The 5th Seminar on Earthquake Engineering
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INTERNET-BASED STRUCTURAL ANALYSIS OF BRACED STEEL STRUCTURES

Motohide TADA[1] and Susumu KUWAHARA[2]

SUMMARY

A lot of applications such as FEM have been developed by many investigators, and served for the precise analysis of member-buckling, local buckling, lateral buckling, and so on. Although the small structural elements can be analyzed precisely by these applications, it is still hard to analyze whole structure in the same precision because of the limited memory-size and CPU-performance. For the analysis of whole structure, we have to deal with rough model and that leads us to the less precision. If we can unify precise applications under internet environment, we can analyze whole structures so precisely. And if we can unify different kinds of applications, various phenomena analyzed by each application can be considered simultaneously in the analysis of whole structure.
As the first step to realize above plan, this paper deals with the elasto-plastic structural analysis of a steel braced frame. Several personal computers were networked. Each computer analyzed beams, columns, and braces, respectively. The stiffness-matrices of each member are transferred to the host computer through internet. Host computer constitutes the global stiffness-matrix for the whole structure, and solves the global stiffness-equation. The incremental deformations of each member are distributed to each computer from the host. Each computer analyzes the next step using the transferred deformations, and replies the revised stiffness to the host.
The results of the pushover analysis and the earthquake response analysis were shown. The stable transfer of information by 1,489 steps for 230 minutes could be successfully achieved. The effect of mid-load in each member on the behavior of whole structure can be adequately considered. And the behavior of whole structure after buckling of braces can be successfully analyzed.

Keywords: *internet, post buckling behavior, pushover analysis, earthquake response analysis collaboration*

INTRODUCTION

When we analyze the elasto-plastic behavior of a building steel structure precisely, considered at most will be elasto-plastic behavior of members, buckling of braces, deformation of beam-to-column connections, and so on. Although lateral buckling of beams and local buckling of members can be analyzed precisely by FEM, the object is limited to a small structural element because of the limited memory-size and CPU-performance. If we want to consider them in the analysis of a whole structure, we have to deal with a rough model, such as a spring with typical force-deformation relationship, by which we can get only rough results.

In the field of numerical analyses, parallel processing and distributed processing have been proposed for the analysis of huge structures. Most of them utilizes a lot of processors of a super computer. Recently, as a network of computers has improved significantly, the parallel processing technique becomes not only for one super computer but also for a group of personal computers on the network (Shibata et al. 2001). Internet-based test which utilizes internet environment for the communication between the loading system and the numerical analysis was reported (Hsieh et al. 2002).

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INELASTIC RESPONSE SPECTRA CONSIDERING THE NONLINEARITY OF THE UNDERLYING SOIL DUE TO THE MODERATE EARTHQUAKES

Yong-Seok KIM[1]

SUMMARY

Seismic design codes developed considering the strong earthquakes may result in unnecessary economical loss in the 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, elastic and inelastic seismic response analyses of a single degree of freedom system on the soft soil layer were performed considering the nonlinearity of the soil for the 11 moderate earthquakes scaled to the nominal peak accelerations of 0.075g, 0.15g and 0.2g. Seismic response analyses for the structure-soil system were performed in one step applying the earthquake motions to the bedrock, using a pseudo 3-D dynamic analysis software. Study results indicated that it is necessary to consider the nonlinear soil-structure interaction effects and to perform the performance based seismic design for the various soil layers rather than to follow the routine procedures specified in the seismic design codes. Nonlinearity of the soft soil excited with the moderate earthquakes also affected significantly on the elastic and inelastic responses due to the nonlinear soil amplification of the earthquake motions, and it was pronounced especially for the elastic ones.

Keywods: *moderate seismic area; soil-structure interaction; elastic and inelastic seismic response; soft soil layer; pseudo 3-D.*

INTRODUCTION

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 response spectra developed for the strong earthquakes may result in unnecessary investment and economical loss for the buildings in the moderate seismic area. (Donald 1991)

The importance of soil-structure 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 Earthquakes. Soil-structure interaction analysis of structures considering the site soil conditions is necessary to predict reasonably the seismic response of a structure in the performance based seismic design. (Krawinkler 1997) But true nonlinear seismic analyses for the soil-structure interaction problem are practically difficult, and nonlinear analyses are performed for the approximate solutions.

In this study, seismic response analyses of a single degree of freedom (SDOF) system lying on the soft soil were performed in one step applying the earthquake excitations to the bedrock. For the nonlinear analyses, a linearized iterative method was utilized. Effects of the nonlinear soil layer on the seismic responses were investigated comparing the responses for the nonlinear soil with those for the linear soil and UBC-97. (ICBO 1997) Study was carried out for a surface medium size mat foundation built on the UBC soil type of S_D using the 11 low and

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PROBABILISTIC ANALYSIS OF THE NON-LINEAR SATURATED CONTROL ALGORITHM

Kyung-Won Min[1], Ji-Hun Park[2], and Hongjin Kim[3]

Summary

The method for the probabilistic analysis on the non-linear control algorithm with actuator saturation is proposed based on the equivalent non-linear system method. Numerical examples are given to verify the approximate probability density function (PDF) results comparing those to the statistically obtained PDF results when the system is subjected to a Gaussian white noise and a Kanai-Tajimi filtered Gaussian white noise. It is shown that the PDF calculated using the proposed equations closely approximates the PDF obtained statistically.

INTRODUCTION

The scale of civil structures and the magnitude of dynamic loads require a huge amount of control force, and the required control forces in real situation may exceed the capacities of control devices. In such cases, the *actuator saturation* needs to be taken into account in the design stage by limiting the maximum control force to the capacities of control devices. Bang-bang type control algorithm, which uses the maximum control force all the time during the operation, is among the most popular control algorithm for the limited control forces (Kirk, 1970, Min et al., 2003). Since the algorithm generates only two cases - maximum control forces in positive and negative directions - depending on the directions of feedback responses, bang-bang control algorithm belongs to non-linear control algorithms. Wu et al. (1995) investigate the effectiveness of various non-linear control algorithms including bang-bang algorithm and compare the effectiveness to that of linear control algorithm. They conclude that non-linear control algorithms are more effective for the reduction of peak response than linear control algorithm when the maximum control forces are limited.

In this paper, the probabilistic analysis is performed on the non-linear control of SDOF systems with actuator saturation. The non-linear controller with actuator saturation employed in this paper is the controller that acts as a linear controller in the transition region and utilizes the maximum control forces outside of the transition region. In the following sections, the equivalent non-linear system theory is briefly reviewed and applied to the non-linear control algorithm with actuator saturation in order to find an approximate solution of PDF. Numerical examples are given to verify the approximate PDF results comparing those to the statistically obtained PDF results.

CONTROL ALGORITHM WITH ACTUATOR SATURATION

Consider a linear SDOF system subjected to a Gaussian white noise and expressed as

$$\ddot{x} + 2\xi_0\omega_0\dot{x} + \omega_0^2 x = \mathbf{b_1}\mathbf{w}(t) + b_2 u \qquad (1)$$

where ξ_0 and ω_0 are the damping coefficient and natural frequency, respectively, x is the displacement, u is

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AN EFFICIENT MODEL FOR SEISMIC ANALYSIS OF FLAT SLAB STRUCTURES WITH THE EFFECTS OF STIFFNESS DEGRADATION

Dong-Guen LEE[1], Hyun-Su KIM[2], and Seung-Jae LEE[3]

SUMMARY

Flat slab system has been adopted in many buildings constructed recently because of the advantage of reduced floor heights to meet the economical and architectural demands. Structural engineers commonly use the equivalent frame method(EFM) with equivalent beams proposed by Jacob S. Grossman in practical engineering for the analysis of flat slab structures. However, in many cases, when it is difficult to use the EFM, it is necessary to use a refined finite element model for an accurate analysis. But it would take significant amount of computational time and memory if the entire building structure were subdivided into a finer mesh. An efficient analytical method is proposed in this study to obtain accurate results in significantly reduced computational time. The proposed method employs super elements developed using the matrix condensation technique and fictitious beams are used in the development of super elements to enforce the compatibility at the interfaces of super elements. The stiffness degradation of flat slab system considered in the EFM was taken into account by reducing the elastic modulus of floor slabs in this study. Static and dynamic analyses of example structures were performed and the efficiency and accuracy of the proposed method were verified by comparing the results with those of the refined finite element model and the EFM.

Keywords: *flat slab structure; stiffness of slab; stiffness degradation; matrix condensation; super element; fictitious stiff beam.*

INTRODUCTION

Flat slab system in which columns directly support floor slabs without beams is adopted for many building structures recently constructed. Since flat slab system has no beams, flat slab system exhibit several advantages such as providing lower building height, good lighting and ventilation, easy arrangement of pipes and wires under slabs, more clear space, architectural flexibility and easier formwork which consequently make construction time shorter. However, flat slab system has some difficulties in making long span structures and large openings in slabs because of the limitations in plan configuration such as aspect ratio of slabs, ratio of column spacing in both directions etc. Especially stiffness degradation is noticeable under lateral loads and it may be necessary to place some appropriate bearing walls in regard to structural plan because of large story drift. Flat slab system was primarily developed for a resistance to gravity loads and many researches on a resistance capacity for lateral loads have been undertaken (Moehle 1990, Mulcahy 1983).

