BEHAVIOR OF STEEL REINFORCED CONCRETE MEMBERS STRENGTHENED WITH INCLINED BARS

Hsieh-Lung HSU[1] and Jung-Cheng HSIEH[2]

SUMMARY

Structural members involve application of concrete are usually vulnerable to torsion due to the low tensile and shear strengths of the material. Premature cracks of concrete due to torsion usually results in inadequate performance when members are subjected to loading coupled with torsion. Therefore, remedy to improve members' torsional resistance and to enhance their bearing performance is essential to the concrete-related designs. This study is focused on the flexural-torsional behavior of steel reinforced concrete (SRC) members strengthened with inclined bars. Test results show that the torsional rigidities of members with inclined bars were significantly increased. It is also found from test comparisons that both flexural and torsional performances of the strengthened members were significantly improved when subjected to combined bending and torsion.

***Keywords**: Steel reinforced concrete, torsion, inclined bars, seismic performance*

INTRODUCTION

Steel reinforced concretes (SRC) consists of structural steel and reinforced concrete are widely used in tall buildings designed for earthquake-resistant purposes because significant structural performance, such as ductility and stiffness, can be accomplished through adequate steel and reinforced concrete details. Currently, study of SRC member behavior is mostly focused on the response under axial load, bending moment and their combinations [Galano and Vignoli 2000; Ricles and Paboojian 1994]. In such concerns, the members are required to possess confining zones with closely spaced stirrups, usually located at the ends of the members, so that member ductility can be achieved. However, for structures subjected to multi-directional earthquakes, torsion and combined loading coupled with torsion are usually observed on the structural members. These loadings often induce unexpected structural responses, for example diagonal cracks at the unconfined areas, causing premature failures of the composite members.

As indicated in many concrete-related studies[Mo et al. 2000; Ali and White 1999], structural members involve

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SEISMIC STRENGTHENING BY PRECAST PRESTRESSED CONCRETE BRACE

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SUMMARY

There are a lot of old buildings that do not meet the current building standard law of Japan. During the Kobe Earthquake many of those buildings suffered the serious structural damage and resulted in the loss of lives. Then the seismic retrofit of existing buildings became the most important issue in Japan. This research presents a seismic strengthening method with precast pre-compressed concrete X-type braces. The features of new method are a) no wet concrete work, b) no re-bar connection or bolt anchorage, c) short construction period and d) low construction cost. Two scaled specimens were constructed and tested under the simulated seismic loading. Experimental results indicated that the lateral resistance of a frame could be greatly enhanced by installing the X-type brace. Structural analysis was also conducted to predict the structural response of the strengthened frame and successful results were obtained.

Keywords: *experiment; analysis; frame; precast concrete brace; dry connection; FSSP device; shear failure; buckling failure.*

1. Introduction

During the 1995 Kobe Earthquake a large number of reinforced concrete buildings suffered serious structural damage and some of them collapsed. Most of those buildings were designed according to the old building standard law of Japan (1950).

After then the seismic upgrading of existing buildings became the most important issue to minimize the earthquake disaster. Upgrading of seismic performance of a building can be achieved by several construction methods such as construction of new in-filled wall, strengthening of existing wall, diagonal steel bracing, column jacketing by steel section or fiber sheet and others. All of methods have their strong points and shortcomings. These upgrading methods give buildings higher strength and/or larger ductility. However the execution of seismic upgrading makes little progress due to several reasons such as stop of building services for long construction period, noisy and troublesome construction work, high construction cost and others.

The purpose of this research is to develop a simple seismic strengthening method which satisfy a) no wet concrete work, b) no re-bar or bolt anchorage, c) short construction period and d) low construction cost. Newly proposed method is to enhance the lateral strength of a building by incorporating precast prestressed concrete X-type braces in a frame.

This research consists of the experimental work and the analytical work. Two half-scale portal frames were constructed with same specifications. They are sub-frames of 4 storied reinforced concrete buildings designed according to old building standard law of Japan. First frame was strengthened with a relatively slender X-type brace, which was expected to fail in buckling. Second frame was strengthened with a X-type brace, which was

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RC COLUMNS RETROFITTED BY STAINLESS STEEL WIRE MESH

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SUMMARY

A seismic design provision for bridges was implemented about only a decade ago in Korea. Therefore upgrading the seismic resistance of older bridge substructures is necessary. The objective of this study is to investigate the seismic capacity of the non-seismically detailed RC bridge columns before and after applying a seismic retrofitting method using stainless steel wire mesh. Total eight circular section RC bridge column specimens with lap splice length of 32 cm were constructed. The test results indicated that the existing non-seismically circular columns in Korea have poor seismic capacity while the stainless steel wire mesh retrofitting method can improve their seismic capacity such as flexural strength and ductility considerably.

Keywords : *bridge column, lap splice, permeable polymer mortar, seismic retrofit, stainless steel wire mesh*

INTRODUCTION

In Korea, a seismic design code for bridges has been adapted since 1992 to mitigate the structural damages during earthquake attacks. Therefore it could be presumed that bridge columns designed before implementing current seismic design provisions would be vulnerable to seismic loading. Recently Steel Jacketing and Carbon Fiber Sheet have been applied to improve the safety of older bridge[1)]. In this study, a seismic retrofitting method using stainless steel wire mesh with permeable polymer mortar is proposed to improve the seismic capacity of pre-1992 bridge column in Korea. It may be expected that the lateral confining pressure from the stainless steel wire mesh would improve the bond transfer at the lap splice of column longitudinal reinforcement, possibly inhibiting bond failure in the potential plastic hinge region. To investigate the structural performance of non-seismically detailed circular RC bridge columns before and after seismic retrofitting for harmonic cyclic lateral load under a constant axial load, eight specimens were constructed. From the experimental results, the existing circular bridge columns have poor seismic capacity while the proposed retrofitting method improves their seismic capacity considerably.

EXPERIMENTAL PROCEDURE

Column Details

To investigate the expected improved performance of the columns from stainless steel wire mesh, nine column specimens of 400 mm diameter and 2 m height were recently tested. Design variations among columns are given in table 1. All columns were constructed with lap splices of 20 times the longitudinal bar diameter in the potential plastic hinge region. Column LS32 was reference “as-built” model without retrofit measures to ensure the effectiveness of the stainless steel wire mesh retrofit on the other seven columns to be assessed. The lengths of wire mesh retrofit were chosen to be from 384 mm (1.5 L_p) to 640 mm (2.5 L_p) where L_p represent the plastic hinge length. Figure 1(a) and Fig. 1(b) show the typical specimen before and after retrofitting, respectively.

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REINFORCED CONCRETE SQUAT WALLS RETROFITTED WITH CARBON FIBER REINFORCED POLYMER

By Shyh-Jiann Hwang[1], Tsung-Chih Chiou[2] and Yaw-Shen Tu[3]

SUMMARY

For seismically insufficient buildings, to retrofit the RC partition walls using the Carbon Fiber Reinforced Polymer (CFRP) is of particular interest at the present juncture in Taiwan after Chi-Chi Earthquake. This paper describes theoretical and experimental studies related to the seismic retrofits of the RC frames containing walls using CFRP materials. Three "as built" RC frames with or without walls and two "retrofitted" RC frames with walls had been tested under simulated seismic actions. Experimental observations and theoretical analyses indicated that the shear resisting mechanism of the RC squat walls can be modeled as the struts and ties, and that shear strength of squat wall can be reasonably predicted by the softened strut-and-tie model. The test results of the retrofitted squat walls indicated that the CFRP with sufficient end anchorage is an effective retrofitting measure.

Keywords: carbon fiber reinforced polymer; compressive softened theory; reinforced concrete; seismic retrofit; shear strength; squat wall; strut-and-tie.

INTRODUCTION

The poor performances of the low-rise RC buildings with nonductile reinforcing details had been widely observed during the Chi-Chi earthquake. This simulates an urgent need of seismic assessment and retrofitting of these structures. However, seismic retrofitting of each component of the nonductile RC frames is extremely difficult and expensive. Fortunately, the existing low-rise buildings in Taiwan contain a lot of partition walls which are lightly reinforced RC walls. By retrofitting these walls as the lateral-force-resisting elements, the existing frames can be treated as members that are not proportioned to resist forces induced by earthquake motions. This retrofitting strategy may alleviate the strength and deformation requirements of a nonductile RC frame. Due to the greatly reduced cost, the retrofitting of the existing buildings with nonductile frames is more feasible.

