Deconstructible and robust bridges for the future

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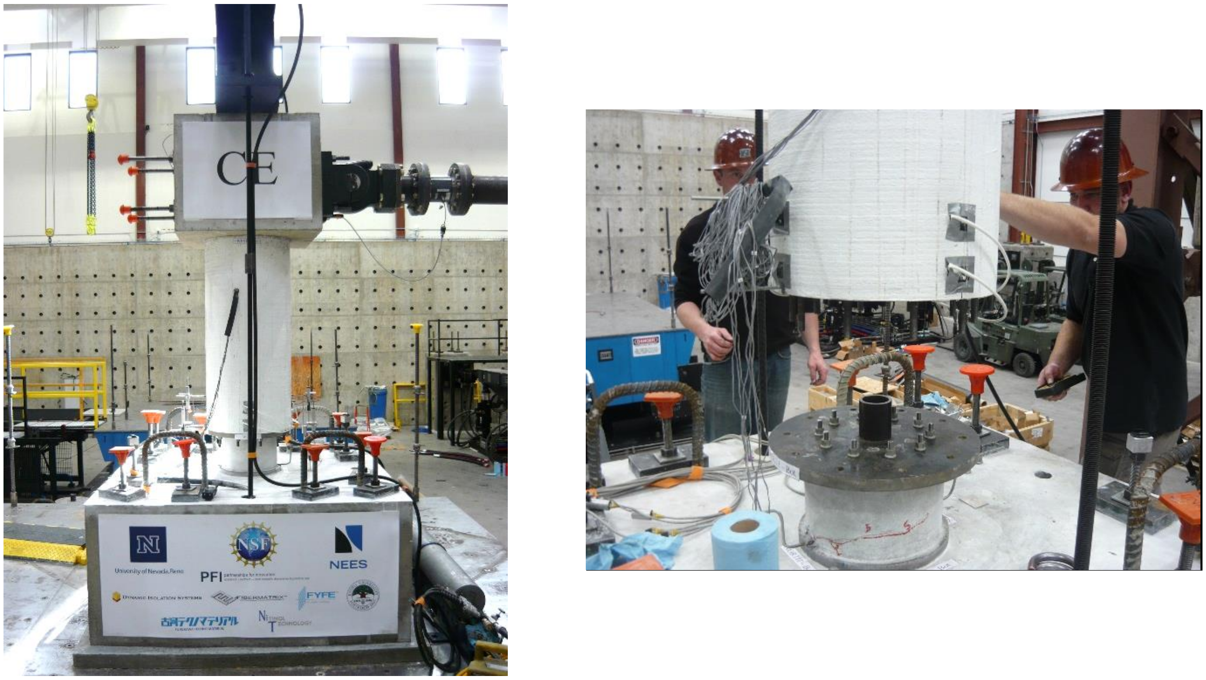
Have you ever thought about what happens to reinforced concrete bridges when, because of age, damage, or obsolescence, they are decommissioned and have to be torn down? How much of the concrete and steel debris do you think is actually recycled or can be reused? Not a whole lot! In fact, most -if not all- of the concrete demolition waste in the United States ends up in landfills. Why is that? Because bridges and bridge components are not designed to be recycled or reused, like auto parts or electronics. The end result is a significant environmental impact because manufacturing new construction materials leads to waste, energy consumption, and greenhouse gas emissions, all of which could contribute to climate change.

Now think about how concrete bridges are designed to resist earthquakes. Like the majority of structures, most highway bridges are designed to prevent collapse and to possibly minimize the loss of life under a high level of ground shaking. Designing run of the mill structures to remain elastic and damage-free under a strong earthquake is cost-prohibitive. Besides, in this competitive and economically conscious environment, every owner wants to get the 'best bang for the buck'. The outcome? Extensive damage and permanent tilting of the bridge after strong earthquakes even when the bridge meets the design objective of collapse prevention. Look for example, at what happened in California after the 1989 Loma Prieta and 1994 Northridge earthquakes. Many bridges were left severely damaged and had to be rebuilt, costing money and headache to the taxpayers because of the resulting massive traffic disruption. In fact, it does not take much for an earthquake to leave a bridge out of commission, because even a relatively small permanent tilting in the columns can send the bridge to the junkyard as it is unsafe to keep it open to traffic under those conditions.

