Memorial Bridge Hydrokinetic Power Generation

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Abstract

In recent years renewable energy has become an important topic for many engineers and scientists with a large focus on tidal energy. Tidal energy is important because it is much more reliable than weather based (solar and wind) energies and more understandable. To further the study of tidal energy, a proposal is being submitted to the New Hampshire Department of Transportation to permanently mount a structure holding three hydrokinetic turbines on each bridge pier of the new Memorial Bridge with the goal of producing enough energy to cover the lighting requirements. It is also a possibility that the turbines will be able to power a structural monitoring system for the bridge.

Throughout the year, the direction of this project has evolved from a temporary proof of concept deployment to a permanent incubator deployment. The project began in September with the proposal to temporarily deploy a turbine from the existing Memorial Bridge in Portsmouth, NH. This deployment would collect data from the turbine such that a judgment could be made if this would be a feasible place to permanently use turbines as a source of energy generation. It was then disclosed to the public that the Memorial Bridge was slated to begin demolition at the end of January 2012.

The planned demolition resulted placing the focus on a shorter deployment plan that would take place over one day instead of the initial one month. The new proposal included deploying the structure from the fixed span of the bridge for a few hours to develop an understanding of the power generated by the turbine over a tidal cycle. A meeting with the NHDOT to discuss the new plan concluded with the NHDOT expressing interest in a permanent deployment structure.

During the second semester research focused on environmental constraints and permitting, turbine selection, power estimates, and the structure needed to contain hydrokinetic turbines in a substantial flow. The final result is a formal proposal to the DOT to put this project into motion with cooperation from Archer Western, HNTB, and all other parties involved.

The project has so far concluded that implementing a hydrokinetic research and generation platform is both feasible and recommended for the Memorial Bridge site, as it will provide an unique and invaluable resource for furthering New Hampshire's commitment to renewable energy research and production, with the potential to generate approximately 21 megawatt-hours yearly per array.

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1 Introduction

The initial goal of this project was to investigate the deployment of a turbine on the underside of the non-lifting flanking spans of the Memorial Bridge, in Portsmouth, NH on the Piscataqua River. The goal of the deployment was to investigate the available removable power source as well as the impact it would have to the surrounding bridge structure, as the project initially lacked permission for pier mounting.

A bridge is an ideal mounting location for many reasons as it is a pre-existing structure generally built in the narrow section of rivers where the flow is accelerated. The existing structure allows for mounting options that may otherwise not be feasible as well as the fact that ship traffic is already aware of its presence and calls for minimal invasion into water traffic. The bridge also provides a need for electric power, and a hydrokinetic deployment allows for one to meet that need without significantly disrupting the flow, as a traditional hydropower dam would cause.

2 Project Background

2.1 Project Site

Memorial Bridge The original Memorial Bridge was a truss lift bridge which first opened in 1923. The span crosses the Piscataqua River from the city of Portsmouth, NH to local business and residential areas in Kittery, ME. It is an integral part of both communities as it provides the only pedestrian and bicycle access across the river. With two lanes, the bridge had 12,000 vehicles crossing daily. The bridge normally allowed 19 feet of clearance under the span, and 150 feet when fully raised. During the summer months, the span lifts every half hour from 7 a.m. to 7 p.m., making 4,000 lift cycles per year. [4]

In 2011 the bridge was closed to automobiles, and eventually pedestrians in early 2012. The NHDOT awarded a contract to Archer-Western Contractors demolish the old bridge and construct an HNTB designed replacement. The bridge began demolition with plans to rebuild and open a replacement by July 2013.

Projected Energy Needs The NHDOT informally estimates the non-lift related power needs of the bridge at approximately 5-10 kilowatts. This power use estimate is for the old bridge with somewhat antiquated technology. This number may be reduced by the use of modern high-efficiency LED lighting, which may allow the broader distribution of power to other elements. The present plan for the new bridge provides for traffic lighting using one dozen 175-watt metal-halide bulbs, necessitating a power need of 2.1kilowatts, and speculative estimate of 10.7 megawatt-hours of energy per year. Potential elements powered by the turbine array include:

- Aesthetic lighting
- Traffic, aerial, and marine navigation lighting
- Bridge safety monitoring
- Surveillance cameras
- Informational and educational monitoring and displays

2.2 Existing Project Resources

This project an integration of TECH 797: Undergraduate Ocean Projects and CIE 788: Project Planning and Design. Each course provides resources for the project; both fiscal and academic. The project is a continuation of previous research performed by undergraduates in TECH 797: Ocean Projects. Research done by previous groups consisted of building a barge mounted test structure for towed deployments of a Gorlov Turbine, as well as collecting data using this structure.