Since these partition walls are detailed with temperature reinforcement only, which might result in insufficient strength. The common practice in Taiwan now is to tear down the partition walls then to recast with the RC structural walls. This retrofit scheme is time consuming and causes tremendous inconvenience to the residents. Seeking for the other alternative is of ever-increasing expectance.

The repair of understrengthed or damaged reinforced concrete members by the external bonding of Carbon Fiber Reinforced Polymer (CFRP) laminates is becoming increasingly popular in the construction industry. The use of CRFP laminates for this application offers several desirable attributes, such as high strength, resistance to corrosion, light weight, and ease of handling. Retrofitting the RC partition walls by the bonding of CFRP might be a feasible solution of the aforementioned problem.

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BUCKLING BEHAVIOR OF TUBE BRACES WITH SINGLE SHEAR THROUGH-GUSSET CONNECTION

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SUMMARY

Through-gusset HTB-connections of single shear type are often used for axially compressed tubes. In this case, the eccentricity with the amount of gusset-thickness may cause the reduction of buckling strength as compared with the double shear type. This paper deals with the estimation of buckling strength and mode for such eccentric systems. Analytical results show that the buckling strength of the eccentric system can be significantly reduced when the stiffness and the strength of the gusset-plate are comparatively small. The accuracy of the analytical estimation is confirmed by comparing them to the results of buckling tests.

***Keywords**: inelastic buckling load, axially compressed member, tube, eccentric compression*

INTRODUCTION

The authors have been studied the buckling load and the mode for the axially compressed tubes with through-gusset connections (Tada et al. 1998, 2000, and 2000). Through these studies, it is obtained that two buckling modes, those are the bowing of whole member and the buckling only at the connection region, take place for the different proportion. In some cases, the buckling load for the latter mode may be smaller than Euler's load of the pin-ended tube. While these studies dealt with the connections of the double shear type, the single shear type as shown in Fig. 1 is commonly used for the small sectional size. As the single shear connections induce the eccentricity so much as the thickness of the gusset plates, it is important to study the buckling behavior of such eccentric systems. This paper deals with the analytical study to obtain the buckling load and the mode for such eccentric systems, and then these analytical results are confirmed by comparing them to the test results.

Although the term "buckling" is originally defined for the bifurcation problem, it is widely recognized as the term of the unstable problem in this paper. Accordingly, "buckling load" represents the maximum load, and "buckling mode" represents the collapse mechanism associated with the plasticity of sections.

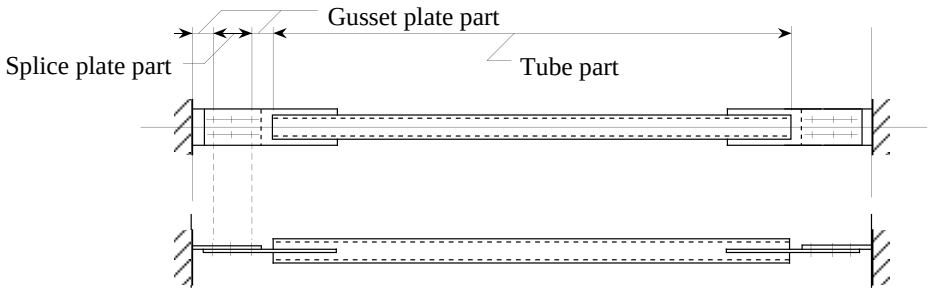

Fig. 1 Axially compressed tube with single shear through-gusset connection

The contents of this paper were already published in (Tada et al. 2002).

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Cyclic Seismic Testing of Reduced Beam Section Steel Moment Connections: Effects of Panel Zone Strength and Beam Web Connection Method

Cheol-Ho Lee[1], Sang-Woo Jeon[2], Jin-Ho Kim[3]

SUMMARY

This paper summarized the results of a full-scale cyclic seismic testing on four reduced beam section (RBS) steel moment connections. Specifically, these tests addressed a bolted web versus a welded web connection and strong versus medium panel zone (PZ) strength as key test variables. Specimens with medium PZ strength were designed to promote balanced energy dissipation from both PZ and RBS regions, in order to reduce the requirement for expensive doubler plates. Both strong and medium PZ specimens with a welded web connection were able to provide satisfactory connection rotation capacity required of special moment-resisting frames. On the other hand, specimens with a bolted web connection performed poorly due to premature brittle fracture of the beam flange at the weld access hole. Unlike the case of web-welded specimens, specimens with a less costly bolted web connection could not transfer the actual plastic moment of the original (or unreduced) beam section to the column. No fracture occurred within the beam groove welds of any connection in this testing program. If fracture within the beam flange groove weld is avoided using quality welding procedure as in this study, the fracture issue tends to move into the beam flange base metal at the weld access hole. Supporting analytical study was also conducted in order to understand the observed base metal fracture from the engineering mechanics perspective.

Keywords: *RBS steel moment connection; panel zone; beam web connection; seismic testing.*

INTRODUCTION

As a response to the wide spread damage in connections of steel moment-resisting frames that occurred during the 1994 Northridge and the 1995 Kobe earthquakes, a number of improved beam-to-column connection design strategies have been proposed. Of a variety of the new designs, the reduced beam section (RBS) connection has exhibited satisfactory levels of ductility in numerous tests and has found broad acceptance in a relatively short time. Nevertheless, there remain many design issues that should be examined more thoroughly (Jones et al. 2002, Gilton-Uang 2002, Chi-Uang 2002). The primary objective of this experimental study was to investigate the effects of the beam web connection and panel zone strength on seismic performance of the RBS connection.

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STUDY ON EXPOSED TYPE OF COLUMN BASES SUBJECTED TO TENSILE FORCE

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SUMMARY

This paper discusses the effect of tensile force on the strength, the deformation capacity and the failure mode of exposed type of column bases. Eight specimens were tested under horizontal load and vertical load. Test variables were ratio of tensile axial force, anchor bolts layout, direction of loading and with/without shear connector. In some test specimens subjected to tensile force ratio $n \leq -0.6$, the severe uplift deformation of the column bases was observed, and fractures of anchor bolts occurred. The column base moment of these specimens was unstable. Numerical analyses were carried out to investigate the cyclic behaviour of the column bases. In the results of numerical analyses, the cyclic behaviour of the column bases subjected to tensile force ratio $n \geq -0.4$ was stable. While, in the column bases subjected to tensile force ratio $n \leq -0.6$, the deformation of base columns progressed with increasing severely under constant amplitude.

Keywords*: exposed type of column base; loading test; numerical analysis; tensile force; fracture of anchor bolt.*

INTRODUCTION

The 1995 Hyogoken-Nanbu earthquake brought dawn serious damages on steel structures at City of Kobe and its neighbouring towns. Damages to column bases were critical in the overall damages to buildings. Most of the damages to column bases were occurred in exposed type, and especially, fractures of anchor-bolts leaded to serious damages of buildings in many cases.

The over turning moment of earthquakes causes tensile force on outer columns of buildings. The primary cause of fractures of anchor-bolts may be tensile axial force to column bases. This study was planed to clarify the behaviour of exposed type of the column bases subjected to tensile force, shear force and bending moment.

Tests and numerical analyses were carried out to investigate the effect of tensile force on the strength, the deformation capacity and the failure mode of column bases.

