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IREE: Integration of International Collaboration into a PreNEESR Project to Advance a Prefabricated Structural System for Seismic Design

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ABSTRACT: Over the past two decades, experimental and analytical research has demonstrated the performance of precast structural wall systems using unbonded post-tensioning for seismic applications. However, these wall systems are not as economically viable as monolithic reinforced concrete structural walls in resisting the lateral loads, thus limiting their usage in real-world applications. To overcome this challenge, a new precast wall system concept was developed by the authors. This new system known as the PreWEC (Precast Wall with End Columns) system improves the lateral load capacity through multiple means, making it an economically feasible precast concrete solution. This system consists of a precast concrete wall and two concrete or steel end columns. The wall and columns are anchored to the foundation using unbonded post-tensioning and joined horizontally by a specially designed, easily replaceable, low-cost connector. While the unbonded post-tensioning help the system to recenter after subjecting to lateral loads such as that from an earthquake, the connectors between the wall and the columns will be largely responsible for dissipating the energy imparted to the building during an earthquake event. The behavior of this system was analytically investigated previously and lacked the experimental validation. The IREE supplement award helped to conduct a large-scale experiment at the National Center for Research on Earthquake Engineering (NCREE), Taiwan, to study the viability of the proposed precast concept. In addition to gaining new engineering knowledge, the visit to Taiwan provided unique opportunities for the authors to collaborate and exchange ideas with the local students and professors, learn about the capabilities of their earthquake testing facilities and techniques, and understand the culture and historical heritage in Taiwan.

INTRODUCTION

A collaborative research project was awarded by the National Science Foundation (NSF) to the University of Minnesota (PI: Cathy French), Iowa State University (PI: Sri Sritharan) and University of Puerto Rico at Mayagüez (PI: Ricardo López) in Dec. 2004. The scope of the project was to improve the behavior, analysis, and design of nonrectangular concrete walls and to demonstrate the new collaboration potential involving information technology (IT) and advanced large-scale experimental capabilities made available by NSF through the George E. Brown, Jr. Network for Earthquake Engineering (NEES) program. As part of this project, a combined experimental and numerical investigation has been undertaken on T-shaped concrete walls subjected to multi directional loading and rectangular walls subjected to in-plane lateral loading. The experimental part of the project included large-scale tests of two T-walls and three rectangular walls at the NEES MAST facility of the University of Minnesota. The ISU research team was largely responsible for numerical simulation of the wall behavior using an open source analysis package OpesSees. To achieve this task successfully, two new constitutive material models had been added to OpenSEES.

The ISU research team of the IREE supplement award (PI: Sri Sritharan, Associate Professor; Student Researcher: Sriram Aaleti, a PhD Candidate) conducted an analytical investigation to improve the efficiency of precast wall systems in a previous study and introduced a new concept for a precast wall system. This was expected to be a cost-effective system and can be designed to match the lateral load capacity of a comparable monolithic reinforced concrete wall. However, the viability of the concept was never proven through an experimental study.

Established in 1990, the National Center for Research on Earthquake Engineering (NCREE) is a joint effort between the Taiwan National Science Council (NSC) and the National Taiwan University (NTU). The focus of this institution located in Taipei, Taiwan, is to upgrade seismic resistant design standards for all constructions and to provide feedback to the engineering community through research and development. A four year research program was initiated in 2004 by NCREE on self-centering structural systems. The concept of the precast wall system was discussed with the NCREE researchers during a self-centering systems workshop conducted by NCREE in collaboration with researchers from the U.S. Following this workshop, the PI at ISU learned of the opportunity to obtain supplemental funding through IREE and thus discussed the possibility of performing a proof test for the new wall concept at NCREE. The Director of NCREE supported this plan and subsequently the PI received funding from IREE to participate in this joint venture.

It is anticipated that the experimental validation of the lateral load behavior of the precast wall system will help motivate the precast industry and earthquake engineering community to use the new concrete wall system in seismic regions. This international project also broadens the U.S.–Taiwan collaboration on self-centering systems for earthquake-resistant design and contributes to fundamental knowledge on development of cost-effective, easily repairable building systems.

The authors of this paper are the participants of the IREE program. Sriram Aaleti participated in the construction, erection and testing of the large-scale test at NCREE during a 3.5 month stay from November 21, 2007 to March 9, 2008. Sri Sritharan visited NCREE from December 3 to 15 in 2007 and March 2nd to 10th 2008 to coordinate and supervise the IREE research activities and establish future research collaborations.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

The research activities of the 3.5-month long international cooperation supported by the IREE program included a) the design, fabrication and large-scale testing of an innovative precast wall system for seismic regions; and b) the development and validation testing of a cost-effective energy dissipating connector for utilization in the PreWEC and future precast systems for seismic applications. The precast wall system for the test was designed with the same dimensions as the rectangular walls, which were tested at the NEES MAST laboratory. The main objective of the IREE research was to show that PreWEC can be designed to provide comparable resistance and superior behavior to equivalent monolithic concrete walls.