2.3 Hydrokinetic Turbines

A turbine is a device that generates mechanical power from a moving fluid. It converts the kinetic energy of the fluid to mechanical energy [6]. A hydrokinetic turbine is designed to work in a free-flow environment such as a river or open water tidal stream. The recent interest in marine hydrokinetics (MHK) is primarily on tidal energy and wave energy conversion (WEC) devices.

Hydrokinetic turbines are a relatively young technology that is rapidly developing. Within hydrokinetics, there are several classifications of turbines.

First, the orientation of the rotational axis is specified as either crossflow or axial flow turbines. Crossflow axis turbines rotate perpendicular to the current flow aligned either vertically or horizontally in the water column. Vertical crossflow turbines are similar in orientation to egg-beaters, while horizontal crossflow are reminiscent of paddle-wheels. While axial turbines rotate parallel to the flow, similar to a wind turbine. The orientation of the axis is not crucial to generating power; however the axis orientation can make generation easier. A vertical axis crossflow turbine may spin in any flow direction while a horizontal axis crossflow turbine needs to be perpendicular to the flow in order to reach maximum efficiency. An axial flow turbine must be aligned parallel to the flow to maximize efficiency. Furthermore, turbines may also be lift or drag driven. A lift driven turbine generally requires velocities greater than 1 m/s [2 knots], while a drag driven turbine will spin at much lower velocities in exchange for lower efficiencies. Considering this, a lift driven turbine will most likely be more effective because the flow at the Memorial Bridge is faster than 1m/s nearly 2/3 of the time.

This project began with the proposal to test a Gorlov turbine presently in the possession of the University. The Gorlov turbine is a vertical axis turbine with helical blades and measures 1 meter in diameter by 1.25 meters in height. This turbine was tested extensively by an ocean engineering graduate student and was deployed using a structure built by a senior project group in 2008.

Turbines are being researched to use in the modular structure. Through technical discussions with Free Flow Power, a company based out of Boston, MA, a basis for turbine requirements and specifications was reached. Free Flow Power has developed an axial-flow rim-mounted direct-drive turbine for deployment on the Mississippi River. This turbine is 3 meters in diameter and 4 meters in length, and has been the basis for the design of the modular casements to house the turbines in the support structure, with the understanding that the FFP turbine works in one directional flow, and not the bidirectional flow experienced in the Piscataqua, these specifications were used based on FFP's success with deployment in the Mississippi River.

2.4 Deployment Structure

Original Plan Initial plans for test deployment consisted of refitting the existing Gorlov test derrick and structure for a suspended mount under the Portsmouth side span. This plan was abandoned due to the impending demolition of the bridge, as well as direction from the NHDOT, who recommend a larger, pier mounted, long term deployment structure.

Updated Structure The new plan calls for a pier mounted structure which will be anchored to both the pier and micropiles sunk into the bedrock. Connected to the micropiles will be a rail and deck system which will allow for the modularization of the turbine mounting. This rail system may allow for up to four turbines, and the ability to interchange the turbines for possible testing of different turbines as well as the ease of maintenance.

2.5 Modular Turbine Casement

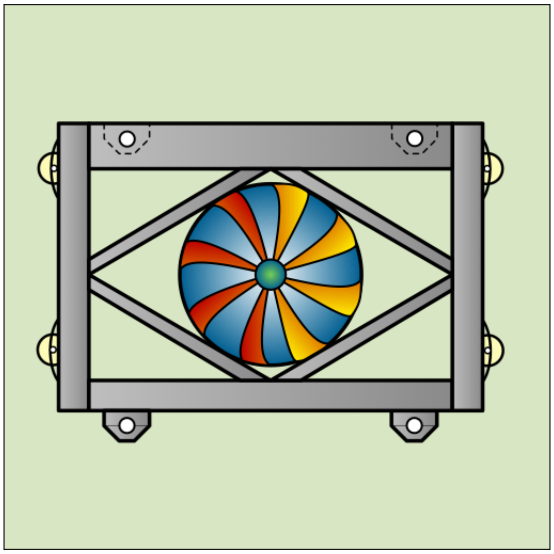


Figure 1: A concept sketch of the proposed modular encasement.

