THE “LIVING BRIDGE” PROJECT: TIDAL ENERGY CONVERSION AT AN ESTUARINE BRIDGE POWERING SUSTAINABLE SMART INFRASTRUCTURE

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INTRODUCTION AND BACKGROUND

The “Living Bridge” project will create a self-diagnosing, self-reporting “smart bridge” powered by a locally available renewable energy source, *tidal energy*. The project will transform Memorial Bridge, a vertical lift bridge over the tidal Piscataqua River connecting Portsmouth, NH and Kittery, ME, into a living laboratory for engineers, scientists, and the community.

As marine hydrokinetic (MHK) energy conversion systems mature, estuarine bridges could serve as an ideal location to deploy turbines. The hydrokinetic resource is often strongest at the narrow locations where bridges are located. The bridge piers could serve as supporting structure for both the bridge and hydrokinetic turbines, and the permitting process for the turbines could take advantage of all the permitting work and studies required for bridge construction. The Living Bridge Project aims to show that these advantages are significant.

The Living Bridge project includes the installation of a tidal turbine on the Portsmouth-facing side of Pier No. 2 at Memorial Bridge. It will power structural health monitoring, environmental and underwater instrumentation. Utilizing locally available tidal energy can make bridge operation more sustainable, can “harden” transportation infrastructure against prolonged grid outages and can demonstrate a prototype of an “estuarine bridge of the future”.

In addition, the deployment location is highly visible and provides excellent opportunity for outreach, which is an integral part of the project.

DEPLOYMENT LOCATION

Tidal Estuary

The Great Bay Estuary (GBE) system is one of the most energetic tidally driven estuaries on the East Coast of the United States. It connects the Gulf of Maine to Great Bay, NH, about 10 miles inland, via the Piscataqua River which forms the border between New Hampshire and Maine. The tidal range in the Gulf of Maine is on the order of 4 m; this causes almost half of the volume of Great Bay to be exchanged each tidal cycle. The overall input of freshwater tributaries to the system is low, representing only 1% or less of the tidal prism under normal conditions. This makes the GBE a tidally dominated, well-mixed system with near ocean salinity. The GBE is well studied and surveyed (1976, 2007) [1, 2] and has been modeled numerically to understand its dynamics and circulation. The first order dynamics of this system and tidal analysis results were discussed by [3]. The M2 tidal constituent is dominant by more than an order of magnitude over the two other semidiurnal constituents N2 and S2.

Tidal Energy Resource Assessment

The Memorial Bridge location is well-suited for a tidal energy demonstration project. While it does not have the fastest currents in the estuary[1], it still reaches tidal current speeds exceeding 2 m/s during spring ebb tides, making it a good “nursery” test site. At the project location, the nominal depth is about 18 m and the maximum tidal range under normal conditions is about 4 m.

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[1] The fastest tidal currents in Great Bay Estuary occur at the UNH Tidal Energy Test Site at General Sullivan Bridge, with max. velocities of 2.8 m/s [4].

