HUALIEN EARTHQUAKE in Taiwan, Feb. 6, 2018. Tilting of the Yun-Men-Tsui-Ti Building.
1. PERIODIC MATERIAL-BASED THREE-DIMENSIONAL (3D) SEISMIC BASE ISOLATORS FOR SMALL MODULAR REACTORS

Authors: Y. L. Mo, Professor, Dept of Civil and Envir. Engineering, University of Houston, Houston, TX, USA • FNU Witarto, Ph.D Candidate, Dept of Civil and Envir. Engineering, University of Houston, Houston, TX, USA. • K. C. Chang, Professor, Dept. of Civil Engineering, National Taiwan University, Taipei, Taiwan. • S. J. Wang, Associate Professor, National Taiwan University of Science and Technology, Taipei, Taiwan. • Yu Tang, Principal Civil Engineer, Argonne National Laboratory, Lemont, IL, USA. Robert P. Kassawara, Principal Technical Leader, Electric Power Research Institute, Palo Alto, California, USA.

Abstract: The concept of frequency band gaps in periodic materials has inspired the development of a new type of seismic base isolation systems known as the periodic foundations. This paper focuses on the experimental validation of 3D periodic foundation supporting a small modular reactor building. A large-scale 3D periodic foundation with a small modular reactor (SMR) building model was tested on a shake table using various input waves. The frequency band gaps of the test specimen were able to filter out the damaging frequency content of the input seismic waves. The test results motivate the application of periodic foundations for a safer nuclear structures in the seismic-prone regions.

2. SHEAR BEHAVIOR PREDICTION OF NON-DUCTILE REINFORCED CONCRETE MEMBERS IN EARTHQUAKE

Author: Shyh-Jiann Hwang, Director General, National Center for Research on Earthquake Engineering (NCREE), and Professor, National Taiwan University

Abstract: Prior to the introduction of modern seismic codes in the late 1990s for Taiwan, many reinforced concrete buildings were designed without adequate detailing and reinforcement for seismic protection. For these vulnerable buildings, enhancements to the seismic capacities through retrofitting are urgently needed. With the development of Performance Based Earthquake Engineering (PBEE), the engineering solutions with economic consideration can be achieved to release the pressure of immense amount of demand. However, the PBEE technique requires a good grasp of building lateral displacement. This is a current dilemma to predict the lateral displacement of reinforced concrete elements. The objective of this talk is to report the current advancement of technology to predict the lateral load-displacement curve of reinforced concrete elements, such as columns, shear walls, infilled walls with openings. In addition, some innovative retrofitting measures to upgrade the seismic capacities of reinforced concrete walls are introduced.
3. EXPERIMENTAL STUDY OF NOVEL RC FRAMES CONSIDERING EARTHQUAKE AND PROGRESSIVE COLLAPSE

Authors: Xinzheng Lu, Professor, Beijing Engineering Research Center of Steel and Concrete Composite Structures, Tsinghua University, China. • Kaiqi Lin, Ph. D. Candidate, Key Laboratory of Civil Engineering Safety and Durability, Ministry of Education, Tsinghua University, Beijing, China. • Donglian Gu, Ph. D. Candidate, Key Laboratory of Civil Engineering Safety and Durability, Ministry of Education, Tsinghua University, Beijing, China. • Yi Li, Associate Professor, Key Laboratory of Urban Security and Disaster Engineering, Ministry of Education, Beijing University of Technology, China.

Abstract: Earthquake and progressive collapse are two critical hazards increasing the collapse risks of RC frames. Existing research has revealed that considering the seismic design and progressive collapse design individually for a structure may lead to an undesirable overall structural performance and unnecessary waste of materials. In this study, two novel RC frames are proposed to satisfy the demands of both seismic and progressive collapse designs. Both seismic cyclic and progressive collapse tests are conducted to validate their performances. The experimental results indicate that such two newly proposed frames will have important potential for the multi-hazard prevention of RC frames.

