capacity of the SMA and ECC were reached. The test results showed a significant reduction in permanent displacement and limited damage as compared to the conventional construction.

Test result of SMA and ECC column.
(credit: University of Nevada – Reno)

Research Funding

The WSDOT Research Office and the Federal Highway Administration (FHWA) teamed together to grant funds to support the project. FHWA funds were awarded through the Innovative Bridge Research and Development (IBRD) Program, which is a part of their Special Federal-aid Funding Program. The IBRD Program's purpose was to promote innovative designs, materials, and construction methods in the construction, repair, and rehabilitation of bridges and other highway structures. The funding amount provided to perform structural testing, procure the innovative materials and document the implementation was $400,000 (FHWA) and $20,000 (WSDOT).

Websites:

WSDOT Bridge Design Manual – Chapter 14 – Accelerated an Innovative Bridge Construction:

http://www.wsdot.wa.gov/publications/manuals/fulltext/M23-50/Chapter14.pdf

WSDOT Project Website:

http://www.wsdot.wa.gov/projects/viaduct/

University of Nevada – Reno Research Website:

http://wolfweb.unr.edu/homepage/saiidi/WashDOT/index.html

WSDOT Research Website:

http://www.wsdot.wa.gov/Research/default.htm

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Washington State Department of Transportation
SEPTEMBER 2016

Shape Memory Alloy and Engineered Cementitious Composite

Shape Memory Alloy (SMA)

Shape memory alloys are a special type of metal that are manufactured from either a combination of nickel and titanium, or are copper based. These alloys have been used in robotic, automotive, biomedical, and aerospace applications. For an innovative bridge application, the metal is shaped into round bars and replaces steel rebar in certain locations of bridge columns.

Steel rebar used in bridges are similar to paper clips. If bent a little bit, it will spring back to its original shape. It can be bent up to the yield point and it'll return. If bent too much, the paper clip won't spring back and it has exceeded the yield point. Earthquake energy is dissipated using this current seismic design philosophy, by stretching steel rebar beyond the point to it won't spring back.

For SMA, the alloy will deform like steel beyond the yield point, but it will spring back. This means the alloy is superelastic. Energy can still be dissipated by stretching the SMA and once the earthquake motions subside, the SMA will return to its original shape.

The SMA isn't needed for the entire height of the column and compared to steel rebar, it is expensive. So, the SMA is only used in certain regions of the column. It is connected to steel rebar using couplers. The couplers require the SMA and steel to be headed at the ends. The coupler slips over the head and screws together, to attach the SMA to the steel rebar.

Bridge column rebar with SMA coupled to steel rebar.

SMA to steel rebar coupler unassembled.
(credit: University of Nevada – Reno)

Engineered Cementitious Composite (ECC)

Engineered cementitious composite is substituted in the column wherever the SMA is located. ECC is similar to conventional concrete, except that is has an added ingredient. Small polymer fibers are mixed in to stop cracking when columns are bent during an earthquake. The properties of ECC have led it to be nicknamed bendable concrete. If conventional concrete was used with SMA, the concrete would break up when the large forces of an earthquake shook the bridge.

Acceptable earthquake damage from Nisqually Earthquake.

Acceptable earthquake damage.

Current Seismic Design Philosophy

The current seismic design philosophy for the majority of bridges is to maintain life safety by providing a low probability of collapse. It is uneconomical to construct a bridge that can withstand expected earthquakes without some damage. So, significant damage to some elements of a bridge is considered necessary and acceptable. For concrete columns, damage could include concrete cracking and/or spalling and rebar stretching. These could lead to permanent deflection or considerable leaning of the bridge.

The damaged conditions may require the bridge to be restricted to limited access, or the bridge may be closed. Potential damage may even restrict emergency vehicle from access to the bridge.

The location where this damage occurs is in the hinge region of columns. Generally, these are in the vicinity of the top and/or bottom of columns, where they connect to either the foundation or crossbeams. They should be in places where an engineer could inspect the damage and access whether the bridge can continue carrying traffic or should be closed.

The repair of columns may require patching of broken up concrete, shoring for entire column replacement or even complete bridge replacement. These repair and their costs can be significant hindrance to the states infrastructure.

Use of SMA and ECC for Seismic resilience

Introducing SMA and ECC in the hinge regions of columns can improve seismic resilience, by keeping bridges open to traffic after an earthquake and minimize column damage. Using SMA has been shown to significantly reduce permanent deflection. ECC is used to eliminate considerable cracking and spalling in the hinge region.

The use of SMA and ECC could permit a bridge to be used by traffic without significant repairs immediately after an earthquake. This will limit the impact to the traveling public and provide critical access to emergency response vehicles during response efforts.

SR 99 Alaskan Way Viaduct Replacement Off-Ramp Bridge. (credit: Parsons Brinckerhoff's Design Visualization Group)

Bridge Description

The first bridge in the world to innovatively incorporate SMA and ECC into column construction will be in Seattle, WA. The bridge is part of the SR 99 Alaskan Way Viaduct Replacement program and will be located at the south end of the new tunnel, near CenturyLink Field and Safeco Field. The two lane off-ramp bridge will be composed of three spans of precast post-tensioned segmental concrete tub girders.

The innovative materials won't be noticeable. Like all other bridges where concrete encases the steel rebar, the ECC will encase the SMA bars. And the ECC will look like all the other concrete in the bridge.

Research Testing

Testing is needed to prove any new innovative materials will work in an actual bridge. The research team at the University of Nevada – Reno, led by Dr. M. Saiid Saiidi, have been testing SMA and ECC with all various types of equipment. They've tested the materials in tension, compression, bending and shear. They've also used their shake-tables to simulate a real earthquake with a quarter-scale bridge.

SMA/ECC scale bridge on shake table. (credit: University of Nevada – Reno)

Three scaled down bridge columns were tested to evaluate the performance of SMA and ECC. Two columns were constructed with SMA and ECC. The other column was similar to the current column construction using conventional concrete and steel rebar, used to compare and contrast the results of the SMA and ECC.

Each column was subjected to displacements similar to an actual earthquake. The columns were pushed and pulled at increasing stages. Tests incremented with higher and higher force until the ultimate

University of Nevada – Reno research test specimen. (credit: University of Nevada – Reno)

Test result of conventional steel rebar and concrete column. (credit: University of Nevada – Reno)