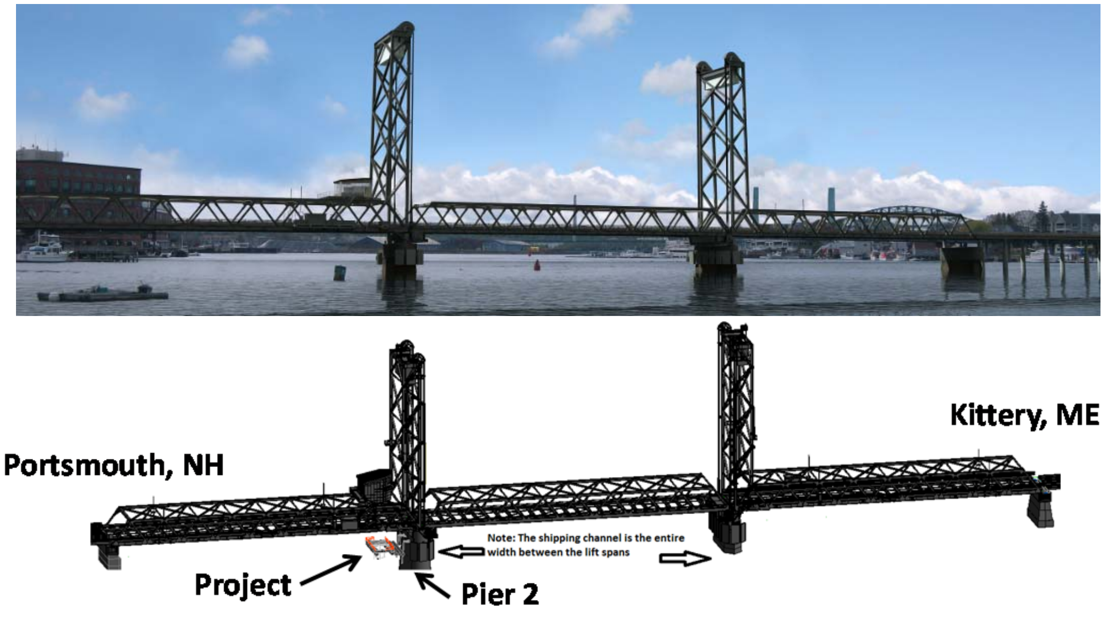

FIGURE 1. MEMORIAL BRIDGE BETWEEN PORTSMOUTH, NH, AND KITTERY, ME (TOP, LOOKING NW). CAD MODEL OF BRIDGE WITH TIDAL ENERGY CONVERSION PROJECT LOCATION (BOTTOM).

A tidal energy resource assessment was performed using long term bottom-deployed Acoustic Doppler Current Profiler (ADCP) data from surveys at two locations: near the planned deployment location in 2013-14 for 123 days [5], and mid-channel in 2007 for 35 days [2]. Following [5], the mean kinetic power density at the deployment location was determined to be 0.67 kW/m^2. Changes in available kinetic energy with ebb/flood and spring/neap tidal cycles were analyzed, and compared to electrical energy demand. The deployment site exhibits more energetic ebb tides than flood tides, resulting in a mean kinetic power asymmetry of about 5.0 [6], which can largely be explained by the local bathymetry of the tidal estuary. The fastest current measured was 2.05 m/s on an ebb tide [5]. Tidal current velocity scatter plots on a compass rose for both surveys [2, 5] are shown in Figure 2, overlaid on a bridge satellite image. A small directional asymmetry can also be observed.

The tidal energy resource assessment was used to develop a turbine rotor sizing tool. A energy system model was then used to calculate the net energy availability under various tidal turbine and energy storage (battery bank) configurations.

TIDAL ENERGY CONVERSION SYSTEM

In the design process for the tidal energy conversion system a broad range of turbine types and installation options was initially considered. Due to ease of deployment and cost, a system with a cross-flow, vertical axis turbine installed on a floating platform was selected. The main elements of the system are

1. Turbine deployment platform (TDP), for mounting the tidal turbine
2. Vertical guide posts (VGP), which will attach to the bridge pier
3. Electrical connection to pier cap (w/ option of energy storage system)

A rendering of the tidal energy conversion system is shown in Figure 3.

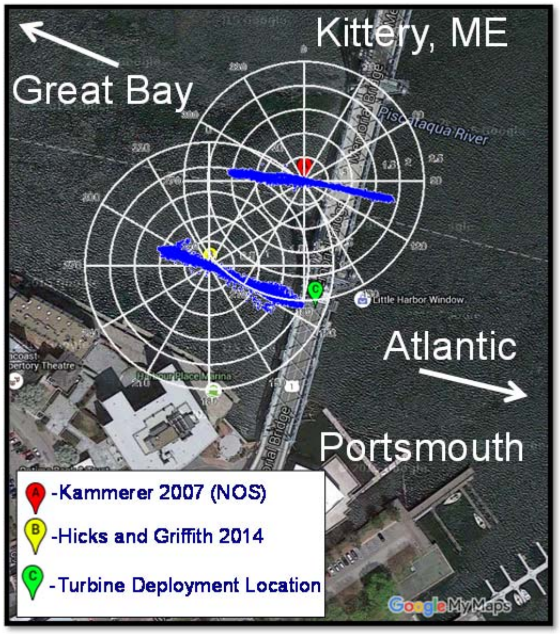

FIGURE 2. VELOCITY SCATTER FOR THE TWO ADCP SURVEYS [3, 4]. THE PROJECT DEPLOYMENT SITE IS SHOW WITH THE GREEN MARKER.

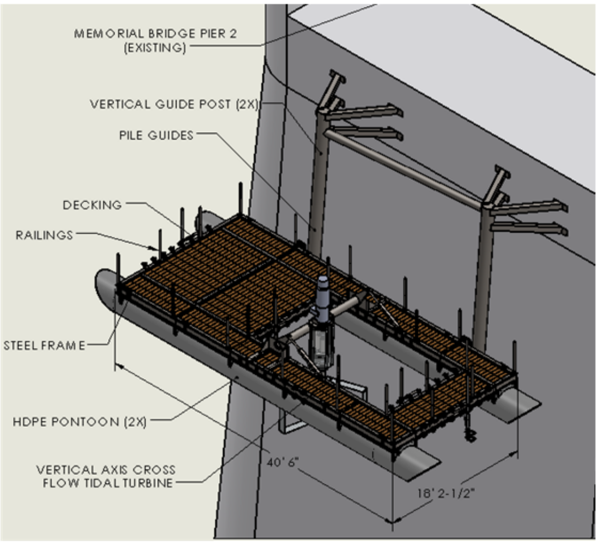

FIGURE 3. RENDERING OF “LIVING BRIDGE” TIDAL ENERGY CONVERSION SYSTEM, INSTALLED ON PIER NO. 2 OF MEMORIAL BRIDGE.

