The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

TORSIONAL RESPONSES OF AN RC LOW-RISE BUILDING MODEL HAVING IRREGULARITIES AT GROUND STORY

Han Seon LEE[1] and Kyung Ran HWANG[2]

SUMMARY

A 1:5 scale five-story reinforced concrete building model having the irregularities of a soft/weak story, and torsion at the ground story, was subjected to a series of uni- and bi-directional earthquake simulation tests. Analysis of the test results regarding torsion behaviors leads to the following conclusions: (1) Under severe table excitations, the inertial torsional moment varied significantly under almost constant maximum base shear, and was resisted by both X- and Y-directional frames, in proportion to their instantaneous rigidity. When the X-directional frames yielded, over 90% of the inertial torsion was resisted by the Y-directional frames. (2) The natural eccentricity varied from zero to infinity, with the variation of the torsion moment and the two orthogonal base shears. As the intensity of the table excitations increased to the level of MCE in Korea, the eccentricities at the instants of peak values in drift and base shear approached the strength eccentricity, with the range of the eccentricity reduced to within ±10% of the transverse dimension of the model. The reason for this reduction is considered to be the significantly increased contribution of the transverse walls to the total torsional resistance. (3) The model resisted most of the base torsion with the peripheral frames, after yielding of the inner core walls. The model represented dual values of stiffness, of 50MN/rad when the core walls did not yield, and 30MN/rad when the core wall did yield.

Keywords*: reinforced concrete; irregular; natural; accidental; torsion; eccentricity*

INTRODUCTION

Many low-rise residential apartment buildings have recently been constructed in densely populated areas in Korea. As a result of the lack of available sites, the ground floor is generally used for a parking space, and adopts a piloti story. This type of building, as shown in Figure 1(a), commonly has a high degree of irregularity of soft story, weak story, and torsion at the ground story. In the 1995 Kobe and 2011 Christchurch earthquakes, buildings with significant horizontal and/or vertical irregularities were found to perform very poorly. In particular, the large inelastic deformation at perimeter lateral resisting systems, which are walls or columns, occurred through inelastic torsion amplification (Kam and Pampanin, 2011).

To improve the seismic design code regarding the torsional behavior of a building, many researchers studied the inelastic torsional behavior of buildings having regularity and irregularity, using simplified models. Generally, the objective of this research is that the maximum drift or ductility demands in any part of the elements (both stiff and flexible ones) of the torsionally unbalanced model do not exceed those of the torsional balanced model, under any circumstances.

Although many analytical studies on torsion have been performed, experimental studies have rarely been carried out. With this in mind, this study investigates the torsional behavior in the shake-table responses of a low-rise RC building model, which has a high degree of irregularity of soft story, weak story, and torsion at the ground

[1] *Professor (corresponding author), School of Civil, Environmental, and Architectural Engineering, Korea University. Korea; hslee@korea.ac.kr*
[2] *Research assistant (Ph. D Student), School of Civil, Environmental, and Architectural Engineering, Korea University. Korea.*

EXPERIMENTAL STUDY ON THE IMPACT DAMAGE OF REINFORCED CONCRETE WALLS CAUSED BY COLLISION OF TSUNAMI DEBRIS

Hidekazu WATANABE[1], Susumu KONO[2], and Satoshi NAKAMURA[3]

SUMMARY

On 11th March 2011, Tohoku earthquake which was most powerful earthquake ever recorded in Japan was occurred. At the same time, tsunami triggered by the earthquake. According to damage investigation reports of the tsunami, Structural damages of the reinforced concrete (hereafter RC) buildings from tsunami debris are confirmed. In order to design tsunami-resistant RC buildings, development of evaluation method for the performance of the RC buildings for tsunami debris is necessary. However, there are few experimental studies about impact damage of the RC buildings caused by collision of tsunami debris. In this study, collision experiments were conducted using lateral impact loading system to evaluate the performance of RC walls for impact force. Experimental results are shown as follows. The performance of specimens were evaluated the using existing methods. As a result, the scabbed specimens can be predicted the results using Chang formula. However, all perforated specimens are not on the safe side compared with the evaluations.

Keywords: *Impact damage, Tsunami debris, Collision experiment, Reinforced concrete walls.*

INTRODUCTION

On 11th March 2011, Tohoku earthquake which was most powerful earthquake ever recorded in Japan was occurred. At the same time, tsunami triggered by the earthquake. According to damage investigation reports of the tsunami, Structural damages of the reinforced concrete (hereafter RC) buildings from tsunami debris are confirmed. In order to design tsunami-resistant RC buildings, development of evaluation method for the performance of the RC buildings for tsunami debris is necessary. However, there are few experimental studies about impact damage of the RC buildings caused by collision of tsunami debris. In this study, collision experiments were conducted using lateral impact loading system to evaluate the performance of RC walls for impact force.

EXPERIMENTAL PROGRAM

Specimen details

The sixteen RC plates were designed as specimens in this study. The specimens were made as part of RC walls to investigate the effects on local damage of RC walls caused by impact loading. The specimens are listed in Table 1.The specimens were square plates, 1300mm on a side. There are three variables for the specimens; the thickness of wall, the specified concrete compressive strength, and velocity level. The reinforcement ratio of all specimens was 0.33% for both longitudinal and transverse bars. The thickness of cover concrete is 15mm in all specimens. The reinforcement detail of a typical specimen is illustrated in Fig. 1. In this study, the welded wire mesh (CD5) is used as a reinforcement.

[1] *Assistant Professor, Structural Engineering Research Center, Tokyo Institute of Technology, Japan; watanabe@serc.titech.ac.jp*
[2] *Professor, Structural Engineering Research Center, Tokyo Institute of Technology, Japan; kono@serc.titech.ac.jp*
[3] *Graduate student, Environmental Science and Technology, Tokyo Institute of Technology, Japan; nakamura.s.ba@m.titech.ac.jp*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

AN EXPERIMENTAL STUDY ON CONFINED RC WALL BOUNDARY REGIONS UNDER UNIAXIAL MONOTONIC AND CYCLIC REVERSAL LOADINGS

Eko YUNIARSYAH[1], Rafik TALEB[2], Susumu KONO[3], and Masanori TANI[4]

SUMMARY

The aim of this paper is to present the experimental results on eight RC elements with a rectangular section representing wall boundary regions tested under uniaxial monotonic and cyclic reversal loadings. All specimens were constructed with the same cross-sectional dimensions but had varying transverse reinforcement spacing, number of cross-ties, and its diameter. The main purpose of the experimental tests was to investigate the effects of reinforcement detailing and loading history on axial load capacities and failure modes. It was found that the lack of closely spaced transverse reinforcement caused buckling of longitudinal reinforcement. Moreover, a compression zone could not be sustained and spread of concrete crushing by confined core concrete could not be ensured. A limit on the maximum spacing of transverse reinforcement and the minimum number of ties should be considered to improve confinement and to provide the lateral support of longitudinal bars.

Keywords: *RC rectangular walls; confined boundary region; confinement; buckling failure; concrete crushing.*

INTRODUCTION

Reinforced concrete structural walls are commonly used as lateral-load resisting components in multi-story building structures. When well designed and detailed, walls are considered to perform well under earthquake loading. In Japan, structural walls normally have boundary columns to provide good confinement and carry a large amount of axial force. Nevertheless, the AIJ Standard for Structural Calculations of Reinforced Concrete Buildings 2010 (AIJ 2010) allows the use of rectangular RC walls if boundary regions are confined like boundary column. Unfortunately, this kind of walls did not perform well during recent earthquakes in Chile (2010) and Christchurch, New Zealand (2011). One of the main type of damages observed is damage to multi-story walls near their base, exhibiting buckled or fractured vertical reinforcement and crushed concrete concentrated over a relatively short height of wall as shown in Fig. 1. It was reported that the failures are attributable to lack of confinement and detailing at wall boundaries (Wallace and Moehle 2012). Therefore, more studies are required to assess their performance during earthquakes, in particular issues associated with quantity and configuration of transverse reinforcement required at wall boundaries (spacing and number of ties), as well as expected axial strain demands under various load histories.

In order to investigate the effects of reinforcement detailing and loading history on the capacity and failure modes of confined boundary regions of RC rectangular walls, eight RC elements with a rectangular section representing wall boundary regions were constructed by varying hoop spacing, number of cross-ties, its diameter and tested under uniaxial monotonic and cyclic reversal loadings until failure.

[1] *Doctoral Student, Dept. of Environmental Science and Tech., Tokyo Institute of Technology, Japan, e-mail: yuniarsyah.e.aa@m.titech.ac.jp*
[2] *Doctoral Student, Dept. of Environmental Science and Tech., Tokyo Institute of Technology, Japan, e-mail: taleb.r.aa@m.titech.ac.jp*
[3] *Professor, Materials and Structures Laboratory, Tokyo Institute of Technology, Japan, e-mail: kono@serc.titech.ac.jp*
[4] *Research Engineer, Int. Institute of Seismology and Earthquake Eng., Building Research Institute, Japan, e-mail: mtani@kenken.go.jp*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

BOND STRENGTH MODEL FOR BEAM RE-BARS IN INTERIOR BEAM-COLUMN JOINTS

Hong-Gun Park[1], Hyeon-Jong Hwang[2], and Tae-Sung Eom[3]

SUMMARY

In interior beam-column joints subjected to cyclic loading, bond-slip of beam reinforcement significantly increases the inelastic deformation of the connection. In the present study, a bond strength model was developed to evaluate bond-slip of beam re-bars in beam-column joints. The proposed model consists of bearing bond strength and friction bond strength, which were defined from the existing cyclic loading test results of beam-column joints. The predictions of the proposed model were compared with the test results of existing concrete block specimens and beam-column connections. The results showed that the proposed model correlated well with the cyclic test results in terms of the bond strength degradation, bond-slip at the joint interface, and the strain distribution of beam reinforcement.

Keywords: *bond-slip; strain based bond model; interior beam-column joint; cyclic loading.*

INTRODUCTION

Seismic performance of reinforced concrete beam-column joints is significantly affected by the concrete diagonal cracking and bond-slip of beam flexural bars in the joint (Lee et al., 2009; Hong et al., 2011; Lee and Lin, 2011). **Fig. 1** shows the load transfer mechanism in interior beam-column joint subjected to cyclic loading. Under cyclic loading, due to the residual tensile deformation, compression force as well as tension force is developed in the flexural bars of the two beams even before complete closing of the flexural cracks at the joint interface. Thus, a large bond strength is required to resist the forces of the beam re-bars in the joint. However, the development length of the beam flexural bars is limited by the column depth h_c. As a result, it is difficult to secure a sufficient development length of the beam flexural bars in the joint with a small column depth.

To restrain the bond-slip of re-bars, current design criteria (ACI 318, 2011; ACI-ASCE 352, 2002; NZS 3101, 2006; Eurocode 8, 2004) specify the requirement of column depth-to-beam longitudinal bar diameter ratio h_c/d_b. In ACI-ASCE 352 (2002), h_c/d_b is defined with the yield strength ratio of re-bars. In NZS 3101 (2006) and Eurocode 8 (2004), additional design parameters including concrete tensile strength, column axial load, and the required seismic performance are considered. However, the current design criteria show large differences in the requirement of h_c/d_b ratio.