To mount turbines to the structure, it is proposed to use a channel rail system on the structure in which a turbine may be fitted upon using an encasement capable of mounting a variety of turbine designs.

This encasement would be designed for the outer parameters to match those of the structure rails, while the inner dimensions would allow for differing designs to be mounted in place.

As visible in fig.1, the proposed casement would allow multiple turbines to be pinned together. The casement would also use rollers to slide within the rail channels, providing for relative ease in raising or lowering the turbines.

As the turbines are expected to be operated for research purposes, ease of removal to exchange turbines, or inspect for wear and damage are important.

3 Fall Semester

3.1 Initial Proposal

In September a proposal was submitted to TECH 797 advisors to deploy a temporary structure from the truss members of the Memorial Bridge in Portsmouth. The project was broken down into several major tasks which included determining the present state of the bridge and tidal current measurement, taking initial measurements of the current using the Acoustic Doppler Current Profiler, analysis of the initial measurements and design of a structure, and deployment of the structure containing a Gorlov turbine and sensors to monitor the loads placed on the bridge. Once these measurements were taken, the data would be analyzed and used to suggest a future project.

3.2 Current Analysis

3.2.1 Introduction

Before a well defined proposal and design for powering the bridge's electric needs with tidally generated energy can be developed, a clear assessment of the available power is necessary. This available power is the power flowing through a unit cross section of area. Harvesting the power and generating electricity typically reduces the available power, and the water to wire efficiency controls this.

3.2.2 Theory

The equation for the power available in a fluid is

$$P_{fluid} = \frac{1}{2}\rho v^3 * A, \tag{1}$$

where ρ is the density of the fluid, seawater being $1025 kg/m^3$, v is the velocity of the fluid, and A is the cross sectional area of the fluid perpendicular to the flow. Dividing by area, the Power Density of the fluid, or the power available per area of fluid flow is

$$P_{dens} = \frac{1}{2} * \rho v^3. \tag{2}$$

The water to wire efficiency is ultimately the most important number when discussing power output as it reveals the amount of power delivered to the consumer. This includes an understanding of the efficiency of the turbine, gearbox, generator and power conditioning. Water-Wire Efficiency is defined as

$$\eta_{W-W} = \eta_{Turbine} * \eta_{Gearbox} * \eta_{Generator} * \eta_{Conditioning}. \tag{3}$$

and the power delivered from the turbine to the consumer is

$$P_{W-W} = P_{fluid} * \eta_{W-W}. \tag{4}$$

To estimate the energy available over time, integrate the Power equation over the desired timeframe, in the desired units. In this situation, Watt-Hours over One Year is needed,

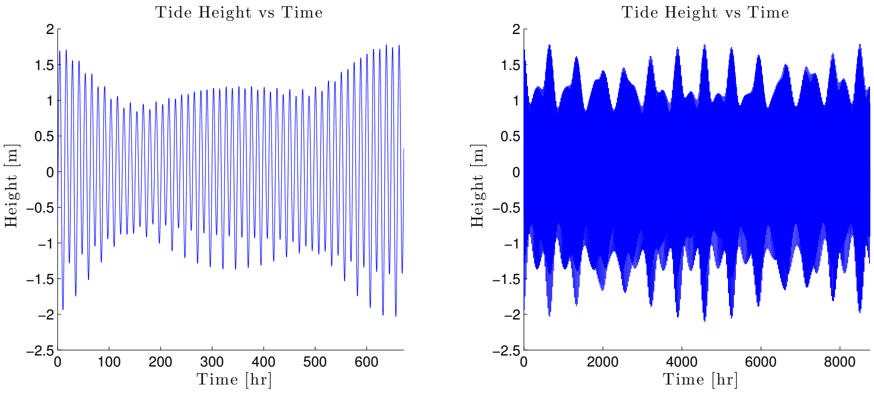
$$E = \int_0^{8766} P dt. \tag{5}$$

This can be done to find the Energy Density, Available Fluid Energy, and Water to Wire (or usable) Energy, if integrating using Power Density, Fluid Power, and Water to Wire Power respectively.