Structural engineers commonly use the equivalent frame method (EFM) in practical engineering for the analysis of flat slab structures (Grossman 1997, Vanderbilt 1981). In the equivalent frame method, flat slab system is modeled by equivalent frame and elastic analysis is performed. The floor slabs in column strip are severely deformed with columns when plat slab structure is under lateral loads. However, the slabs between column strips are hardly deformed. Thus, the effective width that can resist a bending is used for the width of the equivalent

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SHAKING TABLE TESTS OF A HIGH-RISE RC BEARING-WALL STRUCTURE WITH IRREGULARITIES OF WEAK STORY AND TORSION AT BOTTOM STORIES

Han-Seon Lee[1] and Dong-Woo Ko[2]

SUMMARY

Recently, many high-rise reinforced concrete (RC) bearing wall structures of multiple uses have been constructed, which have the irregularities of weak (or soft) story and torsion at the lower stories simultaneously. The study stated herein was performed to investigate seismic performance of such a high-rise RC structure through a series of shaking table tests of a 1:12 model. Based on the observations of the test results, the conclusions are drawn as follows: 1) Accidental torsion due to the uncertainty on the properties of structure can be reasonably predicted by using the dynamic analysis with the center of mass being shifted by 5 percent of the dimension of the building perpendicular to the direction of the excitations than by using equivalent lateral force procedure. 2) The mode coupled by translation and torsion induced the overturning moments not only in the direction of excitations but also in the perpendicular direction: The axial forces in columns due to this transverse overturning moment cannot be adequately predicted using the existing mode analysis technique, and 3) Whereas the model responded mainly in the coupled translational and torsional mode under the moderate earthquake excitations, it changed this mode to the torsional mode as soon as the flexible side underwent the large inelastic yielding and stiffness degradations under the severe excitations. The hysteretic curve and the strength diagram between base shear and torque (BST) clearly reveal the predominant mode of vibrations and the failure mode.

Keywords: *reinforced concrete, shaking table tests, irregularity, torsion, overturning moment*

INTRODUCTION

Due to the severe shortage and for the effective use, of the sites for new constructions in metropolitan areas in Korea, the buildings of different uses along the height have been built frequently during the past decade. The most common structural system has been the moment-resisting space frame for the lower stories and the bearing-wall system for the upper stories since the lower stories usually accommodate the parking area, commercial space, garden, or just open spaces for the architectural reasons and the higher stories are generally used as apartment. This type of building structures have the vertical irregularity of soft or (and) weak story since many upper bearing walls discontinue at the lower stories and may also form plan irregularity where the layout of important lateral-force-resisting vertical elements such as shear walls may be asymmetric for some architectural reasons.

The study on the seismic performance of such building structures which have only vertical irregularities were conducted in the past (Lee et al. 2002). The objective of this study stated herein is to investigate the seismic performance of a high-rise reinforced-concrete bearing-wall structure having irregularity of both weak story and torsion at the bottom stories.

The torsional behavior of building structures have been studied by several researchers including Chopra(1995),

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CYCLIC SEISMIC TESTING OF STEEL MOMENT CONNECTIONS REINFORCED WITH RIBS

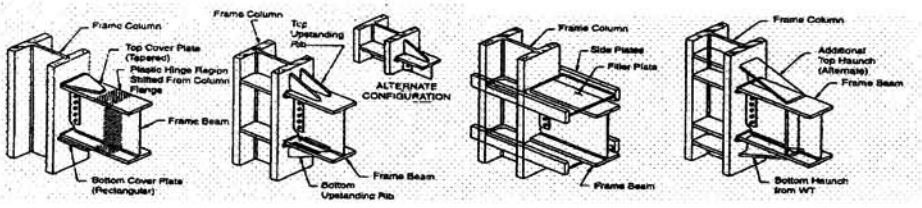
Cheol-Ho LEE[1], Jong-Hyun JUNG[2], Myung-Ho OH[3], and En-Sook KOO[4]

SUMMARY

A simplified design procedure as well as load transfer model for rib-reinforced seismic steel moment connections was proposed recently. As a follow-up study, an experimental program was implemented to verify the proposed procedure and to develop some schemes that would prevent cracking at the rib tip. All the specimens designed following the proposed procedure exhibited satisfactory levels of connection plastic rotation. A combined strategy, or rib reinforcement plus slight trimming of the beam flange in the form of the radius-cut, pushed the plastic hinging and local buckling of the beam away from the rib tip and effectively reduced the cracking propensity at the rib tip. The strut action of the rib and resulting reverse shear in the beam web were also identified through the strain gage readings in this experiment

1. Introduction

The 1994 Northridge and the 1995 Kobe earthquakes caused widespread failure of welded moment connections in steel moment-resisting frames. A variety of improved moment connections have been proposed after the earthquake. The more popular strategies to circumvent the problems associated with the pre-Northridge moment connection include strengthening the connection or weakening the beams that frame into the connection. Fig. 1 shows examples of moment connections for various strengthening strategies [1]. The aim of strengthening is to allow stable yielding of the beam by relocating the plastic hinge of the beam away from the beam-to-column groove welds.



(a) Cover Plate (b) Upstanding Rib (C) Side Plate (d) Haunch

Fig. 1. Examples of moment connections per strengthening strategy [1]

Upstanding rib in Fig. 1(b) may be used to reinforce welded steel moment connections. For example, Zekioglu et al. [2] used rib reinforcement to supplement the taper-cut reduced beam section (RBS), i.e., to further limit the stress in the beam flange welds and to provide increased redundancy for the connection. Rib reinforcement may also be used to address the situation where the frame design requires an excessive RBS (greater than 50 percent of the beam flange) due to short spans, or larger beam depths [3].
Engineers often use rib plates to enhance the seismic performance of welded steel moment connections, based on classical beam theory, assuming that the moment of inertia is increased near the face of the column so that the tensile stress in the groove weld is reduced. However, employing the classical beam theory in the design of some welded steel moment connections has been brought into question after the Northridge earthquake. Goel et al. [4]

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CHARACTERISTICS OF ENERGY CURVES OF DIFFERENT STEEL CONNECTIONS

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SUMMARY

The evolving energy theory is discussed and applied to experimental results of 46 steel beam-column connections with various connection types. Using the hysteresis-based energy theory, it shows that an objective comparison is possible between different materials, sizes and details. In addition to energy curves, the strength ratios at every loading cycle to the maximum behavioral strength are presented, which relate the safety threshold to cumulative plastic drift angle. It may be tentatively concluded with care that the energy content, as long as normalized, may be NOT so sensitive between different structural system with different details and sizes. However, difference in materials may matter.

***Keywords**: hysteresis; (normalized) energy; energy curve; energy absorption efficiency; cumulative plastic drift angle; and steel connections.*

INTRODUCTION

Traditionally, the physical quantities having the significance in seismic analysis and evaluation have been referred to force (or strength) and displacement (or ductility). In accordance with the majority of state-of-the-practice methods of analysis (ATC 1983, ATC 1987, ATC 1992, ATC 1996, FHWA 1994), force and displacement are separately treated as the target quantities to control the seismic performance of structures. For example, the structural system is required to limit the story drift to a specified value for a prescribed performance level in addition to the code-based strength design. This may seem to be reasonable but a fatal mistake may result from the ignorance of cyclic and duration effects of earthquake loading, that cannot be properly considered in the current state-of-the-practice methods of analysis.

In order to overcome the probable defect and supplement the imperfect state-of-the-practice approach, the experimental study is preferred. However, every experimental program performed by various researchers may have an individual significance but may not be related to one another and the seismic performance cannot be appropriately compared with each other. Every researcher may claim the performance of her/his devised system to be superior to the others in an ambiguous confidence without any objective evidence. Here is the difficulty, since every structural system (or subassemblage) is different from each other in material property, details, sizes and location in a whole structure. How can those experimental results of various structures or structural elements with different configurations be objectively compared? The energy-based analysis model (Akiyama 2002, Chang and Mander 1994, Mander, et al. 1998, Kim 2001) can include the cyclic and duration effects of earthquake loading and all different structural configurations but is still evolving into several versions. Depending upon the goal to seek, different approach should be used. For characteristics of energy capacity and comparison between structural systems, the hysteretic energy is considered. For individual failure mechanisms or their subsequent emergence, the mechanism-based strain energy is considered. For complete analysis, energy in both demand and capacity is required.

