Keynote Speech

Factors influencing the lateral drift capacity of structural walls

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Earthquakes and laboratory tests since 2010 have demonstrated that thin, slender walls may not possess the deformation levels allowed in modern codes and standards. Results from recent wall panel tests conducted at UCLA indicate that, depending wall geometry and detailing, the lateral drift capacity well-detailed walls can vary by a factor of two. Based on these tests and a small database of approximately 30 slender walls, a lateral drift capacity prediction equation was developed in a displacement-based design format and used to identify key parameters impacting lateral drift capacity. It is demonstrated that, in addition to provided boundary transverse reinforcement, drift capacity of slender walls is most impacted by compression depth (c), wall thickness (b), and wall length (l_w). Given that ACI 318-14 and other international codes do not consider all of these factors, equivalent performance is not expected for all walls that satisfy detailing requirements required by modern codes. Lower drift capacities are noted for walls with neutral axis depths that exceed two to three times the wall thickness, walls with slender cross sections ($l_w/b > 15$) and walls design with high shear demand; such characteristics are common for walls in modern buildings in the US. The results indicate that slender walls may fail prior to achieving the drift demand determined from ASCE 7 analysis approaches (including NL-RHA). Subsequently, a comprehensive database was created with results from more than 160 ACI 318 compliant wall tests to develop a robust expression to predict wall lateral drift capacities. Based on estimates of lateral drift capacities (from the database) and drift demands (from analysis), a simple design check is proposed to require that drift demand be compared with drift capacity to verify that a given wall can achieve the estimated drift demand with a prescribed reliability. The developed displacement-based model provides key data to understand parameters that impact wall drift capacity, and the new design approach provides a rational framework for design of buildings that utilize structural walls as a lateral-force-resisting systems.

Analysis of damage potential of the 912 Gyeongju earthquake

Cheol-Ho Lee[1]

SUMMARY

This study presents the seismic damage potential of the M5.8 Gyeongju earthquake last year from diverse earthquake engineering perspectives using the accelerograms recorded at three stations near the epicenter. In the time domain, strong motion durations are evaluated and compared with statistical averages of the ground motions with similar magnitude, epicentral distance and soil conditions while Fourier analysis is performed to identify damaging frequency contents contained in the records. Effective peak ground accelerations are evaluated from the calculated response spectra and compared with apparent peak ground accelerations and the design spectrum in Korean Building Code 2016. All these results are used to consistently explain the reason why most of seismic damage in the earthquake was concentrated on low-rise stiff buildings but not quite significant. In order to comparatively appraise the damage potential, the constant ductility spectrum constructed from the Gyeongju earthquake is compared with that of the well-known 1940 El Centro earthquake. Seismic design and retrofit implications of M5.8 Gyeongju earthquake are discussed for further research efforts and improvements of relevant practice.

***Keywords**: strong motion duration; frequency contents; effective peak ground acceleration; constant ductility spectrum; seismic damage.*

INTRODUCTION

An earthquake of M5.8 on the Richter scale hit the Gyeongju area on Sep 12, 2016 (hereafter, 'the 912 Gyeongju Earthquake'). It not only strongly shook the cities of Gyeongju, Ulsan, Pohang, Daegu and Busan, but also caused tremor in some parts of Seoul. This was the strongest earthquake ever recorded since the strong motion instrumentation program was introduced in the late 1970s in Korea, and it threw the entire country into fear of earthquakes. Fortunately, there were no earthquake-related deaths, and damages were mostly confined in low-rise/non-seismic buildings, even though some local peak ground acceleration (PGA) of the earthquake exceeded 400 gal. According to the Gyeongju city, more than 5,000 houses and 180 public facilities were damaged by the earthquake, resulting in economic loss of 26 billion won due to direct and indirect costs.

In the 912 Gyeongju earthquake, serious structural damage such as the short-column shear failure of the concrete columns was also observed as shown in Fig. 1. Short-column shear failure is a typical failure mode that can occur when non-seismic concrete columns are partially blocked with infilled walls. Most of the damages reported, however, were of non-structural type, as shown in Fig. 2, including damage to non-structural partition walls or ceiling systems in low-rise buildings and the loss of roof tiles in Hanok (a traditional Korean-style house).

This article is based on the basic studies conducted by the author and his coworkers right after the earthquake (Lee 2016, Lee et al. 2016) and summarizes the time and frequency domain analysis results of the measured ground motions, the elastic and inelastic seismic responses of SDOF (single degree of freedom) structures subjected to the ground motions recorded in the 912 Gyeongju earthquake. Based on these basic analysis results, damage potential contained in the measured ground motions and probable causes of the observed damages are presented.

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Shaking table tests of rocking base-isolated structures subjected to bi-axial earthquake loads

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SUMMARY

Literatures have showed that traditional sliding base-isolated systems may have long-period resonant-like response induced by a ground motion containing strong long-period frequency spectra. In this paper, a new type of isolator with variable-frequency rocking bearing is proposed. The system allows the bearing remain still under a moderate seismic load but start to rock back-and-forth during severe earthquakes. And the vibration is damped throughout each impact of the bearing on structural footing or foundation surfaces. Based on the force-displacement relation and analytical damping of the system, seismic response of the structure may be estimated through a modified elastic response spectrum. The objective of the paper is to investigate seismic performance of this base-isolated structure subjected to bi-axial earthquake loads. To validate proposed idea, a one-bay-one-story spaced structure base-isolated with rocking bearings was constructed. In total, 236 shaking table tests were conducted with various investigated parameters including aspect ratio of bearings, the shape of rocking plates (plane or polynomial), bi-directional earthquakes and waveforms of ground motion. Test results indicate that vibration behavior was nonlinear with respect to rocking amplitude. And structural response of the structure excited by bi-horizontal earthquakes is the largest, followed by uni-axial and then bi-directional with horizontal plus vertical earthquakes. Due to the restrain of vertical spring force at rocking interface, seismic response of structures excited by simultaneously horizontal plus vertical earthquakes is found similar to those excited by uni-axial earthquakes. It is also found that seismic response is increased with the increase of aspect ratio of bearings, while the effect of rocking surface is marginal. Without any damage incurred under earthquakes, radiation damping of the rocking system is found less than 4% for all tests.

***Keywords**: Rocking Bearing; Base-isolation; Damping Ratio; Shaking Table Tests*.

INTRODUCTION

It has been learned that seismic isolation is an effective technology to protect structures from earthquake attacks (Naeim and Kelly, 1994). Seismic isolation is achieved through the installation of a soft layer below the protected structures, so that seismic energy transmitted up to the super-structure due to a ground motion is isolated. The flexibility required in isolation system to reduce seismic response may be alternatively obtained by allowing part of structure to uplift, rocking or stepping during large horizontal motions (Dowrick 1987). For example, bridges with insufficient tensile pile capacity at footings allow the uplift of structures during strong earthquakes. This rocking behavior dominates the pier response and minimizes the damage to the footing and columns. More recently, control of rocking behavior of steel braced frames has been investigated by researchers (Eatherton et al. 2014 and Wiebe et al. 2013). The system consists of three main components: a steel braced frame that remains essentially elastic by uplifting at the column bases during ground motions, vertical post-tensioning (PT) that provides resistance to overturning and provides self-centering forces, and replaceable energy-dissipating elements that resist overturning and act as structural fuses that yield, effectively limiting the

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Mechanical behavior of low-yield-point circular hollow section steel damper under bi-directional loading: examination based on experimental results

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SUMMARY

The purpose of this study is to investigate the mechanical behavior of low-yield-point circular hollow section steel damper (LYCHSD) under bi-directional loading. In our past study, we conducted a uni-directional loading test on the LYCHSD and investigated its effectiveness as a shear type damper. On the other hand, the LYCHSD has a characteristic of resisting external forces in all direction due to circular cross-sectional-shape and it can be utilized as a device absorbing seismic energy inputted in multi-direction. LYCHSD can damp vibration of buildings in the following two cases: 1) used in combination with an insulator at the isolation layer, 2) used as a coupled vibration control system between buildings with different natural periods. Therefore, a bi-directional loading test is conducted considering aspect ratio and steel pipe material of the LYCHSD as a main parameter. Consequently, similar to the specimens under uni-directional loading, the specimens under bi-directional loading showed stable spindle-shaped hysteretic response, while the rate of strength increase and failure modes showed same tendency. Moreover, it was indicated that the total cumulative plastic deformation capacity in each direction of specimens under bi-directional loading was nearly equivalent to those specimens under uni-directional loading.