TEST

Test Specimen

Eight test specimens were prepared for this study. Figure 1 shows an example of test specimens. Each specimen was composed of a column, a base plate, four anchor-bolts and a concrete footing beam. The columns of all specimens

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STRENGTH AND DEFORMATION OF BOLTED BEAM-TO-COLUMN CONNECTION ACCOMPANIED BY PANEL ZONE YIELD

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SUMMARY

This paper presents a research on the strength and deformation capacity of bolted beam-to-column connection for steel moment frames which make the most use of the panel zone yield. The advantages expected from this connection are 1) the steady and low-cost quality assurance related to the construction work of the structural joints achieved by bolted connections, and 2) the sufficient seismic energy dissipation obtained by panel zone yield and by avoiding fracture or unstable collapse. In this supposed connection system, flanges of beams are connected to wide flange columns by double angles. In the fabrication of this system, welding is avoided as much as possible and high-strength bolts are adopted as often as possible. During strong earthquakes, beams and columns are retained in the elastic range and the plastification is limited to the panel zone and joint elements of the double angles. To secure the expected collapse mechanism can be achieved, the possible mechanisms of the bolted beam-to-column connection are investigated and the collapse strength of each mechanism is formulated. The results of the full-scale loading tests revealed the stable hysteretic behavior and the good deformation capacity of this system as well as the validity of the stiffness and the strength values estimated from the proposed formulas.

Keywords: *steel frames, beam-to-column connection, bolted connections, panel zone yield, full-scale loading test, plastic collapse strength, deformation capacity*

INTRODUCTION

According to the recent investigations on earthquake response analysis of moment frames considering the yield of the panel zone, it is found that panel zones of beam-to-column connections are expected as effective energy dissipation elements against strong ground motions (Kawano et al. 1983, Hasegawa et al. 1991, Akiyama & Matsuo et al. 1993). When the panel is weaker than connected beams in strength and the width-thickness ratio of the flanges and the web of columns are within the adequate limit, the panel zone exhibits stable hysteresis characteristics in a large shear deformation. Since the panel zone possesses sufficiently large energy dissipation capacity, it is expected that the panel zone is unnecessary to repair after large earthquakes.

In many beam-to-column connections of steel moment frames, the flanges of the beams are connected to the column by welding. However, since the fabrication of steel frames relies on the workmanship of welding operators, the variation of the connection quality is a crucial issue to secure the seismic performance of frames in the light of lessens learned from recent large earthquakes. In order to avoid this issue concerned with the quality of welding, it should be effective to use high-strength bolt principally and not to use as little welding as possible. Furthermore,

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INTERFACE SHEAR TRANSFER FOR HIGH STRENGTH CONCRETE AND HIGH STRENGTH SHEAR FRICTION REINFORCEMENT

Susumu KONO[1], Hitoshi TANAKA[2], and Fumio WATANABE[1]

ABSTRACT

The shear transfer at construction joints for members was investigated experimentally using twenty-six direct shear type specimens in order to study the effects of high strength concrete, the high strength shear friction reinforcement, and interface roughness. The displacement-controlled cyclic loading was applied and shear stress transferred along the interface was separated into the contributions of concrete and dowel actions. In the dowel action, the flexural action dominates the shear-frictional reinforcement and the average tensile strain at the interface did not reach the yield strain at the peak stress. The assumption that reinforcement has yielded at the peak stress was not met in the test. In the concrete action, stress transfer depends on the concrete strength and the surface roughness and the combined effect of concrete strength and surface roughness needs to be considered in a design equation. If earthquake force acts cyclically to the interface, it is not safe to count on the experimental results based on the monotonic loading test since the shear resistance in the direction opposite to the virgin direction could become smaller. This effect is pronounced for specimens with coarse interface and considered to be caused by the wearing of the interlocking mechanism.

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DUCTILITY OF SELF-COMPACTING CONCRETE COLUMN

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SUMMARY

In this paper, the experimental results of two reduced-scale bridge column specimens, SCCR1 and NCR1, are presented. SCC was adopted in the construction of specimen SCCR1. During concrete placement, no vibration in any form was applied. On the other hand, the control specimen, NCR1, was cast using conventional concrete and extensive manual vibration was provided in the process of concrete placement to ensure the extent of concrete consolidation. Self-compacting concrete (SCC) is a specially proportioned concrete that can flow in its gravity and fill in the formworks without the need of any internal or external vibration. While being highly fluid, SCC needs to be sufficiently cohesive as well to prevent segregation or blockage of aggregates during flowing. It is believed that the advantages of SCC on structural performance of concrete members come from the following two effects. One is the enhancement in bond strength of rebar and another is the improved consolidation induced increase in confinement when the column is under compression. Both of the effects may contribute to the moment capacity as well as to the ductile behavior of column members. As a result, the observed moment capacity and ductility of SCCR1 is comparable to NCR1. The non-vibration practice of SCC is thus verified.

***Keywords**: Self-compacting concrete; concrete placement; bridge column; bond strength; ductility; plastic hinge; moment capacity.*

INTRODUCTION

In the construction of reinforced concrete structures, consolidation has to be applied to the concrete mixture to ensure the quality of concrete placement. Insufficient consolidation may result in defects, such as honeycombs, voids, or vacancies, in RC members. These construction deficiencies would lead to reductions in durability and structural performance. However, in members with congested reinforcements or with large dimensions, consolidation may not always be an easy task to carry out. The selection of concrete with proper workability is usually governed to resolve the difficulties in concrete placement. With the increasing use of congested reinforcements in moment-resisting members, e.g. due to seismic consideration, there is a growing interest in specifying high workability concrete, such as high performance concrete (HPC).

In general, HPC possesses high strength as well as high workability and has been adopted as a solution to the situation that demands particularly high durability. In order to resolve the problems with concrete placement, a special type of concrete, called self-compacting concrete, has been developed that requires no consolidation at all. It has been verified that, with non-vibration construction, the application of self-compacting concrete can enhance the uniformity of materials in RC members and, thus, help to ensure the designed structural performance (Okamura and Ozawa 1995, Ozawa et al. 1995). However, the practice of non-vibration concreting is totally against the conventional practice of construction that demands sufficient consolidation during concrete placement. Apparently, the application of SCC requires a certain extent of training and

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SIZE EFFECT ON SEISMIC DAMAGE AND PERFORMNANCE EVALUATION OF R/C BEAM-COLUMN JOINTS

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SUMMERY

To establish the performance-based seismic design for reinforced concrete beam-column joints, in this report, the seismic damage and the shear performance of beam-column joints were focused on. The shear failure process in joints was shown, and the shear stress - shear distortion relationship in joint panels was modeled. According to database analysis of reversed cyclic loading experiment on 1/3 to 1/1 scale reinforced concrete interior beam-and-column subassemblages, the relationship between damage progress and shear stress-shear distortion characteristic was examined. Based on above examinations, the influence of scale effect for the seismic damage in reinforced concrete beam-column joint was not almost recognized for the shear performance of the joint panels. The relationship between the damage and the experienced shear distortion was summarized as the damage map, and the schematic relationship among experienced shear distortions and observed damage conditions and residual seismic performance was shown. By applying these relationships and expected frame ductility requirement, the design criteria to control the damage to beam-column joints was proposed.

Keywords *: reinforced concrete, beam-column joint, seismic performance, seismic damage, evaluation method, size effect*

INTRODUCTION

To establish the performance-based seismic design, it is necessary to prepare the evaluation methods for strength and deformation capacity of structural members with sufficient accuracy. Moreover, it is important to make clear the relationship between the expected seismic damage, such as crack behavior and concrete crushing, and restoring force-deformation characteristics. It is required that the remaining performance of the damaged building after the earthquake can be evaluated by observed damage conditions. Structural engineers must have the judgment materials for its serviceability, reparability and safety for the collapse (AIJ 1999b).

In reinforced concrete (R/C) moment resisting frame structures, recent research works show that the seismic performance of beam-column joints significantly affects the frame behaviors. The seismic performances to be evaluated for the beam-column joints are: (1) the shear performance of the joint panels, (2) the performance on bond and anchorage of beam and column longitudinal reinforcement, and (3) the performance of supporting the axial load of upper floors at the joint as a part of the column.

In this report, the seismic damage and the shear performance of beam-column joints were focused on. The relationship between load-deformation curves and observed damages were examined. The standard values of various limit conditions of serviceability, reparability and safety for collapse were discussed. And the design criteria to control the damage to beam-column joints was proposed. The results of this study have been partially reported (Teraoka et al. 2000b).

