CONTRIBUTIONS TO THE CONSTRUCTION OF A BUILDING FOR SEISMIC AND FIRE RESEARCH

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August 2011

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1.0 ABSTRACT

Since nonstructural components and systems (NCS) can cause serious injury to people and potential damage to infrastructure, it's vital to properly design and construct NCS against earthquake and fire. This paper explores the necessity for conducting earthquake and post-earthquake fire research in a full-scale building in order to test the performance of NCS in a real building. Many construction challenges, material testing and instrumentation issues are addressed which are required for the completion of the building and monitoring its response during testing. Results from this study will be used for education regarding NCS under seismic forces and fire in addition to future code-change proposals.

2.0 PROJECT OVERVIEW

The Englekirk Structural Engineering Center (ESEC) is working in a project titled *Full-Scale Structural and Nonstructural Building System Performance During Earthquakes & Post-Earthquake Fire.* The project is sponsored by the Network for Earthquake Engineering Simulation and by the National Science Foundation (Grant No. CMMI-0936505) as well as several Industry partners. The project involves the construction of a full-scale five-story building made out of reinforced and prestressed concrete, the building is fully furnished with Nonstructural Components and Systems (NCS). The purpose of the project is to test the building's response when subjected to seismic loads using the NEES shake table and post-earthquake fire by conducting non-thermal and live fire tests. The project data and results will be compared against commercial research performance and predictions made by computational modeling. The outcomes of this project will be transferred to practice by producing and distributing educational materials and resources. This will include workshops and seminars for high school, college students and faculty; furthermore, educational programs for practicing engineers and professional organizations will be made available. (UCSD 2011) The results will also impact seismic and fire requirements in future building codes.

Nonstructural components and systems are components of a structure that do not serve as load-carrying or load-transferring components in a structure, except it's self-weight at times. The building will be equipped with several categories of NCS including architectural, mechanical, and electrical NCS. Some of these components include elevators, stairs, partitioning walls, pipes and ducts, fire sprinklers and riser system, smoke and fire barriers, concrete cladding, ceiling subsystems, and glazing systems. A big percentage of the total investment of the building is spent in the construction of NCS. Proper seismic design and construction techniques are required to reduce the collapse of NCS to prevent damage of infrastructure and avoid loss of life. This includes how the NCS interact within themselves and with the rest of the building especially when subjected to seismic forces and/or fire.

A particular subject of interest for the NEES-REU students is the "full-scale dynamic response and kinematic interaction of complex structural and nonstructural components and systems." (UCSD 2011) Specifically the outer wall system of the building. Due to the broadness of this project, the NEES-REU students are focusing on one of the nonstructural components for their research. The students will focus on concrete cladding panels for the walls of the building as shown in Figure 1. The cladding panels are not designed to transfer any vertical load; instead they simply transfer their self-weight to its anchor points and can resist wind and earthquake loads. Some of the topics to be explored include failure and damage created by collapsing concrete cladding on past earthquakes and new design and construction requirements needed to prevent future collapses. Two of the main focus topics are the seismic gap between panels and the anchoring mechanisms to the structure. These two systems have to account for movements in the structure created by wind, earthquake and thermal expansion and contraction due to temperature changes. It is imperative that the anchor points resist the movement of the panel and that the seismic gap is designed adequately for the irregular movement between panels. This ensures that the concrete panel will be less likely to collapse under any of these situations.

