Handout CAP 15-049

Living Bridge: Bridge Monitoring with Tidal Energy

1. PROJECT ABSTRACT

This project will create the prototype for a self-diagnosing, self-reporting "smart bridge", powered by a local renewable energy resource, at the Memorial Bridge in Portsmouth, NH. This project promotes infrastructure sustainability on three fronts: by (1) installing a sophisticated structural, environmental sensing network that is (2) powered by tidal energy, while assessing how the tidal turbine (installed at the bridge pier) impacts the bridge structure and environment and (3) deploying an innovative and interactive community engagement strategy. There are several innovations on the Memorial Bridge (gussetless truss member connections) that will be monitored and evaluated through instrumentation and assessed for possible use on other infrastructure projects. Powering transportation infrastructure by locally available renewable energy increases its resilience against long and short-term power-outages and decreases the infrastructure carbon footprint. This "Living Bridge" will be the prototype for sustainable estuarine bridge design utilizing tidal energy.

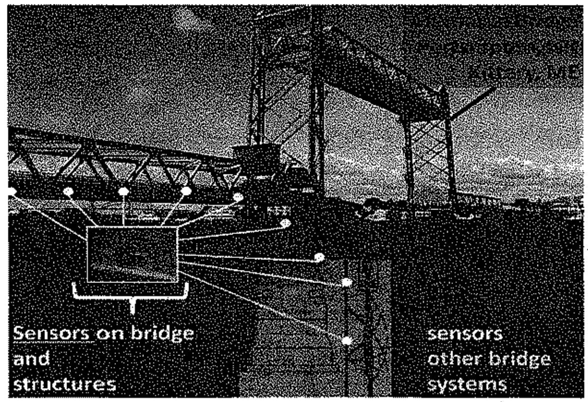

Figure 1: Project overview: installing (1) bridge monitoring and (2) tidal energy systems

2. PROJECT DESCRIPTION

Table 1. Project goals and relationship to TIDP/AID program goals.

	Project Objectives	A	B	C	D	E
1	Deploying sensor network at the Living Bridge for structural health and environment monitoring	X			X	
2	Deploying tidal energy conversion system at the Living Bridge		X			X
3	Monitoring/assessing infrastructure performance (structural integrity and the impact of tidal energy system)	X	X		X	X
4	Enabling the Living Bridge to communicate information related to bridge performance and environment to the local community			X		
	TIDP and AID Goals (Selected)	A	B	C	D	E
A	Improve highway/bridge safety, reliability and service life					
B	Improve highway/bridge sustainability and environmental protection					
C	Improved user satisfaction					
D	Improved tools, technologies, and models for infrastructure management, including assessment and monitoring of infrastructure condition (Title 23-Highway, U.S.C., Sec. 503)					
E	Technology transfer and adoption of ... systems that are designed to minimize environmental impacts (Title 23-Highway, U.S.C., Sec. 503)					

The Memorial Bridge, constructed in 2013, is a "gussetless" truss vertical lift bridge carrying US Route 1 across the Piscataqua River connecting Portsmouth, New Hampshire with Kittery, Maine. This bridge is the only pedestrian link between Portsmouth and Kittery and serves an important infrastructure function connecting the two communities via walking and biking. Working with the bridge design firm, construction firm and owner, HNTB, Archer/Western, and the New Hampshire Department of Transportation (NHDOT), respectively, the Living Bridge team has developed a monitoring system, tidal power conversation system and public outreach program for the Memorial Bridge.

Innovation 1: Bridge Sensors and Monitoring System
NHDOT and the Living Bridge team will install the sensors described in Table 2 on the Memorial Bridge. The information collected from the structural sensors will be used to validate a structural finite element model of the bridge to capture in-service performance for objective bridge management. The sensors and monitoring system will collect data to assess the effectiveness of bridge structural innovations, including the "gussetless" truss connections, metalized steel coating and vertical lift balance system. The impact of the structures on the estuarine environment will be assessed by measuring the water turbidity, underwater noise, tidal currents, and ambient conditions such as wind speed and sea level. The monitoring system will be powered by tidal energy, and will also collect information on the impact of the tidal energy conversion system on the bridge structure and estuarine environment.

Table 2. Sensors proposed for the Memorial Bridge.

Bridge Sensors	
Existing sensors:	Proposed new sensors:
• Pavement • Traffic • Video (pedestrian/bicycle traffic)	• Atmospheric (wind speed and visibility) • Structural (accelerometers and strain gauges) • Underwater (camera, temperature, pH, turbidity, tidal current, water level)
Synergy: Leverage sensors and communication network installed by the NHDOT. Traffic and wind data will be compared to the data measured by the structural sensors; high traffic demand and wind load will increase structural responses.	

