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ABSTRACTS

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Paper No. 001

SIMPLIFIED GROUND MOTION PULSES IN THE NEAR-FAULT REGION

Long-jun Xu[1,2] and Li-li Xie[2]

Near-fault ground motions with long-period pulse have been identified as critical in the design of structures. To aid in the representation of this special type of motions, 8 simple pulses that characterize the effects of either the fling-step or forward-directivity are considered. Relationships between pulse amplitudes and velocity pulse period for different pulses are discussed. Then, response spectral and Fourier amplitude spectral characteristics for the simple pulses are identified and compared in terms of fixed PGA and PGV, respectively. It is concluded that response spectra and Fourier amplitude spectra are all strongly affected by the duration of pulses and the shape of the basic pulse. These special aspects of pulse waveforms, their elastic response spectra and Fourier amplitude spectra should be well accounted for in the estimation of ground motion pulses for use in engineering studies, in particular when local site effects are considered in the near-fault region.

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Paper No. 003

STRONG GROUND MOTION SOURCE SCALING AND ATTENUATIONMODELS FOR EARTHQUAKES LOCATED IN DIFFERENT SOURCEZONES IN TAIWAN

Vladimir Sokolov[1] , Chin-Hsiung Loh[2], and Wen-Yu Jean[3]

The ground-motion database collected recently in Taiwan was used for evaluation of strong ground motion models. The database contains more then 2800 acceleration records from M > 3.0 – 3.5 earthquakes occurred in 1993-2004. The records were obtained at rock (class B) sites located in the northern and eastern parts of Taiwan. Parameters of attenuation models (geometrical spreading and anelastic attenuation) were evaluated using acceleration spectra corrected for the site effect. The horizontal-to-vertical Fourier spectral ratio of the S-wave phase was used for the correction. The analysis was performed for three characteristic zones, namely: shallow (hypocentral depth < 30-35 km) earthquakes occurred beneath central Taiwan, shallow offshore earthquakes occurred to the east of island, and deep earthquakes (depth > 35 km). Analysis of spectra corrected for site effect, attenuation, and the influence of upper crust (*kappa*-factor) showed that the source spectra in Taiwan region may be described by the Z-square spectral model (Brune, 1970). The value of seismic moment is estimated from regional relationships between seismic moment and local magnitude. The stress parameter should be considered as a magnitude-dependent quantity (120-150 bars for M 5.0 and 250300 bars for M 6.8) for shallow earthquakes beneath central Taiwan. The offshore and deep earthquakes are characterized by relatively constant values of the stress parameter.

Keywords: Strong Ground Motion, Attenuation Relation, TSMIP, Taiwan

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Paper No. 004

SITE-SPECIFIC PREDICTION OF SEISMIC GROUND MOTION WITH BAYESIAN UPDATING FRAMEWORK

Min Wang[1] and Tsuyoshi Takada[2]

Prediction of the ground motion with the past attenuation relation is widely adopted in the seismic risk analysis. The past attenuation relation can capture the mean characteristics of the ground motion and its uncertainty is about from 0.4 to 0.7 in natural logarithm. As is known, the regression coefficients and the uncertainty of the past attenuation relation are obtained with the classical regression using the data observed at different stations and in different earthquakes, which means these regression coefficients and variance are common to be adopted for different stations. However, we prefer to acknowledge that the mean characteristics and variance are different one another, that is, some or all regression coefficients and variance are different station by station. Especially in the site-specific risk analysis, a more accurate site-specific attenuation relation is preferred to the past attenuation relation. The uncertainty for a specific site in the prediction of ground motion is needed rather than the common uncertainty. The Bayesian updating approach is an effective methodology to solve this problem. In the Bayesian inference, the parameters are considered as random variables and the inference are made by considering their distribution conditional on the data. Based on the Bayesian updating approach, the site-specific attenuation is developed with the observations at the site in this paper. Rather than developing a new attenuation relation, a correction term in a linear model is developed to the existing past attenuation relation in common use. If there are few data available, the variables of the correction term should be reduced, say only the constant term remains. If there are sufficient data in the space of the variables, the correction term in a linear model of magnitude and distance is suggested. This makes the prediction more flexibility. The relative uncertainties associated with the parameters inferred by the Bayesian approach are also accounted for. Applications of the Bayesian updating at two actual sites of K-NET and SK-NET are illustrated as examples. The differences of the predictions between the past attenuation relation and the results from Bayesian inference are discussed. The uncertainty associated with the prediction in terms of predictive distribution accounts for all uncertainties, that is, inherent variability, model uncertainty and statistical uncertainty.

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Paper No. 005

CUBOIDAL INFINITE ELEMENTS FOR SOIL-STRUCTURE-INTERACTION ANALYSIS IN MULTI-LAYERED HALF-SPACE

Choon-Gyo Seo[1], Chung-BangYun[2], Jae-Min Kim[3]

This paper presents 3D infinite elements in Cartesian coordinates for the elastodynamic problem in multi-layered half-space. Five kinds of infinite elements are developed for horizontal, horizontal-corner, vertical, vertical-corner and vertical-horizontal-corner elements developed by using approximate expressions of multiple wave components for the wave function in exterior far-field soil region. The elements can contain many wave components with modified wave numbers and is available to the multi-wave propagating problem. Numerical example analyses are presented for the compliance and impedance functions of rigid disk and rectangular footings on homogeneous and layered half-space. Earthquake response analysis have been carried out for a layered soil medium also. The numerical results obtained show the effectiveness of the proposed infinite elements.

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Paper No. 009

SELECTION OF TIME SERIES FOR SEISMIC ANALYSES

Jennie Watson-Lamprey[1] and Norman Abrahamson[2]

To obtain design time series, it is common practice to select empirical recordings of ground motion and modify them by scaling or by making them spectrum compatible. Even after making time series spectrum compatible, the computed non-linear response of a system can vary greatly depending on the recordings selected. A method for generating a time series selection procedure based on record properties, not simply magnitude and distance is presented. The procedure is for use in non-linear analyses that are intended to result in an average response of the non-linear system.

A proxy of the non-linear system is generated. Using a suite of recorded and scaled ground motions as inputs, a regression analysis is performed to develop a model for the proxy response based on the properties of the record and the proxy. Candidate scaled time series are evaluated to find those that yield a response of the proxy that is near the expected response for an event. Those scaled time series with responses near the expected value are selected as the optimum time series for defining average response even if the scale factors are larger than commonly accepted.

Results for applications to structural response and slope stability are discussed. The resulting time series selection methods allow for wider magnitude and distance bins for candidate time series, and reduce variability in the response of the system.

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Paper No. 010

UNIFORM SPECTRA AND DESIGN SPECTRA FROM SCENARIO EARTHQUAKE

TAO Xiaxin[1] and TAO Zhengru[2]

Site-specific spectra are commonly adopted in seismic design of critical facilities. The spectra depend on regional earthquake environment, attenuation feature of ground motion, and local site condition. At first, uniform spectrum was introduced and widely adopted. Then its disadvantages were pointed out by researchers and engineers, and are summarized in this paper. An approach of deriving design spectra from scenario earthquake were presented afterwards, and applied in practice. The latter is questioned for the determine procedure of scenario earthquake. A procedure is described in detail in this paper via a case demonstration. And the adaptability of the approach at both short and long period ranges is validated by the case study.

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Paper No. 011

EARTHQUAKE ACTION FOR SITES OF US COMPANY IN CHINA

Zheng-ru Tao[1] and Xia-xin Tao[2]

Some offices of a famous US based company are located in cities of China. In order to reduce the loss in future earthquake, the company wants to have the seismic risk of these offices evaluated by FEMA 310 with just the hazard information on seismic zoning map of China. Since the earthquake action provisions in seismic building codes of both China and USA are quite different, the two procedures to construct response spectra are compared in detail. The main difference is pointed out that the characteristic period from Chinese code is shorter than the corresponding values from FEMA 310. 72 design response spectra from GB50011-2001 and 25 spectra from FEMA 310 are constructed to compare maximum amplitude and characteristic period of spectra by both procedures. A final relationship as a table is obtained by least squares method over the whole period range and graphical comparison. The result also shows that the seismic design levels in both countries are not different so much.

Keywords: building code, earthquake action, response spectra

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Paper No. 015

PROBABILISTIC SEISMIC HAZARD ANALYSIS AND ESTIMATION OF SPECTRAL STRONG GROUND MOTION ON BED ROCK IN NORTH EAST INDIA

M. L. Sharma[1], and Shipra. Malik[2]

The present paper consists of the probabilistic seismic hazard analysis for the North East Indian region which is one of the most seismically active regions in India. The region has been divided into three major seismogenic sources namely, the regional features in the Himalayas i.e., Main Boundary Thrust and Main Central Thrust, Shillong massif and the north south trending Arakan Yoma seismic belt. The probabilistic seismic hazard estimation is carried out for ten seismogenic zones which are further subdivisions of seismogenic sources based on the seismotectonics modeling of the area. The complete as well as the extreme part of the catalogue is used to make maximum likelihood estimates of maximum probable earthquakes for various return periods. The maximum b-value estimated is 1.04 for Shillong plateau (Seismogenic Zone III) while the return periods of magnitude 6.0 have been estimated as about seven years for the eastern boundary thrusts (Seismogenic Zone VIII and IX) which are part of the Arakan Yoma ranges. The hazard in these individual zones is presented in form of seismic zoning at the bed rock level for 10% and 20 % exceedance values of strong ground motion in 50 years. The epistemic errors has been considered using logic tree method by using the spectral attenuation relationships developed for this area as well as those developed for similar tectonic environments elsewhere and adopted for the region. The spectral acceleration at different structural periods is presented for major cities in the region. The PGA value ranges from 0.05g to 0.6g for 10% exceedance while the PGA value ranges from 0.01g to 0.4g for the 20 % exceedance in 50 years. The results of the probabilistic seismic hazard analysis in the present study may be used for the seismic microzonation of the area and for earthquake engineering use.

Key Words : PSHA, Himalaya, Return Period, Maximum Likelihood, Seismogenic zones, spectral acceleration

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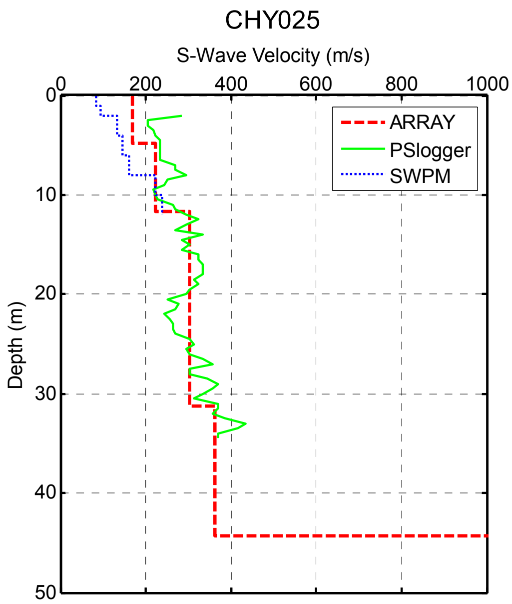
Paper No. 019

COMPARISON OF DIFFERENT METHODS FOR INVESTIGATION OF SHALLOW SHEAR WAVE VELOCITY STRUCTURES

Chun-Hsiang Kuo[1], Kuo-Liang Wen[2], Tao-Ming Chang[3], Hung-Hao Hsieh[4] and Ding-Shing Cheng[5]

In the past years, we conducted array measurements of microtremor in several tens of Free-Field Strong-Motion Stations to estimate shallow shear wave velocity structures. In the same stations, the velocity structures were also investigated by using the stress wave propagation method (SWPM) method. Central Weather Bureau (CWB) and National Center for Research on Earthquake Engineering (NCREE) launched a project to build the Engineering Geological Database for Strong Motion Stations since 2000 and measured the shear wave velocity using Suspension PS Logger method. In this study, we will compare the results from three different methods, ARRAY, SWPM and PS-Logger in the selected fifteen sites which distribute in two counties.

The figure shows an example of the CHY025 site. The diameter of microtremor survey is from 4 to 65 meters, and sensor distance of SWPM is from 2 to 32 meters. The measured depth of PS-Logger is 34.5 meters.



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Paper No. 021

SITE EFFECT ANALYSIS FROM DE ANSE MICROTREMOR SURVEY IN THE TAIPEI BASIN

Kuo-Liang Wen[1], Tao-Ming Chang[2], Shih-Chi Lin[3], Che-Min Lin[4]

Although Taipei basin already had a very dense observation network of strong motion accelerometers under the Taiwan Strong Motion Instrumental Program (TSMIP) which conducted by the Central Weather Bureau. A dense microtremor survey was done in the Taipei basin area by using large dynamic range digital recorder, because it can quickly yield the ground motion and spectral characteristics of the site. The variations of amplitude and predominant frequency throughout the basin are analyzed by using the horizontal-to-vertical spectral ratio method. The relationships between these variations and the geological structure of the Taipei basin are studied. The results from the microtremor survey consisted with that from the TSMIP earthquake records. Which shows that microtremor survey can served as a rapid method for realizing the characteristics of the ground motion and the microtremor results can served as a reference in earthquake resistant design, microzonation, and ground motion prediction in the Taipei basin.

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Paper No. 022

DISCUSSIONS ON MICROZONATION OF TAIPEI BASIN

Cheng-Hsing Chen[1], Chi-Chin Tsai[2] and Jiunn-Shyang Chiou[3]

A new seismic microzonation map for the area of Taipei Basin had been published in the latest version of Taiwan Seismic Specification for Structures (2005). It was developed based on the contour map of parameter C_v, which defines the normalized response spectra deduced from past strong ground motions recorded in the Taipei Basin. However, this proposed microzonation did not consider the site geologic condition. To investigate the relationship between microzonation with the site geologic condition, the values of Vs_{30} at the seismograph stations were firstly calculated to observe the relationship of Vs_{30} and C_v values. Vs_{30} is an averaged shear velocity within 30 m below the ground surface. In addition, this paper uses earthquake data and geologic data to identify the ground period of sites within the Taipei Basin and compares the contour map of ground period with the proposed microzonation map. To estimate the ground period of Taipei basin, the methods of spectral analyses were applied in this study. The spectrum analysis was performed by using the earthquake data recorded during the Chi-Chi earthquakes and the Jia-Yi earthquake.

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Paper No. 023

AN HHT SYSTEM FOR DESCRIBING SITE EFFECTS

S.Garcia[1], F. Correa[2] and M. Romo[3]

The traditional Fourier-spectra-based tools do not adequately capture the evolutionary and localized features of the natural-systems responses. When these systems are subjected to seismic loads the Fourier analysis may misinterpret the information due to the time-variation of frequency characteristics in non-stationary processes. This study explores the use of the Hilbert-Huang Transform (HHT) for analyzing earthquake recordings and the associated dynamic-soil behavior. The HHT, integrated by the Empirical Mode Decomposition (EMD) and the Hilbert Transformation (HT), enables engineers to analyze non-stationary oscillation systems and to obtain more detailed intensity descriptions on time-varying frequency diagrams. HHT is used in this work to examine responses of soft-soils deposits in Mexico City. The results indicate that the proposed methodology is able to extract some motion characteristics useful in geoseismic studies which are not properly seen when are employed conventional data processing techniques.

Keywords: Hilbert-Huang Transform, site effects, signal analysis, nonlinear behavior

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Paper No. 025

SEISMIC RESPONSE OF SOIL SITES IN HONG KONGBY NUMERICAL MODELING

Yuk-Lung Wong[1], Yi-Fan Yun[2], Xun Guo[2] and John X. Zhao[3]

We present numerical modelling results for three typical soil sites in Hong Kong subjected to a large number of rock site ground motions. The sites selected are naturally deposited colluvium and alluvium sites (Group I and II Sites), and reclaimed soil sites with layers of soft marine deposit (Group III Sites). The rock site motions selected are from both intra- and interplate earthquakes with PGAs from 0.005g to 0.25g. Our results show that variation of normalized spectra is not always consistent with increasing rock site shaking levels, and exhibits a very large scatter at most spectral periods. Variation of peak ground accelerations (PGA) shows that soil nonlinearity is unlikely to cause PGA deamplification in most soil sites in Hong Kong for a rock site excitation with a PGA of 0.1g or less. For a soil site without soft marine deposit layers, mean spectral ratios are likely to be significantly large than 1.0 for all periods and can be as high as about 3.0 at first modal period of a site. For a site on reclaimed land with soft marine deposit layers, deamplification can possibly occur in a period range of 0.2-1.0s but significant amplification at periods beyond 1.0s is observed from our numerical results. Mean amplification ratios of soil sites with soft marine deposit layers can be in a range of 1.5 – 2.5 at the first modal period of the site. This level of amplification would lead seismic load as the control design load for many buildings in soft soil sites in Hong Kong.

Keywords: Seismic response, Soil sites in Hong Kong, Numerical modeling

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Paper No. 026

UNCOUPLED NUMERICAL ANALYSES FOR GROUND LATERAL SPREAD EFFECTS ON SINGLE PILE

San-Shyan Lin[1], Y.J. Tseng[2], C.H. Wang[3], and W.F. Lee[4]

It's known that the effects of liquefaction on piles are often damaging. Permanent ground deformation or ground lateral spreading is observed to be the main cause for the distress of piles. The purpose of this paper is to use uncoupled method for analysis of ground lateral spread effect on piles. The computer code, CYCLIC-1D developed at University of California at San Diego and accessible from the web, is used for lateral ground deformation estimation. Subsequently, the pile performance is studied considering the effect of ground deformation obtained from Cyclic-1D. Three centrifuge tested examples were studied by the aforementioned method. Reasonable agreement was obtained between the predicted and the measured results.

Keywords: soil liquefaction, pile, lateral displacement

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Paper No. 027

RESPONSE OF RENYI-TAN DAM DURING THE 921-JIJI EARTHQUAKE

Meen-Wah Gui[1] and Hsien-Te Chiu[2]

Taiwan is located in one of the world earthquake-active zones, i.e. at the junction of the Manila and Ryukyu trenches in the Western Philippine Sea. In 1999, a devastating 921-JiJi earthquake struck Taiwan and caused severe properties losses and claimed thousands of lives. In addition, excessive ground deformation also caused severe cracks to the nearby Shi Gang concrete dam and caused the dam to completely losses its ability to retain water. This has resulted in a series of dam safety assessment from both the government agencies and research institutions in Taiwan. This study examined the behavior of Renyi-Tan earth dam during this JiJi earthquake. A series of numerical analyses treating the dam materials to obey Finn's model has been performed using the finite difference program FLAC. The numerical results were presented and evaluated from the viewpoint of displacement, excess pore pressure, stress path, and accelerations. The results showed that the dam was still intact during the JiJi earthquake because the generated excess pore water pressures in the dam body were only about 60% of its effective overburden stress, which inhibited the dam from liquefaction.

Keywords: dynamic response, numerical analysis, earth dam, excess pore-water pressure

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Paper No. 030

A CONTINUOUS HYPERPLASTICITY MODEL FOR CLAYS UNDER CYCLIC LOADING

Suched Likitlersuang[1]

The fact that soils can only exhibit truly elastic behaviour at very small strains is commonly known, so that soil behaviour under cyclic loading at small to moderate strains involves hysteretic behaviour. As the amplitude of cycling loading increases the soil stiffness decreases and the damping ratio increases. These are well established experimentally, but theories that successfully describe this behaviour are less well developed. This study presents a simple model for the behaviour of clay under cyclic loading which can capture the main features of small-strain cycling. An essential part of the model is that an effect of immediate stress history can be modelled. The model is described using the "continuous hyperplasticity" framework. Essentially this involves an infinite number of yield surfaces, thus allowing smooth transitions between elasticity and plasticity. The framework allows soil models to be developed in a relatively succinct mathematical form, since the entire constitutive behaviour can be determined through the specification of two scalar potentials. An implementation of the continuous hyperplasticity model is also carried out. Finally, comparisons between theoretical prediction and cyclic undrained triaxial compression test data of Bangkok Clay are presented.

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Paper No. 031

STUDY AND ANALYSIS ON SHAKING TABLE TESTS OF DYNAMIC INTERACTION OF SOIL-STRUCTURE CONSIDERING SOIL LIQUEFACTION

Peizhen Li[1], Xilin Lu[2] and Yueqing Chen[3]

Shaking table model tests and analysis on soil-structure interaction system with liquefaction soil are described in this paper. A flexible container is fabricated to minimize the box effect. Pile foundation is used in the test. A 12-story cast-in-place R.C. frame model are used as superstructure, and Shanghai soft soil is employed as model soil. In the tests, macro-phenomena of soil liquefaction and structure failure due to natural earthquake are reproduced well, such as sand to boiled, water to be emitted, foundation and structure to be sunk. The failure status of scale model agrees with the actual failure phenomena of prototype. Some important findings from the present tests and calculation are as follows. (1) Based on these tests, the issues of the development of excess pore water pressure in soft soil under simulated earthquake excitations are investigated. (2) Excess pore water pressure in soil increases with the increasing of excitations. And variation of excess pore water pressure is related to the situation of measuring point, soil characteristics, the spectral characteristics of seismic excitation, and so on. (3) Excess pore water pressure does not always dissipate in short time immediately after the excitations, but it may keep on increasing too.

The effective stress method of considering the soil as equivalent linear material in divided time intervals is introduced. And the method is realized in ANSYS program by using the ANSYS Parameter Design Language. Furthermore, the method of equivalent linearity is improved to the method of calculating nonlinearity step by step. Nonlinear model and computer simulation method of high-rise building considering liquefiable soil-structure interaction is established through comparison between shaking table test and theoretic analysis. The rule drawn from the calculation is agreed with those from the tests, though there have some difference between the calculation and tests in quantity.

In the seismic research of high-rise building, the effect of the liquefaction of soil on the seismic response of soil-structure interaction system is a very important and complicated problem. The analytic model and calculation method put forward in this project will develop the seismic analysis theory of structure, and will also develop the dynamic similitude theory and computer analytic method of model test. The practical value lies in improving the seismic design method of structure and giving guidance to the engineering design.

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Paper No. 033

IMPLEMENTATION OF BENDER ELEMENTS TO MEASURE IN-SITU STIFFNESS OF SOFT CLAYS

Young-Jin Mok[1], Jae-Woo Jung[2], Man-Jin Han[2], and Chul-Soo Park[2]

Bender elements, composed of thin piezo-ceramics and elastic shims, have been used to measure shear wave velocities of specimens in laboratories. As a preliminary stage of their field applications, an in-house research of optimizing suitable bender elements and their geometrical arrangement has been carried out in a barrel of kaolinite-water mixture. Two types of measurement configuration, similar to cross-hole and in-hole seismic testing, have been implemented. Prototype instrumented rods were penetrated into a soft clay layer in the west coast of Korea and excellent shear waves were recorded. Development of penetration device(mandrel) and associated instrumented rods are in progress for deeper investigation.

In cross-hole configuration shown in Fig. 1, one rod was mounted with source benders and the other rod with receiver benders, respectively. Each pair of source and receiver benders was used to generate one cycle of harmonic wave and to monitor the shear wave motion at each location. The qualities of the shear wave signals were excellent as shown in Fig. 2, where the arrow indicates the first arrival of shear wave energy. In in-hole type as shown in Fig. 3, the instrumented rod was penetrated with mandrel, and a pair of source and receiver benders was popped out by pulling out the mandrel. Shear wave signals of phenomenal quality were also recorded as shown in Fig. 4.

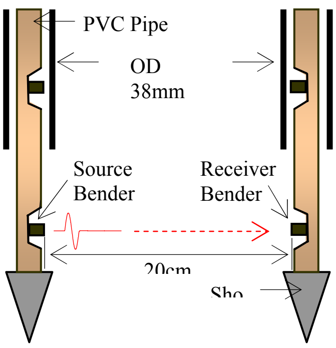

Fig. 1 Cross-Hole Configuration

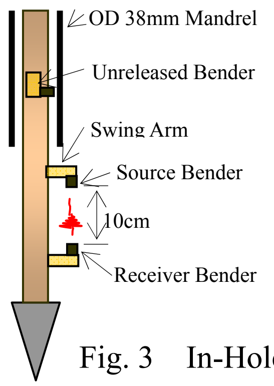

Fig. 3 In-Hole Configuration

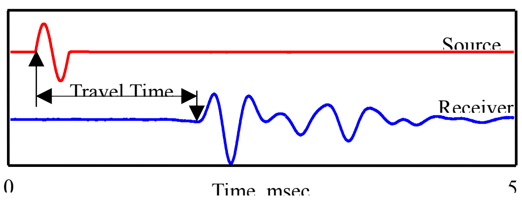

Fig. 2 A Typical Shear Wave Signal Recorded in Cross-Hole Measurement

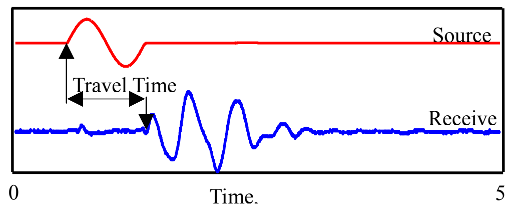

Fig. 4 A Typical Shear Wave Signal Recorded in In-Hole Measurement

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Paper No. 034

RECENT STUDIES ON SEISMIC SOIL-PILE-STRUCTURE-INTERACTION IN SOFT CLAY

Juan M. Mayoral[1] and Migue[l] P. Romo[2]

The evaluation of performance of deep foundation systems under seismic loading is one of the most complex problems in earthquake engineering, due to the varying degrees of nonlinear soil response observed during severe earthquakes. Strong shaking may lead to large excess pore pressures and strain-induced softening, increasing the amount of nonlinear behavior in the near, intermediate and free field domains. These effects overall become more significant for multi-directional shaking, which may reduce the soil stiffness and increase permanent deformations of the structure and/or soil even further. In particular, in the near field, lateral multi-directional movements of the pile can cause radial degradation of the soil stiffness, and can create radial gapping, which in turn, reduces the confinement of the pile, leading to an increase in bending moments on the structural members. Similarly, two-directional shaking may generate larger shear strains in the intermediate and free field. In practice, however, the seismic soil-pile-structure interaction problem is often oversimplified and the nonlinear effects are ignored. This paper revisits recent studies and developments directed to improve our understanding of these phenomena in soft clay, including analytical and experimental results. The predicting potential of non-conventional analysis techniques, including soft computing and nonlinear dynamics is discussed.

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Paper No. 035

THE EFFECT OF SOFT SOIL LAYER ON DYNAMIC PROPERTY FOR THE SLOPE

Liu Liping[1,2] Zhan bin[1] Li yingmin[1] Yang Shijun[1]

The slope with soft soil layer is easier to be destroyed under earthquake than that without soft soil layer. In the paper, numeric analysis is used to analyses the effect of soft soil layer on earthquake response for the slope. In the analysis, the slope is regard as the plane strain model and the finite element method is used. The parameters which influencing the earthquake response of the slope, including the depth, the thickness, the obliquity of soft soil layer are analyzed and the conclusions are valuable for the dynamical analysis of slopes in application.

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Paper No. 038

A CASE STUDY OF LIQUEFACTION ASSESSMENT USING SWEDISH WEIGHT SOUNDING

Mahdi Habibi[1], Akbar Cheshomi[2] and Ali Fakher[3]

Evaluation of liquefaction potential of soils is one of the important aspects of geotechnical earthquake engineering practice. After the publication of "simplified procedure" in 1971, it has become a widely used method of practice for liquefaction assessments. Several in-situ tests have been used for evaluating resistance of soils to liquefaction. The most common are SPT, CPT, V_s measurement and BPT. Swedish Weight Sounding test is a common in-situ test in some countries like Nordics, Japan and some east European countries. Also, It has been used in Iran for geotechnical design purposes in some projects. The paper presents a case study of using Swedish Weight Sounding results to assess liquefaction potential in Shahid Rajaei Port development in Iran, which is a very large development plan. The site consists of reclaimed sandy areas filled with dredged materials. An extensive geotechnical site characterization program has been undertaken in the project using different tests such as SPT, CPT, Dynamic Probing and laboratory tests, as well as Swedish Weight Sounding for research purposes. Regarding the case study of the mentioned project, the paper concludes on the validity of using Swedish Weight Sounding for liquefaction assessment

Keywords: Liquefaction assessment, Low-cost site characterization, In-situ tests, Swedish Weight Sounding test (WST).

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Paper No. 039

3-D NONLINEAR ANALYSIS OF SOIL-PILE INTERACTION IN LIQUEFIABLE SOIL USING ADAPTIVE MESH REFINEMENT

Xiaowei Tang[1] Yuan Di[2] Maotian Luan[3] Sumio Sawada[4] Tadanobu Sato[5]

Since liquefaction due to strong earthquakes leads to serious damages of pile foundations, nonlinear analysis of the liquefaction phenomenon by FEM has been conducted in the fields of soil-pile interaction and pile foundation design recently. As a type of numerical approximation, errors are inevitable in the analysis results obtained using FEM. The accuracy of the finite element method is still a major concern of numerical analysis, particularly when a non-linear material response is occurred and large deformation is involved.

In soil-pile interaction analysis, errors involving elements surrounding piles are very large. This error in the finite element method is caused by discretization. Reducing element size uniformly minimizes error, but the number of nodes and elements are increased at the calculation time. Our objective was to use a fine mesh in the area of large error and a normal or coarse mesh in that of low error. Adaptive mesh refinement, which refines the mesh of the finite elements according to an error indicator, has been developed and used to solve this error problem.

In this research, *h*-adaptive finite element method was used in the nonlinear analysis of soil-pile interaction considering large deformation caused by soil liquefaction. The adaptive procedure was used only for soil elements in order to analyse the liquefaction of saturated sand.

A posteriori error estimate based on the L_2 norm of strain or stress error was adopted. It effectively estimates elements error after each calculation step in the nonlinear finite element analysis of soil. The superconvergent patch recovery technique was used to get smoothed value for error estimation. Calculations based on this method can easily implement any code and clearly are advantageous for saving computation time. The efficacy of this error estimator in the dynamic analysis of porous media was shown by a simple example to be a reliable error indicator for mesh refinement. A fission procedure belonging to *h*-refinement was adopted for the mesh refinement of soil elements. After one calculation step, elements which exceed a given error limit are fissioned into 8 elements, and the next step executed.

A numerical example was given to show the efficacy of our method. The soil-pile interaction system in saturated sand was analysed, including the liquefaction process. The findings show that this adaptive scheme provides substantial improvement in accuracy with minimal additional computation.

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Paper No. 040

STUDY ON THE CHARACTERISTICS AND INFLUENCE FACTORS OF RESPONSE SPECTRUM IN BLASTING VIBRATION

Cong-mou Lin, Feng-jin Dong, Lin Zhang and Ze-guan Chen[1]

The influence factors and the general research situation of blasting vibration to structures are elucidated briefly. The blasting vibration was monitored. on site. Using the data from the monitoring of blasting ground vibration, the response spectrum of velocity, acceleration and displacement are fitted out． These spectrum are analyzed and compared． Influence of blasting parameters on response spectrum are discussed． The displacement spectrum, the velocity spectrum and the acceleration spectrum can be used as design criteria in the dynamic response analysis of the structures. The method provides an effective tool for studying blast seismic effect, specially, for constituting velocity-frequency criteria.

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Paper No. 041

EVALUATION OF DYNAMIC PROPERTIES OF LARGE SATURATED SAND SPECIMEN IN THE SHEAR BOX

Jiunn-Shyang Chiou[1] Chia-Han Chen[2] and Tzou-Shin Ueng[3]

The responses of saturated sand under shakings are studied in a physical model test by using a large biaxial laminar box on the shaking table at the National Center for Research on Earthquake Engineering (NCREE), Taiwan. The laminar shear box is composed of 15 layers of aluminum alloy frames with a specimen size of 1880 mm × 1880 mm × 1520 mm. Vietnam sand was used for tests and prepared by wet sedimentation method. Pore water pressure and accelerations within the soil, and accelerations on the frames at various depths were measured during tests under shakings of various amplitudes. To investigate the dynamic properties of soils, this paper used three methods, travel-time curve, amplification curve and motion of free vibration, together to analyze acceleration records to estimate the effective shear-wave velocity and damping ratio of soil specimen. The obtained shear-wave velocities by travel-time curve are between 51-87 m/s and those by the latter two methods are between 55-70 m/s. The latter two methods also can be applied to estimate the damping ratio and obtained damping ratios for non-liquefied cases are about 4-12%.

Keywords: shear velocity, damping ratio, shaking table test, laminar shear box

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Paper No. 042

LIQUEFACTION AND LATERAL SPREADING EFFECTS ON PILE FOUNDATIONS

Ahmed Elgamal[1] Linagcai He and Jinchi Lu

A shake-table series of experiments has provided valuable data for liquefaction-induced lateral spreading effects on pile foundations. In this paper, this data is employed to calibrate a nonlinear elasto-plastic computational model, within the open framework for simulation OpenSees. The calibrated model is used to look at a number of related scenarios, including remediation and liquefaction countermeasures. On this basis, a user interface is under development, to allow further numerical studies by interested researchers worldwide. The components of this interface are described, and an illustrative case study is presented.

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Paper No. 043

EFFECT OF GROUND MOTION DURATION ON SEISMIC RESPONSE OF STEEL MRF STRUCTURES

Abdolrahim Jalali[1] and Vahid Hakimvand[2]

Steel Strong ground motion duration of earthquake input has profound effect on seismic behavior and safety of structures. Some of the important processes such as stiffness degradation, reduction in strength and fatigue, depend on the number of load or stress cycles occur during the earthquake loading. Effect of ground motion duration on seismic behavior of steel structures has been studied in this research work. Horizontal components of 19 recorded accelerograms from ten earthquakes having moment magnitude (M_w) of 6.5-7.5 and recorded on sites of type B $(V_s = 360 - 750 m/s)$ according to USGS classification, have been selected in this study. In order to examine solely the effect of ground motion duration on response, the selected accelerograms have been scaled to be compatible with a site specific design response spectrum. For all of records the ground motion duration has been determined according to four very well known definition of duration namely, bracketed duration, uniform duration, significant duration and finally effective duration. Nonlinear time history analysis of three MRF steel buildings of three bay with four, six and eight stories have been conducted. All of the model buildings have medium ductility and have been designed according to UBC97-ASD. For all of analyses the scaled ground motions have been used as input motions. Several sets of structural response measures related to peak deformations at different stories such as inter- story drift normalized by story height (IDR), maximum peak inter-story drift ratio over all stories (MIDR), average peak inter-story drift ratio over all stories (AIDR) and peak roof drift ratio (RDR), which is the ratio of the peak lateral roof displacement to the building height were obtained from the dynamic analyses. In addition, these were then statistically studied (jointly) as functions of various definition of ground motion duration. Results of these multivariate multiple linear regressions (MMLRs) studies served to indicate which definition of ground motion durations predict the building response most accurately.

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Paper No. 045

SEISMIC BEHAVIOUR OF CABLE-STAYED BRIDGES: A STATE-OF-THE ART REVIEW

Galo E. Valdebenito[1] and Ángel C. Aparicio[2]

Bridges are civil works for which is required their structural integrity and accessibility after the occurrence of an earthquake. However, it is known that these systems are very vulnerable, as it has been demonstrated after the occurrence of the earthquake events of San Fernando (1971), Loma Prieta (1989), Northridge (1994), Kobe (1995) and Taiwan (1999). Considering the existent bridges, cable-stayed ones are without a doubt a very important alternative, since they can be used for long-spans being next to suspended bridges the most impressive engineering works. Because of their importance, for span lengths that exceed 200 m, it is desirable a conservative design, being common to require an elastic or almost elastic structural response for the design earthquake of very low occurrence probability. Hence, requiring an elastic response and additional energy dissipation on the structural elements, it is possible to use active or passive devices for the energy dissipation and seismic control. Born for military use, energy dissipation and base isolation devices began their incursion in the civil world quickly, improving the seismic behaviour of constructions and being with the active control the new tendencies in seismic protection of bridges of any kind. This paper corresponds to an actualized state-of-the-art review about the seismic behaviour of cable-stayed bridges with special attention in the non-linear seismic behaviour, damping, cable vibration effects, tower response, influence of support conditions, near-fault effects, spatial variability effects and the seismic behaviour of multi-span and curved bridges. Incorporation of additional systems of passive and active protection, including the latest investigations on passive devices in the new Rion-Antirion Bridge (Greece), and the use of new intelligent strategies based on hybrid and semi-active systems are the final part of this work.

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Paper No. 046

PERFORMANCE OF MULTI-COLUMN BENT EXTENDED PILE-SHAFTS UNDER EARTHQUAKE LOADS

S. T. Song[1], and Y. H. Chai[2]

A cost-effective foundation design for bridge structures involves the use of the multi-column bent extended pile-shafts, where the supporting pile-shaft is extended above ground as a column having approximately the same diameter. In seismic design, it is important to recognize that the overall response of a bridge supported on extended pile-shafts is characterized by an increased flexibility due to the compliance of the soil. For proper design of the extended pile-shaft, the influence of the soil on the overall performance of the structure is essential and must be taken into account accordingly.