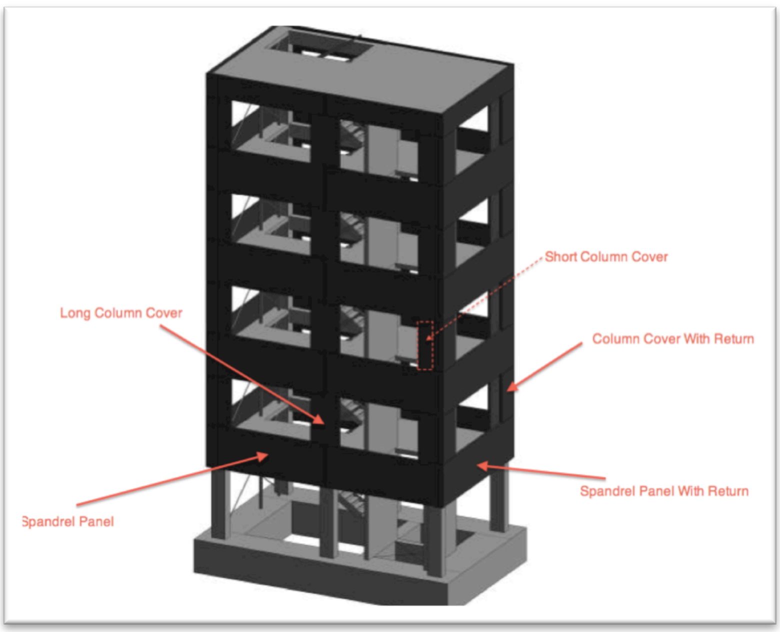

Figure 1 Computer rendering of the building showing different types of concrete cladding walls. (Drawing by Diana Lin)

Several mechanisms to be tested will be developed in order to anchor different panels along the length of the building. The cladding panels will be equipped with sensors to determine strains, accelerations, and displacement on the panels. Data acquired from the sensors, as well as visual inspection of the panels will be used in order to determine which connection mechanisms performed satisfactory or poorly. Their corresponding displacements, strains, and accelerations will be evaluated and compared with the visual inspection and computer models to determine the damage inflicted by the seismic movement in each particular cladding panel. By looking at this damage an assessment can be made to determine what kind harm can be inflicted on people, building component, and infrastructure if this damage would have occurred on a real occupied building.

3.0 LITERATURE REVIEW

Nonstructural components including cladding and glazing/windows may account for up to 85% of the original construction costs of a typical commercial building (FEMA E-74) and the design, construction, and performance of these are critical during an earthquake. Failure of nonstructural components during an earthquake "may result in injuries or fatalities, cause costly property damage to buildings and their contents; and force the closure of residential, medical and manufacturing facilities, businesses, and government offices until appropriate repairs are completed" (FEMA E-74). According to the Federal Emergency Management Agency (FEMA) there are three ways to categorize potential damage and risk generated by nonstructural components, which are defined by FEMA in the following performance levels.

> **Life Safety (LS)—***Could anyone be hurt by this component in an earthquake?*
> **Property Loss (PL)—***Could a large property loss result?*
> **Functional Loss (FL)—***Could the loss of this component cause an outage or interruption?*
> (FEMA E-74)

The *Life Safety* performance level is easily understood by its defined question. Many types of nonstructural components can easily fall and injure or kill someone if they are not properly fastened. If falling glass, ceilings, or even lighting fixtures lands on someone's head they can cause serious injuries. "*Property losses* may be the result of direct damage to a nonstructural item or of the consequences produced by its damage" (FEMA E-74). For example, a high tech facility may have components and materials which are worth many times more than the building itself; if these components are destroyed they can potentially lead to a serious economic loss for the facility. *Functionality Loss* refers to the problems that a facility might have in order to perform its regular operations. A good example would be an elevator breakdown inside a hospital that needs to be used in order to move patients from different floors.

In order to experimentally determine what type of connection failure in cladding panels leads to what type of performance level, a team of civil engineers at San Jose State University conducted pushover analysis of precast concrete cladding panels using force-defection relationships (McMullin et al. 2011). Results from this study were compared with the performance levels by FEMA, and the conclusions was reached that "if connections fail by yielding then many of the performance levels are achievable, however if weld fracture controls the behavior then life-safety and collapse prevention performance levels cannot be achieved" (McMullin et al. 2011). One of the main reasons that a collapse is inevitable in this situation is because cladding panels are typically attached to the structure by a determinant system of connections with no redundancy, this means that the loss of a single gravity-load carrying connection will lead to a collapse mechanism and a possible life-threatening situation (McMullin et al. 2011).

Although the cladding panels are nonstructural components they still have to be designed to resist movement due to environmental factors such as thermal expansion, wind, and earthquakes. The most critical movement created by environmental factors is interstory drift (or racking); this is essentially defined as relative horizontal movement between adjacent stories of a multi-story building. The biggest movement is by far created by seismic forces (Brenden 2006). Other considerations are the vibration characteristics of the panels, particularly to avoid low frequencies in the cladding panels matching the resonant frequency of the building (Merrick et al. n.d.). If the cladding panels where to resonate with the building, a potential amplitude increase may lead to cracking and possible failure of the cladding panels. It is the responsibility of the structural engineer to make sure that all of the design requirements of the structure to hold the cladding are analyzed, tested, and carefully detail the structure to cladding panel connections (NIBS 2011).