Also of importance to any structure is the drag created via the fluid flow, this is similar to the power equations, but the velocity is only squared, rather than cubed, and a drag coefficient must be evaluated depending on the turbine and structure design,

$$D = C_D A * \frac{1}{2}\rho v^2. \tag{6}$$

where C_D is the coefficient of drag. The current in the Piscataqua River is tidal dependent. As a semi-diurnal tidal zone, the tidal cycle passes twice in the tidal day, approximately twenty-four hours and fifty minutes, with two ebbs and two floods. As the tide floods it fills Great Bay, and as it ebbs, it runs back east to the Atlantic. The velocity of the current is dependent on the height of the tide, and tide height is dependent on a number of factors, known as tidal constituents, each one a cyclic force consisting of their own strength and frequency. The primary drivers of ocean tides consist of solar, and more importantly lunar constituents. The moon phase is strongly correlated with the height of the tides; neap tides occur at the half moons, and give smaller tidal differences from the mean height, while spring tides occur at the new and full moon and give the largest gain in tidal amplitude. The larger amplitudes of tide height occur within similar time frame to the smaller amplitudes, this causes the differences in the velocity of the current. The variation in tide levels is shown in the plots (figure 2) of the tidal constituents for Seavey Island, as given by NOAA.



(a) Tidal Variation over Lunar Cycle (b) Tidal Variation over entire Year

Figure 2: Theses plots show the predicted tidal variation over time, revealing the significance of the lunar cycle on available power

High velocity spring tides are beneficial for increased power, in exchange for increased drag on the turbine structure, and potentially greater strain on the bridge. Lower velocity neap tides reduce the strain on the bridge along with the available power resource. Both of these factor are important, as a balance between power production and structure stress must be considered and evaluated.

3.2.3 Data Resources

The primary assessment came from data collected during a 2007 NOAA funded current survey The NOAA survey data came from a three month study using a bottom mounted acoustic doppler current profiler (ADCP) taking measurements at six minute intervals over the course of the survey. An ADCP is capable of taking velocity measurements over a range of depth. Short term transect data gathered using a boat mounted ADCP transiting the river also provided data on the current flow as a cross section of the river.

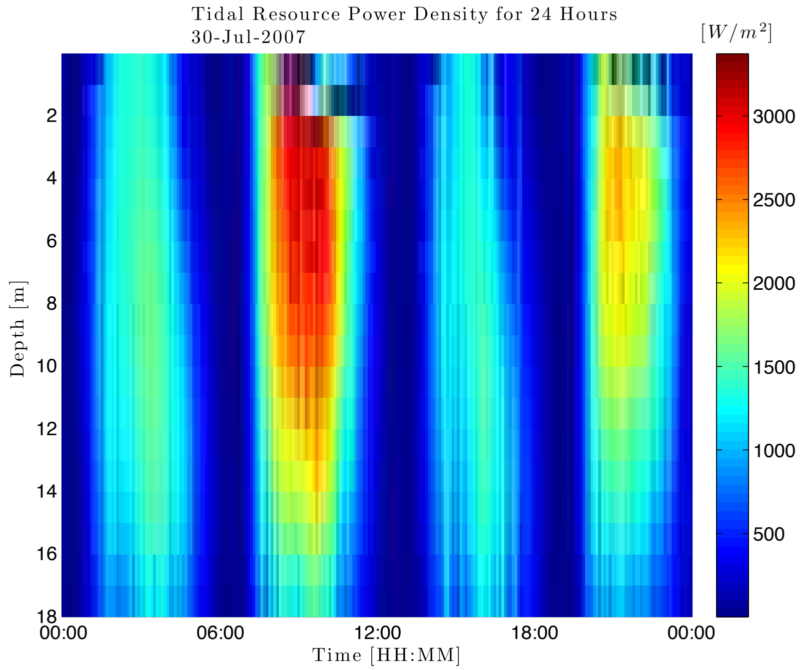


Figure 3: A plot highlighting the Power Density over the depth of the river, over the course of 24 hours at center stream.

3.2.4 Results

The NOAA time series ADCP data was analyzed using Matlab to estimate the total resource, the potential energy density, as well as the ideal turbine depth placement. Figure 3 is a representative plot of the available power density by depth over the course of a 24 hour period, which is nearly an entire tidal cycle. It is apparent from this plot that the ebb (outgoing) tide provides the stronger of the currents, with a maximum power density greater than 3kW for short periods of time.