For fixed-head extended pile-shafts subjected to lateral loading, the maximum bending moment occurs at the pile-shaft/cap-beam connection. The magnitude of the bending moment under a design level earthquake can be sufficiently large to cause plastic hinging at the pile-shaft, with potential for severe damage of the structure. A well-reported failure is the Struve Slough Bridge, which collapsed after the 1989 Loma Prieta earthquake due to serious damages occurred at the pile-head. Since yielding of the pile-shaft can be expected at the design level earthquake, post-yield performance of the soil-pile system, particularly the global displacement and local inelastic deformation, becomes critically important. As practices move towards performance-based engineering, an approach capable of incorporating soil properties in the process of seismic performance assessment will help to advance the state-of-the-art in bridge engineering.

The procedure for seismic performance assessment of extended pile-shafts in multi-column bents is presented in this paper using the Struve Slough Bridge. An analytical model capable of determining the kinematic relation between the imposed displacement ductility factor and curvature ductility demand is developed to assess the local inelastic deformation of extended pile-shafts under earthquake loading. The level of damage is assessed by comparing the local curvature ductility demand with the curvature ductility capacity of the pile-shaft. Results indicated that the observed damage was consistent with the flexural failure expected of the inadequate transverse reinforcement in the pile-shaft. The poor detailing of the transverse reinforcement was the likely cause of buckling of the longitudinal reinforcement, which was followed by crushing of the concrete and eventually led to the dislocation of the superstructure from the substructure and final collapse of the bridge.

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Paper No. 047

DYNAMIC COLLAPSE OF DUCTILE RC COLUMNS UNDER NEAR-FAULT EARTHQUAKE

Chiun-lin Wu[1], Yuan-Sen Yang [1], Shyh-Jiann Hwang[2], and Chin-Hsiung Loh[2]

This paper presents shake table experiment NCREE of Taiwan, which intended to study dynamic characteristics of flexural failure mode of RC columns. To do so, a ½-scale single story RC portal frame composed of 2 ductile columns inter-connected by a strong beam was constructed. A steel protective beam system was built outside the table to catch frame specimens when structural collapse occurred. Near-fault record TCU082ew from the 1999 Chi-Chi Taiwan earthquake was utilized as the input motion. This instrumented observation of dynamic collapse helps gain further insight into dynamic stability problems. During the tests, consumer digital camcorders were employed to record the progress of structural collapse; displacement histories were obtained through both Temposonics LDTs and image processing technique, the latter of which was shown very helpful in measuring low frequency signals such as displacement histories when collapse or large displacement was expected. Collapse mechanism of flexural-shear-axial was observed in these experiments. On the other hand, collapse analysis usually indicates involvement of discontinuum mechanics; however, experimental data show that hysteretic modeling approach may be sufficient to match the needs of engineering practice in description of nonlinear structural dynamic response prior to complete structural collapse. The preliminary numerical simulation results show that more efforts still need to be made among engineering community in order to predict structural response with more accuracy, and, as such, experimental data from collapse tests provide a great platform for setting up benchmark problems for verification of new numerical simulation methods. It is concluded that if a higher hazard level at 2% exceedance probability in 50 years and near-fault ground motions are to be considered in performance-based earthquake engineering, global/local collapse needs to be carefully accounted for in structural dynamic analysis.

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Paper No. 048

APPROXIMATE ANALYTICAL EVALUATION OF ELASTIC STORY DRIFT OF STEEL MOMENT FRAMES WITH RADIUS-CUT REDUCED BEAM SECTION

Cheol-Ho Lee[1]

A simplified analytical procedure is presented to evaluate the elastic story drift of steel moment frames with the radius-cut RBS (reduced beam section) connections. Due to the geometric configuration of the RBS, the mathematical formulation is complicated when applying the conjugate beam method to compute the component of story drift contributed by the beam. In this study, the problem is circumvented by replacing the original radius-cut RBS with an equivalent beam of constant width. The equivalence between the two is established by imposing the equal flange elongation criterion over the RBS region. This approach is justified based on the finite element analysis. The story drift components contributed by the column, the panel zone, and the beam are then formulated into a closed form solution for a typical beam-column subassembly. The derived results can readily be used by the designers to estimate the magnitude of RBS frame story drift and the effect of the stiffness variations.

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Paper No. 049

EXPERIMENTAL INVESTIGATION ON RECTANGULAR SRC COLUMNS WITH MULTI-SPIRAL CONFINEMENTS

C.C. Weng[1], Y.L. Yin[2], J.C. Wang[3], C.Y. Liang[4] and C.M. Huang[4]

Presented herein is a study on compression tests of a series of full-scale rectangular SRC (steel reinforced concrete) columns confined with a new type of multi-spiral cages. The multi-spiral is a device of five interconnected spiral cages, named “5-spirals” or “Yin’s spirals” in this study, with a large circular spiral at the center and four small ones at the corners. The innovation of applying the 5-spirals to rectangular SRC columns is to take its superiority in concrete confinement as well as its efficiency in automatic production for the precast construction industry. The major parameters of this study included the cost effectiveness of the multi-spirals, and the strength and ductility of the spirally confined SRC columns. As compared to the reinforced concrete column tied with traditional rectilinear hoops, the test results showed that, with significant cost savings of the confinement steel, the SRC columns confined with 5-spirals demonstrated excellent performances in both strength and ductility.

Keywords: Rectangular SRC Column; Multi-Spiral Confinement; 5-Spirals; Precast Construction; Compression Test; Compressive Strength; Ductility Improvement; Cost Effectiveness.

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Paper No. 053

SEISMIC CAPACITY EVALUATION OF BRIDGES WITH SCOURED GROUP PILES FOUNDATION

I. C. Tsai[1] and E. H. Chen[2]

For the sake of steep river bed and heavy rain in typhoon season, scoured foundation for cross river bridges are very popular in Taiwan because of general scouring and local scouring. During earthquake, plastic hinges won't occur at the bottom of the columns as expected in the design. Instead, it will happen at the top of piles or somewhere in the piles. In this situation, both total lateral load capacity and the corresponding ductility will be less than those of bridges without scouring. As a result, the seismic capacity of scoured bridges will be reduced dramatically.

In this study, nonlinear static pushover analysis and capacity spectrum method are conducted to access the seismic capacity of scoured bridges. Hinge properties which are necessary input for this analysis are user defined considering flexural, flexural-shear and shear failure modes. In other word, the interaction of shear strength with ductility ratio are taken into consideration in this study.

Case studied are provided which are designed first according to the seismic design code of Taiwan without considering the scouring . Afterwards, seismic capacities are accessed and compared assuming different depth of scouring in group piles foundation. Results of analysis reveals that seismic capacity reduced more when the depth of scouring is getting deeper.

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Paper No. 055

CYCLIC PERFORMANCE OF SHEAR WALL SUPPORTED ON FRAME WITH STEEL REINFORCING

Guo-Qiang Li[1] and Da-Guang Cui[2]

The structure of shear wall supported on frame has been widely used in China for buildings to provide large commercial space at bottom storeys. In order to improve the seismic behavior of this type of structure with the frame normally in reinforced concrete, the frame with steel reinforcing is proposed. An experimental investigation was conducted to study the behavior of the proposed structure subjected to simulated seismic load. The tests exerting constant vertical load and monotonic or cyclic lateral load were carried out on four one-forth-scale specimens, three consisting of steel members encased in reinforced concrete frame supporting concrete shear wall. The load-bearing capacity, deformation, ductility, and their failure modes were discussed based on the test results. The results of the experiment indicate that the system of shear wall supported on frame reinforced with steel members possess exceptional strength, ductility, and has better energy dissipation capability for earthquake-resistance.

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Paper No. 056

FULL-RING EXPERIMENTAL STUDY OF THE LINING STRUCTURE OF SHANGHAI CHANGJIANG TUNNEL

Liang Lu[1] Xilin Lu[2] and Peifang Fan[3]

Recent years, more and more shield driven tunnels have being designed and constructed in big cities of China. Some general commercial FEA software are used to analyze the shield tunnel lining structures, but the experience of tunnel lining structure test is relatively lack in China. Tongji University has taken the lead in researching the tunnel lining structures by experimental approaches in China, two single-circular tunnel linings in 1999 and one double-circular tunnel lining in 2002 with full scales were tested.

This paper presents the method, test set-up, data acquisition system and part of results of the full-scale static test of the circular shield tunnel lining of the Shanghai Changjiang tunnel, the world's biggest one in diameter. The full-scale test model of the shield tunnel lining is a reinforced concrete structure, which is 4.0m high, 15.0m in outer diameter, and 0.65m in thickness of tube shell. In the test procedure, 44 radial loading forces were exerted on the specimen surface along the ring to simulate the designed soil and water pressure with the total load of 89800kN under the maximum loading case. And 44 axial loading forces were exerted on the specimen along the ring to simulate thrust forces of the shield driven machine with a total load of about 132000kN. Total 498 measuring sensors were allocated on the specimen to measure the overall structural deformation, stresses of the reinforcing steel bars and concrete surfaces, open angles of the joints' surfaces and the stresses of the joint bolts. At the same time, the destroyed shape and the stretching status of the cracks were observed and recorded.

The loading apparatus was accurate and effective to simulate the real forces exerted on the tunnel lining structure. The test result data agree well with the results of 3-D FEM simulations.

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Paper No. 057

CALCULATION AND VERIFICATION OF STRUCTURAL DEFORMATIONS BASED ON STRONG MOTION RECORDS COLLECTED IN REAL EARTHQUAKES

Chao-Hsun Huang[1] and She-Ming Chen[2]

In order to observe dynamic responses of building structures during real earthquakes, the Taiwan Central Weather Bureau initiated a seismic monitoring program, commonly known as the Taiwan Strong Motion Instrumentation Program (TSMIP), in 1992 by installing strong motions arrays inside over 40 buildings to record the acceleration histories of the building bases as well as specific floor levels. In this study, the floor displacements of selected buildings were calculated directly from these records with the baselines corrected using a statistical method. Independent structural analyses were also performed on these buildings based on original design documentations. By comparing the results of both analyses, the validity of the direct displacement calculation procedure and the accuracy of structural analyses were examined.

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Paper No. 058

APPLICATION RESEARCH OF VIRTUAL-ELEMENT METHOD IN FULL-RANGE NONLINEAR ANALYSIS OF RC PLANAR FRAME

Zhou Deyuan[1] Wu Yongfei[2] Zhang Hui[3]

To obtain the results of full-range nonlinear analysis, negtative-eigenvalue problem of structural stiffness matrix is the key problem to get over. Arc-length method is the most effective method in present, but poor in stability and sensitive to step length, and sometimes it can't get solution for the load factor in the quadratic equation. A new method using virtual element is presented in this paper. The new method add a new element which keeps elastic in each load step to the present structure for better performance of the new stiffness matrix, which ensure proportional load and give a possible channel to get the soft stage in full-range nonlinear analysis. The new method is applied in a program using fiber model to calculate the full-range nonlinear analysis of RC planar frames. The method is verified with the results of SAP2000 and the push-over experiments. Suggestions are given for the improvement and optimization of the virtual-element method.

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Paper No. 060

SHAKING TABLE TESTS OF SELF-CENTERING DESIGNED BRIDGE SUB-STRUCTURES

Chin-Tung Cheng[1] and Wei-Hong Lu[2]

The columns, cap beam and foundation of one-fifth scale bridge sub-structures were precast and then post-tensioned together. The bridge models were designed to perform in a way of self-centering after an earthquake. The advantage of self-centering eliminates permanent drift and reduces the possibility of being demolished. The restoring force for the structure is provided by the gravity load in the superstructure and prestressing tendons passing through columns and anchored inside the cap or foundation beams. Seismic energy is dissipated through each impact of column rocking on beam surface. Therefore, radiation damping of the bridge system was theoretically evaluated and validated by shaking table tests. Research parameters include material used as rocking interface (plastic or steel), amount of prestressing tendon and gravity load, and types or intensity of earthquakes. Test results showed that self-centering designed bridge sub-structures rocked on beam surface, up to 5% of column rotation, to mitigate seismic energy without inducing any damage. With higher friction coefficient, plastic interface exhibited less damping ratio than the steel interface did. Analysis of Fast Fourier Transform (FFT) showed that bridge structures vibrated in lower frequently if provided with less prestressing tendons (restoring force) or subjected to higher intensity of ground shaking (inertial force). The comparison of theoretical and test results showed that the predictions of radiation damping were conservative due to minor sliding and transverse vibration in columns.

key words: self-centering, bridge structures, radiation damping, shaking table tests.

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Paper No. 061

EFFECT OF HYSTERESIS TYPE ON DRIFT CAPACITY FOR GLOBAL COLLAPSE OF MOMENT FRAME STRUCTURES FOR SEISMIC LOADS

Zhenhua Huang[1] and Douglas A. Foutch[2]

It is conjectured that different hysteresis behavior may lead to different levels of response because of degradation in strength and stiffness. To examine the existence and magnitude of this effect, this research aims to: 1. Determine the global collapse capacities of several classes of moment frame buildings under seismic loads. 2. Develop seismic criteria for design and evaluation of moment frame buildings that reflect and account for the global drift capacity. To achieve these objectives, seismic analyses of 9-story moment resisting frame buildings were conducted to evaluate the effects of the hysteretic behavior of beam-to-column connections, structural stiffness, structural strength, and P-delta on the collapse potential. Six hysteresis models: bilinear, strength degradation, stiffness degradation, stiffness degradation + strength degradation, pinching, and pinching + strength degradation are evaluated. For the 9-story buildings, the effects of hysteresis behavior are very significant for both global drift capacities and Sa capacities. Two interesting results are that (1) strength degradation significantly decreases both the global drift capacity and the Sa capacity, whereas, (2) the existence of stiffness degradation increases the global drift capacity by 14% and the Sa capacity by 44% beyond the base bilinear model. Details of the study and other results are summarized in the paper.

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Paper No. 063

SEISMIC PERFORMANCE OF HIGH DAMPING CONCRETE STRUCTURES

Liu Ping[1] and Wan Zeqing[1]

Advancing the damping ratio of materials to improve the damping property of concrete structure effectively, and embodying the structural high damping has been a new way for structural vibration controlling. Based on the structural dynamics principle, the validity of improving the damping property for decreasing the vibration response was analyzed when the structures produce resonance. The dynamic responses of the normal concrete structure, local high damping concrete structure and entire high damping concrete structure were simulated by using ANSYS respectively. The analysis included modal analysis and harmonic analysis. The response results of the structures made of three different materials were compared. The results of simulation analysis show that the dynamic responses of the high damping concrete structure were improved, compared with that of the normal concrete structure. However, when the high damping concrete was only used in the columns of the structure, the results were close to that of entire high damping concrete structure. Such can offer references for researching the application style of high damping concrete in civil engineering.

Key words: high damping concrete; seismic response; FEM analysis

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Paper No. 064

EFFECT OF URM INFILLS ON SEISMIC PERFORMANCE OF RC FRAME BUILDINGS

Yogendra Singh[1] Dipankar Das[2]

Use of unreinforced masonry infills as partitions, in frame buildings is a common practice in India and many parts of the worlds. The infills are, generally, not considered in the design and the buildings are designed as bare frames. This study investigates the effect of masonry infills on the seismic performance of RC frame buildings. For this purpose, three buildings, 4 storey, 8 storey and 16 storey tall, having identical plan, have been considered. Linear analysis and design of each bare frame building has been performed as per the relevant Indian codes of practice. The effect of infills on dynamic characteristics, yield patterns and seismic performance has been studied with the help of Non-Linear Push-Over Analysis. It has been observed that infills contribute to a large increase in the stiffness and strength of the structure while the deformation capacity of the structure gets reduced. In case of uniformly infilled frame buildings designed as per codes, it has been observed that infills fail before frame elements. It has also been observed that due to strut action of infills, high axial forces get generated in columns of uniformly infilled frame buildings and as a result, columns fail earlier than those of bare frame buildings.

Keywords: Earthquake, Masonry infills, Reinforced concrete frame, Non-linear modeling, Pushover analysis

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Paper No. 068

INTERACTION OF FLOOR DIAPHRAGMS WITH STEEL SELF-CENTERING MOMENT FRAMES

Maria E. M. Garlock[1], Jie Li[2], and Mary Lisbeth Blaisdell[3]

Recent research has developed a family of new earthquake-resistant structural systems for steel moment frames referred to as *self-centering moment-resisting frames* (SC-MRFs). These frames have the potential to eliminate structural damage under a design basis earthquake (DBE) and return to its original vertical position (i.e. self-center) following a major earthquake. The self-centering behavior is achieved by post-tensioning (PT) the beams with either high strength strands or bars. The behavior of a SC-MRF is characterized by a gap opening and closing at the interface of the beam tension flange and column flange under earthquake loading. Energy dissipation is provided by supplemental elements that deform under the gap opening behavior. The gap opening behavior also causes the SC-MRF to expand, where in the deformed position the distance between the column centerlines increases relative to the original distance. This behavior imposes new design requirements on the floor diaphragm design, and, in turn, the response of the floor diaphragm imposes additional design requirements on the SC-MRF.
The objective of this study is to analytically evaluate the effects of the floor diaphragm stiffness, strength, and configuration on the seismic response of SC-MRF systems. The floor diaphragm is represented by collector beam elements that transmit inertial forces from the floor diaphragms to the SC-MRF. Several SC-MRF models, which include the interaction of the floor diaphragm with the SC-MRF, are subjected to several ground motions. The beam sizes, column sizes, and connection details remain constant in each model. The collector beam stiffness, strength and configuration varied. The axial forces that develop in the beams of a SC-MRF are comprised of several factors such as: the initial PT force, the additional PT force due to strand elongation imposed by the gap opening, the axial forces introduced by the floor diaphragm interaction, and a portion of the floor inertial forces. This paper examines each component and evaluates the relative magnitude of each to the total axial force in the beam.
Based on such analyses described above design recommendations for the floor diaphragms of SC-MRF systems are provided. The study shows that the floor diaphragm design significantly affects the seismic performance of a SC-MRF. The axial force that develops in the SC-MRF beams due to the floor diaphragm can be up to half of the total axial force in the beam. If the floor diaphragm design is too stiff, unacceptably large axial forces develop in the SC-MRF beams. In summary, the design of the floor diaphragm must be considered when designing this SC-MRF system.

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Paper No. 069

PREDICTION METHOD FOR MOMENT-ROTATION BEHAVIOR OF EXPOSED-TYPE STEEL COLUMN BASES UNDER BI-AXIAL BENDING

Jae-Hyouk Choi [1] Kenichi Ohi[2]

It has already been proved that assuming them as pinned or fixed supports is not a suitable way to simulate their actual behavior because in most cases, column bases have strong semi-rigid behavior highly affecting the overall behavior of the structure. In order to reflect the column base behavior to the frame design work, the column base can be modeled as a kind of semi-rigid and partial strength connection with plastic rotation capacity. In this paper, standard M-θ skeleton curve of exposed-type column base and estimation method on inelastic behavior under bi-axial bending is proposed. Also, a method to simulate the inelastic behavior of column base in case of biaxial bending by expanding uni-axial restoring force characteristic model to bi-axial model is proposed, anchor bolt yielding type and base plate yielding type respectively.

Keywords: Exposed-type column base, Biaxial bending, Anchor bolt yielding type, Base plate yielding type

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Paper No. 072

THE ANALYSIS OF RC FRAMES WITH BRICK WALLS BY USING THE EQUIVALENT COLUMN MODEL

Yeou-Fong Li [1] and Cheng-Wei Chen[2]

In this paper, an effective repair-rehabilitation working method is proposed for moderately damaged reinforced concrete (RC) building structures after major earthquakes. Three RC frames with nil, half-height and full-height brick walls are designed and tested at the National Center for Research on Earthquake Engineering (NCREE). After the columns of these non-ductile RC frames are damaged, steel wire cables with non-shrinkage motar and carbon fiber reinforced plastics (CFRP) are used in the proposed method to confine reinforced concrete columns. The stress-strain relationship of the confined concrete, proposed by Li et al. (2003), is used in the theoretical sectional analysis. The columns are confined by steel wires and CFRP and the Response 2000 program (Bents, 2001) is used to obtain the moment-curvature relationship of these confined columns. The "equivalent column model" is proposed in this paper and is used to analyze the brick panel inside the RC frames. Finally, the frame and the equivalent column are engaged and then analyzed following a non-linear pushover analysis to obtain the lateral strength-displacement envelope of each frame. The analytical results can reasonably predict the lateral force-displacement relationships of these RC frames.

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Paper No. 075

PERFORMANCE EVALUATION OF REINFORCED CONCRETE FRAME SUBJECTED TO PULSE EXCITATIONS

Shu-Hsien Chao[1] and Chin-Hsiung Loh[2]

A modified algorithm based on the force analogy method (MFAM) to simulate the inelastic response of frame structure with P-Delta effect was developed. An inelastic deteriorating hysteretic model, which includes strength, stiffness degradation and pinching effect, is implemented in the analytical model to provide the moment versus plastic rotation relationship of reinforced concrete element in FAM. Three deteriorating hysteretic loops with slight, moderate and severe deteriorating characteristics are used to simulate the response of the reinforced concrete frame. The performance of reinforced concrete frame, designed according to the new seismic design code, is studied by incremental dynamic analysis (IDA). A total of eight generic frames with different height and different fundamental structural periods are used to perform the IDA. The relationships between earthquake demand parameters (EDPs) and intensity measures (IMs) are constructed for different structural periods. The influence of different hysteretic loops on earthquake demand parameters is also discussed. Finally, the preliminary performance-based seismic design for reinforced concrete frame is proposed in this study.

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Paper No. 078

DYNAMIC ANALYSIS AND THE RESULTING NONLINEAR RESPONSE OF BUILDING STRUCTURES LOCATED IN SEISMICALLY ACTIVE REGIONS IN TURKEY

Baki Ozturk, Ph.D.[1]

This study focuses on the investigation of the behavior of representative buildings in Turkey which are modeled as MDOF(multi-degree-of-freedom) systems. In the dynamic analysis, ground motions recorded in Turkey during both Marmara Earthquake (August 17th., 1999) and Duzce Earthquake (November 12th., 1999) are used. The investigation was based on the dynamic response of building structures and their response histories. In this study, the base shear strength coefficient, C_y of the representative buildings and; the ground velocity increment, DV of the ground motion records are the main parameters which are considered during the investigation. The nonlinear response of building structures are evaluated, considering the behavior of regular reinforced concrete frames which constitute the representative buildings in Turkey.

Keywords: nonlinear response, ground velocity increment, multi-degree-of-freedom systems, base shear strength coefficient

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Paper No. 079

THREE-DIMENSIONAL CRITICAL SEISMIC GROUND ACCELERATION TIME HISTORIES FOR HIGH-TECH FACILITIES

You-Lin Xu[1] and Xiao-Jian Hong[2]

High-tech facilities engaged in the production of semiconductors and optical microscopes are extremely expensive. Of the total investment of a high-tech facility 75% accounts for the cost of high-tech equipment while only less than 5% is spent on the construction of a building. When high-tech facilities are located in seismic regions, the safety of both building and high-tech equipment during an earthquake becomes a critical concern and the seismic resistant design of high-tech facilities faces a number of challenging issues. For instance, seismic ground motion can act along any horizontal direction and accordingly the maximum structural and equipment response associated with the most critical directions of seismic ground motions should be examined. Moreover, not only horizontal accelerations but also vertical acceleration will affect the safety of high-tech equipment. Accordingly, three-dimensional seismic analysis should be carried out. Since high-tech equipment sitting on a building floor is very heavy and may not be uniformly distributed over the building floor, possible torsion vibration of the building during an earthquake may occur even though the building itself is symmetric. To reduce seismic vibration of both building and high-tech equipment, vibration control technique with linear and nonlinear dampers may be implemented into a high-tech facility. In consideration of all factors aforementioned, it may require to carry out three-dimensional seismic analysis of a high-tech facility in the time domain with respect to the most critical directions of seismic ground motion. However, the standard seismic resistant design of a high-tech building is based on the response spectra stipulated in seismic design codes. As a result, how to generate three-dimensional critical seismic ground acceleration time histories compatible with the response spectra stipulated in seismic design codes becomes a primary issue prior to seismic analysis and design of a high-tech facility.

This paper thus presents a framework for generating three dimensional critical seismic ground acceleration time histories compatible with the response spectra stipulated in seismic design codes. The most critical directions of seismic ground motions associated with the maximum structural and equipment response of a facility are first identified based on the response spectrum method for the general case of three motion components. A new numerical method is then proposed to derive the power spectrum density functions of ground accelerations which are compatible with the response spectra stipulated in seismic design codes in critical directions. The ground acceleration time histories are generated by applying the spectral representation method to the power spectrum density function matrix and then multiplied by envelope functions to consider nonstationarity of ground motions. The proposed framework is finally applied to a typical three-story high-tech facility to examine its feasibility, and the numerical results demonstrate the feasibility of the proposed approach.

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Paper No. 080

SEISMIC PERFORMANCE OF SCBF BRACED FRAME GUSSET PLATE CONNECTIONS

Charles W. Roeder[1], Dawn E. Lehman[2], Shawn Johnson[3], David Herman[4] and Jung Han Yoo[4]

Steel braced frames are stiff and strong structures for reducing damage during small, frequent earthquakes. Special concentrically braced frames (SCBFs) provide inelastic performance through buckling braces during severe earthquakes. Tensile yield and buckling of the brace places severe force and deformation demands on the brace-beam-column gusset plate connections. The design of these connections is currently based upon the AISC Uniform Force Method combined with the AISC Seismic Design Provisions. An analytical and experimental study into the seismic performance of SCBF and BRBF gusset plate connections is in progress. To date, 11 large-scale SCBF experiments have been completed. The experiments are single story, single bay braced frames which are tests under cyclic loading with boundary conditions simulating multi-story frame behavior. The specimens are approximately full size for a lower story of 3 to 4 story building. The experimental results are being combined with nonlinear analyses and experimental results obtained from past component tests to evaluate current and improve current connection design methods.

The results of these experiments will be summarized. The experiments show that improved seismic performance of SCBFs may be achieved by permitting greater flexibility and inelastic deformation in the gusset plate and by designing the gusset plate welds based upon the plastic capacity of the gusset plate. A new clearance requirement for out-of-plane brace rotational capacity is proposed. Nonlinear cyclic finite element analyses have been performed, and the results of these analyses will also be described. The combined analytical and experimental work show that the relative stiffness of the brace, gusset plate, and surrounding beam and column elements play a major role in achieving ductility from the frame and the connection. Very stiff, strong beams may have an adverse effect on braced frame behavior, because the increased stiffness concentrates inelastic damage in other, less robust portions of the structure. The results are correlated to the existing design methods, and a proposed improved design procedure will be discussed. This design procedure balances the resistances predicted for the various yield mechanisms and failure modes of the brace and its gusset plate connection

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Paper No. 082

A STUDY ON PUSHOVER ANALYSIS OF REINFORCED CONCRETE WALL FILLED WITHIN FRAME STRUCTURE

Yu-Chi Sung[1], Chun-Chai Chuan[2]

This paper proposes an efficient approach to the pushover analysis of the reinforced concrete (RC) wall filled within frame structure. Incorporating with equilibrium and compatibility conditions, the softened model of the concrete as well as the elastoplastic model of the reinforcement was taken into account for the analysis of a RC wall. Accordingly, the mechanical contributions from three important components of a RC wall including transverse reinforcement, longitudinal reinforcement and concrete can be traced, respectively, when subjected to monotonic lateral load. Summing up those contributions, the equivalent structural strut along the diagonal of the frame can be estimated to simulate the action of the RC wall, and its structural nonlinearity can be obtained for sequential pushover analysis.

To testify the accuracy of the proposed approach, the reported result of the cyclic loading test for sixteen specimens of the discussed structure was adopted as the base for the necessary investigation. It shows that the analyzed results are significantly consistent with those of the experimental results. This study can not only provide an acceptable analytical result of the RC wall filled within frame structure but also give an easy estimation of the equivalent structural strut correspondingly, which might help the engineers do the structural design.

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Paper No. 083

ANALYSIS AND CONTROL FOR SEISMIC POUNDING RESPONSES OF URBAN ELEVATED BRIDGES*

Zhong-Xian Li[1] and Fu-Qing Yue[2]

Urban elevated bridges may suffer great damage due to the pounding between adjacent bridges during earthquake. In this paper, the analytical method and control measure for the seismic pounding responses of the urban elevated bridges are systematically investigated. Based on Hertz contact theory, a method to determine the coefficient of restitution and the spring stiffness of pounding of the equivalent Kelvin impact model for seismic pounding analysis of the urban elevated bridges is proposed. The finite element models for nonlinear seismic pounding analysis are built, and the influence of different parameters on the seismic pounding responses of the urban elevated bridges is analyzed, which include gap of span, stiffness of bearing, non-linearity of pier, pile-soil interaction, and seismic wave. The influence of spatial variation of ground motion on the seismic pounding responses of the urban elevated bridges is further studied. A method to calculate critical separation distance was founded based on random vibration theory. The performance of using viscous damper to mitigate the seismic pounding effect of the urban elevated bridges is analyzed, and its parametric design method is also proposed. The semi-active control on the seismic pounding responses between adjacent segments of the isolated urban elevated bridges is performed using the MRF-04K magnetorheological damper proposed previously. Finally, some conclusions are given as follows. (1) The pounding of bridges is caused by the coaction of many factors, which makes the seismic responses of the bridges more complex and non-linear. (2) The spring stiffness of pounding in the equivalent Kelvin impact model is influenced by the parameters including the Hertz contact stiffness, the relative velocity of motion of the adjacent girders and the ratio of lengths of the short girder to the long girder. (3) Considering the non-linearity of pier and the pile-soil interaction, the pounding responses may be increased, especially for the multi-span continuous girder bridge. (4) The spatial variation of ground motion has significant influence on the seismic pounding responses of the urban elevated bridges. (5) The viscous damper can diminish the relative displacement of adjacent spans and the pounding effect is greatly suppressed without increasing ductility demand in the piers. (6) Installing MR dampers between superstructure and piers will get much better performance than installing it between adjacent segments, and the relative displacement and bearing deformation decrease remarkably by semi-active control.

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Paper No. 084

NUMERICAL SIMULATION OF THE PROGRESSIVE FAILURE AND COLLAPSE OF STRUCTURE UNDER SEISMIC AND IMPACT LOADING

Chung-Yue Wang[1], Ren-Zou Wang[2] and Keh-Chyuan Tsai[3]

In this study, the explicit vector form intrinsic finite element (VFIFE) method is used to simulate the nonlinear behavior of the building system under seismic and blasting loadings. This VFIFE method can do the motion analysis of structure with large deformation and rotation from continuous states to discontinuous states. Three dimensional frame elements of the VFIFE method are used to model the structure system. The progressive failure of structure components was investigated in detail by considering the material nonlinearity and associated failure criteria into the analysis. In order to simulate the progressive collapse behavior of the structure, the mechanisms of contact detection and contact force calculations among frame elements are also developed.

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Paper No. 086

EFFECTIVENESS OF ROCKING SEISMIC ISOLATION ON BRIDGES

Kazuhiko Kawashima[1] and Takanori Nagai[2]

This paper presents an analysis on the effectiveness of rocking seismic isolation of bridges supported by spread foundations. Separations of the footing from and contacts of the footing with the underlying ground which could occur during an extreme ground motion result in mitigation of bridge response. The separations and contacts of the footing must have occurred in past earthquakes although their effect was not rigorously included in seismic design. The effect of rocking seismic isolation is presented for a 10 m tall standard bridge supported by spread foundations under three directional excitation. It is shown that the effect of rocking seismic isolation is significant in reducing the plastic deformation of the columns at the plastic hinge regions although this increases the deck and columns response displacement.
Keywords: Rocking isolation, Seismic isolation, Bridge

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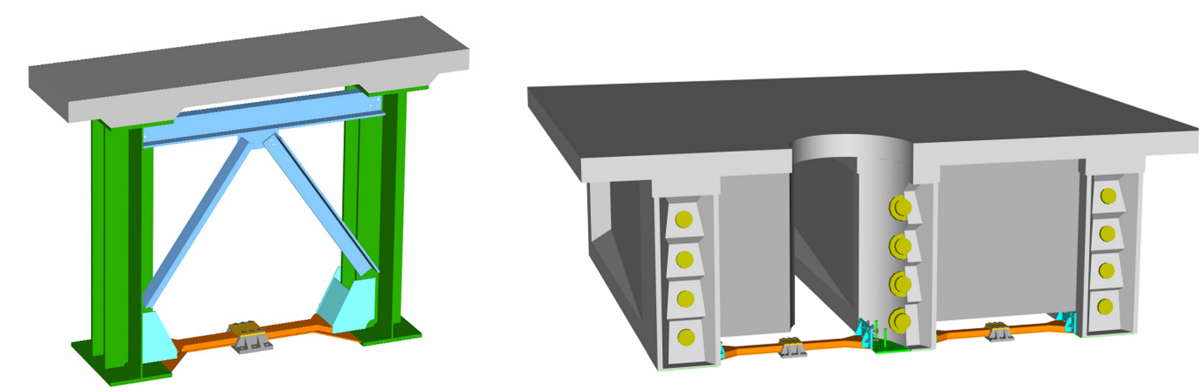
Paper No. 087

STUDY ON APPLICATION OF ENERGY-DISSIPATING SACRIFICIAL DEVICE (EDSD) FOR ENHANCING SEISMIC PERFORMANCE OF GIRDER BRIDGES

Sang-Hyo Kim[1], Ho-Seong Mha[2], Kwang-Il Cho[3], Jeong-Hun Won[4] and Jin-Hee Ahn[5]

A new Energy-Dissipating Sacrificial Device (EDSD) is developed for steel plate girders, which can effectively dissipate the energy stored in the structures during seismic actions. A simplified bridge analysis method is utilized first to see the effectiveness of the EDSD, and then using a commercial FEM program, the seismic performance of the device is examined on the whole bridge system. To verify the performance of the EDSD, various seismic responses of a sample bridge with the EDSD are analyzed in terms of energy, member forces and deformation. The full scale model tests are conducted to certify the performance of the EDSD when it is applied on existing bridges. The results show that the proposed EDSD under seismic excitations can significantly decrease the energy stored in the bridge structures and reduce the relative displacements of each superstructure to the ground. The EDSD is also found to function as a structural fuse under strong ground motions, sacrificing itself to absorb the excessive energy. Consequently, economical enhancement of the seismic performance of bridges can be achieved by employing the newly developed energy-dissipating sacrificial device.



(a) Plate girder bridge (b) PSC girder bridges

Figure 1. EDSDs applied at girder bridges

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Paper No. 088

ANALYSES OF PRINCIPAL AXES OF STRONG GROUND MOTION RECORDS OF THE CHI-CHI, TAIWAN EARTHQUAKE

Viet-Anh Phung[1], David Lau[2] and Hong Hao[3]

There is a growing importance of the modeling of multi-component ground motions for properly use in the three-dimensional dynamic response analyses of important structural systems. Realistic modeling and proper use of multi-dimensional ground motions for earthquake response analyses require that principal axes of strong ground motions be accurately determined. These components need to be uncorrelated with each other. The Penzien-Watabe model is often used to define the set of orthogonal of principal axes in which the principal axes are correlated with the direction from the recording station to the earthquake epicentre. The principal axes are determined as the eigenvectors and the principal variances are the corresponding eigenvalues of the covariance matrix. The objective of this paper is to present the analyses of the principal axes of strong ground accelerograms recorded during the Chi-Chi, Taiwan earthquake of 21 September 1999. The effects of distance to the fault, ground motion amplitude, soil condition and directivity to the direction of computed principal axes are evaluated. Direction of major principal axis is correlated with the direction from the station to the earthquake epicentre. Time-dependent characteristics of principal axes and principal variances are determined through the use of moving-window analysis. The results indicated strong correlation between directions of principal axes and directions of the recording stations to the fault.

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Paper No. 089

RESPONSE OF SELF-CENTERING STEEL MOMENT RESISTING FRAMES WITH POST-TENSIONED COLUMN BASES UNDER SEISMIC LOADING

Hoseok Chi[1] and Judy Liu[2]

The column bases at ground level in self-centering steel moment resisting frames (SC-MRFs) may suffer damage by plastic hinging under the Design Basis Earthquakes (DBE). The formation of plastic hinges at column bases may hinder the self-centering behavior of the SC-MRF. In this research, in order to eliminate damage at column bases and enhance the self-centering capability (i.e., negligible residual drift) of the SC-MRF, a post-tensioned column base connection is proposed. The feasibility of using post-tensioned column base connections in the SC-MRFs was investigated for a 6-story, 4-bay office building in the Los Angeles (LA) region by nonlinear static and dynamic analysis. Based on the analysis results, it was found that if the shear resistance is provided properly, use of the post-tensioned column base connection in the SC-MRFs results in self-centering behavior at column bases and elimination of damage in columns under the DBE.

