# THE "LIVING BRIDGE" PROJECT: TIDAL ENERGY CONVERSION AT AN ESTUARINE BRIDGE – DEPLOYMENT AND FIRST DATA

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## INTRODUCTION AND BACKGROUND

The "Living Bridge" project created a self-diagnosing, self-reporting "smart bridge" that will be powered by a locally available renewable energy source, *tidal energy*. The project transformed 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. The project provides the marine hydrokinetic (MHK) industry with an easily accessible open-water test site for tidal energy conversion devices of up to 3m (10ft) in diameter.

Estuarine bridges could serve as an ideal location to deploy marine hydrokinetic (MHK) energy conversion systems. The hydrokinetic resource is often strongest at the narrow locations where bridges are located. The bridge piers can serve as supporting structure for both the bridge and hydrokinetic turbines, and the MHK permitting process can take advantage of the permitting work and studies required for bridge construction.

The Living Bridge project includes the installation of a tidal turbine on the Portsmouth-facing side of Pier No. 2 at Memorial Bridge. Utilizing locally available tidal energy can make bridge operation more sustainable and can "harden" transportation infrastructure against prolonged grid outages. The project aims to demonstrate a prototype of an "estuarine bridge of the future".

This paper gives a project update with regards to construction and tidal turbine deployment, and presents first data from estuarine instruments.

## 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 GBE is 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 [3].


**FIGURE 1. MEMORIAL BRIDGE BETWEEN PORTSMOUTH, NH, AND KITTERY, ME (LOOKING NNW). TIDAL ENERGY CONVERSION PROJECT/TEST SITE LOCATION IS ON PORTMOUTH-FACING SIDE OF PIER #2.**

The Memorial Bridge location is well-suited for a tidal energy demonstration project, and for hosting a scaled tidal energy test site. It reaches tidal current speeds greater than 2m/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.

**TIDAL TURBINE DEPLOYMENT SYSTEM**

The tidal turbine deployment system consists of:
(A) Vertical guide posts (VGP), attached to the face of the bridge pier. The VGPs are galvanized steel 16in pipes, 22ft tall, allowing the platform to travel vertically with changing water levels. The maximum travel is the 100 year flood elevation plus 2.5ft for wave motion (design wave).
(B) The Turbine deployment platform (TDP), 50ft x 20ft (15m x 6m) nominal: mounting of tidal turbine, turbine pitching mechanism, attaches to VGP via pile guides. It uses two HDPE pontoons for buoyancy and a galvanized steel frame for structural strength. Turbines are deployed in a moon pool via a turbine pitching mechanism. Both axial and cross-flow turbines, with turbine diameters up to 10ft (3m) can be deployed. The orientation of the moon pool was chosen so that turbines can be rotated out of the water under load during the stronger ebb tides.

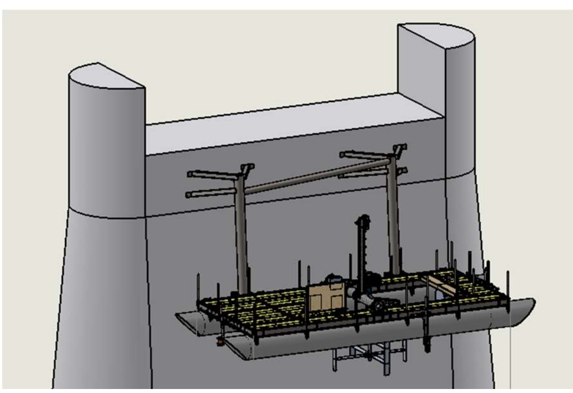

**FIGURE 2. TURBINE DEPLOYMENT PLATFORM (TDP) MOORED TO VERTICAL GUIDE POSTS.**

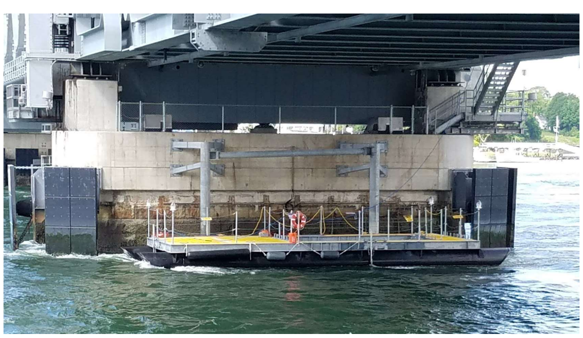

**FIGURE 3. TURBINE DEPLOYMENT PLATFORM (TDP) AT MEMORIAL BRIDGE DURNG AN EBB TIDE (FLOW IS LEFT TO RIGHT).**

(C) Electrical connection to pier cap. The turbine deployment system can either be connected to the bridge grid (480V) or run as a stand-alone system with a load bank (currently up to 25 kW).
The design of the turbine deployment system, and loading due to wind, waves and currents was discussed in more detail in [4, 5, 6, 7]. A rendering of the turbine deployment system is shown in Figure 2. Figure 3 shows the TDP during a test deployment at Memorial Bridge.