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SEISMIC DESIGN OF RC WALL FOR DUCTILITY ENHANCEMENT

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SUMMARY

Ductility enhancement of reinforced concrete bearing wall subjected to high axial loading and moment can be attained by improving the deformability of compression zone or by reducing the neutral axis depth. For this, the once predominant code approach to determine the compression zone was advanced by considering rectangular stress block parameters varying with extreme compression fiber strain. Two existing methods for ductility enhancement were slightly modified to conveniently apply to the seismic improvement of compression zone of the wall: confinement of concrete due to transverse steel and boundary elements. In order for the confinement of compression zone to be effective, spacing between transverse steel should not be greater than 150mm in 150~200mm thick walls. The design charts were suggested to appropriately dimension the boundary elements in accordance with the architectural requirement.

Keywords*: boundary element; compression zone; confinement; reinforced concrete bearing wall; and wall-slab building system.*

INTRODUCTION

High-rise apartment buildings have been of typical pattern of dwellings in regions of dense population. In particular, those buildings in Korea consist of thin reinforced concrete (RC) walls supporting slabs without beams and columns, as shown in Fig. 1, as an example. Such a feature may be attributed to the purpose of maximization of service area and efficiency to shorten the construction period. RC bearing walls in those buildings can be characterized by deep rectangular section with high aspect ratio (height/depth ratio), considerably small amount of steel compared to usual columns, unexpectedly low confinement of concrete, and nevertheless, applied high axial loading. The structural validity of such bearing wall-slab building system has been empirically verified against gravity and wind loading, but not much portion of its ultimate behavior under earthquake loading has been known, since a severe ground motion has not been experienced in Korea over past several generations and few experimental studies for the structural system have been reported. This is because of its too large prototype size to accommodate in the laboratory for testing to destruction. Therefore, it is crucially important to analytically predict its behavior based on the appropriate assumption and rational mechanism.

When a bearing wall of high-rise apartment buildings subjected to earthquake–induced deformation, some large flexural-compressive stresses are likely to occur at an end of the wall due to its high aspect ratio, thin thickness and axial loading. This may result in crushing concrete at the compression end and thus limiting ductility of the structural system. In order to secure and further enhance the ductility capacity of the bearing wall system at large deformation demand, the seismic design may employ the following methods: (1) confinement of concrete at compression end; (2) barbell-shaped cross section with boundary elements; and (3) placement of diagonal web reinforcement. The first two methods are to improve the flexural deformability, while the third one is to suppress the chance of unwanted shear failure. Sittipunt and Wood (2000) experimentally verified the validity of diagonal web reinforcement to improve ductility capacity of slender RC walls. However, in order for this method to be effective, the sufficient flexural deformability should be assured by implementing the first or second method.

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DAMAGE EVALUATION OF REINFORCED CONCRETE COLUMNS UNDER LARGE AXIAL LOAD AND LATERAL DEFORMATION

Susumu KONO*1, Yusaku ARAI*2, Hakim BECHTOULA*2, Fumio WATANABE*3

This study aims to evaluate damage to reinforced concrete columns under large axial load and cyclic reversal bilateral bending so that appropriate evaluation procedures can be proposed in future. In an experimental program, four large scale columns with a 600 mm x 600 mm square section were tested under the reversal bilateral deformation with variation in axial load level to study the effects of loading history on the damage progress. In an analytical program, a simple fiber model was employed to predict the deterioration of moment capacity and the variation of axial strain at a plastic hinge region.

Keywords: *Damage evaluation, plastic hinge, axial load, biaxial lateral loading, corner column*

NOTE: This paper was presented at the first FIB Congress 2002 in Osaka.

1 INTRODUCTION

After several large-scale earthquakes in the last decade, it is widely accepted that the economical and appropriate rehabilitation strategies can be determined only by an appropriate damage evaluation. The damage evaluation also has been increasing its importance because more structures are designed based on the performance based design criteria and behaviors for different load cases need to be precisely predicted. Although various damage indices have been proposed [1][2], those methods do not give enough information to evaluate damage of each structural member for determining the retrofit measures and cost.

This study aims to evaluate damage to reinforced concrete columns, that experience large axial load and cyclic reversal bidirectional lateral deformation so that appropriate evaluation procedures can be proposed in future. In an experimental program, four large scale columns, with a 600 mm x 600 mm square section and a 2.0 shear span to depth ratio, were tested under the reversal bidirectional lateral deformation with variation in axial load level in order to study the effects of loading history and intensity on the damage progress. Since the columns were designed based on the current ductile design guideline in Japan [3], the shear failure was inhibited and the damage gradually progressed with concrete crushing and yielding of reinforcing bars. In an analytical program, a simple fiber model was employed to predict the deterioration of moment capacity and the variation of axial strain at a plastic hinge region. The limit deformation capacity based on the existing models was compared to the test results to see their applicability. Progress of cracking and spalling was observed and compared with each other and with half-size specimens.

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EVALUATION OF HIGHER-MODAL STRUCTURAL RESPONSE FOR NEAR-FIELD EARTHQUAKES

Ching-Tung HUANG[1]

SUMMARY

This paper presents an investigation of multi-mode effects of tall building structures idealized as a continuous shear-beam model subjected to near-field pulse-like ground motions. The investigation is based on three analytical approaches; a damped wave solution approach, a fundamental-mode approach and a modal summation approach. In the modal summation approach, all modal damping ratios are assumed to be equal and a set of Green's functions for the shear strain response is explicitly derived. Study results show that the occurrence of major spectral differences is conditioned on the ratio of the fundamental structural period to the predominant excitation pulse duration. Seismic analyses for a set of recorded near-field earthquake data indicate a strong correlation between the characteristics of effective response spectra and the ground pulse parameters

***Keywords**: near-field earthquake; Green's functions*

INTRODUCTION

Evaluations of seismic demands for near-field earthquakes are drawing increasing attentions since the recent major earthquake events such as the Northridge, Kobe and Chi-chi earthquakes. In these events, intensive seismic energy was directly released in a densely populated urban area and caused significant structural damages. Near-field ground motions generally exhibit distinct long-period displacement pulses or velocity pulses with very high peak ground velocity. Several research studies (Hall et al. 1995, Iwan 1997) have indicated that tall building structures are particularly vulnerable to near-field earthquake excitations partially due to their high ground shaking intensities and partially due to their peculiar pulse-like motion. Appropriate measures for near-field seismic demands are deemed necessary for designing structures with safety in the near-field regions.

Studies of seismic demands for pulse-like ground motions can be traced back to as early as the 1960's by Veletsos et al. (1965). These studies are based on single-degree-of-freedom (SDOF) spectral analyses for both elastic and inelastic systems. From elementary dynamic theory, the SDOF analyses generally yield good demand estimation when the structural systems are dominated by a single mode-like response. While for a tall building structure subjected to a ground shock, the higher-mode contributions may become substantial and the building deformation would thus be dominated by a wave-like response. To consider the wave-like response, various researchers have performed studies for flexible tall building structures based on an idealized continuous shear-beam system with uniform stiffness and mass distributions. Hall et al. (1995) employs a deformation wave analysis for undamped shear-beam systems to derive a correlation formula for the maximum base shear strain/force and the peak ground velocity. Iwan (1997) introduces a non-dispersive damped wave solution that allows an efficient evaluation of the inter-story drift ratios approximated as the shear strain deformations. This solution method is further employed to calculate a new spectrum referred to as the drift spectrum. The drift spectral analyses for many near-field earthquake records show that the traditional SDOF spectral analyses may significantly under-estimate the local structural deformation particular for large period structures. Very recently, Chopra and Chintanapakdee (2001) also conduct a comparative study based on the wave analysis, the modal

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VIBRATION OF BUILDING FLOOR SYSTEM SUBJECTED TO WALKING LOADS

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SUMMARY

For the finite element vibration analysis of structures subjected to walking loads, walking loads are usually considered as nodal loads. Since most of walking loads act on elements not on nodes, the walking loads applied on the elements should be converted to the equivalent nodal walking loads. This paper begins with measuring walking loads by using a force plate equipped with load cells and investigates the characteristics of the walking loads with various walking rates. It is found that the walking loads are more affected by walking rates than other parameters such as pedestrian weight, type of footwear and surface condition of floor. And the measured walking loads are used as input loads for finite element model of walking induced vibration. Finally, this paper proposes the equivalent nodal walking loads that are converted from the walking loads acting on elements based on finite element shape functions. And the proposed equivalent walking loads are proved to be applicable for efficient analysis of floor vibration induced by walking loads.