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Paper No. 090

SHAKE TABLE TESTS OF RC FRAME WITH SHAPE MEMORY ALLOY BRACING BARS

Wen-I Liao[1] and Y. L. Mo[2]

In recent years, researchers have focused their study on many possible approaches to enhancing the seismic performance of structures. One promising solution which is receiving attention today is the application of Shape Memory Alloys (SMA). In this study, high seismic performance RC frames have been proposed to have SMA bars acting as a kind of structural bracing system at both sides of a frame to increase the energy dissipation capacity of the RC frame. This paper presents the results of the shake table tests on a single-bay single-story RC frame with SMA bars. The height and span of the designed frame were 2.0 m and 2.3 m, respectively. SMA bars were provided in the directions of 40 degrees to the horizontal. The type of SMA bar used in the study is the Superelastic SMA bar. The force-displacement hysteretic loops of the RC frame with SMA bars under seismic loading are presented and compared with the test results of the bare RC frame. Test results show that the SMA bars can effectively reduce the maximum story drift of the tested frame. It was found that the reduction of story drift and base shear was depending on the characteristic of the input ground motion.

Keywords: Shape memory alloys, Shake table, RC frame

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Paper No. 092

EVALUATION OF MECHANICAL ANCHORAGE OF ECCENTRIC REINFORCED CONCRETE EXTERIOR BEAM-COLUMN JOINTS SUBJECTED TO CYCLIC LOADING

Hung-Jen Lee[1] Si-Ying Yu[2] and Jen-Wen Ko[3]

This paper presents the cyclic responses of eight reinforced concrete exterior beam-column joints, namely, four concentric and four eccentric joints, which are subjected to in-plane lateral displacement reversals. The specimen variables are joint eccentricity, joint aspect ratio, and anchorage of the beam bars terminating within the joint. Four joints used traditional reinforcement for the beam longitudinal bars with standard 90-degree hooks anchored in the joint. The other four connections used headed reinforcement consisting of screw-deformed bars and mechanical anchorage devices to improve the anchorage of the beam bars, the constructability of steel cages, and the seismic performance of connections. Performance of the beam-column joints are evaluated and compared with each other. The behavior of joints with mechanical anchorage devices are as good as, or better than those companion joints with 90-degree hooks. Use of double mechanical devices could avoid push-out failure of the beam bar embedded in the joint, and further improve the ductility and energy dissipation capacity. Joint eccentricity between the beam and column centerlines had detrimental effects on the seismic performance of beam-column joints. Current ACI design produces for estimating the nominal joint shear strength are not capable of preventing the test joints from shear failure at large drift levels. Rather than ACI traditional cross-sectional approach, the proposed strut-and-tie modeling agreed better with the test results. Experimental verification is provided to help further understand the behavior of beam-column joints.

Keywords: beam-column; headed reinforcement; eccentric; joint; seismic design; shear; strut

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APPLICATION OF MODIFIED CAPACITY SPECTRUM METHOD TO PERFORMANCE-BASED REHABILITATION OF SCHOOL BUILDINGS

Juin-Fu Chai[1] and Tsung-Jen Teng[1]

In this paper, an energy-based and normalized performance index is proposed to measure the damage state through the full range capacity curve determined from a static pushover analysis. The critical value of the proposed index to indicate the global instability was inferred by the in-situ pushover test of three full-scaled school buildings. Based on the modified capacity spectrum method, the elastic supply strengths of a building at any performance state can be assessed from the capacity curve that can be determined either by the static pushover analysis or from the in-situ test data. In this paper, an energy-based modified capacity spectrum method which involves the effect of strength degradation is developed by modifying the strength reduction factor that is defined by the seismic design code for new buildings in Taiwan. The proposed method is compared with the coefficient method (specified by FEMA 440) and further, validated by the nonlinear time history analyses of the target building. Based on the estimated IM-DM curve, the maximum nonlinear response of a school building before or after rehabilitation under any selected seismic hazard level can be evaluated, and the acceptance criteria can be defined by the demand-capacity factor method for a certain level of confidence in the building's ability to meet the desired performance objectives.

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Paper No. 094

MIXED LOAD / DISPLACEMENT CONTROL STRATEGY FOR HYBRID SIMULATION

Narutoshi Nakata[1], B. F. Spencer, Jr.[2], and Amr S. Elnashai[3]

Owing to multiple actuator interaction and the nonlinear nature of coordinate transformations, spatial mixed load-displacement control algorithms are still major theoretical and practical challenges. This paper presents a mixed load and displacement control strategy for coupled multi-axial control systems that can be employed for static and hybrid simulation. The method is based on an incremental iterative approach employing the Broyden update of the stiffness Jacobian of the test specimen. Experimental verification is performed on reinforced concrete (RC) columns employing a state-of-the-art six-degrees-of-freedom self-reacting box at the University of Illinois at Urbana-Champaign. Experimental results indicate that the proposed mixed-mode testing method exhibits excellent control performance and robustness even when the specimens are highly inelastic. The framework and example application are transferable to other simulation platforms.

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Paper No. 095

SEISMIC ENHANCING PRACTICE OFAN EXISTING CHINESE PALACE STYLE BUILDING

Ting-Fu Wang [1] Feng-Yu Wang[2] Chih-Wen Chen[3]

This paper describes the seismic rehabilitation of a Chinese traditional palace architectural style building with irregular hybrid structure, constructed early 1980s in Taiwan. The evaluation with strength design adaptation, linear dynamic procedure and current nonlinear static procedure were employed. Both equivalence elastic response spectrum and inelastic response spectrum of push over analysis for the capacity spectrum rehabilitation of building were included. The ground motion at the dependent site of March 31, 2003(331 EQ) and September 21, 1999 (921 EQ) were also selected for linear response history analysis. Procedures to member model were : (1) bending moment in hinge element at beam ends; (2) bending-shear forces in beam model as elastic element with hinge elements; (3) shear forces, axial forces and bending moment in nonlinear beam-column element with axial force-bending moment interaction (P-M-M) including three type hinge modes as bending, bending-shear, and shear; (4) equivalence column element in shear wall hinge elements; (5) truss members as elastic elements and (6) nonlinear inelastic dampers with axial forces in fluid viscous device(FVD) elements for enhancing the building seismic capacity. The capacity spectrum of the structures were developed base on the existing concrete strength, reinforce bars, steel and size of members as as-built drawings shown and reports on the structure investigation early 2005. The seismic performance level of the buildings were defined as essential/ hazardous object and it should be : (1) beyond life safe of the structure for maximum considered earthquake at 2500-year return period (2% in 50 years, EPA = 0.32g); (2) immediate occupancy of the structure for design earthquake at 475-year return period (10% in 50 years, EPA =0.24g) and (3) full operational of the structure within yield limit state for serviceability earthquake at approximate 72-year return period. The results show that the proper arrangement and use of fluid viscous dampers (FVD) in seismic enhancing of the structure including its pile foundations will attain this seismic performance level. It is also shown that these seismic evaluation procedures are practicable for the irregular hybrid structures.

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Paper No. 098

FINITE ELEMENT SIMULATION ANALYSIS ON STRENGTHENING OF REINFORCED CONCRETE COLUMNS WITH DIFFERENT KINDS OF FRP SHEETS, PART Ⅱ: RUPTURE OF FRP SHEETS AND INTERACTING MECHANICS

ZHANG Dachang[1], WU Zhishen[2]

Based on the analyses of load-deformation behavior for all cases, the failure mechanics, rupture of FRP sheets and its interacting mechanics of RC columns are thoroughly investigated, in which different types and amount (i.e. reinforced stiffness) of FRP sheets are applied. Firstly, deformation behavior, distribution and growth of principal compression stress and principal tensile strain are compared, and the failure mechanics of RC columns with 4-type of axial force ratio are discussed before and after strengthened with different FRP sheets. Whereafter, the growths of horizontal tensile strain of typical nodes along compressive diagonal are checked, and the rupture behaviors of FRP sheets and corresponding relations with the load-deformation behavior are examined. Lastly, the growths of compressive strain of concrete and tensile strain of main bars at the end of columns are studied, and the interacting mechanics between FRP sheets and RC columns, and failure modes of RC columns after strengthening are investigated.

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Paper No. 099

SEISMIC PERFORMANCE EVALUATION OF AN IRREGULAR HIGH-RISE BUILDING

Ying Zhou[1] and Xilin Lu[2]

In this paper, the seismic performance of an irregular high-rise building with two large openings (20m by 20m) in elevation was studied. There were two transfer stories in the building, which were set for structural requirement as well as architectural function. The analytical model of the building was first established in the finite element program of Strand7®. Plate element and beam element were employed for the structural walls, columns and beams, respectively. Some points on member skeleton curves of structural members were obtained using the software named Section Builder®, and Takeda constitutive rule included in the Strand7 was applied for the constitutive rule of the members. Then, nonlinear time-history analysis of the structure under multi-earthquake inputs was carried out. The dynamic properties and displacement responses were compared to the results of the dynamic model test.

Compared to the test, it was concluded that the nonlinear dynamic responses can be accurately reflected by the analytical model developed in this paper. Further conclusions come that the analytical parameters could be logically obtained by calculating member skeleton curve in Section Builder and then inputting them in the Strand7 model. Seismic performance of the irregular high-rise building was evaluated on both the analytical responses and experimental results. Up to now, the construction of the target building with improved design has been completed.

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Paper No. 101

COMPARISON OF TWO SELF-CENTERING STEEL MOMENT FRAME MODELING TECHNIQUES: GAP ELEMENT MODELS, AND NON-LINEAR ROTATIONAL SPRING MODELS

Mark Dobossy[1], Maria E. M. Garlock[2], and Erik VanMarcke[3]

In recent years, much research has been developed on the design and performance of self-centering steel moment-resisting frame (SC-MRF) systems for high-risk seismic zones. The SC-MRF connections consist of energy dissipation devices (e.g., bolted top and seat angles, friction devices or steel bars) and a post-tensioning system (e.g., high strength steel strands or steel bars) that run parallel to the beam. The strands compress the beam flanges against the column flange to develop the resisting moment to service loading. During overloading, such as that which occurs during DBE earthquake, a gap develops at the interface of the beam tension flange and column flange. Energy dissipation is provided by supplemental elements that deform under the gap opening behavior. The gap opening behavior also causes the SC-MRF to expand, where in the deformed position the distance between the column centerlines increases relative to the original distance.

While researchers from various institutions have agreed on the advantages of SC-MRF systems, their approach to modeling the connections has varied. To date, two types of analytical models have emerged to simulate and analyze such systems: (1) *gap element models* that simulate SC-MRF connections through the use of gap elements which open and close, as well as post-tensioned cable elements, and (2) *rotational spring* models using non-linear rotational springs with hysteretic, flag-shaped moment rotation curves at each connection. This paper examines these two models and presents the advantages, disadvantages, accuracies and inaccuracies of each. Such an analysis is important for current research that is developing on SC-MRF systems.

While the gap element model gives a higher level of detail as to the behavior of the connections, it is quite taxing computationally, and thus is not appropriate for parametric studies that are based on statistical evaluations that require thousands of analyses. It was found that the rotational spring model, while much faster, has some limitations which must be considered. For example, since gap opening is not directly modeled, the expanding nature of the SC-MRF is not captured; therefore the additional beam axial forces developed by the expanding strands and the interaction between the floor diaphragm and SC-MRF is neglected. The consequences of these differences are quantified and a different model, that is a compromise between the two models, is proposed.

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Paper No. 102

SENSITIVITY AND RELIABILITY ASSESSMENT OF SELF-CENTERING STEEL MOMENT FRAME SYSTEMS

Mark Dobossy[1], Erik VanMarcke[2], and Maria E. M. Garlock[3]

Researchers from various institutions have recently developed innovative steel moment frame systems for earthquake-resistant design that, following a major earthquake, have the potential to reduce or eliminate structural damage and return to its original vertical position (i.e. self-center). As the development of these steel moment frames with self-centering behavior progresses, it will be necessary to specify design parameters and a workable design method. This will require a good understanding of the sensitivity of the structure to changes in these parameters as well as the reliability of structures built based on the proposed method. This research investigates a risk assessment methodology (using Monte Carlo simulation) of the seismic response of self-centering steel moment frame prototype buildings.

First, we perform a series of conditional seismic reliability assessments of the structure. Synthetically generated earthquakes with magnitudes and distances within narrow ranges that are consistent with ground-motion attenuation curves for design basis (DBE) and maximum credible (MCE) earthquakes (as well as levels in between), are applied to the structure, and peak relative rotations between the beam and column are recorded. This data is then used to generate fragility curves (with respect to relative rotation) for the structure. From these, one can assess the risk of a particular design at a specific site having significant structural damage. The second study is a parametric sensitivity analysis. The effect of both increased damping and the use of energy dissipation devices at the connections are analyzed. The same sets of synthetically generated earthquakes are applied to structures assigned various levels of damping and energy dissipation.

The resulting fragility curves quantitatively express the effect these parameters have on the response statistics (such as mean and variance) and on the risk of earthquake-induced failure. Increasing the damping or other types of energy dissipation reduces the risk of serious structural damage, as well as the response variance, for a structure in a given seismic setting. The results can then be used to develop a reliability-based seismic design procedure for these self-centering steel moment frames.

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Paper No. 103

NONLINEAR CYCLIC AND EARTHQUAKE RESPONSE ANALYSIS OF REINFORCED CONCRETE STRUCTURES

Ryan Deng[1], David Lau[2], Heng-Aik Khoo[3], and Keh-Chyuan Tsai[4]

This paper presents a simplified method based on energy formulation for nonlinear analysis of reinforced concrete frame structures up to ultimate failure, which has been implemented in Open System for Earthquake Engineering Simulation framework (OpenSees). In the simplified method, a reinforced concrete member is modeled by an equivalent member of homogeneous nonlinear material with a derived stress-strain relationship, which satisfies the requirement that the equivalent member has the same moment-curvature behaviour as the original member. One advantage of the simplified method is its simplicity which can be easily implemented in most structural analysis computer program with nonlinear modeling capacities. The developed model can accurately predict the nonlinear hysteretic behaviour of reinforced concrete structures with frame members of arbitrary shapes and reinforcing details under severe earthquake excitations. Numerical examples of single bridge column structures of regular reinforced concrete members or double-skinned concrete filled tube members and a 2-story 2-bay reinforced concrete frame are analyzed using the simplified method under monotonic, cyclic and earthquake loadings to demonstrate the validity and accuracy of the simplified method. The effects of confinement, steel hardening, stiffness degradation and softening, pinching, and strength deterioration are simulated in the developed method. A correlation study has been carried out to compare the computer simulation results by the developed method with the experimental measurements of a full scale 3-story 3-bay reinforced concrete steel frame tested at the National Center for Research on Earthquake Engineering (NCREE) Taiwan, as a part of the joint research between Carleton University and NCREE. Results from the proposed method agree well with experiment test results and predictions from finite element and fiber models.

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Paper No. 104

NEAR-FAULT GROUND MOTIONS WITH PROMINENT ACCELERATION PULSES PART 1: EVALUATION OF PULSE CHARACTERISTICS AND THE STRUCTURAL DAMAGE POTENTIAL

Mai Tong[1], Vladimir Rzhevsky[2], George C. Lee[3], Jincheng Qi[4]and
Junwu Dai[5] and Xiaozhai Qi[6]

Recent major earthquakes (Northridge 1994, Kobe 1995 and Chi -chi 1999, etc.) have shown that many near-fault ground motions possess prominent acceleration pulses. Some of the prominent ground acceleration pulses are related to the large ground velocity pulses, others are caused by mechanisms that are totally different from those causing the velocity pulses or fling steps. Various efforts to model accelerat ion pulses have been reported in the literature. In this paper, we summarize some research results from our recent study of acceleration pulse prominent ground motions and analysis of acceleration pulse induced structural damage effects: (1). Temporal characteristics of acceleration pulses (2). Ductility demand spectrum of simple acceleration pulses with respect to equivalent classes of dynamic systems and pulse characteristic parameters (3). Estimation of fundamental period change under the excitation of strong acceleration pulses. By using the acceleration pulse induced linear acceleration spectrum and the ductility demand spectrum, a simple procedure has been developed to estimate the ductility demand and the fundamental period change of an RC structure under the impact of a strong acceleration pulse.

This paper is part I to a companion paper on Near-Fault Ground Motions with Prominent Acceleration Pulses, Part II. The analysis and experiments reported in this paper were carried out through an international cooperation research project between the Institute of Engineering Mechanics, China Earthquake Administration (IEM, PRC) and Multidisciplinary Center for Earthquake Engineering Research (MCEER, USA).

Keywords: ground motions, acceleration pulses, structural response, velocity, displacement

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Paper No. 105

TORSIONAL POUNDINGS BETWEEN TWO ADJACENT ASYMMETRIC STRUCTURES

K.T. C[1]hau, L.X. Wang[2], and X.X. Wei[3]

Seismic pounding between adjacent buildings is one of the major causes for structural damages during the strike of earthquakes. This undesirable phenomenon has been observed in numerous earthquakes, including 1995 Kobe earthquake a[4]nd 1989 Loma Prieta earthquake. Although a large number of investigations have been conducted, there has been no study on shaking-table-tests in investigating torsional seismic poundings between realistic building models, especially for modelling multi-storey asymmetric buildings with transfer system which are very common in Hong Kong. Developed upon our earlier theoretical study (Chau and Wei, 2001) and shaking table study (Chau et al., 2003), two multi-degree-of-freedom steel models are used to investigate the potential seismic poundings between two 21-storey adjacent buildings in Hong Kong. The two structures are of different natural frequencies and damping ratios. Both sinusoidal waves and 3 earthquake ground motions (i.e. 1941 El Centro, 1989 Loma Prieta and 1994 Northridge earthquake) have been used as input. Different impact phenomena were observed for various separation distances, frequencies and magnitudes of ground excitations. That is, the pounding phenomenon is highly nonlinear. The maximum responses as well as the maximum pounding forces have also been investigated. It was found that poundings between the two towers may be periodic or chaotic, depending on structural characteristics and the frequency content of the shaking table input. Torsional poundings between the two models were observed at both top and mid-levels because of the higher mode responses. Energy transferred from the more massive building to the lighter building through impacts causes abnormally large vibrational response of the lighter building, which when stands alone would not suffer any vibrational damages.

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Paper No. 107

SHAKING TABLE TESTS ON WOODFRAME CONSTRUCTION

Xilin LU[1] Wensheng LU[2] Chun NI[3] and Hanbo LI[4]

Seismic tests on 6m×6m 2-storey wood-frame construction model were carried out in successive stages on the shaking table of Tongji University. The full-sized model was made of light wood-framed walls and I-joist floors. The frame was sheathed with OSBs attached with studs by closely spaced nails to provide the necessary stiffness and strength to be capable to resist the expected in-plane lateral loads. The openings on exterior walls along north and south side at 1st storey were constructed unsymmetrical with different sizes. Three kinds of typical strong ground motions were applied to excite the model, with peak amplitudes of 0.10g, 0.20g, and 0.4g separately. After each excitation, the specimen was inspected for evidences of damage or deterioration, and any changes were documented and photographed. Between two successive test phases, white noise vibration measurements were operated to determine the dynamic behavior of the model, and then damaged sheathing OSBs were replaced by new boards. The large openings in braced walls at 1st storey caused considerable reduction in lateral stiffness and server earthquake damages. As a result, the seismic performance of the tested wood-frame construction was approved poor under severe earthquakes.

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Paper No. 108

POST-TENSIONED MOMENT CONNECTIONS WITH A BOTTOM FLANGE FRICTION DEVICE FOR SEISMIC RESISTANT SELF-CENTERING STEEL MRFS

James M. Ricles[1], Richard Sause[2], Michael Wolski[3], Choung Y. Seo[4] and Jun Iyama[5]

Conventional moment resisting frame (MRF) systems develop damage and may have permanent drift under the design basis earthquake (DBE). Under the NSF funded NEESR-SG research program, new earthquake-resistant structural steel MRF systems are being developed by a research group led by Lehigh University in collaboration with Princeton and Purdue Universities. These innovative self-centering (SC) structural systems are designed to be damage-free and without residual drift under the DBE.

The moment connection in a SC-MRF is a post-tensioned connection, with post-tensioned high strength steel strands running parallel to the beam. Lehigh University has been developing a concept that uses a friction energy dissipation device that is attached to the beam bottom flange and column to enable the moment connection to have energy dissipation capability without interference from the composite slab. This device is referred to as a bottom flange friction device (BFFD). The BFFD consists of a vertically oriented slotted plate shop welded to the bottom beam flange and two outer built-up angles field bolted to the column. Sandwiched between the two outer angles are brass friction plates on both sides of the slotted plate. High strength bolts with disc spring washers provide the normal force, compressing the entire assembly together. The beam remains in contact with the column under service loads. At a specified level of seismic loading, the beam decompresses from the column face and a gap opening occurs as the beam rotates about either the beam top flange (for positive moment) or the beam bottom flange (for negative moment). Upon unloading, the post-tensioning force causes the connection to close the gap at the beam-column interface, and return the connection to its initial configuration. During gap opening and closing under seismic loading the BFFD provides the connection's primary energy dissipation.

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Paper No. 109

EXPERIMENTAL STUDY ON A NEW RETROFITTED SCHEME FOR SEISMICALLY DEFICIENT RC COLUMNS

Zi-Xiong Guo[1], Jie Zhang Wu[2] and Yong Yang[3]

This paper introduces a scheme to retrofit seismically deficient reinforced concrete (RC) columns or piers with square section is proposed that using prestressed steel plate hoop(PSPH) was presented and experimentally investigated. In the present study, six half-scale short RC column specimens were tested under cyclic loading and the failure mechanism, strength, ductility, hysteretic character, and energy dissipation capacity were examined. The main parameters of the present test were axial compressive ratio of the columns and the prestressed level of the PSPH. Based on the test results, the following were concluded: (1) the prestressed SPH can efficiently postpone the occurring and mitigate the developing of diagonal cracks in substandard shear details short columns, and improve the failure mode of shear deficiency columns to obtain a favorable seismic behavior when seismic retrofitted is needed. This retrofitted technique is still effective for those columns with high compressive ratio; (2) the displacement ductility ratio of the retrofitted specimens increased over 3 times than that of the un-retrofitted specimen, and the ductility ratio could be further enhanced by increasing the prestressed level; and (3) the prestressed SPH can effectively confine the column concrete and thus a favorable seismic behavior can be expected. Nevertheless, the expected retrofitted efficiency diminished when the prestressed level of SPH is equal or less than 0.15.

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Paper No. 112

PERFORMANCE OF TUNED MASS DAMPERS FOR RESPONSE REDUCTION OF STRUCTURES UNDER NEAR-FIELD AND FAR-FIELD SEISMIC EXCITATIONS

Babak Kamrani-Moghaddam[1], Mohammad Rahimian[2] and Amir K. Ghorbani-Tanha[3]

Tuned Mass Damper (TMD) is a passive energy absorbing device usually installed on the roof of a tall building to improve the response of the structure under irregular external excitations such as earthquakes and winds by changing its dynamic behavior. The modern concept of TMDs for structural applications can trace its roots in dynamic vibration absorbers invented by Frahm in 1909. Since its introduction, numerous numerical and experimental studies have been carried out to examine the effectiveness of TMDs in reducing seismic response of structures.
In near-field zone, ground motion properties can be different from those of far-field zone and are influenced by some phenomena such as rupture mechanism, direction of rupture propagation relative to the site and permanent ground displacements resulting from the fault slip. Therefore, near-field acceleration records contain both high frequency and long period components compared to the far-field records. Since the frequency content of an earthquake has great influence on the response of structures, it is important to study the behavior of a given structure under near-field and far-field records of a same earthquake.
In this paper, the performance of using TMDs in response reduction of structures under near-field and far-field earthquake ground motions will be addressed. The 3-, 9- and 20- story structures are used for this study. First, time history analyses are performed to calculate the response of each structure subjected to near field and far field earthquake records. The same procedure is followed for the models with TMDs.
Comparison of results clarifies TMD's effectiveness on seismic response reduction of the structures located in near-field or far-field earthquake zones.

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Paper No. 114

EXPERIMENTAL AND THEORETICAL POST-BUCKLING STUDY OF STEEL SHEAR WALLS

Abdolrahim Jalali[1] and Arash Sazgari[2]

Steel shear walls has been extensively used as a lateral force bearing system in the design of new buildings, and retrofitting of existing structures. Seismic response evaluation of steel shear walls has the subject of extensive analytical and experimental research work during last decades. In this research, theoretical and experimental post-buckling study of steel shear walls has been considered. Thus, study has two parts. In the first part the available theoretical relations based on strip which has been also included in appendix M of standard CAN/CSA-S16.1-94, have been improved and used to predict yield displacement and yield strength of a steel panel. The second part describes experimental results of a $30cm \times 50cm$ panel of steel shear wall with hinged boundary frame under cyclic loading in order to evaluate force-displacement relation and post-buckling behavior of test specimen accurately. The experimental results especially at plastic range show much higher displacement than the available theories. The obtained drift during the rupture of panel is 5%. Included in the second part is a finite element analysis of the tested shear wall panel which, accurately predicts the pre-yielding and post-buckling behavior of the panel, and shows good agreement with experimental results. For the finite element analysis of the test panel, ABAQUS 6.5 has been used. The first stage in the simulation is a linear eigenvalue buckling analysis. About 30 modes of the panel have been considered in the analysis. The second stage involves introducing the imperfection into the structure. A combination of modes is used to construct the imperfection. To compare the results obtained with different imperfections, the imperfection size must be fixed. The measure of the imperfection size used in this study is the out of plane distance, which is computed as the normal distance from mid-surface of panel to the perturbed node minus normal distance from mid-surface of the perfect structure. The scale factor associated with each eigenmode used to seed the imperfection has to be computed. The results produced by the linear analysis must be used and scale factors must be determined so that the out of plane distance is equal to a specified value. This value is usually taken as a fraction of the panel thickness. The final stage of the analysis simulates the post-buckling response of the panel for a given imperfection. The primary objective of the simulation is to determine the static buckling load. The modified Riks method is used to obtain a solution since the problem under consideration is unstable. The simulation results have shown good agreement with experimental results.

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Paper No. 115

VULNERABILITY OF CODE-COMPLIANT RC BUILDINGS UNDER MULTI-AXIAL EARTHQUAKE LOADING

Aman Mwafy [1] and Amr Elnashai [2]

In the vicinity of the source of moderate-to-strong earthquakes, the ratio of peak vertical to horizontal acceleration (V/H) often exceeds the values around 2/3rd adopted in design codes. The difference in frequency content between the vertical and horizontal ground motions (VGM and HGM, respectively), when coupled with difference between the vertical and horizontal dynamic characteristics of structures, cast doubt regarding the adequacy of the simplified approach adopted in seismic design codes. There are also increasing field evidences confirming the significance of VGM. These evidences were even observed in regions where state-of-the-art in earthquake design practice is applied, such as Japan and the USA. The objective of this paper is to investigate the effect of VGM on seismic response and force reduction factors 'supply' of multi-storey RC buildings located in the vicinity of active faults and designed to modern seismic codes employing capacity design principles. A comprehensive set of local and global response parameters is selected to assess the building response under multi-axial earthquake loading (HGM and VGM). These include assessment of the shear supply-demand response of structural members using a realistic ductility- and axial force-sensitive shear strength approach. Near-field earthquake records with moderate-to-high V/H ratios are selected to provide realistic conclusions regarding the effect of VGM. The wide range of buildings and performance criteria selected and the state-of-the-art modeling approaches adopted render the results of this study indicative of response trends. It is concluded that the lower the contribution of horizontal seismic forces to the seismic response, the higher is the significance of vertical motion. The fluctuation of axial force in vertical structural members significantly increases when including VGM. This not only has direct consequences on tension and compression response but also has considerable impact on the shear capacity. Although the investigated buildings are designed and detailed according to modern seismic codes, the importance of including VGM in seismic design and assessment of RC buildings in the vicinity of active faults is emphasized.

Keywords: Vertical ground motion, RC buildings, seismic codes, shear failure, near-field records

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Paper No. 116

EFFICIENT COMPUTATION FOR DYNAMIC ANALYSIS OF INELASTIC STRUCTURES WITH SMOOTH HYSTERESIS

Chi-hsiang Wang[1] and Chuenn-Yih Chang[2]

The most widely used technique for time-history nonlinear structural analysis may be the step-by-step, second-order integration algorithms, such as the Newmark-β method. To capture the rapid cyclic reversals of external excitation, the sometimes non-negligible contribution of high-frequency vibration modes, and the gradual or sharp change in resistance due to yielding or unloading, it is often necessary to make the integration time steps small. The use of small time steps, however, requires intensive computational effort, particularly with Monte Carlo simulations, which require multiple runs of analysis. Moreover, if the resistance varies smoothly, rather than piecewise, due to material or geometric nonlinearity, the time steps need to be made even smaller to avoid unacceptable linearization error.

This paper presents a higher-order step-by-step integration algorithm for analysis of structures with smooth hysteretic behavior under earthquakes. This algorithm solves the integral of the equation of motion; it therefore requires the ground motion velocities, rather than the ground motion accelerations typically used in conventional 2^{nd}-order algorithms, as the excitations. A velocity time history is smoother and has fewer cyclic reversals than its acceleration counterpart, making possible the use of large incremental time step sizes that in turn lessens computer time. Systems of single-degree-of-freedom (SDOF) with (1) linear, (2) non-pinching, hysteretic, and (3) pinching, hysteretic, behaviors under the SAC ground motions are investigated. The computational efficiency of the developed algorithm is compared to that of the average acceleration method. Numerical studies found that for inelastic systems under earthquake excitation, the developed algorithm gives more accurate result and is more efficient than the average acceleration method even when typical ground motion time steps, e.g. 0.02 second, are used. If larger time step sizes are taken, for the SDOF inelastic systems considered herein, the higher-order algorithm can save more than 50% of computer time than the average acceleration method. Response statistics obtained using the SAC ground motion suite shows that the higher-order algorithm could be a powerful and efficient method that saves significant computer time for Monte Carlo simulations.

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Paper No. 117

FORCE TRANSFER MECHANISMS AND SHEAR STRENGTH OF REINFORCED CONCRETE BEAM-COLUMN ELEMENTS

Wu-Wei Kuo [1], Shyh-Jiann Hwang[2], and Ying-Zhi Chen[3]

This paper studies the force transferring mechanisms and shear strength of reinforced concrete (RC) beams. The transferring mechanism of shear forces in RC beams can be characterized as the load paths in the disturbed regions and the beam regions. The domains of different regions are proposed to be determined by the beam geometry, the longitudinal and transverse reinforcement. The inclination angles in each region are defined according to the proposed load paths of the force transferring. The disturbed regions are failed due to shear compression failure and shear tension failure. The failure mode of the beam region is shear tension failure. The shear tension failure is the yielding of shear reinforcement and the shear compression failure is the diagonal crushing of concrete. The shear strength due to the shear compression failure can be predicted by the softened strut-and-tie model, and the shear tension failure can be calculated according to the ACI 318-05 code approach. Accuracy of the proposed model is gauged by comparing with the available test data. Finally, the proposed model of beams is applied to columns.

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Paper No. 118

THE COMPARISON OF DIFFERENT ELASTIC-PLASTIC ANALYSIS METHOD OF COMPLEX HIGH - RISE STRUCTURES UNDER STRONG EARTHQUAKE ACTION

Jun Teng[1] Zuo-Hua Li[2] Hong-Jun Liu[1] Bo-Tao Ma[2]

The complex high-rise structures under strong earthquake action will achieve the plastic state partially, so the elastic-plastic analysis of structure is essential part for seismic design under strong earthquake action. The existing analysis methods of high-rise structures are divided into two kinds: static push-over analysis method and elastic-plastic dynamic analysis method. Static push-over analysis method is considered usually a simplified elastic-plastic analysis method, and it avoids the complexity of elastic-plastic dynamic analysis method, but applicable extent of this method is limited, especially the limitation is great for the complex high-rise structure which the high-order vibration modes and torsional effect cannot be neglected. But elastic-plastic dynamic analysis method not only gets accurate structure internal force and deformation, but also estimates the yielding mechanism, the weak link, and the destruction form of structures.

This paper based on large general finite element software-ABAQUS, and made use of rich elements and material of ABAQUS and formidable nonlinear computation function, and selected the corresponding computation model and the value computational method. Finally this paper analyzed the dynamic response of complex high-rise structure under strong earthquake action, and some comparison results are given. Through with static pushover analysis results and shake table test results contrast, the applicable extent of static pushover analysis method are given, it shows that elastic-plastic dynamic analysis method is more reasonable, and the computed results are more precise, and it is a more reliable analysis method of structure checking calculation under strong earthquake action.

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Paper No. 119

SUBSTRUCTURE DAMAGE IDENTIFICATION USING SEQUENTIAL NONLINEAR LSE METHOD

Jann N. Yang[1] and Hongwei Huang[2]

A challenging problem in structural system identification and damage detection lies in the requirement of a large number of sensors and the numerical difficulty in obtaining reasonably accurate results when the system is large. To address this issue, the substructure identification (SSI) approach has been developed based on measured response data and external excitations. However, due to practical limitations, only a limited number of sensors can be installed in the structural health monitoring system, indicating that the response data may not be available at all degrees of freedom of the structure and that the external excitations may not be measured (or available). In this paper, a new data analysis method, referred to as the sequential nonlinear least-square estimation with unknown inputs and unknown outputs (SNLSE-UI-UO) along with the sub-structure approach will be used to identify structural damages at critical locations of the complex structure. In our approach, only a limited number of response data are needed and the external excitations may not be measured. The accuracy of this approach is demonstrated using a substructure of a long-span truss with finite-element formulation. Simulation results demonstrate that the proposed approach is capable of tracking the changes of structural parameters, leading to the identification of structural damages.

Keywords: System Identification and Damage Detection, Substructure Identification, Structural Health Monitoring

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Paper No. 120

ANALYSIS OF DAMPING PARAMETER OF CAIYUANBA BRIDGE IN CHONGQING

Gang Liu[1], Zongming Huang[2], Chaowei Ling[3] and Pu Yang[4]

Abstract: With the increasing of bridge span, movable supports are more and more adopted to bridges in order to prevent the second internal force under these conditions of temperature difference, concrete shrinkage and creep. So viscous dampers have been widely used so that the relative displacement can be under control when the dynamic loads act on bridges. Taking into consideration of the characteristics of Caiyuanba Bridge, damping parameters are calculated and analyzed in this paper. It is validated that the effect of the damper is enhanced when damping exponent is increased or velocity coefficient is reduced. Besides, the sensitivity of damping parameters of Caiyuanba Bridge is studied.
Keyword: bridge, damper, parameter analysis

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Paper No. 121

SEISMIC BEHAVIOR OF PRECAST REINFORCED CONCRETE WALLS

Yaw-Jeng Chiou[1] Yuh-Wehn Liou[2] Chin-Chi Huang[3] and Fu-Pei Hsiao[4]

This study experimentally investigates the seismic behavior of precast reinforced concrete walls by test of large-scale specimens. The parameters of connected steel cover plate, orientation of wall reinforcements, steel ratio of wall, and strength of concrete were studied. The results show that the precast reinforced concrete wall can effectively increase the earthquake resistance of structures and protect the structural frame. The performance of the precast reinforced concrete wall can be fully developed by using connected steel cover plates with two channel plates which were fixed by M16 chemical anchors. The modified conventional reinforcement with more steel at the corners produces better performance than the other orientations. The larger steel ratio and stronger concrete also definitely increase the earthquake resistance of structures.

Keywords: precast reinforced concrete wall, large-scale test, earthquake resistance

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October 12-13, 2006

Paper No. 122

DESIGN CONCEPTS FOR SELF-CENTERING STEEL CONCENTRICALLY-BRACED FRAMES

Richard Sause[1], James M. Ricles[2], David Roke[3], Choung-Yeol Seo[4], and Kyung-Sik Lee[5]

Conventional CBF systems have limited drift capacity before brace buckling and related damage lead to deterioration in strength and stiffness. CBFs with buckling-restrained braces have greater drift capacity, however, these systems may sustain substantial permanent drift during seismic loading. Under the NSF funded NEESR-SG research program, a new type of CBF system is being developed, with increased drift capacity (before damage) and decreased permanent drift under seismic loading. These self-centering concentrically-braced frame (SC-CBF) systems are intended to provide significant non-linear drift capacity while limiting damage and residual drift and are motivated by the goal of minimizing structural damage under seismic loading. Initial seismic performance objectives have been developed. The hazard levels considered are the design basis earthquake (DBE) and the maximum considered earthquake (MCE), and the performance levels are immediate occupancy (IO) and life safety (LS). The initial performance objectives are to achieve IO performance (effectively no damage) under DBE level ground motions, and to achieve better than LS performance (some minor damage) under MCE level ground motions.

The fundamental lateral load behavior of the SC-CBF system is rocking on its foundation, which occurs when the column under tension from overturning moment decompresses and uplifts from its support. To control the rocking behavior, high strength post-tensioning (PT) bars, oriented vertically over the height of the CBF, as well as gravity loads, prestress the CBF to the foundation. The CBF is designed for the tension column to decompress at the base at a selected level of lateral loading, initiating a rigid-body rotation (rocking) of the frame. The PT bars provide a restoring force to return the CBF to the foundation (to self-center the CBF). The rigid-body rotation substantially limits the member forces that develop in the beams, columns, and braces. However, the rigid-body rotation induces deformation and eventually yielding of the PT bars. The PT bar yield limit state is the initiation of structural damage (the IO performance level), which also (neglecting strain hardening in the PT bars) establishes the lateral load capacity of the frame. To minimize structural damage before PT bar yield, the frame members (braces, beams, and columns) are designed to resist the internal forces that develop at PT yield. The LS performance level should be reached at lateral drift levels far beyond the PT bar yield limit state.