Keywords*: Low-yield-point circular hollow section steel damper*; *Bi-Directional loading*; *Cyclic deformation capacity.*

INTRODUCTION

A shear type damper is a kind of steel damper that absorbs earthquake energy as plastic shear deformation of steel material. *Kim et al. 2016*, proposed a low-yield-point circular hollow section steel damper (LYCHSD) as a shear type damper and examined the effectiveness as a shear type damper from the result of one directional (uni-directional) cyclic loading experiment. On the other hand, the LYCHSD has a capacity to resist external forces in all direction due to the circular cross-sectional shape, and it is expected to be utilized as a device absorbing seismic energy inputted in multi-direction. The application area of LYCHSD is shown in Fig.1. Fig. 1 (a) shows a case where LYCHSD is used in combination with an isolator at the isolation layer, and Fig. 1 (b) shows a case where LYCHSD is used as a coupled vibration control system between buildings with different natural periods. In these cases, it is considered that the LYCHSD could be utilized as a mechanism to absorb the earthquake energy in an arbitrary direction and to damp vibration of the buildings. Therefore, in this research, we aim to provide basic knowledge of LYCHSD under bi-directional loading. Cyclic loading test were conducted with constant amplitude under bi-directional loading and grasp its mechanical behavior. In addition, the obtained

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A displacement-controlled semi-active friction damper with leverage mechanism

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SUMMARY

For seismic protection of structural systems, a semi-active friction damper (SAFD) whose slip force is adjustable in real time, usually provides better control performance than that of a passive damper, since its damping force is adaptive to seismic excitation. However, traditional SAFDs are usually force-controlled devices, whose the slip force is varied by controlling the clamping force directly applied on the friction interface of the damper. Consequently, a huge clamping force has to be generated and the precise control of this force in real time may cause difficulty. To overcome this problem, a displacement-controlled SAFD, called a Leverage-type Controllable Friction Damper (LCFD) is proposed and studied experimentally in this study. The LCFD system consists of a traditional passive friction damper and a leverage mechanism with a movable central pivot (fulcrum). By adjusting the position of the pivot in real time, the equivalent friction force of the LCFD system can be controlled accurately without changing the damper clamping force. To verify the feasibility of this novel system, a prototype LCFD was installed in a single DOF seismic structure that was tested dynamically by using a shaking table. Both the experimental and theoretical results in this study have demonstrated that the friction damping force of the seismic structure with a LCFD can be varied in a desired manner through a displacement control method rather than a force control approach. It also demonstrated that, as compared with passive friction dampers, the energy dissipation capacity of the LCFD can be maximized in earthquakes of various intensity levels.

Keywords*: leverage mechanism; friction damping; semi-active control; position control; energy dissipation device*

INTRODUCTION

Seismic response modification using energy dissipation devices is one of the most widely used technologies for seismic protection of structures. Friction dampers are one kind of energy dissipation devices that have been installed in numerous civil-engineering structures (Pall et al. 2000, Pasquin et al. 1998). Generally, a friction damper consists of one or more friction interfaces. A normal force is then applied to the interfaces to generate an energy-dissipating friction force when a seismic force is exerted on the structure where the damper is installed, consequently the damper will provide an additional energy dissipation mechanism for the structure (Soong and Spencer 2002]. This type of “passive” friction damper (PFD) does not require additional control energy to operate, and is thus easier to implement and more reliable. However, the internal parameters, such as the slip force, of a PFD are typically fixed values. In practice, the level of the slip force is predetermined according to the design earthquake load specified in a design code. Once the damper is designed and manufactured, the slip force may no longer be altered. This implies that the PFD cannot be adjusted in real time, in order to achieve better damping effect in an earthquake with intensity or characteristics that are different from the ones specified

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Seismic performance of two-story R/C frames enhanced by rectangular cross-section walls

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SUMMARY

A couple of 60%-scale one-bay two-story reinforced concrete frames were constructed and tested under vertical and lateral loadings. They had rectangular cross-section walls built between upper and lower beams and not connected to columns. The objective of the loading tests was to capture seismic performance of R/C frame enhanced by this type of walls. The experimental parameters were wall thickness and wall reinforcing details, such as the amount of horizontal reinforcement and boundary confinement. Load cells were installed under the first story wall to obtain axial force, shear force and flexural moment subjected to the wall. Both frames failed in the failure mechanism that had been intended in the design, developing plastic hinges at the wall top and bottom, the second story beam ends and the column ends. Lateral load carrying capacity and deformation capacity significantly increased in the frame whose walls had larger section, larger amount of reinforcement and concrete confinement. The maximum axial force measured in the first story wall was approximately 1.6 times the axial force applied before lateral loading. Significant reduction in shear force and axial force was observed after the wall failure. Lateral load carrying capacity of the walls could be predicted with good accuracy by using axial force measured in the first story wall.

Keywords: *reinforced concrete; rectangular cross-section wall; failure mode.*

INTRODUCTION

In the past large earthquakes including the 2011 Tohoku Earthquake, NILIM and BRI (2012) reported that many non-structural R/C walls with small thickness and small amount of reinforcement were heavily damaged, and functional continuities of many buildings were disrupted after the earthquake. Authors have been carrying out a research on new type of structural system which intends to reduce seismic response and damage by utilizing structural performance of seismically enhanced walls with improved structural detail. The basic concept of this structural system is as follows: 1) main seismic resistance mechanism is R/C moment resisting frame, 2) flexure-yielding rectangular cross-section R/C walls are built on the same vertical axis between upper and lower beams of each story and not connected to columns, 3) walls are given improved reinforcement detail and designed to yield at both ends. This system has both high seismic performance of wall system and flexibility of architectural plan originated from moment resisting frame. Case study of structural design on this type of R/C structures was also conducted and the effectiveness of this system was confirmed (Hattori, 2016).

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Shear strength evaluation of RC beams

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SUMMARY

Although compatibility-aided truss model allows accurate estimation of the actual strength, identifying many variables makes the overall calculation quite complex. Alternatively, the shear strength at the yielding of shear reinforcement can be relatively easily calculated. This paper presents a simplified equation for the shear strength calculation of reinforced concrete beams based on compatibility-aided truss model. The proposed equation utilizes the conditions at the yielding of shear reinforcement to minimize the number of variables, thereby simplify the calculations. The proposed equation predicted the actual shear strength of the specimens obtained from the ACI-DAfStb Database with reasonable agreement.

Keywords *: RC beams; shear behavior; truss models; shear strength*

INTRODUCTION

In the classic truss model, the shear strength of RC beams was evaluated based only on the equilibrium conditions, and the inclination of cracked concrete diagonal members in the truss was assumed to be 45° to the member axis. The classic model was improved by compatibility-aided truss models, such as the Modified Compression Field Theory (MCFT, Frank and Michael (1988)), the Rotating Angle Softened Truss Model (RA-STM, Hsu (1988)), and the Fixed Angle Softened Truss Model(FA-STM, Hsu and Zhang(1997)). These models evaluated the shear strength and deformation of RC membranes under pure shear by calculating the angle of the principal compressive stress of concrete based on the equilibrium and compatibility conditions. Later, these truss models based on the RC membrane under pure shear were further developed to predict the shear behavior of RC beams or columns by considering the effect of compound stress induced by bending moment, shear force, and axial force (Collins and Mitchell (1997), Bentz and Collins (2001)).

Great efforts have been made to propose revised truss models by applying modifications to the theories, thus to better predict the actual shear strength of RC members. A large number of models are currently available for estimating the shear strength of RC beams; however, the shear design method is still under debates, mainly due to the lack of rational design equations. Some of the models are too complex to be implemented in a code of practice, and therefore many simplified equations have been proposed (Bentz *et al*.(2006), Bentz and Collins (2006). Many countries use their own design codes that are based on different theories, and the codes have been revised constantly. For example, the Japanese design guideline (AIJ (1990)) utilizes the theory of the plasticity truss model. Eurocodes (EN 1992-1-1 (2004)) is based on the truss model with a variable-angle of principal compressive stress of concrete, considering the strength reduction factor of concrete ($\beta_s = 0.6(1 - f'_c / 250)$, and the angle is defined as $1.0 \le \cot\theta \le 2.5$. In the design specifications of AASHTO and Canadian standards (2014), the calculation of the crack angle is based on compatibility-aided truss model.

One of the greatest advantages of compatibility-aided truss models would be the accuracy in the shear strength estimation. However, the calculations are quite complex, because the model requires identifying many

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Experimental investigation on the post-earthquake seismic capacity of RC column members

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SUMMARY

To quantify the post-earthquake seismic capacity of reinforced concrete (RC) column members, experimental data for 6 column specimens with flexural, flexural-shear and shear failure modes are used to derive residual factors of seismic capacity for specified damage states in this work. According to the damage states of RC columns and their corresponding residual factors of strength, stiffness and energy dissipation, the nonlinear behavior of damaged RC column members can be defined in the detailed seismic performance assessment method for the residual seismic performance of earthquake-damaged RC buildings.

