# Super-Elastic Copper-Based and Iron-Based Shape Memory Alloys and Engineered Cementitious Composites for Extreme Events Resiliency

## Background:

Displacement capacity and energy dissipation in conventional RC columns comes at the cost of severe damage to concrete and steel and permanent displacement of the bridges and other structures including marine structures during extreme events such as earthquake, ice load, collision by vessels and vehicles, tsunamis, check floods, and blasts. The resiliency of these structures can be significantly increased if these problems can be eliminated using shape memory alloy (SMA) and engineered cementitious composite (ECC). Comparison of residual displacement in laboratory testing of column models demonstrated that residual displacement was 86% lower than that the columns with conventional materials. The Washington State Department of transportation (WSDOT) implemented SMA/ECC in the columns of the SR-99 on-ramp bridge in downtown Seattle. With the price of Nickel-Titanium SMA (NiTi) being 90 times the mild steel cost, bridge owners may be reluctant to adopt the material. To offset SMA material costs, a new generation of Copper-Aluminum-Manganese (CAM) SMA bar that is approximately 80-90% less expensive than NiTi is emerging. The alloy is composed of 72% Copper, 17% Aluminum, and 11% Manganese. No. 10 CAM bars have been developed and were recently tested along with Headed Reinforcement Corp's (HRC) couplers at University of Nevada – Reno (UNR) with good results, i.e. large-diameter bars for use in actual bridges have already proven to be feasible. CAM bars are connected to steel bars that extend into the column and footings or cap beams. No CAM-reinforced columns incorporating the (HRC) splice has yet been studied, however, an exploratory study was conducted by shake table testing of a column model incorporating threaded CAM bars. These bars had to be machined to a dog bone shape to avoid fracture at the threaded ends. Engineered Cementitious Composite (ECC) was used in the plastic hinge region. ECC is a fiber-reinforced cement-based concrete which has high tensile ductility and high compressive and tensile strengths. The column performed very well in limiting residual displacement while eliminating plastic hinge damage. Another SMA type, the low-cost iron-based SMA is also emerging, although its performance under extreme loads is yet to be studied. The advantage of Fe-SMA over CAM, should it prove successful, is having material characteristics that are similar to those of conventional steel that is readily used in bridge construction while being at a low cost.

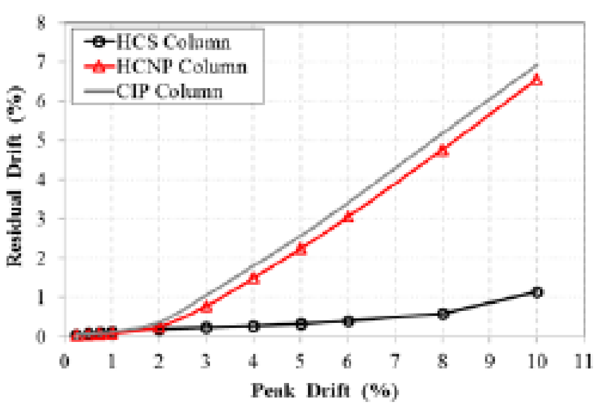


Fig. 1- Residual drift for RC vs. SMA/ECC

Fig. 2- CAM bars with HRC couplers


Fig. 3- Damage after 3.5 time design earthquake

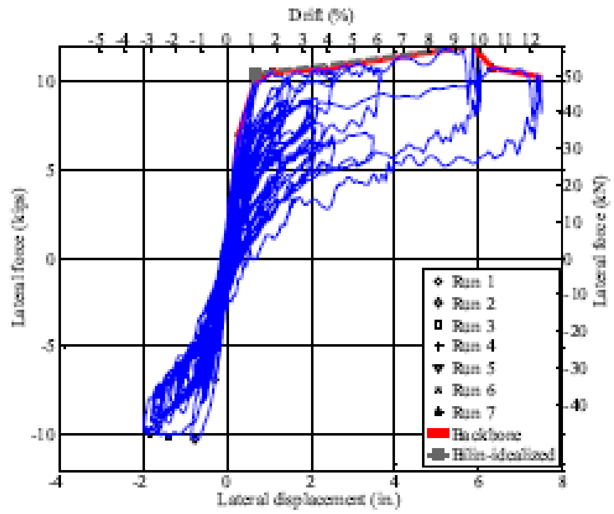


Fig. 4- Measured hysteresis curve

**Objectives:**

The objective of this research project is to 1) evaluate and test several innovative columns which have self-centering feature to provide minimum residual displacement after earthquake; 2) improve column serviceability after earthquake by decreasing damage and spalling of concrete within column plastic hinge region; and 3) provide cost comparison among columns having different engineered materials; and 4) develop self-centering column design specifications. Particularly, in this proposed research, the low-cycle fatigue characteristics, corrosion resistance, machinability and coupling mechanisms with traditional steel rebar, and cost of CAM and Fe-SMA super-elastic alloy (SEA) bars will be studied. Direct comparisons will be made with Nickel-Titanium (NiTi) SEAs (and traditional steel reinforcing bars as applicable) to illustrate the advantages/disadvantages of each material. If successfully demonstrated for their suitable characteristics, the CAM and Fe-SMA SEA bars could replace their NiTi counterparts at a significantly lower (up to ten times) cost and accelerate their applications in bridges. Therefore, the outcomes of this project are directly relevant to state departments of transportation and bridge and structural engineers and designers. This proposed project will build on the success of previously implemented WSDOT's application of shape memory alloy/engineered cementitious composite (SMA/ECC) in the columns of the SR-99 on-ramp bridge in downtown Seattle while making a direct impact on advancing and securing the national transportation network.

**Scope of Work:**

**Phase 1** ($120,000, 12 months)

• Task 1: Test CAM and Fe-SMA SEAs under repeated cyclic loading to determine low-cycle fatigue lives at three different temperatures: -40°C, 25°C and 50°C. Compare to NiTi SEAs and steel rebar.

• Task 2: Based on the material properties obtained/compared in Task 1, conduct moment curvature analyses on various cross sections to find optimal combinations of CAM, Fe-SMA, steel and ECC that result in hinge properties offering superior seismic performance.

**Phase 2** ($280,000, 24 months)

• Task 3: Conduct cyclic/dynamic test on large-scale column models incorporating large-diameter CAM bars and Fe-SMA to assess resiliency of the new generation of SMA/ECC combination.• Task 4: Perform both cyclic polarization testing and long-term salt spray testing followed by gravimetric mass loss and mechanical loading to determine corrosion characteristics.

• Task 5: Quantify the cost impact of using CAM and Fe-SMA SEAs by comparing representative conventional bridges and their SMA/ECC counterparts.
• Task 6: Develop design specifications and illustrative examples.

### Comments:

Pooled fund participation is considered for states subjected to seismic and other extreme events for their contribution. This three-year research project is estimated to cost $400k and we are seeking commitments of between $20 k to $30 k per state depending upon the number participating. FHWA has also indicated their support and their contribution will depend on the number of states making a commitment to participate. The study will be initiated immediately the Phase 1 threshold funding is obligated for funding.

**Subjects:** Bridges; Resiliency; Extreme Events; Seismic; Tsunami; Hurricanes, Flexible Structures; Marine Structures; Hydraulics and Hydrology ; Materials and Construction ; Safety and Human Performance.