The present paper discusses the hysteresis-based energy model and demonstrates its application to determine the characteristics of energy curves of various steel connection groups. For this, the experimental force-displacement hysteretic loops of forty six steel beam-column connections obtained from the SAC joint

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SEISMIC BEHAVIORS OF WUF-B CONNECTIONS

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SUMMARY

The purpose of this study is to evaluate the seismic performance of Welded Unreinforced Flange – Bolted web (WUF-B) connections designed and detailed in compliance with the FEMA 350 recommended seismic design criteria (FEMA 350, 2000). Three full-scale test specimens were made, which were designed and detailed in compliance with the criteria for WUF-B connections in FEMA 350. The main variable of the specimens was panel zone strength. Test specimens were loaded with quasi-static reversed cyclic loading. The test results of this study were compared and discussed with former research results

***Keywords**: WUF-B; Connections; Inelastic action; Seismic Design; joints; Plastic hinges*

INTRODUCTION

Moment Resisting Steel Frames (MRSFs) are widely used in steel structures for lateral force resisting systems due to their superior ductility and energy dissipation capacity. Shortly after the Northridge earthquake (1994), the SAC steel projects (phase 1, phase 2) were performed. Numerous experimental tests and analytical studies on MRSFs were conducted to investigate the causes of the brittle failures and provide reliable and economical solutions to the problems in MRSFs. This study focuses on MRSFs having welded Unreinforced flange-bolted connections.

Stojadinovic et al. (2000) performed cyclic tests of ten WUF-B connection specimens. The specimens had modified details that include the use of a notch-tough metal and an improved welding procedure. The beam flange attachment details are identical to those in FEMA 350 except weld access hole details.

None of the specimens satisfied the criteria for the plastic rotation capacity of SMRSFs that is 0.03 rad according to the 1997 AISC seismic provision (1997). From the test results, Stojadinovic et al. (2000) verified that the notch-tough weld metal and newly weld procedure improve the performance of unreinforced moment resisting connections.
Ricles et al. (2002) performed cyclic tests of eleven full-scale column connection specimens to develop improved details for unreinforced welded flange moment connections. The beam flange attachment details are identical to those in FEMA 350 including access hole detail which is referred to as modified access hole (Mao et, al., 2001). The beam web was attached to the column flange using a Complete Joint Penetration groove weld (CJP) and continuous fillet weld was applied to the edges of the shear tab except for four specimens (T2, T3, T4, and T6).

Ricles et al. (2002) recommended two types of web attachment details, as follows;

1) The beam web is CJP welded to the column flange, and a shear tab is attached to the beam web using a supplementary fillet weld.

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CYCLIC BEHAVIOR OF STEEL MOMENT CONNECTIONS STRENGTHENED BY FLANGE RIB

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SUMMARY

Steel moment connections reinforced with flange rib can provide promising cyclic ductility. This paper presents experimental data on four large scale connection test specimens reinforced with the lengthened flange rib, which is characterized by consisting of a main reinforced part, a curved part and an extension. Test results showed that, under cyclic load, all four specimens developed a plastic hinge formed in the expected location away from the column. The lengthened flange rib connections are capable of providing desirable plastic rotational capacities as well as maintaining the required flexural strength.

Keywords: *steel moment connection; plastic hinge; cyclic behavior; plastic rotation.*

INTRODUCTION

Steel moment-resisting frames were considered reliable before the Northridge earthquake caused damages on the beam-to-column connections. Many fractures have been found in the connections (Mahin 1998; Tremblay et al. 1995). Since then, steel moment connections received intensive investigation on improving the performance of the pre-Northridge connections. The majority of these researches have included the reinforced connections and the reduced beam section (RBS) connections (Engelhardt and Sabol 1998; Uang and Bondad 1998; Engelhardt et al. 1996; Chen et al. 1996). Several reinforcing schemes were adopted to strengthen the connections, such as the use of cover plate, haunch, and flange rib (Engelhardt et al. 1995; Zekioglu et al. 1997; Anderson and Duan 1998). Both reinforced and RBS connections use the strategy to control the yielding mechanism at a desirable location away from the beam-column interface.

Among the flange rib connections, cyclic behavior and modes of failure were not the same as described in the literature. Engelhardt et al. (1995) conducted two specimens reinforced by welding two tapered ribs on top and bottom beam flanges. They found that specimens could form plastic hinge on the beam located at the end of the ribs, but at which the beam flanges also fractured when specimens reached maximum plastic rotation of 2.5 and 3% radians. Zekioglu et al. (1997) conducted the experiment that specimens were reinforced by two triangular rib plates welded to each beam flange, but the beam flanges were also shaved. Their test results showed that all three specimens fractured at the narrowest section of the beam flange, whereas showing promising ductile performance. That was contributed to the presence of the rib for decreasing the stress demand at the beam-column interface, and the presence of RBS for increasing the plastic rotation capacity. Anderson and Duan (1998) conducted three specimens that a triangular fin plate was welded to the top and bottom beam flanges. Specimens developed high plastic rotation capacities. Final failure of the specimens included the weld fracture between fin plate and column flange.

Obviously, the previous studies demonstrated that connections strengthened by ribs could decrease the stress in the groove weld and move the plastic hinge location away from column face. However, the rib plate of those specimens could induce the stress concentration on the beam flange due to the shift of critical section from

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NETWORKED HYBRID TEST FRAMEWORKS AND EXAMPLES

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SUMMARY

A project, Internet-based Simulations for Earthquake Engineering (ISEE), had been launched in National Center for Research on Earthquake Engineering (NCREE) to develop techniques of networked collaborative structural experiments. This paper gives description to a Platform for Networked Structural Experiments (PNSE) as one of the two approaches under the ISEE project. The PNSE links a numerical simulation program and a number of facility control programs geographically scattered around the world by the Internet. All those calculation and facility control modules are linked by point-to-point TCP connections under a multi-client/server architecture. An application protocol, the Networked Structural Experiment Protocol (NSEP), which defines relevant events and activities in structural laboratories, as well as communication rules between the client and server, was proposed to work with the PNSE for collaborative experiments. Results of transnational numerical simulations and real experiments prove the validness and the effectiveness of the PNSE.

***Keywords**: ISEE, structural experiments, network, Internet, TCP/IP, pseudo dynamic test, application protocol.*

INTRODUCTION

For structural laboratories to meet the increasing demands on testing large and realistic specimen, a more practical solution is to link a number of laboratories by the Internet to collaboratively perform a single experiment. Researchers in Japan and Korea have conducted some tests jointly to investigate the practicability of pseudo dynamic tests between these two countries (Sugiura et al., 1998; Yun et al., 2000; Watanabe et al., 2001). The NEES (Network for Earthquake Engineering Simulation) project, envisioned by the National Science Foundation of USA, also aims at exploring the tremendous benefits of sharing and integrating laboratory resources via network (National Science Foundation 2000b).A project, the Internet-based Simulations for Earthquake Engineering (ISEE), have been launched in National Center for Research on Earthquake Engineering (NCREE) in Taiwan to construct a platform that links numerical simulation programs and facility control programs around the world by the Internet for networked structural experiments. Within the framework of ISEE project two approaches, the Database Approach (Yang 2003) and the Application Protocol Approach, provide different platforms to achieve this goal. This paper briefly describes the architectures and practical implementation of the Application Protocol Approach.

The Transmission Control Protocol / Internet Protocol (TCP/IP) suite was designed as an open standard to meet the demand of data transmission on rigorous network conditions (Postel 1981a, 1981b). TCP guarantees reliable data transmission by providing services such as acknowledged delivery, error detection, retransmission if necessary, data sequence preservation, and flow control. IP provides addressing, routing, fragmentation and reassembly for data packets. TCP/IP stack thus handles all those tedious works for data transport between hosts on heterogeneous networks. The characteristic of open standard and the fact of support from almost all currently available operating systems make TCP/IP the foundation of the today's Internet. With TCP/IP, any two hosts on line can communicate to each other without difficulty provided they have the same application protocol, which is a set of predefined rules describing the information, and sending and receiving behaviors of the application.

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SEISMIC CAPACITY ASSESSMENT OF REINFORCED CONCRETE BUILDINGS USING AMBIENT VIBRATION MEASUREMENTS

Liang-Jenq LEU[1], Chuen-Yu LIU[2]

SUMMARY

A simple method for assessing the seismic capacity of RC buildings is proposed in this study. The method employs the fundamental vibration periods identified from ambient vibration measurement. To this end, regression formulas relating the stiffness and strength of RC buildings are derived first, on the basis of push-over analysis results of 18 typical RC buildings models. The criteria for ultimate stage of RC buildings can be system ductility or roof drift ratio. The ultimate base shear and its corresponding peak ground acceleration can be calculated. The proposed simple seismic assessment method is applied to one RC building, which shows that it is not only easy to use but also accurate enough.