The power density was averaged by water depth, revealing the ideal depth range for turbine placement. This is visible in figure 4, where it apparent that velocity, and thus power density decreases near the river bed due to the fluid boundary layer against the surface.

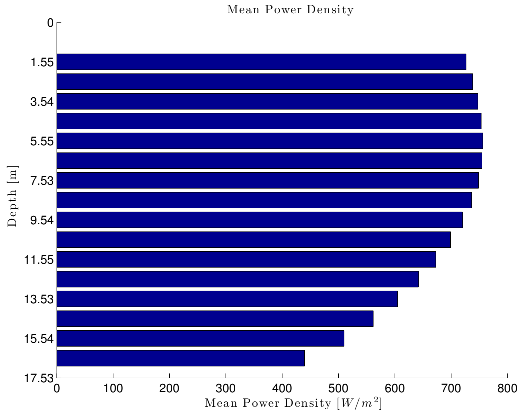


Figure 4: A plot highlighting the Mean Power Density, segmented by depth at center stream.

Table 1 combines the mean power density results with the anticipated energy density data.

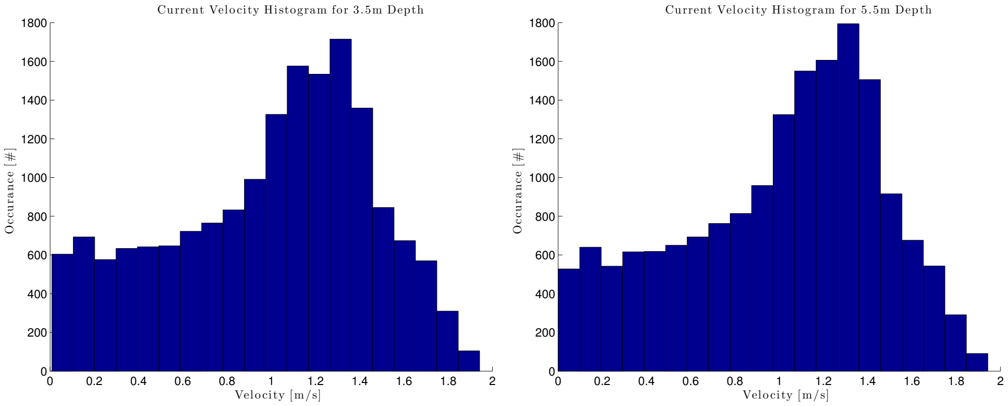
Figure 5 represent the velocity distribution at multiple depths within the range of maximum mean power densities. These distributions show the large percentage the current velocity is above 1m/s, an assumed cut-in velocity for lift-driven devices.

Table 1: A table highlighting the Mean Power and Expected Yearly Energy available per square meter by depth

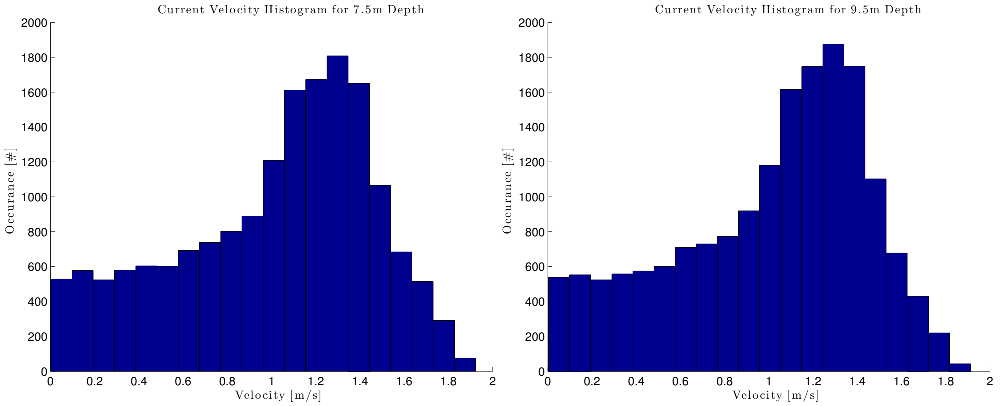
Bin #	**Approximate Depth [m]**	**Mean Power Density** $[W/m^2]$	**Yearly Energy Density** $[\boldsymbol{MWh}/m^2]$
1	17.53	439.6	3.8
2	16.55	509.9	4.4
3	15.54	561.7	4.9
4	14.54	604.7	5.3
5	13.53	641.7	5.6
6	12.53	672.6	5.8
7	11.55	698.7	6.1
8	10.55	719.8	6.3
9	9.54	736.3	6.4
10	8.53	748.3	6.5
11	7.53	754.6	6.6
12	6.55	756.1	6.6
13	5.55	753.3	6.6
14	4.54	747.3	6.5
15	3.54	738.1	6.4
16	2.53	726.4	6.3
17	1.55	611.5	5.3
18	0.55	392.3	3.4