Keywords*: Reinforced concrete; column member; residual factor of strength; residual factor of stiffness; residual factor of energy dissipation.*

INTRODUCTION

In Taiwan, concrete structures damaged by earthquakes are identified with a yellow or red tag after inspection, warning those who will enter the building or prohibiting entry, respectively. After a building is identified as damaged, the owner or user must repair, retrofit, or dismantle it within a specified period. Additionally, the danger tag can only be removed after a government inspection deems the structure safe. Unless a building is completely damaged or collapsed, or unless its drift ratio exceeds collapse criteria, engineers may have difficulty determining whether a building should be retrofitted or demolished without a detailed financial loss estimation. On the basis of investigations made after several major earthquakes occurred in Taiwan, e.g., Ruei-Li earthquake (July 17, 1998), Chi-Chi earthquake (September 21, 1999), and Chia-Yi earthquake (October 22, 1999), a number of low-rise buildings suffered damages of various degrees. Especially in Chi-Chi earthquake, nearly half of the school buildings, which are almost categorized into low-rise reinforced concrete (RC) buildings (building height is lower than 15 m), in the central area of Taiwan collapsed or were damaged seriously. Even in Taipei City, which is about 150 km far away from the epicenter, there were 67 school buildings damaged were damaged in Chi-Chi earthquake. Additionally, school buildings are usually required to act as emergency shelters soon after a disastrous earthquake event. Therefore, a post-earthquake emergent assessment procedure for decision-making for earthquake-damaged buildings is needed.

Many seismic assessment methods for buildings have been developed in recent years (ATC, 1996; FEMA, 1997 and 2000); however, those methods seldom mention re-evaluating the seismic residual of earthquake-damaged buildings. The guidelines developed by JBDPA (2001 and 2005) for evaluating the residual seismic performance of earthquake-damaged buildings can be used to determine the damage class of a building; however, the procedure is only suitable for the preliminary seismic performance assessment. Restated, a preliminary seismic performance assessment does not provide sufficient data for engineers or users to make decisions on earthquake-damaged buildings. Additionally, for the detailed seismic performance assessment of low-rise RC building structures in Taiwan, engineers need to use the nonlinear static analysis method, which is different with the method proposed in the JBDPA guidelines (2001 and 2005). Therefore, a post-earthquake detailed seismic performance assessment method is needed to evaluate the residual seismic performance of an earthquake-damaged RC building for the post-earthquake maintenance strategy.

In the JBDPA guidelines (2001 and 2005), the reduction factors are suggested using limited experimental data.

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Shear strength of corroded reinforced concrete short columns

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SUMMARY

In reinforced concrete (RC) structures, reinforcement corrosion during service life deteriorates the seismic structural capacity of the structures. The present study evaluates the seismic performance of corroded in-service RC columns showing shear failure under cyclic load. Four RC columns with shear-span ratio 2.3 and light transverse reinforcement were obtained from an in-service RC moment frame building constructed in 1987, and quasi-static cyclic tests were conducted to investigate the seismic behavior of these columns. For the test parameters, axial compression force ratios and longitudinal bars arrangements were considered. The test results showed that as the compression force ratio increased, the failure modes of the in-service RC columns shifted from shear-bond failure to shear-compression failure, and the deformation capacity decreased. The shear strength of the column specimens was evaluated by addressing the effect of reinforcement corrosion.

Keywords*: RC column; in-service building structure; quasi-static cyclic test; corrosion; shear strength.*

INTRODUCTION

In seismic regions of China, a number of masonry filled RC moment frame structures that use low transverse bar ratio in columns were constructed in the 1970s and 1980s (Shi, 2012). Particularly, in the masonry filled RC moment frame structures, short columns are usually designed in the opening of the masonry walls. The failure mode of the short columns is dominated by shear-flexural behavior, which exhibits lower deformation capacity compared with the columns governed by flexural behavior. During the service life of RC moment frame structures, reinforcing bars have been corroded and concrete has undergone the process of carbonization and chloride ion erosion, which deteriorate the earthquake resistance of the short columns. Rebar corrosion causes the spalling of cover concrete, ductility decrease of rebars, and bond strength degradation between rebars and concrete (Coronelli and Gambarova, 2004). When the corrosion of rebars is heavy, RC structures even lose the load-carrying capacity, and should be demolished and rebuilt (Isecke, 1983; Cederquist, 2000). Structural behavior of the corrosion damaged RC short columns obtained from actual structures has not been studied. Thus, in the old building structures subjected to earthquake load, the structural behavior of the short columns should be investigated.

In the present study, earthquake resistance of corrosion damaged in-service RC short columns was investigated by cyclic loading tests and analysis. Four RC columns with shear span ratio 2.3, which show shear-flexural behavior, were obtained from a masonry infilled RC moment frame structure used for over 20 years. Three RC columns were tested under quasi-static cyclic loading, and one RC column was used to measure the material properties of concrete and rebars. Three axial compression ratios and two different reinforcement details were considered. The structural performance of the column specimens was discussed.

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Performance and design models of precast concrete seismic-force-resisting systems

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ABSTRACT

In this SEEBUS paper, an innovative precast concrete (PC) T-wall system and PC wall-steel coupling beam system are introduced. Performance of the developed fast-track PC seismic force-resisting systems were experimentally verified using cyclic tests of large-scale specimens. The test results of PC T-walls showed that the PC T-wall without diagonal reinforcement performed quite well in terms of lateral stiffness, strength and ductility. All the details of the bolt type connections between the lower and upper panels proved to be robust and practical. Furthermore, the test results of PC wall-steel coupling beam systems showed that a certain length of embedded steel sections was needed to develop the nominal shear strength and corresponding deformation of the PC wall-steel coupling beam system and that the use of top-seat angles was also necessary for satisfactory seismic performance. Finally, design models for the prediction of lateral strength and displacement or shear strength of the developed PC T-walls and coupling beam systems and for the minimum embedment length of the steel section.

Keywords*: Precast concrete; seismic force-resisting system; T-wall; PC wall-steel coupling beam system; design model; fast construction.*

INTRODUCTION

Reinforced concrete (RC) structural walls with various cross-sections such as T-shaped, L-shaped, and rectangular sections and coupling beams have been used for both low-rise and high-rise buildings in many countries (Wallace, 2012). Such asymmetric wall systems are often necessary for architectural purposes; however, the asymmetric walls tend to influence the structural behavior, constructability and economic feasibility of a building depending on their arrangement and cross-sectional shapes. The T-walls have asymmetric characteristics in terms of lateral strength, stiffness and ductility. No previous experimental and analytical studies of precast concrete (PC) "T-walls" were conducted up to date. Seismic force resistance of PC walls is generally achieved by emulating cast-in-place detailing and/or by the use of post-tensioning. In this study, the former method is adopted to connect two rectangular walls, along with an innovative bolting system consisting of end-threaded reinforcing bars, hex nuts and C-shaped steel plate connections (Fig. 1) (Lim et al., 2016a).

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Performance of unbonded post-tensioning monostrand anchorages under concentric and eccentric cyclic loads

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SUMMARY

During the last decades, there has been an increasing interest in applying unbonded post-tensioned (PT) precast concrete (PCa) structures in seismic regions for the purpose of reducing residual damage. The efficiency of these structural systems relies on the adequate performance of strand anchorages to transmit the prestress forces. Even though unbonded PT anchorage systems have been largely used in PCa members, their application to earthquake-resistant members is not well documented yet. As a result, more research is needed on unbonded PT anchorages for their use in members to be subjected to seismic demands. This paper describes the results of an experimental investigation on the performance of monostrand anchorages subjected to both concentric and eccentric cyclic loads. Moreover, the influence of anchorage type, loading patterns and strand size on the ultimate deformation capacity of the anchorages is discussed. Two types of commercially available anchorage systems were tested in this study. Two sizes of seven-wire, uncoated, low-relaxation PT monostrands were considered. Several cyclic loading protocols were applied to evaluate the performance of the anchorages under different conditions of seismic loading. Cyclic frequencies of 1 to 4Hz were applied to the specimens. The results showed that ultimate deformation capacity of the strands was limited by fracture of individual wire (or some wires) inside the anchorages. It was found that this premature failure occurred at strains as low as 1.4%. Based on the results, strains in unbonded post-tensioned strands should be limited to about 1.0% when designing self-centering rocking precast concrete structures.