***Keywords**: Ambient vibration; seismic capacity; push-over analysis; regression formulas; RC buildings.*

INTRODUCTION

In the literature, two major types of methods can be distinguished with regard to the seismic assessment of RC buildings, including detailed methods and simple methods. Although accurate, detailed seismic assessment methods, such as ATC-40 capacity spectrum method (ATC 1996), take plenty of time to establish structural models and to run non-linear analysis. Simple seismic assessment methods are usually convenient to use but their accuracy may not be enough. This study aims at proposing a seismic assessment method of RC buildings that is both accurate and computationally inexpensive.

As all buildings are designed according to the regulations in the building code, their stiffness shall be related to the strength (seismic capacity) in some way. Therefore, if one can establish the relationship between the stiffness and seismic capacity of buildings, it is possible to assess the seismic capacity by knowing its stiffness. In this study, the stiffness of buildings is represented by their fundamental vibration period, which can be determined by ambient vibration measurements easily. The strength is in terms of their system ductility or ultimate roof drift ratio. Given the system ductility or ultimate roof drift ratio and the fundamental vibration period of a RC building, the proposed method aims at calculating the ultimate base shear and the ultimate peak ground acceleration.

LITERATURE REVIEW

Using the periods identified from ambient vibration measurements to evaluate the seismic capacity of RC buildings was first proposed by JARPA (JARPA, 1997). The JARPA concluded from the seismic assessment results of 7 RC school buildings that

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EVALUATION OF SEISMIC ENERGY DISTRIBUTION IN STRUCTURES – A MODAL PUSHOVER ANALYSIS PROCEDURE

Chung-Che CHOU[1] and Chia-Ming UANG[2]

SUMMARY

Energy serves as an alternative index to response quantities like force or displacement to include the duration-related seismic damage effect. A simplified procedure similar to the response spectrum method has been developed to estimate the energy absorbed in each mode from energy spectra, and the distribution of the energy along the frame height is evaluated based on the energy shapes established by a non-linear modal pushover analysis. A case study of moment frames subjected to various ground motions shows that (1) the proposed procedure which includes the higher mode effects can reasonably predict the total energy and the energy distribution in a structure, (2) the majority of the seismic energy is contributed by the first mode response, and (3) the second-mode energy needs to be considered to predict the damage in the upper stories.

Keywords: *Energy, modal pushover analysis, energy shape, moment frames.*

INTRODUCTION

Study on the energy demand in a single-degree-of-freedom (SDOF) system is abundant, but study on the energy demand in multistory frames is limited. Lawson et al. (1994) showed that the hysteretic energy demand in a structure cannot be predicted by a static pushover analysis. Fajfar and *Gašperšič* (1996) showed that the hysteretic energy demand in a multi-degree-of-freedom (MDOF) system cannot be evaluated reliably from an equivalent SDOF system; the researchers attributed the problem to the higher mode effect. This effect also made it difficult to predict the energy distribution along the height of building structures (Seneviratna and Krawinkler 1997, Shen and Akbas 1999). A recent study by Chopra and Goel (2001) showed that the story drift along the building height can be estimated if more than one equivalent SDOF systems are considered.

The purpose of this study (Chou and Uang 2003) is to present a procedure that can be used to predict the seismic energy demand at each floor of an MDOF system without performing a nonlinear time-history analysis. The procedure requires a static pushover analysis of an MDOF system to determine the modal yield force and ductility factor of an equivalent SDOF system for the first few (say, two) modes. After the ductility is determined for each mode, the energy spectrum can be used to determine the contribution of each mode. The absorbed energy of each mode is then distributed along the frame height based on the specific energy shapes, established from the pushover analysis. A case study is presented to verify the accuracy of the proposed method.

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A PRELIMINARY PARAMETRIC STUDY ON ASEISMIC CAPACITY OF TRADITIONAL SCHOOL CLASSROOM BUILDINGS

Shang-Hsien HSIEH[1], Pin-Pin TENG[2], and Hsueh-Cheng WANG[3]

SUMMARY

The aseismic capacity of school classroom buildings may be influenced by many of the building's architectural and structural characteristics, such as strength of materials used, story height, sizes of beams and columns, number of stories, number of classrooms per story, etc. This paper tries to parameterize these characteristics in the modeling of school classroom buildings and studies their influences on the aseismic capacity of school classroom buildings. The focus of this research is on the traditional elementary and high school classroom buildings in Taiwan. A framework is developed first to construct a large case base containing aseismic capacity estimation results of various numerically simulated school building cases. Then, the large amounts of data in the case base are analyzed to study the influences of selected parameters on the aseismic capacity of traditional school classroom buildings.

Keywords: *Parametric study; Aseismic capacity; Traditional school classroom buildings.*

1. INTRODUCTION

The structural safety of a school classroom building is important because the building usually serves as a temporary shelter when a severe natural disaster occurs. After the 1999 Chi-Chi earthquake collapsed many school classroom buildings in the central Taiwan, there has been a great concern on the aseismic capacities of all school classroom buildings in the country. Therefore, several researchers have since conducted some parametric analysis on aseismic capacity of school buildings. For example, Li et al. (2002) investigated the influences of number of stories, number of spans, and allocation of shear walls on the aseismic capacity of school buildings. They performed detailed aseismic capacity assessment on thirty two-dimensional numerical building models. The results of the study show that, for buildings with the same sizes and reinforcement of beams and columns, the more stories or spans they have, the less their aseismic capacities are. The decrease of a building's aseismic capacity was found to be about 15%-25% whenever one more story is added to the building. In addition, Liu and Chiu (2002) evaluated the aseismic capacity of sixteen school building models using the static push-over method. The results of their study show that the reinforcement ratio of columns is better between 2% and 2.5% for good aseismic capacity of school buildings and the spacing of the transverse stirrups is better less than 15cm. The influences of concrete strength and number of stories on the aseismic capacity of school buildings were also studied. The results show that the aseismic capacity of a school building may vary up to 15% for every 70kg/cm^2 increase or decrease of the concrete strength. The decrease of a building's aseismic capacity was found to be about 30% whenever one more story is added to the building.

To investigate the factors of influence on the aseismic capacity of traditional elementary and high school classroom buildings in Taiwan, this research characterizes three-dimensional school classroom building models with a set of architectural and structural parameters. The parameters include number of stories, number of classrooms per story, material strength of concrete and steel, story height, sizes and locations of beams and

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FULL-SCALE TEST ON THREE-STORY STEEL MOMENT FRAME FOR ASSESSMENT OF SEISMIC PERFORMANCE IN VERY LARGE DEFORMATION RANGE

Tomohiro Matsumiya[1], Dawei Liu[2], Masayoshi Nakashima[3], and Keiichiro Suita[4]

SUMMARY

This paper is a progress report of the full-scale test on a three-story, two-span by one-span steel moment frame. The test was conducted to characterize the cyclic behavior of steel moment frames beyond the deformation ranges considered in the contemporary seismic design, to examine the correlation between the local damage and global behavior, to reevaluate the composite action between steel beams and RC floor slabs, and to investigate the effects of exterior finishes on the structural behavior. The paper introduces design of the test structure, loading program, measuring schemes, and test results. Although detailed data processing and analyses are still underway, the following observations are notable. Balanced deformations between the beams, columns, and column bases (primarily due to yielding of the anchor bolts) mitigated the beam plastic rotations rather significantly. Pinching behavior was observed for cyclic loading with larger amplitudes (up to 1/25 in the overall drift angle) primarily because of cyclic yielding and resulting slip-type hysteresis experienced at the column bases. The degree of composite action changed in accordance with the deformation amplitude; increases in strength became less notable (meaning that the composite effect decreased) for larger deformation amplitudes. The effect of ALC panels (used for exterior finishes) on the structural behavior was nearly null, which indicates that the attachment details adopted for installation of ALC panels were satisfactory.

***Keywords**: steel; moment resisting frame; full-scale test; failure; composite action; building.*

INTRODUCTION

"Performance-based engineering" has become a standard norm for research, development, and practice of earthquake engineering particularly after the 1994 U.S. Northridge and 1995 Hyogoken-Nanbu (Kobe) earthquakes (for example, Performance 1995; Recommended 2000; NEHRP 2000; Notification 2000; Midorikawa et al 2000). Relevant themes of challenges range from the characterization of strong motions and their effects on the structural response, quantification of multiple levels of performance associated with the functionality, damage, and safety limit states, examinations into the interaction of various nonstructural components and building contents with building performance, among many others. To verify individual research findings and assure the expected performance of innovative developments and practices, *real data* obtained from "observations" and "experiments" are essential. They are rather difficult to acquire, however. A large earthquake event occurs very scarcely, which makes it difficult to monitor or measure the real behavior of structures at such an event. Building structures are massive; hence it is difficult to fabricate and load these structures in the laboratory, whereas miniature models are known to fail to duplicate the prototype behavior because of lack of similitude. Considering these circumstances, the writers conducted a comprehensive experimental project in which a full-scale, three-story steel building frame was loaded quasi-statically to failure.