4. VALIDATION OF THE PARC_CL 2.0 CRACK MODEL BY THE CYCLIC TESTS OF 1/13 - SCALE NUCLEAR CONTAINMENT STRUCTURES

Authors: Beatrice Belletti, Assoc. Professor, Università di Parma, Dipartimento di Ingegneria e Architettura, Parma, Italy • Alessandro Stocchi, Ph.D., Università di Parma, Dipartimento di Ingegneria e Architettura, Parma, Italy. Francesca Vecchi, Ph.D. Fellow, Università di Parma, Dipartimento di Ingegneria e Architettura, Parma, Italy.

Abstract: The evaluation of the non linear behavior and crack propagation in RC containment vessels is fundamental because of their structural and radiation protection functions. The new PARC_CL 2.0 RC model, developed at the University of Parma, is described in the paper. The cyclic response of a 1/13 scaled RC containment vessel is then investigated by means of the a multi-layer shell modelling approach. A validation of the model is provided through the comparison with experimental results provided by NCREE lab (Taipei). The proposed modelling proved to be in good agreement in terms of capacity, failure mode, drift, and crack propagation.
5. EFFECT OF HIGH STRENGTH REINFORCEMENT FOR SHEAR STRENGTH AND SHEAR-FRICTION STRENGTH OF SHEAR WALLS SUBJECTED TO CYCLIC LATERAL LOADING.

Authors: Hong-Gun Park, Professor, Dept of Architecture & Arch. Engrg, Seoul National University, Seoul, Korea. • Jang-Woon Baek, Researcher, Institute of Engineering Research, Seoul National University, Seoul, Korea. • Sung Hyun Kim, Ph.D. candidate, Dept of Architecture & Arch. Engrg, Seoul National University, Seoul, Korea.

Abstract: In the shear design of massive walls in nuclear power plants, the use of high-strength reinforcing bars need to be considered to satisfy the high strength demand of NPP walls and to enhance the constructability and economy. Recently, the use of Grade 550 MPa shear re-bars in RC walls for shear and shear-friction provisions is being reviewed in ACI 349 committee. In the present study, RC walls with Grade 420 MPa and Grade 550 MPa and higher were tested under cyclic lateral loading to investigate the effect of high strength reinforcement on the shear strength and shear-friction strength. On the basis of the test results, design recommendations for current shear and shear-friction provisions are proposed.

6. RESEARCH ON RESILIENT REINFORCED CONCRETE BUILDING STRUCTURAL SYSTEM

Authors: Susumu Kono, Professor, Tokyo Institute of Technology, Yokohama, Japan, • Ryo Kuwabara, Graduate Student, Tokyo Institute of Technology, Yokohama, Japan, • Fuhito Kitamura, Graduate Student, Tokyo Institute of Technology, Yokohama, Japan, • Eko Yuniarsyah, Graduate Student, Tokyo Institute of Technology, Yokohama, Japan, • Hidekazu Watanabe, Research Fellow, Building Research Institute, Tsukuba, Japan, • Tomohisa Mukai, Research Fellow, Building Research Institute, Tsukuba, Japan, • David Mukai, Associate Professor, University of Wyoming, Laramie, USA.

Abstract: Two real scale five-story reinforced concrete buildings were tested in BRI in order to evaluate damage of structural members such as beams, columns and walls. Accompanying wall tests were conducted to study damage level at different loading stages and develop different low damage wall systems. The paper focuses on the evaluation of cracks, that is, evaluation of width, numbers, and length of residual cracks. Numerical procedures using FEM analysis are introduced and the computed results are compared to the real scale experimental results. The information will be helpful to evaluate cost of repair after earthquake damage.
7. DEVELOPMENT OF LARGE-DIAMETER REINFORCING BARS FOR THE SEISMIC RESISTANCE OF REINFORCED CONCRETE BRIDGE COLUMNS

Authors: Juan Murcia-Delso, Assistant Professor, Dept of Civil, Architectural and Environmental Engineering, University of Texas, Austin, TX, USA
P. Benson Shing, Professor, Dept of Structural Engineering, University of California, San Diego, CA, USA