Keywords*: anchorage; unbonded; post-tensioning; monostrand; cyclic loading; eccentric loads.*

INTRODUCTION

During the last decades, there has been an increasing interest in applying unbonded post-tensioned (PT) precast concrete (PCa) structures in seismic regions to control residual damage (Kurama 2002). Unbonded PT anchorage systems have been largely used in PCa members subjected to service load, but their application to earthquake-resistant members is still not well documented. Moreover, it was noted that cyclic loading on unbonded PT strand-anchorage systems might cause premature failure of strands inside anchorages (Walsh and Kurama 2010; Weldon and Kurama 2007). Consequently, further research is needed on unbonded PT anchorages for their seismic applications to meet performance-based criteria. This paper describes the results of an experimental evaluation on the behavior and failure mechanism of monostrand anchorages subjected to both concentric and eccentric cyclic loads. In addition, this paper addresses the influence of high-amplitude low-frequency loading on the elongation capacity of strand at fracture.

OUTLINE OF THE EXPERIMENT

Test specimens consisted of strands assembled with anchorages at both ends. The configurations used for the

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In-plane loading tests for confined and in-filled masonry panels in RC frames with eccentric openings

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SUMMARY

This paper presents a sequential series of the tests for confined and in-filled masonry panels with eccentric openings. The specimens included two confined and two in-filled masonry panels surrounded by identical RC frames. Each construction type has a specimen with eccentric door and window openings, respectively. An additional in-filled masonry specimen with door opening was retrofitted with a new method proposed by this research. All specimens were tested with displacement-controlled cyclic lateral in-plane loading in a double-curvature manner. Constant vertical force was applied during the tests. The test results showed that the specimens without retrofit had asymmetric behavior under cyclic loading. Because of the lack of confinement around the openings, the confined and in-filled panel acted similar when they were pushed by the column. The difference between the two construction types only showed when the loading was pulling back. The windowsills in these tests did not appear to affect the panel behavior, but caused short -column effect to the frame and decreased the deformation capacity. The proposed retrofit method improved the strength and energy dissipation of the specimen significantly but had no effect on the deformation capacity.

***Keywords**: confined masonry; in-filled masonry; opening; retrofit.*

INTRODUCTION

This research continued a series of lateral loading testing research on confined and in-filled masonry panels with openings. The masonry panels are the most common types of partition walls in low-rise RC buildings. Confined masonry (CM) panels are constructed prior to the boundary frames and connected to the frames with shear keys. In-filled masonry panels are constructed after the RC frames so there are only mortar-filled interface between the panels and the frames. In Taiwan, the CM buildings have a height limitation of 12m and shall not exceed three stories. The regulation makes CM become rare among new buildings. However, there are still a large number of existing CM buildings in rural regions. The CM buildings in Taiwan are quite different from the standard CM buildings in Southern Europe, Latin America, and other parts of Asia (EERI 2012). The RC tie column and beam sections in standard CM are usually small and considered to be hinge-connected. Taiwanese CM buildings have larger beam and column sections, typically 300-350mm x 400-450mm. The beam-column joints are moment-connected. There is no requirement for placing tie members around the openings, as required for the standard CM buildings (Meli and Brzev 2011). It means that the shear connection between the panels and the frames might be the only difference between the confined and in-filled masonry panels used in Taiwan.

The subject of this research is the existing low-rise RC street buildings. Before a major revision in the seismic regulations for building codes in 1997, most of the low-rise RC buildings were not constructed with a ductile design. Figure 1 shows the ground floor plan of a typical street building. Each single span unit has a main entrance facing the arcade and the street on the west. Therefore, the interior partition walls in the north-south

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The state of the practice of timber structures in Korea

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SUMMARY

In the past few years, the tall building industry has become increasingly interested in the use of timber as a major structural element in skyscrapers. In the near future, this movement will lead to the next stage where timber will form a much bigger part of the built environment. Currently, there is a worldwide wave of research, using mass timber or engineered wood products that are as robust as concrete and steel. As a part of this movement, this paper presents the possibilities of cross laminated timber (CLT) as a building material and their characteristics. A few examples of timber structures in Korea are also presented. Then, challenges and area to be improved for engineers will be discussed.

***Keywords**: timber; engineered wood; CLT; high-rise; KBC2016*

INTRODUCTION

A multidisciplinary approach is essential to achieve the aim of sustainability using timber in the urban environment. Cross laminated timber (CLT) has become a well-known engineered timber product of global interest. The orthogonal, laminar structure allows its application as a full-size wall and floor element as well as a linear timber member, able to bear loads in- and out-of-plane. This article provides a summary on some selected topics related to CLT, in particular characteristic material properties, design and connections. Making use of general information concerning the product's development and global market, the state of knowledge is briefly outlined, including the newest findings and related references for background information. In view of ongoing global activities, a significant rise in production volume within the next decade is expected. Prerequisites for the establishment of a solid timber construction system using CLT are (1) standards comprising the product, testing and design, (2) harmonized loadbearing models for calculating CLT properties based on the properties of the base material board, enabling relatively fast use of local timber species and qualities, and (3) the development of CLT adequate connection systems for economic assembling and an increasing degree of utilization regarding the load-bearing potential of CLT elements in the joints. The establishment of a worldwide harmonized package of standards is recommended as this would broaden the fields of application for timber engineering and strengthen CLT in competition with solid-mineral based building materials. Environmental advantages of timber are widely recognized. And the cost efficiency of sustainable construction will be the main driver of an increased use of more timber.

As demand for timber in high-rise increased, new type of hybrid system has been proposed. CLT-concrete composite system is a hybrid construction technique used for strength and stiffness upgrading of existing floors and new construction such as multistory buildings. This technique connects a CLT panel to a concrete slab cast above it, using a connection system to transfer shear forces between timber and concrete. This connection system can be either mechanical fasteners such as nails, screws, and toothed metal plates embedded into the timber, or notches cut from the timber or a combination of both. These floors provide many benefits compared with traditional timber floors such as greater strength and stiffness, less susceptibility to vibration, improved seismic and fire resistance, better acoustic separation and thermal mass. The lower weight imposes lesser loads on the

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Numerical analysis of a fuzzy-controlled stiffness controllable mass damper system

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SUMMARY

The conventional tuned mass damper (TMD) is an effective control device for vibration suppression. However, larger stroke is required for better performance. A TMD with fixed design parameters may not alleviate the responses of structure subjected seismic loadings because the frequency content of earthquake is complex and unpredictable. Moreover, the optimal designed damping ratio is difficult to be provided through passive damping devices. To resolve this problem, leverage-type stiffness controllable mass damper (LSCMD), a fuzzy-controlled semi-active mass damper, is proposed in this study. Fuzzy Logic Controller (FLC) with conventional triangle membership functions and fuzzy control rules (FCRs) based on observing the hysteresis loops of linear quadratic regulator (LQR) theory and the least energy control method (LECM) rule are adopted in this study. The target pivot position of the leverage mechanism can be determined in real time to provide the additional damping characteristic through the controllable stiffness of the LSCMD. By adopting the proposed FCRs, the control performance of the LSCMD is compared with the LQR and the LEM rules. Different semi-active control rules will drive the pivot position of the lever-arm of the LSCMD and be able to control the damper stiffness and restoring force in real time. On the stroke suppression performance, FCRs are better than LQR. Moreover, FCRs and LEM have similar control performance on displacement suppression at the target structure. The simulation results show that the FCRs based on the FLC have good control results and they do not need to identify the precise parameters of system.

Keywords: *Semi-active Control, Stiffness Controllable Mass Damper, Leverage Theorem, Discrete-time Optimal LQR Control, Least Energy Control Method, Fuzzy Logic Controller.*

INTRODUCTION

A tuned mass damper (TMD) mounted in structures to reduce the amplitude of mechanical vibrations is an effective control device [Frahm 1909]. In recent years, the applications of TMDs for aseismic design are increasing [Lin et. al. 2010a; Miranda 2005]. But the optimal frequency ratio and damping ratio of a TMD need

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Vision sensing-based control force estimation of tuned liquid column dampers under real-time hybrid simulation

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SUMMARY

In this study, a fast computer vision method is developed exclusively for dynamic liquid height measurement of a tuned liquid column damper (TLCD) to replace a series of the conventional sensors installed at a TLCD tested. The fast vision sensing system is based on binary pixel counting of the portion of images steamed in a pseudo-dynamic test and achieves near real-time measurements of control force of a TLCD and experimentally evaluated through a wide range of lab scale dynamic tests.

