July 2009

SeismicWaves

How the National Earthquake Hazards Reduction Program Is Advancing Earthquake Safety

Safely Spreading the Benefits of Precast Construction

The Diaphragm Seismic Design Methodology Project

Should scientific research advance knowledge, commercial activity, or the public good? These objectives are sometimes viewed as competitors in a zero-sum game or as rivals for increasingly scarce societal resources. The Diaphragm Seismic Design Methodology (DSDM) Project is serving all of these objectives, however, and that is just one of several attributes that make this a remarkable research effort.

A Convergence of Interests

Precast concrete structures, particularly parking garages, were among the types of buildings found to be vulnerable when a powerful earthquake struck Northridge, CA, in 1994. This event heightened concerns about the safety of the floors in these structures, which not only support building contents, but also help the building withstand the side-to-side movements induced by earthquake ground shaking. Several kinds of reinforcements are built into precast floors to form *floor diaphragms* intended to resist lateral forces while maintaining vertical support.

The diaphragms used in regions of high seismicity, both before and since the Northridge disaster, have been the subject of economic as well as safety concerns. Cast-in-place concrete toppings are typically applied over precast floors in these areas to resist lateral forces. This adds to the time and materials required for precast construction, negating the economic advantages that normally incentivize its use. That has made the superior durability and quality associated with precast construction less available to those living and working in earthquake-prone regions. Precast construction is used in a variety of structures, including parking garages, dormitories, hotels, stadiums, prisons, and office buildings.

In the decade following the Northridge earthquake, it was recognized that definitive improvements in the design of precast concrete diaphragms would require more fundamental knowledge about the seismic behavior of these structural elements. In 2003, a convergence of interests—in making precast diaphragms safer, in spreading the advantages of precast construction to seismic zones, and in generating the scientific knowledge needed to enable these advancements—gave rise to the DSDM project.

Integrated and Comprehensive

The DSDM project, which got under way in 2004 and will be completed in 2011, has successfully integrated research activities in comprehensive and challenging ways. This is reflected in the number of organizations and individuals involved, the scope of the objectives pursued, the range of diaphragm behaviors examined, and the mix of design approaches and research methods employed in the project.

The consortium formed to carry out the project includes engineering research teams located at the University of Arizona, at Pennsylvania's Lehigh University, and at the University of California, San Diego (UCSD). A panel of industry experts, the DSDM Task Group, helped plan the scope of the project and is guiding the implementation of project results. This group includes several members and staff from the Precast/Prestressed Concrete Institute (PCI), a leading industry trade organization. PCI member companies have donated precast products for use in DSDM experiments, and PCI has provided major funding for the project. Co-funders include the Charles Pankow Foundation, which supports the advancement of construction speed and efficiency through innovations in precast structural design, and the National Science Foundation (NSF), which, through its participation in the National Earthquake Hazards Reduction Program, supports fundamental research in structural earthquake engineering and other areas.[1]

The DSDM project has three primary objectives: (1) to advance knowledge of the seismic behavior of precast floor diaphragms; (2) to use this knowledge to create a methodological framework for diaphragm design, to design diaphragms suitable for regions of high seismicity, and to develop a diaphragm design procedure for use in such regions; and (3) to implement this design procedure industry-wide. To accomplish these objectives, DSDM researchers have studied the full range of behaviors that interact to determine the seismic response of floor diaphragms. These include the behaviors of the individual connections and joints that link floor segments to each other and to other parts of the structure, of the diaphragm as a whole, and of the entire structure.

[1] Additional information about NSF support for the DSDM project is available at www.nsf.gov/awardsearch/ under award numbers CMMI-0324522, CMMI-0402490, and CMMI-0623952.

The researchers have also conducted a tightly integrated mix of experimental testing (involving precast concrete specimens) and analytical simulations (involving computer models of such specimens). At Lehigh University, which houses one of the 15 research facilities that make up the NSF-supported George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), the project team experimentally tested samples of diaphragm connections currently in use. The results were used at the University of Arizona to develop computer models of floor diaphragms, study the capacity of these diaphragms to resist seismic forces, and design improved connections. The new connections were used in diaphragm joints tested back at the Lehigh NEES facility, and the diaphragm models were incorporated into models of precast structures at UCSD.

Half-scale parking structure on the NEES shake table at UCSD in 2008. Courtesy of UCSD Jacobs School of Engineering.

UCSD researchers subjected these computer models to earthquakes by simulating the types of ground motions that would be expected to occur in four localities with differing seismic hazards (Berkeley, CA; Charleston, SC; Knoxville, TN; Seattle, WA). Based on these simulations, they developed estimates of the mathematical values or "design factors" that their methodological framework indicated were needed for the design of precast diaphragms.

Culmination and Outcomes

DSDM experiments culminated in the summer of 2008 at the NEES facility located in UCSD's Englekirk Structural Engineering Center, which features the largest outdoor shake table in the United States. The UCSD project team constructed a three-story, half-scale precast parking garage on the shake table utilizing the diaphragm design factors, connections, and joints developed in the project.

The researchers subjected this building to a series of 15 simulated earthquakes, each lasting about 20 seconds. The shake table generated the same range of ground motions that UCSD had earlier used in its computer simulations—but this time a real structure underwent real shaking. Hundreds of sensors installed throughout the building recorded a wealth of data about the seismic responses of the floor diaphragms and other elements of the structure.

By comparing these responses to those predicted by their computer models, the DSDM researchers can fine-tune the models to ensure that they accurately represent the seismic behavior of precast floor diaphragms. This critical process is now well under way, and as the models are finalized, they are being used to fine-tune the estimates of diaphragm design factors. These factors, in turn, are being incorporated into a new procedure for designing diaphragms, which the researchers are documenting in a comprehensive design document entitled "Draft Seismic Design Methodology for Precast Concrete Diaphragms."

The DSDM consortium expects to complete this document in 2010. In addition to the design procedure and a classification of prequalified diaphragm connections, the Methodology will feature design examples based on prototypical precast structures. Engineers nationwide will be able to use this resource to design reliable and economical precast diaphragm systems for regions of high seismicity as well as areas that are less seismically active.

The DSDM Task Group is working with PCI on plans for disseminating the Methodology through PCI's Web site and technical literature. Task group members have also begun to shepherd the design procedure through the standards-development processes of the American Society of Civil Engineers and American Concrete Institute. These organizations coordinate the development of key national standards relating to seismic design and construction; these standards, which are expected to be updated next in 2011, are incorporated by reference into the *International Building Code*, which U.S. states and localities use to regulate building design and construction.