3.2.5 Conclusion

The NOAA data provided a reasonable estimate of 750 W/m^2 available in the center stream, with a yearly energy density of 6.5 MWh/m^2. With expected capacity factors in the range of 30 to 40%, this allows for a reasonable expectation of 2 MWh/m^2. This places this project in the realm of possibility to power both modern LED aesthetic lighting as well as required bridge lighting, which was estimated at 12 MWh per year, though there is no definitive answer on the actual needs of the new bridge. The data supports the viability of turbines covering a twelve meter zone of vertical depth, with mean power densities above 720 W/m^2.



(a) 3.5 meters (b) 5.5 meters



(c) 7.5 meters (d) 9.5 meters

Figure 5: Velocity distributions across the proposed turbine zone.

3.3 Environmental Aspects

According to the NHDOT categorical exclusion report, salt used to melt ice was noted as the number one cause for corrosion of the bridge material. Corrosion of the bridge was very minimal but the use of salt posed as the biggest impact to corrosion during the winter months. As an alternative to this, implementation of another de-icing mechanism was looked into to prevent the use of salt on the bridge. This idea included the use of heated wiring, similar to that used on roofs during the winter, for melting the ice on the bridge.

The National Environmental Policy Act(NEPA) permit was the center point of environmental constraint research during the fall semester. The NEPA permit requires the design of any structure, or modification of any structure, to be designed keeping in mind the environmental impacts which it could have. Two main environmental constraints looked at were sediment disturbance and the impact deployment would have on marine life. The fall semester structure was designed to be a temporary deployment for testing purposes and avoided having to come into contact with the bottom of the river. For experimental purposes, it was safe to assume that the turbine would not impact marine life around the bridge. Impact on marine life is further explained in Section 4.2.1 of the report which provides a full breakdown of both environmental constraints.

3.4 NHDOT & Archer-Western Meeting

A meeting with the New Hampshire Department of Transportation and Archer Western Contractors was set to familiarize both parties with the idea of a possible temporary deployment. The proposed deploymentoff the left flanking span of the Memorial Bridge used high strength cable that would hold a support structure in place for a Gorlov Turbine. It was emphasized that no fracture critical member of the superstructure would be used in the deployment of the support structure. A temporary deployment would provide a platform for testing on the bridge that could include devices such as a tension link load cell, strain transducers and strain gages as well as gathering data from the turbine. These possible methods would evaluate and analyze stresses from the support structure in correlation to the bridge superstructure. As a result of the meeting, both sides agreed that the idea of a temporary deployment would not be feasible with the demolition of the Memorial Bridge fast approaching. It was agreed that a permanent deployment would be more realistic and beneficial. The project team pursued a design for a permanent deployment of a support structure mounted to the bridge piers taking into consideration power density estimates, environmental concerns and constraints, and the schedule of Archer Western Contractors.

In attendance of this meeting was Robert Landry,P.E. and Keith Cota,P.E. from the New Hampshire DOT, along with Stephen DelGrosso, P.E. representing Archer Western Contractors, as well as Dr. Edward Lovelace of Free Flow Power Corporation. The undergraduate team was present along with advisors Dr. Erin Bell, Dr. Kenneth Baldwin, and Dr. Martin Wosnik.

4 Spring Semester

4.1 Structural Considerations

4.1.1 Permanent Structure

After analyzing the existing support structure from the 2008-2009 deployment, it was evident that corrosion had taken place. It was determined the structure would not be able to potentially support an array of turbines. Based on evaluation and with a permanent deployment, a new structure would have to be constructed to support three turbines. This structure would consist of numerous steel members that would be galvanized for protection from the elements.