Keywords*: tuned liquid column damper; control force; vision-based sensing; real-time hybrid simulation*

INTRODUCTION

Structural control is needed to reduce the dynamic responses of the structures and to maintain their functional performances. The tall and slender structures are vulnerable to dynamic loading such as wind and earthquakes. While the structures operate within safety limits, they may suffer from lack of serviceability due to undesirable vibrations induced by the dynamic loading. One of the pervasive strategies widely applied to attenuate structural vibration is the installation of a secondary mass damper on the top floor of a building, i.e., a device generating a reaction force induced from the oscillating motion of a secondary mass. The secondary mass is a small fraction of the entire mass of the primary structure and interfaced to inherent damping devices for increasing the energy dissipation capability. Depending on the oscillatory media, the secondary mass dampers are categorized into two groups: tuned mass damper (TMD) and tuned liquid damper (TLD). The TMDs are mechanical devices of a solid mass with springs and dashpots attached to the primary building (Kwok et al. 1995) and the TLDs are liquid containers (Fujino et al. 1992). As the counterpart of the TMDs, the TLDs have proven their advantages: for example, simplicity, low cost, easy installation and maintenance, just to name a few (Min et al. 2005; Xu et al. 1992; Gao et al. 1997; Balendra et al. 1999). Two different types of the TLDs have been investigated and adopted in construction sites (Min et al. 2014). Tuned Liquid Mass Damper (TLMD) and Tuned Liquid Column Damper (TLCD) utilize wave braking/sloshing in free liquid surface and energy dissipating liquid motions of oscillation in narrow tubes, respectively. Referring to numerous design parameters relating the configuration of the TLCDs and resultant tuning feasibility to determine their dynamic characteristics, practical advantages of the TLCDs over the TLMDs have frequently been emphasized in the literature (Min et al. 2014; Wu et al. 2005; Yalla et al. 2000).

Prior to installation of a TLCD at a site, a factory test for verification and tuning of dynamic characteristics must be conducted with the pre-fabricated TLCD. Majority of the previous studies regarding the TLCD are categorized into theoretical (Gao et al. 1997; Colwell et al. 2008; Di Matteo et al. 2017; Sakai et al. 1989) and small-scale experimental studies (Hitchcock et al. 1997; Min et al. 2015; Matteo et al. 2014). The analytical and parametrical studies are extensively conducted to confirm effects of mass ratio, structural stiffness, and geometries of the TLCD to the vibration reduction. In the studies, numerous approximate techniques have been proposed to simulate the nonlinear damping force, since exact analytical solution of the liquid motion is difficult to obtain. As a result, small-scale shaking table tests have been conducted to evaluate the TLCD especially for experimental investigation of nonlinear damping effect. Real-time hybrid simulation (RTHS) is an experimental

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Seismic performance evaluation of building structures using stud-type dampers

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SUMMARY

Seismic load resisting structural systems using stud-type damper devices, hereinafter named as stud damper frame (SDF) systems, have been increasingly used in building structures in recent years. The stud-type dampers (SDs), such as stub columns, are installed within a bay between columns attaching top and bottom beams, and typically adopted to increase structural strengths, stiffness or additional damping. The SDFs have an advantage of significantly increasing the versatility of architectural space in the building compared to that using braced/shear wall types of devices. The seismic performance as well as the design methodology of SDF systems are still unclear among the general practice, and the literatures on the seismic assessment of SDFs are extremely limited. A comprehensive analytical work has been conducted to achieve the seismic assessment of SDFs through nonlinear time history analysis. SDFs with various building heights and under earthquake loads at various seismic hazard levels have been examined in the study. The prototype buildings have been designed at the location of San Francisco, California in the United States, and a series of ground motions has been selected upon the PEER NGA database and scaled to different hazard levels as the seismic excitation. Several design parameters of SDs, such as initial elastic stiffness, post-yielding stiffness and yield strength, has been investigated and compared to each other to clarify the influences of those parameters on the seismic performance of the SDF buildings. A proposed case with early yielding and large post-yielding stiffness of SDs was shown to generally improve the seismic performance in the frequent earthquakes, and consistently limit the residual story drifts throughout all hazard-level earthquakes. The results would provide an analytical evidence and a guidance for the performance-based design method for SDF buildings.

***Keywords**: Steel Building Structures; Metallic Dampers; Post-yielding Stiffness; Seismic Performance Assessment*

INTRODUCTION

Many seismic load resisting systems (SLRSs) have been developed and greatly adopted in buildings in past few decades. Among those, special moment resisting frames (SMRFs) have been mainly used to achieve large structural ductility. To create more economical structural systems, the dual systems combining SMRFs and steel braces or shear walls were increasingly adopted in the practice to efficiently enlarge the structural stiffness as well as additional damping, such as special concentrically braced frame, buckling restrained frame, and steel plate shear wall frame dual systems. However, the braces and shear walls potentially and unavoidably block up the architectural space in the bay installed and limit the use of the space in the buildings, which is extremely valuable especially for the buildings in the urban areas. It therefore resulted in a relatively low adoption intention of the SLRSs with braces and shear walls in new constructed buildings.

More recently, the dual systems using stud-type damper devices, hereinafter named as stud damper frame (SDF) systems, have been preferred and increasingly adopted in building structures. The stud-type dampers (SDs), such

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Development of bi-gradation velocity feedback for isolated structure with controllable friction damper

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SUMMARY

A semi-active isolation system, which is used for seismic protection of structural systems and generally has better control performance than a passive damper, is proposed. Traditional systems adjust their friction resistance force by directly controlling the normal force applied on the friction interface. However, this is not easy to accomplish. In order to avoid problems associated with active and passive systems, a previously developed semi-active system named Leverage-type controllable friction damper (LCFD) is used in this research. LCFD system combines a traditional passive friction damper and a leverage mechanism that has a movable central pivot. By controlling the position of the pivot in real time, the equivalent friction force of the LCFD system can be accurately adjusted. Nevertheless, this system requires the application of an appropriate control law to effectively reduce structural response during an earthquake. In this study, Bi-gradation velocity control (BGVC), which is based on the control law of proportional displacement control (PDC), is applied in the LCFD system in order to determine the pivot position. Both control laws have the same advantages, as they merely require the related-to-the-ground displacement or velocity, are simple and can be easily implemented in practice. By adapting BGVC, the excessive isolator drift induced by a near-fault earthquake can be significantly suppressed, and less control force is used in slight excitations to mitigate the acceleration response. The results of numerical analysis demonstrate that the seismic response of a structure using the LCFD with the BGVC yields a lower response. It also show that the semi-active system requires lower control energy than the active system.

Keywords*: semi-active control; friction damper; displacement control; isolated structure.*

INTRODUCTION

Currently, most of the semi-active friction dampers belongs to force-control method, where the control force is generated by changing the normal force applied on the friction face. As the friction coefficient of different materials is generally less than one, it becomes a big challenge in practical implementation, where the required control force may be several times of the applied normal force. To overcome this issue, a semi-active control mechanism named leverage-type controllable friction damper (LCFD) was proposed. By switching the location of the pivot point, the friction force can be easily manipulated via the force arm. Moreover, better control precision can also be achieved with the proposed displacement-based control mechanism.

The LCFD is equipped several characteristics. Similar to the active control system, a rapid seismic control capability is supported. Moreover, the reliability, robustness, and easy maintenance are also provided. As no external energy is input to the structure, the system can be operated with small power demand under earthquake

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Cyclic behavior of retrofitted L- and T-shaped reinforced concrete columns

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SUMMARY

This study examines the seismic performance of one L-shaped and two T-shaped large-scaled reinforced concrete (RC) columns retrofitted from rectangular columns those typically seen in Taiwanese street houses. An innovative retrofit technique was proposed where additional longitudinal reinforcement were not embedded into the existing foundations. Testing was carried out using single curvature cyclic lateral loading with constant axial load. From the test results, this proposed retrofit technique was proven to be effective in term of increasing the initial stiffness and lateral load capacity of the rectangular columns. The retrofitted columns exhibited ductile behaviors with greater displacement ductility and less cracks in comparison with their monolithic L- and T-section counterparts. In addition to that, the ratio of additional reinforcement ratio of the retrofit parts had a slight influence to the maximum load capacity but had a remarkable affect to the ductility of the retrofitted columns.

Keywords*: reinforced concrete, seismic; retrofit; L-column; T-column.*

INTRODUCTION

In street houses, it is typically seen that several stories from ground level require big openings for commercial use or parking garage. The elimination of wall in such stories causes a loss of seismic resistance along the street direction and results in soft-story mechanism (Teresa 2012). At the same time, the limitation of the columns geometry in order to optimize the living space might introduce the unfavorable weak-column strong-beam mechanism, where the sum of moment resisting capacity of the columns at a given joint is inferior to that of beams.

Sugano (1996) proposed a number of rehabilitation techniques to increase the seismic resistance of existing reinforced concrete buildings, namely bracing, infilling, or jacketing. In some cases, these techniques are unfavorable due to the interference with the living space. In addition to that, the RC jacketing technique usually involves with the embedment of the additional longitudinal reinforcement using the epoxy resin, which requires a certain quality of preparation. Julio (2003) reported an unexpected case where the embedded reinforcement slipped out because the drilled holes were not cleaned adequately. Hayashi (1980) conducted testing on the columns jacketed by mortar and steel wire mesh. Even though the additional steel reinforcement was not embedded into the foundation, it was able to increase the column shear strength and avoided the brittle shear failure.