The ISU researchers designed the test specimen and test setup (see Figure 1) with assistance from the researchers of the host institute (i.e., NCREE). The interactions with the researchers from the host institute helped understand the design and construction practices of Taiwan, thus enabled customizing details of the test specimen to locally available products. The researchers from both countries also had discussions with the precast construction company in Taiwan, who eventually fabricated the wall panel for the test unit, to learn of their construction practice. To explore the prospects of using the wall system and to learn of the engineering practice in Taiwan, the host institution also provided an opportunity to meet with the lead designer of the Taipei 101—the tallest building in the world and an engineering marvel in an active seismic zone. This meeting was very informative on the design practices used for tall buildings in Taiwan.

All of the above mentioned activities and the various experimental research undertaken at the host institution helped the student researcher to experience a variety of research projects and to interact with the several researchers in Taiwan. Through these interactions, he gained new knowledge on new experimental and numerical simulation techniques as well as on different structural systems and their behavior. During the cause of the project, Sriram Aaleti was able to participate in a workshop conducted at NCREE on base isolation and bridge bearings and was able to interact with the Japanese researchers on these topics.

The IREE project started with the design of the test specimen from Nov. – Dec. 2007. The design phase included various input from NCREE researchers and representatives of the precast construction company. In January 2008, three tests were conducted at NCREE on the newly designed low cost connector to experimentally validate their overall performance and energy dissipating ability. The results of the connector tests were good and confirmed its application to PreWEC. The fabrication of the test specimen was completed by the first week of February 2008. The test specimen was erected by the end of February 2008 and the testing was completed on March 7th 2008.

The preliminary conclusions of the IREE research are as follows:

1. The performance of the PreWEC system was excellent and it superseded the comparable cast-in-plane concrete walls tested at UMN (see Figure 2). The analytical simulation, which was performed using a simplified methods and a detailed finite element model, accurately captured the observed experimental force-displacement behavior of the wall system.

2. The precast wall system only experienced minor damage to the wall and end columns, but the easily replaceable connectors fractured at 3.5% drift. In comparison, the cast-in-place walls experienced excessive damage (see Figure 3).
3. The cyclic behavior of the cost-effective mild steel connector was exceptionally good (see Figure 4)

The IREE research provided the necessary data to confirm the innovative and cost-effective precast wall system concept for seismic applications. The experimental data also provided a means to validate the existing analytical methods. Because the PreWEC test was done using a code accepted procedure, it is believed that this system can be used in real-world applications in not too distant future.

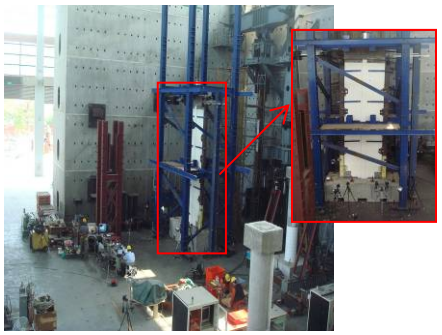

Figure 1: PreWEC system test setup

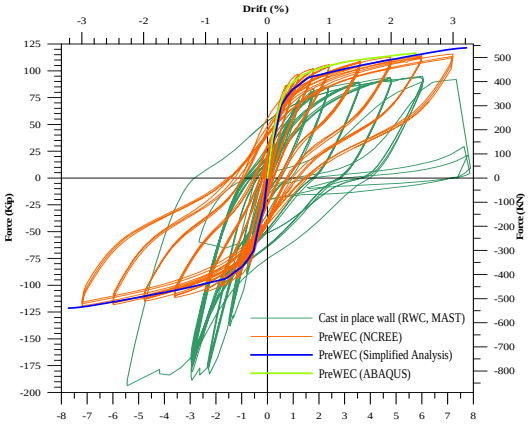

Figure 2: Comparison of experimental behavior of PreWEC system and a cast-in-place wall (RWC)

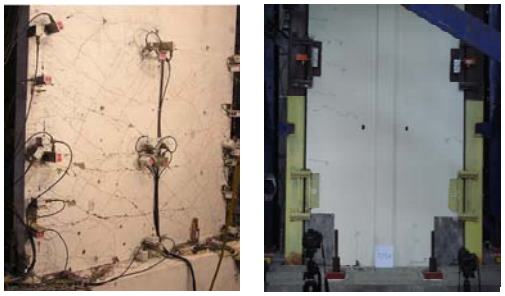

Figure 3: Comparison of damage that occurred to the PreWEC system at 2 % drift

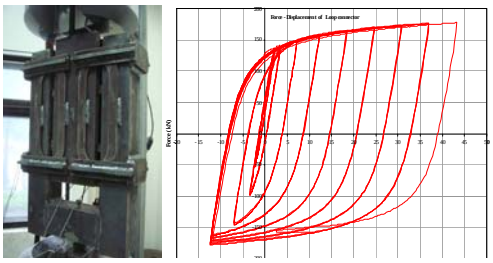

Figure 4: Mild steel connector and its behavior under cyclic shear loading.