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DEVELOPEMENT OF EARTHQUAKE-RESISTANT WELD-FREE STEEL BUILDING STRUCTURES WITH MECHANICAL JOINTS

Keiichiro SUITA[1], Kazuo INOUE[2], Praween CHUSILP[3], and Feng ZHOU[4]

SUMMARY

This paper presents a new steel building system, named 'weld-free' system, developed to overcome the quality assurance problem encountered in construction of steel moment resisting frames with conventional welded connections. The weld-free system adopts mechanical joints as beam-to-column connections and utilizes innovative column base connections. In this system, beam-to-column connections are equipped with buckling-restrained braces whose mechanical behavior has been verified by previous experimental studies. Major findings obtained from those studies are reviewed in this paper. Next, experimental verification of the newly proposed column base connections is presented. The cyclic tests were conducted on five full-scale models of foundation beam-column subassemblies with the innovative column base connections and one baseline specimen with the conventional base plate connection. The test results revealed large and stable hysteresis loops of the proposed system and verified the validity of the presented stiffness and strength prediction methods. Finally, an overview of the on-going full-scale tests of a weld-free steel building is described to demonstrate the real application of the weld-free system.

***Keywords**: Steel frames; earthquake resistant structures; bolted connections; knee braces; hysteretic dampers; column base; cyclic tests.*

INTRODUCTION

In construction of low- to medium-rise buildings in Japan, steel moment resisting frames (MRFs) are commonly adopted with beams welded to columns and columns connected to reinforced concrete foundation beams through base plates and anchor bolts. During the 1995 Hyogoken-Nanbu earthquake, several buildings experienced cracks and brittle fractures at welded beam-to-column connections, and not a few buildings sustained fractures at anchor bolts (*Reconnaissance* 1995). The damage was also observed in some relatively new buildings designed in accordance with Japanese seismic codes. After the tremor, modifications of welded beam-to-column connection details have been suggested to mitigate stress concentrations (*Technical* 1996). Although the modified connections have shown satisfactory performance in the laboratory, it is realized that the quality of welds is difficult to control in practice as long as the structural fabrication relies on workmanship. The defects as well as insufficient deposition are often of concern regardless of the connection details adopted. Besides, the post-Kobe Japanese practice generally requires larger volume of weld, implying that the connections become more relevant to the quality assurance problem. As a response to the damage observed at column bases, the design procedure for column base plate connections has been revised. However, the key connection details still remain unchanged despite shortcomings inherent in this type of connection, including severely pinched hysteresis behavior and susceptibility to fracture at anchor bolts.

To overcome the difficulty in the weld quality assurance as well as to enhance the seismic performance of column bases, a novel structural system, named 'weld-free' system, has been developed. The configuration of

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SEISMIC BEHAVIOR OF STEEL BEAM AND REINFORCED CONCRETE COLUMN CONNECTIONS

Chin-Tung CHENG[1] and Cheng-Chih CHEN[2]

SUMMARY

This research aims to investigate the seismic behavior of steel beam to RC column connections with and without floor slab, acting as a proof test for the design of a three-story three-bay reinforced concrete column and steel beam (RCS) in-plane frame at the NCEER, Taiwan tested in the year of 2002 by the international research corporation between Taiwan and USA. Based on the design of this RCS frame, six "cross shape" RCS joint sub-assemblages were constructed and tested. Parameters such as composite effect of slab and beam, stirrups in the panel zone, effect of cross beam, loading protocol and analytical model for the shear transfer in panel zone were investigated in this study.

***Keywords**: beam-column connections; composite beam; shear transfer.*

INTRODUCTION

Reinforced concrete columns and steel beams form together to resist seismic loading are referred as the RCS moment frame systems. Using RC rather than structural steel columns can result in material cost savings, increased structural damping and lateral stiffness of the building. To date, RCS connections can be characterized as two main categories: beam through type and column through type. Based on literatures, beams continuously passing through column panel zone (beam through type) behaved in a ductile manner under seismic loading; however, orthogonal moment connection in the panel zone may be labor intensive. Column through type using diaphragms or cover plates to connect steel beams and column wall may facilitate field construction, however, extra effort in connection details to ensure a better seismic capacity in terms of strength and ductility is needed.

Since 1989, researches on RCS composite system have been started by Deierlein et al. (1989), and Sheikh et al. (1989) in Texas University, where 15 beam-through-type connections without slab were tested. Two failure modes were distinguished such as panel zone yielding and bearing failure of column concrete due to cyclic loading from beams as shown in Figure 1. In 1993, Konno (1993) tested a series of RCS connections without slab. Research parameters included hoop details in panel zone, column axial load, and bearing strength of concrete. Test results showed that seismic capacity of RCS systems is not less than RC or Steel structures. Since 1997, corporations for research on RCS construction system have been conducted in US and Japan such as Baba and Nishimura (2000), Kim and Noguchi (1997), Nishiyama et al. (1997), Parra-Montesinos and Wight (2000), and Bugeja et al. (2000).

To study the composite effect of slab and steel beam on the moment connections, Yu et al. (2000) have tested several composite steel beams to steel column or SRC column connections. Test results showed that composite effect varied with types of connection, distribution of shear stud, floor thickness and amount of RC steel in slab. In general, shallow beam depth used in low-to-mid-rise building tends to have larger composite effect. Moreover, test results also revealed that slab provided support for the beam flange to prevent lateral torsional

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Seismic Design of Buckling-Restrained Braces Using Energy-Balance Concept

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SUMMARY

A simplified seismic design procedure for frames with buckling-restrained braces (BRB) was proposed based on the energy balance concept and the equal energy assumption. The input seismic energy was estimated from a design spectrum, and the elastic and hysteretic energy were computed from energy balance concept. The size of braces was determined so that the hysteretic energy demand is equal to the hysteretic energy dissipated by the BRB. According to analysis results, the maximum displacements of 3-story structure designed in accordance with the proposed procedure generally coincide well with target displacements. However the maximum displacements of the 8-story structures turned out to be on the conservative side.

Keywords : *seismic design, hysteretic energy demand, buckling restrained braces, energy-balance concept, equal energy concept*

INTRODUCTION

An energy-based seismic design method, which utilizes hysteretic energy of a structure as a main design parameter, is now considered as a potential alternative to the conventional strength-based seismic design method. The method is considered to be more advanced in that the accumulation of earthquake-induced damage can be taken into account in the design procedure.

In this study a simplified seismic design procedure for steel frames with buckling-restrained braces was developed based on the energy balance concept, which provides seismic input energy from a design spectrum. Leelataviwat et. al. [6] proposed a seismic design method for moment-resisting framed structures based on the energy balance concept. As the design procedure utilizes the equivalent single degree of freedom (SDOF) system to estimate the input and the hysteretic energy demands, the seismic energy demands obtained in multi-story structures with BRB were compared with those of corresponding equivalent SDOF structures.

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PERFORMANCE-BASED DESIGN FOR TRUSS-FRAME STRUCTURES USING ENERGY DISSIPATION DEVICES

Toru TAKEUCHI[1] and Kazuaki SUZUKI[2]

SUMMARY

Truss frame generally had to be designed elastically even against large seismic force, because of fragile characteristics led by member buckling. In this paper, damage tolerant design for truss frame structures using energy dissipation members in critical positions are discussed. Detailed designs for high-rise rack warehouse are studied, and simple method for evaluating the effect of these members is proposed.

***Keywords**: SEEBUS; earthquake engineering; truss structures; performance- based design; vibration control; hysteretic damper.*

INTRODUCTION

In seismic area, plastic design with moment frames have been popular for long time, with the concept of ductile characteristics led by plastic-hinges on bending beam ends. On the other hand, truss frame structures, popularly used for long-span roofs or industrial facilities, had to be designed elastically against design loads, because of less-ductile characteristics due to the axial member's buckling. However, designing truss structures elastically against large earthquake is not economic, not elegant in design, and remaining risks for fragile collapse in the event of seismic level exceeding the design criteria.

Recently, passively controlled buildings have become popular in Japan, and various types of passive energy dissipation devices are put in practical use. Many of them are incorporated within moment frames, achieving damage tolerant design, which keeps main structures in elastic even with great earthquake. The same concept can be applied for truss frame structures by incorporate energy dissipation members in critical positions, plasticize them firstly while other truss members are kept before buckling, and control entire structure ductile (Fig.1). This design concept will enable truss frame structures to be slender, elegant, economic and safe from buckling even in heavy seismic areas.

In this paper, above design concept is applied to practical design of high-rise automatic rack warehouse, using hysteretic energy-dissipation members, introducing their details and effects.