Keywords*: equivalent walking loads; force plate; walking rate; floor vibration*

INTRODUCTION

Recently, building structures requiring large open spaces show low inherent damping due to decline in the use of non-structural members such as curtain walls. Furthermore, high-strength material and efficient structural scheme lead to longer spans and more flexible floor systems. Structures with low damping and lightweight have higher possibility of experiencing excessive vibrations than those of heavy-type construction. These excessive vibrations make occupants uncomfortable and raise serviceability problem in buildings. Long span structures with low natural frequencies such as shopping malls, large offices and assembly rooms may experience signification dynamic responses due to human activities such as walking, jumping and stamping. It is now widely accepted that walking load is a major source of floor vibration disturbance. For many years, assessment of serviceability of building structures subjected to walking loads and the parametric studies about walking loads have been the majority of research work. But the application of walking loads into the vibration analysis using finite element packages is rarely studied. It is in general that walking loads are treated as nodal loads for finite element vibration analysis of structures. This method requires a large number of nodes and mesh models corresponding to walking strides. Since most of them act on elements not nodes, it is needed to propose new application method of walking loads that are applied on the elements.

In this research, walking loads are directly measured by using a force plate in which two load cells are equipped. Walking loads with various walking rates are measured to analyze dynamic loads-time traces. And heel drop tests are conducted to obtain the dynamic characteristics of actual floor system such as natural frequency and damping ratio. The experimentally measured responses under pedestrian walking excitation and the corresponding analytical responses are compared to verify the validity of equivalent walking loads proposed in this paper. The objective of this paper is to propose new application method of walking loads that are converted from the loads acting on elements based on finite element shape functions for efficient analysis of floor vibration induced by walking loads.

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RESEARCH AND APPLICATION OF SEISMIC SAFETY EVALUATION ON NONSTRUCTURAL ELEMENTS IN HOSPITALS

George C. Yao[1]

SUMMARY

An evaluation procedure of nonstructural elements was developed and applied to several regional hospitals. This evaluation procedure composes of two parts: one is for the evaluation of mechanical systems, the other for critical medical spaces. In the mechanical system, a quantitative logic tree approach was adopted and found effective to identify weak links in mechanical systems. A checklist was developed for different critical medical spaces to alert hospital administrators about vulnerable architectural elements and medical equipments in earthquakes. This paper also briefly discusses research result on the suspended ceilings and base-isolated machines. It was found that the ASTM approach to strengthen a suspended ceiling system could indeed increase its seismic strength. However, through a full-scale model room (5mX8m) testing of suspended ceiling systems, it was concluded that diagonal bracing wire might not be needed for the kind of earthquake motions in Taiwan. Shaking table tests of isolated-machine indicates that spring isolator without a housing is most vulnerable in earthquakes. Appropriate housing can increase an isolated-machine's seismic capacity. Rubber isolator performed the best among all the isolator types tested.

Keywords*: hospitals; earthquake engineering; nonstructural components.*

INTRODUCTION

Due to damages and malfunctions of mechanical systems, such as emergency power supply, HVAC and utility water supply, many hospitals in the disaster area of the 1999 Chi-Chi earthquake couldn't maintain their normal emergency medical services after the quake, although structures of these buildings performed well. Lessons learned from the Chi-Chi earthquake demonstrated that nonstructural components should be included in the seismic resistant design of a hospital to guarantee both life safety and operation capability of critical facilities.

However, nonstructural parts of a medical facility contain too many systems and objects. It is unrealistic and unnecessary to take all these components into seismic resistant design, instead, only mechanical systems that will affect critical functions are to be considered. In this research, an evaluation method developed by the EQE is adopted and modified to analyze the mechanical system damages of 4 regional hospitals in central Taiwan in the Chi-Chi earthquake.

Safety evaluation of nonstructural objects in a medical space to maintain a life safety environment and normal medical service is another topic of this study. Based on experiences gained from the Chi-Chi earthquake, authors developed an evaluation form for important medical spaces. The purpose of this form is to estimate the safety and functional vulnerability of these spaces. It is also presented in this paper the research results of two vulnerable nonstructural elements: the direct hung suspended (DHS) ceilings and base-isolated machines.

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USE OF MAGNETOSTRICTIVE DEVICE TO INVESTIGATE DYNAMIC BEHAVIOR OF SINGLE PILES

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SUMMARY

The Importance of loading tests in the pile foundation practice is further reinforced by the prevalent emphasis on performance based design in recent years. In this context, availability of the different categories and methods for loading test can be useful in selecting a testing method or a package of testing methods to suit the purpose and the reliability desired in a given situation. This research concerns an attempt at developing a method of dynamic loading test on single piles to evaluate the bearing capacity as well as the dynamic characteristics. The method involves the use of a new technology involving the magnetostrictive device, which makes it possible to apply relatively large amplitude cyclic loads over fairly wide frequency ranges. The method is termed as 'harmonic loading test' and the preliminary results from its application to bored steel pipe piles are promising. The method is under development together with the analytical method for adequate simulation of the test results observed. Some salient features of the method together with some important intermediate results are discussed in this paper.

Keywords*: Magnetostrictive device; Harmonic loading test, Pile foundation; Quality control; Dynamic loading; Bearing capacity of piles*

INTRODUCTION

Considering the use of piles that may be traced back to primitive human habitation (Fleming et al., 1992), sound theoretical basis for the analysis and design of pile foundations is very recent phenomenon. In spite of the significant theoretical developments and refinements during the past three decades, relatively large variability of the axial capacity of piles predicted by existing methods is unavoidable because of the inherent local variability of the ground and the effect of pile installation. Consequently, it is considered rational to rely on the results of loading test on single piles while taking critical design decisions concerning pile foundations. Various methods of loading test, consisting of static, rapid and dynamic categories (Karkee, 2000 and Karkee & Kishida, 1999) are available for evaluation of the static load bearing characteristics of piles. When the applied loading itself is not static, the measured response requires further analytical processing to estimate the static response because all the existing loading test methods are meant to evaluate static axial capacity. When the structures supported on pile foundations are subjected to rocking motions under seismic excitation, the resistance of piles against pull out (tensile) forces becomes an important consideration in addition to the capacity to resist top down (compressive) loading. Static pull-out loading tests are sometimes conducted for this purpose. However, the rocking motions under earthquake excitation are basically dynamic in nature and the dynamic characteristics of piles in the axial

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INELASTIC RESPONSE SPECTRA CONSIDERING THE NONLINEARITY OF THE SOFT SOIL DUE TO THE MODERATE SEISMIC EXCITATIONS

Yong-Seok Kim*

SUMMARY

Seismic design codes developed taking into account the strong earthquakes may result in unnecessary economical loss in the low or moderate seismic area, and the importance of the performance based design considering the soil-structure interaction is recognized for the reasonable seismic design. In this study, seismic elastic and inelastic response analyses of a single degree of freedom (SDOF) system on the soft soil layer were performed considering the nonlinearity of the soil for the 11 moderate earthquakes scaled to the nominal peak acceleration of 0.15g. The seismic response analyses of a SDOF system including the soil layer were performed in one step applying the earthquake motions to the bedrock, utilizing a pseudo 3-D dynamic analysis software of the soil-structure system. The study results indicated that seismic response spectra of a SDOF system assuming the rigid base or the linear soil layer does not represent the true behavior of a structure-soil system, and it is necessary to take into account the nonlinear soil structure interaction effects and to perform the performance based seismic design for the various soil layers, having different characteristics, rather than to follow the routine seismic design procedures specified in the design codes for the reasonable and economical seismic design. The nonlinearity of the soft soil excited with the moderate seismic motions also affected significantly on the elastic and inelastic seismic response spectra of a SDOF system due to the nonlinear soil amplification of the earthquake motions, and it was pronounced especially for the elastic response spectra.