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Paper No. 124

SEISMIC CAPACITY EVALUATION OF KOUHU ELEMENTARY SCHOOL BUILDINGS

Chia-Wei Wu and Qiang Xue[1]

Evidence from Chichi earthquake indicated that school buildings in Taiwan were most seriously damaged. It is an urgent task to assess seismic performance of existing school buildings so that the young generation will be well protected. In order to understand seismic capacity of these buildings correctly, in Aug. 2005, NCREE performed three in-situ pushover tests in Kouhu Elementary School at Yunlin county, including one original frame and the other two frames retrofitted with either RC walls or brick walls. Before the test, a competition was announced to encourage individuals to evaluate seismic capacity of these frames numerically. In this paper, the champion work is presented. The paper focuses on how to use nonlinear static analysis to evaluate traditional elementary school buildings including the assumptions used in the analysis such as material properties and its degradation, RC wall simulation, hinge properties assignment, member failure mechanism, etc. By comparing the capacity curve and the failure modes of the test and numerical results, it is shown that all numerical results are close to but conservative than the test results. Some member failure behavior is difficult to simulate using the widely used analytical package. Finally, suggestions on possible improvement are made.

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Paper No. 126

UNIFORM COMPRESSION OF BONDED ELASTIC LAYERS

Seval Pinarbasi[1], Ugurhan Akyuz[2] and Yalcin Mengi[3]

Elastic layers bonded to rigid surfaces have widely been used in many engineering applications. It is known that while the bonded surfaces influence the shear behavior of the layer only slightly; it can cause drastic changes on its compressive behavior. Since most of the earlier analyses have been based on assumed displacement fields besides some assumptions on stress distributions, usually only the "average" solutions could be obtained. In this study, behavior of bonded elastic layers under uniform compression is formulated by using the approximate theory based on a modified version of the Galerkin Method developed by (Mengi, 1980a). Reduced governing equations are derived for layers of any symmetrical cross-sectional shape. Closed form expressions are obtained for displacements, stresses and compression modulus for infinite-strip-shaped layers by using both the zeroth and first order theories. Through a detailed study on stresses developing in an infinitely long rectangular bonded layer, the effects of shape factor and Poisson's ratio on stress distributions and on the magnitudes of maximum stresses are determined.

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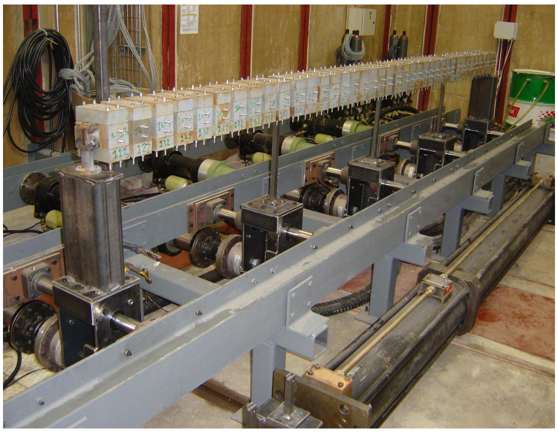
Paper No. 127

EXPERIMENTAL MODELLING OF MULTIPLE SUPPORT EXCITATION OF LONG SPAN BRIDGES

Adam J Crewe[1] and James A P Norman[2]

Eurocode 8 Pt 2 recommends that bridges longer than 400m, or bridges built on significantly varying ground types, should be assessed under the effects of multiple support excitation (MSE). However, previous analytical work has suggested that for shorter bridges MSE can also have an effect on the response. This paper outlines the results of experimental tests that confirm that for bridges as short as 200m, multiple support excitation can have a significant effect on the response of the bridge. For the bridge configurations tested, the displacements caused by multiple support excitation were up to 36% larger than when multiple support excitation was not taken into consideration. To generate the multiple input motions to each of the piers the bridge model was shaken by five parallel single axis shaking tables. The response of the bridge to three different sets of input time histories are presented in this paper. Type 1A and 1D response spectrum compatible time histories, which correspond to hard and soft soil conditions, and real data from the SMART1 array in Taiwan. The tests show that when a time delay (caused by a finite ground wave velocity) is introduced between the input motions to each pier, there is a larger response in the first and third piers, whilst there is no reduction in response of the middle pier. This occurs because the synchronous input (with all piers exactly experiencing the same input motion) only excites the symmetrical first and third modes, whilst the time-delayed input excites all of the first three modes. These typical results reveal that if we consider synchronous excitations only in the design of bridges, the response of some piers may be underestimated and hence the design may be unsafe. At present, the Eurocode 8 pt 2 does not require bridges of the length being modelled to be analyzed for MSE if the ground conditions are homogenous. However, these results reveal that even though the input motion was the same for all inputs, with only a small time delay between inputs at each pier, the response of the outer piers was significantly increased.



The five parallel shaking tables supporting the model bridge

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Paper No. 128

SEISMIC BEHAVIOUR OF PANEL ZONES IN BEAM TO COLUMN CONNECTIONS WITH NON-PLANNER WEBS IN MOMENT RESISTING STEEL FRAMES

Rasul Mirghaderi[1] and Mahmoud Moradi[2]

Most of seismic provisions given so far in codes are based upon analytical and experimental studies for panel zones behaviour of beam to column connections, are limited to I-beam to H-column connections with planner webs. There are not enough documented studies for the cases when beam web(s) and column web(s) are not in one plane. Since, use of built up box columns in Asian countries is a common practice,and for them, beams are connected directly to the face of column flanges, so the mobilization of column panel zones are due to proper passage of beam flange forces from column flanges in an out of plane state which has a very low strength and stiffness.

In this paper the results of analytical studies of using a pair of horizental continuity plates at beam flanges level inside of column section as a suitable path are presented for transfer of beam seismic moments to column panel zones.

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Paper No. 129

COMPARISON OF NONLINEAR STATIC AND NONLINEAR DYNAMIC ANALYSES IN THE ESTIMATION OF THE MAXIMUM DISPLACEMENT FOR STRUCTURES EQUIPPED WITH VARIOUS DAMPING DEVICES

Payam Tehrani[1] and Shahrokh Maalek [2]

In this study, the nonlinear static and nonlinear dynamic procedures in the determination of maximum displacements of an existing 9 story steel structure retrofitted with different methods have been compared. These methods include the use of the EBF systems; RC Shear Walls and use of Passive energy dissipators such as metallic TADAS dampers, viscous dampers, viscoelastic dampers and friction dampers. Each damping system has been modeled for several damping ratios and damper properties. In nonlinear dynamic procedure, the response of the structure to seven scaled earthquake records matched to the design spectrum has been obtained and the average value of the responses is used for comparison. At the same time in nonlinear static procedure, the maximum displacement of the structure in two different load distribution patterns namely uniform and spectrum patterns have been obtained. The results demonstrate that nonlinear static procedure determines the maximum displacement of the structure conservatively. Particularly with the use of the Viscous Dampers in the structure difference between the results, will become more pronounced. In addition, it seems that this difference increases when the structure becomes more flexible.

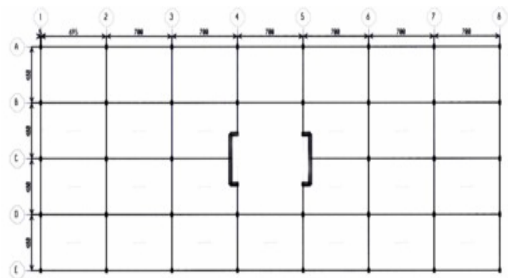

Fig.1: Typical Story Plan of the Existing Building

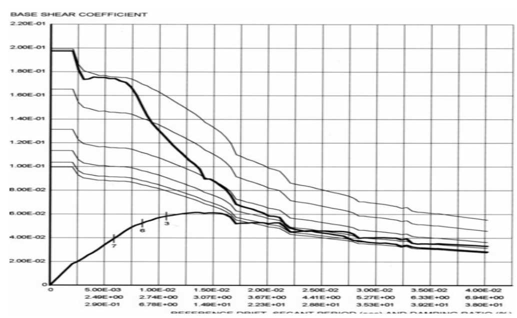

Fig.2: Sample Pushover Curve for the Existing Building

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Paper No. 132

TUNED MASS DAMPER FOR SEISMIC RESPONSE REDUCTION OF TEHRAN TOWER

Mohammad Reza Okhovat[1], Mohammad Rahimian[2] and Amir K. Ghorbani-Tanha[3]

Appealing to the principle of vertical residence and stemming the horizontal expansion of the city, the Tehran Tower is being built on 35,000 square meters site with total area of 200,000 square meters. With a height of over 170 m, this 56-story concrete building is in final stages of construction and would be the highest residential building of Iran. Since Tehran is located in a high-risk earthquake zone, all of the structures must design for seismic loads. In this building, lateral loads are carried with three main concrete shear walls which are located in an angle of 120° and gravity loads are transferred from concrete slabs to some secondary shear walls.

Since the introduction of tuned mass dampers (TMDs) by Frahm in 1909, numerous studies have been carried out to examine the effectiveness of these devices in reducing seismic response of structures. The objective of incorporating a TMD into a structure is to reduce energy dissipation demand on the primary structural members under the action of external forces. This reduction is accomplished by transferring some of the vibration energy of the structure to the TMD and dissipating the energy at the damper of the TMD.

The purpose of this study is to design and evaluate the effectiveness of TMD for response control of Tehran Tower under seismic excitations. A lumped mass model of the building is provided with 112 translational and 56 rotational degrees of freedom using solid and shell elements. Time history analyses are performed to calculate the response of the structure subjected to representative earthquake records. The same procedure is followed for the model fitted with TMD. Comparison of the results clarifies the effectiveness of TMD on response reduction of the tower. A parametric study has been performed to demonstrate the effects of damper parameters on structural responses.

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Paper No. 133

THE USE OF PASSIVE DAMPERS AND CONVENTIONAL STRENGTHENING METHODS FOR THE REHABILITATION OF AN EXISTING STEEL STRUCTURE

Payam Tehrani [1] and Shahrokh Maalek[2]

In this study, the effect of using several rehabilitation methods to improve the seismic performance of an existing 9 story steel structure has been investigated using nonlinear static and nonlinear dynamic analyses. These methods include the use of the EBF systems; RC Shear Walls and use of Passive energy dissipators such as metallic TADAS dampers, viscous dampers, viscoelastic dampers and friction dampers. Each damping system has been modeled in the structure for several damping ratios and damper properties. In nonlinear dynamic procedure, the response of the structure to seven scaled earthquake records matched to the design spectrum has been obtained and the average value of the base shears, base moments and dissipated energy in structural members have been used for the comparison. The results demonstrate that the use of the passive dampers in the structures, in comparison with the conventional methods of strengthening, substantially reduces the base shear and structural damages in the structure.

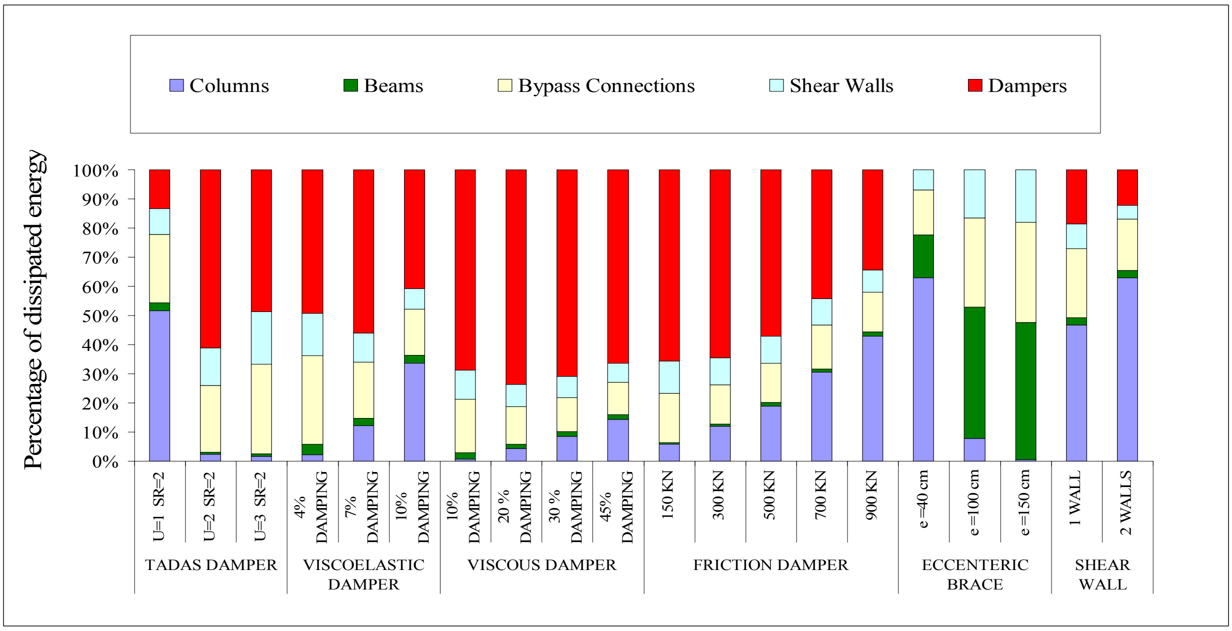

CHART1. Average dissipated energy in each element for the use of various devices (Y direction)

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Paper No. 134

SEISMIC BEHAVIOR OF PRE-STRESSED STEEL BEAMS AND CFT COLUMN CONNECTIONS WITH X-SHAPED DAMPERS

Lai-Yun Wu[1], Lap-Loi Chung[2], Jia-Chain Chen[3], Sheng-Fu Tsai[3], and Huan-Yu Bao[3]

The structural system of post-tensioned pre-stressed steel beams with concrete filled tubular (CFT) columns has remarkable performance in strength, ductility, load-bearing capacity and construction duration. After the structure is experienced an earthquake, the beams and columns can return to their original location. However, behavior of beam-to-column connection is so complicated that it is not widely applied. For the beam-to-column connections of this structural system, a detail design method was proposed in this research. The end of H-beam was welded with X-shaped damper. Then the X- shaped damper was bolted to the CFT column as an energy dissipation element to ensure the integrity of the major structural elements while experiencing an earthquake. This research established a mechanics model of the beam-to-column connection and performed a series of structural earthquake-resistant experiments. The research results proved the beam-to-column connection have remarkable earthquake-resistant performance in strength, ductility, energy dissipation and self-centering ability. The structural system remained standing strong even when story drift reached 6% and plastic angular of displacement of the beam-to-column connection reached 5%. It demonstrates the earthquake-resistant performance of this beam-to-column connection exceeds the regulatory requirements for earthquake-resistant connections in Taiwan and U.S.

Keywords: pre-stressed structure, concrete filled tube (CFT), X-shaped damper.

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Paper No. 138

SELF-LEARNING SIMULATION FOR MODELING OF FLEXIBLE CONNECTIONS IN STEEL MOMENT RESISTING FRAMES

Gun Jin Yun[1] Jamshid Ghaboussi[2] and Amr S. Elnashai[3]

The inelastic response of beam-column connections significantly affects the seismic performances of steel frames. Accurate models of beam-column connections are important both in understanding the seismic behavior and in design. An effective approach towards developing accurate models for connections is self-learning simulation, which is presented in this paper. The latter simulation method has the unique advantage in that it can extract material models from global structural response. Self-learning simulation is based on auto-progressive algorithms that employ the principles of equilibrium and compatibility, and the self-organizing capability of artificial neural network material models. Steel beam-column connections are represented by point plastic hinges that are modeled by a new neural network representation for modeling of cyclic behavior of connections. The neural network based connection model has significant advantages over conventional models in that it can handle complex behavior due to local buckling and tearing of components. Moreover, its implementation is more efficient than conventional connection models since it does not need interaction equation and plastic potential. In this paper, the performance of the neural network based connection model is verified with experimental data and the proposed self-learning simulation methodology is demonstrated with a simulated structural testing of a two-story one bay frame with semi-rigid connections.

Key words: Nonlinear Finite Element Analysis, Neural Network, Steel Beam-Column Connection, Inelastic Hysteretic Model, Self-Learning Simulation

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October 12-13, 2006

Paper No. 142

ADVANCED ANALYSIS OF HIGHWAY OVER-CROSSING BRIDGE WITH SOIL-STRUCTURE INTERACTION

Oh-Sung Kwon[1] and Amr S. Elnashai[2]

In this study, an analysis of a highway over-crossing bridge including a novel representation of soil-structure interaction is presented. As a benchmark structure, the Meloland Road Over-crossing Bridge is selected. The structure was heavily instrumented and recorded several sets of earthquakes. The approach embankments, abutments, and supporting pile groups are modeled as three-dimensional finite element idealizations in OpenSees with realistic soil material models. The bridge structure is modeled in Zeus-NL, the Mid-America Earthquake Center analysis platform. The stiffness values of embankments and pile groups are evaluated and compared with previous studies. The mode shape and fundamental properties of the soil-structure system are compared with those determined from system identification of the bridge based on measured ground motion. Response history analysis is conducted by distributed computation of geotechnical and the structural model on four separate processors, representing four geographically distributed simulation sites. The analysis results show that the response of the embankments has a significant role in bridge behavior. From the simulation point of view, it is demonstrated that the analysis of large interacting systems using distributed computation leads to significant reduction in computation time.

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Paper No. 143

NEAR-FAULT GROUND MOTIONS WITH PROMINENT ACCELERATION PULSES
PART II: SHAKING TABLE EVALUATION OF STRUCTURAL
SHAKING TABLE EVALUATION OF STRUCTURAL

Junwu Dai[1], Xiaozhai Qi[2], Mai Tong[3] and George C. Lee[4] and Vladimir Rzhevsky[5]

This paper is part II to a companion paper on Near -Fault Ground Motions with Prominent Acceleration Pulses, Part I. The experimental study reported in this paper was carried out through an international cooperation research project between the Institute of Engineering Mechanics, China Earthquake Administration (IEM, PRC) and Multidisciplinary Center for Earthquake Engineering Research (MCEER, USA).

Based on the evaluation of acceleration pulse characteristics and damaging potential, a series of shaking table tests on three R/C single story structures and one high-rise building structure (54 floors) were carried out under either pulse-dominant full-time-history ground motions or corresponding segregated pulse excitations. Test results showed that the observed values of acceleration, velocity and displacement under segregated pulse excitations were all not less than those under full-time-history ground motions, and the pulse effects were obvious in both elastic and inelastic responses. Damage check and visual inspection of the specimens after each test showed that the segregated major pulses had almost the identical damage potential as the original time-history records. These phenomena verified that the major pulse in pulse-dominant ground motions recorded in Chi-chi earthquake (Taiwan 1999) have the controlling effect for most type of building structures. Moreover, to compare the difference of the story lateral deformation-force relationship of structures under static and earthquake dynamic load, a fourth single story R/C frame structure identical to the above mentioned 3 single story structures was used for the quasi-static test. The results showed that the dynamic lateral resistant capacity of the structures in shaking table tests was about 20% higher than that of the same structure under quasi-static loadings. The comparison suggested that the numerical estimation based on the quasi-static test results is conservative for dynamic loadings.

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Paper No. 145

FRAGILITY ANALYSIS METHOD FOR BUILDINGS WITH PLAN IRREGULARITIES

Seong-Hoon Jeong[1] and Amr S. Elnashai[2]

A methodology for the derivation of fragility curves for structures with plan irregularities is presented herein. In order to characterize the damage state of irregular structures, a spatial (3D) damage index is formulated and employed as the damage characterization measure. The procedure is illustrated through a reference derivation of fragility curves for an irregular RC building under bidirectional earthquake loadings. Via the comparison between fragility curves derived by the spatial and the previously-existing damage indices, it is shown that employing the latter for the fragility analysis of irregular structures may be inaccurate and even unconservative.

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Paper No. 146

SIMPLE SURVEY ON SEISMIC PERFORMANCE OF ELEMENTARY AND SECONDARY SCHOOL BUILDINGS IN TAIWAN

L.L. Chung[1], S.J. Hwang[1] W.Y. Jean[1] Y.K. Yeh[1] and C.W. Sher[1]

In the past years, Taiwan was attacked by three major earthquakes. They are Ruei-Li, Chi-Chi and Chia-Yi earthquakes. According to the reconnaissance reports, school building was the type of structure that was most seriously damaged. Lack of integral planning, weakness along corridors, effect of short columns, imbedded pipelines and lack of lateral reinforcement are some of the answers to the collapse of school buildings even though the design seismic force for school buildings is 25% higher than the ordinary buildings. Serious casualties and losses may be resulted from the collapse of school buildings under strong earthquakes. Furthermore, school buildings are usually assigned as emergency shelter soon after earthquakes. Therefore, in this paper, an economic and efficient method for simple survey on seismic evaluation of typical school buildings is proposed based on the common structural types, seismic weaknesses, failure modes and experimental data. It is used to grade the seismic performance of school buildings.

Keywords: school buildings; seismic performance; simple survey

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Paper No. 147

IN-SITE PUSH OVER TESTS AND SEIMIC ASSESSMENT ON SCHOOL BUILDINGS IN TAIWAN

Yi-Hsuan Tu[1], Shyh-Jiann Hwang[2] and Tsung-Chih Chiou[3]

In Taiwan, many school buildings suffer severe damage in earthquakes. Based on the experience of the Chi-Chi earthquake, some common failure behaviors, such like failing in the longitudinal direction that has no walls and short-column effect were found due to their typical architectural pattern. After the earthquakes, seismic assessment and retrofit are needed urgently for the rest of the existing school buildings. Since in-site test is the most direct way to realize the actual behavior of structures, 4 in-site push over tests of school buildings were carried out to study the effects of different retrofitting measures and to verify the seismic assessment methods. The specimens include a 2-floor building with 3 classrooms of Hsin-Cheng Junior High School, Hualien, and 2-floor school building of Kouhu Elementary School, Yulin. The latter was consists of 8 classrooms and cut into 3 specimens, each has 2 classrooms, while the rest 2 classrooms reinforced by steel bracing to provide reacting support. Specimen in Hualien was a typical school building with no walls in the longitudinal direction, while specimens in Yulin has an typical one, one with original brick wing walls, and one with new RC wing walls as retrofit in the longitudinal direction. 6 hydraulic actuators were placed at the top of each floor of each specimen to provide lateral loading along the longitudinal direction. While being lateral loaded, some of the specimens were subjected to extra vertical loads by added weights on the slabs. Another vertical loading test was also executed in one classroom in Hualien with part of columns cut. The test results show that wing walls can be efficient retrofit on the lateral strength of school buildings. A seismic assessment method is introduced and the comparison between analytical method and test result is presented in this paper.

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Paper No. 149

DYNAMIC PERFORMANCE OF CONCRETE SLIDING INTERFACES

Eduardo Botero J.[1], Bogart C. Méndez U[2]., Juliana C. Zapata[2], Miguel P. Romo O.[3]

Several shaking table tests were carried out on two concrete blocks where one was fixed to the shaking table and the other was resting on top of the inferior block. The static friction of the concrete in the interface was determined for undisturbed conditions. Then 2000-loading cycles were applied to the blocks and the kinetic friction was determined from the interpretation of the acceleration time histories recorded on the top block. This process was repeated nine times to asses its effect on both the static and kinetic friction coefficients. Furthermore, by comparing the input (motion in shaking table) with the output (motion on the upper block) the amount of energy transmitted across the interface was determined for each experimental stage (every 2000 cycles). The results show that static and kinetic friction coefficients vary significantly with repeated loading, thus modifying the energy transmission across the sliding interface. Accordingly, the response characteristics of the upper block changes with time.

Keywords: Concrete, interface, friction, sliding

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Paper No. 150

EXPERIMENTAL ASSESSMENT OF RC BEAM-COLUMN CONNECTIONS STRENGTHENED WITH CARBON FRP

Kihak Lee[1]

Many RC structures built without seismic provisions have exhibited brittle shear failures in the beam-column joint area, and resulted in large permanent deformations and structural collapse. This paper presents the results of an experimental investigation pertaining to the use of carbon fiber-reinforced polymer(FRP) for strengthening of RC beam-column connections. The selective upgrade is obtained by choosing different combinations and locations of carbon FRP sheets to determine the effective way to improve the structural performance of joints. Experimental results demonstrate significant improvement of flexural capacity and ductility of beam-column connections originally built without seismic details.

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Paper No. 152

WEAKENED AND STRENGTHENED STEEL MOMENT CONNECTIONS

Chung-Che Chou[1], Chia-Ching Wu[2], Chih-Kai Jao[2], and Yuang-Yu Wang[3]

The effectiveness of using the reduced flange plates (RFPs) or welded rib plates for seismic response of steel moment connections was investigated through cyclic testing of six full-scale specimens. The first scheme was to utilize RFPs to connect the beam flanges to the column, without any direct connection of the beam flange to the column. Plastic hinging occurred in the RFPs instead of the beam, eliminating buckling of the beam. The second scheme was to strengthen the steel beam by welding rib plates between the column face and inner side of the beam flanges to minimize the amount of work for retrofitting an existing building. Ideally, the stress in the welds between the beam flange and column would be reduced and buckling of the beam would be forced away from the column face. Test results of the RFP connections showed that (1) the connections developed beam plastic moment and reach more than an interstory drift of 4% without strength degradation, (2) the RFP was effective in dissipating energy before buckling, and (3) no buckling of the beam was observed in the tests. Test results of a rib plate connection showed that the presence of the rib plates reduced the beam flange strain by about 75% compared to a bare steel moment connection. Both types of connection specimens were also modeled using the non-linear finite element computer program ABAQUS to perform a correlation study.

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Paper No. 153

IMPROVING SEISMIC PERFORMANCE OF POST-TENSIONED COLUMN TO BASE CONNECTION

Hsieh-Lung Hsu[1] and Jin-HauWan[2]

Post-tensioned precast structural systems are considered efficient structural forms for building constructions. The validity of such designs is justified only when adequate seismic performance is achieved. In order to develop desirable structural performance, the column base connections must possess sufficient stiffness and strength. This study investigated the feasibility of adopting rubber pad in the seismic design of post-tensioned precast column to base connection. Test results show that the re-centering mechanisms of the connections were effectively sustained. The energy dissipating device also added significant stiffness to the system and exhibited stable hysteretic behavior under various magnitudes of post-tension, which justified its applicability to the seismic design of post-tensioned column to base connection.

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Paper No. 154

EXPERIMENTAL AND ANALYTICAL PERFORMANCE ASSESSMENT OF IN-SITU PUSHOVER TESTS OF SCHOOL BUILDINGS IN TAIWAN

Yuan-Tao Weng[1] Ker-Chun Lin[2] Shyh-Jiann Hwang[3]

The 1999 Chi-Chi earthquake revealed the poor performance of the RC school buildings in Taiwan. It also indicates an urgent need of seismic evaluation and retrofit for the remaining schools. In order to realize the behavior of a typical school building subjected to lateral load, a series of in-situ test for two existing 2-story RC school buildings was carried out. Three types of lateral loading patterns were subjected to three 2-story 2-classroom frame specimens respectively: monotonic static pushover, cyclic static pushover, and earthquake time history input. This present paper is devoted to the experimental program, test results and analytical assessment. Moreover, the responses to free vibration, forced vibration and mircotremor measurement were recorded in order to identify the dynamic behavior of frame specimens. These experiments provide reliable and efficient data of real interest for a clear understanding of the actual building behavior, especially the effects of the seismic performance of a school building subjected to cyclic lateral loading collocating with pseudo dynamic test (PDT). The advantage of integrating these data in the seismic evaluation is presented and discussed. Results of these tests are reported, analyzed and interpreted in this paper. Test results present that the effect of the decay of structural strength and stiffness induced by cyclic loading should be considered in seismic evaluation procedure properly.

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Paper No. 155

THE SUB-STRUCTURAL PSEUDO DYNAMIC TESTS OF A FULL-SCALE TWO-STORY STEEL PLATE SHEAR WALL, PART 1: PHASE I TESTS

C.H. Lin[1], K.C. Tsai[2], Y.C. Lin[1], K.J. Wang[3], Y.T. Weng[3], W.D. Hsieh[4], B. Qu[5] and M. Bruneau[6]

This is the first part of a two part paper describing a 2-story steel plate shear wall frame (SPSWF) specimen tested by using sub-structural pseudo dynamic testing procedures in February, 2006. And this paper focuses on the design method and procedures, experimental setup and phase I test result. In recent years, several researchers have confirmed that the steel plate shear wall (SPSW) can be a viable seismic force resisting system for building structures. Although the SPSW can cost-effectively satisfy the lateral stiffness, strength and ductility requirements for seismic buildings, research on large-scale SPSW structures are rather limited. Considering the small-scale structure tests could not obtain precise seismic behavior close to the performance of real world, measuring eight meters tall and four meters wide, the 2-story SPSW specimen constructed for this purpose. The thickness of SS400 grade steel plate for first story wall is 3mm; second story, 2mm. All the boundary beam and column elements are A572 GR 50 steel. Each of SPSWs has horizontal tube restrainers on both sides to minimize the out-of-plane displacement and the buckling sound. In phase I test, the specimen was tested under pseudo-dynamic loads using three ground accelerations, which were recorded in the 1999 Chi-Chi earthquake and scaled up to represent seismic hazards of 2%, 10%, and 50% probabilities of exceedance in 50 years. Test results show that 1) the SPSWF specimen sustained three earthquakes without any significant wall fracture or overall strength degradation, 2) the horizontal restrainers are very effective in improving the serviceability of SPSWs, 3) the responses of the SPSWF can be simulated accurately using the strip model and the tension-only material property implemented in PISA3D computer program.

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Paper No. 157

SEISMIC PERFORMANCE OF RC COLUMNS STRENGTHENED WITH DYNEEMA FIBER-REINFORCED POLYMER SHEETS

Z.S. Wu[1], D.S. Gu[2], G. Wu[3], and H. Hirahata[4]

Dyneema fiber is a new type of composite material with great performances on ultimate tensile strain and energy absorption superior than other fiber sheets such as aramid and carbon fiber sheets. An experimental investigation was conducted to study the seismic behavior of reinforced concrete columns strengthened with DFRP (Dyneema Fiber Reinforced Polymer) sheets and dry Dyneema fiber sheets (DFS) without resin impregnation. All specimens were tested under cyclic lateral shear force with constant axial load. Test variables included axial load, reinforcing ratio of the FRP sheets, column height-to-diameter ratio and the polyester resin. Test results show that seismic resistance of retrofitted columns can be improved significantly as a result of the confining action of the DFRP sheets. It is confirmed that the seismic performance of RC circular columns can also be improved with dry Dyneema fiber sheets without resin impregnation and bonding due to its good energy absorption..

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Paper No. 158

CAPACITY DESIGN PROCEDURES AND TESTING OF PERFORATED STEEL PLATE SHEAR WALLS

Darren Vian[1] & Michel Bruneau[2]

Steel plate shear walls (SPSWs) are a lateral force resisting system that has seen increased usage as a primary system in buildings over the past thirty years in North America and Asia, for both retrofit and new construction. Early designs only allowed for elastic behavior, or shear yielding in the post-elastic range, an approach that typically resulted in the selection of relatively thick or heavily-stiffened infill panels. However, following research of the early 1980s, the use of un-stiffened and relatively thinner plates for the infill panels was introduced, by allowing shear buckling and subsequent diagonal tension field action development in the panels as the method of lateral load resistance, resulting in more efficient designs, from the perspective of the panels, as well as the surrounding frame members that are typically capacity designed for the forces exerted by the wall panels.

While researchers worldwide have made many advances in understanding the hysteretic characteristics of this structural system, there remain unresolved issues that require further research attention to ensure practical implementation and predictable ductile behavior and during a given seismic event. For example, although calculations may indicate that thinner infill plates could be used in a given situation, the minimum steel plate thickness available often far exceeds the value required from the design calculations. Building with thicker-than-required plate may lead to as-built systems that are much stiffer and stronger than designed, resulting in higher floor accelerations and force demands on retrofitted framing, and also result in concentrated hysteretic energy dissipation at individual stories along the building height. Refined design limits for boundary frame members are also needed to ensure ductile behavior and prevent undesirable failure modes. In particular, design to prevent column hinging as observed in past experimental studies is important, as well as robust design of the anchor beams. From the context of SPSW infill panels interacting with other building systems, utilities passing through the plane of an SPSW-retrofitted bay must be diverted elsewhere and accommodated by other means, such as costly stiffening around panel cutouts, to allow penetration of the panel.

This paper introduces a procedure for the efficient design of anchor beams, those beams at the upper and lowermost levels of a multi-story SPSW frame, which "anchor" the tension field forces developed in an SPSW infill panel. In addition, some practical concepts to allow for utility passage are introduced, utilizing both reinforced and unreinforced perforations of solid panels.

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Paper No. 159

PSEUDO-THREE-DIMENSIONAL NONLINEAR SEISMIC RESPONSE ANALYSIS OF STEEL FRAME-CONCRETE TUBE HYBRID STRUCTURES

Ling-xin ZHANG[1] Shu-ling YANG[2] and Xiu-li DU[3]

In this paper, the spatial restrain effects of the transverse steel beams between steel frame and concrete tube are applied to the two-dimensional model to give the pseudo-three-dimensional nonlinear seismic response analysis model of the hybrid structures. In the model, the element type of the transverse beam is selected rationally, i.e. one end of the transverse beam is hinged with the concrete tube, and the other end is rigid with the frame. Thus, the spatial restrain effect problem of the steel frame-concrete tube hybrid structures is solved in a simple and feasible way. And then, the pseudo-three-dimensional nonlinear seismic response analysis method of the hybrid structures is given by using the determined analysis model, and the corresponding analysis program is complied on the basis of the large special computer program DRAIN-2D and added to DRAIN-2D as subroutines. Finally, the pseudo-three-dimensional nonlinear seismic response analysis method is illustrated by an example.

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Paper No. 160

NEAR-FAULT PULSEA-LIKE EFFECT ON STRENGTH REDUCTION FACTORS

Chang-Hai Zhai[1], Hong-Bo Liu[2] and Li-Li Xie[3]

As near-fault pulse-like strong ground motions have severe damage potential for the structures, it is significant to study the effect on strength reduction factors. The recent earthquakes in Taiwan (September 20, 1999, Chi-Chi) have significantly increased the amount of data available in the near-fault. With the near-fault pulse-like ground motions recorded in Chi-Chi earthquake, the near-fault pulse-like effect on strength reduction factors is investigated and the fitting expressions of modifying the strength reduction factors for near-fault effect are presented. It is concluded that during the short or medium period range the strength reduction factors given from the near-fault pulse-like ground motions are significantly less than those from the far-fault ground motions and it is unsafe for using most of the existing strength reduction factors in near-fault areas, because most of the existing strength reduction factors are obtained from the far-fault ground motions. The conclusions can provide valuable insights to practice and development of seismic code.

Keywords: Strength reduction factors; near-fault effect; Chi-Chi earthquake

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Paper No. 161

EXPERIMENTAL STUDY OF AN ADAPTIVE EXTENDED KALMAN FILTER FOR STRUCTURAL DAMAGE IDENTIFICATION

Shinya Wu[1], Li Zhou[2], Jann N. Yang[3]

An important objective of health monitoring systems for civil infrastructures is to identify the state of the structure and to detect the damage when it occurs. Analysis techniques for damage identification of structures, based on vibration data measured from sensors, have received considerable attention. Recently, a new adaptive tracking technique, based on the extended Kalman filter approach, has been proposed for the damage identification of structures on-line, when the measured data involve damage events. Simulation studies have demonstrated that the proposed adaptive extended Kalman filter (AEKF) approach is capable of tracking the variations of structural parameters, such as the degradation of stiffness, due to damages. In this paper, we present experimental studies to verify the capability of the AEKF approach in identifying the structural damage by conducting a series of experiment tests. A small-scale 3-story building model is used and the white noise excitations are applied to the 3rd floor of the structure. To simulate structural damages during the test, an innovative device is proposed to reduce the stiffness of some stories. Different damage scenarios have been simulated and tested. Measured response data and the AEKF approach are used to track the variation of story stiffness during the test. The tracking results are then compared with the experimental data of stiffness. It is demonstrated that the tracking results for structural damages correlate very well with the measured experimental data on the stiffness of each story.

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Paper No. 162

TOMOGRAPHIC IMAGING OF CRACK DAMAGE IN CEMENTITIOUS STRUCTURAL COMPONENTS

Tsung-Chin Hou[1] and Jerome P. Lynch[2]

Cement-based materials are widely used in the construction of civil infrastructure systems. However, normal wear-and-tear and extreme loading can result in the damage and deterioration of such important civil structures. In this study, a novel approach to the detection of cracks in fiber reinforced cementitious composites (FRCC) is proposed. The approach is based upon the electrical properties of cementitious materials. Alternating current (AC) signals are introduced in a cementitious component while voltages are measured along the component outer surface. Redundant sets of electrical input-output behavior of a cementitious element can then be used to solve a complex inverse problem in which a multi-dimensional mapping of the internal conductivity of the cementitious material is found. Termed electrical impedance tomography (EIT), the approach has the potential to be used for monitoring the performance and health of cementitious structures in the field. Since cement-based materials are naturally piezoresistive, mapping of the internal conductivity of a structural element would provide an indirect means of mapping internal strain fields. Furthermore, cracks represent a drastic reduction in the conductivity of the component; as a result, conductivity mapping has the potential to also detect and quantify (orientation and dimensions) crack damage. In this study, the EIT approach is formulated and validated upon a set of FRCC structural elements loaded in axial tension. The EIT method proves reliable in identifying localization of crack damage during loading.