STRUCTURAL DESIGN OF RACK WAREHOUSE

The high-rise automatic rack warehouse are composed of 52m high, 5 lines of 1.3m-2.6m wide trussed structures connected each other at their top by horizontal beams (Fig.2). Each line of trusses is independent between the ground level and the top to keep spaces for vertical cranes, the aspect ratios of each set of trusses reaches 20 to 40. As diagonal braces stiffen the frames in longitudinal direction, this transverse direction is critical in strength and deflections. Walls are attached on the side trusses and roofs are on top beams, the rack structure itself composes the

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OVERVIEW OF THE 2003 ZEMMOURI ALGERIA EARTHQUAKE

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SUMMARY

Following the May 21st, 2003 big earthquake a technical survey campaign was launched from the second day to assess damages and losses in order to help public power to make decisions and to take urgent measures. Nearly one thousand engineers participated in this campaign concentrated generally around the most damaged areas at Algiers and Boumerders prefectures. As a first step, the authors carried out a statistical analysis of the collected data, which showed that reinforced concrete frame buildings were the most damaged category. Apartment buildings were also the facility that suffered a large damage compared to others. Statistical analysis of human losses and casualties was also carried out. It was found that female category and youth were the most affected during this catastrophe. In order to give more details about the type of damaged buildings and the different causes that led to such calamity, a recent small-urbanized zone of around 4km^2 located in Algiers prefecture was investigated in detail by the authors. A total of 725 buildings were evaluated. Analysis of the collected data showed that damage was randomly distributed on the area. This result would strengthen the assumptions of poor materials quality and lack of good details and design, as regards to other assumptions, for instance soil conditions effect. Reinforced concrete constructions were the most affected among other types where about 18% of constructions suffered moderate to heavy damage. Data analysis showed that the most affected constructions are those in the range from 5 to 6 stories while constructions with one story did not suffer any damage. Typical observed damages were, mainly, due to poor longitudinal and/or transversal reinforcement in the columns, very poor concrete quality, lack of shear reinforcement at beam-column joint, soft story, pounding and also formation of short columns.

***Keywords**: earthquake, ground motion, reinforced concrete, technical survey, damage assessment.*

INTRODUCTION

On May 21st, 2003, at 19:45 local time, a severe earthquake with a magnitude of 6.8 hit the northern-center part of Algeria, where the epicenter was located in the Mediterranean Sea, seven kilometers north of Zemmouri city, and 60 kilometers East of the capital Algiers. The main shock was followed by severe tremors with high magnitudes. The main shock and aftershocks induced severe damages and disturbed and/or disrupted the health services, school buildings, some roads, water supply lines, electricity, and telecommunications in the region. The worst affected prefectures are Boumerdes and Algiers. The most damaged cities include Bourmedes, Zemmouri, Thenia, Bordj-menail, Belouizdad, Bordj-el-bahri, Rouiba, and Reghaia. Other neighboring regions to Algiers and Boumerdes, like the prefectures of Tizi-ouzou, Bouira, Blida, Tipaza and Chlef were also affected by the enormity of the earthquake, however, the catastrophe and damage level were far below those of Algiers and Boumerdes. Officially, 2278 persons died, 11450 human casualties, more than 180.000 homeless, 10280 collapsed constructions and US$5.000.000.000 as a first estimation of direct economical loss.

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DAMAGE OF WOODEN HOUSES IN NORTHERN MIYAGI, JAPAN, EARTHQUAKES OF JULY 26, 2003

Yasuhiro HAYASHI[1], Hidemaru SHIMIZU[2], and Yoshiyuki SUZUKI[3]

SUMMARY

This paper reports the results of our investigation on the wooden house damage during the Northern Miyagi, Japan, earthquakes. First, earthquake observation records are summarized. Next, the PGVs are estimated from the toppling ratios or displacement of tombstones to be more than 90cm/s in the area, where the wooden house suffered serious damage. Then, from the simplified surveys of damage, it is demonstrated that the ratio of one-story houses is much larger than that of two-story houses. This damage tendency is analyzed and explained by using an equivalent linear SDOF system. Finally, four houses, which have one story and were built 100 years or more ago, are compared in seismic performance based on the response limit strength design method.
Keywords *: Northern Miyagi earthquakes, traditional wooden houses, peak ground velocity, damage*

INTRODUCTION

A series of strong earthquakes occurred three times in the Miyagi Prefecture, northern Japan, on July 26, 2003 as shown in Fig. 1 and in Table 1. These shallow inland earthquakes[1)] are called as the Miyagi Northern earthquakes. The main shock of the earthquakes is occurred at 7:13 AM with magnitude M6.2. The epicenter is located at latitude N38.402, longitude E141.175, with focal depth 12km. The foreshock and the biggest aftershock were occurred at 0:13 and 16:56 in the same day, respectively. Very high JMA (Japan Meteorological Agency) intensity of more than 6- at many stations during three earthquakes and thousands of buildings are severely damaged. Especially, these earthquakes caused collapse of many wooden houses. This paper reports our investigation on the wooden house damage in the most heavily damaged area.

Table 1 Parameters of the July 26, 2003 Northern Miyagi Earthquakes

Date	Time	Location		Depth	Magnitude	Max JMA intensity
26-Jul-03	13:08.3	38.432 N	141.168 E	12km	M5.5	6-
27-Jul-03	13:31.5	38.402 N	141.175 E	12km	M6.2	6+
28-Jul-03	56:44.5	38.497 N	141.193 E	12km	M5.3	6-

EARTHQUAKE OBSERVATION RECORD

The strong-motion networks[2-5)] by the NIED (National Research Institute for Earth Science, and Disaster Prevention, Japan), NILIM (National Institute for Land Infrastructure Management), JMA and local offices in this area are deployed very densely and a lot of ground motion recordings are observed. Many records are obtained by the local town offices. But, only the JMA seismic intensity and peak ground acceleration were printed out, and unfortunately, most of these digital data are lost because of overwriting by many aftershock data. The NILIM published lists of the peak ground acceleration values and SI values.

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SEISMIC PERFORMANCE OF PRECAST COLUMN-FOUNDATION CONNECTION ASSEMBLED BY POST-TENSIONING

Minehiro Nishiyama*1 and Fumio Watanabe*2

SUMMARY

In order to develop design recommendations for column-foundation connection assembled by post-tensioning in seismic regions, cyclic loading tests were carried out on 14 test units simulating such kind of connections under earthquake loading. The tests were consisted of two series: *Series A* was mainly for comparison between precast reinforced and precast prestressed concrete column-foundation connections, and *Series B* for investigating differences between test units with grouted and ungrouted tendons. The main experimental parameter other than the above was an axial load level.

INTRODUCTION

Post-tensioned precast construction has been getting popular in Japan because of the following advantages over conventional cast-in-situ construction: 1) Easier framing and less concrete casting at construction sites. 2) Shear transfer at the interface between members which are connected is easily achieved by friction due to prestressing force. 3) Full depth crack opening at the beam-column interface under cyclic loading at a large inelastic deformation, which may result in pinched hysteresis curves, is suppressed by prestress. 4) Permanent displacement after major earthquakes is smaller than that for ordinary reinforced concrete.

One type of the post-tensioned connections used in practice is a column-foundation connection. Ordinary precast reinforced concrete system is also often used. In Japan non-prestressed precast columns are more popular than prestressed ones. However, from the viewpoint of construction and restriction of construction time, there is a case that precast prestressed concrete system may be a better solution.

In Japan use of unbonded tendons for primary seismic resistant members like girders, columns and structural walls had been prohibited. This year the code has been revised and now unbonded tendons can be used for structural members if a kind of displacement-based design different from the currently used allowable stress based design is utilized, and some measures is taken against tendon fracture: protection for girders from falling down.

In this paper, two series of loading tests are reported. One is *Series A* in which dual-phase composite prestressing

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Experimental Investigation of Concrete-Filled Carbon Tubes(CFCT) Subjected to Lateral Loads under Constant Axial Load

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ABSTRACT

Concrete-filled carbon tube(CFCT) without any reinforcing bars are tested to investigate the lateral capacity of columns. The full-scale circular and square CFCT with various winding angle with respect to longitudinal axis of tube are subjected to lateral loads under constant axial load. The effect of thickness and winding angle of carbon tube on the lateral behavior of concrete columns is studied experimentally. The assumed ultimate moment capacity of confined columns compared with test data. The stress-strain model proposed by the authors considers the influence of winding orientation of carbon fibers on the confining capability of concrete core.