4.0 NEES-REU STUDENT CONTRIBUTIONS

This research project requires an extensive amount of work and is being conducted over several years. The initial phase of the project began back in November 2009 and expected to be completed by October 2012. The construction phase of the project is currently underway followed by the instrumentation phase. Construction is moving at a quick pace and there are many tasks to complete in order to keep the project on schedule and avoid any unnecessary delays. NEES-REU students have been given several duties in order to achieve this.

4.1 FABRICATION AND PLACEMENT OF STEEL EMBEDMENT PLATES

One of the tasks related to the concrete cladding project is the fabrication and placement of the steel embedment plates (embeds) to be used as the connection mechanism between the cladding panel and the building. A connection mechanism showing the steel embeds in the column and the cladding panel can bee seen in Figure 2. In order to fabricate the steel embeds the NEES-REU students converted hand-sketched drawings of steel embed into professional fabrication drawings. The drawings show all dimensions, material properties, and weld specifications for the fabricator to clearly understand how to build the required steel piece. Besides having to properly communicate using a drawing with a steel fabricator, it was important to get from several steel fabricators the best possible price and expected delivery time for the required steel embeds. Figure 3 shows the initial drawings of a steel embed with its corresponding final product. Following the fabrication, the NEES-REU students installed the embeds in the structure and secured them before the concrete was poured in the building. The embeds are placed in a specific position by carefully following construction and connection drawings and by measuring the exact position in the building specified by the drawings.

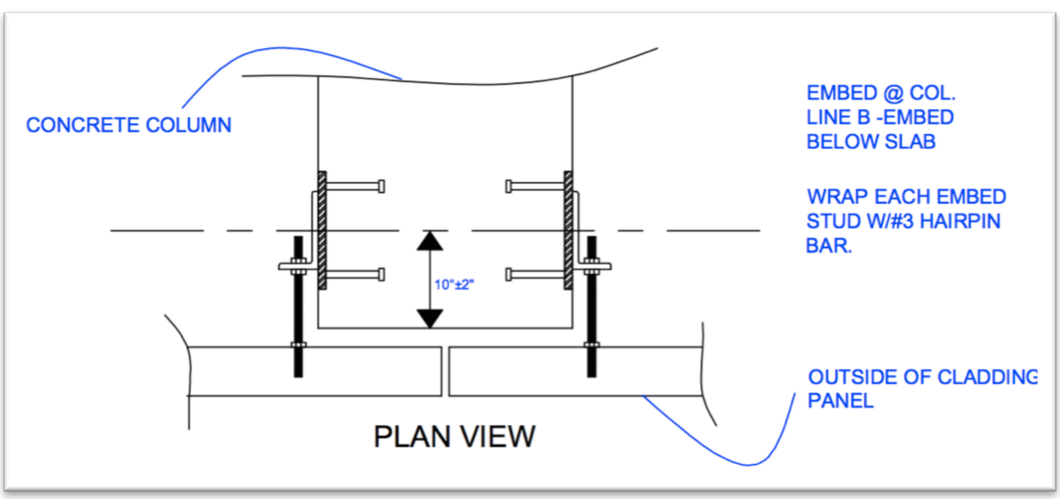

Figure 2 A connection mechanism showing steel embeds in the column. (Drawing by Cecilia Luu)