Keywords: electrical impedance tomography, damage detection, structural health monitoring

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Paper No. 163

APPLICATION OF SCRAMNET SYSTEM IN REAL-TIMEPSEUDODYNAMIC TEST AND SIMULATION

Shih-Yu Chu[1], Shih-Chieh Lo[2] and Ming-Hung Li[3]

The real-time pseudodynamic test (RTPDT) is a combination of numerical analysis and experimental test that can emulate the dynamic behavior of structures under environmental loading such as seismic in real time. The speed and quality of information communication between numerical model and experimental measurements will dominate the results of test. The real-time pseudodynamic test simulator is proposed in this study that is constructed on a pair of shared common RAM network (SCRAMNet) hardware connected by fiber-optic cables. The dynamic response of a portal frame system with linear spring as its diagonal bracing is verified experimentally by applying proposed real-time pseudodynamic testing technique via this SCRAMNet simulator. Corresponding proof tests are also performed by a conventional INSTRON 8800 material testing machine.

Keywords: Real-time Pseudodynamic Testing, Time-delay Compensation, Shared Common RAM fiber optical network system, SCRAMNet Simulator

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Paper No. 164

SLIDING ISOLATION USING VARIABLE FREQUENCY BEARINGS FOR NEAR-FAULT GROUND MOTIONS

Lyan-Ywan Lu[1], Jain Wang[2], Chao-Chun Hsu[2]

Even though it has been recognized that base isolation can be an effective technology for mitigating the structural response induced by normal earthquakes, recent studies have also revealed that conventional isolation systems with a constant isolation frequency may exhibit the behavior of low-frequency resonance, when the system is subjected to a near-fault earthquake whose waveform usually possesses a long-period velocity pulse. In this study, a sliding isolator with variable isolation frequency, which is a function of the isolator displacement, is proposed. The isolator is similar to a friction pendulum system (FPS), but the sliding surface has been made of an axially symmetric surface with a variable curvature, rather than a spherical surface with a constant radius. A six-order polynomial function has been employed for defining the radial line of the sliding surface. A parametric study has been conducted to decide the optimal values of the polynomial function. Since the isolation frequency of the proposed isolator is not a constant, the low-frequency resonance with long-period components of a near-fault earthquake can be prevented. Numerical study has demonstrated that, when subjected to a long-period pulse-like earthquake, the proposed isolator is able to simultaneously reduce the isolator drift and structural acceleration, as compared with those of a conventional FPS system.

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Paper No. 165

DESIGN TABLE OF OPTIMAL PARAMETERS FOR TUNED LIQUID COLUMN DAMPER RESPONDING TO EARTHQUAKES

Jong-Cheng Wu[1] and Cheng-Hsin Chang[2]

Due to the economical development of Taiwan in the past decades, the modernization renders to the rapid population growth in cities, and further facilitated more and more construction of higher buildings in many urban areas where the space is highly limited. Because of their stiffness lessened, the building displacement and acceleration on which building serviceability and comfort of occupants depend are frequently excessive responding to earthquake excitation. In searching possible solutions to alleviate this threat, the use of the passive control device, Tuned Liquid Column Damper (TLCD), has been broadly adopted as an appropriate vibration suppression technique in the industry both on its performance and low construction cost as well. There has been much literature investigating the control efficiency of TLCD for different types of structures, some of which discussing the issue of determining its optimal design parameters, such as the frequency tuning ratio and the head loss coefficient for undamped structures under earthquake excitation. However, since civil structures always contain damping in reality, it is quite necessary to further discover the optimal parameters of TLCD design for damped structures from the practical design point of view. This task serves the main objective in this paper.

In this paper, useful design tables for designing tuned liquid column dampers (TLCD) for damped single-degree-of-freedom structures under a white noise type of broad-banded earthquake loading are proposed as quick guidance for industrial practice. The design tables provide a list of necessary optimal parameters including frequency tuning ratio, head loss coefficient as well as the corresponding reduced response to be used as the design reference. The solutions of optimal parameters in design tables were obtained through numerical optimization search, by which it is also found that for a given mass ratio and horizontal length ratio, using uniform cross-section for all columns can always achieve the best performance. Finally, the parameters obtained were also compared with those from the closed form formula, which assume no structural damping, to investigate the difference from a practical point of view.

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Paper No. 166

SEISMIC RESPONSE IDENTIFICATION OF BUILDING SOIL-STRUCTURE INTERACTION USING GENETIC ALGORITHM

Ching-Yun Kao[1], Chin-Hsiung Loh[2] and S. T. Mau[3]

Genetic algorithm (GA) has been the subject of considerable interest in recent years, since they appear to provide a robust search procedure for solving difficult problems. GA uses multiple points to search for the solution rather than a single point in the traditional gradient based optimization method. Furthermore, due to the way GA explores the region of interest it avoids getting stuck at a particular local minimum and locates the global optimum. GA is slow in execution and is best applied to difficult problems. In this paper GA is applied to seismic response identification of building soil-structure interaction (SSI). The proposed identification method using GA is implemented in frequency domain based on the transfer function between the total translational response at foundation level and the total translational response at the top of the structure. The effect of SSI, particularly the dynamic soil properties during earthquake excitation, will be identified. Moreover, the structure properties considering effect of SSI are compared with those neglecting effect of SSI. The proposed system identification method is demonstrated on a 7-story RC building example.

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Paper No. 167

BEHAVIOUR OF LAMINATED RUBBER BEARING UNDER LOW TEMPERATURE AND ITS EFFECT ON THE DYNAMIC RELIABILITY OF ISOLATED STRUCTURE

Yongfeng Du[1], Hui Li[1], Yugong Ma[2] and Jianmin Jin[2]

Base isolation technique has found wide application in the last few decades, and a lot of isolated buildings have been built worldwide. Of all the isolated buildings that have been built, laminated rubber bearings have been used most. However, there will still be some technical issues concerning base isolation need to be given attention to at the stage of application. For example, many earthquake prone regions experience low temperatures in winters. With the change of the environmental temperature, the mechanical behaviour of laminated rubber bearing may subject to certain changes. Very few investigations concerning rubber isolators under low temperature have been reported. One of such tests has been performed under a temperature of - 20℃ in a joint study by the researchers of Japan and China (Zhou, 1997). But the extreme low temperatures of many cities in winter in northern part of China are much lower than this value.

To meet the needs of practical engineering application of base isolation in cold regions, an experimental study is carried out to investigate the behaviour of laminated rubber bearing under the low temperature of –20ºC, –35ºC and –50ºC, respectively (Deng, 1999; Yin, 2001; Du, 2005). This paper presents a brief introduction to the experimental study of laminated rubber bearings under low temperature, and highlighted the major changes of laminated rubber bearings under low temperature. Based on result of parameters of laminated rubber bearings under normal and low temperature, the dynamic reliability of base isolated structure is analyzed.

The isolated structure is modelled as linear elastic under minor earthquake. Both isolator and super structure are assumed to be elasto-plastic under major earthquake, and Bouc-Wen hysteretic model is adopted to represent the isolator, while degrading Bouc-Wen model is used for the superstructure. The pseudo excitation method (PEM) is employed to calculate the random response of the structures. Double damage parameters of maximum story drift and hysteretic energy are adopted as limit state index according to the requirement of “no damage under minor earthquake, not collapse under major earthquake” specified by Seismic Design Code of China. The dynamic reliability of the structural system is calculated by assuming that the stories are serially connected and that the failure of all the stories is correlated. The conditional failure probability of isolated structures under normal low temperature is compared with that under low temperature through numerical example, and the crack probability is seen to be doubled under a low temperature of –50ºC.

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Paper No. 168

DAMAGE DETECTION FOR BUILDING STRUCTURE WITH TIME VARYING PARAMETERS USING ADAPTIVE MONTE CARLO FILTER BASED ON VARIABLE FORGETTING FACTORS

Myungjin Chung[1], Tadanobu Sato[2], and Chung Bang Yun[3]

A new algorithm with adaptive Monte Carlo filter(MCF) is proposed for identification of non-stationary dynamic characteristics such as abrupt changes of system parameters. The concept of variable forgetting factor is employed on the process and observation noises in this study, while only the observation noises have been considered in the conventional adaptive particle filtering techniques including MCF. The forgetting factor is defined as the ratio of the probability density functions of the baseline noise distribution and its hypothetical distribution. The effectiveness of the proposed method has been investigated on the identification of the dynamic characteristics of a shear building model with abrupt changes of the damping and stiffness parameters subjected to a strong earthquake motion. The identified parameters show rapider tracking ability for the abrupt changes and better convergence to the true values than those by the ordinary MCF.

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Paper No. 170

KOCED PROGRAM: VISION, IMPLEMENTATION AND LESSONS LEARNED

Jae Kwan Kim[1] and Peggy C. Cho[2]

The Korea Ministry of Construction and Transportation (KMOCT) launched the Korea Construction Engineering Development Collaboratory Program (KOCED Program) in 2004 to establish a comprehensive base for construction-related testing, research and education. With the ultimate goal of strengthening Korea's international competitiveness in construction technologies, the KOCED Program aims to promote research and development and to set up a nationwide education program to produce highly qualified researchers and practitioners in the various fields of construction engineering.
During the next decade 12 large scale experimental facilities will be built and operated at the major regional universities. These facilities are going to be linked with the users along with a digital data repository and supercomputers using a grid architecture high performance information network. It will become a collaboratory, operating on a shared-use basis. A digital data repository and a high performance computing facility will be integrated into this grid system. It was inspired by the NEES Program of the United States. While NEES is concerned with earthquake engineering only, KOCED Program encompasses the entire civil engineering field.
In 2004 this program was officially started. As the first step, the Korea Ministry of Construction and Transportation (KMOCT) created the KOCED Program Management Center (KOCED PMC) for the purpose of managing the whole program. The mission of the KOCED PMC is to develop a consortium that will operate the collaboratory, to develop and implement grid system that will inter-link all the facilities, and to coordinate the construction process of the testing facilities.

This paper will describe the outline of the KOCED Collaboratory Program and report on the current progress and future plans. In addition the author will discuss the obstacles and difficulties that he encountered since the initiation of the program. These experiences will be very helpful to those who intend to launch similar programs in their countries.

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Paper No. 172

3D FINITE ELEMENT MODEL OF THE BILL EMERSON CABLE-STAYED BRIDGE AND ITS CALIBRATION WITH FIELD MEASURED DATA

Gen-Da Chen[1] and Wen-Jian Wang[2]

The Bill Emerson Memorial cable-stayed bridge was instrumented with a seismic instrumentation system of 84-accelerometers. The instrumentation system provides an opportunity for real-time monitoring of the structural condition of the bridge. It generates a vast amount of data continuously. The ultimate goal of this study is to develop a structural health monitoring system using necessary data compression and system identification techniques. The focus of this paper is on the establishment of a three-dimensional finite element model (3-D FEM) of the Bill Emersion Memorial cable-stayed bridge and its calibration with field measured truck-induced vibration data. Frame elements were used to represent steel girders, floor beams and the main components of towers. Cable elements and shell elements were employed for steel cables and post-tensioned precast concrete panels/slabs, respectively. The natural frequencies and mode shapes of the bridge model were determined with modal analysis. Truck-induced vibration data were obtained from the 84-channel seismic instrumentation system and used to calibrate the 3-D FEM. In addition, the results from the 3-D FEM were compared with those from two simplified models. It was determined from the 3-D FEM that the fundamental frequency of the bridge is approximately 0.34 Hz, corresponding to the vertical vibration of the bridge deck. This frequency is in excellent agreement with the field measured data but is 10% higher than that of the simplified models.

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Paper No. 173

SEISMIC PROTECTION OF PRECISION EQUIPMENT USING SMART ISOLATION SYSTEM

Lyan-Ywan Lu[1] and Ging-Long Lin[2]

Without seismic protection, precision equipments in high-technology factories can be fragile and vulnerable to earthquake attacks. In this study, a smart isolation system (SIS), which consists of sliding-type bearings and a variable friction device, is proposed and its performance for the seismic protection of precision equipment is investigated. Due to the static friction of the sliding bearings, motion of the SIS will not be activated nor amplified by a low-amplitude excitation, such as ambient vibration. When the SIS is activated by an earthquake, the slip force of the variable friction device, which provides a resistant and energy dissipating force to the system, can be regulated on-line by a controller. In order to suppress the response of the isolated equipment in a severe earthquake or a near-fault earthquake, SIS is able to effectively reduce the acceleration of equipment, and at the same time prevent a large isolator displacement that may damage the underlying piping system of the equipment. This is usually can not be achieved by a conventional passive isolation system.

Keywords: precision equipment, base isolation, friction damper, semi-active control, predictive control

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Paper No. 174

A NEW ACTIVE SENSING DEVICE FOR WIRELESS TELEMETRY-BASED STRUCTURAL HEALTH MONITORING

Seunghee Park[1], Benjamin L. Grisso[2], Daniel J. Inman[3], and Chung-Bang Yun[4]

A new active sensing device is proposed for the practical use of an impedance-based structural health monitoring (SHM) technique. This device consists of a miniaturized impedance measuring chip and a self-sensing macro-fiber composite (MFC) patch. The conventional impedance-based SHM technique, which uses an impedance analyzer, HP4194A, has never been attractive for real world-application. However, the proposed active sensing device can be a powerful tool for a variety of *in-situ* SHM applications in civil, mechanical, and aerospace systems, since (1) the new miniaturized impedance measuring chip is low-cost, portable, and readily combined with a wireless telemetry and (2) the self-sensing MFC patch, which consists of rectangular piezo-fingers sandwiched between inter-digitated electrode (IDE) pattern layers, can be permanently attached to a structure and provide meaningful information regarding the structure's integrity through its high-frequency excitation. The final goal of this research is to develop an intelligent multi-functional sensor which will utilize energy harvested from the ambient environment, analyze the sensing data on a single chip, and wirelessly provide the status of the structure to an end user. In this study, the effectiveness of the proposed active sensing device has been verified through a series of experimental studies: (a) detecting corrosion in an aluminum beam and (b) inspecting loosening bolts in a jointed aluminum structure.

Keywords: Impedance-based structural health monitoring, Active sensing, Miniaturized impedance measuring chip, Self-sensing macro-fiber composite patch, Intelligent multi-functional sensor, Wireless telemetry.

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Paper No. 175

EXPERIMENTS AND SIMULATION OF REINFORCED CONCRETE BUILDINGS SUBJECTED TO REVERSED CYCLIC LOADING AND SHAKE TABLE EXCITATION

S.J. Hwang[1], M. Saiid Saiidi[2], Sara Wadia-Fascetti[3], JoAnn Browning[4], Jerry P. Lynch[5], Kamal Tawfiq[6], K.C. Tsai[7], G. Song[8], and Y.L. Mo[9]

An integrated experiment and analysis research program is proposed to address the complex behavior of reinforced concrete buildings subjected to multi-directional earthquake loading and the subsequent interactions resulting from the nonlinear response of individual components that compound further the multi-directional affect of the ground motion. Additional contributions resulting from the research include integration of state of the art wireless sensing technologies, embedded "smart" aggregate sensors, and smart shape memory alloys for use in structural bracing systems. Results will impact a broad community ranging from K-12 students to practitioners. The entire effort is led by a diverse team of participants from institutions around the country and the National Center for Research on Earthquake Engineering (NCREE) in Taiwan. Emphasis is placed on using simulation response histories to provide actuation forces applied to the Reinforced Concrete (RC) buildings subjected to reversed cyclic loading. The associated simulated response will be fed back into building characteristics for additional shake table simulations. The facilities, expertise, and support of NCREE will be used for tests on one near full-scale RC building (Bldg 1). Analytical simulation studies of Bldg 1 will be performed using OpenSees incorporating nonlinear elements recently calibrated at the University of Houston. NEESR Two similar buildings will be tested under shake table excitation at the University of Nevada, Reno (UNR). Strain rate effects will be identified by comparing an identical building (Bldg 2) tested at UNR with the NCREE results. A third specimen (Bldg.3) will be modified with innovative bracing system constructed from superelastic shape memory alloy strands in lieu of the reinforced concrete walls. The results will be used to correlate analytical tools, examine the impact of real-time dynamic loading and the new design methodologies. An integral element of the three specimen tests includes the use of novel wireless telemetry for data collection and distributed data interrogation.

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Paper No. 178

SHAPE MEMORY ALLOY-BASED SMART SYSTEM ON STRUCTURAL SEISMIC RESPONSE MITIGATION AND MONITORING

Hui Li[1] and Chen-Xi Mao[2]

An innovative smart system based upon shape memory alloy (SMA) is developed in this study. This SMA-based system can act as passive damper and novel displacement transducer simultaneously by using the pseudoelasitcity and strain self-sensing ability of SMA materials. After that, a new algorithm based upon extended Kalman filter and wavelet multi-resolution technique is proposed. Considering only the limited structural response can be measured by the monitoring system in practice, the focus of this algorithm is on estimating the structural seismic response on entire degree of freedom and further identifying the nonlinear characteristics of story shear versus interstory drift of structures. Such SMA-based smart system together with the new algorithm can provide great potential to assess the structural damage after earthquake. To develop this SMA-based smart system, a large number of performance tests are conducted firstly, on the pseudoelasticity and strain self-sensing property (i.e. electric resistance versus applied strain) of a NiTi SMA wire (1.2 mm diameter). The experimental results indicate that both the pseudoelasticity and strain self-sensing property of NiTi wire are independent of loading frequency in a given frequency range. Furthermore, the sensitivity coefficient of electric resistance versus applied strain for this NiTi wire is determined through the test results. Subsequently, construction design of the innovative SMA-based smart system is described in detail. Such SMA-based system is then installed in the first story of a 5-story scaled structural model and the shaking table tests are conducted. The experimental results indicate that the seismic response of this building model is decreased evidently by introduce of the SMA-based system. At the same time, the interstory drift in the first story is measured by the SMA-based system and is compared with that monitored by the LVDT attached on the structure. Finally, the displacements, velocities, and accelerations on each story are estimated by using the new algorithm proposed in the present study and the relationship of story shear versus interstory drift on each story are also identified.

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Paper No. 179

A STUDY ON ELECTRICAL PROPERTY AND FATIGUE LIFE OF CARBON FIBER REINFORCED CONCRETE

Hong-zhe Dai[1] and Wei Wang[1] and Si-gang Wu[2]

For recent years, the concrete construction industry has faced a great challenge in view of the deterioration of infrastructures, and health monitoring systems are critically needed for the civil infrastructure in order to enhance safety and provide timely repair. Generally, a health monitoring system involves the extensive use of sensors, embedded in structures during their manufacturing process, or externally bonded at the critical positions on the structure. A valid alternative to the use of sensors is the adoption of fiber-reinforced materials with a small percentage of conductive fibers, commonly called "self-monitoring" material. Much attention has been paid by researchers in recent years on this carbon fiber cement composite.

An amount of research to date has contributed in analyzing the fatigue behavior of carbon fiber reinforced mortar (CFRM) during dynamic compression. But it is well known that concrete is a type of widely used engineering material more than mortar. Concrete differs from mortar as concrete contains coarse aggregates, and this increases both the heterogeneity of CFRM and the uncertainty of its electric property. Therefore, this work is focused on fatigue behavior and electric behavior of carbon fiber reinforced concrete (CFRC).

This paper tests and analyses three point bending specimen in order to realize electrical property and fatigue life of CFRC under cyclic flexural loading. The test results show that the process of fatigue deformation, for CFRC with different strength grades, is similar to that of plain concrete. Fatigue damage occurs as load cycling progresses, which indicates that the greater the stress ratio, the faster the strain develops and the greater the electrical resistance fluctuate increases. The occurrence of electrical resistance is attributed to the damage of the conductive network. This mechanism formed in this study provides a means for CFRC to monitor its extent of fatigue damage and predict its fatigue life.

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Paper No. 181

SEISMIC ISOLATION OF A SCALED BRIDGE MODEL USING ROLLING-TYPE BEARINGS

Meng-Hao Tsai[1], Kuo-Chun Chang[2], and Si-Yi Wu[3]

Concurrent with the growth of the application of the seismic isolation technique to civil structures, a variety of isolation systems has been developed during the past two decades. From past experiences, it may be concluded that simplicity, reliability, and cost-effectiveness are three important factors for practical application of a seismic isolation device. It is evident that sufficient studies and tests are required to achieve the aforementioned three factors for any practical isolation device. In this paper, the seismic response of an isolated structure by a rolling-type bearing is evaluated first using an approximated formulation. The rolling-type bearing is composed of a solid metal cylinder and two steel plates, which are designed to possess a concave surface with a constant sloping angle. The cylinder is expected to roll on the concave surface under seismic excitations. An approximated formula is derived to estimate the peak acceleration response of the isolated structure. Moreover, shaking table tests of a 1/7.5 scaled bridge model isolated by the rolling-type bearings are conducted. Test results verify that the rolling-type bearings are effective on reducing the seismic force of the bridge. The seismic force transmitted by the rolling-type bearings will be independent of the earthquake intensities when the sloped rolling mechanism is completely triggered. Also, comparison between the measured and estimated peak acceleration responses is made to evaluate the appropriation of the derived formula on predicting the maximum structural acceleration.

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Paper No. 182

SEISMIC ANALYSIS OF STEEL FRAMED BUILDINGS WITH SELF-CENTERING FRICTION DAMPING BRACES

Songye Zhu[1], Yunfeng Zhang[2], and Le-Wu Lu[3]

This paper deals with a novel type of passive energy dissipation device termed self-centering friction damping brace (SDB) and its application to seismic hazard mitigation of steel concentrically braced framed buildings. The SDB uses superelastic Nitinol wire strands to enable its self-centering mechanism and enhanced energy dissipation capacity is achieved by friction effect over the sliding surfaces of SDB. Unlike conventional passive damping devices, SDB has the potential to minimize the permanent drifts of concentrically braced frames after strong earthquakes and withstand several moderate earthquakes without the need for repair or replacement. Experimental results of SDBs presented here demonstrate its self-centering capability. Nonlinear time history analysis which involves a 3-story steel framed building subjected to two suites of twenty earthquake ground motions was conducted and the analysis results are presented in this paper. It is shown that SDB can effectively control the seismic response of framed building structures while minimizing their permanent drifts.

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Paper No. 183

NUMERICAL SIMULATION OF DAMPING OF VIBRATION CONTROL OF TLD STRUCTURES

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Turned Liquid Damper (TLD) is an efficient control approach of passive dissipative damping of vibration of which the rule and design method has been concerned. Most previous research was relied on tests and has got fruitful achievements. Though the simplified analysis method of damping of vibration effect has also been developed based on those tests, its application has been greatly limited due to the rough models. Recently, with the development of computer technology, it is likely to do research into TLD numerical modeling analysis of fluid-structure interaction, which will become a valuable supplement.

The fluid-structure interaction of general structural analysis software is applied to conduct the seismic response analysis of fluid-structure interaction in the high-rise frame structure controlled by TLD of roof tank installation. Meanwhile, current test rules and simplified methods are also compared and checked. Besides, it initially discusses as well as examines the calculation and model building of fluid-structure interaction whereby realizing the TLD numerical modeling of fluid-structure interaction and summarizes the TLD damping of vibration rule of high-rise frame structure.

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Paper No. 184

ENERGY SECANT METHOD FOR ENERGY CONSERVATION OF TIME STEPPING SOLUTION TO NONLINEAR ELASTODYNAMICS

Yan Li[1], Bin Wu[2] and Jinping Ou[3]

The energy increment equation within a time step is the sufficient condition for stable time integration schemes. The equation has two solutions in a time step. One is the beginning-point displacement, the other is the end-point displacement which is the desired solution. The false solution, i.e. the beginning-point displacement, may be obtained due to iterative computation in the process of solving the equation. So the key is to remove the wrong solution from the energy increment equation. The energy equilibrium of energy secant method (ESM) is achieved when the secant slope of the function, which describes the change of total energy and external work, is zero. The ESM successfully eliminates the wrong solution and obtains the desired one. The key difficulty of achieving the energy equilibrium of ESM relates to the distribution of potential energy to each freedom degree. It is proved that the ESM can guarantee the conservation of energy of system. The unconditional stability is thereby automatically achieved. Energy momentum method (EMM) by Simo and Tarnow, constraint energy algorithm (CEA) by Hughes et al and ESM are compared in terms of energy conservation and computational cost. The comparison shows that the ESM, EMM and CEA conserve the energy of system. Moreover, the ESM has its superiority over the other methods, such as less iteration steps and calculation time. The ESM, EMM, CEA and average acceleration method are compared through a numerical example of nonlinear elastic spring. The displacement and energy responses of the example verify the correctness of the theoretical analysis.

Keywords: energy secant method, energy conservation, numerical stability, nonlinear elastic system

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Paper No. 185

REAL-TIME SUBSTRUCTURE TEST OF JZ20-2NW OFFSHORE PLATFORM WITH MR DAMPERS

Bin Wu[1] Qianying Wang[2] Pengfei Shi[3] and Jinping Ou[4]

The environment surrounding offshore platforms is harsh and complicated, due to dynamic forces such as sea wind, wave, current, ice, earthquake and so on. As effective and reliable devices for vibration control, magnetorheological (MR) fluid dampers have drawn great attention of researchers and engineers. To suppress the vibration mainly induced by ice and earthquake loads, MR dampers are incorporated in JZ20-2NW platform located in Bohai Sea of China, which is the first offshore structure with MR dampers in the world.

Numerical simulation and structural test are the common methods to evaluate the control effect of MR dampers. With numerical simulation method, the relation between damper force and displacement or velocity of MR dampers is usually simplified to a defined model, which may lead to imprecise results. In particular, the preliminary experimental and analytical studies on the MR dampers manufactured for JZ20-2NW platform showed that the currently available mathematical model failed to capture the mechanical and electrical behavior of the dampers with satisfactory accuracy. As for the structural test, we quite often have to carry out the test with structural model and MR dampers of reduced scales because of test cost and the limitation of the capacity of test facilities. But the internal structure of MR dampers is so complicated that it is not easy to identify the relation of mechanical behaviors between MR dampers with the full scale and reduced scale.

In order to accurately evaluate the performance of JZ20-2NW platform with MR dampers, we adopt the real-time substructure testing (RST) technique. RST is an experimental technique in which only the critical nonlinear part of structures is tested physically and in real time, while the remainder is simulated numerically by the computer. This technique makes it possible to evaluate the performance of the full-scale JZ20-2NW platform and dampers.

This paper describes the simplification of computational model, control algorithm, accuracy analysis of RST, and control performance evaluation based on RST results of the JZ20-2 NW offshore platform with MR dampers subjected to earthquake and ice loads.

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Paper No. 186

ANALYSIS FOR SEISMIC RESPONSE OF WUTONG TV-TOWER WITH VARIABLE STIFFNESS TUNED MASS DAMPERS

An-Zhi YAN [1, 2] Jun TENG [1] and Zhi-Xiong LU [1]

A new semi-active continuously and independently variable stiffness (SAIVS) device has been developed and patented by Nagarajaiah. The semi-active variable stiffness tuned mass damper (SATMD) based on the device has been verified effective under the building stiffness variation. The state space equation of TV-Tower with multiple SATMD has been constructed by considering mainly dominant modes of the Tower in this paper. The frequency tuning of the SATMD is achieved by using empirical mode decomposition and Hilbert transform algorithm (EMD/HT). From the numerical analyzed under El Centro seismic record, the SATMD which tuned in a simplicity divisiory range of frequency can reduce the seismic response significantly even when the TV-Tower stiffness changes by ± 15% and is robust, and it's only less effectiveness than active tuned mass damper (ATMD) which controlled by LQR algorithm; whereas, the TMD loses its effectiveness under the TV-Tower stiffness variation, and the ATMD have to take more extra energy than SATMD.

Keywords: Seismic response, SATMD, Semi-active control strategy, Variable stiffness

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Paper No. 187

OPTIMUM MODAL CHARACTERISTICS FOR MULTISTORY BUILDINGS ISOLATED WITH LRBS

Abdolrahim Jalali[1] and Peyman Narjabadifam[2]

Improving the performance of available base-isolation technologies in conjunction with optimum using of dynamic properties of superstructure such as stiffness, damping and mass has gained lot of interests in the earthquake engineering field. In this study, the effect of superstructure characteristics on performance of multi-story buildings isolated with lead-plug laminated rubber bearings has been investigated. The superstructure characteristics considered at current research are superstructure mass, superstructure stiffness and superstructure damping, which were varied in the range that is compatible with engineering practice. Comparing the study results, it has been observed that, there is optimum amount for each of the dynamic properties of the superstructure, which will make design criteria achievable in seismic base-isolation of multi-story buildings. To this purpose, five reinforced concrete moment resisting frame buildings with two, five, nine, fourteen and twenty stories were considered. They were designed according to UBC97, in fixed-base form and base-isolated form. Five different amount for superstructure base-mass were assigned and 25 related models were created. Variations in superstructure stiffness and superstructure damping were considered in the same manner. All of 85 model buildings were subjected to five ground motion records which have been scaled to have PGA = 0.4g. Nonlinear time-history analyses of created models were conducted by using ETABS 8.5.0. Fundamental periods, modal participation factors and base-shears were studied for all of the model buildings. Comparing analysis results in term of base shear variations for different parameters considered, it was concluded that, superstructure characteristics have considerable effect on performance of isolated systems and optimal performance of base isolated multi-story buildings is achievable by modifying superstructure characteristics. It was shown that, performance of low-rise base isolated buildings is not so sensitive to the variation in superstructure characteristics, while adding base-mass and increasing the damping of superstructure in middle-rise buildings will improve the isolation performance. In addition, increasing stiffness and damping of superstructure can result in effective isolation and improved seismic behavior in high-rise buildings.

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Paper No. 188

SEISMIC RESPONSE CONTROL BY INTERCONNECTING ADJACENT BUILDINGS - FEASIBILITY STUDY -

Shunsuke Otani[1], Yuu Azuma[2] and Koichi Ohami [3]

Seismic response control is a technology to control seismic response amplitudes of a structure by dissipating kinetic energy through vibration control devices placed at locations where large relative displacement takes place within or peripheral of the structure.
Feasibility was studied to interconnect adjacent buildings at floor levels by viscous dampers or hysteretic dampers to control the seismic response amplitudes making use of relative floor displacements of the two buildings caused by different periods of vibration and vibration mode shapes.
Five-story and ten-story linearly elastic buildings were idealized by mass-and-spring models. These models were interconnected at floor levels by (a) rigid elements, (b) elastic truss members with parallel viscous dampers, or (c) truss members with bilinear hysteretic characteristics.
Natural periods of the two systems were selected to represent typical dynamic characteristics of existing buildings. Floor weights were assumed to be uniform from the bottom to the top floor, but the stiffness was assumed to vary linearly with height.
The effect of building sizes was studied by varying the floor weight of the five-story system from one-third to three times the floor weight of the ten-story system. The interconnected systems were subjected to artificial ground motion satisfying a target response spectrum.
Story drift response was reduced at stories connected by rigid truss members, but story drift increased significantly at the upper free stories, especially when the large size five-story system was connected at the lower levels. Viscous dampers and hysteretic dampers were effective reducing floor acceleration and inter-story drift response to protect the building contents and structural members.
The study indicated positive feasibility of seismic response reduction by connecting adjacent buildings at floor levels with viscous or hysteretic dampers.

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Paper No. 189

AN ENERGY DISSIPATION BASED SEMI-ACTIVE CONTROL OF CIVILSTRUCTURES WITH A NEW MECHATRONIC VIBRATIONCONTROL DEVICE

Kazuhiko Hiramoto[1], Taichi Matsuoka[1], Katsuaki Sunakoda[1],
Takafumi Ohtake[1] and Paul Roschke[2]

We propose a new mechatronic vibration control device (VCD) for vibration suppression of civil engineering structures. The VCD consists of an electric motor that can generate a variable damping force and a moving mass that produces a large inertia force which is proportional to the relative ac-celeration between two floors of the structure. The variable damping property of the VCD is realized by changing the value of an electric resistance connected to the electric motor. With the capability of the variable damping a simple semi-active control strategy based on Lyapunov method is adopted. We discuss issues about an appropriate selection of the Lyapunov matrix and the performance anal-ysis of the semi-active system based on the theory on dissipative dynamical systems. A simulation result of NCREE benchmark building with the proposed VCD shows the effectiveness of the present hardware and the semi-active control technique.

Keywords: Mechatronic vibration control device, Semi-active control, Lyapunov function, Dissipation theory

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Paper No. 190

STRUCTURAL HEALTH MONITORING SYSTEM FOR BUILDINGS WITH AUTOMATIC DATA MANAGEMENT SYSTEM

A. Mita[1], T. Inamura, S. Yoshikawa[2]

Structural health monitoring (SHM) systems that monitor the condition of buildings and infrastructures in order to promptly and quantitatively evaluate risks due to their deterioration or large earthquakes are promising for prolonging the lives of buildings while keeping them in healthy conditions. The proposal of feasible SHM systems that can evaluate the safety and reliability of buildings and ensure the asset value is thus urgently demanded. As damage detection methods have been studied extensively, the technology pool for SHM has been widened and deepened. However, in the course of developing such a system, it has been recognized that the establishment of a database that provides the statistical information on many structures is one of the most important issues for utilizing the sophisticated tools effectively.

Although many researchers have advocated the necessity of such a database for gathering building information, designers and contractors are kind of reluctant to reveal the information to third parties. In addition, it is not easy to set a foot in a building which is mostly private-owned. In contrast, the purchasers, users or owners of buildings keep eager to know the safety and reliability of their properties. Thus, the needs for the SHM systems vary widely depending on which stakeholder initiates it even for a particular building.

Given these backgrounds, an SHM study group in the Consortium for Building Research and Development was newly established to promote the use of SHM. The SHM study group initiated the use of the SHM system presented in this paper. The system has been developed at Mita laboratory, Keio University and it acquires on-line building data by using automatic sensor systems and upload tools. Eight buildings are currently monitored using the system at this moment.

We use the sensor system being developed and the MATLAB-based server developed by us. The MATLAB Web Server is an ideal deployment tool to develop a Web application for release of the identified results as we already have many damage detection tools coded for MATLAB. For example, the story stiffness is identified using complex modal properties obtained by numerical algorithm for subspace state space system identification. This algorithm is implemented to the system.

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Paper No. 192

VIBRATION CONTROL OF SEISMIC RESPONSE FOR HIGH-TECH BUILDING FACILITIES

Hong-Jun Liu[1] and Jun Teng[2]

Many high technology plants, such as semiconductor and optical instruments industry, have been worried by the impact induced by the rail traffic and earthquake. This paper reports a study on vibration control of seismic response for high-tech building facilities. The research work aims at the optimization algorithm for the identification of damper parameters directly against to the parameters influencing the property of MR damper. From the various models of MR damper, the Bouc-Wen model is chosen for research. This model can comprehensively simulate the properties of the damper in reducing vibration at every using stage. It's proved that the model can be according to the experiment in very small error. The genetic algorithm and the simulated annealing algorithm are studied in theory. The main points in design are determined. For the genetic algorithm, the individual is treated as a binary chromosome containing 10 genes. From the contrastive curve between the probability of genetic operation and the optimal result, the value of crossover and mutation probability are determined. For the simulated annealing algorithm, such main points for design as the function of determining initial temperature, the function of annealing and the function of generating new solutions are also determined. Based on these algorithms, the identification results can be achieved. Through the contrast and analysis between the calculation and experiment, the respective advantage and shortcoming for these two algorithms are achieved. The simulated annealing algorithm can accept the bad solution in stated probability, which is helpful to jump out of the local optimization. But the convergence speed of SA algorithm is too slow. From the analysis for the optimization result, the conclusion is achieved: compared with the genetic algorithm and simulated annealing algorithm, the simulated annealing/ genetic algorithm is more suitable for solving the problem of identifying model parameters.

Keywords: Intelligent Floor System, Genetic Algorithm, Vibration Control, Simulated Annealing Algorithm

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Paper No. 193

EFFECTS OF DIFFERENT FAULT RUPTURE SCENARIOS ON PERFORMANCE OF TUNED MASS DAMPERS FOR SEISMIC RESPONSE CONTROL OF STRUCTURES

Amir K. Ghorbani-Tanha[1], Hamid Zafarani[2], Assadollah Noorzad[3] and Mohammad Rahimian[4]

In present study the effects of fault rupture parameters on the response of a multistory structure equipped with a tuned mass damper (TMD) under simulated earthquake excitations is investigated. The stochastic finite-fault simulation technique of Beresnev and Atkinson (1997, 1998) which implements the concept of fault discretization wherein sub-events are represented as stochastic point sources is used. The numerical results for a structure with and without TMD subjected to simulated earthquake records are obtained and comparisons are made in terms of defined performance indices to demonstrate the effects of fault rupture parameters on the structural response. The results demonstrate that precise description and estimation of the effective parameters in generation of strong motion are of great importance. Moreover, it is shown that it is not meaningful to use a limited number of ground motion time histories which are representative for some special scenarios to evaluate the performance of control systems and one should examine whether enough scenarios have ran to capture the expected variability of ground motion. This enables designer to make a more realistic judgment about the overall performance of the TMD for improving seismic response of the structure.