Abstract: This paper presents a study on the development of large-diameter reinforcing bars embedded in well-confined concrete under seismic load conditions. Bond-slip tests and bar pull-push tests were conducted on large-diameter bars up to #18 in size. A bond stress-vs.-bar slip law was developed and implemented in a finite element analysis software. The model was validated with test data and used in a Monte Carlo simulation to evaluate the adequacy of the AASHTO requirements for tension bar development. Based on the results of this study, an improved development length formula was proposed. Large-scale tests were conducted to determine the minimum development length required for large-diameter bars connecting a bridge column to an enlarged pile shaft. Design recommendations were proposed based on the test and numerical results.
8. REVERSED CYCLIC TESTS OF 1/13 SCALE CYLINDRICAL CONCRETE CONTAINMENT STRUCTURES

Authors: Chiun-Lin Wu, Research Fellow, National Center for Research on Earthquake Engineering (NCREE), Taipei, Taiwan • Thomas T.C. Hsu, Moores Professor, Dept. of Civil and Envr. Engineering, University of Houston, Houston TX, USA • Che-Yu Chang, Asst. Research Fellow, NCREE, Taipei, Taiwan. • Hu-Jhong Lu, Asst. Research Fellow, NCREE, Taipei, Taiwan. • Hsuan-Chih Yang, Assoc. Research Fellow, NCREE, Taipei, Taiwan. • Chang-Ching Chang, Assoc. Research Fellow, NCREE, Taipei, Taiwan. • Yu-Chih Chen, Assoc. Research Fellow, Sinotech Engineering Consultants, Ltd. Taipei, Taiwan • Yuan-Sen Yang, Assoc. Professor, Dept. of Civil Engineering, National Taipei University of Technology, Taipei, Taiwan

Abstract: Nuclear containment structure is one of the most important infra-structure systems ensuring the safety of a nuclear power plant. In this paper, the structural behavior of cylindrical concrete containment structure was investigated using two 1/13-scaled nuclear containment specimens subjected to reversed cyclic loadings. The presentation will first describe the experimental program, including the dimensions, the reinforcement detailing, the test setup, and the loading method. Second, the experimental results are discussed including the cracking patterns, the total load versus displacement curves and the failure modes. Third, the test results were compared to the analytical results predicted at the University of Houston using a 3-D finite element program with the CSMM-based shell elements. The predicted results agree very well with the experimental data.

9. RECENT ADVANCES ON SEISMIC RETROFIT OF REINFORCED CONCRETE SHEAR WALLS WITH FRP

Authors: David Lau, Prof., Dept of Civil and Envr. Engrg, Carleton Univ, Ottawa, Canada. • Jeffrey Erochko, Assoc. Prof., Dept of Civil and Envr. Engrg, Carleton University, Canada. • Ahmed Hassan, Graduate Student, Dept of Civil and Envr. Engrg, Carleton University, Canada • Joshua Woods, Graduate Student, Dept of Civil and Envr. Engrg, Carleton University, Canada

Abstract: This paper presents the results from a comprehensive experimental and computer simulation study on the use of externally-bonded fibre-reinforced polymer (FRP) tow sheets for the seismic retrofit of reinforced concrete (RC) shear walls. The effectiveness of the FRP retrofit scheme in recovering or enhancing the capability and performance of deficient RC shear wall structures are investigated. A new tube anchor system and its improvement to the performance of the FRP system are discussed. Design procedures for the new tube anchor system are also presented. A recent experimental investigation of a multi-storey shear wall building by hybrid simulation techniques is presented.
10. **SEISMIC RESPONSE OF SHEARWALL BUILDING SUBJECTED TO LONG DURATION GROUND MOTION**

**Authors:** C. E. Ventura, Professor, Civil Engineering, UBC Vancouver, Canada  
A. Bebamzadeh, Graduate Research Assistant, Civil Engineering, UBC Vancouver, Canada  
M. Fairhurst, Research Associate, Civil Engineering, UBC Vancouver, Canada

**Abstract:** The damage caused by large subduction earthquakes is due in part to high number of load reversal cycles. Experimental and analytical studies indicate that shaking duration and number of cycles contribute to the damage. Currently, building codes do not include design provisions for shaking duration. This paper investigates how shaking duration affects the response of tall, shear-wall buildings in British Columbia, which is located in the Cascadia Subduction Zone. A 20 storey archetype building model is analyzed with suites long- and short-duration ground motions. The results of are useful for the elaboration of design provisions to account for shaking duration.