[1] *Professor, Department of Architecture and Architectural Engineering, Seoul National University, Korea, e-mail: parkhg@snu.ac.kr*
[2] *Postdoctoral researcher, Dep. of Architecture and Architectural Eng., Seoul National University, Korea, e-mail: hwanggun85@naver.com*
[3] *Assistant professor, Department of Architectural Engineering, Dankook University, Korea, e-mail: tseom@dankook.ac.kr*

EFFECT OF BI-DIRECTIONAL LATERAL LOADING ON IN-PLANE SHEAR RESISTANCE OF RC WALL

Takanori Matsui[1], Yuki Idosako[2], Masanobu Sakashita[3], and Minehiro Nishiyama[4]

SUMMARY

Shear wall deforms not only in in-plane direction but also in out-of-plane direction by earthquake ground motions. Structural behavior of shear walls is unclear when it deforms in its out-of-plane direction along with in-plane direction. To investigate the influence of out-of-plane deformation on in-plane shear resistance, four 1/4-scale reinforced concrete shear walls were constructed and tested under bi-directional cyclic lateral loading simulating earthquake ground motions. The vertical load was also applied as service load. The test variable was the ratio of out-of-plane to in-plane deformations, which was 0, 1, 2 or 3. The maximum lateral loads of the specimens subjected to bi-directional loading was approximately 10-15% less than that of the specimen subjected to uni-directional loading. Sliding between the bottom of shear wall and the foundation block was observed in all specimens at deformations larger than about Rx (in-plane drift angle) = 0.50%. In all specimens, reduction in the lateral load carrying capacity was not remarkable until about Rx=1.5%. Sliding deformation was dominant in in-plane direction, and damage was concentrated at the bottom of the walls. The damage at the bottom caused axial shortening, and the progress was remarkable as the ratio of out-of-plane deformation became larger. All specimens were able to sustain the axial load until the tests ended. Sliding shear capacity of the specimen subjected to uni-directional loading was calculated by the methods based on Paulay’s study and AIJ Guidelines. Sliding shear capacity calculated by AIJ Guidelines agreed well to the maximum capacities experimentally obtained.

Keywords: *bi-directional lateral loading; shear wall; sliding; sliding shear capacity.*

INTRODUCTION

When a wall is subjected to bi-directional lateral loading, out-of-plane deformation may decrease the effective sectional area of concrete compressive struts and the resistance due to aggregate interlocking along crack surface. It leads to the reduction of the shear stiffness and shear resisting capacity. To evaluate structural performances of buildings in which shear walls are arranged, it is necessary to clarify structural behaviors of shear walls to be deformed in out-of-plane direction.

There are some experimental studies on the influence of out-of-plane deformation on in-plane seismic resistance. Experimental research on structural walls failing in flexure has been conducted by, for example, Endou et al., Hiraishi et al., and Sato et al., but there is little experimental research on shear walls. The objective of this study is to investigate the influence of out-of-plane deformation on in-plane shear resistance of walls failing in shear by bi-directional cyclic lateral loading.

[1] *Graduate Student, Department of Architecture and Architectural Engineering, Kyoto University, Japan; rc.tmatsui@archi.kyoto-u.ac.jp*
[2] *Graduate Student, Department of Architecture and Architectural Engineering, Kyoto University, Japan; rc.idosako@archi.kyoto-u.ac.jp*
[3] *Assistant Professor, Department of Architecture and Architectural Engineering, Kyoto University, Japan; sakashita@archi.kyoto-u.ac.jp*
[4] *Professor, Department of Architecture and Architectural Engineering, Kyoto University, Japan; mn@archi.kyoto-u.ac.jp*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

STRUCTURAL DESIGN OF THE TALLEST BUILDING IN KOREA

Jong-Ho Kim[1], Yeonki Jung[2], Jidong Kim[3], Jaehyuk Lee[4], and Taejin Kim[5]

SUMMARY

The Lotte World Tower, a high-rise part of the second Lotte World Amusement Complex is being constructed at Jamsil, Seoul Korea. This 123-story building with six underground levels consists of sales area, offices, hotel and residences. The height is 555m and it is the tallest building in Korea. The slabs from 2nd to 86th floors used as sales, offices, and residences are made of steel beams and deck slabs; The hotel floors above 86th floor consist of 225~300mm thick flat slabs. The underground slabs including ground level are made of reinforced concrete. The lateral load resisting system is composed of central reinforced concrete core wall, two sets of steel outriggers, eight of reinforced concrete mega-columns, and two sets of steel belt trusses. The uppermost lantern is made of diagrid structure. As a wind tunnel test, high frequency force balance test was conducted after 50% schematic design phase, and the reanalysis was conducted twice at the end of the schematic design and after 60% design development phase. It was proved that this building has a very nice serviceability against wind load. Important structural elements like perimeter beams, belt trusses on the typical levels, and steel columns on the hotel levels were secured to have robustness and redundancy and to prevent loss of their functions and sudden collapses in case of fire or unexpected impact.

***Keywords**: Tall building; Outriggers; Mega-column; Belt truss; Structural Health Monitoring.*

INTRODUCTION

Recently in Korea, there have been a number of governmental projects which pursues development of tall building complex and utilization of inner city regeneration. Out of these projects, many high-rise buildings having 100 to 150 stories were planned in Korea. And among these plans, Jamsil Lotte World Tower is being constructed for the first time. Ever since Korea has accomplished economic growth, a number of Korean general contractors have won large-scale contracts from many different countries and showed competitive level of construction technologies of high-rise buildings. Throughout these experiences, Korean design offices also have proved their potential of competitiveness in tall building design industry. Especially, nowadays high-quality steels for building structures are provided by domestic steel manufacturers so design engineers could have completed a lot of challenges in the tall building design projects.

The construction site of Jamsil Lotte World Tower is across the existing Lotte World, a theme park, to host a hotel, a shopping mall, offices, residences, culture centers and conference halls. The construction area and gross floor area (GFA) of Jamsil Lotte World Tower is 87,182.8m^2 and 810,998m^2, respectively. It is composed of a high-rise building and several low-rise buildings.

Jamsil Lotte World Tower (Lotte Tower) has 123 floors and 6 underground floors. Within 330,000m^{2}of GFA, it can host shopping mall, offices, residences, hotel and an observation tower at the top of the building. The height of Lotte Tower is 555m, and it will be the tallest building in Korea among constructed buildings. For core walls, mega

[1] Chairman, Chang Minwoo Structural Consultants, Korea, e-mail: jhkim@minwoo21.com
[2] Principal, Chang Minwoo Structural Consultants, Korea
[3] President, Chang Minwoo Structural Consultants, Korea
[4] Team Manager, Lotte CP Project, Korea
[5] President, Chang Minwoo Structural Consultants, Korea, e-mail: taejin@minwoo21.com

STUDY ON DYNAMIC BEHAVIOR OF HIGH-RISE BASE-ISOLATED BUILDING BASED ON ITS RESPONSES RECORDED DURING THE 2011 TOHOKU-OKI EARTHQUAKE

Kazuhiro MATSUDA[1], and Kazuhiko KASAI[2]

SUMMARY

Seismic responses of a high-rise base-isolated building in Tokyo Institute of Technology were recorded during the 2011 Tohoku-oki earthquake. The purpose of this paper is to point out various important findings on the building responses from the recorded data, as well as to create the data base for fostering immature research areas on high-rise base-isolated buildings and monitoring. This paper explains a variety of numerical techniques such as transfer function curve-fitting procedure for system identification, comparison with conventional structure by modal analysis, damper hysteresis, axial force variation of rubber bearing, and dynamic characteristic variation due to input amplitude. Reliability of recorded results is confirmed by various methods, and applicabilities of the techniques for the high-rise isolated building are discussed.

Keywords: *Earthquake Records; High-Rise Building; Base-Isolated Structure; System Identification; Modal Analysis; 2011 Tohoku-Oki Earthquake*

INTRODUCTION

At 14:46 on March 11, 2011, the East Japan Earthquake of magnitude 9.0 occurred off the Sanriku coast of Japan. The earthquake has a recorded seismic intensity of 7 in northern Miyagi prefecture, which is the highest intensity on the Japan Meteorological Agency scale. The East Japan Earthquake exemplifies how effective seismic protection technologies are at preventing earthquake damage, such as seismic base isolation and supplemental damping, have been increasingly used in Japan since the 1995 Great Hanshin Earthquake, with a hope to better protect not only human lives but also building functionality and assets.

The response records of the buildings should be collected. Since the response-control technologies are new and have not often been validated through response to actual earthquakes, there have been some desires to find their true capabilities. The collected records and examination also should be released to be useful for design method. In this paper, recorded and examined results of base-isolated building are discussed. In particular, dynamic properties of a high-rise base-isolated building such as vibration period and damping ratio are focused.

BASE-ISOLATED TALL BUILDING AND MONITORING SYSTEM

Seismically Isolated Tall Building

Figure 1 illustrates the out view and elevation plan of the 20-story seismically isolated building, and it is called as “J2-building”. Example Building is an office building of Tokyo Institute of Technology located in Yokohama, Kanagawa Prefecture (Kikuchi et al. 2005). The foundation and 1st floor of this building are RC structure. The other floors are composed with hybrid structure both steel beams and CFT columns. So called Mega-Braces (□ -

[1] *Assistant Professor, Structural Engineering Research Center, Tokyo Institute of Technology, Japan; matsuda@serc.titech.ac.jp*
[2] *Professor and Director, Structural Engineering Research Center, Tokyo Institute of Technology, Japan; kasai@serc.titech.ac.jp*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

EXPERIMENTAL STUDY OF A PIEZOELECTRIC SLIDING ISOLATION SYSTEM FOR SEISMIC PROTECTION OF EQUIPMENT

Lyan-Ywan LU[1], Kuan-Wen PONG[2]

SUMMARY

The magnitude and content of an earthquake is usually hard to be predicted precisely. To make seismic isolation systems more adaptive to earthquake motions that may have diverse characteristics, a semi-active isolation system called the “Piezoelectric Sliding Isolation System (PSIS)” is introduced in this study for the seismic protection of precision equipment. The PSIS system is composed of a sliding isolation platform and a piezoelectric friction damper (PFD). Depending on the feedback signal of the PSIS response, the friction force of the PFD can be regulated on-line by an embedded piezoelectric actuator. As a result, the seismic response of the PSIS can be effectively controlled and mitigated. The feasibility of the PSIS is verified dynamically via a shaking table test in this study, and the comparison between the experimental and theoretical results has shown the good consistency. The experimental results also demonstrate that, the PSIS is able to substantially suppress both the displacement and acceleration responses in an earthquake with either near-fault or far-field characteristics. The study also shows that, even though the semi-active PSIS system can only provide a passive control force, it is able to achieve the same level of control performance as an actively controlled isolation system, which shares the same optimal feedback gain as that of the PSIS.