Keywords: Stochastic Simulation of Ground Motion, Finite-Fault Method, Fault Rupture characteristics, Structural Control

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Paper No. 194

CARBON GEOPOLYMER SENSOR

Chang, P[1] and Wang W.[2]

Smart sensing using the structural element as a sensor can potentially reduce the cost of structural health monitoring (SHM) and make its application practical. Carbon fibers are sensitive to strain. They are typically applying in an epoxy matrix. A novel matrix made of inorganic material shows superior bonding properties. The result shows that carbon fiber can be used to measure long-term deformation adequately.

KEYWORDS: structural health monitoring, smart sensing, carbon fiber sensor, Geopolymer..

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Paper No. 195

DAMAGE DETECTION AND QUANTIFICATION IN SHEAR BEAM BUILDINGS

S. Bisht[1] and M. P. Singh[2]

Vibration data-based damage identification and quantification has been a topic of continued research interest in the civil engineering community. Several methods have been reported in the literature with good success in simulated studies. These methods usually utilize the vibration data to determine the modal properties of the structure which are then used in damage detection and quantification. The authors have also proposed a method for damage quantification based on damage indices defined using the flexibility or the rotational flexibility matrix, which in turn are obtained from the modal properties. The method has been successfully applied to the IASC-ASCE SHM analytical benchmark problem. In the present study, the effect of using incomplete modal information on this damage identification and quantification method is studied. It is observed that although information about all modes of the undamaged structure or the knowledge about the undamaged structural model is essential, damage can be identified and quantified even if not all modes are available for the damaged structure. The error in the damage quantification, however, increases as fewer modes are used. Thus, the higher modes though not important in the calculation of flexibility matrix may still be relevant in precise quantification of damage-induced change in stiffness values.

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Paper No. 196

ZIGBEE SENSOR NETWORK FOR STRUCTURAL HEALTH MONITORING

Yung-Bin Lin[1], Kuo-Chun Chang[2], Jin-Chong Chen[3], Ping-Hsiung Wang[4] and Lu-Sheng Li[5]

A wireless monitoring system should provide relevant data from the observed structure without the requirement to inspect. So the data has to be transmitted in a sufficient way to the users. An on-site central unit for data collection and storage in a database and further to analyze the data from sensor node is needed. In this paper, wireless sensor network (WSN) using Zigbee standard for structural health monitoring is test in the laboratory and the field, respectively. Results reveal that this WSN system has the potential for field applications.

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Paper No. 199

NUMERICAL SIMULATION OF 3-STORY STRUCUTURE WITH VIBRATION CONTROL DEVICE

Taichi Matsuoka[1], Kazuhiko Hiramoto[1], Katsuaki Sunakoda[1],
Takafumi Ohtake[1] and Paul N. Roschke[2]

In a previous paper, the authors proposed a vibration control device using an inertia mass and a generator that is suitable for structural damping. The device consists of a ball screw, an inertia disk, a gear, an electric power generator, and a controller as shown in Fig.1. Linear motion of the structure due to seismic vibration is converted into rotary motion by the ball screw, and electric power is converted by a generator through a gear. From the theory, the device has the resisting force characteristics of the sum of the damping force created by the resistance of the controller, and the inertial force from the disk that acts as a flywheel.

In this paper, numerical simulations of a 3-story structure with the vibration control device attached to the first floor are carried out. Both frequency response and response to seismic excitation are calculated. A diagram of the new device and the 3-story laboratory structure are shown in Fig.1 With regard to seismic response, the Imperial Valley (1940) El Centro NS component is normalized to a maximum acceleration of 2 m/s^2 and applied horizontally to the base floor; the displacement and acceleration responses of each story are evaluated. It is clear from the frequency response that the resonant frequency of the structure can be shifted toward the low frequency range with the aid of the inertial device. The optimum operation of the device to minimize seismic response can be derived by selecting an appropriate rotating moment of the inertia disk, and by adjusting a damping coefficient. The vibration tests of the 3-story structure with the damper installed are carried out at the National Center for Research on Earthquake Engineering in Taiwan.

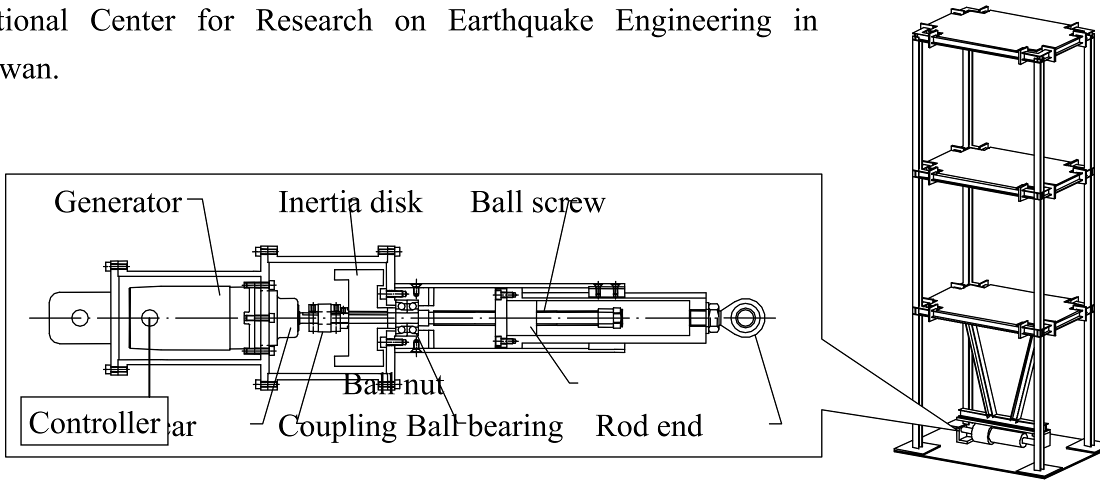

Fig.1 Schematic diagram of the vibration control device and the 3-story structure

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Paper No. 201

DISTRIBUTED SENSOR APPLICATIONS FOR CIVIL INFRASTRUCTURE MONITORING AND SENSING RICH APPROACH TO THE DESIGN OF MODERN MECHATRONIC SYSTEMS

G. L. Fenves[1] and M. Tomizuka[2]

Sensor technology is having a dramatic effect on improving the performance for a wide scale of engineering systems. In the first part of the paper advances in sensors sensor networks on large-scale civil infrastructure will be examined. The civil infrastructure includes the constructed facilities such as for transportation, water resources, and the built environment, particularly in densely populated urban regions. Traditional civil infrastructure is designed to be passive under long-term use. New sensor technology is providing the ability to monitor, diagnose, and make decisions about the condition of infrastructure, the prognosis of future performance, and inform decision-making. Examples of sensors and sensor networks for monitoring infrastructure performance under operating conditions and for extreme events will be discussed. Trends in sensor technology and the architecture of sensor networks as distributed computing systems will provide new opportunities for improving the performance and reducing the life-cycle cost of civil infrastructure.

The second part of this paper explores advantages of aggressive usage of sensors in the design and operation of mechatronic systems, i.e. sensing rich approach. Advantages include enhanced system performance, added functionality, flexible operation of the system and reduced design and operational costs. Such advantages of sensing rich approach will be elaborated by two examples. The first example is the power transmission mechanism or drive train under servo control, which represents a fundamental element of any motion control system. The sensing rich design is based on distributed measurements of positions and accelerations at multiple points of a drive train. These measurements improve the performance of drive train servo systems in terms of speed, positioning accuracy and vibration suppression. The second example is vehicles for automated driving. The California PATH (Partners for Advanced Transits and Highway) Program invested a significant amount of effort on various aspects of automated driving on automated highways. This effort has shown the technical feasibility of automated highway systems based on a number of sensors.

The common aspects of distributed sensor systems for civil infrastructure and mechatronic systems will be identified and suggestions made for future research that will leverage new developments for a wide range of engineering applications.

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Paper No. 202

PARAMETER IDENTIFICATION OF LTV DYNAMICAL SYSTEM BASED ON WAVELET METHOD

Z. Y. Shi[1] L. Shen[2] and S. S. Law [3]

An identification algorithm of the linear time-varying (LTV) dynamical system is developed in this paper. The excitation and response signals are first decomposed using the Daubechies wavelet scaling function. Then the differential vibration equations of the time-varying system are transformed into simple linear equations based on the orthogonality of the scaling functions. The physical parameters can be identified directly by solving the linear equations. The parameter identification equations of linear time-varying discrete and continuous systems are developed in the paper. Numerical results demonstrate the accuracy and the validity of the proposed method for identification of smoothly, periodically and abruptly time-varying parameters.

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Paper No. 204

EXPERIMENTAL STUDY OF A RC STRUCTURE WITH TOGGLE-BRACE-DAMPERS

Jenn-Shin Hwang[1], Shiang-Jung Wang[2], Yin-Nan Huang[3] and Chun-Hsiang Tsai[4]

This paper presents the results of an experimental evaluation on the effectiveness of applying viscous dampers to reinforced concrete moment-resisting building structures. The unique feature of these moment-resisting concrete building structures, as the common practice in Taiwan, is that lightly reinforced concrete exterior walls and interior partition walls are provided in construction but not considered for their contribution of stiffness and strength in the design process. With these additional walls it is suspicious that, with the small relative story displacement and velocity, the effectiveness of supplemental dampers will be very limited. However, the test results show that an efficient installation mechanism, the toggle-brace-damper system, is effective even with a small relative story drift in the seismic response control of the structure. In addition, on contrast to the usually assumed behavior, the slender wall system subjected to lateral seismic force reveals a double curvature behavior in each story rather than a cantilever behavior as a whole. Furthermore, for energy consideration, the "momentary input energy method" is found to be more rational than the "absolute input energy method" to evaluate the damage potential to structures and to demonstrate the effectiveness of supplemental viscous dampers to structures.

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Paper No. 205

INNOVATIVE MONITORING INSTRUMENTS ON ALL CABLES OF CABLE-STAYED BRIDGES

Zheng-Kuan Lee [1] Yung-Bin Lin[2] Kuo-Chen Chang [3] ,and Chien-Chou Chen[4]

To evaluate the cable tensions of a cable-stayed bridge, conventionally piezoelectric sensors or force-balanced sensors are applied to measure the vibration signal spectrum of cables. Connected to a signal analyzer (such as a PC) through electrical wires in parallel, those sensors are tied-up to the cable-tendon to be measured. However, with limited sensors and signal channels, the measurements of all cable vibration could only be implemented part by part. Practically, it is difficult to measure all cable vibration simultaneously. For overcoming the mentioned difficulties, an innovative optic-fiber health monitoring system on the cables of a cable-stayed bridge is designed in this article. Herein this paper will not only introduce the mechanism of the new system but also the application to a real cable-stayed bridge. With the new device, it becomes possible to monitor all cables of a cable-stayed bridge economically, simultaneously, and regularly, even in wind-rain weather condition.

Keywords: Cable-stayed bridge, FBG sensor

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Paper No. 207

REAL-TIME FEEDBACK CONTROL OF STRUCTURES USING WIRELESS SENSORS

Yang Wang[1], Andrew Swartz[2], Jerome P. Lynch[1], Kincho H. Law[2] Kung-Chun Lu[3], Chin-Hsiung Loh[3]

In recent years, substantial research has been conducted to advance structural control as a direct means of mitigating the dynamic response of civil structures. In parallel to these efforts, the structural engineering field is currently exploring low-cost wireless sensors for use in structural monitoring systems. To reduce the labor and costs associated with installing extensive lengths of coaxial wires in today's structural control systems, wireless sensors are being considered as building blocks of future systems. In the proposed system, wireless sensors are designed to perform three major tasks in the control system; wireless sensors are responsible for the collection of structural response data, calculation of control forces, and issuing commands to actuators. In this study, a wireless sensor is designed to fulfill these tasks explicitly. However, the demands of the control system, namely the need to respond in real-time, push the limits of current wireless sensor technology. The wireless channel can introduce delay in the communication of data between wireless sensors; in some rare instances, outright data loss can be experienced. Such issues are considered an intricate part of this feasibility study. A prototype Wireless Structural Sensing and Control (WiSSCon) system is presented herein. To validate the performance of this prototype system, shaking table experiments are carried out on a half-scale three story steel structure in which a magnetorheological (MR) damper is installed for real-time control. In comparison to a cable-based control system installed in the same structure, the performance of the WiSSCon system is shown to be effective and reliable.

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Paper No. 208

PERFORMANCE-BASED SEISMIC DESIGN OF SUPPLEMENTAL DAMPERS IN INELASTIC SYSTEM

Bo Li[1] and Xing-wen Liang[2]

The common practice for design of supplemental dampers in existing building requires performing the iterative computation to achieve a given performance objective. In the context of performance-based seismic design, a simplified yet effective design procedure for viscous dampers is presented based on the improved capacity spectrum method in which no iteration is needed when estimating target displacement of the structural to be retrofitted. The proposed method consists of the following main steps: first evaluate the seismic performance of the structure to be retrofitted using the improved capacity method; and second if the exhibited behavior of the structure can not satisfy the acceptable performance criterion the total damping required to meet the predetermined performance level can be evaluated using single step method. The amount of added viscous damping required to meet a given performance objective is evaluated from the difference between the total demand for effective damping and inherent damping plus equivalent damping resulting from hysteretic deformation of system. Application of the method to inelastic system is illustrated by means of two examples, using Chinese design response spectrum and mean response spectrum constructed by an ensemble of earthquake ground motions recorded on the firm sites. Nonlinear dynamic analysis results indicate that the maximum displacements of structures installed with supplemental dampers designed in accordance with the proposed method match well with the given target displacements. The advantage of the presented procedure over the conventional iterative design method is also highlighted.

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Paper No. 210

DEBONDING MONITORING OF CFRP STRENGTHENED RC BEAMS WITHOUT REFERENCE DATA NOR PRIOR DECISION BOUNDARIES

Hoon Sohn[1], Seung Dae Kim[2], Chi Won In[3], Kelly E. Cronin[4] and Kent Harries[5]

As carbon fiber-reinforced polymer (CFRP) laminates have been widely accepted as valuable materials for retrofitting civil infrastructure systems, an appropriate assessment of bonding conditions between host structures and CFRP laminates becomes a critical issue to guarantee the performance of CFRP strengthened structures. This study attempts to develop a continuous performance monitoring system for CFRP strengthened structures by autonomously inspecting the bonding conditions between the CFRP layers and the host reinforced concrete (RC) beam. The uniqueness of this study is to develop a new concept and theoretical framework of nondestructive testing (NDT), in which debonding is detected "without using past baseline data" and "without prior decision boundaries." The proposed reference-free damage diagnosis is achieved in two stages. In the first step, features sensitive to debonding of the CFPR layers but insensitive to loading conditions are extracted based on a concept referred to as a time reversal process. This time reversal process allows extracting damage-sensitive features without direct comparison with past baseline data. Then, a statistical damage classifier is developed in the second step for autonomous decision regarding the bonding condition of the CFRP layers without relying on preset decision boundaries. The threshold necessary for decision making will be adaptively determined without predetermined threshold values nor user involvement. Monotonic and fatigue load tests of full-scale CFRP strengthened RC beams are conducted to demonstrate the potential of the proposed reference-free debonding monitoring system.

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Paper No. 212

THE ANALYSIS OF INSTRUMENT RESPONSE ERRORS FOR FORCE-BALANCE ACCELEROMETER AND THEIR CORRECTION METHOD

Yu Hai-Ying[1]

The analysis of instrument response errors for force-balance accelerometer of digital accelerograph system is carried through in this paper, a method for correcting instrument response errors has been put forward (the differential-differential method) , i.e. the un-correction acceleration data are treated by low-pass filtering, they are differentiated twice with approximate ideal differentiators to obtain the corrected accelerogram. In allusion to the earthquake instrument system (KIS) of Daya bay nuclear power station, the instrument response correction demonstration is given, and the corresponding compute processing software are compiled. The method is applicable for instrument response correction processing of accelerogram recorded by digital accelerograph of China strong motion network.

Keywords: Digital accelerograph Force-balance accelerometer Instrument response errors correction Accelerogram Software

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Paper No. 215

ANALYSIS AND DEVELOPMENT OF A NERVOUS SYSTEM FOR CIVIL STRUCTURING

Rahmat A. Shoureshi[1] and Amy Shen[2]

While there has been significant progress in structural health monitoring systems, there still exists the need for a self-powered, distributed diagnostic system that can be embedded within a civil structure. In order to provide a true distributed sensor and control system for civil structures, we have developed a Structural Nervous System that mimics key attributes of a human nervous system. This nervous system is made up of building blocks that are designed based on human body's mechanoreceptors as a fundamentally new approach for the development of a structural health monitoring and diagnostic system that utilizes the recently discovered plant-protein forisomes, a novel non-living biological material capable of sensing and actuation. In particular, our research has been focused on producing a sensory nervous system for civil structures by using forisomes as the mechanoreceptors, nerve fibers, neuronal pools, and spinocervical tract to the nodal and central processing units.
This paper will present up to date results of our research, including the design and analysis of the structural nervous system.

Keywords: Structural Nervous System, Self-Powered Monitoring System, Forisomes

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Paper No.216

STRUCTURAL STRENGTHENING USING PASSIVE CONTROL SYSTEMS

C. A. Syrmakezis [1]

Passive control systems are proved to be very efficient in dissipating seismic energy, when introduced into the load-bearing system of structures. This capability can also be exploited for structural retrofitting, in order to achieve reliable and durable repair and strengthening results.
In this paper a methodology for the analysis of retrofitted structures, using the finite element method, is presented. The methodology is applied in two directions, either for modern structures, or for masonry historical structures and monuments.
For the demonstration of the methodology two case studies are presented. The first one involves a reinforced concrete hospital building named "section B" in the hospital complex "Agios Andreas", in Patras, Greece. It is a four-story flexible reinforced concrete structure, which has suffered several earthquakes in the past. Required intervention, without any interruption of its operation, could only be satisfied by the application of a brace control system. In the second case, the historical structure is an 11th century church called "Nea Moni", on Chios Island, Greece. The monument is included in the Catalogue of Monuments of the International Cultural Heritage of UNESCO. Its particularity is owed to its conjugation with a semi-underground water tank, called Cistern. Non-intrusive retrofitting using damper devices is performed and reduction of its seismic vulnerability is investigated.

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Paper No. 218

SCENARIO SIMULATION OF AN ELECTRIC POWER SYSTEM AND APPLICATION TO ITS SEISMIC MITIGATION

Gee-Yu Liu[1], Yi-Jen Wang[2] and Chih-Wen Liu[3]

Catastrophic earthquakes may cause severe power outages, induce huge direct and indirect losses, and raise difficulties in emergency management. It becomes very important to be facilitated with a scenario simulation tool to estimate the likely power outage under a seismic condition and evaluate the level of seismic risk their power systems are exposed to. Adequate measures could be taken thus to upgrade the seismic preparedness more effectively. In this study, the hazard-induced outage of an electric power system were first examined and conceptually split into two phases. Phase 1 refers to the system's prompt response to its physical damage. Phase 2 refers to a while after the shock when system operators start to restore the power supply. Analysis procedures for estimating these two phases of power outage were addressed next. The procedures involve re-organizing the power network to isolate the damaged equipment or nodes and lines with abnormal voltage and current, and conducting power flow analysis which takes into account the response of system operators. The power system in Taiwan was then investigated, of which transformers of high voltage grades were assumed vulnerable. By employing a series of hazard-consistent scenario earthquakes, its seismic performances considering both phases of power outage was computed through the Monte Carlo simulation. Two definitions of importance factors, one designating to where the threat is and the other how critical a transformer is to the system performance, have been proposed. Both can be used by utility decision makers to make adequate choice of where to mitigate the seismic hazards.

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Paper No. 219

SEISMIC RELIABILITY ANALYSIS AND OPTIMIZATION OF LARGE-SCALE GAS SYSTEM

Liu Wei[1] and Li Jie[1,2]

As an essential component of lifeline engineering systems, gas system plays a more and more important role in modern cities, especially in a large or huge city. The seismic reliability analysis and optimization of gas system is always an important topic in earthquake engineering field and has drawn intensive attentions of many researchers in the past few decades.

Based on elastic foundation beam method, the axial seismic response of gas pipeline is expressed as the sum of a series of cosine functions. According to the corresponding code in China, a limit state equation about the gas pipelines is presented and the seismic reliability of the pipelines is calculated using first-order reliability method (FORM). For gas network systems, recursive decomposition algorithm based on disjoint minimal path, a high efficiency algorithm for the reliability analysis of large-scale networks, is proposed to analyze the seismic connectivity reliability of the network. The algorithm solves the most difficult problem, NP hard problem, in analyzing the connectivity reliability of large-scale networks. Considering that the aim of the research is to provide a tool for the seismic design of new networks or seismic reform of existed networks, an optimization model is presented for gas network. In this model, the genetic algorithm is used to optimize topological structures of the networks. A large-scale gas network, gas network of Shenyang City, is investigated in detail in this paper. The results can be used to evaluate the gas network under earthquake and can be used for the seismic reform of gas network.

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Paper No. 220

IDENTIFYING CRITICAL INFRASTRUCTURES IN A ROAD NETWORK BASED ON EMERGENCY RESPONSE ACCESSIBILITY

Afshin Shariat Mohaimani[1], Navid Kalantari[2] and Mahmoud Mesbah[3]

Transportation networks play an important role in search and rescue action after an earthquake; therefore, it is necessary to keep the transportation network reliability as an essential lifeline at an acceptable level with respect to the expected performance of the network after an earthquake. Providing accessibility and transportation network ability to satisfy the post-earthquake demand are two of the most important measures of performance; hence, this article first uses a Time- Space accessibility measure that is based on the expected performance of the network after an earthquake, then a method for identifying critical infrastructures in a road network is presented by using the upper bound and lower bound method for estimating accessibility reliability with respect to damage probability of the network components. This method could be used for road transportation network assessment.

Key words: emergency response, network assessment, earthquake, reliability, accessibility, network vulnerability

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Paper No. 221

PROTECTING PRECISION MACHINERY USING GUIDEWAY SLIDING ISOLATOR WITH GAP SPRING AND DAMPERS

George C. Yao [1] Wen-Chun Huang [2] Fan-Rue Lin[3]

Guideway sliding isolator is one of the most efficient ways to protect the precision machinery from damage because of the earthquake. However, it brings large displacement between the machine and the floor. In order to improve the performance, viscous dampers, as the energy absorber to reduce the displacements, and gap springs, providing the resilient force to eliminate the relative and residual displacements, are both added to the system. The special feature of gap spring is that a spring is initially kept away from the machinery with a gap so that it could avoid the isolation system resonate to the seismic waves. In this paper, a numerical model to simulate the machinery and the full scaled shaking table test of a 22-tons-weight specimen were both performed to study the behavior of Guideway sliding isolator with gap spring. Testing results show that absolute acceleration transmitted to the specimen can be very low if the frictional coefficient of the guideway isolator is under 0.05, and the gap springs are useful to control the relative displacements of the system under the acceptable level. Numerical model is shown to be effective and correct since the test results are well correlated to the analyzed one.

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Paper No. 223

DEVELOPMENTS OF THE CURRENT PERFORMANCE-BASED SEISMIC DESIGN CODE FOR BUILDINGS IN TAIWAN

Qiang Xue[1] Chia-Wei Wu[2] Cheng-Chung Chen[3] Kuo-Ching Chen[4]

Performance-based design has been widely recognized as an idealized method for future seismic design in practice. A draft seismic design code for buildings by introducing performance-based design methodology has been proposed in this research. First of all, the current code provisions have been examined according to the theoretical basis of PBSD. Several key issues have then been investigated to clarify why, what and how to incorporate the methodology of PBSD in domestic seismic design code currently. In the proposed draft code, transparent seismic design objectives and criteria for buildings of different use group have been established quantitatively. Drift limit for each considered earthquake level is clearly established. Site feasibility requirement, conceptual design scope and basic rule have been modified considering use group. A performance objective oriented preliminary design procedure is proposed. Direct displacement-based design procedures have been summarized in the appendix. Methods and procedures for seismic performance evaluation have been presented. Finally in this paper, what we have learned through the applied examples will be summarized. We believe that performance-based seismic design technology will bring a new era to engineering practice with increased confidence and reliability on seismic safety.

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Paper No. 224

RESPONSE ANALYSIS STUDY OF A BASE-ISOLATED BUILDING BASED ON SEISMIC ISOLATION CODES WORLDWIDE

Demin Feng[1], Tian-Chyuan Chan[2], and Shuguang Wang[3], Hsi-Yun Chen[4] and Yaw-Nan Chang[5]

After the 1994 Northridge earthquake in the United States of America, the 1995 Hyogoken-Nanbu earthquake in Japan and the 1999 Chi-Chi earthquake in Taiwan, the number of seismically isolated buildings has increased rapidly. Over the same period, building codes have been revised and updated to include requirements for design of seismically isolated buildings. A test study is presented in order to understand and illustrate the differences in the isolation provisions of the building codes of Japan, China, the USA, Italy and Taiwan. The concept of the design spectrum in each code is summarized first. To consider the seismic region coefficients, the target construction sites are assumed to be in Tokyo, Beijing, Los Angeles, Potenza and Taipei, respectively.

The procedures to do response analysis of a seismically isolated building are summarized based on the building codes of Japan, China, the USA, Italy and Taiwan. While a dynamic response analysis method is recommended in all five building codes, a simplified design procedure based on equivalent linear analysis is also permitted under limited conditions. The main limitations are summarized as follows. A construction site class is limited to hard soil conditions, except in the Italian code. The maximum height of the superstructure is limited, except in the Taiwanese code. In the Japanese and Chinese codes, the limitation on the height of the target building is more relaxed. Thus the target buildings capable to adopt isolation technologies extended widely. No tension is allowed in the isolation devices, except in the USA code.

Subsequently, a typical 14-story reinforced concrete building, isolated with lead-rubber bearings is analyzed using each of the five building codes. The building's characteristics such as weight, height, hysteresis properties and soil condition are fixed in all cases. The properties of the LRB isolation devices are also kept constant, with a total yield force for the isolation system of four percent of the total weight. In the time history analysis methods, ten synthetic ground motions are used which are fitted to the design spectrum of each of the five codes in the frequency domain. There are eight random phases and two real earthquake record phases. The average response values are taken as design values to compare with the results by the equivalent linear analysis method. The deformation of the isolation level and the base shear force coefficient of the superstructure are compared.

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Paper No. 226

PERFORMANCE-BASED SEISMIC DESIGN OF SPECIAL TRUSS MOMENT FRAMES

Shih-Ho Chao[1] and Subhash C. Goel[2]

Special truss moment frame (STMF) is a new type of steel structure suitable for high seismic zones. It dissipates earthquake energy through ductile special segments located near the mid-span of truss girders. STMFs generally have higher structural redundancy compared to other systems because four plastic hinges can form in the chords of one truss girder. The redundancy can be further enhanced if web members are used in the special segments. Simple connection details are needed for the girder-to-column connections. One other advantage of using STMF systems is that the truss girders can be used over longer spans and higher overall structural stiffness can be achieved by using deeper girders. In addition, the open-webs can easily accommodate mechanical and electrical ductwork. As a consequence, this system is gaining popularity in the U.S., especially for hospital and commercial buildings.

This paper presents an investigation in which a recently developed performance-based plastic design methodology was used to design the STMF system rather than conventional elastic method. This newly developed performance-based method has been successfully applied to moment frames and also extended to EBF, BRBF, and CBF recently. The procedure begins by selecting a desired yield mechanism for the frame. Design base shear and lateral forces are determined from input spectral energy for a given hazard level needed to push the structure in the yielded state up to a selected target drift. The frame members are then designed by following the plastic design method in order to develop the needed strength and the intended yield mechanism. The proposed design procedure was validated by extensive non-linear analyses for a number of ground motion records. The results confirm the validity of the proposed method for the study STMF in terms of meeting all the performance design objectives, such as target drifts, and intended yield mechanism. An important advantage is that, generally, no nonlinear analysis is needed to check the structural performance after design by using this methodology.

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Paper No. 227

A SEISMIC DESIGN METHOD FOR STEEL CONCENTRIC BRACED FRAMES FOR ENHANCED PERFORMANCE

Shih-Ho Chao[1] and Subhash C. Goel[2]

Concentric braced frames (CBF) are very efficient and commonly used steel structures to resist forces due to wind or earthquakes. Based on research performed during the last twenty years or so, current seismic codes now include provisions to design ductile concentric braced frames called Special Concentric Braced Frames (SCBF). When designed by conventional elastic design methods, these structures can undergo excessive story drifts after buckling of bracing members. That can lead to early fractures of the bracing members, especially in those made of popular rectangular tube sections.

This paper presents some results of a brief study in which a recently developed energy based plastic design methodology was applied to CBF with buckling type braces which exhibit somewhat "pinched" hysteretic loops. Originally the method was developed and successfully applied to moment frames and recently also extended to EBF. The design concept uses pre-selected target drifts and yield mechanisms as performance limit states. The design lateral forces are derived by using an energy balance equation where the energy needed to push the structure up to the target drift is calculated as a fraction of elastic input energy which is obtained from the selected elastic design velocity spectra. Plastic design is then performed to detail the frame members and connections in order to achieve the intended yield mechanism and behavior. Results of inelastic static and dynamic analyses carried out on example frames designed by the proposed method showed that the frames met all the desired performance objectives, including the intended yield mechanisms and the story drifts in order to prevent brace fractures under varied hazard levels. On the other hand, when designed by current code procedures as SCBF the same structures showed very poor response due to premature brace fractures leading to unacceptably large drifts and instability.

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Paper No. 230

AN IMPROVED CAPACITY SPECTRUM METHOD BASED ON INELASTIC DEMAND SPECTRA

XIAO Ming-kui[1], DONG Yin-feng[2], LIU Gang[3], CHENG Guang-jun[4]

The capacity spectrum method which intervenes between static inelastic analysis and elastic dynamic analysis is a simplified method to analysis the elastoplastic response and evaluate the performance of regular structures under strong ground motions to a certain extent of approximation. To address the existing problems, two aspects of improvements are made on the present capacity spectrum method. Firstly, by using the yield strength factor as an elastoplastic index, the inelastic demand spectra corresponding to the design acceleration response spectra specified in the Code for Seismic Design of Buildings in China are defined and formulated, while in the conventional methods the elastic demand spectra of high damping ratio are often used and can not reflect the structural elastoplastic response demand precisely. Secondly, according to the energy equivalent criteria the yield displacement and yield force of the equivalent SDOF system are determined based on the structural design parameters directly which are usually determined by bilinear modeling of Pushover curves of structures under area equivalent assumption in some present standards as FEMA-356 and Eurocode 8 specify. The comparison of results shows the improved method is more simple and precise which can be easily carried out in structural seismic design.

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Paper No. 231

DISPLACEMENT PROFILE FOR DISPLACEMENT BASED DESIGN OF DUAL FRAME SYSTEMS

Altuğ Yavaş[1]

Direct Displacement Based Design (DDBD) method designs reinforced concrete structures on the basis of seismic induced displacement demand rather than force demands. DDBD has been developed for several types of structures in the last decade. In this study, displacement profile for wall-frame type structures to be used in the DDBD of dual frame is investigated. An iterative two phase method that uses DDBD in the first phase and nonlinear time history analysis in the second phase is proposed for determining the displacement profiles. Displacement profiles for six, eight and twelve story four span dual-frame type structures are determined. The effects of the number of the bay and the base shear ratio carried by the wall are also investigated. A new displacement profile function is proposed for the DDBD of dual frames.

Keywords: Direct Displacement Based Design, Displacement Profile, Dual Frame

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Paper No. 232

THE EFFECT OF SEISMIC BUILDING CODE PROVISIONS ON REDUCING THE COLLAPSE RISK OF REINFORCED CONCRETE MOMENT FRAME BUILDINGS

Abbie B. Liel[1], Curt B. Haselton[1], and Gregory G. Deierlein[2]

Recent developments in earthquake engineering research have enabled simulation of structural collapse under seismic loading, providing quantitative measures of collapse risk. This paper examines the seismic collapse risk of reinforced concrete (RC) frame structures in the U.S., including modern and older existing structures designed for California, as well as modern code-conforming structures designed for lower seismic regions in the central and eastern U.S. Employing the performance-based earthquake engineering methodology, as developed by the Pacific Earthquake Engineering Research Center, each structure is analyzed using nonlinear dynamic models to capture its important failure modes and collapse behavior. The probabilistic collapse assessment also incorporates variability in ground motions and uncertainties in structural behavior and modeling. By comparing the collapse risk generated by this methodology, conclusions can be drawn about the effectiveness of building code provisions in reducing seismic collapse risk.

The comparison between existing and new RC moment frame structures in California illustrates improvements in building code provisions, as measured in terms of reduction of collapse risk. This comparison is based on four-story reinforced concrete moment frames designed to be representative of a) pre-1970 non-ductile reinforced concrete construction (designed according to the 1967 Uniform Building Code) and b) modern ductile reinforced concrete construction (designed according to the 2003 International Building Code). Both are designed for the same site in Los Angeles, and have the same plan and elevation, but exhibit significant differences in detailing. The smaller collapse risk of the modern structure provides an explicit measure of the improvements in building codes over the last four decades.

A second group of 4-story RC moment frame structures is also considered, including a) special, b) intermediate, and c) ordinary moment frames designed according to the 2003 International Building Code. These structures are designed with different strength and detailing requirements as permitted according to the site's seismic hazard, e.g. ordinary moment frames have no seismic detailing requirements, but are penalized by a lower R-factor, and are prohibited in high seismic areas. From this comparison, the uniformity of safety provided by seismic building code provisions among regions of varying seismicity may be evaluated.

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Paper No. 233

CODE RELATED ISSUES IN SEISMIC DESIGN OF BUILDINGS IN KOREA

Taejin Kim[1], Dong-Guen Lee[2], Hyun Ko[3], and So-Hoon Cho[4]

The strong shaking in the high seismicity regions can cause severe damage in building structures and change the structural properties of the buildings during the shaking. Lots of information in the seismic codes developed for the high seismicity regions have been gathered from observations for such strong shaking. However, the seismic behavior of structures in low seismicity regions such as Korea may be quite different from that in high seismicity regions. The objectives of this study are to investigate the seismic code issues related to the design of buildings in Korea and to make suggestions to improve the seismic design code for the low seismicity regions. In this study, 5, 10, 15-story framed structures were designed using the seismic loads corresponding to the seismic zone 1, 2A, 5 in UBC97, and their seismic behaviors were investigated with variations in ground motions, natural periods, seismic design factors such as overstrength factors, and effective section properties of members.

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Paper No. 234

DEVELOPMENT OF A DESIGN METHODOLOGY FOR SEISMIC ISOLATED BUILDINGS CONSIDERING A RANGE OF PERFORMANCE OBJECTIVES

Troy A. Morgan[1] and Stephen A. Mahin[2]

In the past 20 years, seismic isolation has see a variety of applications in design of structures to mitigate seismic hazard. In particular, isolation has been seen as a means of achieving enhanced seismic performance objectives, such as those for hospitals, critical emergency response facilities, mass electronic data storage centers, and similar buildings whose functionality following a major seismic event is either critical to the public's welfare or the financial solvency of an organization. While achieving these enhanced performance objectives is a natural (and oftentimes requisite) application of seismic isolation, little attention has been given to the extension of current design practice to isolated buildings which may have more conventional performance objectives. The development of a rational design methodology for isolated buildings requires thorough investigation of the behavior of isolated structures subjected to seismic input of various recurrence intervals, and which are designed to remain elastic only under frequent events. This paper summarizes these investigations, and proposed a consistent probabilistic framework within which any combination of performance objectives may be met. Analytical simulations are presented, the results are summarized. The intent of this work is to allow a building owner to make informed decisions regarding tradeoffs between superstructure performance (drifts, accelerations) and isolation system performance. Within this framework, it is possible to realize the benefits of designing isolated buildings for which the design criteria allows consideration of multiple performance goals.

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Paper No. 235

A STUDY ON NECESSITY FOR CHECKING ELASTO-PLASTIC DEFORMATION OF RC FRAME STRUCTURE IN SEISMIC APPRAISER

Pu Yang [1], Ying-min Li [1], chang Wang[2]

A seven-story RC frame structure is appraised according to Standard for Seismic Appraiser of Building (GB50023-95) and its elasto-plastic response under the action of an earthquake of fortification intensity is analyzed using static nonlinear analysis method and time-history analysis method respectively. Results indicate that the elasto-plastic deformation of the structure doesn't satisfy the displacement requirement of preventing collapse of structure under the action of an earthquake of fortification intensity. So it is necessary to check the elasto-plastic deformation under the action of earthquake of fortification intensity in seismic appraiser.