11. **DRIFT CAPACITY AT ONSET OF BAR BUCKLING IN RC STRUCTURAL WALLS SUBJECTED TO EARTHQUAKES**

**Author:** Mario E. Rodriguez, National University of Mexico, Mexico City, Mexico

**Abstract:** In performance-based earthquake engineering for RC buildings with structural walls, it is necessary to link drift demands with the likelihood of onset of bar buckling. This damage state has been observed in RC buildings with structural walls that responded to recent earthquakes. This research uses a database of RC rectangular walls tested by several authors under cyclic reversal lateral loading. In this database, the observed failure mode was related to bar buckling of longitudinal reinforcement. A procedure is proposed for predicting drift capacities of RC walls considering buckling of longitudinal reinforcement. Results using this procedure are compared with experimental results.

12. **NUMERICAL MODELING AND EXPERIMENTAL RESPONSE OF REINFORCED CONCRETE WALLS WITH DISCONTINUITIES UNDER CYCLING LOADING**

**Authors:** Leonardo M. Massone, Assoc. Professor, Dept of Civil Engrg, Univ. of Chile, Chile.  
Fabián Rojas, Asst Professor, Dept of Civil Engineering, University of Chile, Chile.  
Gonzalo Muñoz, Engineers, Dept of Civil Engineering, University of Chile, Chile.  
Ignacio Manríquez, Engineers, Dept of Civil Engineering, University of Chile, Chile.  
Sebastián Díaz, Engineers, Dept of Civil Engineering, University of Chile, Chile.  
Ricardo Herrera, Assoc. Professor, Dept of Civil Engineering, University of Chile, Chile.

**Abstract:** In this work, the behavior of slender RC walls with different types of discontinuities at the base, under cyclic lateral displacement, are numerically and experimentally studied. First, a robust quadrilateral element with 3 DOF per node using a model of smeared RC material based on a rotating angle approach, is presented. Second, a series of tests of walls with setbacks, and central openings at the first floor, their experimental results, observations, and comparison with the model of the wall, are presented. It is observed that the model is able to capture in a good way the global and local response.
13. ASSESSMENT OF THE BOUNDARY REGIONS STABILITY OF SPECIAL RC WALLS

Authors: A.G. Haro, Professor, Departamento de Ciencias de la Tierra y la Construcción, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador. M. Kowalsky, Professor, North Carolina State University, Raleigh, NC, USA. Y. H. Chai, Professor, University of California, Davis, CA, USA.

Abstract: In the aftermath of the Chile 2010 and New Zealand 2011 earthquakes, the out-of-plane buckling mechanism of reinforced concrete structural walls (RCSW) was reported for the first time in real structures. However, this failure mode had been studied since 1980s through experimental observations that constituted the basis of phenomenological models created to prevent and assess buckling instability of RCSW. Based on these models, a less conservative approach is proposed that was validated through an experimental and analytical study conducted on prisms simulating special boundary regions of planar RCSW, which is described in this paper.

14. DUCTILITY DEMAND OF A HIGH-RISE RC FLAT-PLATE CORE-WALL BUILDING STRUCTURE IN A MODERATE-SEISMICITY REGION: SOUTH KOREA

Authors: Kyung Ran Hwang, Research Assistant Professor, School of Civil, Environmental, and Architectural Engineering, Korea University, Korea. Han Seon Lee, Professor, School of Civil, Environmental, and Architectural Engineering, Korea University, Korea.

Abstract: An analytical model, calibrated with the results of shake-table tests on a 1:15 scale 25-story RC flat-plate core-wall building model, is used to verify the demand of ductility at the critical elements. Under the maximum considered earthquakes in Korea, the maximum chord rotation of coupling beams and slabs reaches 0.01rad with the maximum roof drift of 0.47%. The maximum curvature of the wall at the base is only 16% of the value of the ultimate curvature, 0.041rad/m, derived from the minimum plastic rotation 0.0064rad, implemented by ACI 318-11 for the special wall boundary. These results imply that the seismic requirements for ductility can be greatly alleviated in the moderate-seismicity regions.
15. ESSENTIAL REQUIREMENTS FOR REINFORCED CONCRETE STRUCTURES OF LIMITED AREA AND HEIGHT

