TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT
Q3/2023

Lead Agency:

Washington State Department of Transportation (WSDOT)

INSTRUCTIONS:

Lead Agency contacts should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project #	**Transportation Pooled Fund Program - Report Period:**
TPF-5(491)	☐Quarter 1 (January 1 – March 31) ☐Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☐Quarter 4 (October 1 – December 31)

TPF Title (follow link to TPF webpage)**:**

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

Lead Agency PM: Mustafa Mohamedali, PE PMP	**Lead Agency PM Phone:** 360-704-6307	**PM E-Mail**: mohamem@wsdot.wa.gov
Lead Agency Technical Lead: Amy Leland, PE SE	**Lead Agency Tech Lead Phone:** 360-705-7181	**Tech Lead E-Mail**: LelandA@wsdot.wa.gov
Principal Investigator(s): Bora Gencturk/USC Saiid Saiidi/UCLA	**PI Phone Contact:** 213-821-1036	**PI Email:** gencturk@usc.edu
Lead Agency Project ID: UCB 1874	**Other Project ID (i.e., contract #):** T-1874	**Project Start Date:** 2022-12-01
Original Project Start Date: 2022-12-01	**Original Project End Date:** Phase 1 - 2023-11-30 Phase 2 – 2025-11-30	**If Extension has been requested, updated project End Date:** N/A

Project schedule status:

☐ On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

(A) Overall Project Statistics:

Commitments to date $ (3yrs)	Obligations to date $	% Obligated	Contracted to date $	Expended to date $	Expended to date as % of $ contracted	Completed this quarter $
290,000	210,000	72.41%	120,000	97,083	80.90%	43,373

(B) Project Description:

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.

(C) Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

The remaining low-cycle fatigue tests on NiTi and NiTiCo bars have been completed. With these final tests, the experimental program in Phase I of this project has been successfully completed. Additionally, significant progress has been made in terms of moment-curvature analysis of column cross-sections that are reinforced with either of NiTi, NiTiCo or Cu-Al-Mn shape-memory alloys (SMA). All the geometric parameters of the models as well as material properties have been finalized. The parametric moment-curvature analyses considering the column diameter, reinforcement ratio and the axial load index have been mostly completed for the three materials.

(D) Anticipated work next quarter:

The remaining work in the next quarter is to finalize the moment-curvature analyses, process the results, and prepare the final report for Phase I of the project.

(E) Significant Results:

The yield strength of Ni-Ti-Co was found to be around 650 MPa (94 ksi), which is 60% higher than Ni-Ti SMA (around 400 MPa, 58 ksi). The maximum recovery strain (superelastic limit) and fracture strain of Ni-Ti-Co were found as 7% and 7.5%, respectively, both of them are close to Ni-Ti SMA (superelastic limit of 7%, and fractures train of 8.5%). At room temperature (23 °C), the fatigue life of Ni-Ti-Co SMA was observed to be close to that of Ni-Ti SMA, both of which fractured after around 100 cycles of 5% strain fatigue loading. The yield strength and energy dissipation of Ni-Ti-Co SMA degraded faster than Ni-Ti SMA. At low temperature (-40 °C), the fatigue resistance of Ni-Ti-Co SMA was found to be superior to Ni-Ti SMA (at 0 °C) in terms of the yield strength and energy dissipation, as well as the resistance to residual strain accumulation. Both materials exceeded 400 cycles of 5% strain amplitude prior to failure. At high temperature (50 °C), the energy dissipation and fatigue life of Ni-Ti-Co SMA was found to be not as good as that at 23 °C and -40 °C, and slightly lower than that of Ni-Ti SMA. The stress-strain curves of Ni-Ti-Co SMA narrowed rapidly and fractured within 50 cycles.

In terms of moment-curvature analysis, since Cu-Al-Mn SMA had a lower yield strength than that of Grade 60 steel, to achieve the same flexural capacity as the RC column, the column diameter and reinforcement ratio had to be higher than those of RC columns. To satisfy the clearing space between longitudinal bars, the column diameter of Cu-Al-Mn column had to be about 1 ft larger than that of RC. In some cases, the diameter and reinforcement of the NiTi column had to be increased to match the flexural capacity of RC column. However, since the strength of Ni-Ti SMA is 30% higher than that of Cu-Al-Mn SMA, less reinforcement was needed for Ni-Ti column in comparison with the Cu-Al-Mn column. The high yield strength of Ni-Ti-Co SMA enabled it to achieve the same flexural strength as the RC column without having to increase the column diameter.

(F) Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

As we approach the end of the Phase 1 contract, we have only $90k remaining of the obligated funds from a total of outstanding $190k commitments. Based on this status, we met with the TAC to decide between two options: (1) break-up Phase 2 into smaller chunk of tasks to enable the project to continue until more funds are obligated or to (2) suspend work for now until sufficient funds are received to complete all of Phase 2.

The TAC unanimously voted to continue the work and Phase 2 was broken up into smaller tasks. A task proposal was requested from the researchers for Task 3a and adopted after comments by the SMEs and revision by USC for a task order to the value of $90k. This task includes fabrication and testing of two columns at the end of which, given the funding we will continue with two more columns.

(G) Potential Implementation:

We will have a better idea on the implementation trajectory of the findings on completion of Phase 1 (proof of concept) of this study which will lead to Phase 2, within the scope of this pooled fund, if successful and if adequate funding is committed and obligated to conduct Phase 2. The results of Phase 1 look very promising so far!