Keywords: *Semi-active isolation, piezoelectric actuator, equipment seismic protection, near-fault earthquake, shaking table.*

INTRODUCTION

Seismic protection of equipment in many important facilities, such as high-technology factories, hospitals, computer centers etc., may have great importance, since these facilities may completely lose their functionality in a severe earthquake due to the malfunction or damage of interior critical equipment (Amick et al. 1997). For some vibration-sensitivity equipment, the failure can be caused not only by equipment overturning, but also by excessive equipment acceleration. It has been demonstrated in many cases that seismic isolation can be a very effective means for the protection of critical equipment. Nevertheless, recent studies have also revealed that when a conventional isolation system of a constant frequency is subjected to earthquakes with strong near-fault characteristics, the conventional system may suffer from a low-frequency resonance-like response that will cause considerable amplification on the isolator displacement and endanger the isolated object (Makris et al. 2000). The reason for this amplification is primarily due to the fact that the period of the pulse waveform in a near-fault earthquake is usually between 2 to 7 seconds, which happens to be the range of the isolation period commonly adopted for seismic isolation.

In order to enhance the isolation performance, some researchers have recently proposed the concept of semi-active isolation systems, which are sometimes called smart isolation systems. A semi-active isolation system generally consists of a passive isolation system with a certain type of semi-active device or smart device, such as the MR damper, variable friction device, variable stiffness device and so on (Spencer et al. 2003, Lu et al. 2010, Lu et al. 2009, Lu et al. 2009). The function of the semi-active device, which is usually installed under the isolation system, is

[1] *Professor, Dept. of Civil Engineering, National Cheng Kung University, Tainan, e-mail: lylu@mail.ncku.edu.tw.*
[2] *Graduate student, Dept. of Construction Engineering, National Kaohsiung First University of Science & Technology, Kaohsiung Taiwan.*

SEISMIC PERFORMANCE OF STRUCTURES BASE-ISOLATED WITH ROCKING BEARING

Chin-Tung CHENG[1] and Chih-Hong Chao[2]

SUMMARY

The objective of this research aims to improve the weakness existing in the traditional sliding base-isolated bearing such as extensive displacement under earthquakes. Therefore, the motion of rocking bearing in this design will not be initiated until moderate earthquakes and the structure may rock in rigid body motion to isolate seismic energy under severe earthquakes. And the superstructure remains undamaged and self-centered due to the restoring force by the self-weight in the superstructure and springs installed in the rocking interface. And the vibration is damped throughout each impact of the bearing on the base of structures and foundation surface. Based on the force-displacement relations and the effective damping of the systems, the seismic response of the structure may be estimated through a modified elastic response spectrum. To validate the proposed idea, a one-bay-one-story spaced structure with rocking-isolated bearing was constructed and tested by a shaking table. Investigated parameters include aspect ratio of the bearing, geometry of the rocking toe (line, spherical or polynomial surface), stiffness of the restoring spring and exciting wave forms. Test results showed that structures with lower aspect ratio of the bearing or a rocking toe with polynomial curves vibrated in a higher natural frequency, while other parameters may have marginal effect on the vibration of isolated structure.

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

INTRODUCTION

To protect the buildings from the attack of earthquakes, many energy dissipation or base-isolation techniques have been proposed. However, there are advantages and disadvantages existing in these techniques. New concepts or improving techniques have been continuously proposed. Often referred is the self-centering function proposed for moment-resisting or braced frames. To mitigate the damage in the plastic hinges of building structures, the self-centering function is advantageous in eliminating permanent drift, maintaining post-earthquake serviceability and reducing the possibility of demolition after earthquakes. Mander and Cheng (1997) developed a self-centering design method for bridge piers referred to as Damage Avoidance Design. The self-centering was achieved by using post-tensioned strands to connect precast foundation beam and bridge pier. The bridge pier rocked on foundation beam surface to mitigate highly strain demand on the beam and column interface. This rocking behavior dominates the pier response that minimizes the damage of the footing and columns.

Research on the rocking behavior of structures can be dated back to the early work of Housner in 1963. To assess the seismic response of rocking structures, Priestley et al. (1978) developed a practical methodology using standard displacement and acceleration response spectra based on the assumption of representing a rocking block as a single-degree-of-freedom (SDOF) oscillator with a constant damping. Their results were then applied in the FEMA 356 document (2000). However, Makris and Konstantinidis (2003) showed that rocking spectra were not identifiable by the response spectra of a SDOF oscillator and recommended a damping ratio for rocking structures.

[1] *Professor, Department of Construction Engineering, National Kaohsiung First University of Science and Technology, Taiwan, e-mail:ctchenge@nafust.edu.tw*
[2] *Graduate student , Department of Construction Engineering, National Kaohsiung First University of Science and Technology, Taiwan*

NEW STRUCTURAL SYSTEM WITH DOUBLE REINFORCED CONCRETE BEAMS FOR LONG-SPAN STRUCTURES

Jae-Man Lee[1], Kil-Hee Kim[2], Kwang-Man Kim[3], Yong-Jun Lee[4], Jung-Yoon Lee[3]

SUMMARY

A new reinforced concrete structural system suitable for long-span structure was developed. The system consists of slab, column, double beams, and drop panel. To investigate the structural performance of the system, four specimens of 30% scale were constructed and tested. By the test accepting two experimental parameters, the amount of longitudinal bars in beam and drop panel, the effect of the parameters on the structural behavior of the system was mainly scrutinized. The specimens with low amount of reinforcement for the economical structural system maintained their capacity until the deformation corresponding to eight times of deflection at yielding of reinforcement. Also, significant reduction effect of the negative moment due to the presence of drop panel was achieved. All specimens is satisfied with the criteria for the allowable deflection, *l*/480. An increase in the amount of longitudinal bars in beam leads to an increase in deformation and load carrying the capacity of specimen at yielding of reinforcement in beam. ‘Flexible drop panel’ (with small amount of reinforcement) and ‘stiff beam’ (with large amount of reinforcement) led to the excessive opening of cracks adjacent the side section of drop panel and leads to the deterioration of load carrying the capacity of specimen. On the other hand, ‘stiff drop panel’ (with large amount of reinforcement) caused the degradation of capacity due to the damage in beam (crushing). The amount of reinforcement in beam only affected the serviceability of the system (deflection at service load).

Keywords: *Reinforced concrete; Long-span structure; double-beam; drop panel; Reduction of deflection; Negative moment*

INTRODUCTION

By the recent needs from construction industries such as reductions of the construction time-period and rationalization of the construction technologies, the development of a rational long-span structure is necessary. From the previous research (Bradford et al., 1992; Oechlers et al., 1999). the development of a rational long-span structure will be one of the most important field in order to achieve the saving the construction cost and effective usage of the inner spaces. In order to complete the long-span structural system, the development of long-span member (over 13m length minimum) with new structural materials and the state of the art structural engineering technologies is required.

Many achievements from the former researches were made to develop the long-span structure. In general, steel and prestressed concrete structure has been an alternative for the long-span structure for a long time. However, both the systems have not been fully applied to the construction projects in Korea because either of high cost and techniques are required. To improve the structural weak points of the steel structural system, long-span composite structure and the void-slab system have been proposed. Fig.1 illustrates the representative long-span composite structural systems

[1] *Research Fellow, Institute of Construction and Environmental Technology, Sungkyunkwan University, Korea; masqurade2@gmail.com*
[2] *Professor, Department of Architectural Engineering, Kongju National University, Korea; kimkh@kongju.ac.kr*
[3] *President & CEO, Baro Construction and Engineering, Korea; barock@baro-ck.com*
[4] *Ph. D Candidate, Architectural Engineering, Kongju National University, Korea; lyj8315@kongju.ac.kr*
[5] *Professor, Department of Architectural Engineering, Sungkyunkwan University, Korea; jungyoon@skku.edu*

SEISMIC PERFORMANCE OF LOW-RISE STEEL INTERMEDIATE MOMENT RESISTING FRAMES

Hyung-Joon Kim[1] and Jin-Young Park [2]

SUMMARY

Current seismic design codes including ASCE 7 and KBC2009 explicitly and/or implicitly prescribe that structures designed according to the seismic codes should satisfy both performance criteria: 1) life safety under design earthquakes and 2) collapse prevention under maximum considered earthquakes. In the design stage, the life safety criterion is usually confirmed by the comparison of calculated maximum story drifts with the codified limitation for story drift. However, the other seismic performance criterion, collapse prevention, is not explicitly checked during the seismic design of a structure. Hence, it is valuable to investigate if structures designed by a current Korean seismic code, KBC 2009 meet with the collapse prevention seismic performance or not. In this study, a 5-story prototype building seismically resisted by steel intermediate moment-resisting frames was designed according to KBC 2009. Nonlinear time-history analyses were carried out with 20 historical ground motion records and the global and local seismic responses of the prototype buildings were observed. From the observations, this study tries to find out its collapse capacity and to, in turn, address whether or not the studied structure meets the collapse prevention criterion. Analysis results show that the prototype steel moment frames satisfy both the seismic criteria and the column ductility becomes a critical factor on the collapse performance in the prototype steel framed building.

Keywords: *Steel Intermediate Moment-Resisting Frames, Life Safety, Collapse Prevention, Collapse Performance, Collapse Capacity, Ductility Capacity*

INTRODUCTION

Structural engineering communities have increasingly paid attention to the performance based seismic design (PBSD) since Northridge earthquake (1994, USA) and Kobe earthquake (1994, Japan) induced significant structural damage to structures which had been seismically designed according to modern seismic codes. In the PBSD, Life Safety (LS) under a design based earthquake (DBE) and Collapse Prevention (CP) under a maximum considered earthquake (MCE) have been long recognized as the basic seismic performance criteria that are satisfied with structures designed according to current seismic codes. In the current Korea Building Code, KBC2009 (2009) even which does not totally adopt the concept of PBSD, the LS criterion coupled with a seismic hazard corresponding to a DBE seismic hazard level is stated in terms of the limitation of maximum story drift ratios. However, the KBC2009 does not describe any specific requirements for the CP criterion although seismic intensities for the MCE are embedded into the code to consider the seismic hazard of a structure of interest.

This study investigates to confirm if a low-rise steel moment-resisting framed building designed according to the KBC2009 satisfies both the seismic performance criteria. For this purpose, a 5-story steel intermediate moment-resisting frame was selected as a prototype structure and was designed to meet with the requirements

[1] *Associate Professor (corresponding author), Department of Architectural Engineering, University of Seoul, Korea; hyungjoonkim@uos.ac.kr*

[2] *Graduate Student Researcher, Department of Architectural Engineering, University of Seoul, Korea*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

EXPERIMENTAL EVALUATION OF COMPOSITE COLUMNS CONFINED BY MULTIPLE INTERLOCKING SPIRALS

Ching-Yu LIANG[1], Cheng-Chih CHEN[2], Cheng-Chiang WENG[3], Samuel Yen-Liang YIN[4], and Jui-Chen WANG[5]

SUMMARY

This paper presents an experimental investigation on the composite steel and reinforced concrete columns confined with multiple interlocking spirals. The multi-spiral cage is composed of a central large spiral and four small corner spirals. The application of the multiple spirals to composite columns is to take the advantages of concrete confinement as well as efficiency in automatic production for the precast construction. The variables of the specimens included type of the lateral reinforcement, spacing of the lateral reinforcement, and shape of the structural steel section. The test results showed that the composite columns confined with multiple interlocking spirals demonstrated excellent performances in both strength and ductility, as compared to the composite column with traditional rectilinear hoops. Moreover, the use of the multiple interlocking spirals resulted in significant savings of the confinement reinforcements.