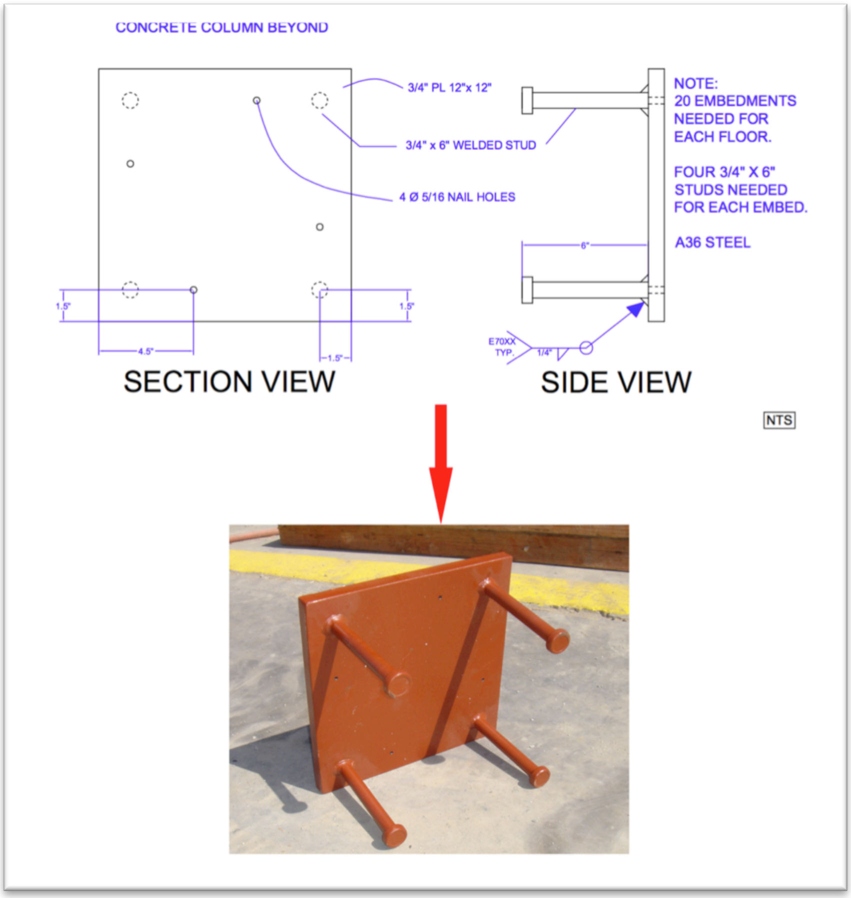

Figure 3 Fabrication of a steel embed from initial drawing to final product. (Drawing by Cecilia Luu)

4.2 MATERIAL TESTING AND METHODS

On concrete pour days student are assigned to perform concrete slump tests and prepare test cylinders. The concrete slump test is a quick and easy way to determine the workability of fresh concrete and the consistency between batches (trucks) under field conditions before is poured in the structure. Students are also required to prepare 6in X 12in cylinders which are clearly labeled depending on the truck, pour date, and date to be tested. The concrete cylinders are taken to a lab where they are tested for the concrete compressive test after 7 and 28 days and during the first and last day of testing (shaking) of the building. The compressive strength results are used to determine if the concrete strength corresponds to the one specified by the engineers which where used for the structural analysis of the building. Both the slump test and the cylinders must be meticulously performed and prepared in accordance with ASTM standards to ensure consistency among all tests. Figures 4 and 5 show NEES-REU students preparing the test cylinders and performing the concrete slump test.

Figure 4 Preparing 6in X 12in test cylinders.

Figure 5 Performing a concrete slump test.

4.3 INSTRUMENTATION

Another critical task required to obtain strain measurements from the building is to correctly place strain gages in the rebar by following a set of drawings showing the exact placement of each. There are several steps taken to correctly place a strain gage in the rebar and prevent it from being damaged during the pouring of the concrete. One of the most important steps is the grinding of the rebar; this has to be carefully done with good precision in order to avoid grinding the rebar diameter too much and jeopardizing its performance. The strain gages have to be glued to the rebar and covered by several layers of insulating paste; a special cushioning tape must protect them also. See Figures 6 and 7. This is done to prevent the strain gages to be damaged during the placement of the rebar in the building and when the concrete is being vibrated. Using an ohmmeter, the strain gages are checked to make sure they are working; this is done after placing the strain gages in the rebar, after placing the rebar in the building, and after pouring concrete. The lead wires of each strain gage are run down the length of the rebar and labeled in order to keep track of which wire (strain gage) corresponds to which data measurement obtained. See Figure 8.