Key words: RC frame structure, seismic appraiser, nonlinear dynamic analysis, seismic performance, elasto-plastic deformation

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Paper No. 238

THE INTERNATIONAL BUILDING CODE AND ITS IMPLICATIONS ON SEISMIC DESIGN

W.S. Pong[1] , Anson Lee[1] and Z.H. Lee[2]

The study begins with a discussion of the history and development in the last few decades of building code for seismic design in the United States. Then, it focuses on a comparison of the Uniform Building Code 1997 (UBC1997) and the International Building Code 2003 (IBC 2003) as they relate to seismic design. The study compares the seismic provisions of UBC 1997 and IBC 2003 for design base shear in various seismic zones and soil types. In conducting this case study, it was generally observed that IBC 2003 takes into account more factors in deriving values for each criterion. It introduced the seismic design category that combines the occupancy or seismic use group with the soil modified seismic risk or the soil characteristics at the site of the structure. The results of this case study show that there are significant differences in some criterion. This point should not be underestimated. It would be wise to remember that building codes serve as a guide to reaching minimum standards. It is, therefore, imperative that the structural engineer professional not only keep up to date with the codes and their differences, but also be aware that what is most important is to have a good working knowledge and understanding of the fundamentals of seismic design principles.

Keywords: International Building Code, Uniform Building Code, Design Base Shear, Design Response Spectrum, Importance Factor, Redundancy Factor

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Paper No.239

TAIWAN HIGHWAY BRIDGE ASEISMIC EVALUATION

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Taiwan is located in a seismic hazard region, therefore, the assessment and retrofit of older bridges is very important. In order to ensure the safety of traffic network, a project has been carried out to assess the aseismic capacity of over 2200 bridges on the Taiwan Roadway System. The assessment process is divided into two stages. The first stage is the preliminary assessment which all the bridges will be evaluated using a simple seismic review sheet to determine the evaluation points. Less than 30 points means that the bridge is O.K.; while as over 60 points indicates that the further investigation is needed for the bridge. On the second stage, 5% of total bridges (approximate 110 bridges) will be selected to do the detail analysis. The state of the art nonlinear static analysis (pushover analysis) is adopted to calculate the ductility capacity of the bridge. Based on the assessment results, a retrofit strategy will be established. This paper will illustrate the assessment process and introduce the preliminary results.

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Paper No. 240

STABILITY OF RHOMBUS MECHANISM DAMPER SYSTEMS

Fu-Sheng Lin[1], Yung-Feng Lee[2], and Deh-Shiu Hsu[3]

Common building structures provide enough stiffness to reduce relative displacements between floors. While using the fluid damper as an energy-dissipating devices, it is necessary to magnify the displacement of damper to increase aseismatic energy-dissipating efficiency. The idea of rhombus mechanism damper system has been proposed to increase the damper displacement to dissipate energy. By means of numerical analysis with SAP2000 software package, it is confirmed that the rhombus mechanism damper system can effectively magnify the displacements, and thus reach the goal of energy dissipation and reduce the seismic responses. Out of plane unstable problem could be occurred because of the geometry unstable of three hinge coincide in a line for the mentioned mechanism. The study aims to find critical point of out of plane buckling for the rhombus mechanism damper system under real design situation to verify the feasibility of such a system in reality. Thus, theoretically, the feasibility of the proposed rhombus mechanism damper systems is then assessed according to its unstable possibilities.

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Paper No. 242

A STUDY ON THE SEISMIC RESISTANT DESIGN OF BUILDINGS WITH VELOCITY DEPENDENCE PASSIVE ENERGY DISSIPATION DEVICES

Tian-Chyuan Chan [1], Yan-Hong Lee[2] Demin Feng[3]

The norms for the structural design of domestic seismic resistant buildings with energy dissipation have been included in "the specification of seismic resistant design of buildings" decreed and enforced on July 1, 2005 in Taiwan. However, the experience that general designers have for the function of energy dissipation devices and design methods needs to be further improved, and illustrations shall be established so as to compare simulated parameters, application effects and advantages as well as disadvantages amidst different energy dissipation devices.

This study has constructed manufacturer's specification catalogue for velocity dependence passive energy dissipation devices and compiled applied cases. It has also investigated the parameters of the building structural analysis with the devices in the four categories of passive energy dissipation devices, namely solid viscous-elastic damping wall energy dissipation device, solid viscous-elastic damping bar energy dissipation device, fluid viscous-elastic energy dissipation device and fluid viscous energy dissipation device. To compare with the buildings without installing dampers, this study has investigated the seismic resistant effect by applying energy dissipation devices to the buildings.

The study shows that the greater the damping strength, the smaller the seismic response to the overall building will be. Also, with a smaller floor shear force, displacement will be comparatively reduced. Compared with traditional buildings, the study reveals that by adding a solid viscous-elastic energy dissipation device (damping bar) to a building, the displacement of each floor may reduce 24.4% whereas floor shear force may decrease 27.1%. If setting up the solid viscous-elastic energy dissipation device (damping wall) to a building, the displacement of each floor may reduce about 22.2% whereas floor shear force may decline 24.3%. With fluid viscous-elastic energy dissipation device to a building, displacement of each floor may reduce 4.9% whereas floor shear force may decrease 7.4%. With viscous energy dissipation device to a building, the displacement of each floor may reduce 5.73% whereas floor shear force may decline 7.1%.

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Paper No. 243

SEISMIC DAMAGE ASSESSMENT OF ELEMENTARY SCHOOL BUILDINGS IN TAIPEI CITY

Howard Hwang[1] and Hsiu-Ling Wei[2]

This paper presents a seismic damage assessment of all elementary school buildings in Taipei City. First, we collect pertinent data on 139 elementary schools and 559 schools buildings. In this study, we consider four scenario earthquakes to occur on the Sanjiao fault or in the Yilan and Hualien area. At each school site, the peak ground acceleration (PGA) is estimated using an attenuation relation and a site amplification factor; the occurrence of liquefaction is evaluated based on the Taipei liquefaction potential map. The capacity of each school buildings is determined based on a fragility curve and building deficiencies identified from a school survey. We determine the damage state of each school building caused by the scenario earthquakes and then identify most vulnerable school buildings. This study may provide a useful resource for school authority to make decision on seismic retrofit of elementary school buildings in Taipei City.

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Paper No. 244

EVALUATION OF NONSTRUCTURAL COMPONENT FRAGILITIES IN RISK ASSESSMENT OF HOSPITALS

Keng-Chang Kuo [1], Yoshiyuki Suzuki [2], Yasuhiro Hayashi [3], Hiroshi Kambara [4]

Post-earthquake functionalities of critical facilities, such as hospitals, can be evaluated by the logic-tree analysis (e.g. Fig.1). The probability of loss of the functionality is calculated based on fragilities of the related components. Earthquake damage data supply a practical approach to derive fragility. However, fragilities derived from damage data of nonstructural components are few due to the difficulties to survey interior damage of buildings. The aim of this study is to derive fragilities of critical nonstructural components from damage survey data, and to make an evaluation sheet for use in the logic-tree analysis.

First, after three major earthquakes occurred in Japan in 2003, damage surveys by questionnaire were conducted on hospitals near the earthquake observation stations. The damage ratios were obtained by correlating the statistical results of damage to the recorded seismic intensities. Fig. 2 shows the results of fallen ceilings. Secondly, fragilities are derived from the damage ratios, by the following 4 steps. (1) Seismic capacity of each component is classified into three groups: basic, deficiency 1 and deficiency 2, according to the construction conditions. (2) Seismic capacity is expressed by lognormal distribution. Based on earthquake damage experience, the acceleration corresponding to damage probability of 1% for the three groups are set as the relation: 1A to 0.57A to 0.33A. (3) Existing ratios of three groups are set by damage report review. (4) The damage ratios are sum of the product of multiplying the fragility with existing ratio of each group, thus the acceleration corresponding to damage probability of 1% is obtained by best fitting the damage ratios. Finally, with the derived fragilities, an evaluation sheet was made, in which a table with rows of seismic capacity groups and columns of acceleration levels was shown to read the damage probability.

Due to the diversities in practice of nonstructural components among countries, the process, from damage surveys to fragilities and evaluation sheets, adopted in this study can be used to derive a country's data that reflect local practice.

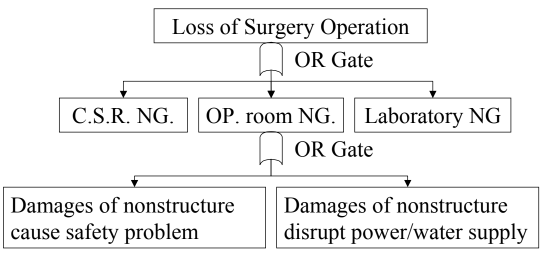

Fig. 1 Logic-tree analysis example of loss of surgery operation

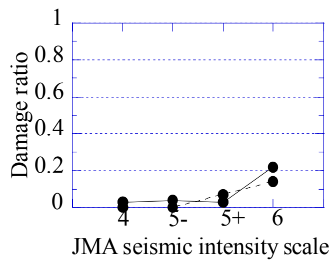

Fig. 2 Damage ratios of fallen ceilings
(Line/Dashed: Hospitals constructed before/after 1981)

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Paper No. 245

SEISMIC VULNERABILITY ASSESSMENT BASED ON MODIFIED DISCRIMINANT ANALYSIS

M. Semih Yucemen[1]

Seismic performance assessment of existing reinforced concrete buildings has gained significant attention in the last decade due to their poor performance during earthquakes. In a recent study (Yucemen, et al., 2004), the past performance of reinforced concrete buildings during major earthquakes have been compiled and analyzed comprehensively by using the discriminant analysis technique in order to study the empirical correlations between the significant damage inducing parameters and the observed damage and thus develop a preliminary evaluation methodology for the assessment of the seismic vulnerability of existing low- to mid-rise reinforced concrete buildings located in Turkey. The main aim of this study is to develop a simple statistical basis for the extension of the procedure developed in the above mentioned study to other cases.

In performing the discriminant analysis, firstly the potential discriminating variables are determined, then the best discriminating variables are identified and finally the discriminant functions, which are linear combinations of the best discriminator variables, are derived. The values computed from the discriminant functions, which can be interpreted as the damage scores, are used for the classification of the buildings into different damage states.

A damage database of nearly five hundred representative buildings experiencing the 12 November 1999 Duzce earthquake have formed the damage database to be utilized in the study. In determining the estimation variables to be used in the analysis, no consideration was given to the properties of the ground excitation and the soil properties, based on the assumption that all of the buildings in the damage database have experienced almost the same ground motion and on the observation that the soil profile did not show significant variation over the region. Accordingly, seismic damage is evaluated only on the basis of structural parameters and the characteristics of the earthquake excitation and the soil parameters are ignored. The following variables are chosen as the basic damage inducing parameters (Yucemen, et al., 2004): the number of stories, existence of soft story, normalized redundancy score, overhang ratio, the minimum normalized lateral stiffness and minimum normalized lateral strength indices.

The Bayesian discriminant analysis concepts are implemented to modify the cutoff values in order to apply the discriminant functions derived based on the 12 November 1999 Duzce earthquake to other cases, as well as to incorporate prior probabilities into the classification functions in order to improve the accuracy of predictions.

The high correct classification rates obtained for the seismic damage data associated with the 12 November 1999 Duzce earthquake support the predictive ability of the proposed model.

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Paper No. 247

SEISMIC DAMAGE ASSESSMENT OF POTABLE WATER PIPELINES

Chin-Hsun Yeh[1], Ban-Jwu Shih[2], Che-Hao Chang[2], W.Y. Walter Chen[2],
Gee-Yu Liu[3] and Hsiang-Yuan Hung[4]

Seismic damage assessment of potable water systems is a very important task in proposing disaster mitigation plans. This paper adopts a traditional way to estimate the possible number of repairs of the buried pipelines under strong earthquakes, i.e., through regression analyses to obtain empirical formulas for estimating the repair rate of buried pipelines. Although peak ground acceleration, peak ground velocity, permanent ground deformation, seismic intensity, etc., have been studied in the existing regression formulas of repair rate; however, these parameters are often taken into consideration separately. The existing regression formulas often over-estimate the damage of buried pipelines, especially in the region far away from seismic sources. This study aims to investigate the effects of ground shaking and permanent ground deformation simultaneously in obtaining the regression formulas of repair rate. PGA is used to indicate the intensity of ground excitation and ground strain is used to indicate the degree of ground deformation. The regression formulas will integrate with Taiwan Earthquake Loss Estimation System (TELES), which has been developed by the National Center for Research on Earthquake Engineering in Taiwan, to study their applicability and correctness.

Keywords: seismic damage assessment, buried pipelines, repair rate, moving average method

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Paper No. 248

COMPARISON OF RISKS DUE TO NATURAL HAZARDS IN JAPAN

Tsuyoshi Takada[1] and Yoshito Horiuchi[2]

Japan is the country that suffers from various kinds of natural hazards such as earthquakes, typhoons, snowfalls etc. Japan central as well as local governments are quite keen to mitigate the disaster due to these natural hazards since there have been serious disasters such as Niigata Earthquake in 2004, dozens of typhoons in 2003, and heavy snowfalls in the winter of 2005. Therefore, they have been confronted with the problem on what kinds of hazard and how much they ought to spend their budgets under the limited amount of budgets available. The most rational solution to this would be based on people's consensus as well as relative comparison of risks due to these hazards. They, however, have made decision based on people's temporary subjective perception just after disasters, not based on objective and In this context, this paper, focusing on the following three risks in Japan; earthquakes, typhoons and snowfalls, describes risks in each region throughout Japan based on the past statistics or hazard estimation, and compares the risks at particular region and the risks region by region. Architectural Institute of Japan (AIJ) load recommendations (AIJ, 2004) is utilized to estimate each hazard, which has been revised for structural design of buildings. In the AIJ recommendations, basic statistics of load intensities are given in the form of map. For earthquake ground motions, a hazard map of the annual maximum peak ground acceleration (PGA) on the engineering bedrock is provided, for wind, that of the annual maximum wind speed at 10 meter height on the surface roughness category II, and for snow, that of the annual maximum snow depth is given. From these map describing basic statistics of load intensities, combining with building fragility information, building risk curves due to each hazard are estimated.

After the comparisons of the risks, the paper finds that earthquake risk among others, which is, of course,a big threat, is not so significant in most of the regions, but wind risk uniformly distributes throughout Japan. Some of region such as Shizuoka, where a big earthquake called "Tokai earthquake" come with more than 90 percent within the next 50 years, has quite high seismic risk. These interesting findings can be useful information for multiple risk management of government as well as local authorities.

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Paper No. 250

AN ENHANCED HILBERT-HUANG TRANSFORM METHOD FOR ANALYSIS OF EARTHQUAKE GROUND MOTIONS

Dong Yinfeng[1], Ji Shuyan[2] and Li Yingmin[3]

Some limitations to the Hilbert-Huang transform (HHT) for nonlinear and nonstationary signal processing are remarked. As an enhancement to the HHT, a time varying vector autoregressive moving average (VARMA) model based method, which is different from the Hilbert transform approach commonly used in the original HHT, is proposed to calculate the instantaneous frequencies of the intrinsic mode functions (IMFs) obtained from the empirical mode decomposition (EMD) of a signal. By representing the IMFs as time varying VARMA model, the Kalman filter is used to estimate the time varying model parameters, and then the instantaneous frequencies of IMFs calculated according to the time varying model parameters can be used to yield the Hilbert spectrum in parallel with the envelopes derived from the cubic spline interpolation of the maxima of IMFs. The daily length of day dataset covering the period from January 20th, 1962 to January 6th, 2001 and the North–South acceleration component of the 1940 Imperial Valley earthquake recorded at El Centro, California, USA, are analyzed with both the enhanced and the original HHT method. The analysis results show that the enhanced method is more accurate and produces more physically meaningful and readable Hilbert spectrum, which can broaden the application fields of the HHT in engineering.

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Paper No. 251

SUPPORT VECTOR MACHINES FOR STRUCTURE NONLINEAR RESPONSE SIMULATION

LI Ying-min[1] and DONG Yin-feng[2]

The state of arts of the nonlinear dynamic response analysis of structures is reviewed briefly and some common issues are discussed. To address the problems of existing methods, a support vector machines (SVM) based two-stage method is proposed to simulate and predict the nonlinear dynamic response of structures. In the first stage, an autoregressive moving average with exogenous input (ARMAX) model is used to represent the acceleration response as the output of a single-input single-output (SISO) system and the least square method is used to estimate the model parameters with which the linear acceleration response of the system can be simulated and predicted assuming zero initial conditions. Then the linear velocity and displacement is estimated using numerical integration of the predicted acceleration. In the second stage, using the predicted linear responses (acceleration, velocity and displacement) and the excitation to reconstruct the input vector, SVM is used to approximate nonlinear mapping from the system input to output and the trained SVM can be used to simulate and predict the nonlinear dynamic response conveniently. The nonlinear dynamic response of a frame structure is simulated and predicted with the proposed and the neural network based methods and the comparison of the results demonstrates that the SVM based method shows perfect performance in generalization and accuracy. Some notes on SVM for nonlinear system simulation are also remarked at the end.

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Paper No. 252

SITE EFFECTS OF SHALLOW AND WIDE BASIN BASED ON 2-DIMENSIONAL MODELING WITHIN SPATIAL GEOTECHNICAL INFORMATION SYSTEM

Chang-Guk Sun[1] and Choong-Ki Chung[2]

The site effects relating to the amplification of ground motion under earthquake loading are strongly influenced by both the subsurface soil condition and geologic structure. In this study, the site effects at the Gyeongju area in Korea were examined by site investigation including borehole drilling and in-situ seismic tests. Geologic information of ground surface obtained by site visit and collected pre-existing site investigation data were also accumulated into geo-knowledge database. Subsurface of Gyeongju area with abundant historical earthquake events is composed of alluvial soil deposit of a maximum of 40 m thickness overlying weathered residual soils and rock bed. A Geotechnical Information System (GTIS) based on GIS framework were implemented to effectively find out spatial geologic structure of study area and it indicated Gyeongju basin has a shallow and wide shape. 2-dimensional finite element (FE) analyses for two typical cross sections of the study area were performed and the resulting seismic responses show that the earthquake ground motions were amplified during the propagation of shear waves through the soil layer overlying the bedrock and the duration of shaking near the basin edges was prolonged due to the surface waves generated by interactions of shear waves with basin geometry. Furthermore, 1-dimensional FE seismic response analyses for representative soil sites in the basins were additionally conducted, and it gives identical results with the 2-dimensional seismic responses at most locations in the basins with the exception of the locations near the basin edges, because the basins in this study are very shallow and wide.

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Paper No. 253

DEVELOPMENT OF MANAGEMENT SYSTEM FOR EXPERIMENTAL DATA AT NCREE

Wen-Hsiang Tu[1], Yuan-Sen Yang[2], Wei-Chung Cheng[3], Shang-Hsien Hsieh[4] and Keh-Chyuan Tsai[5]

This paper reports a continuing research effort on the development of a management system for earthquake engineering experimental data at National Center for Research on Earthquake Engineering (NCREE). In this research effort, a preliminary data model suitable for modeling typical experiments at NCREE has been revised. A suite of data management software tools based on the revised data model is also prototyped, including a desktop metadata editor and a management server. The desktop editor software adopts Extensible Markup Language (XML) technology to implement the data model and provide an interface for editing and sharing experimental data. The management server adopts relational database to implement the data model and provide a central environment to store, arrange and manage all experimental data. In addition, the future work on the development of the experimental data management at NCREE is discussed.

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Paper No. 254

SEISMIC DATA COMPRESSION AND INTEGRATED STRUCTURAL HEALTH MONITORING SYSTEM

Yunfeng Zhang[1] and Jian Li[2]

This paper presents a new concept for an integrated structural health monitoring (SHM) system and its potential use in seismic application. The integrated SHM system incorporates sensor data compression, interactive data retrieval and structural system identification to address the challenging issues arising from current SHM practice. Since rapid data analysis is highly desired during or immediately after strong earthquakes to enable rapid emergency relief and disaster assistance efforts, innovative sensor data compression techniques are needed to facilitate fast and reliable remote transmission of seismic data from monitored structures to central information processing station. Real sensor data measured from a prototype integrated SHM system which is comprised of a model steel bridge, a real-time data acquisition system with remote access were used in this study to demonstrate the concept for the integrated SHM system. The performance of the integrated SHM system with lossy data compression is also discussed in this paper.

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Paper No. 255

NETSLAB-BASED REMOTE HYBRID TESTING IN CURRENT HIERARCHICAL NETWORK ENVIRONMENT

Yu-rong Guo[1], Yan Xiao[2] and Qing Hu[3]

Remote hybrid testing (also called geographically distributed hybrid testing) concept is very promising in conducting large-scale testing for complex structural systems under strong earthquake excitation, in which many components may exhibit severe non-linear behavior. Testing platforms have been developed and real remote hybrid tests have been carried out in several countries. But handy and robust data exchange in various network environments is still a challenging task. The current Internet is based on hierarchical network infrastructure and has seen ubiquitous deployment of "middleboxes", such as firewalls and network address translators. The presence of middleboxes sets barriers for peer-to-peer (P2P) communications. To facilitate the remote hybrid testing for structures, a network communication platform, named NetSLab (Networked Structural Laboratories), has been developed. The socket-based NetSLab is capable of transferring control and feedback data among remote structural testing laboratories or computers connected by Internet. To keep its simplicity for understanding, developing and maintenance, two new concepts, Dynamic Unified Data Packet (DUDP) and Generalized Data Communication Agency (GDCA), were introduced into NetSLab. Currently, a simple method has been adopted to update the original NetSLab to provide across firewall/proxy communication. In this method, a public IP address is needed and the standard HTTP (80) port is used as the communication port. NetSLab simply adopts regular Internet surfing model and replaces the Internet Information Service (IIS) and Internet Explorer (IE) function by its own components. Based on NetSLab, remote hybrid testing applications have been developed and trial and actual tests have been carried out at and between the Hunan University, China and the University of Southern California, USA. Also, communication speed tests were performed over various network environments. The tests showed that the NetSLab-based communication was stable and efficient in the current hierarchical network environment. This may greatly facilitate carrying out remote hybrid testing, particularly in China in which the widely used Network by researchers is usually protected by restrictive firewalls.

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Paper No. 258

NUMERICAL STUDY ON SEISMIC BEHAVIOR OF BEAMS FOR BOLTED BEAM-COLUMN CONNECTIONS

Lai-Yun Wu[1], Lap-Loi Chung[2], Guo-Luen Huang[3], Zheng-Kuan Lee[4], and Ren-Zuo Wang[4]

From research, the conventional beam-column connections with full penetration welding possess only 5‰ plastic rotation and the deformation capacity is seriously inadequate. The ideal design is that welding is carried out at the shop and bolting at the site. Therefore, bolted beam-column connections are developed. In bolted connections, moment is transferred by tie rods. All welding is performed at the shop and no more welding is necessary at the site. A lot of experiments have been studied for bolted beam-column connections for the past years. To make sure that plastic hinges are away from the welding, wing plates are welded at beam ends in bolted beam-to-column connections. This paper studies the effects of wing plates numerically by simulating cantilever beams using the ABAQUS finite element program. The simulation result agrees with the experimental data through convergence analyses and cyclic loading analyses.

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Paper No. 261

APPLICATION OF AN EXPERIMENTAL SOFTWARE FRAMEWORK FOR INTERNATIONAL HYBRID SIMULATION

Andreas Schellenberg[1] and Stephen Mahin[2]

Hybrid simulation is a versatile, powerful and economically viable experimental method. However, it is far less utilized than quasi-static or shaking table testing. One of the main reasons limiting the use of hybrid simulation is the absence of a common framework for its development and deployment; thus, to realize the full potential of hybrid simulation, an environment independent software framework is needed that is robust, transparent, scalable and easily extensible. In order to achieve this desired flexibility, the software framework should be highly modular and transparent in its operation to users. Therefore, based on object-oriented software design methodologies, a set of interrelated software classes is described herein, which in their unity form a framework for integrating experimental testing with standard structural analysis frameworks. In this paper, the open source Framework for Experimental Simulation and Control (openFRESCO) is used in combination with the object-oriented finite element software framework OpenSees (Open System for Earthquake Engineering Simulation) and the graphical user interface OpenSees Navigator, to achieve a hybrid simulation environment of unparalleled convenience and versatility. The deployment enables an unlimited number of users to connect multiple laboratories throughout the world, define specialized experimental set ups, implement advanced integration operators and utilize high performance control methodologies, in a highly modular and scalable fashion.

By utilizing both the object-oriented experimental and finite element software frameworks, geometric nonlinearities, three-dimensional effects, multiple support excitation and soil-structure interaction can be investigated by incorporating them into the analytical model. One of the most advantageous applications to incorporate geometric nonlinearities into the analytical model is in large displacement tests where a structure is tested until collapse. Contrary to shaking table testing, no large physical masses have to be present in the experimental part of a hybrid simulation. Such large masses could severely damage testing equipment once a test specimen collapses. Hence, the gravity loads as well as the resulting geometric nonlinearities are all modeled analytically. In order to demonstrate a hybrid simulation, wherein a structure is tested under large displacement effects until collapse, a simple one-story frame with two unequally ductile columns is used. Other implementations will also be illustrated

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Paper No. 262

SIMULATION TECHNIQUES FOR COLLAPSE ANALYSIS OF RC BRIDGE UNDER STRONG EARTHQUAKE

Limin Sun[1], Xinpeng You[2] and Cen Zhou[3]

Collapse analysis is becoming increasingly significant as the performance-based design is being gradually adopted in the seismic design of bridges. To deal with the strong nonlinearity and large deformation of the structure, a dynamic finite element method based on explicit time integration (ETI) was introduced in this study. Some simulation techniques were used to realize the fracture of structural member; and the contact and impact of broken reinforced concrete member with each other were also taken into consideration in the method.

The simulation of the whole collapse process of Cypress Double-deck Viaduct in 1989 Loma Prieta was performed with the above method. The analysis results agree well with the damage observed in site and this indicated that the simulation method and techniques proposed is capable to be utilized for collapse analysis of RC bridges. With simulation results of collapse analysis, failure modes and potential collapse mechanism of RC bridge under strong earthquake can be illustrated.

A new double-deck viaduct with Y type pier was built in Shanghai recently. Its upper deck is urban arterial highway and the lower deck is urban light railway system. With the proposed simulation techniques, the response of this viaduct under earthquake was analyzed and the simulation results were verified by a pseudo-dynamic test with this bridge. With the analysis result, the seismic vulnerability of the double-deck viaduct was assessed and suggestion was proposed to improve the seismic performance of bridge.

Many high pier RC bridges are been constructed crossing deep valleys at mountain areas in the western China, where the geotechnical condition is more complicated and the earthquake is more active. To verify the seismic response performance and to predict the damage mechanism of a high pier bridge under strong earthquake, a high pier RC at a typical mountain area was investigated as an example. The bridge is a multi-span continuous frame structure with high piers. Its deck consists of two parallel separate girders with curve. In this simulation, first, detail nonlinear analysis for bridge elements those might be heavily damaged during earthquake were analyzed using advanced elasto-plastic constitutive model. Then, based on that, a simplified constitutive model were established for the collapse analysis of the whole bridge.

The methodology and results of the simulation in this paper is expected to be helpful for the seismic design and analysis of RC bridge.

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Paper No. 264

NEW METHODOLOGY OF GENERATING MULTIPLE SPECTRUM COMPATIBLE EARTHQUAKE ACCELEROGRAM FOR TAIWAN AREA USING NEURAL NETWORKS

Chu-Chieh Jay Lin[1]

Taiwan is located in an earthquake prone region. The geology constitution of Taiwan is constantly changing. There are at least 42 active faults in Taiwan area based on published literature. Since the beginning of the 20th century, eight catastrophic earthquakes had struck Taiwan; a magnitude 7.3 Chi-Chi earthquake hit central Taiwan in 1999 and caused serious irreversible damages such as split ground, wrecked roads and collapsed bridges as well as taking more than 2300 lives. In the same time, the huge number of earthquake accelerograms of 921 Chi-Chi earthquake and its aftershocks were also recorded. Therefore, we need a method to systematically process and utilize these massive volumes of the recorded accelerograms for structural design and analysis.

Earthquake response spectra are often used in analysis and design of structures. In some cases, it is desirable to develop an artificial earthquake accelerogram compatible with a given design spectrum. As more non-linear dynamic analyses are being performed, the need for developing accelerograms from design spectra is increasing and the method for generating realistic accelerograms become more and more important.

A new neural network based methodology for generating spectrum compatible artificial earthquake accelerogram is proposed by Lin and Ghaboussi on 1999 and developed using the historical US earthquake records as well as the learning capabilities of neural networks to extract the knowledge of the inverse mapping directly from the response spectra to earthquake accelerograms. In its two-stage approach, the "replicator neural networks (RNN)" (as a data compression tool) and the "stochastic neural networks (SNN)" were used and a multi-layer feed-forward neural network learns to relate the response spectrum to the compressed Fourier spectrum. The methodology is capable of generating multiple earthquake accelerograms from a single design spectrum. Using historical Taiwan earthquake records and MATLAB software, the methodology is modified based on the original method and proposed to generating artificial earthquake accelerograms for Taiwan area.

This research will provide a systematic methodology to utilize the massive volumes of the recorded accelerograms as well as to generate a stochastic ensemble of spectrum compatible artificial earthquake accelerograms for Taiwan area from any design spectrum to be used in nonlinear dynamic time history analysis.

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Paper No. 266

DAMAGE OF VILLAGE BUILDINGS IN RECENT YUNNAN EARTHQUAKES

Ben-yu Liu[1], Sheng Miao[2], Liao-yuan Ye[3] and Mei-ling Xiao[4]

In recent years, several earthquakes occurred in Yunnan province. All of these quakes mainly struck in mountainous countryside. The buildings in these areas are very poor constructed, while some of buildings are strongly damaged, there were some standstill after these earthquakes. This paper firstly introduced these building damages in Yunnan. The preliminary discussed and some research is presented on the reasons for the damage or undamaged of these buildings. Some principles for earthquake-resistant building construction in high intensity country area are presented in the end.

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Paper No. 267

LEARNING FROM THE 2004 INDIAN OCEAN TSUNAMI – STRUCTURAL ASPECTS AND CLUES FOR TSUNAMI RESISTANT DESIGN

Panitan Lukkunaprasit[1]

The unprecedented devastating Indian Ocean tsunami which struck the western coast of southern Thailand on December 26, 2004 caused more than 5,300 deaths, and heavy damage to buildings including ports in the affected areas. Prior to the event, the lack of historical records of destruction by tsunamis on Thai coastlines made the public, and even most academics, to be unaware of the possibility of tsunamis occurring along the coasts of the country. Consequently, the country was not prepared for the hazard, leading to great catastrophe and economic losses. Valuable but costly lessons have been learned from the seismological, engineering, environmental, social and economic viewpoints. This paper touches mainly on the structural damage in Southern Thailand, where run-up heights were 3-7 m above ground levels. Clues valuable for the safe and economical design of buildings against future tsunamis are outlined. Restoration and re-construction activities done after the disaster are also addressed.

The damage caused by the tsunami clearly reveals inadequate design and construction of foundations, columns, joints, as well as retaining structures. Excessive damage could be attributed to the non-seismic design and construction in Thailand, featuring relatively small columns with light transverse reinforcement. The prevalent scouring of the soil supporting retaining walls and footings of buildings suggests putting buildings on piles in locations close to the shorelines or water ways. The current practice of weakly connecting infill masonry panels to the boundary reinforced concrete frames with widely spaced dowels has proved to work well in detaching the brick walls from the frames under excessive water pressure, thereby releasing the force transmitted to the building. The superior performance of non-structural un-reinforced brick walls with openings has been observed, and reinforced concrete frames with such walls should be advantageous in providing a sound low cost structural system with strength and robustness. The collapse of pre-cast concrete slabs in a port structure due to uplift by the waves suggests that pre-cast systems are not suitable, since complicated design, detailing and construction are needed to provide uplift capacity to the structure.

Whereas most non-engineered buildings collapsed, it is interesting to note that a large number of engineered buildings, which have not been designed for seismic or tsunami loadings, have survived in water heights up to about 6 m above ground level. This suggests that it is possible to design tsunami resistant structures with reparability performance level. This assumes practical significance in that tsunami resistant buildings can be used as evacuation shelters for life saving in flat terrains. Concerted research efforts on tsunami loadings and tsunami resistant design of buildings should be a high priority.

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Paper No. 268

SEISMIC DESIGN OF JOINTED PRECAST CONCRETE WALL SYSTEMS

Sri Sritharan[1] and Sriram Aaleti[2]

Four seismic precast frame systems and one jointed precast wall system were experimentally investigated using a 60% scale five-story test building in Phase III of the PRESSS (PREcast Seismic Structural System) program. The seismic frames provided the lateral load resistance in one direction of the test building while the jointed wall system was primarily responsible for lateral resistance in the orthogonal direction. Excellent response of the jointed wall system was observed when the building was subjected to a series of seismic tests in the wall direction. The observed damage was limited to minor spalling of cover concrete at the wall toes even at drifts greater than the design drift. Furthermore, the wall system re-centered at the end of each segment of the earthquake loading.

The wall system consisted of two individual precast walls that were connected to the footings using unbonded post-tensioning at the center of each wall. A link between the precast walls in the horizontal direction was established using stainless steel UFP (U-shaped Flexural Plate) connectors located along a vertical joint between the walls. The UFP connectors also served as passive energy dissipating devices, where hysteric damping was attained by flexural yielding of the U-plates.

This paper summarizes a seismic design methodology for jointed precast systems consisting of two or more precast walls that are anchored to the foundation using unbonded post-tensioning. The application of the proposed methodology is demonstrated through design of three different jointed wall systems.

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Paper No. 270

A GENERALISED MATHEMATICAL MODEL FOR CONTROLLED ROCKING SYSTEMS

Quincy T. Ma[1] and John W. Butterworth[2]

A new mathematical model for representing controlled rocking systems is presented in a generalised, non-dimensional format. The model establishes a universal rocking wall and analyses its dynamic behaviour under sinusoidal base excitation. Consideration of the phase diagram representation of the response, together with exploitation of features in the mathematical functions in the governing differential equation, lead to the proposed closed form equations for predicting the peak possible response of the system. A significant benefit of the formulas is that they allow the important maximum possible response to be obtained without the need for time integration. Validity of the preliminary equations is demonstrated by a series of time-history analyses and shake table tests on a single degree of freedom model.

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Paper No. 272

DEVELOPMENT OF AN OBJECT-ORIENTED GRAPHICAL USER INTERFACE FOR THE STRUCTURAL ANALYSIS PROGRAM

Ming-Chieh Chuang[1], Bo-Zhou Lin[2], Fang-Wei Hsu[3] and Keh-Chyuan Tsai[4]

Computer software for academic research (e.g. DRAIN2D) is often deficient in Graphical User Interface (GUI) and commercial software doesn't open GUI's framework to the user. The advantage of GUI is so evident and the requirements of GUI always exist. Thus, there exist sufficient reasons to research on the GUI's framework. This article introduces that how to build an extensible and flexible GUI system for the structural analysis program. Changes of requirement are considered in this exploratory study and the authors proposed Pattern-Oriented Design by which GUI's framework becomes true object oriented. Authors adopt the nonlinear structural analysis program PISA3D as the analysis engine and implement a GUI named GISA3D for PISA3D using the proposed methodology. In addition to collaborations and consequences of design pattern, authors show the essential difference between VISA3D and GISA3D in this paper.

Keywords: PISA3D, GISA3D, VISA3D, GUI, Pattern-Oriented, Object- Oriented

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Paper No. 273

SEISMIC RESPONSE OF PRECAST SEGMENTAL BRIDGE SUPERSTRUCTURES WITH BONDED TENDONS

Marc J. Veletzos[1] and José I. Restrepo[2]

Precast segmental construction of bridges can accelerate construction and minimize the cost of bridges in highly congested urban environments and environmentally sensitive regions. Despite their proven benefits, the use of precast segmental bridges in seismic regions of the United States remains very limited. A main obstacle to their use is the concern about the seismic response of segment joints. Recent research has shown that segment joints can undergo very large rotations that open up gaps in the superstructure, without significant loss of strength. While the ultimate performance of segment joints has been investigated, the expected response during a significant seismic event remains uncertain. Using the Otay River Bridge as a case study, this paper will investigate the response of segment joints using detailed non-linear time-history analyses. A suite of ten near field earthquake records have been used to determine the median joint response as well as to quantify the effect of vertical motion on the joint response.