In this study, an innovative retrofit technique was proposed to transform the rectangular columns into L-section or T-section depended on their locations whether at the corners of the entire complex or at two ends of partition walls separating two adjacent housing units. This technique not only can increase the seismic capacity along the weak direction of the column thanks to the advantage of the effective depth, but also it less interferes with the living space because most of the retrofitted parts are embedded into walls. Furthermore, the embedment of the additional longitudinal reinforcement is no longer required; thus, it can significantly reduce the amount of preparation work.

Three large-scale specimens were made including one L-column and two T-columns retrofitted from rectangular

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Numerical study on seismic structural performance of steel encased concrete piles

(This paper contains part of work submitted for completion of M. Eng. to Department of Civil Engineering, Tokyo Institute of Technology)

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SUMMARY

This study examines the bending behavior of precast steel encased (SC) piles up to the ultimate damage state. Work presented here is in continuation to previous works done under the same project, titled “Structural Performance Evaluation of Earthquake Resilient Concrete Pile System”, wherein tests were carried out on SC piles under different loading conditions. Using data from these experiments, a companion analytic tool is presented here to predict the structural behavior of such piles by finite element analysis using OpenSees. Flexural behavior is studied by focusing on the moment vs. curvature, strain vs. displacement and load vs. displacement relationships. A set of 6 piles, tested previously, under combination of cyclic lateral and high, constant axial loads is analyzed here to improve the estimation of yielding and load carrying capacities. A comparison between test results and numerical is presented by comparing various points of interest in the moment-curvature relationship, that is, failure of steel casing in tension and compression, maximum compressive and tensile stresses in concrete, maximum load capacity and ultimate load capacity. It is seen that the analysis efficiently captures the pile behavior and accuracy increases with employment of linear tension softening in concrete model and isotropic strain hardening in the steel model. The work presented here shall act as a comprehensive database to understand performance of SC piles beyond the point of ultimate deformation.

***Keywords**: numerical analysis; OpenSees; steel-encased concrete piles.*

INTRODUCTION

With increase in use of pile foundations in buildings, numerous instances of damage to pile foundations have been reported. Horizontal cracks at deeper parts of piles due to liquefaction was a unique feature of damage in the Hyogoken-Nanbu earthquake of 1995 as reported by Karkee and Kishida (1997) and Tokimatsu et al. (1996). Such damages are not only extremely difficult to repair but also very difficult to detect. Specifically, steel-encased piles are extensively used these days in Japan and elsewhere as foundation system for off-shore structures, buildings, bridge piers and towers. Structural response of cased piles is complicated because of the biaxial stresses in steel casing. It is subjected to shear and longitudinal stresses from axial loads and flexure in pile and also hoop stresses due to the concert confined inside the steel casing.
Piles are tested without soil to study the pile behavior under large deformations. Only a few researches like Peterson (1999) and Park et al. (1983), have focused solely on the seismic performance of steel encased (SC) piles. These discuss effects of combined axial and lateral load on the pile behavior considering the axial load to

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Behavior of beam-to-column moment connections using SM570 high-strength steel

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SUMMARY

This study elucidates the cyclic behavior of four beam-to-column moment connections using SM570 high-strength steel. Four specimens were designed to be reduced beam section (RBS-QCA), welded unreinforced flange – welded web (WUF-W), and widened beam flange (WF1 and WF2). Specimens represent an exterior beam-to-column connection and were cyclically tested. Test results indicated that all the specimens developed significant yielding and plastification on the beam away from the column associated with local buckling of the beam flange and web, especially the specimens RBS-QCA and WF-series. For specimens RBS-QCA and WUF-W, minor cracks occurred at the tip of the penetration groove weld and the root of the weld access hole, but the cracks did not cause the fracturing of the beam flange. Using the SM570 high-strength steel, specimens achieved 5% rad story drift angle and were satisfactory ductility requirement by either reduced beam section, welded unreinforced flange – welded web, or widened beam flange.

***Keywords**: high-strength steel; moment connection; plastic hinge; reduced beam section.*

INTRODUCTION

The development of the high-strength steel has been increased significantly in recent decades (Azizinamini et al. 2004; Bjorhovde 2004). High-strength steel has been used widely in bridges and buildings (Greco and Earls 2003; Earls and Shah 2002; Miki et al. 2002). The frequent use of the high-strength steel is SM570 in Taiwan. In Taiwan, China Steel Corporation had developed a high-strength steel SM570M-CHW which can be used in earthquake resistant design. The specified yield strengths of SM570 steel range from 430 to 450 MPa while those of SM570M-CHW steel range from 420 to 540 MPa. Their tensile strengths are in the range of 570 to 720 MPa. One of the mechanical properties significantly affects the plastification of the steel plate is the yield ratio. The yield ratio is defined to be the ratio of the yield strength to tensile strength. The yield ratio of steel plates used in seismic design, such as SN steel, is regulated to be less than 0.80 because steels with high yield ratio result in a less ductility and energy absorption. The steel with lower yield ratio can develop larger plastic zone to achieve a better ductile behavior. The yield ratio of the SM570M-CHW is specified to be less than 0.85.

In the high-rise buildings, special moment frame are widely used. Therefore, the beam-to-column moment connections are designed to have ductile behavior by forming plastic hinges on the beam section. However, the 1994 Northridge earthquake and 1995 Kobe earthquake damaged many moment connections (Mahin 1998; Nakashima et al. 1998). Aftermath of the earthquake, there are several improvements to enhance the ductile behavior of the moment connection, such as reduced beam section, cover plate, rib plate, widened beam flange, and haunch (Engelhardt et al. 1998; Engelhardt and Sabol 1998; Uang et al. 1998; Chen et al. 2005; Chen et al. 2013). This study investigates experimentally the seismic behavior of the moment connections using SM570

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Cyclic lateral loading test for prefabricated composite column with bolt-connected steel angles

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SUMMARY

To improve structural performance and constructability, a prefabricated steel-reinforced concrete (PSRC) column was developed. In the PSRC column, longitudinal steel angles are placed at the corners of the cross section, and the angles are bolt-connected with transverse tie plates. A cyclic loading test was performed for six composite columns to investigate the load-carrying capacity, deformation capacity, and failure mode. The test results showed that the closely spaced tie plates and Z-sectional tie plates improved the bond performance between the steel angles and concrete without failure of bolt-connection, which increased the deformation and energy dissipation capacity of the PSRC column. After cover concrete crushing, the slender angle was vulnerable to buckling, which promoted cover concrete spalling.

Keywords: *composite column; steel angle; transverse tie plate; bolt connection; cyclic lateral loading; bond strength; energy dissipation; local buckling*

INTRODUCTION

In concrete-encased steel (CES) composite columns, a steel section (e.g., H-section) is conventionally placed at the center of the cross section to prevent local buckling of the steel. However, from a structural point of view, it is inefficient to increase the overall flexural capacity of the column [Fig. 1(a)]. Besides, because of the reinforcing bars placed around the steel, field rebar work is required, which further deteriorates overall constructability.

Many researchers have studied the composite section with steel angles at the corners of the cross section Poon (1999), Montuori and Piluso (2009), and Campione (2013) performed axial load tests to investigate the structural capacity of the RC columns externally strengthened with steel angles and transverse steel tie plates. The test results showed that the axial load-carrying capacity and deformation capacity of the column were improved because of confinement effect resulting from the angles and tie plates. However, the steel angles without concrete encasement were vulnerable to local buckling when the lateral restraint of the tie plates was insufficient. According to Kim et al. (2008), who performed a fire resistance test for composite columns with exposed steel angles, the load-carrying capacity of the column significantly decreased, showing premature buckling of the steel angles as well as failure of weld-joints under high temperature.

For better structural capacity and constructability, a prefabricated steel-reinforced concrete (PSRC) composite column was developed [Fig. 1(b)]. In the initial PSRC column, four steel angles are placed at the corners of the cross section (with concrete encasement), and the angles are weld-connected using transverse tie bars. Because the steel cage comprised of the angles and tie bars can be prefabricated in factories, field rebar work is unnecessary. Further, the steel angle can provide enough strength and stiffness to resist construction load even when beams and slabs are superimposed on the steel cage. For the PSRC column with welded transverse bars, Hwang et al. (2016) and Eom et al. (2014) performed compression tests and pure flexural tests, respectively.