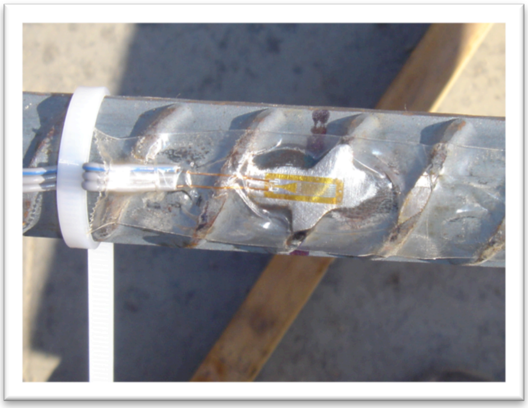

Figure 6 Strain gage in grinded rebar.

Figure 7 Insulation covering strain gage.

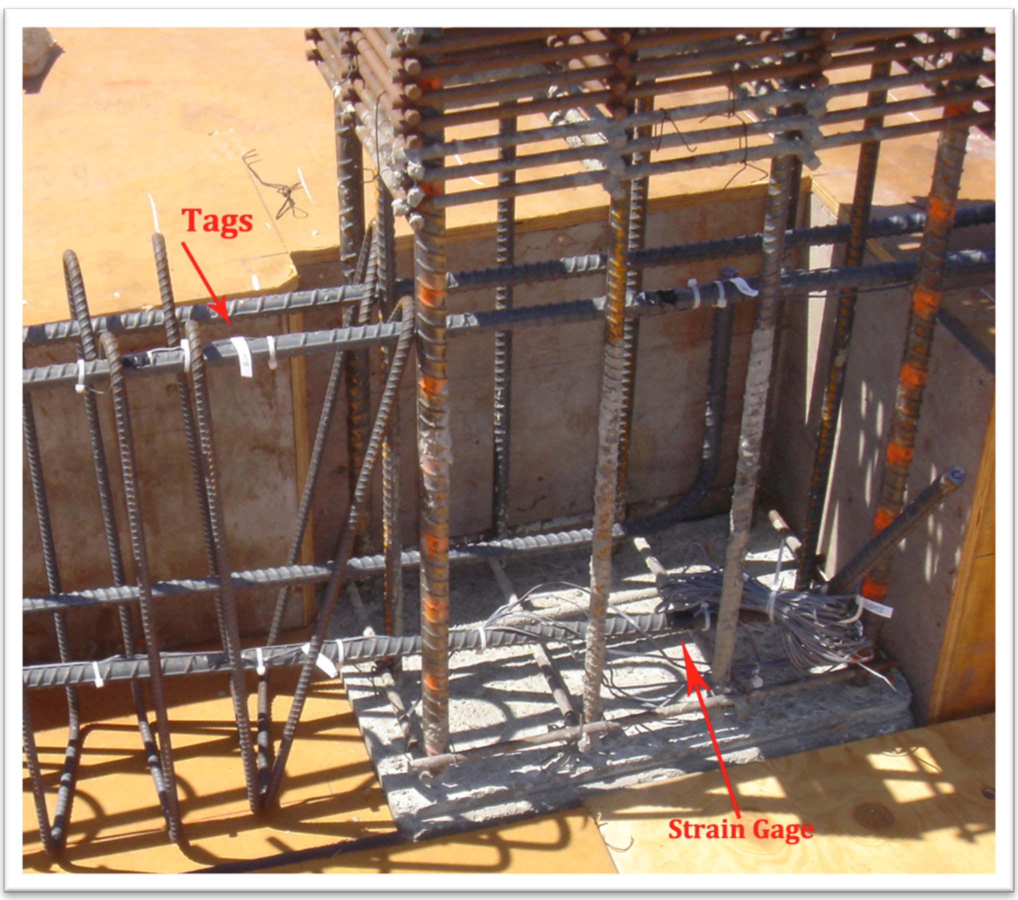

Figure 8 Placement of strain gage, tags, and wires along rebar.

5.0 CONCLUSION

The fabrication and placement of the steel embeds, the material testing, and the instrumentation of the strain gages might seem like a minimal task compared to the overall multi-year long project but the fact is that small tasks like this are essential for the completion of the project. All of the work mentioned above is necessary in order for the research project to be successful and increase the knowledge of how nonstructural components and systems perform under an earthquake and post-earthquake fire. The connection designs between the cladding panel and structure will be tested and analyzed. The stain gages, together with the material testing performed, will help to monitor the building's performance under an earthquake.