**Authors:** Luis E. Garcia, Universidad de los Andes, Bogotá, Colombia
Santiago Pujol, Purdue University, West Lafayette, Indiana, USA
Juan Francisco Correal, Universidad de los Andes, Bogotá, Colombia

**Abstract:** There is a worldwide criticism that current structural design standards and codes might be too complex for many applications. An international agreement between ACI, and two Colombian institutions was signed and as a result the document ACI 314, Guide to the simplified design of Reinforced Concrete Buildings was developed. Earthquake resistant requirements are based on the use of structural concrete walls (shear walls) that limit the lateral deformations of the structure and provide lateral strength. The design can be carried out using solely the document and a hand calculator without need for a computer. The manuscript will focus on the way the document was developed and how it is organized.

16. THE SEISMIC STRENGTHENING OF CONCRETE STRUCTURES BY ULTRA-HIGH PERFORMANCE CONCRETE.

**Authors:** Sung-Gul Hong, Professor, Department of Architecture and architectural engineering, Seoul National University, Seoul, Korea
Yousun Yi, Ph.D. Candidate, Dept. of Civil, Architectural and Environmental Engineering, University of Texas, Austin, TX USA
Inyoung Gu, Ph. D. Candidate, Department of Architecture and Architectural engineering, Seoul National University, Seoul, Korea

**Abstract:** This paper investigated the behavior of concrete walls and columns strengthened by ultra-high-performance concrete (UHPC). UHPC is one of promising construction materials which provides high strength and durability with high-flow at placing. The jacketing methods using UHPC to increase sectional area for existing concrete walls and columns for seismic upgrading demonstrated increase in strength and ductility by the experimental programs in the paper. This paper also compared with analytical approaches for verification of upgrading. Based on this research some design equations for seismic jacketing is proposed.
17. EFFECT OF STRAIN PENETRATION ON RC BEAM-COLUMN JOINTS SUBJECTED TO SEISMIC LOADING

**Authors:** Jung-Yoon Lee, Professor, School of Civil, Architectural Engineering and Landscape Architecture, Sungkyunkwan University, Seoul, Korea
Jongwook Par, Engineer, Lotte Engineering and Construction Inc, Korea.

**Abstract:** Since RC beam-column joints are crucial elements in the survival of RC frame structures, a brittle failure such as that associated with shear failure or bond failure in the joints must be avoided. Also, limited research has been carried out to evaluate the deformation capacity of an RC joint. This paper presents the results of an analytical and experimental study aiming on predicting not only the strength but the deformation of RC joints failing in shear, after plastic hinge develop at the end of the adjacent beams. Thirty five experimental results of RC joints reported in the technical literature were compared with the deformation as predicted by the proposed method. Comparisons between the observed and calculated deformation capacities of the considered RC beam-column joint assemblies showed reasonable agreement.

18. CAPACITY-BASED INELASTIC DISPLACEMENT SPECTRA FOR SEISMIC EVALUATION AND DESIGN OF REINFORCED CONCRETE BRIDGES

**Authors:** Kuo-Chun Chang, Professor, Dept of Civil Engineering, National Taiwan University, Taipei, Taiwan. • Ping-Hsiung Wang, Assistant Research Fellow, National Center for Research on Earthquake Engineering (NCREE), Taipei, Taiwan. • Yu-Chen Ou, Professor, Dept of Civil Engineering, National Taiwan University, Taipei, Taiwan.

**Abstract:** This paper is aimed at constructing inelastic displacement spectra associated with the corresponding damage state (i.e., the capacity-based inelastic displacement spectra) for RC bridge columns using a newly developed smooth hysteresis model proposed by the authors. Nonlinear time history analyses of SDOF systems having different degraded hysteretic behaviors identified from the tested columns with various design parameters subjected to far-field and near-fault pulse-like ground motions were conducted. The computed results show that for far-field earthquakes, the inelastic displacement spectra agree with those provided by many design codes/manuals such as the seismic retrofitting manual of FHWA (2006). However, they do not tell information about the corresponding damage conditions and the design limit to prevent collapse. For near-fault earthquakes, all the currently proposed spectra tend to significantly underestimate the inelastic displacements as compared with this study.
19. **ISSUES RELATED TO THE RAPID SEISMIC REPAIR OF CONCRETE BRIDGE COLUMNS**