Keywords: *composite column; multiple interlocking spiral; confinement; axial load-carrying capacity.*

INTRODUCTION

The use of composite steel and reinforced concrete structures is aimed to gain advantages from both the reinforced concrete and structural steel. Concrete encased steel composite columns are one of the major structural columns. The concrete cladding the structural steel performs functions for the structural steel column such as (a) fireproof coating; (b) enhancement of rust protection; and (c) delaying the probability of local buckling. In addition, concrete encased steel composite columns can achieve high axial load-carrying capacity and high lateral stiffness because of the use of the reinforced concrete, as compared to the steel columns (Morino 1998; Roeder 1998).

A typical cross section of a concrete encased steel composite column is shown in Fig. 1. It is noted that the lateral reinforcements in a square column are usually rectilinear hoops. The lateral reinforcements are designed to keep the longitudinal bars in position and to prevent their buckling. Moreover, the lateral reinforcements provide the shear strength of the column as well as the passive confinement for the concrete core. However, the use of the rectilinear hoops results in a heavy workload in both fabrication of the rectilinear hoops and setup in the concrete encased composite columns. The entire process is heavily relied on skilled labors which are time-consuming and expensive.

Spiral transverse reinforcement used in reinforced concrete columns can develop great axial load-carrying capacity and ductile performance (Shah et al. 1983; Sheikh and Toklucu 1993; Essawy and El-Hawary 1998). Unlike the rectilinear hoops, spirals are continuous and can provide better confining effect upon concrete core than the rectilinear hoops do (Mander et al. 1988; Saatcioglu and Razvi 1992). However, the application of the spirals to a square column becomes doubtful because the spirals fail to confine the concrete located at four corners of the columns. Recently, an innovative multi-spiral confinement was proposed by Yin et al. (2012) to be utilized for a

[1] *Ph. D. Candidate, Department of Civil Engineering, National Chiao Tung University, Taiwan; eddylung@gamil.com*
[2] *Professor, Department of Civil Engineering, National Chiao Tung University, Taiwan; chrischen@mail.nctu.edu.tw*
[3] *Retired Professor, Department of Civil Engineering, National Chiao Tung University, Taiwan; frankweng123@gmail.com*
[4] *Ph. D., CEO and Chief R&D Officer of Ruentex Group, Taiwan; samuel@ mail.ruentex.com.tw*
[5] *Ph. D., Assistant Vice President, Ruentex Engineering & Construction Co, Ltd., Taiwan; rt007745@mail.ruentex.com.tw*

CYCLIC LOADING TEST ON RHS COLUMNS UNDER BI-DIRECTIONAL HORIZONTAL FORCES AND CONSTANT AXIAL FORCE

Takanori ISHIDA[1], Yuko SHIMADA[2], and Satoshi YAMADA[3]

SUMMARY

Columns are subjected to bi-axial bending moment, since buildings behave 3-dimensionally under seismic excitations. However, only few researches on post-local-buckling and deterioration behavior of Rectangular Hollow Section (RHS) steel columns under bi-directional horizontal forces have been reported. In this study, at first, the simple horizontal loading protocol was proposed based on the investigation of random horizontal displacement orbits obtained by elasto-plastic response analyses of multi-story steel frames subjected to bi-directional horizontal ground motions. After that, using the simple loading protocol, a series of tests on RHS columns subjected to bi-directional horizontal cyclic loading and constant axial force were conducted. The experimental results were compared with the analytical results using multiple shear spring (MSS) model.

Keywords: *RHS columns; Local buckling; Deterioration behavior; Bi-directional horizontal loading test.*

INTRODUCTION

Rectangular Hollow Section (RHS) steel tubes are generally used as columns for middle-rise and low-rise steel buildings in Japan. Columns are subjected to biaxial bending, since buildings behave 3-dimensionally under seismic excitations. In order to evaluate the seismic resistance of steel building structures, it is important to clarify the biaxial bending behavior of RHS-columns including strength deterioration governed by local buckling. However, only few researches on post-local-buckling and deterioration behavior of RHS columns under bi-directional horizontal forces have been reported.

In this study, to investigate the hysteresis of RHS columns including post-local-buckling and deterioration range under biaxial bending, a series of tests on RHS columns subjected to bi-directional horizontal cyclic loading and constant axial force was conducted. In addition, experimental results were compared with analytical results using multiple shear spring (MSS) model. The simulated RHS column behavior agreed with experimental results including deterioration range.

CYCLIC LOADING TEST ON RHS COLUMNS UNDER BI-DIRECTIONAL HORIZONTAL FORCES

Test Specimen

The test specimen consist of RHS column; □-200x9 (BCR295, Width-to-thickness ratio: 22.2, length: 1734mm) and steel plates welded to both ends of RHS-column to connect to the loading frame, as shown in Figure 1. Tensile coupon test of the flat part of RHS column was conducted using JIS-1A testing sample and the

[1] *Researcher, Department of Built Environment, Tokyo Institute of Technology, Japan, e-mail: ishida.t.ae@m.titech.ac.jp*
[2] *Assistant Professor, Graduate School of Engineering, Chiba University, Japan, e-mail: yshimada@faculty.chiba-u.jp*
[3] *Professor, Structural Engineering Research Center, Tokyo Institute of Technology, Japan, e-mail: naniwa@serc.ac.jp*

SEISMIC TESTS OF LARGE-SCALE STEEL ENERGY DISSIPATING BRACES: DUAL-CORE SELF-CENTERING BRACE AND SANDWICHED BUCKLING-RESTRAINED BRACE

Chung-Che CHOU[1], Ping-Ting CHUNG[2], Yu-Tsen CHENG[2]

This paper is also submitted to the 5th Asia Conference on Earthquake Engineering, Taipei, Taiwan, 2014

SUMMARY

This paper presents cyclic tests of large-scale dual-core self-centering braces (DC-SCBs) and sandwiched buckling-restrained braces (SBRBs). The DC-SCB provides a flag-shaped response with good post-yielding stiffness while minimizing residual drifts in cyclic loading. However, the SBRB provides a full isotropic hardening response with low post-yield stiffness and large residual drifts in cyclic loading. A new test program was developed to characterize the hysteretic response of these two types of steel energy dissipating braces. A total of three large-scale SCBs and SBRBs that were around 7.5 m long were tested to evaluate their cyclic behavior and durability. The DC-SCBs and SBRBs performed well under a total of six phase tests. The maximum axial strength of both DC-SCBs and SBRBs was near 6000 kN at an interstory drift of 2.5%. In all tests, the SBRBs maintained low axial stiffness, large energy dissipation and large residual deformation, but the DC-SCBs maintained large axial stiffness, minimal residual deformation and around one-third of energy dissipation as produced by the SBRBs.

Keywords: *Dual-core self-centering brace; Sandwiched buckling-restrained brace; Cyclic tests.*

INTRODUCTION

A post-tensioned (PT) technique, which uses high-strength steel tendons to compress a beam to a column or a column to a footing, can eliminate welding of the steel beam to the steel column or cast-in place concrete work in the field. The PT beam-to-column connections or PT columns have been demonstrated to be effective in eliminating residual deformations of structures in earthquakes (Ricles et al. 2001, Christopoulos et al. 2002, Chou et al. 2006). However, a slab that is typically used in a building frame limits opening of the gap at the beam-to-column interface, affecting the self-centering (SC) property of the frame (Chou et al. 2008). Therefore, a single structural member, which can have both SC and energy dissipation properties to eliminate the effects of slab-restraint on the SC performance of structures, has been developed in the past few years. Chou et al. (2012) proposed a steel dual-core self-centering brace (DC-SCB), which utilizes three conventional steel bracing member sets, two energy dissipative devices, and two sets of tensioning elements that are in a parallel arrangement. The two inner cores and the addition of a second set of PT elements in the DC-SCB double the axial elongation capacity of the SCED or halve the axial strain demands on PT elements of the SCED (Christopoulos et al. 2008). The mechanism and kinematics of the DC-SCB have been verified successfully from the brace tests by using either the fiber-reinforced polymer (FRP) composite tendons or high-strength steel tendons as the PT elements (Chou and Chen 2012, 2013, Chou and Chung 2014). Hysteretic modeling and seismic analyses of steel-braced frames with either BRBs or DC-SCBs have shown that the SCB frames generally exhibit smaller peak interstory drifts and residual drifts than those of BRBFs (Chou et al. 2014, Tremblay et al. 2008).

The objective of this work was to evaluate the cyclic behaviors of DC-SCBs and SBRBs, which were designed for

[1] *Professor, Department of Civil Engineering, National Taiwan University, Taipei, Taiwan, cechou@ntu.edu.tw*
[2] *Former Graduate Student , Department of Civil Engineering, National Taiwan University, Taipei, Taiwan*

A CASE STUDY OF SEISMIC PERFORMANCE OF SPECIAL CONCENTRICALLY BRACED FRAME WITH STRONGBACK SYSTEM

Chui-Hsin CHEN[1], Yao TANG[2] and Yi-Rung Tsai[2]

SUMMARY

In conventional SCBF structures, the buckling of the braces leads to severe reduction in system strength and stiffness. Therefore soft story mechanisms followed by large permanent deformation are commonly observed in CBF structures. The strongback system using additional structural components along the height of the building to resist local deformation is able to improve the distribution of the drift. This research conducted case studies to investigate the effects of strength and stiffness of the strongback system on the behavior of typical three-story SCBF system. The primary variables to be investigated are stiffness factor α (strongback stiffness/SCBF stiffness) and strength factor β (strongback strength/SCBF strength). We conducted nonlinear static and dynamic analyses to evaluate the effectiveness of α and β on structural demand parameters including drift concentration factor (DCF), maximum drift ratio and permanent drift ratio. Analyses results show that although strongback system with higher α and β will reduce DCF, maximum drift ratio and permanent drift ratio of SCBF systems, it is noneconomic. On the other hand, strongback systems with $\alpha<0.0048$ and $\beta<0.054$ have only little effects on improving structural behavior. The case studies suggested that $0.0096\leq\alpha\leq0.012$ and $0.080\leq\beta\leq0.107$ accounting for both efficiency and economics can be used in the design of the selected SCBF systems.