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In-plane cyclic behavior of shear-critical steel-plate composite walls

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SUMMARY

This paper summarizes the results of in-plane cyclic tests of four steel-plate composite (SC) walls with boundary elements. The tests were executed in the laboratory of National Center for Research on Earthquake Engineering (NCREE) in Taiwan. Thick steel plates were used as boundary elements of the four specimens and all specimens were designed to be shear-critical. The design variables considered in the testing program were aspect ratio of SC wall (0.7, 1.04, and 1.46) and thickness of boundary elements (3 and 5 cm). The failure mode and cyclic behavior of each specimen are reported. The strengths of the specimens are compared with the predictions of selected literatures. The impact of wall aspect ratio and thickness of boundary elements on in-plane shear strength of SC walls is discussed.

Keywords: *steel-plate composite wall; boundary element; cyclic loading test; aspect ratio*

INTRODUCTION

Steel-plate-concrete (SC) composite walls are being constructed in nuclear power plants (NPPs) in the United States and China and a couple of supertall buildings in China. These walls are composed of steel faceplates, infill concrete, welded connectors that tie the plates together and provide out-of-plane shear reinforcement, and shear studs that enable composite action of the faceplate and the infill concrete and delay buckling of the faceplate. The use of SC walls in safety-related nuclear facilities in Korea, Japan, and the United States has been studied (e.g., Ozaki et al. 2004, Varma et al. 2014, Epackachi et al. 2015) for the past 20 years. In earlier days, most of numerical studies and test data in the studies of SC walls have focused on the elastic range of response, because NPPs are designed to remain elastic under design basis shaking. Since a decade ago, the nonlinear behavior of SC walls has drawn more and more attention.

A SC wall is very often connected with perpendicular SC walls at the ends. The perpendicular walls become the boundary elements of the longitudinal wall. Ozaki et al. (2004) and Varma et al. (2014) developed an approach to predict the yield point of an SC wall subjected to in-plane later force using composite shell theory. The approach was simplified and codified in AISC N690-12s1 (AISC 2015) for the purpose of design. Booth et al. (2015) further proposed that the in-plane shear strength of a SC wall with boundary elements should include two parts: the shear force required to yield the steel plates and an incremental shear resisted by the concrete in diagonal compression up to the failure of the wall. Huang et al. (2016) reported the test results of 3 SC walls with boundary elements, including two shear-critical specimens with an aspect ratio of 0.75 and a flexure-critical one. The results showed that both the recommendations of AISC N690-12s1 and Booth et al. underestimated the strengths of the two shear-critical specimens. They concluded that the underestimate might be due to the impact of aspect ratio of walls, which was not included in both documents.

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Column-to-beam strength ratio required to reduce likelihood of column yielding in earthquake-resistant RC moment frames

Chang-Soo Kim[1] and Hong-Gun Park[2]

SUMMARY

Current design codes require the minimum column-to-beam strength ratio at joints to reduce the likelihood of yielding in columns. However, the requirements may not prevent hinging in columns due to the inelastic moment distribution under earthquakes and the higher mode effect of dynamic response. To investigate the strength ratio required to ensure the strong column – weak beam behavior of RC special moment-resisting frames under earthquakes, a numerical study was performed considering various parameters (plastic rotations of beams and columns, design earthquake load and its lateral profile, gravity loads, stiffness ratio, design method for beam strength, joint location, and frame height). The results showed that the strength ratio is strongly affected by the parameters and it varies with the height ratio. Thus, the design strength ratio needs to be proposed as a function of the height ratio covering the practical ranges of the parameters.

***Keywords**:* column-to-beam strength ratio; strong column – weak beam; reinforced concrete special moment-resisting frame; inelastic behavior; seismic design.

INTRODUCTION

For RC special moment-resisting frames, ACI 318 (2014) and KBC (2016) require that the sum ΣM_{nc} of nominal flexural strengths of columns at each joint exceed the sum ΣM_{nb} of nominal flexural strengths of beams by at least 20% (Eq. (1) and Fig. 1), to reduce the likelihood of yielding in columns.

$$\Sigma M_{nc} \geq \frac{6}{5}\Sigma M_{nb} \tag{1}$$

where the flexural strengths are evaluated at the faces of the joint, and the contribution of slab reinforcement for negative moment (slab in tension) within the effective slab width should be considered in the calculation of the beam strengths.

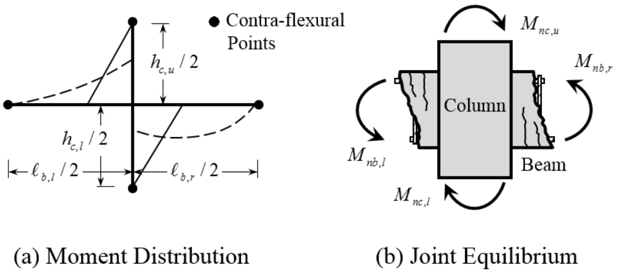

Figure 1 Moment Equilibrium at Joint

In a similar manner, Eurocode 8 (2004) specifies the requirement of Eq. (2).

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Space and width od cracks on reinforced concrete beams under shear and flexural loads

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SUMMARY

Recently, life-time of concrete structures is prolonged. In terms of maintenance, to estimate residual cracks is important for reducing running cost of concrete structures because wide residual cracks must be repaired by epoxy resin and so on. In this research, an experimental study was conducted on three reinforced concrete beams to investigate the space and the width of cracks on concrete beams where the flexural capacity of these three beams are same. The test parameter is the number and the diameter of main reinforcing bars. The residual cracks of a beam with large reinforcing bars (less number of reinforcing bars are used compared with other two beams) were wider than other two beams. This result indicates that running cost of concrete beams is different even if the flexural capacities of the beams are same.

Keywords*: Crack space; crack width; bond; repair; residual crack.*

INTRODUCTION

In these decades, concrete buildings has become strong enough to resist the earthquakes. In fact, most of reinforced concrete buildings survived the Tohoku earthquake in 2011 (Kabeyasawa, 2012), and it makes life-time of concrete building longer than before. When life-time of concrete buildings is prolonged, the buildings will experience many moderate earthquakes. Therefore, maintenance of the buildings is an important issue in terms of its running cost. To reduce the running cost of concrete buildings, it is necessary to control the cracks on buildings.

Watstein (1943) and Kakuta (1969) investigated about the width and the space of cracks on concrete beams where tensile axial force is applied to reinforced concrete beams. In these researches, stress distribution in reinforcing bars is assumed based on the uniaxial tension. The methodology used in these researches is not applicable to the reinforced concrete beams under shear and flexural loads. In the Japanese standard (Architectural Institute of Japan, 2010), a way to estimate the width and the space of cracks on beams under long term loading, however, it is not applicable to beams under short term loading.

In this research, an experimental study was conducted to investigate the space and the width of cracks on beams under shear and flexural loads.

EXPERIMENTAL PROGRAM

Specimen

Three one-half scaled specimens were constructed as shown in Fig. 1. The width (180 mm), depth (300 mm) and length (900 mm) of these beams are identical. Test parameters are the number and the diameter of the reinforcing bars. Concrete was casted as shown by an arrow in Fig. 1.

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Seismic interaction between shear and torsion in a 5-story torsionally unbalanced RC frame structure

Kyung Ran Hwang[1] and Han Seon Lee[2]

SUMMARY

Linear and nonlinear time history analyses of a three-dimensional five-story RC moment frame structure were carried out to observe the characteristics of the relationship between shear and torsion in the elastic and inelastic ranges. The degree of torsional irregularity of this structure, 1.27, exceeds the regularity limit of 1.2, in KBC 2016. Input ground accelerograms are selected from the records of 1999 Kocaeli earthquake (EQ) and 1994 Northridge EQ. The seismic behaviors under Kocaeli EQ are nearly elastic, while significant inelastic behaviors under Northridge EQ are observed. The major findings are as follows: (1) Though the critical drift demands are known to occur generally in the flexible edge, the spectral intensity of input ground motion corresponding to the torsion-dominant modes has caused a larger drift in the stiff edge than in the flexible. (2) The resistance eccentricity, e_x, presented as a percentage of plan dimension perpendicular to the applied force, varies from the zero to infinity within a roughly elliptical boundary formed by the shear force and torsional moment, though it has distinct value e_{x2} = 20.3% in the second mode and e_{x3} = -30.7% in the third mode, far from the static eccentricity, e_{sx} = -12.8%. (3) The torsional moment resisted by the Y-directional frame, T_y, is always accompanied with T_x. At the peak drifts in the elastic range, the ratio of T_x:T_y is determined by the dominant modes as 50%:50% and 30%:70% in the second and third modes, respectively. After the yielding of Y-directional frames, the ratio of T_x:T_y varies irregularly. (4) If only the relationship between the torsional moment and torsional deformation is viewed, it appears that the energy is sometimes generated by the increased torsional moment with the constant torsional deformation and by the decreased torsional deformation with the increased or constant torsional moment. Actually, this apparent energy generation is an illusion because the inelastic behaviors between story shear force and interstory drift in the corresponding frames exhibit the normal energy dissipation.

