

Research

Steel Diaphragm Innovation Initiative Improves Seismic Design Tools

Researchers pave the way for future explorations that could speed up construction of steel frames



The five-year research program considered the seismic design of corrugated metal decks, with and without concrete topping, as a diaphragm system that is an integral part of the steel structure.

Photo courtesy Canam, Vulcraft, Steel Deck Institute

In a few months, Northeastern University expects to make research history by testing the behavior, under seismic loads, of a full-scale, composite, concrete-filled steel-deck diaphragm system. The novel experiment culminates unprecedented collaborative research on the seismic performance of steel floor and roof diaphragms in steel structures. The five-year initiative already has aligned and improved design methods and relevant standards used throughout the U.S., not merely in high-seismic zones, according to those involved.

The program not only validates current design practices for different steel structures, it also promises to improve the seismic design and behavior of “bare” and concrete-topped decks under earthquake loads, says Ben Schafer, a professor of civil engineering at Johns Hopkins University and principal investigator for the nearly \$2-million Steel Diaphragm Innovation Initiative. The design tools developed allow “more reliable designs” for seismic performance and offer slight efficiency gains that can result in the application of less concrete as a deck topping, Schafer says.

The findings also pave the way for future explorations that could speed design and onsite construction. These include the study of modular deck systems and bare metal floor decks that are free of concrete topping, says Schafer.

Known as corrugated metal decking, steel diaphragms are ubiquitous in steel frames. They are considered advantageous because they are relatively low weight, use recycled material and offer potential redundancies from a large number of connection points between the diaphragm and other structural elements, say the sponsors of the initiative, which include the American Iron & Steel Institute (AISI), the American Institute of Steel Construction (AISC), the Metal Building Manufacturers Association, the Steel Deck Institute, the Steel Joist Institute, the Cold-Formed Steel Research Consortium and structural consultant Walter P Moore.

The investigation has resulted in the adoption of new provisions in seismic codes and standards that will increase the already high level of seismic safety of steel buildings, according to AISI, which, along with the other sponsors, is trying to make steel structures more attractive to engineers.

“These efforts expanded the capabilities of structural engineers to successfully employ steel in seismic diaphragm systems in essentially any situation,” say the authors in a 101-page final report on the research, published in March by AISI and released last month.

Until the recent research, funded by \$1.4 million from the sponsors and \$540,000 from the National Science Foundation, data had not been compiled and research was largely focused on the strength of isolated systems instead of ductility or whole-building performance, according to participants.

The initiative involved myriad design simulations and physical testing. The work resulted in a better understanding of diaphragm-structure interaction. That in turn led to new design approaches and new 3D modeling tools, say the researchers.

Under the study, researchers considered steel diaphragms as a system that is an integral part of a building.

“The ductility in these systems can be quite good and helps to address any variability in forces that might occur due to the variability in earthquakes,” says Jerome Hajjar, a professor of civil engineering at Northeastern University and a co-principal investigator, with professors of civil engineering Matt Eatherton, at Virginia Polytechnic Institute and State University; and Sam Easterling, at Iowa State University. In total, there were 21 investigators involved in the research.

Unified Design Requirements

“The project unified design requirements, creating a cohesive basis” across the National Earthquake Hazards Reduction Program Provisions and relevant standards from the American Society of Civil Engineers, AISC and AISI, says Charlie Carter, AISC’s president. The unified requirements also will render the next edition of the model International Building Code “similarly cohesive,” he adds.

Achieving corresponding changes in the standards required “extensive coordination” among the standards-writing committees, says John D. Hooper, director of earthquake engineering at Magnusson Klemencic Associates and an ASCE 7-22 committee member.

Specifically, there are changes to the design approach for steel floor and roof diaphragms in AISC 342, ASCE 7-22 and AISI 400. The changes include establishing special seismic detailing requirements to ensure ductility and deformation capacity in steel-deck diaphragms and establishing the diaphragm design force reduction factor, called R_s , for bare-steel deck diaphragms using special seismic detailing and concrete-filled steel-deck diaphragms.

“For the first time, engineers are able to reliably provide ductility and deformation capacity in steel-deck diaphragms,” says Hooper. This will be especially helpful in the design of rigid-wall, flexible-diaphragm structures where the ductility comes from the roof diaphragm, he adds.

For this, researchers expanded building archetype designs. They performed thousands of nonlinear time-history analyses of 3D steel buildings and validated the alternative-diaphragm design procedures for concrete-filled steel decks and for bare steel decks in buckling restrained braced frames and concentric braced frames.

The program kicked off in 2015. The final report is available for free download on the AISI website, under “reports.”

To date, research has been conducted in the form of cantilever diaphragm tests, generally designed to identify the effect that one factor has on strength and behavior of the system. The Northeastern test system builds off the knowledge gained from these previous tests but advances beyond typical assumptions and necessary simplifications of cantilever diaphragm tests, says Hajjar.

The Northeastern, multi-bay test program is intended to document the inherent strength and ductility in typical composite diaphragms and provide a baseline test for future exploration of innovative diaphragm designs. The 28-ft by 20-ft specimen includes two chord members that span 28 ft and two collector members that span 20 ft. Findings will be appended to the final report.

To fill knowledge gaps, the five-year program focused on traditional floor systems. Time was limited for study of irregular situations, such as floor cutouts, irregular floor plans and eccentric architecture, which create unusual demands on the diaphragms.

Schafer hopes to study special cases in the future, along with bare decks and modular systems. For now, the focus is on educating practitioners about changes in the codes and standards so they can take advantage of the advances.

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