***Keywords**: soft story, SCBF, strongback, stiffness factor, strength factor, drift concentration factor(DCF).*

INTRODUCTION

CBF structural systems are widely used world-widely. It is efficient to provide lateral strength and stiffness to the structures. However, due to the buckling behavior of braces, the strength and stiffness reduced severely under large earthquake excitations. Moreover, it is not uncommon that soft-story mechanism occurs in CBF structures leading to permanent damage or collapse of the structures. Previous study (MacRae et al. 2004) considered the contributions of gravity columns to lateral force resistance, and concluded that the gravity columns were able to reduce the deformation concentration. Despite of the gravity columns, Tremblay (2003) used elastic truss structures incorporating with CBF or BRBF to create uniformly deformed structures. Ji et al. (2009) investigated the effects of continuous gravity columns on braced frame structures and concluded that sufficient number of gravity columns reduce the deformation concentration effectively. More recently, Wada et al. (2010; 2011) and Qu et al. (2011; 2012) acknowledged the contributions of additional structures to change the energy dissipation mechanism of original structures and employed post-tensioned rocking walls and shear dampers to improve the mechanism of a moment resisting frame building. It was a successful application of strongback concept.

To quantify the design parameters of strongback system for its application to CBF structures, we investigate how the strength and stiffness of strongback system affect the global behavior of CBF frame in this study. Through nonlinear static and dynamic analyses, we looked into the demand parameters such as maximum drift ratio, permanent drift ratio, drift concentration factor (DCF) which was defined as DR_{max}/DR_{avg} in literature(MacRae et al. 2004).

[1] *Assistant Professor, National Chiao Tung University, Taiwan, e-mail: chchen.nctu@gmail.com*
[2] *Graduate Student Researcher, National Chiao Tung University, Taiwan*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

MITIGATION OF OFF-TUNING EFFECT OF FLOOR VIBRATION BY USING ASYMMETRIC TUNED MASS DAMPER

Sung-Yong KIM[1], Cheol-Ho LEE[2], and Dong-Guen LEE[3]

SUMMARY

When floor vibration problems occur in existing buildings, tuned mass damper (TMD) can be a viable solution to repair. Normally, TMD should be tuned to the natural frequency of the floor, as closely as possible, to reduce the vibration. However, TMD loses its control efficiency when the floor natural frequency changes as a result of uncontrollable variation of a floor mass weight or when off-tuning occurs. This paper introduces the use of asymmetric tuned mass damper (ATMD) to enhance the robustness of floor vibration control under uncertain natural frequencies. The proposed ATMD consists of two linear springs with different stiffness and one viscous damping device such that the floor vibrational energy can be dissipated through both translational and rotational motions of the tuned mass. In order to determine the optimal tuning parameters of the ATMD, a novel strategy named "Generalized Den Hartog Procedure" is proposed. The proposed procedure seeks to minimize the maximum of the floor accelerance (objective function in this study) under the constraint condition that the maxima of frequency-perturbed objective functions are balanced. In this manner, the proposed procedure can deal with floor frequency variation while maintaining simplicity and intuitive nature of the original Den Hartog procedure. Based on analytical and test results, it is shown that the ATMD designed according to the proposed procedure exhibits robustness and effectiveness in vibration control superior to conventional TMDs.

Keywords*: floor vibration; off-tuning effect; robustness; tuned mass damper; vibrational control.*

INTRODUCTION

Tuned mass damper (TMD) is a dynamic vibration absorber used to attenuate vibration of a primary structure. Since the concept of TMD first appeared in the early 20th century (Frahm 1911), a lot of related researches have been conducted. One of the critical issues for a TMD application is to determine its optimal tuning conditions. One classical and very interesting solution was proposed by Den Hartog (1956) for damped TMDs under harmonic loading. The key idea used by him will be discussed and generalized in this paper. Based on various optimum criteria and loading cases, many researchers proposed the optimum tuning conditions (frequency and damping) for damped TMDs attached to undamped main structures. For example, Warburton (1982) derived the optimal tuning parameters which minimize various response indices such as displacement, velocity, and acceleration of a main structure subjected to harmonic and white noise random excitations.

Single-mass tuned dampers, but with two degrees of freedom, have also been investigated to enhance the efficiency of the vibration control (Zuo and Nayfeh 2004; Zuo and Nayfeh 2006; Li and Zhu 2006). Especially, Zuo and Nayfeh (2006) developed optimization algorithms for two degree of freedom TMDs based on the H_2 and H-infinity norms to minimize the response under random and harmonic excitations. They found that TMDs with two degrees of freedom perform more effectively when the TMDs have two springs and one viscous damping device.

However, the efficiency of conventional TMDs is often very sensitive to the variation of natural frequency of a

[1] Graduate Student, Department of Architecture and Architectural Engineering, Seoul National University, Korea, e-mail: sungyong.kim7@gmail.com
[2] Professor, Department of Architecture and Architectural Engineering, Seoul National University, Korea, e-mail: ceholee@snu.ac.kr (corresponding author)
[3] Professor Emeritus, Department of Architectural Engineering, Sungkyunkwan University, Korea, e-mail: dg19491947@gmail.com

PERFORMANCE VERIFICATION OF A LEVERAGE-TYPE STIFFNESS-CONTROLLABLE MASS DAMPER

Shih-Yu Chu[1], Lyan-Ywan Lu[2], Shih-Wei Yeh[3] and Chih-Hua Peng[4]

SUMMARY

The mitigation of structure vibration subjected to strong wind by using a tuned mass damper (TMD) has been applied practically and is demonstrated be an effective technology. However, 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. To solve this problem, a semi-active mass damper (SAMD) whose designed parameters can be adjusted according to structural responses through the application of appropriate control force to the original passive device has been proposed in recent years. A leverage-type stiffness controllable mass damper (LSCMD) is adopted in this study to improve the performance of a conventional TMD. Based on the discrete-time optimal LQR output feedback control algorithm, the control performance of the LSCMD can be improved as deigned. Therefore, the target pivot position of the leverage mechanism can be determined in real time to provide the controllable stiffness for the LSCMD. To demonstrate the performance and verify its feasibility of the proposed LSCMD, a shaking table test is conducted. From the comparisons of experimental and numerical results, the structural responses subjected to white noise earthquake and Chi-Chi earthquake can be suppressed with smaller stroke when equipped with LSCMD.

Keywords*: Semi-active Control, Stiffness Controllable Mass Damper, Discrete-time Optimal LQR control, Leverage Theorem, Shaking Table Test.*

INTRODUCTION

A tuned mass dampers (TMD) has been demonstrated that it is an effective technology for reducing the structural vibration due to wind loads (Chung et al., 2011; Warburton, 1982). Based on this fact, recently some researchers have investigated the possibility of using TMD to alleviate the structural responses induced by seismic excitations (Ikago et al., 2012; Rakicevic et al., 2012; Marano and Greco, 2011; Miranda, 2005). In order to attain a desirable responses, the frequency and damping ratio of a TMD have to be set to its optimal values, which usually depend on the characteristics of the excitations (Ikago et al., 2012; Marano and Greco, 2011; Marano et al., 2010; Marano and Quaranta, 2009; Marano et al., 2007). Unfortunately, the frequency contents and magnitudes of a seismic load is usually complicate and hard to be predicted precisely. As a result, the control performance of a TMD under a real earthquake may not be as good as the expected one, which is optimally designed under a design earthquake. In order to solve this problem by making TMDs adaptive to seismic excitations, some researchers have advocated using the technology of semi-active mass dampers (SAMDs).

[1] *Associate Professor, Department of Civil Engineering, National Cheng Kung University, Taiwan, e-mail: sychu@mail.ncku.edu.tw*
[2] *Professor, Department of Civil Engineering, National Cheng Kung University, Taiwan , e-mail:lylu@mail.ncku.edu.tw*
[3] *PhD Candidate, Department of Civil Engineering, National Cheng Kung University, Taiwan, e-mail: n68981042@mail.ncku.edu.tw*
[4] *Graduate Student, Department of Civil Engineering, National Cheng Kung University, Taiwan, e-mail: burst1986@gmail.com*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

A FAST COMPUTER VISION METHOD FOR LIQUID HEIGHT MEASUREMENT OF TLCDS

Junhee KIM[1], Chan-Soo PARK[2], and Kyung-Won MIN[3]

SUMMARY

In this study, a fast, high precision, and cost-effective computer vision method is developed exclusively for dynamic liquid height measurement of tuned liquid column dampers (TLCDs). The robust image processing algorithm developed enables fast and accurate measurement of the liquid height simply by counting binary digits in image pixels representing liquid columns of the TLCDs without requiring conventional retardant image processing techniques. In laboratory tests with a prototype of the TLCDs, accuracy of the proposed computer vision method is confirmed through comparison with conventional contact sensors.

Keywords*: structural control; tuned liquid column dampers; computer vision-based sensing; liquid height measurement.*

INTRODUCTION

Structural developments in design and construction of buildings and towers have rendered structures tall, slender, and flexible. 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. Structural control is needed to reduce the dynamic responses of the structures and to maintain their functional performances. A constant flow of developing novel and effective devices incorporated in structures for attenuation of structural vibration has been seen over the past decades (Kareem et al. 1999).

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. 2005; Wu et al. 2005; Yalla et al. 2000).

[1] *Assistant Professor, Department of Architectural Engineering, Dankook University, Yongin, Korea, e-mail: junheekim@dankook.ac.kr*
[2] *Graduate Student, Department of Architectural Engineering, Dankook University, Yongin, Korea*
[3] *Professor, Department of Architectural Engineering, Dankook University, Yongin, Korea, e-mail: kwmin@dankook.ac.kr*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

AN ASSESSMENT FOR THE DESIGN OF HIGH-DAMPING RUBBER BEARINGS USING BILINEAR AND EFFECTIVE LINEAR MODELS

Pei-Chuan CHAO[1] and Yin-Nan HUANG[2]

SUMMARY

Engineers usually simplify the behavior and use bi-linear model to represent the hysteresis loop of a high damping rubber bearing (HDRB) for response history analysis (RHA). However, the impact of this simplification has not been well studied. In this study, a numerical model in literature is used to represent the behavior of HDRB. The model is validated using experiment data and used as the benchmark model in this study. To study the impact of using bi-linear model to simulate the hysteresis behavior of HDRB, a series of RHA were performed using both the benchmark and bilinear models subjected to near-fault and far-field ground motion sets at two levels of ground-motion intensities, namely, design basis and maximum considered earthquakes. The pros and cons of using bi-linear model for the design of HDRB system are presented based on the analysis results. The results of RHA are also compared with those computed using the equivalent lateral force (ELF) procedure recommended in building codes. The use of the ELF procedure for the design of HDRB system is discussed.

Keywords: *High damping rubber bearing; bi-linear model; equivalent lateral force; hysteresis behavior; response history analysis.*

INTRODUCTION

Seismic isolation systems have been widely used to protect superstructures from the threat of strong ground motions. By prolonging the period of structure and offering additional damping, the systems can effectively reduce seismic responses of buildings.

Among all kinds of seismic isolators, high damping rubber bearing (HDRB) is favored due to its outstanding performance of dissipating energy and distinct material characteristics under various circumstances (Aiken et al. 1992; Kelly et al. 1986; Kelly and Naeim, 1999). At low shear strains, HDRB has higher stiffness and damping and capable to reduce responses under wind load and seismic load below design level. At intermediate shear strains, the stiffness of HDRB is low and constant, which makes the bearing fairly linear and flexible. At high shear strains, the shear modulus of the bearing will increase, so its deformation could be limited.