**INSTRUMENTATION SYSTEM**

The tidal turbine deployment system installation at Memorial Bridge includes instruments and sensors, which are broadly organized into two instrumentation and data acquisition systems:
(1) SCADA system on bridge: The standard TDP instrumentation includes two downward looking FlowQuest 1000 acoustic Doppler current profilers (ADCP) (located about 20ft upstream and downstream of the turbine attachment location), a Valeport CTD+ (Conductivity, Temperature, Pressure, Turbidity, Chlorophyll) and two underwater cameras, which all connect through a MacArtney Multiplexer to the Living Bridge SCADA system. Turbine performance data (power, RPM), data from strain gages on the VGPs (8 uniaxial strain gages) and from two weather stations (one mounted on the TDP, one on top of the south bridge tower) is also recorded through the SCADA system. The instruments connected to the SCADA system are deployed long-term with the platform. The SCADA system also records data from all structural health monitoring sensors on the bridge as part of the NSF/FHWA Living Bridge project (16 strain rosettes (3 readings each, principal stresses), 2 uniaxial strain gages, 2 biaxial tilt meters, 15 biaxial accelerometers).
The SCADA system records all data into a database. The data is transferred via internet to a server at UNH, and can be downloaded from there via the Living Bridge web site [8].
(2) A mobile data acquisition system that can be deployed during measurement campaigns: This system is based on the Modular Ocean Instrumentation System (MOIS) developed by the National Renewable Energy Laboratory (NREL) [9] and uses a National Instruments CompactRIO platform for data acquisition and control. This data acquisition system is used for two LCM 100kN load cells (mounted on turbine pitching mechanism) for measuring streamwise rotor thrust, a wave measurememt system consisting of a 2m Akamina Wave Staff and a Yost Labs Inertial Measurement Unit (IMU), and for more detailed flow measurements using Nortek Vector acoustic Doppler velocimeters (ADV's) and Signature 1000 ADCP's. For deployments of the TDP at other

locations, i.e., the UNH CORE Tidal Energy Test Site at General Sullivan Bridge (about 5 miles upriver), this mobile data acquisition system can also be used for the standard TDP instrumentation and to record turbine performance data.

### Instrument mounting system

A custom, adaptable instrumentation mounting system was designed using mostly off-the-shelf components. It is robust, corrosion-resistant and allows easy and safe deployment of instruments mounted at the end of a pipe strut from above the platform deck. Available mounting locations on the platform are shown in Figure 4. Instruments can be added and/or relocated as necessary. A custom mobile traversing traversing system for flow measurements can be deployed in the moon pool and on either end of the pontoons, for detailed inflow and wake measurements.

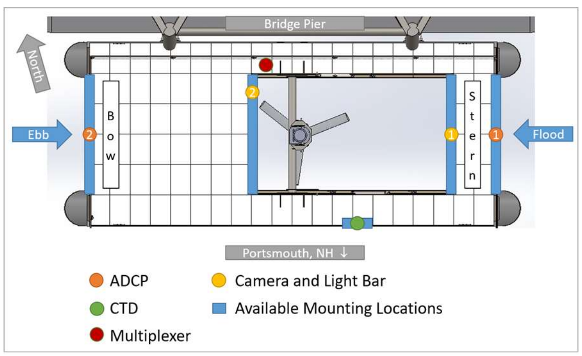


**FIGURE 4. TOP VIEW OF TURBINE DEPLOYMENT PLATFORM (TDP), WITH MOUNTING LOCATIONS OF SELECTED INSTRUMENTS INDICATED. NOTE LOCATIONS OF ADCP'S #1 AND #2.**

### RESOURCE MEASUREMEMTS

The data from several ADCP surveys (bottom-deployed and vessel-mounted) were used in the tidal energy resource assessment leading up to this project; the closest of these was a long-term bottom-mounted ADCP deployment about 30m[1] upriver from the platform deployment location [9], shown at location (B) in Figure 5. Data from this survey are shown in Figure 6. A 15 minute ensemble length was used to allow the ADCP to record for a long period of time. Figure 6 shows a distinct asymmetry between ebb and flood tides at this location, which is (mostly) due to the upstream bathymetry encountered by the flood tide flow. ADCP data near the center of channel, at location (A) at about 56m in the cross-stream direction from location (B), shows much less ebb/flood asymmetry, but also less fast maximum ebb flows [2] (see [7] for further discussion).

[1] This is as close to the site as a 50ft research vessel with an A-frame crane was able to get.