A team of researchers at the University of Nevada, Reno (UNR), under a project funded by the National Science Foundation through the Partnerships for Innovation (PFI) program, recently developed and tested a bridge system meant to address some of the aforementioned shortcomings in modern reinforced concrete bridges. The system is made of several prefabricated components that can be built at a plant and then rapidly assembled onsite, increasing construction speed and safety, which has been the overarching trust of the accelerated bridge construction (ABC) trend that is becoming commonplace in several states. Although a number of earthquake-resistant ABC systems have been developed in the last two decades, the one developed at UNR is unique because it is designed to be deconstructed and reconstructed. This feature would facilitate reusing components and recycling materials when a bridge reaches its useful life, and would ease the repair, upgrade, and maintenance of existing bridge components.

The new system is comprised of concrete columns that have two main pieces, one that constitutes most of the column is designed to remain elastic and the other is a replaceable fuse element at the end that dissipates the energy from the earthquake with minimal damage. The latter is known as the plastic hinge in earthquake engineering. The elastic behavior in the first piece is accomplished by using a prefabricated concrete-filled fiber-reinforced polymer (FRP) tube that provides confinement and shear capacity to the column and is also a stay-in-place form. The second piece comes in different forms each equipped with different low-damage advanced materials such as engineered cementitious composite (ECC), shimmed elastomeric bearings, and superelastic shape memory alloy (SMA) bars. ECC is a type of high-performance cementitious composite that has special fibers and admixtures that increase its tensile ductility and strength and prevent spalling under compression. On the other hand, superelastic SMAs are materials that are able to return to their initial shape with minimal permanent stretching upon removal of the applied stress. Both ECC and shimmed flexural elastomeric bearings were used to prevent concrete spalling and loss of capacity in the zones of the column where concrete damage was expected to take place in an otherwise conventional reinforced concrete column. Instead of mild steel bars, longitudinal SMA bars were used as reinforcement inside the plastic hinge elements to provide energy dissipation and flexural capacity to the column. Due to the superelastic properties of SMA, the bars were able to effectively recenter the columns (bring the column back to the upright position). The effective mitigation of damage and the fact that the columns remained plumb, showed the potential of the system in keeping a bridge serviceable even after a strong earthquake.



Three ¼-scale column models were tested under simulated earthquake motions at the multi-shake-table facility at the University of Nevada, Reno. The test variables included the type of replaceable element at the base of the column and the type of reinforcing superelastic alloy, and each column was tested, disassembled, reassembled, and tested again.

The experimental program consisted first of testing three ¼-scale individual bridge column models under simulated strong near-fault ground motions from the 1994, Northridge, California earthquake. To proof-test the potential for disassembly and reuse of the new system, each column model was disassembled and inspected after the tests, and subsequently reassembled and retested. The disassembly and reassembly procedure was found to be feasible and led to a comparable seismic performance of the reassembled models relative to the original models. To further study the seismic behavior of the new elements at the system level, the researchers tested a three-bent, two-span bridge approximately 70 ft. long under simulated earthquakes on three shake-tables. The input ground motions were also from the 1994, Northridge earthquake, and were of an impulsive nature that tends to cause large permanent tilting in reinforced concrete columns. In the same way it had been done for the individual columns, the two-span bridge model was tested under a series of earthquake motions, and then was disassembled and inspected, and then reassembled and retested. The low damage of the replaceable elements along with negligible permanent tilting of the bridge even under strong earthquakes demonstrated once more the feasibility of the new bridge system. The researchers concluded that the seismic behavior of the reassembled bridge was very similar to that of the original bridge. The study has been a total success in demonstrating the proof of concept, but there is still a lot of work to be done before the new system can be deployed in the field.

For more information visit: http://wolfweb.unr.edu/homepage/saiidi/NSF-PFI/index.html

The new system was successfully evaluated by testing a two-span bridge model and the bridge was then disassembled and reassembled, and subsequently retested