Documented Benefits: The project partnership will build on proven technology to advance the state of the art to create a sustainable transportation infrastructure, which is of national and global importance. There are numerous bridges in the US with long-term structural health monitoring: Indian River Inlet Bridge (Delaware), Powder Mill Bridge (Barre, MA), New Carquinez Suspension Bridge (Vallejo, CA) and more. Monitoring bridges systematically will help bridge owners to proactively assess and maintain bridge performance, and reduce cost.

Performance Goals: Table 1 includes the performance goals for each innovation and how they correlate to the TIDP goals.

Measures for the innovation: The cost-benefit of the monitoring and condition assessment system will be evaluated with respect to traditional infrastructure management protocols.

Current institutional experience: The NHDOT manages two bridges with active structural monitoring programs and a traffic management monitoring program dispersed throughout the state. This project will be the first case where structural, traffic and environmental monitoring programs will be integrated together. The results will be used to validate bridge design innovations, traffic pattern predictions and assess the environmental impact on the estuarine environment. Drs. Bell and Fu have significant experience in the area of structural health monitoring and structural parameter estimation [1][2][3][4][5][6][7].

Significant improvement to conventional practice expected: The environmental data collected will provide insight into the local impact on the estuarine environment and will contribute to the water quality monitoring program for the estuary. The instrumentation system will measure the loads transmitted by the turbine support structure to the pier and the bridge superstructure to assess that the connections function as designed and any possible long term damage.

Innovation 2: Tidal Energy Conversion

Tidal energy is a predictable, renewable energy source. Utilizing this locally available renewable energy makes the transportation and environmental monitoring systems independent of weather- or disaster-related power outages. A unique feature of this project is that it leverages the bridge, a structure vital to society, to support the conversion of tidal energy, which will also be used to connect the bridge and its environment to the public in a new and unique manner.

Documented benefits: In-stream tidal energy conversion relies on tide ebbs and floods that are independent of local weather conditions or time of day, unlike solar or wind energy. When coupled with an energy storage system, e.g., a battery bank, it is a reliable power source. The average power density at the bridge site was found to be nominally 500-700 W/m^2 [8], based on Acoustic Doppler Current Profiler measurements from a bottom-deployed long-term survey by NOS/NOAA [9], as well as shipboard transects. The cross-sectional area of the Lower Piscataqua River at the Living Bridge is nominally 3800 m^2; less than 1% will be occupied by the tidal turbine(s) and support structure.

Performance goals: Table 1 includes the performance goals for each innovation and how they correlate to the TIDP goals.

Measures for the innovation: Instrumentation installed on the deployment frame will be used to measure the spatio-temporal structure of the turbulent inflow (tidal energy resource) and the modified flow downstream of the turbine in its turbulent wake, using acoustic techniques.

Current institutional experience with the innovation: Drs. Baldwin and Wosnik have experience in designing and implementing turbine deployment structures and tidal turbines, both for vertical, cross-flow axis turbines as well as in-stream axis hydrokinetic turbines [10][11][12][13].

Significant improvement to conventional practice expected: Significant potential for advancement exists for this innovation: measurement of modification of the mean flow, turbulence and turbulent kinetic energy transport in the tidal stream (by measuring with and without turbine deployed), to near-wake measurements indicating how to achieve performance improvements for turbine arrays or closely-spaced turbine pairs, to gathering valuable data for fluid-structure interaction models. This innovation deployment will advance the adaption of renewable energy conversion for infrastructure management needs.

Innovation 3: Walking STEM Museum (Outreach)

The Memorial Bridge will be set up as a walking STEM museum. Instead of paintings and artist descriptions found in an art museum, the Living Bridge STEM museum will feature various structural members, sensors, the mechanic lift system and other key components of the bridge (Figure 2). Engineers and manufacturers will be showcased (similar to artists in museums) with an emphasis on local connections; the idea is to establish role models for children. Quick

Response QR codes (2D barcodes) will be printed on the descriptions for the public to access additional information using their mobile devices.

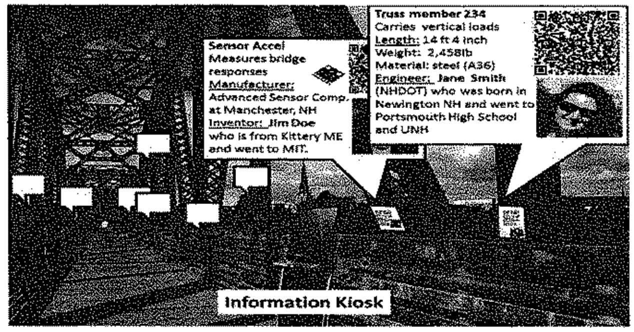

Figure 2. Memorial Bridge as a walking STEM museum; QR codes link to websites with more information on the

Documented benefits: STEM innovation has played a key role in the advancement of society, including improving quality of life and creating jobs and new industries. It is vital to the long-term prosperity of the US to create opportunities for every citizen to be an innovator and that the resulting scientific and technological innovations lead the US in the new millennium [14]. However, the US is falling behind in graduating students (per capita) in the STEM areas, ranking 52nd out of 139 developed and developing nations [15][16][17][18].