Keywords: seismic design; soil-structure interaction; inelastic; nonlinearity; moderate earthquakes

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INTRODUCTION

The response spectra specified in most of the seismic design codes are basically developed considering the strong earthquakes. However low and moderate earthquake records of relatively short duration has the characteristics of narrow banded energy content giving the narrow banded spectral peaks. Using seismic design spectra developed for the strong earthquakes may result in unnecessary investment and economical loss for the infrastructures and buildings to the countries in the low or moderate seismic area. [Donald, 1991]

The importance of structure-soil interaction for the seismic design of structures is now commonly recognized, and the importance of the performance based seismic design is also recognized to protect structures from the strong earthquakes after Northridge and Hyogoken-Nanbu Earthquakes. The soil-structure interaction analysis of structures taking into account the site soil conditions is necessary to predict reasonably the seismic response of a structure in the performance based seismic design. [Krawinkler, 1997] But a true nonlinear seismic analyses for the soil-structure interaction problem are practically difficult, and nonlinear numerical seismic analyses are performed for the approximate solutions. Recently the high performance computer technology makes the nonlinear analyses of the complicate soil-structure interaction problem easier and the seismic analyses of a whole soil-structure system possible.

In this study, seismic response analyses of a single degree of freedom (SDOF) system lying on the soft soil were performed as a whole system applying the earthquake excitations to the bedrock. For the nonlinear analyses, a linearized iterative method was utilized. The effects of the nonlinear soil layer on the seismic response spectra of a SDOF system were investigated comparing the response spectra for the nonlinear soil with those for the linear soil, UBC-97 and AIJ-93. [ICBO, 1997][Dan, 2000] Study was carried out for surface medium size mat foundations built on the UBC-97 soil profile type of S_D shown in Table 1 using 11 records (9 recorded and 2 simulated ones) of the low and moderate earthquakes shown in Table 2. The records have the peak accelerations

STRENGTH INCREMENT OF A CONCRETE FILLED CARBON TUBE COLUMN

Won-Kee HONG[1] Heecheul KIM[2] Suk-han YOON[3] Kyoung-hun LEE[3] Jin-young PARK[3]

SUMMARY

The carbon composite tube can play an important role in replacing or complementing longitudinal and transverse reinforcing steels by providing ductility and strength for conventional columns. In this study, both the experimental and analytical investigations of axial behavior of large-scale circular and square concrete columns confined by carbon composite tube are presented. The specimens are filament-wound carbon composite with $90° + 90°$, $90° \pm 60°$, $90° \pm 45°$, $90° \pm 30°$ winding angle with respect to longitudinal axis of tube. The instrumented large-scale concrete-filled composite tubes(CFCT) are subjected to monotonic axial loads exerted by 10000KN MTS. The influence of winding angle, thickness of tube as well as shape of the column section on stress-strain relationships of the confined columns is identified and discussed. Proposed equations to predict both the strength and ductility of confined columns by carbon composite tube demonstrate good correlation with test data obtained from large-scale specimens.

Keywords: *Carbon composite; Glass fibers; Strength; Filament winding*

INTRODUCTION

One of the early model of column confined by FRP was proposed by Fardis and Khalili[1] who tested concrete cylinders wrapped with bi-directional FRP fabrics under uniaxial compression loading. Behavior of FRP-confined concrete was studied by Nanni and Bradford[2] , suggesting that bilinear curve with a transition zone at a strain of about 0.003 can be used to model the FRP-confined concrete. The columns retrofitted by wrapping and bonding of fiber-reinforced plastic(FRP) sheets showed no damage against the 1994 Northridge earthquake (Loud[3]). The concrete-filled glass FRP tube was the next application for better axial performances of columns by Mirmiran and Shahawy[4]. Mirmiran and Shahawy[5] carried out uniaxial compression tests on concrete-filled FRP tubes with findings that fiber composites are effective way of confining columns, providing strength, ductility, and large energy absorption capacity. In their study experiment on a total of thirty 152.5x305mm cylindrical specimen which were filament-wound of E-glass at $\pm 75°$ angle was presented to show a unique characteristic of confinement with E-FRP. Mirmiran[6] also investigated the effect of column parameters such as shape, length, and bond on FRP-confined concrete. Effect of length to diameter ratio on the confinement of columns was studied in this effort. Saafi et al[7] performed experimental and analytical study of concrete columns confined by carbon and glass FRP composite tube. They proposed equations to predict the compressive strength, failure strain and the entire stress-strain curve of concrete-filled FRP tube.

Even though it is recognized that carbon composite tube possesses much higher ultimate strength capable of providing better confinement effect on columns than glass FRP tube, only a few studies with regards to the confining effects of carbon composite tube are reported. Many previous studies based on the experiment of small-scale specimen lead to very stiffer results compared with concrete member. Dilation ratio is also influenced by specimen size, and it is very difficult to understand the behavior of full-scale application from small-scale experiment. In the present paper, the axial behavior of relatively large-scale circular and square

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CYCLIC BEHAVIOR OF CONNECTIONS BETWEEN STEEL BEAM AND CIRCULAR CONCRETE-FILLED TUBE COLUMN

Cheng-Chih CHEN[1] and Sheng-Hung LO[2]

SUMMARY

An experiment was conducted to investigate the seismic behavior of connection between steel beam and circular concrete-filled tube column. The force transferred mechanism of the beam-to-CFT column connection was established by using the penetrated flange plate through the circular steel tube and concrete core. Four large-scale specimens were designed and fabricated to identify the possible failure mode. Test results indicate that the penetrated flange plate connections possess the satisfactory connection strength and inelastic deformation ability required for the moment connection when the shear strength in the joint is adequately designed.

Keywords*: concrete-filled tube; CFT; flange plate connection; joint shear failure; plastic hinge.*

INTRODUCTION

The use of concrete-filled tube (CFT) column has been studied and used for over past several decades due to its noticeable advantages such as to be not necessary for the formwork, to substitute for the longitudinal reinforcement, to confine the concrete, and to prolong the local buckling of steel tube. Studies (Shams and Saadeghvaziri 1997, Ge and Usami 1992) to investigate the compressive strength of CFT column have shown that the steel tube can provide the confinement effect for the concrete core and substantially increase the ultimate compressive strength and ductility performance. During the construction, steel tube can function as the mold and offer a more cost-effective construction.

It is believed that circular steel tube is more effective in offering post-yield strength and stiffness than rectangular tube (Schneider 1998). However, in spite of the advantages of using the CFT column, it is difficult to attach steel beam to circular CFT column because of its complexity. Only limited test data are available on the joints connecting steel beam to circular CFT column. Alostaz and Schneider (1996, 1998) conducted the finite element analysis and experiment for several types of connection details. Test results indicated that the behavior of the connections highly depended on the connection details. Beutel et al. (2001) further investigated the performance of connection type with embedded reinforcing bars, which welded to the beam flange. Chiew et al. (2001) studied the moment resistance for the semirigid and rigid connections with different types of stiffening details and found rebar stiffener was very effective in improving the behavior. Elremaily and Azizinamini (2001a, 2001b) tested a through beam connection detail and developed design guidelines.

The objective of this research is to develop a connection detail for the improved design of a moment connection between steel beam and circular CFT column to obtain enhanced seismic performance. The detail of the connection is characterized with the flange plates penetrated through steel tube and concrete core. Experimental results are used to investigate the moment resistance and cyclic behavior of such connection type and to identify the mode of failure.

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CYCLIC LOADING TESTS ON POST-TENSIONED BEAM-COLUMN SUBASSEMBLAGES

Minehiro Nishiyama*

Keywords: prestress, beam-column joint, post-tension, failure mechanism, bond, grout, anchorage

INTRODUCTION

Prestress introduced into the beam through the joint of post-tensioned beam-column subassemblages has been considered to increase shear strength of the joint core because of its multi-axial state of stress with column axial load, and larger compressive block in the beam critical section, which results in larger compressive strut in the joint core. However, in some experiments on prestressed beam-column joints [1] it was revealed that prestress was not beneficial on shear strength of the joint core. Effectiveness of prestress on shear strength of post-tensioned beam-column joints is still controversial.

The objectives of this paper are to make failure mechanism of post-tensioned beam-column subassemblages clear in terms of the anchorage location and bond characteristics between prestressing steel and grout mortar. The conclusions obtained in this study would be of importance for the practical design of prestressed concrete beam-column joints.