***Keywords**: asymmetric building, torsion, shear, eccentricity, nonlinear time history analysis*

INTRODUCTION

Severe earthquake (EQ) events have highlighted that unexpected torsional behaviors may cause excessive lateral deformations or even lead to significant damage to building structures. In the current building codes, to prevent the behaviors, the structure should be designed to resist design torsional moment satisfying some regulations for the torsional regularity. The value of the design moment is determined by the design eccentricity, e_d, composed of the static and accidental eccentricities, e_s and e_a. The accidental eccentricity considers all kinds of uncertainty regarding torsion using coefficients.

Most of the previous studies for the enhancement of torsion design have focused on the finding reasonable values for the coefficient of e_d from statistical and probabilistic analyses of various idealized single- or multi-story building structures using various ground motions. However, areas of concern for the use of differing definitions or the making of diverging assumptions have resulted in a basic lack of agreement between the results and conclusions of the research (Rutenburg 1992; Chandler et al. 1996; and Lee and Hwang 2015). Despite such problems, a study for the explicit and direct interaction between dynamic shear and torsion using the realistic building structures was carried out very scarcely.

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Evaluation of crack width in non-structural walls: Experimental results and analytical predictions

Zheng Zhang[1], Rok-Hyun Yoon[2], and Yasushi Sanada[3]

SUMMARY

This paper analyzes two experiment data sets of non-structural walls obtained in the authors' previous study, particularly focusing on their damage of cracking. Damage evaluation in terms of crack width was carried out at different drift levels to quantify the damage developments of non-structural walls. This study proposes several geometric models to predict shear and flexural crack widths on the non-structural walls subjected to cyclic lateral loads. The crack widths of those two experiment data sets were extracted from the literature and evaluated by the proposed models for their validations. Consequently, the models can predict the observed crack widths with reasonable accuracy.

Keywords: *damage; crack width; non-structural wall; seismic performance; seismic slit; structural test.*

INTRODUCTION

Cracking is a very ordinary phenomenon in reinforced concrete (RC) members due to the low tensile strength of concrete, which dramatically affects the members′ structural performance, including stiffness, energy absorption capacity, ductility, and corrosion resistance of reinforcement. Crack widths calculation is performed to maintain serviceability of RC members. Many research works predicted crack widths of RC members based on theoretical models and experimental data: e.g., Tomas (1936) considered a bond-slip model, Gergely and Lutz (1968) used their experimental data to formulate an equation to calculate the crack widths. In most conventional methods and equations to evaluate the crack widths were proposed for RC structural elements. However, RC buildings are usually constructed monolithically with non-structural walls. In the 2016 Kumamoto earthquake in Japan, many non-structural walls in RC buildings suffered severe damage to monolithic non-structural walls, as shown in Fig.1. Large cracks may reduce the service lives of the building functions. Although several

Figure 1 Damage to non-structural walls observed after the 2016 Kumamoto earthquake

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Evaluation of bond capacity in RC members according to configuration of transverse reinforcement

Min-Jun Kim[1], Hyeong-Gook Kim[2], Yong-Jun Lee[3], Dong-Hwan Kim[4], and Kil-Hee Kim[5]

SUMMARY

This study estimates the bond characteristics of the proposed U-shaped transverse reinforcement in reinforced concrete (RC) columns subjected to reversed cyclic anti-symmetric moment. The main test variables are designed to have the configuration of U-shaped transverse reinforcement and the axial force ratio. The proposed U-shaped reinforcement can improve the bond strength of RC columns by confining internal longitudinal reinforcing bars. The specimens are classified into three types: A-type specimens, which confine only the external longitudinal reinforcement; B-type specimens, which confine the internal and external longitudinal reinforcement by existing closed hoops; and C-type specimens, which confine external and internal longitudinal reinforcement by existing closed hoops and the proposed unclosed U-shaped reinforcement, respectively. The experimental results indicated that the B- and C-type specimens showed higher bond strength than the A-type specimens owing to the confinement of internal longitudinal reinforcing bars. Furthermore, the experimental results showed that the proposed U-shaped reinforcement effectively increases the bond strength of RC columns.
***Keywords**: RC Column, Bond, Configuration, Transverse reinforcement*

INTRODUCTION

A reinforced concrete (RC) member is a structure fabricated from a combination of concrete and reinforcement. It exhibits various failure modes such as flexural, shear, and bond failures. Current design codes for building structures recommend flexural failure to induce the ductile behavior of the RC members. However, RC members are inherently exposed to the risk of shear and bond failures prior to flexural failure under various loading conditions. In particular, RC columns subjected to combined lateral and axial loads can be changed in failure mode depending on the strength and confinement conditions of the longitudinal reinforcement. For example, the shear strength of RC columns increases as the axial load increases, whereas the bond capacity and ductility decrease (Architectural Institute of Japan, 2010). Therefore, current design codes for building structures not only limit the strength of the longitudinal reinforcement but also control the amount of transverse reinforcement (Architectural Institute of Japan, 2010; ACI Committee 318, 2014; CSA Committee A23.3-04, 2004; and Architectural Institute of Japan, 1999).

Currently, extensive studies are being conducted on flexure and shear in RC columns. However, there have been few studies on bond failure based on the longitudinal reinforcement in RC columns. Therefore, research is needed to improve the bond capacity between concrete and steel reinforcement. Several researchers have tried to improve the bond strength by increasing the friction between the concrete and steel bar. Rehm and Eligehausen (1979) and Lutz et al. (1966) reported that the bond slip between the concrete and rebar can be affected by the height, spacing, and angle of the rib of deformed bars as well as the state of stress in the surrounding concrete. Fujii and Morita (1982) performed a bond test on RC members and found that bond slip occurs along concrete cracks caused by tensile stress in the surrounding concrete adjacent to ribs. Based on this observation, he proposed a formula to quantify the slip between concrete and steel bar. Fujii and Morita also reported that the bond stress of RC members is influenced by the slip between concrete and steel reinforcement.

Generally, the bond characteristics of longitudinal reinforcement in RC members are affected by the configuration and amount of transverse reinforcement rather than the yield strength of the transverse reinforcement. In this study, a bond test was performed on RC columns with internal longitudinal reinforcement confined by the proposed unclosed U-shaped reinforcement in order to estimate the bond behavior of RC columns according to the confinement conditions of the longitudinal reinforcement.

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Assessment of ultimate drift capacity of RC shear walls by key design parameters

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SUMMARY

In recent earthquakes, several reinforced concrete (RC) shear walls were damaged by flexural failures through concrete compression crushing accompanied with buckling of longitudinal reinforcement in the boundary areas. In order to reduce damage from this failure mode, the ultimate drift capacity of RC shear walls needs to be estimated accurately. In this paper, a parametric study of the seismic behavior of RC shear walls was conducted using a fiber-based model to investigate the influence of basic design parameters including concrete strength, volumetric ratio of transverse reinforcement in the confined area, axial load ratio and boundary column dimensions. This study focused on ultimate drift capacity for both shear walls with rectangular sections and shear walls with boundary columns. The fiber-based model was calibrated with experimental results of twenty eight tests on shear walls with confinement in the boundary regions. It was found that ultimate drift capacity is most sensitive to axial load ratio; increase of axial load deteriorated ultimate drift capacity dramatically. Two other secondary factors were: increased concrete strength slightly reduced ultimate drift capacity while increased shear reinforcement ratio and boundary column width improved ultimate drift capacity.

***Keywords**: Shear Wall; Ultimate Drift Capacity; Fiber Model; Flexural Failure; Parametric Study.*

INTRODUCTION

In 2010 Chile earthquake, RC walls, columns, beam and beam-column joint were severely damaged especially RC walls. The observed damage in RC shear walls consist of spalling and crushing of concrete and bulking of vertical reinforcement. The concrete crushing concentrated at the edge of wall and often propagates along wall length. This pattern of damage caused by compression flexural failure mode and/or tension flexural failure mode. The compression flexural failure defined that concrete at rim of wall section crushes first and then vertical rebar buckles. Concrete crushing occurs because concrete strain demand exceeds the capacity concrete strain. The tension flexural failure has opposite sequence; in cyclic load, vertical rebar is elongated by tensile strain, so it is susceptible to buckle. When load reverses, this rebar buckles first and then concrete crushes.

In 2016 Kumamoto earthquake, a few structural walls in an apartment was reported to have severe damage by concrete spalling at the base of boundary column and longitudinal rebar buckling. With described reason, this building was judged as “unsafe” for reoccupation. Other structural walls were undergone noticeable minor cracks.

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