**Authors:** Zachary Krish, PhD Student, North Carolina State University, Raleigh, NC, USA. • Mervyn Kowalsky, Professor of Structural Engineering, North Carolina State University, Raleigh, NC, USA

**Abstract:** Presented in this paper is research aimed at challenging the assumption that severely damaged bridge columns are not easily repaired. Through the use of plastic hinge relocation and conventional materials, bridge columns exhibiting buckled and fractured reinforcement may be repaired. Several repair methods will be explored with results of both large scale bi-directional tests and analysis presented. In addition, preliminary results regarding the residual drift limits beyond which repair may become difficult will also be discussed.

---

20. **SEISMIC ANALYSIS OF SMA-RETROFITTED CONCRETE COLUMNS USING MATERIAL TESTING INTEGRATED SIMULATION**

**Authors:** Donghyuk Jung, Graduate Research Assistant, Dept. of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, USA. Bassem Andrawes, Associate Professor, Dept. of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, USA.

**Abstract:** There is growing interest in the seismic application of shape memory alloys (SMAs) in concrete structures. However, for the seismic performance of such new class of materials with complex thermomechanical behavior to be fully understood, more advanced simulation tools are required. This study focuses on investigating the application of thermally prestressed SMA spirals as a retrofitting measure for RC columns with insufficient flexural ductility. The study adopts a novel simulation framework which incorporates material testing into numerical simulation, hence the name material testing integrated (MTI) simulation. The new MTI simulation is validated using large-scale experimental testing.
21. **TEST AND ANALYSIS OF A SELF-CENTERING CONCRETE FRAME UNDER SEISMIC ACTION**

**Authors:** Xilin Lu, Professor, State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai, China. • Chun Jiang, Ph.D. Candidate, State Key Laboratory of Disaster Reduction in Civil Engineering. • Ye Cui, Ph.D. Engineer, State Key Laboratory of Disaster Reduction in Civil Engineering. • Xu Lu, Master Candidate, State Key Laboratory of Disaster Reduction in Civil Engineering.

**Abstract:** A new type of self-centering concrete frame was specially designed which consisted of beam-column joint that has limited rotation capacity to release bending moment in the joint, and column foot joint that has uplift and rotation capacity to prevent the joint from damage. Prestressed tendons are used in beams and columns to provide re-centering functions. Shaking table test on this new frame was carried out to investigate the seismic performance and to check the self-centering capacity, and numerical simulation models were developed and verified by the test results. Test and analysis shows that the new type of self-centering concrete frame has excellent seismic performance under very strong earthquakes with a little residual deformation but without any visible damage to the structural members. Design methodology for this new frame was proposed for future applications to engineering practice.

---

22. **STRUCTURAL PERFORMANCE OF SLENDER HIGH STRENGTH SFRC COLUMNS (FC300) UNDER AXIAL AND LATERAL LOADINGS**

**Author:** Yusuke Tanabe, Takenaka Corp, Japan

**Abstract:** This paper describes an experimental study conducted on slender columns made of Steel Fiber Reinforced Concrete (SFRC). The compressive strength of SFRC ranges from 200 to 300 N/mm². The cross section of these slender SFRC columns is reduced to 1/4 that of columns made of ordinary concrete. Lateral loading tests are carried out to investigate the flexural performance of these columns. The test results show that using steel fiber decreases the damage of cover concrete of the columns and increases their flexural strength. In addition, the results show that slender SFRC columns possess high drift capacity.
Tuesday, July 3, 2018
2:00 pm to 4:00 pm:
Thomas TC Hsu Structural Research Laboratory tour given by Dr. Mina Dawood, Associate Professor and Director of Hsu Structural Research Laboratory

All inquiries relating to the Forum should be addressed to:

Forum Administrator:
Cherish Wallace
Dept. of Civil and Environmental Engineering
University of Houston
4726 Calhoun Road
Houston, Texas 77204, USA
Tel: 713-743-4295
E-mail: cwallace@uh.edu