In most design guidelines (AASHTO 2013; ASCE 2010), the design of HDRB involves the equivalent linear assumption and/or Response history analysis (RHA). Engineers often use bilinear model to simulate the hysteresis behavior of HDRB for seismic assessment and design of structures equipped with the system. However, unlike lead rubber bearing or friction bearing, it is difficult to use bilinear model to approximate the highly nonlinear characteristics of HDRB, including the Mullins' and/or scragging effect (Mullins, 1969; Clark et al. 1997), strain-dependent, strain-rate dependent, etc. (Hwang et al., 2002).

Several mathematical models have been proposed to describe the nonlinear behavior of HDRB accurately, for example, a strain-rate independent model presented by Kikuchi and Aiken (1997); the model of Hwang et al. (2002),

[1] *Graduate student, Dep. of Civil Engineering, National Taiwan University, Taiwan*
[2] *Assistant Professor, Dep. of Civil Engineering, National Taiwan University, Taiwan, e-mail: ynhuang@ntu.edu.tw*

FE ANALYSIS OF MULTI-STOREY RC FRAMES WITH ENERGY DISSIPATING SIM PANELS

Yuri TOTOEV[1], and Zhiyu WANG[2]

SUMMARY

A new masonry system is being developed at the University of Newcastle. It uses masonry panels made of dry stack semi-interlocking masonry (SIM) units capable of relative sliding in-plane of a panel and interlocked to prevent sliding out-of-plane of a panel. The major objective for developing this new masonry system is to improve the earthquake performance of framed structures with masonry panels acting as energy dissipation devices (EDD). An experimental program was carried out to evaluate the behaviour of different framed masonry panels. It was found that SIM panels have significant energy dissipation capacity (up to 17% damping) due to friction between masonry units. This paper presents results of a numerical simulation of earthquake vibrations on a multi-storey RC frame infilled with SIM panels and compares it to vibrations of the same frame with traditional masonry panels. It was concluded that SIM panels could improve earthquake resistance of structural frames.

***Keywords**: dry stack; masonry; infill; concrete frame; seismic performance.*

INTRODUCTION

Masonry is one of the most popular building materials. It has many excellent material properties and proven durability. Over time masonry has evolved from a material used for massive structural walls, which work mainly in compression, to more slender walls, which could also be subjected to tension and shear. Earthquake induced tensile and shear stresses often exceed capacity of traditional masonry resulting in substantial damage and failure. The design of masonry with improved earthquake resistance presents a challenge for structural engineers. Several design strategies could be employed to meet this challenge. These can be broadly summarized using the classical equation of motion

$$ku + cu + mu = -mu_g(t) \tag{1}$$

where k is stiffness matrix, u is vector of dynamic displacements (vibrations), c is damping matrix, u is vector of velocities, m is mass matrix, u is vector of accelerations, and $u_g(t)$ is acceleration of the ground.

The reduction in the amplitude of vibration could be achieved by the following changes:

- Modifying the stiffness matrix. This is the most common design strategy. Other materials with better tensile capacities are used to reinforce the masonry and improve its lateral load resistance. Some examples of this approach are reinforced masonry and confined masonry walls. The stiffness matrix could also be modified by changing connections between masonry walls and the rest of the structure to reduce masonry involvement in bearing the lateral load during earthquake. Typical examples of this approach are infill masonry panels.

[1] *Dr, Centre for Infrastructure Performance and Reliability, The University of Newcastle, Australia, e-mail: yuri.totoev@newcastle.edu.au*
[2] *PhD Candidate, Centre for Infrastructure Performance and Reliability, The University of Newcastle, Australia, e-mail: zhiyu.wang@uon.edu.au*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

MULTI-LEVEL EVALUATION OF STONE PAGODAS UNDER EARTHQUAKE LOADING*

Namhee-Kim Hong[1], Sung-Gul Hong[2]

SUMMARY

Stone pagodas in Korea that had been constructed in various ways are uniquely identified in their shapes while their structural behaviors are greatly deviated from those of homogeneous structures. The problems related with the heterogeneity might be apparent in the case of pagodas that greatly varied course size and pattern over heights. This study has focused on the development of a rational way of evaluating an overall seismic vulnerability for the heterogeneous stone pagodas in Korea. In order to address the problem of heterogeneity, multi-level evaluation process will be adopted which consist of (1) decomposition and (2) aggregation. The decomposition is defined as to simplify a complicated problem into several simple and manageable problems while the aggregation to integrate evaluation results obtained for the simple problems. A hierarchy of seismic risk evaluation criteria has been developed to support both decomposition and aggregation processes in a consistent way.

Keywords*: Bar development; strut-and-tie models; structural configuration; cut-off points; bar detailing*

INTRODUCTION

Stone pagodas in Korea that were constructed using the dry construction method without mortar are uniquely identified in their shapes. Their shapes had been changed depending on design trend and material accessibility from low-rise to high-rise while keeping three major parts consisting of (1) top part; (2) body part; and (3) base part. Each part takes on different function from both structural and architectural aspects. This study has focused on the development of a rational way of evaluating an overall seismic vulnerability for the heterogeneous stone pagodas in Korea. In order to address the problem of heterogeneity, multi-level evaluation process will be adopted which consist of (1) decomposition and (2) aggregation. The decomposition is defined as to simplify a complicated problem into several simple and manageable problems while the aggregation to integrate evaluation results obtained for the simple problems. Note that a hierarchy of seismic risk evaluation criteria is needed to support both decomposition and aggregation processes in a consistent way.

Prior to the development of the multi-level evaluation process, structural behavior of stone pagodas under earthquake loadings must be understood. Housner's simple rocking model (1963) that was developed without considering sliding motion provides an overall view for dynamic stability of relatively slender towers. Also, the stone pagodas are considered as an assemblage of rigid blocks and they can be furthermore simplified as a rigid block provided that they do not fail in sliding between blocks. Note that the stone pagodas that are strong in compression but very weak in tension carry their loads through thrust lines which must be provided inside the structural members to secure its safety. In this relation, the concept of limit theorem helps establish the possible ranges for the load path forming along the thrust lines. This study has adopted the concept of Housner's rigid block model and the limit theorem for qualitative analysis while numerical data (NRICH 2012) obtained through the dynamic analysis for stone pagodas

[1] *Dept. of Architecture, Seoul National University, Korea, namheek@snu.ac.kr*
[2] *Dept. of Architecture, Seoul National University, Korea, sglhong@snu.ac.kr*
**This paper was presented in PROHITEC04, 2014.*

SEISMIC PERFORMANCE EVALUATION OF EARTHQUAKE-DAMAGED BUILDINGS IN INDONESIA AFFECTED BY BRICK MASONRY INFILL

Maidiawati[1], Yasushi Sanada[2] and Jafril Tanjung[3]

SUMMARY

This paper discusses the seismic performance of two Indonesian earthquake-damaged buildings considering the brick infill effect by applying a developed analytical model. Masonry infill is replaced by a diagonal compression strut which represents distributed compression transferred diagonally between infill/frame interfaces. The infill/frame contact length can be determined by solving two equations, i.e., static equilibriums related to the compression balance at infill/frame interface and lateral displacement compatibility. Consequently, the equivalent strut width is presented as a function of infill/frame contact length. The developed analytical model was verified by comparing to experimental results of several brick masonry infilled R/C frames, and applied to the seismic performance evaluation of the buildings. It was found that nonstructural brick masonry infill affected lateral strength, lateral stiffness and ductility of the buildings and caused the difference between damage to both. These results indicate the proposed model can be an effective tool for more precisely screening earthquake-vulnerable existing R/C buildings in Indonesia.

Keywords: *SEEBUS; brick masonry infill; infill/frame contact length; reinforced concrete frame building; seismic performance; strut infill model.*

INTRODUCTION

Reinforced concrete (R/C) buildings with masonry infill as exterior/partition walls widely exist around the world, including developing countries with high seismicity. However, the presence of masonry infill is usually neglected in seismic design calculations assuming it to be a nonstructural element. This assumption may result in inaccurate estimation not only of the seismic performance such as lateral stiffness, strength, and ductility of the buildings but also of the seismic demand related to structural characteristics.

A number of past studies on in-plane earthquake simulation test of masonry infilled frames have been conducted by several researchers to evaluate the contribution of masonry infill to lateral stiffness and strength of structures (Lee and Woo 2002, Maidiawati et al. 2011, and Armin B. et al. 1996). The test results revealed that contribution of infill wall can drastically change the performance of frames in terms of the in-plane stiffness and strength.

Recently, various analytical manners, from classical replacing of the infill by diagonal strut to modern computing with sophisticated modeling, have been proposed by a number of researchers for predicting the lateral strength and stiffness of masonry infill in frames structures. The former methods are still useful for evaluating macro behavior such as stiffness, strength, and ductility of full infill, nevertheless the latter modern methods are powerful for investigating micro strain/stress in infill. This study focuses on the former because macro modeling is more suitable for practical seismic evaluation by general engineers. Several diagonal strut models have been proposed by researchers as report by Holmes (1961), Stafford Smith and Carter (1969), Mainstone (1971), Paulay and Preistley (1972), El-Dakhakhni et al. (2003) and Asteris PG (2003) who evaluated the seismic performance of masonry infill

[1] *Ph.D. Department of Civil Engineering, Padang Institute of Technology, Indonesia, e-mail: maidiawati@yahoo.com*
[2] *Associate Professor, Osaka University, Japan, e-mail: sanada@arch.eng.osaka-u.ac.jp*
[3] *Ph.D. Department of Civil Engineering, Andalas University, Indonesia,e-mail: jafriltanjung@ft.unand.ac.id*

ANALYTICAL MODEL FOR CAPACITY CURVE OF CONFINED MASONRY WING-WALLS

Yi-Hsuan TU[1], Tsung-Hua CHUANG[2], and Hsing-Yu YEH[3]

This paper is also submitted to the 5th Asia Conference on Earthquake Engineering

SUMMARY

Wing-walls are the panel segment between columns and openings. They are efficient seismic elements without sacrificing lighting and ventilation in confined masonry (CM) buildings. In order to adequately evaluate the contribution of CM wing-walls in seismic assessment, a backbone model for their capacity curves is presented in this paper. The capacity curves are defined by cracking and ultimate points determined by different failure modes. Equations for the strength and the deformation of flexural, diagonal tension, diagonal compression, and bed-joint sliding failure modes are derived by the authors or modified from the existing models. The contribution of the columns and the column-panel interaction are considered in the model for better estimations of the failure mode and the maximum strength. Experimental results from the tests conducted by the authors and other references are compared with the analytical model. The comparison shows reasonable and conservative estimation.