EXPERIMENTAL WORK

The experimental work is divided into two test series; in Series A the test parameters are location of anchorage of prestressing tendon and amount of prestressing force, in Series B the parameter is type of tendon, i.e., bond strength. Each test series consists of four prestressed concrete beam column joints. All test units had the same dimension of beams (200x300mm) and columns (300x300mm). They were beam-external column joint assemblages.

Series A

The experimental variables were location of anchorage of prestressing tendon (inside and outside the joint core) and amount of prestressing force (axial load level of $0.08f'_cA_b$ and $0.15f'_cA_b$; f'_c is the concrete compressive strength and A_b is the beam sectional area). The test unit is shown in Fig.1. Two of them are the test units whose prestressing steel bars were anchored to the steel plate (120x120, t=30mm) embedded in the joint core. The steel plate was located at the center of the joint core. In the other two, bars were anchored to the steel plate (300x200, t=30mm) attached to the column face. Two types of bars were used; one was 17mm in diameter round bar, and the other was 23mm in diameter

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IMPROVED CYCLIC PERFORMANCE OF WIDE FLANGE BEAM TO TUBE COLUMN JOINTS WITH STIFFENING PLATES AROUND THE COLUMN

Jong-Won PARK[1]

SUMMARY

This paper presents the results of cyclic loading tests of 7 full-scale beam to column subassemblages having improved connection detail: i.e., fillets of the stiffening plates at the column corners and at the ends of the stiffener-to-beam flange weld. Major findings from the test results are as follows: (1) The fillets reduced the stress concentrations which may cause early brittle fractures and improved the cyclic performance greatly compared to the detail without fillets. (2) As the width of the stiffening plate was increased, the stiffness and the peak strength were increased, but the energy dissipation capacity was reduced. (3) All the specimens failed by a fracture, but they could develop total rotation of 0.04 radian required for special moment resisting frames.

Keywords*: beam-to-column connection; full-scale test; fillets; improved cyclic performance; total rotation capacity.*

INTRODUCTION

Research has been carried out on different types of moment connections of wide flange beam to rectangular tube column joints (Shanmugam and Ting 1995, Ricles and Peng 1988, Kato et al. 1981). Practical applications in construction have been found in Japan. The most widely used connection type is running of continuity plates (termed diaphragms in Japan) through the tube as shown in Figure 1(a). The use of through-plates increases the strength and stiffness of the connection significantly. Nevertheless, the column has to be cut and welded at the locations of the beam flanges for the through-plates.

The behavior of beam to column joints with stiffening plates around the tube column as shown in Figure 1(b) was investigated (Yoshisato et al. 1995). If the thickness of the stiffening plates is increased significantly compared to that of the beam flange, then the use of stiffening plates can increase the strength and stiffness of the connection close to those of the through-plates connection type. Since the stiffening plates are fitted around the column, tube column does not need to be cut. Moreover, when the tube is used as a concrete-filled column, concrete can be filled more easily compared to the through-plates connection type.

In a wide flange beam to rectangular tube column joint, the ratio of the beam bending moment carried by the beam web is less than 5% even for very thick tube thickness, and most of the beam moment is transferred primarily through the beam flanges (Tsai 1992). Therefore, a simplified analytical model of beam flange plates in tension connected to a rectangular tube column was used to investigate the nominal strength of the joints with stiffening plates as shown in Figure 2 (Park et al. 1998a). From the principal of virtual work, the nominal strength P can be calculated

$$P = 4M_{pc}\left(\frac{B_c}{x} + \frac{2x}{m} + \frac{t_s}{m}\right) + \frac{2F_{us}t_s h_s}{\sqrt{3}} \qquad (1)$$

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SHEAR TRANSFER IN THE PANEL ZONE OF CFT BEAM-COLUMN CONNECTIONS

CHIN-TUNG CHENG[1]

SUMMARY

A nonlinear force-deformation model to simulate shear transfer behavior in the panel zone of CFT (Concrete-Filled Steel Tube) beam-column connections is proposed. In this model, influence of axial load on the shear transfer behavior is accounted for. To validate the proposed theory, five circular CFT beam-column connections were constructed and tested. Test results showed that all specimens failed by the welding fracture while entering nonlinear stage. It is found that the higher the axial load was applied, the better the ductility of connections was obtained. Comparison of analytical and experimental results shows that the proposed prediction for panel shear falls in a reasonable range for higher axial load tests, but tends to be conservative for lower axial load tests.

Keywords: *SEEBUS; concrete-fill steel tube; beam-column joints; panel zone; shear transfer.*

INTRODUCTION

Steel tubes infilled with concrete to form a composite member are referred as concrete-filled steel tubes (CFT). It is well known that CFT members exhibit many advantages to achieve high seismic performance in terms of strength and ductility. Concrete strength can be enhanced by the confinement of the tube wall; at the same time the infilled concrete also inhibits buckling of the CFT column wall. However, the use of CFT had been hindered by a lack of understanding on the shear transfer in the panel zone of beam-column connections. Literatures referring seismic behaviors of CFT connections are rare when compared to CFT columns, especially for circular column connections.

Alostaz and Schneider (1996) investigated seismic performance of various connection details. Six connections can be characterized as two types of connection details, through column and through beam. Through column connections utilized diaphragms or other stiffeners to connect steel beams to CFT columns. On the other hand, beams passing through panel zone are referred as through beam connections. Test results showed that through beam connections had better seismic performance. However, these connections may have difficulty in field construction due to its complex nature in the panel zone. Recently, Elremaily and Azizinamini (2001) investigated the connection details and shear strength in the panel zone of CFT through beam connections. As mentioned above, through column connections can facilitate the field construction, Fujimoto et al. (1997) and Cheng et al. (2000) studied the connections details in order to improve its seismic performance. Therefore, first intention of this paper is to achieve better performance from the improvement of through column connections. After test of first two specimens, research intention was turned to investigate axial load influence on shear transfer behavior in the panel zone of through column connections that is still uncertain in these literatures and its strength evaluation is over-conservative in the code provisions. It is therefore necessary to clarify the nonlinear behavior of shear transfer in the panel zone of CFT through column connections.

In the evaluation of shear strength of the panel zone, AIJ—SRC (1991) characterized two distinguished failure

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Equivalent Damping Ratio of a MDOF Structure with Additional Damping Devices

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SUMMARY

The purpose of this study is to propose a new method for evaluating equivalent damping ratios of a structure with supplemental damping devices to assess their control effect quantitatively. A MDOF system is transformed to an equivalent SDOF system based on the assumption that the first mode dominates structural response. Approximate closed-form formulas for the evaluation of the first damping ratio are presented for various damping devices. Through numerical analysis of a ten-story building equipped with damping devices, the effectiveness of equivalent SDOF model and closed form formulas are verified.

INTRODUCTION

This study proposes a new and general approach to evaluate the equivalent damping ratios of a structure with any supplemental damping devices, whose control forces are linearly or nonlinearly dependent on the structural responses. Also, this study presents an approximate, but accurate closed-form formulas of the first modal equivalent damping ratios for MDOF structures with damping devices. Lyapunov function, of which derivative can be expressed in autoregressive form, is defined and then, the equivalent damping ratios by using Lyapunov function and its derivative is evaluated(Lee SH,2002). It is assumed that the response of a structure is stationary random process and control devices do not affect the modal shape of structure, and the structure has proportional damping. This assumption can be justified by the fact that supplemental damping devices are minor elements in building structures and proportional damping can describe the mechanism of energy dissipation with little error.

A MDOF system is transformed to an equivalent SDOF system, since general building structures are governed by their fundamental modes. The proposed method is also applied to the equivalent SDOF system and closed form formulas for equivalent damping ratios are derived with probabilistic concept.
To show the effectiveness of the proposed approach, we evaluate the equivalent damping ratios of a structure with viscous dampers(VD), active mass damper(AMD) and friction dampers(FD). They, which are simply obtained from the formulas, are compared to ones obtained by conventional eigenvalue analysis for linear damping devices. RMS and peak responses of top floor, which are simply obtained by equivalent SDOF system, are compared to ones by MDOF system.