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Paper No. 274

JAPAN SEISMIC HAZARD INFORMATION STATION, J-SHIS

Hiroyuki Fujiwara[1], Shinichi Kawai[1], Shin Aoi[1], Toru Ishii[1], Toshihiko Okumura[2], Yuzuru Hayakawa[1], Nobuyuki Morikawa[1], Shigeki Senna[1], Kyoko Kobayashi[1], and Ken Xian-Sheng Hao[1]

The Headquarters for Earthquake Research Promotion (HERP) of Japan published the national seismic hazard maps of Japan in March 2005, which was initiated by the earthquake research committee (ERC) on a basis of a long-term evaluation of seismic activity, and evaluation of strong ground-motion. At the same time, the National Research Institute for Earth Science and Disaster Prevention (NIED) also promoted a special research project, "the National Seismic Hazard Mapping Project of Japan", to support the study of the seismic hazard maps. Under the guidance of ERC, we have carried out this study, which consisted of two kinds of maps; One is a probabilistic seismic hazard map (PSHM) that shows the relation between seismic intensity value and its probability of exceedance within a certain time period. Another one is a scenario earthquake shaking map (SESM).

For the PSHM, we used an empirical attenuation formula following the seismic activity modeling by ERC. Both the peak velocity at the engineering bedrock (Vs=400m/s) and at the ground surface are evaluated for sites with approximately 1km spacing, The potential JMA seismic intensities on ground surface are also evaluated by using an empirical formula.

For the SESMs, based on the source modeling for strong-motion evaluation, we adopted a hybrid method to simulate waveforms on the engineering bedrock and peak ground velocity. In this project, we developed an open web system to provide information interactively, and named this system as Japan Seismic Hazard Information Station, J-SHIS (http://www.j-shis.bosai.go.jp). Our outputs are aimed to meet multi-purpose needs in engineering fields by even providing information of the uncertainty evaluation. The information provided from J-SHIS includes not only results of the hazard maps but also various information required to produce the hazard maps, such as data on seismic activity, source models and underground structure.

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Paper No. 275

POST EARTHQUAKE HOUSING CONSTRUCTION USING LOW COST BUILDING MATERIALS

Raju Sarkar[1]

There are several natural disasters occurring throughout the world round the year and one of them is Earthquake. Earthquakes have been objects of great superstitions and awe throughout recorded history. The severe quakes wreak catastrophic havoc in the human community because of destruction of structures - houses and buildings, bridges, roads, railways and uprooting of transmission towers. Death comes in a violent form - at times to hundreds and thousands. Everything happens suddenly-without warning. The first distressing factor is collapse of dwelling units. Although measuring instruments at the Seismological Laboratories are able to measure the geologic disturbances, nothing has been invented that can forecast an "earthquake" as we understand it. Human knowledge has yet to cross this frontier. But death and destruction can be prevented or vastly minimized if the houses are structurally sound. In a poor country severe earthquake occurs every now and then, the problem of appropriate 'safe' housing must receive adequate attention from architects, engineer, builders, and owners of property.

Nowadays the big industries like steel plants, thermal power plants etc are also becoming the source of wastes viz., blast furnace slag & flyash etc. that causes environmental pollution & poses a problem of disposal. These waste products has been converted into useful building materials which can be used during post earthquake housing construction, solving the problem of disposal on the one hand and providing better construction material at low cost on the other hand along with locally available cheap building materials. Similarly some agricultural wastes (as rice husk) have also been converted into building materials, which are very much useful during reconstruction phase as low cost building materials. In the present paper an attempt has been made to highlight various low cost building materials, which can be used during post earthquake housing construction.

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Paper No. 276

BRIDGE DAMAGE SURVEY IN BANDA ACEH AND SURROUNDINGAREAS AND EARTHQUAKE AND TSUNAMI QUESTIONNAIRES

Hirokazu Iemura[1] and Mulyo Harris Pradono[2]

Bridge surveys show the condition of bridges near the seashore in Banda Aceh city. The bridge decks were slightly displaced (inland direction). Calculations show that the minimum water velocity capable of displacing the decks is around 13.4 km/hour. In fact, the tsunami run up velocity is larger than the minimum velocity above. However, since the deck movements were not uniform in the lateral direction, they were locked to each other and prevented from being washed away. However, bridges along the west coast of Aceh Provinces were mostly washed away. They were experiencing direct and much higher tsunami runoff. One result of the questionnaire is the seismic intensity. The intensity is estimated at 5.52 or 6− in Japanese Meteorological Agency scale (or around VIII in the MMI scale) in Banda Aceh city. Other questionnaires consist of questions asking their experience during and after the earthquake and tsunami. One important result is that even if people had started running away just after the big earthquake, the percentage of expected survivors would have been less than 100%, according to the respondents. The practical implication is that education, socialization (software) and escape structures, warning system, wave resisting structures (hardware) are among important factors for people to be safer against future earthquake and tsunami attacks.

Keywords: tsunami, bridge damage, seismic intensity, questionnaires.

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Paper No. 278

STRUCTURAL HEALTH MONITORING: PROGRESS POTENTAL AND CHANLLENGES

Chin-Hsiung Loh[1]

This paper presents an overview and progress on the structural health monitoring (SHM) researches in the Civil Engineering Department of National Taiwan University. Three major research directions in SHM which are applied to civil infrastructures have been developed:

1. Structural system identification using ambient vibration measurements (or output only): The covariance-driven Stochastic Subspace Identification is proposed if multiple sensors are used to measure the ambient signals. Through SSI-COV method the mode shapes as well as the system natural frequencies and damping rations can be identified. For the analysis of non-stationary and nonlinear data, the WPT can be applied to extract the features from the response measurement.
2. System identification using both input and output signals, particularly the seismic response data of structures: The system identification techniques using input and output data depend on the system is linear, nonlinear or time-variant system. For identification of time-variant system the recursive least square method with forgetting factor is the most common method in this application. The adaptive fading Kalman filter technique is also one the method to identify the abrupt change of modal parameters.
3. Application of identification techniques for damage assessment: In this study three different approaches for damage assessment were studied: Damage assessment using modal strain energy change ratio, Neural networks based damage assessment, and damage assessment using reference-based statistical model.

Three important issues are raised as the challenge for structural health monitoring in the future: 1. Develop wireless sensor networks for SHM. This topic will include the research on communication issue, embedded program in microprocessor for SHM, etc.

2. Develop design-in-service signal processing techniques for SHM. This topic covers using different signal processing tools to extract features from vibration measurement.

3. Develop wireless sensing and control unit for "Smart & Intelligent Structure".

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Paper No. 279

SYSTEM IDENTIFICATION, MODELING AND PERFORMANCE PREDICTION OF A 20-STORY OFFICE BUILDING

He Liu[1], Rakesh Goel[2], Feifei Bai[3], William Scott[4] and Toshifumi Kono[5]

The Atwood Building, a 20-story office building in Anchorage Alaska, is one of the heavily instrumented buildings by the USGS Advanced National Seismic System. The instrumentation includes 32-channel seismic sensors at 10 levels of the building and 21-channel seismic sensors at a downhole array near the building. This paper describes a three-dimensional Finite Element (FE) model, which has been calibrated in two horizontal directions by matching the natural periods from FE analysis with those from system identification applied to ambient vibration data. This model has been used to examine the nonlinear behavior of the building using Incremental Dynamic Analysis (IDA) and Modal Pushover Analysis (MPA) procedures. The extension of MPA to compute member forces is also applied. It is envisioned that this building would serve as a benchmark building for other researchers to use in developing improved analysis and design procedures as well as predicting performance of buildings to future damaging earthquakes.

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Paper No. 280

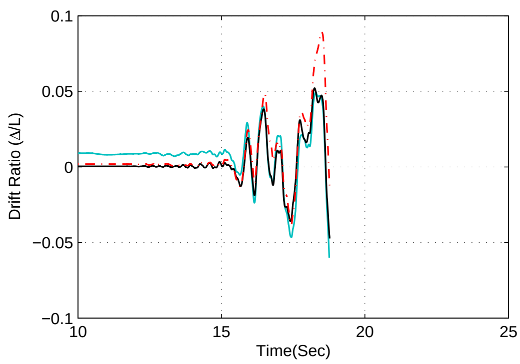
ANALYSIS OF SHAKE TABLE COLLAPSE TESTS FOR RC FRAMES

S. Yavari[1], W.W. Kuo[2], K.J. Elwood[3], C.L. Wu[4], S.J. Hwang[5], and C.H. Loh[6]

Collapse of structures during earthquakes involves a complicated interaction between the lateral demands imposed by the ground motion and the vertical demands imposed by the weight of the structure, in addition to the lateral and vertical capacities of the structural elements. A lack of experimental data at the stage of collapse results in uncertainty in the reliability of assessment procedures at the Collapse Prevention performance level. However, performance-based design methodologies require a thorough understanding of the lateral and vertical load behavior of the structural elements for all levels of performance, including Collapse Prevention. It is, therefore, important to assess the accuracy of analytical models used to predict the collapse behavior of structural elements.

The current paper presents a blind prediction of a shake table collapse test performed at the National Center for Research on Earthquake Engineering (NCREE) in Taiwan. The tested specimen consisted of a three-bay reinforced concrete frame with two ductile columns, two non-ductile columns, and a stiff connecting beam. In order to validate and compare existing analytical models for non-ductile concrete buildings, a comparison of the test data and a recently developed analytical approach was performed. A sample comparison for the test resulting in collapse of the reinforced concrete frame specimen is shown in Figure 1. This comparison illustrates the limitations, weaknesses, and strengths of the analytical model.

Refining the analyses and then validating the obtained results with the existing experimental data provides the opportunity to carry out a series of parametric studies. The studies discussed here include investigations on the effects of column transverse steel ratios and stiffness of the connecting beam on the failure of the frame. Recommendations based on the obtained results will lead to a better prediction of the behavior of existing reinforced concrete structures, and consequently, more cost-effective retrofit strategies.



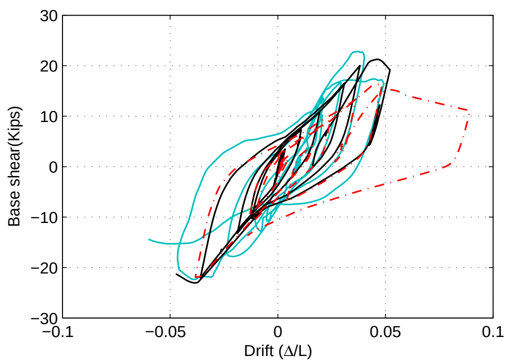


Figure 1. Sample comparison of test data and results from analytical models.

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Paper No. 282

SEISMIC STRUCTURAL ASSESSMENT OF DAMAGED CHITTAGONG PUBLIC LIBRARY BUILDING DURING 27 JULY 2003 EARTHQUAKE

Dr. M. Jahangir Alam1[1], M. Abdur Rahman Bhuiyan[2] and M.Roqibul Islam[3]

Seismic structural damage assessment is a part of post earthquake disaster management program. During the Rangamati Earthquake of Chittagong Hill Tracts in July 27, 2003, the only Public Library located at Chittagong was severely affected and undergone various degrees of damages. This paper deals with the physical damages as well as structural strength assessment of the damaged Public Library building. A detailed overview of several seismic damage evaluation documents framed by FEMA 310 has been elaborated and incorporated for seismic structural strength assessment process. Finite element frame analysis is used incorporating Bangladesh National Building Code (BNBC) seismic provisions. The difficulties existing in the structural system planning of the damaged Chittagong Public Library building and design discrepancies are documented and probable suggestive measure are highlighted in this paper.

Keywords: FEMA, Rangmati Earthquake

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Paper No. 283

GENERATION OF LIQUEFACTION POTENTIAL MAP FOR CHITTAGONG AREA, BANGLADESH

M. Abdur Rahman Bhuiyan[1], Dr. M. Jahangir Alam1[2] and Tuhin Roy[3]

The historical seismicity data of Bangladesh and Adjoining area indicates that Bangladesh is vulnerable to earthquake. As Bangladesh is the world's most densely populated area, any future earthquake shall effect more people per unit area that any other seismically active regions of the world. Liquefaction phenomena have been recorded and developed in many parts of the world where ground shaking is frequent and soils consist of loose fine sand under water table. Most of the parts of Chittagong, the port city of Bangladesh consisting of fine sand and silt deposits are susceptible to liquefaction. The susceptibility of liquefaction within an area of approximately 200 sq. kilometer in the greater Chittagong metropolitan area are assessed based on the Standard Penetration Test (SPT) data from 182 bore holes. The liquefaction potential has been evaluated using three simplified procedures. The analysis results have been classified in to several groups according to susceptibility of liquefaction. To this end, using the analytical results, a liquefaction potential map for the Chittagong city has been drawn to help the Engineers, builders, Architects and Policy Makers to have a general guide to ground-failure susceptibility, effective land use, effective town planning and disaster mitigation.

Keywords: SPT, liquefaction potential and liquefaction resistance factor.

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Paper No. 284

RECENT RESEARCH AND APPLICATION ON SEISMIC CONTROL FOR STRUCTURES IN MAINLAND CHINA

Fu Lin ZHOU[1], Y. ZHOU, Q. L XIAN, P. TANG, W. LIU

This paper briefly introduces the recent research、testing analysis、design and application on seismic isolation、energy dissipation、tuned mass damper and active control for buildings and bridges in mainland China. Paper introduces some typical researches、testing and analysis, including the mechanical tests for bearings and control devices, and the shaking table tests for structural models with different control systems. Paper also introduces the Chinese design codes for structures with seismic isolation and energy dissipation. Paper describes the recent application status and typical examples, especially introduces the largest isolation buildings group in the world, and the using passive and semi active control for structures. Also the paper makes discussion some problems existed on passive and active control technique now and the tendency of development on seismic control in future.

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Paper No. 286

NEXT STEP IS TO SELECT GOOD STRUCTURES BY PEOPLE

Akira Wada[1]

The Industrial Revolution started in the 18th century in Britain. We exceeded modern ages, and had arrived at the present age. People are living in the multistory apartment houses and making jobs in the high-rise office buildings, too. The earthquake hardly occurs in Britain, France, and the east coast of the United States. This civilization extended to the west coasts of the United States and Asian countries, it came to build a lot of buildings. Then, many big seismic hazards have happened in the 19th and 20th centuries.

We did many researches of the seismic engineering of these 100 years. The development of the seismic isolated structures and the damage-controlled structures was advanced. Hereafter, it is time when it accepts the good structures for earthquakes by people, and applies them to an actual building.

When we design buildings against earthquakes, life of people living in the buildings, the values of the buildings themselves and the function of the buildings have to be considered. Under small or medium earthquakes, we promise these three things, but under large earthquakes, we only promise human life. We will give up keeping the value of the building and the function of the building under big earthquakes. In the Urban city, there are so many buildings. When each building as the element of the city could not keep the value and the function of the building under the big earthquake, the city could not live after the earthquake. Then, the Business continuity of the city will be failed. In the discussion of business continuity of the urban city, buildings have to be constructed more strong as using seismic isolated structures or damage-controlled structures.

Finally, we can say that the next step is to select the good structures by people.

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Paper No. 287

CYCLIC SOFTENING OF LOW-PLASTICITY CLAY AND ITS EFFECT ON SEISMIC FOUNDATION PERFORMANCE

Daniel B. Chu1, Jonathan P. Stewart2, P.S. Lin3, and R.W. Boulanger4

Significant occurrences of ground failure in the form of liquefaction, ground softening, and lateral spreading occurred in Wufeng, Taiwan during the 1999 Chi-Chi earthquake (M_w = 7.6). The Wufeng region is located adjacent to the ruptured fault on the foot wall, and experienced peak accelerations ~0.7 g. In the paper, we will describe the results of field investigations and analyses of a small region within Wufeng that exhibited a range of ground performance. The investigated region consists of an E-W trending line of 350 m length. The east end of the line is a residential area with single-story structures for which there was no surface evidence of ground failure. The west end of the line had 5-6 story reinforced concrete structures that were heavily damaged structurally, but which also underwent extensive foundation failures including differential settlement, foundation punching failures, and full foundation bearing failures. No ground failure was observed in the free-field at the west end of the line. Site investigation included cone penetration testing, rotary wash borings with standard penetration testing (with energy measurements), in-situ vane shear testing, and shear wave velocity profiling. Surficial soils consist of low-plasticity silty clays that extended to 8-12 m depth in the damaged area (west side), and 3-5 m depth in the undamaged area (east side). Underlying the clays are relatively dense silty sands interbedded with silts and clays. The clays are lightly over-consolidated (overconsolidation ratios of approximately 2-3) and have PI ranging from 2 to 11.

Analyses were performed of the potential for cyclic softening of the clays, which effectively investigates the potential for large cyclic shear strains to develop. The resistance of the clay to cyclic softening is evaluated using the results of material-specific strength testing (both monotonic and cyclic). The seismic demand applied to the soil is evaluated from ground response analyses (to investigate demand from ground shaking) as well as soil-structure interaction analyses (to investigate demand associated with base shears and moments in both six- and one-story structures). Results of the analysis indicate low factors of safety in foundation soils below the six-story building during earthquake shaking, which contributes to bearing capacity failures at the edges of the foundation due to rocking effects. Similar analyses indicate high factors of safety (above unity) in foundation soils below one-story buildings as well in the free field. Accordingly, analysis of the site within a framework that systematically accounts for the clayey nature of the foundation soils successfully predicted the field performance.

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THE INVESTIGATION OF NONLINEAR PERFORMANCE OF CONCRETE BRIDGES BASED ON DISPLACEMENT CONTROL

G. Ghodrati Amiri[1], H. Razeghi[2] and B. Zakeri[3]

Iran is located on one of the most important seismic belts in the world and in designing structures; special concerns must be paid to seismic design. Bridge is the most important structures in lifeline structures and its effects on economical, social and political developments are considerable, so the seismic performance of bridges which have been designed in linear approach based on force control, must be analyzed in their nonlinear behavior range in case of displacement control. In this paper, seismic performance of four important concrete bridges which have been designed based on design spectra of Code of Practice for The Earthquake Resistant Design of Road and Railroad Bridges are considered. Two of them are set in hazard level one (0.35g) and the two others in hazard level two (0.5g). Because these four bridges are samples of so many built bridges in Iran, therefore nonlinear static analysis have been carried out on them, and their performance points based on design spectra of Iranian Code of Practice for The Earthquake Resistant Design of Road and Railroad Bridges, have been compared with their performance points based on demand of five important earthquakes including Bam (2003), Tabas (1978), Kobe (1995), Imperial (1915)& Northridge (1994) earthquakes.

Keywords: concrete bridges, nonlinear behavior, performance design, displacement control

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Paper No. 293

AN INEXPENSIVE TECHNIQUE TO FABRICATE HYBRDI GLASS/PLASTIC OPTICAL FIBER SENSORS FOR STRUCTURAL HEALTH MONITORING

Haiying Huang[1] and Shantilal Zanwar[2]

Silica-based optical fiber sensors are widely used in structural health monitoring systems for strain and deflection measurement. One drawback of silica-based optical fiber sensors is their low strain toughness. In general, silica-based optical fiber sensors can only reliably measure strains up to 2%. Recently, polymer optical fiber sensors have been employed to measure large strain and deflection. Due to their high optical losses, the length of the polymer optical fiber sensors is limited to 100 meters. In this paper, we present a novel economical technique to fabricate hybrid glass/plastic optical fiber sensors. First, stress analysis of a surface-mounted optical fiber sensor is performed to understand the relationship between the mechanical properties of the fiber/host structure and the stress distributions among the fiber, the bonding material, and the host structure. Next, the concept of fabricating a polymer sensing element on the end face of an optical fiber using ultraviolet irradiation is explained. The experimental set-up and the components used in the fabrication process are described in details. Micrographic images of the fabricated polymer sensing elements are presented and the control of the fabrication parameters is discussed. Potential application of the presented technique to fabricate an intrinsic Fabry-Perot optical fiber sensor is also discussed.

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Paper No. 295

DOWNHOLE MONITORING INSTRUMENTATION AT CHINGLIAO SITE AND ITS MONITORING DATA ANALYSIS

Sheng-Huoo Ni [1], Chi-Chih Ko[2] and Su-yu Chen [2]

The in-situ liquefaction monitoring downhole array was installed at chingliao, Hobee, Tainan, by the liquefaction research group funded by National Science Council in July, 2002. One surface triaxial accelerometer, three depths low frequency triaxial accelerometers, and four pore water pressure transducers were installed in this site. The pore water pressure and seismic response at ground surface and within the soil deposit induced by earthquake will be monitored in full time using personal computer. The monitoring system is now working and waits to be triggered whenever the ground motion is big enough to trigger the recording system. The purpose of this paper is to present the installation of downhole liquefaction instrumentation in the soil deposit to study the soil behavior during earthquake. The data measured from monitoring system of the downhole array is used to calculate the soil dynamic parameters with the parametric system identification and Hilbert-Huang transform method. The study shows that the analytic result is relevant to model order, the intensity of earthquake, the distance between receivers, and the relation among the frequency component of the earthquake, time and amplitude in Hilbert-Huang transform result. Furthermore, the amplification of low frequency can be observed with Hilbert spectrum. The resonant frequency of soil can be estimated for structural design preliminarily by linear-invariant system identification.

Keywords: soil dynamics, downhole arrays, instrumentation, system identification.

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Paper No. 299

REAL-TIME HYBRID TESTING USING MODEL-BASED DELAYCOMPENSATION

Juan E. Carrion[1] and B.F. Spencer Jr[2]

Real-time hybrid testing is an attractive method to evaluate the response of structures under earthquake loads. The method is a variation of the pseudodynamic testing technique in which the simulation is executed in real time, thus allowing investigation of structural systems with time-dependent components. Real-time hybrid testing is challenging because it requires performance of all the calculations, application of the displacements, and acquisition of the measured forces, within a very small time frame (i.e., a single time step). Furthermore, unless appropriate compensation for time delays and actuator time lag is implemented, stability problems are likely to occur during the experiment (especially during testing of structures with high natural frequencies, e.g., stiff structures or multi-degree-of-freedom systems). This paper presents an approach for real-time hybrid testing in which time delay/lag compensation is implemented using model-based response prediction. The efficacy of the proposed strategy is verified by conducting substructure real-time hybrid testing of a steel frame under earthquake loads. Experimental results agree well with the analytical solution and show that the approach is capable of achieving a time-scale expansion factor of one (i.e., real time). Additionally, the proposed method allows testing structures with larger frequencies than when using the conventional polynomial extrapolation method, thus extending the capabilities of the real-time hybrid testing technique.

Keywords: Real-time hybrid testing, experimental testing, delay compensation, substructuring.

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Paper No. 300

BENCHMARK CONTROL PROBLEM FOR SEISMIC RESPONSE ANALYSIS OF A HIGHWAY BRIDGE

Ping Tan[1] and Anil K Agrawa1,[2]

The seismically excited benchmark problem is based on the newly constructed 91/5 highway over-crossing in Southern California. The goal of this effort is to develop a standardized model of a highway bridge using which competing control strategies, including devices, algorithms and sensors, can be evaluated comparatively. To achieve this goal, a 3-D finite-element model is developed in MATLAB to represent the complex behavior of the full-scale highway crossing. A MATLAB based nonlinear structural analysis tool has been developed and made available for nonlinear dynamic analysis. The nonlinear behavior of center columns and isolation bearings are considered in formulating the bilinear force-deformation relationship. The effect of soil-structure interaction is also considered by modeling the interaction using equivalent spring and dashpot. The representative ground motions are considered to be applied simultaneously in two directions. Sample control devices are assumed to be installed between the deck and the end-abutments of the bridge. Evaluation criteria and control constraints are specified for the design of controllers in this benchmark problem.

Keywords: Structural control, Benchmark Problem, Highway bridge

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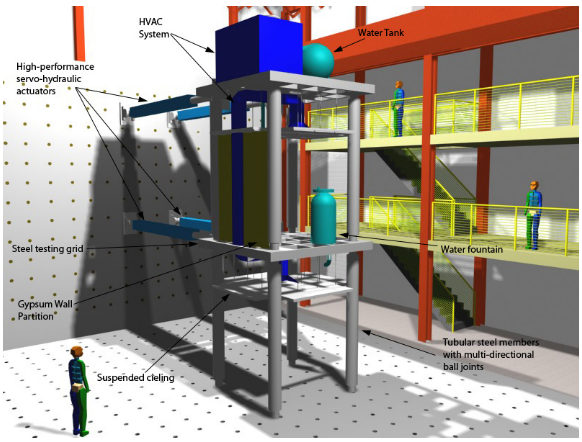
Paper No. 301

EXPERIMENTAL EVALUATION OF NONSTRUCTURAL COMPONENTS UNDER FULL-SCALE FLOOR MOTION

Gilberto Mosqueda[1,] Rodrigo Retamales[2], Dave Keller[2], Andre Filiatrault[3]
and Andrei Reinhorn[4]

Observations during past earthquakes have demonstrated the seismic vulnerability of nonstructural components and equipment with their expensive recovery and/or replacement costs. With the exception of the nuclear industry, the limited data collected form past earthquakes are not sufficient to fully characterize the seismic behavior of nonstructural components and develop effective mitigation measures. To address these limitations, the Structural Engineering and Earthquake Simulation Laboratory (SEESL) at the University at Buffalo (UB) has commissioned under the National Science Foundation's George E. Brown Junior Network for Earthquake Engineering Simulation (NEES) program a dedicated Nonstructural Component Simulator (UB-NCS) composed of a two-level testing frame capable of simultaneously subjecting both displacement-sensitive and acceleration-sensitive nonstructural components to realistic full scale floor motions expected in typical multi-story buildings. Both levels of the testing platform can subject nonstructural components to 3g accelerations, 2.5 m/s velocities and +/- 1 m displacements. A series of experiments are currently underway using the UB-NCS consisting of a hospital room constructed of gypsum wallboards on light gage steel studs. The interior of the room will be furnished with self-standing and anchored building contents typical in acute care medical facilities. The experimental data will be used to evaluate the seismic fragility of both acceleration sensitive medical equipment and displacement sensitive partition walls. This paper summarizes the characteristics and unique capabilities of the UB-NCS equipment, the dynamic testing protocol considered for UB-NCS, and the planned experiments to evaluate the seismic fragility of nonstructural partition walls and medical equipment under realistic floor motion demands in multi-story buildings.



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Paper No. 304

CONFINEMENT ACTION OF REINFORCED CONCRETE COLUMNS WITH NON-SEISMIC DETAILING

Wilson Yuk-Ming Chung[1], Eddie Siu-Shu Lam[2] and Yuk-Lung Wong[2]

Hong Kong is now recognized as an area of moderate seismic hazard. It is necessary to assess the confinement action provided by existing transverse reinforcement detailing in local reinforced concrete columns. In this study, two types of non-seismic detailing have been considered. Type L detailing incorporates 90^0 hooks, whereas type M detailing allows both 90^0 hooks and crossties not effectively anchored to the main reinforcements. Sectional analyses using OpenSees have been conducted to predict the stress-strain relationships of confined concrete with these two types of non-seismic detailing. The results are compared with those obtained from the experiments carried out in previous axial loading tests. The minimum volumetric transverse reinforcement ratios ρ_s for type L and type M detailing are suggested to be 0.5% and 1.1% respectively. Stress-strain relationships of confined concrete for non-seismic detailing are proposed by modifying the Mander's model with a reduction factor β. Appropriate values for type L and type M detailing are β=71.6% (when ρ_s > 0.5%) and β=67.1% (when ρ_s > 1.1%) respectively.

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Paper No. 305

CHARACTERISTICS OF SUPER HIGH DAMPING VISCO-ELASTICDAMPER FOR EARTHQUAKE AND WIND-INDUCED VIBRATION

Brian Lim[1] and Tatsuji Matsumoto[2]

In this paper, the dynamic characteristics of newly developed visco-elastic damper of having greatly improved damping performance compared to the conventional visco-elastic one will be shown. The visco-elastic damper explained here could absorb super minute deformation region such as wind induced vibration which occurs daily basis not only huge earthquake vibration which comes once every 50 years or more. The equivalent damping coefficient *Heq* when giving only 0.05mm deformation in case of static frequency 0.01Hz shows the wonderful value of 0.15. Temperature dependency which had been the conventional weak point of a visco-elastic damper, has also improved dramatically with *Heq (-10 degree C / 20 degrees C)* =1.21 and *Heq (40 degree C / 20 degrees C)* =0.90.
Moreover, with *Heq (0.1Hz / 3.0Hz)* =0.94, the conventional weak points which strongly depended on velocity and little effect for long-period type earthquake have overcome. The new damper demonstrates the effectiveness for a wind induced vibration. Since the secular degradation after the aging test equivalent to 60 years based on the heat aging examination is so small as *Heq (60 years after / initial value)* >0.90 that long-term durability is also approved.

Keywords: Dynamic Characteristics, Visco-elastic Damper, Super Minute Deformation Region, Wind Induced Vibration, Long-period Earthquake, Temperature dependency, Frequency Dependency

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Paper No. 308

EARCHES ON PUSHOVER ANALYSIS METHOD OF MASONRY STRUCTURES WITH FRAME-SHEAR WALL AT THE BOTTOM

Qi Li[1] and Rong-rong Gu[2]

The masonry structures with frame-shear wall at the bottom have their own characteristics of elasto-plastic performance. The pushover analysis method is introduced and the horizontal displacement-pattern and load-pattern are studied. The inverted-triangular distribution pattern, uniformity distribution pattern and combination of the two patterns are adopted in pushover analysis method of this structure.

Keywords: masonry structures with frame-shear wall at the bottom; horizontal load-pattern; horizontal displacement-pattern; pushover analysis

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Paper No. 312

SEISMIC EVALUATION OF WARD BLOCK OF GTB HOSPITAL

D.K. Paul[1],Yogendra Singh[2], Husain K. Jarallah[3] ,and Mukund Joshi[4]

GTB Hospital is one of the largest hospitals of Delhi and it is catering to a large population. The hospital required to be seismically evaluated and if found deficient retrofitting need to be undertaken. The building has to be modelled for carrying out nonlinear static pushover analysis. The beams and columns were modelled as frame elements with the centre lines joined at nodes. The brick masonry infills were modeled as strut elements. The slabs assumed as a rigid diaphragm. The plastic hinge rotation values corresponding to various Performance Levels have been taken as per FEMA 356, considering the axial force-moment and shear force-moment interactions. The strength of masonry struts has been evaluated for shear failure, as per FEMA 356 and for buckling as per ACI 530. The analysis of the building has been done with infills. The performance point of the building has been estimated using both the Capacity Spectrum Method (CSM) and the Displacement Coefficient Method (DCM), with the value of coefficients as per FEMA 440. The building as a whole and the individual components, except the URM infills has been observed to have Immediate Occupancy performance level. However, the URM infills have been observed to fail.

Keywords: Reinforced Concrete Framed Building, Pushover Analysis, Seismic Evaluation

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Paper No. 313

RETROFITTING OF REINFORCED CONCRETE STRUCTURES USING WRAPPING TECHNIQUE

N. Lakshmanan[1], K. Muthumani[2], and T.S. Krishnamoorthy[2]

Pre-disaster preparedness strategies lead to repair/retrofitting of reinforced concrete structures for ensuring satisfactory performance during earthquakes. Repair can lead to increased stiffness, strength, and failure deformation. There is a need to quantify the performance of the structure after repair has been carried out. Performance factors using wrapping technique have been suggested for such quantification. These are adequate in certain cases and may not be totally satisfactory in others. A large scale experimental programme undertaken at SERC has shown that if there are inherent weaknesses on detailing in the original structure, it may not be possible to improve the performance to the desired levels. In these cases, the performance factors may depend on the state of deformation considered for evaluation and may not be unique. There is a need to address this issue, so that suitability of a repair measures can be satisfactorily evaluated.

Keywords: retrofitting, reinforced concrete, wrapping, experimental, performance factor

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Paper No. 314

RESEARCHES ON PERFORMANCE-BASED SEISMIC OF BRICK MASONRY STRUCTURES WITH FRAME-SHEAR WALL AT THE BOTTOM

Kai-fu Zhou[1] and Rong-rong Gu[2]

The idea of performance-based seismic design is introduced and the seismic capability of brick masonry structures with frame-shear wall at the bottom is analyseed in this paper. By dynamic time history analysis, this paper studies the elasto-plastic response of brick masonry structures with frame-shear wall at the bottom under different earthquake intensity. The force and deformation characteristics of this type structures are studied. By an example, the performance-based seismic design method of brick masonry structures with frame-shear wall at the bottom is introduced and some conclusions are listed.

Key words: brick masonry structures with frame-shear wall at the bottom; performance-based; seismic capability

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Paper No. 315

DOWNHOLE SEISMIC ARRAYS AND SYSTEM IDENTIFICATION OF SOILRESPONSE

Steven D. Glaser[1]

Autoregressive-moving average models are the theoretically correct process models for vertical wave propagation in the layered earth, and are used to linearly map deeper sensor input signals to shallower sensor output signals. This same data, when examined in detail with a Bayesian inference model, can also be explained by nonlinear filters yielding commonly accepted soil degradation curves. This seeming contradiction is a result of the lack of constraints available to winnow out a unique model. A solution would be dense but affordable vertical seismic arrays.

Numerous studies have shown the unique utility of vertical seismic arrays for studying in situ site response and soil behavior. The community suffers from the fact the they are very expensive to install and operate. The Terra-Scope system discussed here is an affordable 4-D down-hole seismic monitoring system based on independent, microprocessor-controlled sensor Pods. The Pods are nominally 50 mm in diameter, and about 120 mm long. An internal 16-bit micro-controller oversees all aspects of instrumentation, eight programmable gain amplifiers, and local signal storage. Each pod measures 3-D acceleration (75 ngrms/√Hz noise floor), tilt, azimuth, temperature, and other parametric variables such as pore water pressure and pH.

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Paper No. 316

DEVELOPMENTOFAHANDBOOK ON SEISMIC RETROFIT OF BUILDINGS IN INDIA

Amlan K. Sengupta[1]

The Department of Civil Engineering, Indian Institute of Technology Madras, received a project on developing a Handbook on seismic retrofit of buildings. The Handbook will contain seventeen chapters covering different aspects of seismic retrofit. The first chapter is a stand alone chapter that explains the concepts of seismic design and retrofit in a language suitable for the lay man. Besides the introductory chapters, there are chapters on evaluation and retrofit of various types of buildings. The types of buildings cover non-engineered, masonry, reinforced concrete, steel buildings and historical and heritage structures. The geotechnical seismic hazards and retrofit of foundations are placed as separate chapters. Retrofit using fibre reinforced polymer composites, energy dissipation and base isolation devices are introduced. A chapter on quality assurance and control is included. This paper presents the content of the Handbook and the issues relevant to retrofit of buildings.

Keywords: Buildings, masonry, reinforced concrete, retrofit, seismic.

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Paper No. 317

SEISMIC VULNERABILITY ASSESSMENT OF A RAILWAYOVERBRIDGE USING FRAGILITY CURVES

Shinoj A. Kurian[1], Sajal K. Deb[2] and Anjan Dutta[2]

The main objective of this paper is to develop the fragility curves for typical a railway overbridge by analytical approach. In this study, a sample three span, two lane railway overbridge, situated in a highly seismic region in the country, is considered for development of fragility curve for seismic vulnerability assessment. Capacity of the bridge has been determined by static nonlinear analysis (Pushover analysis). The damage parameters of the bridge were obtained by performing nonlinear time history analysis for different prescribed ground motion histories recorded in the past earthquakes. The fragility curves for the overbridge piers have been constructed assuming a lognormal distribution. The influence of modeling aspects of the overbridge structure on fragility curves has been investigated by considering two different structural models for the response analysis. It is observed that that the fragility curves are more sensitive to the structural modeling for higher damage level.

Keywords: Seismic Vulnerability, Fragility Curve, Bridge, Damage Level

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Paper No. 318

SEISMIC VULNERABILITY STUDY OF THE US HIGHWAY BRIDGE SYSTEMS

W. Phillip Yen[1]

In the fall of 1998, the Federal Highway Administration of the U.S. Department of Transportation initiated a series of studies related to the seismic performance of the U.S. national highway system. The research conducted under this study is intended to provide improved tools for evaluating and assessing the social costs and impacts of earthquakes on highway systems and bridges, and to reduce the amount of damage that may occur to existing and future highway structures from a moderate-to-significant seismic event. This paper summarizes the motivation behind and objectives of the main group of tasks undertaken within the scope of this program: development of loss estimation methods for highway systems; preparation of a manual for the seismic design and retrofitting of long span bridges; development of earthquake protective systems and a systems design manual for bridges; and specialized ground motion, foundation, and geotechnical studies.

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Paper No. 319

THE APPLICATIONS OF ROLLING TYPE BEARINGS TO EQUIPMENT AND STRUCTURES

Sen-Nan Lee[1] and Kuo-Chun Chang[2] Chyng-Maw Su[3]

Equipment base isolation system can protect computer servers, mechanics and valuable antiques from seismic hazard. The rolling type bearings were developed for this purpose and were verified by shaking table tests in NCREE. According to the test results, it can reduce more than 90% acceleration response during earthquake. The rolling type base isolation system has no influence on the operation of computer servers during assembling. Several rolling type isolators can form a large isolated platform and can be applied to different anti-seismic purposes. Building structures and bridges also can be equipped with the rolling type bearings to protect these structures from seismic hazard. The base shear of buildings and bridges can be significantly reduced during earthquake excitations by the rolling type bearings. The rolling type bearings can also be applied to retrofit the damaged structures and bridges.

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