***Keywords**: Confined masonry; Wing-wall; Capacity curve; Strength.*

INTRODUCTION

Confined masonry (CM) consists of masonry wall panels and cast-in-place reinforced concrete (RC) confining elements. The confining elements, including tie-columns and tie-beams, are built after the masonry panels. The vertical edges of the panels adjacent to tie columns are usually toothed as shear keys to integrate the masonry panels and tie columns into composite members. CM buildings are widely used in South Europe, Latin America, and Asia (EERI & IAEE, 2012). The confining elements usually have smaller cross-sectional dimensions than the beams and columns in an RC frame building (Brzev, 2007). The seismic design guide for low-rise confined masonry buildings (Meli & Brzev, 2011) suggests a minimum tie-column/beam size of 150mm thickness with minimum 4-#3 reinforcing bars. CM buildings have also been constructed in Taiwan for decades. However, the differences between CM and RC buildings were not well known until recently. Local engineers tend to use CM for masonry panels in an RC frame building. In this case, the column and beam sections have larger dimensions, and also fail to satisfy the requirement for standard CM buildings (Meli & Brzev, 2011) that there should be confining members around the openings. The wall segments between openings and columns are called “wing-walls”. Wing-walls in Taiwanese CM buildings usually have a slenderness ratio (H/W) between 2.0 to 3.0. They have been found to contribute lateral resistance and stiffness to the building during earthquakes in despite of the high slenderness and the lack of full confinement. However, they also change the behavior of the adjacent column that might result in non-ductile shear failure. Therefore, it is important to evaluate the behavior and effect of wing-walls appropriately in the seismic assessment.

Most of the present analytical models for CM or in-filled masonry panels (Tomaževič & Klemenc, 1997)(FEMA, 2000) are not applicable to panels too slender or without full confinement. Also, few studies have examined CM

[1] *Associate Professor, Department of Architecture, National Cheng Kung University, Tainan, Taiwan; yhtu@mail.ncku.edu.tw*
[2] *PhD, Department of Architecture, National Cheng Kung University, Tainan, Taiwan*
[3] *Master of Science, Department of Architecture, National Cheng Kung University, Tainan, Taiwan*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

PROPOSAL OF SIMPLIFIED BACKBONE CURVE FOR URM WALL INFILLED RC FRAME

Ho CHOI[1], Kiwoong JIN[2], and Yoshiaki NAKANO[3]

SUMMARY

In this paper, a simplified method to practically estimate the backbone curve of unreinforced concrete block (CB) infill in RC boundary frame is discussed mainly based on the frame geometry and the compressive strength of CB wallette. Representative characteristic points of cracking, maximum, and residual strength of CB infill are employed herein, and their values are proposed to estimate the backbone curve. The estimated backbone curves are found to show good agreement with the test results.

Keywords: *URM infill in RC frame, diagonal strut mechanism, backbone curve, FEMA306&356.*

INTRODUCTION

In some regions of Asia, Europe, and Latin America where earthquakes frequently occur, serious earthquake damage is commonly found resulting in catastrophic building collapse. Such damaged buildings often have unreinforced masonry (URM) infills, which are considered non-structural elements in the structural design stage, and building engineers have paid less attention to their effects on structural performance although URM infills may interact with boundary RC frames. The evaluation of seismic capacity of URM infills in boundary RC frames is therefore urgently necessary to mitigate earthquake damage for these buildings.

In the previous study (Jin 2012), in-plane cyclic loading tests of one-bay, one-fourth scale RC specimens with unreinforced concrete block (CB) infills for typical school buildings in Korea were carried out, and the measurement plan using 3-axis strain gauges attached on all CB units was employed to experimentally investigate their seismic capacity. The diagonal strut mechanism and lateral load carrying capacity of CB infills were successfully explained based on experiment data using the principal compressive strains of the infills and the strain-stress relationship of CB wallettes.

In this paper, a simplified method to practically estimate the backbone curve of CB infill in RC boundary frame is further discussed mainly based on the frame geometry and the compressive strength of CB wallette.

EXPERIMENTAL INVESTIGATION OF LATERAL LOAD CARRIED BY CB INFILL IN RC BOUNDARY FRAME

The lateral load carried by CB infill and RC boundary frame is experimentally investigated in the previous study as stated earlier. The experiment outline and the lateral load of CB infill in RC boundary frame are briefly described as follows.

[1] *Research Associate, Institute of Industrial Science, The University of Tokyo, Japan, e-mail: choiho@iis.u-tokyo.ac.jp*
[2] *Research Associate, Dept. of Architecture and Building Eng., Tokyo Metropolitan University, Japan, e-mail: kwjin@tmu.ac.jp*
[3] *Professor, Institute of Industrial Science, The University of Tokyo, Japan, e-mail: iisnak@iis.u-tokyo.ac.jp*

SEISMIC FRAGILITY OF LIGHTLY REINFORCED CONCRETE FRAMES WITH MASONRY INFILL

Jong-Su Jeon[1], Ji-Hun Park[2], and Reginald DesRoches[3]

SUMMARY

Seismic fragility of masonry-infilled reinforced concrete frames is assessed through numerical simulations considering uncertainty in ground motion and building materials. To achieve this aim, numerical model of components is developed; a rational approach to proportion and locate individual struts in the equivalent three-strut model is proposed; and explicit nonlinear column shear response models accounting for the infill-column interaction and soft-story mechanism are employed. The proposed numerical model is used to (1) generate probabilistic seismic demand models accounting for a wide range of ground motion intensity with different frequency contents, and (2) determine limit state models obtained from nonlinear pushover analysis and incremental dynamic analysis. Using the demand and limit state model, fragility curves are developed to estimate the vulnerability of these frames. Moreover, the fragility curves are employed to investigate the impact of various infill properties and failure modes on the frame vulnerability. It is observed that the column shear failure can almost nullify the beneficial effect of the masonry infill for collapse prevention, and is a critical factor in the seismic vulnerability assessment of these frames with light reinforcement against shear failure.

Keywords*: masonry-infilled reinforced concrete frame, equivalent strut model, infill-column interaction, probabilistic seismic demand model, limit state model, seismic fragility.SEEBUS; earthquake engineering; building structures; refined-plastic hinge method; spread of plasticity.*

INTRODUCTION

Masonry-infilled reinforced concrete (RC) frames are composed of the masonry infill and a boundary frame. In the past or current design practice of many countries, infill has been regarded as a non-structural component of which stiffness and strength was neglected. However, many studies have pointed out significant influence of the infill on the seismic response of the structure. Traditionally, it has been thought that the infill makes a beneficial contribution to the mitigation of seismic response (Mainstone, 1971, Saneinejad and Hobbs 1995, Fardis 1997). Despite this advantage for the use of the infill, the infilled frames may have another potential failure mechanism, which is flexural or shear failure of the boundary frame due to the interaction between the infill and boundary frame that can lead to local damage or system collapse (Paulay and Priestley 1992, Crisafulli 1997, FEMA 1998). This failure mechanism can be observed in static and dynamic testing (Mehrabi et al. 1996, Stavridis et al 2012). Thus, overall seismic response of the infilled frames depends on which one of the two contrary effects is dominant. Additionally, early failure of the infill at lower stories causes vertical irregularity by forming soft story after the collapse of the infill (Negro and Colombo 1997, Dolsek and Fajfar 2001, Verderame et al. 2011).

The primary objectives of the current study are to (1) propose explicit numerical models for infill and column, primary components in existing masonry-infilled RC frames, that can simulate the primary earthquake response

[1] Post-Doctoral Researcher, School of Civil and Environmental Engineering, Georgia Institute of Technology, USA, e-mail: jongsu.jeon@gatech
[2] Associate Professor, Division of Architecture and Urban Design, Incheon National University, Republic of Korea, e-mail: jhpark606@incheon.ac.kr
[3] Karen and John Huff School Chair and Professor, School of Civil and Environmental, Georgia Institute of Technology, USA, e-mail: reginald.desroches@ce.gatech.edu

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

SEISMIC EVALUATION OF RC SLAB-COLUMN FRAMES AND PROPOSED CHANGES TO ACI 369 AND ASCE 41

Thomas H.-K. Kang[1], Amy C. Hufnagel[2], YeongAe Heo[3] and Sohyun Moon[4]

SUMMARY

Over the past few decades, flat plate concrete building systems have been widely adopted in the United States and other countries because it enables not only to save construction time and cost but also to make better use of interior spaces. However, it has been observed that such buildings whose columns are cast into the concrete flat plate are highly vulnerable to collapse. Such integrated slab-column frames have suffered severe damage or completely collapsed during the past earthquake events. The main failure mode of these structures is punching shear. Although a general guideline for seismic design and a seismic rehabilitation design guideline for both existing and new reinforced concrete frame structures are specified in ACI 318 and ACI 369, respectively, many uncertainties have still resided in the modeling parameters to accurately predict seismic behavior of the flat plate concrete frame structures. Therefore, a new chart of allowable plastic rotation values for correlating values of gravity shear ratio is presented in this study with the objective of updating the modeling parameters of ACI 369 and ASCE 41. The major issues which lead to errors in evaluating flat plate concrete structural behavior under seismic loads are thoroughly investigated. Also, dominant parameters from previous and recent experiments on integrated slab-column connections subjected to seismic loading are utilized to assess the estimation of seismic performance of the flat plate system based on ACI 369 and ASCE 41. Consequently, although it is confirmed that there is a trend in correlation between the allowable plastic rotation and gravity shear ratio while almost no correlation is observed with reinforcement ratio, more experimental data are necessary to enhance this correlation study. It is also noticed that the current ACI 369 recommendations for allowable plastic rotation values for slab-column connection under seismic and gravity loading are unconservative.

Keywords*: Reinforced concrete; slab-column connections; modeling; plastic rotation; seismic; evaluation.*

INTRODUCTION

Flat plate concrete building systems consist of monolithically cast slab and column frames, and are widely used with and without shear walls in the United States and other countries for several advantages, including economy and building efficiency (Kang et al., 2008; Hueste et al., 2009; Kang et al., 2009; Shin et al., 2010; Hufnagel et al., 2014). This setup reduces story heights, which allows for lower costs for building material, cladding, electrical and mechanical ductwork, and annual heating and air-conditioning. This lowers both dead loads and lateral loads on the structure. Despite these many advantages, there are also many issues such as complexity in modeling and punching shear failure with flat plate building systems.

[1] Associate Professor, Seoul National University, Seoul, Korea, e-mail: tkang@snu.ac.kr
[2] Structural Engineer, Walter P Moore, Houston, TX (Former Master's student of the University of Oklahoma)
[3] Assistant Professor, Case Western Reserve University, Cleveland, OH (Former post-doctoral researcher of Seoul National University)
[4] Master's student, Seoul National University, Korea
** This paper is a part of the paper published in the ACI Special Publication (Hufnagel et al., 2014)*

STRUCTURAL EXPERIMENTS OF ONE-STORY ONE-BAY R/C MOMENT RESISTING FRAMES WITH NON-STRUCTURAL WALLS

Rok-Hyun YOON[1], Yasushi SANADA[2], Suguru SUZUKI[3], Takumi AKAHORI[1], Hiroshi KURAMOTO[4]

SUMMARY

This paper reports cyclic loading test results of three one-story, one-bay reinforced concrete moment resisting frame specimens. Two of the specimens have non-structural walls which are monolithically constructed or structurally isolated by seismic slits. Lateral strengths of the specimens at their mechanisms were 71 kN, 268 kN, and 103 kN for the BF (without non-structural wall), WF (with monolithic wall), and WFs (with isolated wall by seismic slits), respectively. The isolated wall as well as monolithic wall significantly affected the seismic performance of moment resisting frame due to existence of tie bars at wall-frame boundaries. Moreover, the seismic slits effectively reduced damage to the non-structural wall.