EQUIVALENT SDOF MODEL FOR MDOF SYSTEMS

Generally, the dynamic responses of typical civil or building structures are represented well by the first few natural vibration modes. Especially for a structure of which responses are dominated by a fundamental mode, the effect of damping devices on the fundamental mode is enough to estimate the effect of damping devices on the whole system responses. This fact also means that the effects of damping devices on a fundamental mode should

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AN OUTLINE OF PERFORMANCE-BASED SEISMIC CODE OF BUILDINGS IN JAPAN

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SUMMARY

This paper outlines the new performance-based seismic code of buildings in Japan enforced in June 2000. The code provides two kinds of performance requirements: human life safety and damage control of a building. There are two corresponding earthquake motion levels. The earthquake motions are defined in terms of the design acceleration response spectrum, which is specified at the engineering bedrock in order to take the soil condition and soil-structure interaction effect into consideration as properly as possible. The required performance shall be verified by comparing the response values with the limiting values of a building. The evaluation procedures of seismic performance in the new code are in essence a blend of the equivalent Single Degree of Freedom modeling of a building and the site-dependent response spectrum concept, which facilitates the prediction of maximum structural response for earthquakes without using time history analyses.

***Keywords**: Performance-based seismic code, building structures; design earthquake motion; equivalent linearlization; earthquake response.*

INTRODUCTION

The Building Standard Law of Japan was largely revised in June1998 after an interval of about 50 years. The changes related to structural engineering involved drastic revision from prescriptive type provisions to performance-based ones. With the revision, a new structural design code had been developed and enforced in June 2000. In the new code, precise definitions for performance requirements and verification methods based on accurate response and limiting values are specified. The code should be applicable to any kind of materials and any type of buildings such as seismic isolation systems as long as material properties are well-defined and the structural behavior of a building is appropriately estimated.

This paper outlines the structural design method developed for the new performance-based structural provisions, focusing on earthquake engineering. The evaluation procedure for the seismic performance of buildings against major earthquake motions is also introduced.

REQUIRED SEISMIC PERFORMANCE LEVELS FOR BUILDINGS

An outline of requirements for buildings and earthquake motion levels is shown in Table 1. In the first column of the table are the requirements for buildings while in the other columns are earthquake motions to be considered and their corresponding levels. As shown in Table 1, there are two categories for buildings, which are described below.

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PREDICTATION OF INELASTIC SEISMIC DEMANDS USING THE REPRESENTATIVE RESPONSE OF MULTISTORY BUILDINGS

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SUMMARY

Determination of ductility demand and prediction of inelastic seismic responses of a multistory building subjected to the earthquake ground motions have become a very important subject for evaluation of seismic performance in the performance based seismic design. In this study, the system and local ductility demand and inelastic seismic responses of the steel moment framed structures by the inelastic time history analysis are estimated and compared with those obtained from the capacity spectrum method using the pushover analysis. In this study, improved and effective analysis method based on the representative responses of a multistory building for prediction of inelastic seismic demand and evaluation of seismic performance was proposed. The adequacy and validity of the proposed method is verified by comparing the results evaluated by the method suggested in this study and the results obtained from the capacity spectrum method in ATC-40 to the inelastic seismic responses of the example structures from the inelastic time history analysis.

Keywords: *inelastic time history analysis, pushover analysis, representative responses, system ductility demand, local story ductility demand, plastic hinge formation, interstory drift, performance limit.*

INTRODUCTION

Seismic performance of a building structure should be evaluated based on the inelastic behavior. The ductility demand imposed by the earthquake ground motions and the ductility capacity of a structure needs to be compared for seismic performance evaluation. In general, the expected inelastic deformation should be limited within an acceptable range to prevent structural collapse in the earthquake resistant design. Therefore, estimation of ductility demand and prediction of the ductility capacity of a structure under the earthquake excitations have become a very important subjects for evaluation of seismic performance in the performance based seismic design. There are two types of methods for the estimation of system ductility demand by analytical method. One type is based on the seismic responses obtained from inelastic time history analysis and the other is based on those obtained from pushover analysis. Especially, one of the later methods is widely known as the capacity spectrum method suggested in ATC-40. This method is most widely applied to the evaluation of seismic performance in performance based seismic design because of the effective estimation for the resistant capacity and the seismic demand. However, several studies have questioned by a few researchers the validity and accuracy of some of the assumptions made in capacity spectrum method suggested in ATC-40.

In this study, the representative responses that can represent the practical resistance capacity of a structure are used for estimating the inelastic seismic responses of a structure. And by applying the representative responses to the principle of the capacity spectrum method, an improved and effective method for evaluating the seismic performance is proposed in this study. The adequacy and validity of the proposed method is verified by comparing the results evaluated by the method suggested in this study and the results obtained from the capacity spectrum method in ATC-40 to the inelastic seismic responses of the example structures by the inelastic time

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AN INTERNET-BASED ENVIRONMENT FOR COLLABORATIVE NETWORKED PSEUDO DYNAMIC TESTS

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SUMMARY

This paper presents an ongoing research effort to develop an Internet-based environment, called ISEE (Internet-based Simulations for Earthquake Engineering), for collaborative networked structural experiments among geographically distributed structural laboratories. The research effort is a joint one between National Center for Research on Earthquake Engineering (NCREE) and Department of Civil Engineering at National Taiwan University. The first stage of the ISEE development focuses on the realization of collaborative networked pseudo dynamic tests. Two approaches have been employed to provide different solutions for network communication as well as collaborative framework in ISEE. Several collaborative networked pseudo dynamic tests have been conducted to investigate the feasibility and efficiency of both implementation approaches for the ISEE environment.

Keywords*: Distributed Pseudo Dynamic Test; Internet-based Collaborative Networked Structural Experiments*

INTRODUCTION

In the field of Earthquake Engineering, structural experiments are still important means for understanding behaviors of structures and their components. As the scale and complexity of a modern structural experiment increase, existing structural laboratories, even those large-scale ones, are facing increasing difficulties to satisfy various types of demands of experiments with their limited resources. To address this issue, some research efforts have recently been conducted on developing technologies for collaborative structural experiments, allowing two or more laboratories at different geographical locations to jointly conduct a test in a collaborative manner. For example, Japan and Korea have jointly conducted research to investigate networked pseudo-dynamic experiments among laboratories in the two countries (Sugiura et al., 1998; Yun et al., 2000; Watanabe et al., 2001). The National Science Foundation of USA has launched a project, called NEES (Network for Earthquake Engineering Simulation), to explore the tremendous benefits of sharing and integrating laboratory resources (including expensive equipment, experimental data, and simulation codes) via computer network (National Science Foundation 2000a; 2000b; 2001).

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Design of viscoelastic dampers for plan-wise asymmetric structures

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ABSTRACT

In this study a strategy was developed for an appropriate plan-wise distribution of viscoelastic dampers to minimize the torsional responses of an asymmetric structure with one axis of symmetry subjected to an earthquake-induced dynamic motion. The modal characteristic equations of a single-story asymmetric structure with four corner columns and added viscoelastic dampers were derived, and a parametric study was performed to identify the design variables that influence the torsional responses. Based on the results of parametric study a simple and straightforward methodology to find out the optimum eccentricity of added VED to compensate for the torsional effect of a plan-wise asymmetric structure was developed using modal coefficients.

***key words**: plan-asymmetry, stiffness eccentricity, optimum damper eccentricity, viscoelastic dampers*

1. INTRODUCTION

The structural irregularities such as irregular distribution of mass, stiffness, or strength in their floor plan may lead to damages much enlarged compared to the case of structures with their properties symmetrically distributed. Previous experiences indicate that those structures with irregularities are especially vulnerable to earthquake-induced dynamic motions.

Research related to reducing torsional effect of plan-wise asymmetric structure first started from understanding elastic behavior of a structure arising from asymmetry [1]. More recently, another research effort has been imparted on the reduction of torsional responses of a single-story structure by use of supplemental viscous dampers (VD). Goel [2] showed that the torsional response of an asymmetric single-story structure can be reduced by locating VD asymmetrically. He identified three parameters that control the influence of VD on the linear response of an asymmetric structure. Lin and Chopra [3] extended Goel's study, and tried to improve the understanding of how and why plan-wise distribution of

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