BROADER IMPACTS OF THE INTERNATIONAL TRAVEL

The IREE research program provided the student researcher with enriching education and research training through the international research exposure. This award also gave ample opportunities for the student researcher to interact with various research groups at NCREE, allowing him to gain knowledge about variety of experimental techniques and research ideas. The faculty member also gained new knowledge on self-centering system—a primary area of his research, learned of several possible collaboration opportunities with NCREE, National Taiwan University (Contact Person: Professor K. C. Tsai) and National Chiao Tung University (Contact Person: Professor Chung-Che Chou) and promoted the use of NEES IT techniques at NCREE. The proposed wall system also attracted interest from New Zealand researchers from the University of Auckland. With funding from New Zealand, they sent Rick Henry, a PhD student, to Taiwan for 3.5 months to participate in the IREE research. The PI of this award now serves as a co-major professor for this student, who has now secured a Fulbright scholarship to come to Iowa State University and work with the PI for a year. The IREE award no doubt promoted diversity as it: 1) enabled Taiwanese and New Zealand researchers to get involved in the system test; 2) facilitated a female freshmen honor student (Erica Velasco) at Iowa State University to remotely participate in research; and 3) provided an opportunity to conduct a web-based seminar from Taiwan, in which several NTU students participated in person while students and researchers from New Zealand and US participated through WebEx.

The supplement award expanded the scope of the original NSF award by introducing a precast wall system as a better alternative to cast-in-place concrete walls. The director of NCREE and the PI discussed several future research collaborations, one of which is to submit a joint proposal to the NSF-NEES research program and National Science Council to examine the wall performance under real-time earthquake loading. In addition, a collaboration involving a component to implement this system in the field has been planned with Prof. Jason Ingham at the University of Auckland in New Zealand. The supplement award also helped the PI to get familiarize with the test facilities and laboratory policies in Taiwan, which are key parameters for planning and executing successful future collaborations involving large-scale tests.

The PI of the NSF award is a permanent resident of U.S. whereas the student researcher is an international student on an F-1 visa. Communication with the technicians in the laboratory was a barrier as Mandarin was the focal language of communication. However, the research associates and the director of the host institution assisted greatly by translating our requests into Mandarin so that the technicians could understand and execute the research tasks correctly. This barrier actually acted as a catalyst for the researchers to acquire some knowledge of the language. It was an enriching experience for both participants to learn the research and technological trends in Taiwan. The researchers also learned about the Taiwanese culture, traditions and history by visiting the old monuments, museums including the National Taiwan Museum, and participating in celebrations of the Chinese New Year.

DISCUSSION AND SUMMARY

The most significant accomplishments of the international research experience can be summarized as follows:

1. An experimental validation of an innovative and cost-effective precast wall system for seismic regions, which will help promote the precast systems in the United States and educate the precast industry of this new opportunity.
2. Development of a cost-effective mild steel connector for precast wall systems and other applications.
3. Active research collaboration has been established with the researchers at the National Center for Research on Earthquake Engineering (NCREE) and other institutions in Taiwan, including an opportunity to jointly examine the wall performance under earthquake loading in real time.
4. The student researcher has benefited significantly and has acquired knowledge about great variety of research projects and new experimental techniques.
5. The international program helped the student researcher to interact with the researchers from the host institute and exchange research ideas. This program also gave a good chance to understand the culture, traditions and history of Taiwan.

The followings are recommendations for "Best Practices" in future operation of the IREE Program:

1. Enabled opportunities for students to get in contact with other international students who may be already at the host institution.
2. Encourage PIs to look for other funding opportunities while at the host institution.
3. Showcase a large number of completed projects and how the IREE award expanded the original NSF award during the annual IREE conferences.

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BRIEF BIOGRAPHIES OF RESEARCHERS

Sri Sritharan received the BS degree in civil engineering from the University of Peradeniya, Sri Lanka. He received his M.E. degree in civil engineering (structures) from the University of Auckland, New Zealand and a PhD from the University of California at San Diego (UCSD). He is currently an Associate Professor and Assistant Chair in the Civil, Construction and Environmental Engineering department at Iowa State University. His research interests include the behaviour of reinforced and precast concrete structural systems, soil-foundation-structure interaction, and development of numerical models to characterize their seismic behaviour.

Sriram Aaleti received a B.Tech degree from the Indian Institute of Technology, Madras (IITM), India in 2003. He received his MS degree in Civil Engineering from Iowa State University (ISU) in 2005 and is currently a PhD candidate in the Civil, Construction and Environmental Engineering department at ISU. His research interests include the behaviour of precast and reinforced concrete structural wall systems for seismic regions, Finite Element Analysis and Ultra High Performance Concrete (UHPC).