Keywords: *concrete-filled carbon tube(CFCT), lateral capacity of CFCT, strength, filament winding, winding angle*

INTRODUCTION

The concrete-filled carbon tube(CFCT) designed to replace or supplement conventional reinforcing steel also provides many advantages including outstanding confining capability and durability under seismic loadings. CFCT improves moment capacity by both its high tensile strength and increased compressive strength of confined concrete core. Concrete core

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DISPLACEMENT BASED SEISMIC DESING AND ANALYTICAL RESPONSE EVALUATIONS OF A FULL-SCALE CFT/BRB COMPOSITE FRAME

Keh-Chyuan TSAI[1], Yuan-Tao WENG[2] and Min-Lang LIN[3]

SUMMARY

AT time of this writing, a full scale 3-story 3-bay concrete filled steel tube (CFT) composite braced frame has been constructed in NCREE with buckling restrained braces (BRBs) and scheduled to be tested in October 2003. The full scale CFT/BRB frame test is part of an international collaboration between researchers in Taiwan and the United States. Measuring 12 meters tall and 21 meters long, the frame is among the largest frame tests of its type ever conducted. The frame is to be tested using the pseudo-dynamic test procedures applying input ground motions from the 1999 Chi-Chi and 1989 Loma Prieta earthquakes, scaled to represent 50%, 10%, and 2% in 50 years seismic hazard levels. This paper describes the displacement-based seismic design procedures adopted in the design of the structural members. A target story drift limit of 0.025 radian for the 2% in 50 years hazard level governs the design strength of the frame. Nonlinear analyses illustrate that the response of individual BRB member can be satisfactorily simulated by using truss elements implemented in two different general purpose nonlinear response analysis programs. Nonlinear dynamic analyses suggest that the peak story drift is likely to reach 0.025 radian after applying the 2/50 design earthquake on the frame specimen. Analytical results also suggest that the arrangement of 4, 3 and 3 actuators, each having 980 kN force capacity, might be necessary for the 1st, 2nd and 3rd floor, respectively. The BRBs at the upper two floors are more vulnerable than those in the first floor. The failure of moment connections is not likely to occur after the applying four earthquake load effects. CFT columns hinging at the base are expected, but should not fail as the rotational demand is moderate.

Keywords: *concrete filled tube, buckling restrained brace, pseudo-dynamic tests, displacement based seismic design, nonlinear analysis*

INTRODUCTION

Through international collaboration between researchers in Taiwan and the United States, a full-scale 3-story 3-bay RC column and steel beam RCS composite moment frame has been tested in October of 2002 in the structural laboratory of National Center for Research on Earthquake Engineering (NCREE) in Taiwan in October 2002 (Chen et al. 2003). In the year 2003, a full-scale 3-story 3-bay CFT column with the buckling restrained braced composite frame (CFT/BRBF) specimen has been constructed and scheduled to be tested in October in a similar manner. The 3-story prototype structure is designed for a highly seismic location either in Taiwan or United States. The typical bay width of 7m and typical story height of 4m have been found common in Taiwan and US building configuration, it also corresponds well with the 1m spacing of the tie down holes on the strong floor and reaction wall of the lab. The total height of the frame, including the grade beam, is within the strong wall height 15m. The 2150mm wide concrete slab is adopted to develop the composite action of the beams. Measuring 12 meters tall and 21 meters long, the specimen is among the largest frame tests of its type ever conducted. The frame will be tested using the pseudo-dynamic test procedures applying input ground motions from the 1999 Chi-Chi and 1989 Loma Prieta earthquakes, scaled to represent 50%, 10%, and 2% in 50 years

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ROLE OF HOOPS ON SHEAR STRENGTH OF REINFORCED CONCRETE BEAM-COLUMN JOINTS FOR SEISMIC RESISTANCE

S. J. HWANG[1] and H. J. LEE[2]

SUMMARY

This study investigated the effect of joint hoops on the shear strength of exterior reinforced concrete beam-column joints subjected to earthquake-type loading. Nine exterior reinforced concrete beam-to-column subassemblages were tested under reverse cyclic loading. All test specimens were designed to have adequate shear strength of joints according to the softened strut-and-tie model. The parameters investigated include the amount and the detailing of joint hoops. Test results indicated that the function of joint hoop is to carry shear as a tension tie, to constrain the crack width, and not to confine the concrete core. It is found that a lesser amount of hoop reinforcement with wider spacing could be used without significantly affecting the performance of joints. The current ACI's requirements, viewing the joint hoop as confining the concrete core, are not realistic and should be alleviated in its strict detailing rules for joint hoops. Test data also showed that a beam-column joint without hoop can possess satisfactory seismic behavior, as long as the joint is provided with adequate shear strength according to the softened strut-and-tie model.

Keywords: *beam-column joint; design; joint hoop; reinforced concrete; shear strength; test; strut-and-tie.*

INTRODUCTION

The role of horizontal hoop reinforcement in joint for seismic resistance is a subject of much debate. It has been argued that hoops carry a substantial portion of the joint shear directly, with the remainder being carried by the concrete core in the form of a diagonal compression strut (NZS 1995). An alternative argument is that hoops contribute to the shear resistance of joints indirectly by confining the concrete core, thus enhancing its diagonal compressive strength (ACI 2002). These conflicting views about the function of transverse reinforcement lead to different demands for hoop as well as the disparity in detailing rules.

Currently, the ACI 318-02 Code provisions (ACI 2002) emphasize the importance of the confinement of the joint core. In consequence, the closely spaced transverse reinforcement in the end regions of laterally loaded columns must be detailed within joints unless a suitable confinement is provided by the surrounding beams (ACI 2002). The use of crosstie is inevitable since the maximum spacing between legs of hoops is limited to 350 mm on center (ACI 2002). These ACI requirements for adequate concrete confinement result in congested joints which are very difficult to construct. Moreover, the increasing use of high-strength concrete, resulting in larger amount of joint hoops (ACI 2002), poses an even worse situation for construction. It seems necessary to declare whether joint hoops serve to confine or to carry shear in a more concise manner.

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EXPERIMENTAL STUDY ON HIGH SEISMIC PERFORMANCE WALLS

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SUMMARY

The structural behavior of high seismic performance walls subjected to reversed cyclic lateral loading were studied by testing seven large-scale specimens, including mid-, and low-rise framed shear walls. These experimental results were compared with those of four corresponding conventional specimens worked by the authors previously. The parameters of steel ratio and layout of reinforcement of walls were investigated. The reinforcements of walls were designed with 45° reinforcements, 45° and boundary vertical reinforcements, and hybrid conventional and 45° reinforcements. The experimental results show that the pinching effect, which frequently existed in the conventional shear walls, is remarkably improved in the new design high seismic performance walls. The larger steel ratio in the shear walls with 45° reinforcements induces less pinching effect. In addition, most of the maximum load, ultimate displacement, ductility factor, and energy absorption capacity of these new design framed shear walls are higher than the conventional ones. The structural behavior is highly dependent on the layout of reinforcements of walls. The new design shear wall possesses high potential to improve the seismic performance of buildings.

Keywords: *high seismic performance walls; large-scale tests; cyclic loading*

INTRODUCTION

Shear walls have been recognized as efficient earthquake resistance elements (Fintel 1991). Framed shear walls are extensively used as the components of earthquake resistance buildings. However, the conventional shear walls, which the reinforcements are in vertical and horizontal directions, frequently possess pinching effect in the load-displacement curves. The pinching effect will reduce the energy dissipation capability of wall. The improvement of conventional shear wall to reduce the pinching effect sounds an essential research.

Benjamin and Williams (1957) performed a series of tests on low-rise framed shear wall (Height/Width = 0.57) subjected to monotonic loading. They proposed a formula to predict the elastic-plastic load-displacement curves, and obtained the structural stiffness at various loads. Yamada et al. (1974) tested a low-rise framed shear wall (Height/Width =0.44) by monotonic loading. They proposed a displacement model, and studied the parameters of wall thickness and steel ratio of wall. Barda et al. (1976) presented tests on low-rise walls with boundary elements. They studied the parameters of vertical steel of boundary elements, horizontal and vertical steel of wall, and height to width ratio. Mau and Hsu (1987) investigated the shear behavior of framed walls and proposed a formula to predict the strength of walls. Mo and Kuo (1998) presented a displacement control test on small-scale framed shear wall subjected to reversed cyclic lateral loading. They studied the parameters of structural dimension and concrete strength. The experimental results were compared with solutions obtained by truss model and IDARC software, and a large deviation was found between test and analytical results. Recently, Mansour and Hsu (2003) presented the experimental results of reinforced concrete elements under

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AN EFFECTIVE REPAIR-REHABILITATION WORKING METHOD FOR NON-DUCTILE RC FRAMES

Yeou-Fong LI[1], and Yan-Jie LIN[2]

SUMMARY

In this paper, an effective repair-rehabilitation working method is proposed for moderately damaged building structures after major earthquakes. Three reinforced concrete (RC) frames with nil, half-height and full-height brick walls were designed and tested at the National Center for Research on Earthquake Engineering (NCREE). After the columns of these frames were damaged, steel wires and 2 layers of carbon fiber reinforced plastics (CFRP) are used in the proposed method to confine reinforced concrete columns. This repair-rehabilitation working method can increase the shear strength and ductility capacity of columns to resist the earthquake force. The advantages of steel wires are their bending flexibility, material stability and availability. The stress-strain relationship of the confined concrete, proposed by Li et al. (2003), was used in the theoretical sectional analysis. Then, we used the Response 2000 (Bents, 2001) to obtain the moment-curvature curve of the confined columns. For the analysis of brick panel, an "equivalent truss model" was used. Finally, the frame and the equivalent truss were engaged and then analyzed following a non-linear pushover analysis to obtain the strength envelopes of each frame. Results of the experiments show that spirally wrapped steel wire cable and CFRP are an effective repair-rehabilitation working method for damaged RC frames. The analytical results can predict the lateral force-displacement relationships of RC frames accurately.