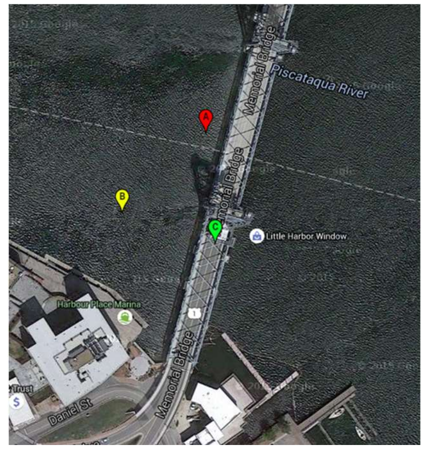


**FIGURE 5. SATELITTE IMAGE OF MEMORIAL BRIDGE: (A) MID-CHANNEL ADCP SURVEY (NOS) [2], (B) ADCP SURVEY FOR THIS PROJECT, (C) TIDAL ENERGY CONVERSION SYSTEM DEPLOYMENT LOCATION WITH PLATFORM-MOUNTED ADCPS.**

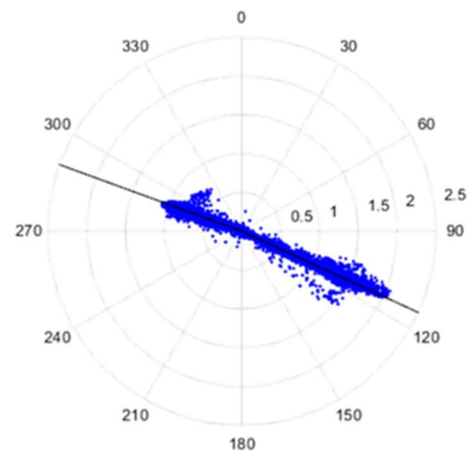


**FIGURE 6. TIDAL CURRENT SPEED AND DIRECTION FROM BOTTOM-MOUNTED ADCP SURVEY (LOCATION B) [9] – 30M UPRIVER FROM BRIDGE PIER, 12.1M ABOVE THE SEAFLOOR, 15-MINUTE ENSEMBLE AVERAGES.**

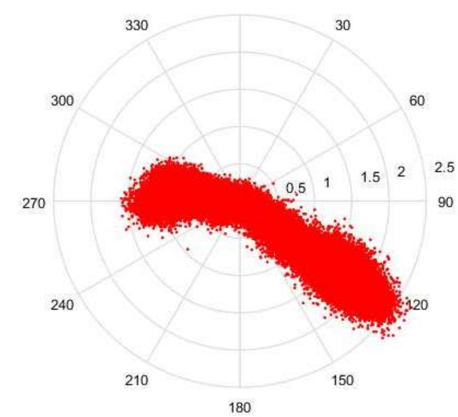


**FIGURE 7. TIDAL CURRENT SPEED AND DIRECTION FROM PLATFORM-MOUNTED ADCP (LOCATION C). PORTSMOUTH-FACING SIDE OF PIER #2, 2M BELOW SURFACE, 2-MINUTE ENSEMBLE AVERAGES. COMBINED INFLOW DATA FROM ADCP'S #1 AND #2.**

The ADCPs at location (B), mounted on the TDP, were connected to and powered by the SCADA system, and were set to record ensemble averages every 2 minutes. This data is shown in Figure 7. The differences between Figures 6 and 7 are striking, but not unexpected. With the shorter sampling interval, there is greater variation in tidal current magnitude and direction. The presence of the bridge pier also affects current direction and magnitude, as flow is deflected and accelerated around the pier. On ebb tides, flow separates off the bridge pier once it reaches a certain velocity and flow angle. This can be seen in Figure 8, with ADCP 1 (outflow, blue) recording a lower velocity than ADCP 2 (inflow, red/black).

These data also give information on the time scale of large eddies present in this tidal flow, which will be further investigated with higher resolution in-situ measurements (ADCP, ADV).

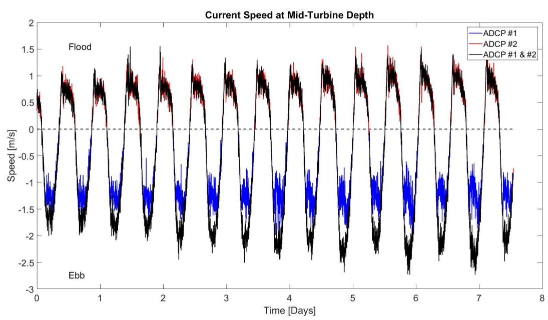


**FIGURE 8. SAMPLE ADCP DATA: ADCP #1 & #2 DATA (BLACK) USES ADCP #1 FOR FLOOD AND ADCP #2 FOR EBB.**

## TURBINE DEPLOYMENT

The Living Bridge project started working with a new MHK turbine vendor, New Energy Corporation of Calgary, Alberta, in November 2017. The project is on schedule to install a cross-flow, vertical axis turbine at the site in April 2018. The turbine will be connected to the UNH TDP via a mounting bracket on the turbine pitching mechanism, and includes a direct-drive generator located above water. The turbine will be 3.2m in diameter and 1.7m tall, for a swept area of 5.4 m$^2$. The turbine is expected to generate peak power of $P_{max} \approx$ 15-20 $kW$ at 2.7 m/s. The New Energy turbine will be deployed on the platform, for the duration of approximately one year.

## 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 "smart estuarine bridge" powered by tidal energy. The project also provides the marine hydrokinetic (MHK) industry with an easily accessible open-water test site for tidal energy conversion devices, axial or cross-flow, of up to 3m (10ft) in diameter.


## ACKNOWLEDGEMENTS

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