***Keywords**: damage; equivalent damping ratio; non-structural wall; repair cost; seismic performance; seismic slit; structural test.*

INTRODUCTION

Reinforced concrete (R/C) buildings are often constructed monolithically with non-structural components. Severe damage to non-structural walls was also observed in a lot of R/C buildings after the 2011 off the Pacific coast of Tohoku earthquake, as shown in Photo 1. Moreover, several past studies reported that such non-structural walls affected the seismic performance of R/C structures (e.g. Kutay et al. and Kabeyasawa et al.). However, no design methodology has been completed to consider structural effects of non-structural walls as well as to prevent their damage for immediate occupancy. The objective of study is to obtain experimental fundamental data on seismic behavior of non-structural walls. This study mainly focuses on R/C non-structural walls used for exterior/partition walls in typical R/C residential buildings. Cyclic loading tests were planned using three 1/2.5 scale, one-story, one-bay R/C moment resisting frame specimens with/without non-structural walls which were monolithically constructed or structurally isolated by seismic slits. This paper experimentally investigates the effects of R/C non-structural walls with/without seismic slits on the seismic performance of R/C moment resisting frame.

Photo 1 Damage to non-structural walls observed after the 2011 off the Pacific coast of Tohoku earthquake

[1] *Graduate Student, Dept. of Architectural Eng., Osaka University, Japan, e-mail: Yoon_rokhyun@arch.eng.osaka-u.ac.jp*
[2] *Associate Professor, Dept. of Architectural Eng., Osaka University, Japan, e-mail: sanada@arch.eng.osaka-u.ac.jp*
[3] *Assistant Professor, Dept. of Architectural Eng., Osaka University, Japan, e-mail: suzuki@arch.eng.osaka-u.ac.jp*
[4] *Professor, Dept. of Architectural Eng., Osaka University, Japan, e-mail: kuramoto@arch.eng.osaka-u.ac.jp*

EXPERIMENTAL STUDY OF ALTERNATIVE DETAILING FOR COUPLING BEAMS

Shyh-Jiann HWANG[1], Erwin LIM[2], Chih-Hung CHENG[3], Ting-Wei WANG[3], and Yu-Hsuan CHANG[3]

SUMMARY

The ACI 318-11 code provision gives much flexibility for the engineers to design coupling beam with intermediate shear span-to-depth ratio ($2.0 \le \ell_n/h \le 4.0$). The coupling beam can be detailed either using a traditional beam reinforcement layout as in special moment resisting frame or as a beam reinforced with two intersecting groups of diagonal bars. Although the available test results strongly indicated the superiority of the ACI 318-11 diagonal reinforcement layout, but this detailing created many construction issues. This study tested several alternative detailings for coupling beam specimens with $\ell_n/h = 3.0$, which includes the aforementioned two different reinforcement layouts. The alternative detailing are the use of partial amount of diagonal reinforcement, the use of steel fiber, and the enhancement on the bond behavior using the vertically distributed longitudinal bars.
Test results indicated that under a large shear demand, although the failure of all test specimens were governed primarily by the flexural behavior, specimen detailed in a traditional way had the poorest deformation capacity among all other specimens. If the coupling beam was either reinforced using steel fiber reinforced concrete or vertically distributed the longitudinal reinforcement the test results showed slight improvement on the deformation capacity. The deformation capacity was greatly enhanced and in proportional with the amount of diagonal reinforcement being used.

***Keywords**: Alternative detailing, Coupling beam, Deformation capacity, Seismic behavior.*

INTRODUCTION

In typical high rise buildings, coupled structural wall is one of the preferred building systems, for it provides not only high lateral stiffness and shear capacity, but also allows openings for architectural or mechanical/electrical considerations. In this structural system, coupling beam, which links between the two separate structural walls, is one of many important structural members needs paying attention for. A properly designed coupling beam may allow higher structural redundancies and more plastic hinges to occur, which finally leads to a more ductile behavior of overall structure.

The ACI 318-11 (2011) currently requires that all the shear demand of deep coupling beams, i.e.: beams with clear shear span-to-depth smaller than 2.0 ($\ell_n/h \le 2.0$) be resisted solely by diagonal bars. Despite the construction difficulty created from this reinforcement layout, the superiority of its seismic behavior has been confirmed by many researchers (Paulay and Binney 1974, Tassios et al. 1996). Meanwhile, for coupling beams with intermediate shear span ratio ($2.0 \le \ell_n/h \le 4.0$), ACI 318-11 allows flexibility for engineers to either reinforce them as traditional beams following the special moment resisting frame provisions or to use two intersecting groups of diagonal bars (full diagonal layout).

Available research data for coupling beams with $2.0 \le \ell_n/h \le 4.0$ (Barney et al. 1980 and Naish et al. 2009) showed that specimens detailed using full diagonal layout as suggested by the ACI 318-11 possessed better structural behavior. However, the placement of the diagonal bars creates some constructability issues in the job site. Several

[1] Professor, Department of Civil Engineering, National Taiwan University , Taiwan, e-mail: sjhwang@ntu.edu.tw
[2] PhD Candidate, Department of Civil Engineering, National Taiwan University , Taiwan, e-mail: d98521030@ntu.edu.tw
[3] Former MS Students, Department of Civil Engineering, National Taiwan University, Taiwan.

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

ANALYTICAL STUDY ON SEISMIC BEHAVIOR OF HORIZONTAL HYBRID STRUCTURE OF WOOD AND RC

Yoshihiro YAMAZAKI[1], and Hiroyasu SAKATA[2]

SUMMARY

In Japan, construction of wood structures for public buildings is encouraged for environmental reason. For example, low-rise large wood building sometimes involves core parts which are usually reinforced concrete structures. This kind of structures is described as "horizontal hybrid structure". However, it is difficult to evaluate seismic force distribution and stress between wood parts and core parts. In this paper, basic vibration properties and characteristics of seismic response of horizontal hybrid structure are discussed. The followings are findings of this research. 1) Since wood parts and core parts have quite different vibration properties, they do not act in the same vibration modes. 2) Most of base shear force is derived from wood part dominant 1st mode and core part dominant 1st mode while responses of wood part elements are derived from only wood part dominant modes. 3) Amplitude of seismic force on wood part was estimated, considering modal characteristics and syntony with ground acceleration.

Keywords*: hybrid structure of wood and RC; vibration properties; seismic force distribution.*

INTRODUCTION

In Japan, construction of wood structures for public buildings is encouraged for environmental reason. Wood is eco-friendly material in terms of reduction of carbon-dioxide emission through construction activity. Nowadays, large wood buildings are built with the help of hybrid structure. For example, low-rise large wood building sometimes involves core parts which are usually reinforced concrete structure as shown in Figure 1. This kind of hybrid structures is described as "horizontal hybrid structure" in this paper. It has advantages in not only seismic resistance but fire resistance.

There are two types of seismic design method for horizontal hybrid structures available. The one is to divide the structure by expansion joint at the connection between wood parts and core parts. Wood parts and core parts can be independently designed. Although it is no longer hybrid structure in terms of seismic resistance, the design method is easily understandable.

Another design method takes advantage of high seismic resistance of core parts when designing wood parts. By transferring seismic force on wood parts to core parts, seismic resistant element such as shear walls can be reduced. Therefore, wide open space without columns and walls can be realized. However, the seismic design is quite difficult because wood buildings generally have flexible floor diaphragm and show complicated seismic force distribution. Previously, earthquake response analysis was necessary to simulate the seismic behavior. It requires time and effort, and it is not suitable situation to promote construction of wood buildings.

In this paper, basic vibration properties and characteristics of seismic response of horizontal hybrid structure are discussed. In order to develop seismic design method with less effort, simulation by static analysis is also demonstrated. Especially, how to estimate amplitude of seismic force on wood parts is presented.

[1] *Assistant Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Japan: yamazaki.y.ai@m.titech.ac.jp*
[2] *Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Japan; sakata.h.aa@m.titech.ac.jp*

The 16th Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for
Building Structures, Seoul, Korea, September 19-20, 2014

CYCLIC TESTING OF PRECAST HIGH-STRENGTH REINFORCED CONCRETE COLUMNS WITH WELDED TRANSVERSE REINFORCEMENT

Yu-Chen OU[1] and Harun ALRASYID[2]

SUMMARY

Six large-scale column specimens were tested to examine the cyclic behavior of precast high-strength concrete columns. High-strength SD685 longitudinal and SD785 transverse reinforcement and high-strength concrete were used. Two precast concrete construction technologies were investigated, namely, grouted coupler splices for SD685 longitudinal reinforcement and butt-welded splices for SD785 transverse reinforcement. Testing was carried out using double-curvature cyclic loading with constant axial load. Test results showed that precast columns with grouted splices in longitudinal reinforcement exhibited similar behavior with their monolithic counterparts. However, precast columns with butt-welded splices in transverse reinforcement show smaller ultimate drift capacities than their counterparts with conventional hooked transverse reinforcement to resist buckling of longitudinal reinforcement. This was due to the reduced ability of butt-welded transverse reinforcement to resist buckling of longitudinal reinforcement.

***Keywords**: Precast Construction, high-strength concrete, high-strength reinforcement, grouted coupler splices, butt-welded splices*

INTRODUCTION

Although reinforced concrete (RC) structures have benefits of higher stiffness, lower cost than steel structure but when used in high rise-building, traditional cast-in-place RC structures are usually less desirable than steel structures. This due to two major issues: large column sizes in lower stories and low construction speed. These problems can be solved by using high-strength materials and precast construction. This study investigates the seismic behavior of precast high-strength RC columns and is a part of Taiwan New RC research effort, which aims to develop high-strength RC structures for high-rise building construction.

This study used high-strength longitudinal (SD685) and transverse (SD785) steel reinforcement having specified yield strengths of f_{yls} = 685 MPa (100 ksi) and f_{yts} = 785MPa (114 ksi), respectively. High-strength concrete with a specified compressive strength of f'_{cs} = 70 MPa (10 ksi) was also used. The SD685 longitudinal reinforcement and SD785 transverse reinforcement were originally developed in Japan (Aoyama 2001) and slightly modified by Taiwan Concrete Institute (TCI 2013). The specifications of the two types of reinforcement can be found in Ou and Kurniawan (2014). Hwang et al. (2013) examined the cyclic beahvior of five large-scale columns under axial load ratios of 0.42-0.67 ($P / A_g f'_c$) with concrete f'_c of 83-112 MPa (12-16 ksi), and with the SD685 and SD785 reinforcement.

Two precast concrete-related construction technologies were tested in this study. Namely, grouted coupler splices for longitudinal reinforcement and butt-welded splices for transverse reinforcement. Grouted couplers were installed in the lower, plastic hinge zone of the columns for the column-footing joint connection. ACI 318 (2011) permits using

[1] Associate Professor, Department Civil and Construction Engineering, National Taiwan University of Science and Technology, Taiwan, e-mail: yuchenou@mail.ntust.edu.tw
[2] Lecturer, Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, Indonesia.