Keywords: *Non-ductile frame, Carbon fiber reinforced plastics, Steel wire*

INTRODUCTION

In 1999, a major earthquake measuring 7.3 on the Richart Scale hit Central Taiwan. After the so-called Ji-Ji Earthquake, some frames and columns of existing buildings suffered shear-failure damage but did not collapse. As already known, the brittle shear failure in RC columns is identified as one of the most dangerous failure modes because it may cause the collapse of buildings. If the non-ductile frames or columns suffering shear-failure damage could be repaired and rehabilitated to meet the current seismic code, it should be more economical and feasible than demolishing and reconstructing the whole building. As seen from the failure of buildings after Ji-Ji Earthquake, most of the damaged buildings have non-ductile frames that fail because of their poor design or construction. It is necessary to develop an effective and efficient repair and rehabilitation working method to prevent the buildings from collapsing during the aftershocks. In this paper, we proposed an effective and efficient repair-rehabilitation working method. The advantages of this method are: (1) it can easily be applied by less-experienced workers; (2) the materials are available and easy to obtain; (3) it does not call for any heavy equipments; and (4) it is faster than other working methods.

In this paper, three major topics will be introduced in the following order. First, the design of the three as-built non-ductile RC frames, and the proposed repaired-rehabilitation working method for the damaged RC frames are introduced. And the experimental setups of the non-ductile RC frames at NCREE are introduced. Next, experimental results regarding the ductility, ultimate lateral force, and energy dissipation of the RC frames are

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Seismic performance and limit states of R/C moment resisting structured frames with non-structural members

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Abstract

In order to establish better performance-based seismic design for R/C moment resisting structured frames with non-structural members, this report examines seismic damage, repair cost and damage impression. Initially, experiments were performed with three half-scale specimens in order to investigate the seismic performance for the structured frames with non-structural elements, such as the mullion-spandrel complex with doors, the sashes and finish materials. Next, repair cost analysis based on the test results was done to investigate the repairable limit. Finally a questionnaire survey was undertaken using digital photographs of damage caused in the initial experiments to investigate the performance limit states based on people's impression of the damage. By applying those relationships, the standard values of limit states based on the experienced maximum story drift angles as four levels ((1) serviceability, (2) minor repair, (3) major repair, and (4) safety) were proposed.

Keywords : *reinforced concrete, non-structural members, , seismic performance, seismic damage, repair cost, damage impression, serviceability, reparability, safety*

1 Introduction

When structural designers design the seismic performance of building structures, the spandrel wall, side wall and mullion-spandrel complex of reinforced concrete are clearly distinguished structural walls and non-structural walls. As for structural walls, the expected performance as a structural member is evaluated in a structural design. On the other hand, the non-structural walls are disregarded in a structural design. Therefore, the influence that the wall exerts on the structural behavior should be reduced as much as possible, and also their influence should be evaluated appropriately

Non-structural members within buildings have typically received a lot of damage during earthquakes. Prior to the 1968 Tokachioki earthquake (which hit northern Japan), Japanese engineers had regarded damage of non-structural members as less important than damage to structural members[1)]. After the Tokachioki earthquake, in 1971 the requirement for the maximum hoop spacing decreased to less than 10cm, in order to prevent brittle shear failure. The focus on the influence of the non-structural members to the seismic behavior of the structure was awakened. In 1981 the new seismic design code was enforced. Since 1981 a seismic design concept in which a moment resisting structured frame of strong columns and weak beams has been adopted. Isolation of the connection between cast-in-place non-structural members and structural members has also been recommended[1)]. Moreover, the installation methods of non-structural members have been variously improved.

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SIMULATION OF DAMAGE PROGRESSION IN LOWER STORIES OF AN 11-STORY BUILDING

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This paper is to be submitted to the 4th International Conference on Concrete under Severe Conditions of Environment and Loading (CONSEC'04) which will be held in Seoul, Korea from June 27 - 30, 2004.

SUMMARY

To investigate the seismic behavior of the lower part of an eleven story reinforced concrete frame building, two 1/4 scale reinforced concrete frames with two stories and one span were tested. Both frames were identical but axial load variation was different. Tested specimens did not show any strength degradation even though they were loaded to a drift of 6 % and 7 %. Beam elongation, column shortening and variation of shear force at each column base were measured. Good agreement was found between the analytical and the experimental load-displacement at the first story, second story and the entire frame. The analytical curvature-drift angle relationships for frame components matched also well the experimental ones.

Keywords: *Damage; ductile RC frame; axial load variation; plastic hinge; beam elongation*

INTRODUCTION

After the accomplishment of the first part of the test program where sixteen isolated small and large-scale reinforced concrete columns were tested under different severe loading history [1][2], two reinforced concrete frames with two stories and one span were designed and tested in Kyoto University to investigate the seismic behavior of the lower part of an entire frame. These frames were scaled to 1/4 in order to fit our loading system. The reinforced concrete frames were designed with the latest Japanese guidelines [3]. The models represented the lower part of an eleven story reinforced concrete frame building prototype. Many researchers [4][5] investigated the column seismic behavior under different type of loading in the past. However, not enough experiments were done for frame structures or beam-column assemblages. Presence of beams and slabs in the structure may change the column seismic behavior dramatically. The first target of our testing was to quantify the bending moment, axial load and shear distribution at the first story columns. The second target was to measure the beam elongations with respect to the frame drift, and the last target was to predict the load-displacement at each story as well as the component deformation analytically.

EXPERIMENTAL PROGRAM

Test setup

The cross section of the columns was 270x270 mm and 180x270 mm for beams. The height of the first and second floors was 765 and 840 mm respectively. The span length, from column axis was 1800 mm. The

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STRUT-AND-TIE MODELS FOR REINFORCED CONCRETE INTERIOR BEAM-COLUMN JOINTS WITH REQUIRED DUCTILITY

Soo-Gon Lee[1], and Sung-Gul Hong[2]

SUMMARY

This paper presents a strut-and-tie model for shear strength of RC interior beam-column joint with consideration of plastic hinge deformation of beams adjacent to the joint. The proposed strut-and-tie model considers both of diagonal strut mechanism and truss mechanism as main transfer mechanisms of joint shear. The effect of beam plastic deformation on the strength of each component within this model is investigated to explain the decrease in the joint shear strength with the increase in its system ductility. The strain of beam longitudinal bars at the column face of joint is taken as the main parameter as the system ductility. The strain of bars in yielding state is derived from the story drift required in seismic design. Once the bar strain from the beam is given, a linear strain distribution within the joint region is assumed to find the bond forces influencing the extent of truss mechanism and determining the strength of diagonal strut for diagonal strut mechanism. This model is applied to a typical interior beam-column joint and the theoretical results show good agreements with experimental results. Using this model, the shear strength of beam-column joints can be expressed in terms of system ductility level. This proposed model may be applied to the displacement based design for RC beam-column joints not only in the high-seismicity zone but in low- or mid-seismicity zone as well.

Keywords: *Strut-and-Tie Models, Interior Beam-Column Joints, Ductility Based Design, Limited Ductility*

INTRODUCTION

A strut-and-tie model is a representation of internal force flows in reinforced concrete members by discrete compression struts and tension ties joined together at nodes [Schlaich et al. (1987)]. As the strength models based on the assumption of ultimate state, strut-and-tie models are today considered by researchers and structural engineers to be a rational tool for the design of D-regions, where the stress is not linearly distributed. Strut-and-tie models require sufficient deformation capacity of components of models. However, while reinforcing steel typically exhibits a rather ductile behavior, the behavior of concrete is far from being plastic. In addition, bond shear stresses transferred between reinforcing bars and the surrounding concrete result in a localization of steel strain near the crack, particularly in post-yield range, reducing the overall ductility of bonded reinforcement. Hence, in order to justify the application of strut-and-tie models to structural concrete it is necessary to ensure a sufficient deformation capacity through appropriate detailing with use of effectiveness factor for concrete.

Recent researches on earthquake engineering, however, are turning toward performance-based design so as to overcome the disadvantages of the current strength-based design concepts, which have no direct relation between seismic load and performance of the structure such as strength and ductility. Current strut-and-tie models, however, provide only required strength of members for seismic design. To overcome this limitation, Marti et al. (1998) suggested a tension chord model to calculate deformation of the tension tie component, which is applied to determine the deformation limit of flexural members and extended to deal with shear problems. Deformation

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