Vertical Guide Posts

The hydrokinetic turbine deployment structure consists of two Vertical Guide Posts (VGP), and a floating Turbine Deployment Platform (TDP). The VGPs are galvanized steel pipes of 16 inch diameter, 22 ft tall. The VGP elevations were designed so that the platform can rise to the 100 year flood elevation plus approximately 2.5 ft for wave motion (design wave at site) and platform free board allowances. The lowest platform travel levels were specified as NOAA’s 1% low water exceedance level minus 2.5 ft for wave motion.

The installation of the VGPs is shown in Figure 4, and the TDP deployed at the VGP structure is shown in Figure 5 (March 2017).

FIGURE 4. INSTALLATION OF VERTICAL GUIDE POSTS (VGP) AT MEMORIAL BRIDGE. NOTE THE INSTALLATION PERSONNEL FOR SCALE (DEC 2016).

FIGURE 5. TURBINE DEPLOYMENT PLATFORM (TDP) DEPLOYED ON VERTICAL GUIDE POSTS, PIER NO. 2 AT MEMORIAL BRIDGE IN PORTSMOUTH, NH (MARCH 2017).

Turbine Deployment Platform

The TDP will be moored to the VGPs, allowing it to travel vertically with changing water levels. The TDP is a twin hulled floating platform with a moon pool in one half of its deck which allows a turbine to be rotated in and out of the currents. The platform uses two HDPE pontoons for buoyancy and a galvanized steel frame to provide structural rigidity. The orientation of the moon pool and turbine rotation was chosen so that the turbine can be rotated out of the water under load during the stronger ebb tides.

Predicted loads on the TDP due to wind, waves, and currents were calculated. A SAP2000 finite element analysis (FEA) model was created for the VGPs and the TDP steel frame. These FEA models were used to ensure the guide posts could withstand the TDP mooring forces due to wind, wave, and currents. The FEA models were also used to ensure the vertical guide posts could withstand vortex induced vibrations. The TDP mooring forces due to waves on the VGPs were determined using empirically derived results [7-9]. To design the TDP steel frame against wave loads DNV-GL specified wave load cases were used [10, 11]. The VGPs are instrumented to measure loads and compare those loads to input forcings measured by a suite of estuarine sensors. The design analysis and fabrication constraints were used to determine the final specifications of the hydrokinetic turbine deployment structure. The structure was designed to enable the deployment of a hydrokinetic turbine at a bridge location, and thereby demonstrate the feasibility of deploying turbines at similar bridge sites.

Additional information w.r.t. the structural design and the operation of the tidal energy conversion system can be found in [12] and [13].

A suite of environmental and underwater instrumentation will be deployed with the platform. It consists of two downward looking ADCPs (up/downstream), a Valeport CTD+

(Conductivity, Temperature, Pressure, Turbidity, pH, Chlorophyll), two underwater cameras, strain gages on VGPs, weather stations.

Marine Hydrokinetic (Tidal) Turbine

Instream Energy Systems of Vancouver, BC was selected as the provider for the tidal turbine. Instream will supply a 3-bladed cross-flow, vertical axis turbine with gearbox and generator above water, which will be connected to the UNH TDP and turbine deployment hardware via a mounting bracket. The turbine will essentially be a marinized version of the one installed and tested at Roza Canal, WA. The turbine will have a 3 m diameter, and the blade height will be 2m (Roza Canal was 1.5m), for a swept area of 6 m^2. With a rotor power coefficient, $C_P \approx 0.38$ and a cut-in speed of about 0.7 m/s, we expect the turbine to generate an average power of about $P_{avg} \approx 1.5$ kW, and a peak power at 2 m/s of $P_{max} \approx 10$ kW.

SUMMARY AND OUTLOOK

A tidal energy conversion system is being installed at Memorial Bridge in Portsmouth, NH, as part of the "Living Bridge" project to create a self-diagnosing, self-reporting "smart bridge" powered by tidal energy.

The vertical guide posts (VGPs), which are part of the deployment structure, were installed in December 2016. The turbine deployment platform (TDP) was first deployed in March 2017.

The TDP with instrumentation will be deployed without a turbine for some time to measure the as-is condition at the site. The tidal turbine will be then be deployed on the platform, for the duration of approximately one year.

The Partnership for Innovation (PFI) funding required the identification and participation of industry partners. At this time there are nine (9) industrial partners involved in various aspects of the project, include a developer of an experimental fish deterrent system.

By the time the METS 2017 conference takes place, the TDP will be installed at the site and first data should be available.

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