Performance goals: Table 1 includes the performance goals for each innovation and how they correlate to the TIDP goals.

Measures for the innovation: The usage information currently being collected by the NHDOT will be used to assess the effectiveness of information STEM-based QR-websites on the bridge structure to create a "Walking STEM Museum" on the bridge structure.

Current institutional experience with the innovation: All parties have outreach experience and will use the resources available at the NHDOT and UNH to create the STEM Walking Museum.

Significant improvement to conventional practice expected: The STEM Walking Museum will create an interactive community engagement program that is typically not available on transportation infrastructure.

3. INNOVATION PERFORMANCE

An outcome of the project will be guidelines to incorporate tidal energy conversion into tidal estuary bridge design and construction. The guidelines will be based on data from the Memorial Bridge on tidal energy conversion, impact on the structural integrity and maintenance needs of the bridge structures as well as environmental impact on estuary and marine life. Sensors and technologies proposed for the Living Bridge will become common for future smart bridges. The data acquired through this project will result in significant cost savings during the life-span of the bridge. Each task listed in the project timeline plays an integral role in the development of a significant advancement in bridge design, construction, management and tidal energy conversion. A series of workshops will be conducted in cooperation with the Technology Transfer Center at UNH during each project year to assess the impact of the innovation.

Assessments of Innovation Performance

Structural Monitoring System	• Compare structural measures/assessments with bridge inspections • Calibrate a structural model for bridge management
Tidal Energy	• Measure how much power is being converted by the turbine; • Compare power converted to power drawn from grid to evaluate if the bridge can be sustainably self-powered.
Walking STEM Museum	• Compare the number of pedestrians using QR codes to the number of pedestrians (an existing NHDOT measure) passing the bridge to assess

impact of the QR code on community engages with the bridge.

Timeline

Year 1	Install sensor network for structure and environment/estuary monitoring system calibrate bridge finite element model from field data record baseline data (without turbine)
Year 2	Install tidal turbine system, record performance data and launch walking bridge museum
Year 3	Assessment of the innovations, change in bridge and estuary behavior due to turbine operation and change in community engagement.

4. APPLICANT INFORMATION AND COORDINATION WITH OTHER ENTITIES

The project applicant is the New Hampshire Department of Transportation, the sub-recipient is the University of New Hampshire. Letters for cooperation with the New Hampshire Department of Environmental Services and the City of Portsmouth are available. The Maine Department of Transportation is interested in the project results as they design the new Sarah Mildred Long Bridge, which also crosses the Piscataqua River, and consider including sensors for structural, environmental and traffic monitoring and tidal turbines for energy conversion, letter available.

5. FUNDING REQUEST:

This project includes a funding request for the entire cost of the installation of the a structural, environmental and traffic monitoring system and personnel ($350K); installation of a tidal turbine system, including a support structure, tidal turbine, generator and battery storage and personnel ($370K); innovative outreach program development for the Memorial Bridge ($50K); travel and supplies to support these efforts ($50 K) and personnel support to evaluate the innovation effectiveness and disseminate the performance and transition of these innovations to other transportation project throughout New Hampshire and New England ($130K).

6. ELIGIBILITY AND SELECTION CRITERIA:

The FHWA/AID program requests proposals which are within six (6) months of being able to be deployed. The Living Bridge project proposed here is an ongoing effort for three years in which NHDOT, the community, university faculty and students and the commercial sector have participated in many exchanges of information to develop this project. The project deployment can occur within six months for the FHWA/AID program.

The FHWA/AID notice of funding availability refers to Section 503 of the TIDP where the TIDP/AID goals are presented. Section C: "Research and technology activities…" has two items listed under which the Living Bridge project is a representative project: item "(x) sustainable infrastructure design and construction", and item "(xv) improved tools, technologies and models for infrastructure management including assessment and monitoring of infrastructure condition".

The efforts in the Living Bridge proposal intersect both of these items in a unique fashion: Making a bridge be 'self sufficient' in terms of generating power from the water moving beneath it and using this power to operate the bridge health monitoring system and environmental loads on the bridge is an improved, sustainable means of performing this task. Tidal energy is independent of local weather conditions and does not require sunlight When coupled with an energy storage system, e.g., a battery bank, it is a reliable source of electric power. This sustainable method of supplying power for bridge health monitoring, even during extreme weather events or prolonged grid outages, will enable a continuous and improved data base for designing and maintaining bridges.

Additional Attachments Yes (PDF files identified by Applicant and Project Title)

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