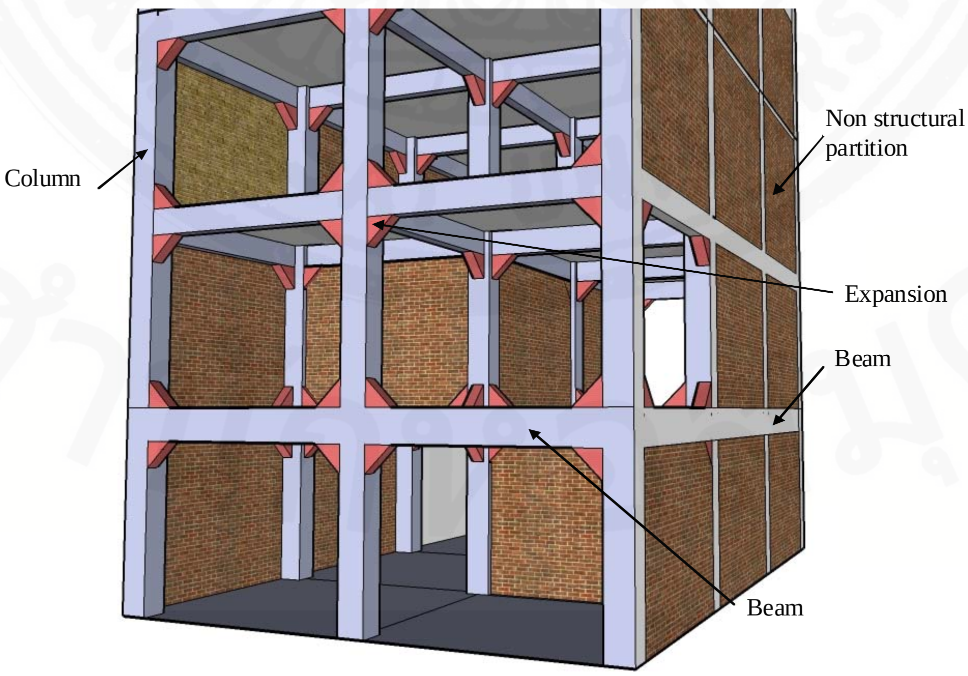

Fig. 1.3 3D Building beam-column frame system retrofitted with planar joint expansion

1.2 Research significance

There are a lot of existing buildings that are designed for seismic forces in many parts of the world. Even in some countries that enforce the seismic design of buildings, many buildings constructed before 1970 are believed to be seismically inadequate because of the lack of ductile reinforcing details and the noncompliance with the capacity design method. These existing buildings may encounter catastrophic collapses in the event of earthquakes. There is an urgent need to investigate the seismic performance of these buildings. This thesis proposes a simple method to check the seismic performance of existing buildings using structural drawings and data from the field survey. These procedures are easy and appropriate for use by practicing engineers. The need to retrofit various critical components of RC building is also an urgent task. The search for an effective retrofit technique has been researched. This thesis presents an effective joint retrofitting method based on conventional construction using local materials and local workmanship. The method is based on the idea of enlarging the joint two-dimensionally using cast in-situ concrete or steel bracket. The thesis also presents analytical modeling of the problem which is highly significant for designers to design the strengthening work and to check the performance of strengthened beam-column joint. The analytical modeling proposed is the strut-and-tie model that is constructed with the aid of finite element analysis and experimental results.

1.3 Objectives

This thesis aims to investigate the seismic performance of existing buildings that are not designed for earthquakes. In other words, these buildings are primarily designed for gravity and or wind load, thus, they lack ductile reinforcement details especially the stirrups around the end of beams and columns and the transverse reinforcement in the joints. The objectives of this thesis is listed as follows

- To develop a seismic evaluation techniques for existing buildings not designed for earthquakes. The proposed evaluation method must be simple and easy to use for practicing engineers. The concept is to use the basic building data obtained from the field survey and structural drawings to check the compliance or noncompliance with respect to modern seismic design code.
- To apply the developed seismic evaluation technique to the database of collected buildings not designed for earthquake and to identify the seismic weakness of the buildings.
- To propose the effective retrofitting technique for sub-standard beam-column joint that is found to be one of the most critical components in the lateral load path of the structure. The retrofitting technique should be based on local materials and conventional construction procedure. It must be effective to prevent joint shear failure and to encourage flexural failure in beams.
- To examine the structural behavior of the beam-column joint strengthened by the proposed procedure in terms of load capacity, ductility, energy dissipation, cracking and failure mode. The strengthened specimen will be deeply analyzed to understand the load resistant mechanism and the force transfer within the strengthened joint.
- To propose analytical modeling for the strengthened beam-column joint that can serve as a rational design tool for practicing engineers. The primary analytical tools

that are considered in this thesis is the nonlinear finite element analysis and the strut-and-tie model.

1.4 Scope of research

The works in thesis focus on reinforced concrete building categorized as medium-rise structures with the number of storey ranging from 5 to 20. Previous researches have shown that these buildings have the natural period in the range of around 1 second which is close to the range of earthquake wave amplified by the soft soil effect in Bangkok, thus these buildings are expected to strongly vibrate due to the resonant effect. The study focuses on governmental and public buildings such as school, universities, hospitals, governmental offices and apartments because these buildings are supposed to provide the lifeline facilities to rescue people in the event of earthquake. The target of the research is at the interior beam-column joint in these buildings. Based on previous studies, it is found that the interior beam-column joint may be seriously damaged because it has no transverse reinforcements in the joint and the column size may be small to provide sufficient joint shear area. The work in this thesis starts with the evaluation of existing buildings to identify the weak components of the structure. The interior beam-column joint has been identified to be one such component that urgently requires retrofit. The retrofitting method for interior beam-column joint is proposed based on the conventional procedure and local materials available in developing countries. The experimental program is carried to check the performance of the method. The test is done using the reverse cyclic quasi static loads. The test is supplemented by nonlinear finite element analysis to deeply investigate the force resistant mechanism of strengthened specimens. Finally, the thesis proposes the strut-and-tie model as a mechanical model that can be used by practicing engineer to design the strengthened beam-column joint and/or to check its performance after retrofitting.