The project is still in the construction phase; the instrumentation phase is expected to peak during September 2011 with the seismic and fire testing planned for December 2011 and January 2012 correspondingly. The final report containing all the experimental results and conclusions is expected for October 2012. This will be followed by a series of community workshops and a presentation for code-change proposals.

6.0 CONTACT INFORMATION

For more information about the project visit the project website at http://bncs.ucsd.edu/index.html or contact:

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7.0 ACKNOWLEDGEMENTS

Partially funded by the NEES-REU program (EEC-1005054) and the NSF (Grant No. CMMI-0936505).

Professors Tara Hutchinson and Jose Restrepo from the University of California, San Diego.

PhD students Michelle Chen, Elide Pantoli, Steve Mintz, and Xian Wang from the University of California, San Diego and PhD student Elias Espino from San Diego State University.

Fellow NEES-REU Students Yujia Liu from the University of California, San Diego and Diana Lin and Cecilia Luu from San Jose State University.

NEES-REU Mentors Alicia Lyman-Holt from and Laia Cari Robichaux from Oregon State University, and Thalia Anagnos from San Jose State University.

All the staff at Englekirk Structural Engineering Center.

8.0 PROJECT REFLECTIONS

The NEES-REU students have been a critical asset in the construction of the building with many different responsibilities and tasks assigned to them across several disciplines. Some of the of the topics that students are experiencing with their participation in this project include; Learning how to draw and interpret construction drawings, time and construction management, safety procedures and regulation in the jobsite, and material testing and instrumentation. Most of these skills can't be learned in the academic environment, they have to be learned, practiced, and experienced in a construction site like the one offered at ESEC.

The ability to understand a fabrication or construction drawing as well as the skill to draft a well-organized and easy to read drawing is crucial. There are hundreds of drawing with very specific details that must be created and understood by everyone involved in the project to avoid any miscommunication, construction mistakes, and potential delays or economic losses. There are a wide variety of drawings that range from structural, construction, part and components, and architectural drawings just to mention a few. The fabrication and installation of the steel embeds is a task that requires engineering responsibility because the steel embeds are the connection points between the cladding panel and the main structure; failure to fabricate and detail the steel embeds properly can cause the cladding panel to fall of the structure with potentially detrimental consequences.

Talking to fabricators to order the steel embeds is one of the "time and construction management" skills that NEES-REU students are learning. There is no other way to get skilled on this besides picking up the phone and talking back and forth with different fabricators and the project treasurer. There are several things that must be discussed and clearly understood by all parties even for small steel parts like the steel embeds. For example, fabrication and raw material cost, delivery cost, delivery time, and quality of work. All of these can vary depending on the amount of steel pieces needed, the available budget, and the required time and place for delivery. On top of the fabrication of the steel embeds, there are many other tasks to be managed in order for the steel embeds to move from initial design to installation in the structure by the contractor. NEES-REU students were in communication by email, phone, and meetings with different key people to coordinate several undertakings and make sure that everyone, from the professional engineer to the contractor, is able to complete individual assignments to achieve a common goal. It is necessary for all of these issues to be resolved and agreed upon in a timely matter to avoid construction delays, economic and/or material losses.

The only way to keep the building construction on schedule and on budget is to have a safe working environment. NEES-REU students have experienced a big change of environment from the safe university library, to the hazardous construction site. A construction site like the one at ESEC is a hazardous place to be and it can potentially turn dangerous without safety precautions and training. On the firs week of the project, students were given the necessary personal protective equipment (PPE) including steel-toed boot, a hard hat, and safety glasses and gloves. Students attended an Injury and Illness Protection Program (IIPP) and a safety tour of ESEC. Furthermore, students are learning how to properly use power-tools and construction equipment, work with chemicals, and follow laws and regulations at a construction site. Every ten days students, staff, and contractors meet to exclusively discuss safety topics, concerns, and/or hazards that everyone must be informed to have a safe and injury-free working environment. Without proper training and safety regulations construction can't continue as planned. Just like they say in every safety meeting; "Everyone is responsible for everyone's safety and we are all supervisors of each other."

9.0 REFERENCES

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