After consulting with Archer Western Contractors, the idea of anchoring a support structure into the micropiles of the pier was suggested. Micropiles would serve as a source of stability and rigidity for the support structure. At first it was believed that the support structure would not be able to come into contact with the mud line at an elevation of 65 feet to minimize sediment disturbance. This precaution was made to limit the amount of permit required if sediment was disturbed. A pre-cast concrete collar that would support the structure at the base of the pier was one proposed method of implementation. The structure would slide over the pier and provide base support for the structure. This method would eliminate any under water welding that would be required if anchoring at the base was decided upon.

After further consultation with the NHDOT, the idea of using piles to support the base of the structure seemed more realistic than the "C-Shaped" collar. The piles would reduce the load on the piers and provide vertical support and stability to the turbine deployment framework. The idea of using a drilled micropile would be very realistic for the contractor given the circumstances of such a schedule driven project. Minor sediment disturbance would emanate from the piles. Two 6 inch diameter steel piles would be drilled 10 feet into bedrock suggested by Archer Western Contractors during the time period allocated for the retrofitting of Pier 2. With the aid of the bathymetry around the bridge, it seemed feasible to take the route of using a steel pile.

Sizing of Support Structure The support structure would be comprised of multiple steel members that will be welded in order to support its self-

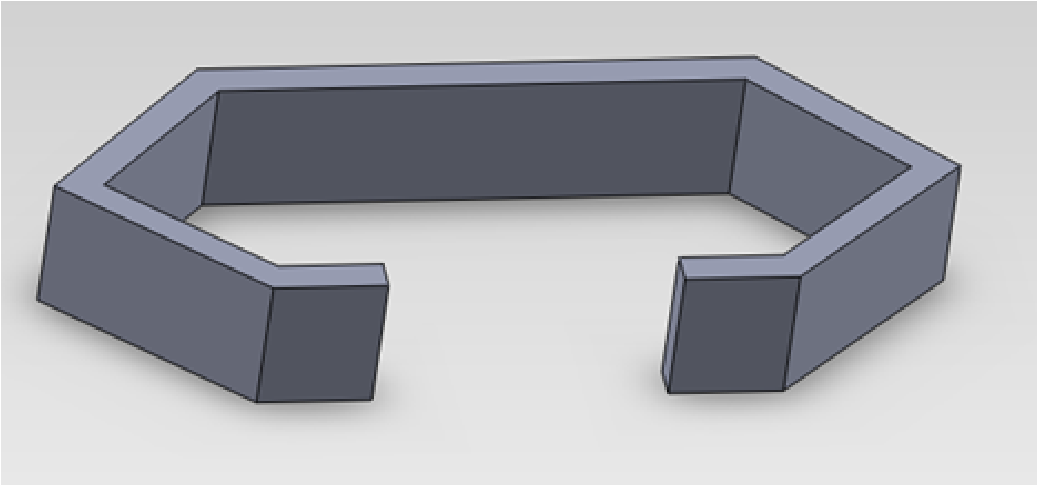


Figure 6: Pier collar concept drawing.

weight and the weight of the turbines. Estimates of size were decided upon in compliance to AISC Steel Construction Manual. One of the critical members of the support structure was a 50 foot section that would experience a concentrated load from the turbines and their respective encasements. After sizing the turbines and their respective encasement, a total of roughly 40,000 lbs. was figured. This weight is concentrated at two points (20,000 lbs each) on the 50 foot beam at 10 feet of center, thus making an un-braced length of 20 feet. As per CIE 793 Steel Design notes provided by Dr. Erin Bell, a beam would need to be designed with concentrated loads acting on it. A Steel W section beam W27X94 was assumed to be adequate for design.

Members were also sized using the loads that would be experienced such as water load. According to Article 3.7.3.1 of the AASHTO LRFD Bridge Design Manual, longitudinal pressure shall be considered. A longitudinal pressure can be calculated by equation 3.7.3.1-1.

$$p = \frac{C_D * V^2}{1000} \tag{7}$$

Where p is the pressure of the flowing water, C_D is the drag coefficient for the pier as specified in [12] and V is the designed water velocity (ft/s). By treating the support structure with turbine array as a square embedded pier giving a drag coefficient 1.4. A velocity of 2m/s (6.56 ft/s) was assumed. This ultimately yielded a pressure of 0.059 ksf (kilopounds per square foot).

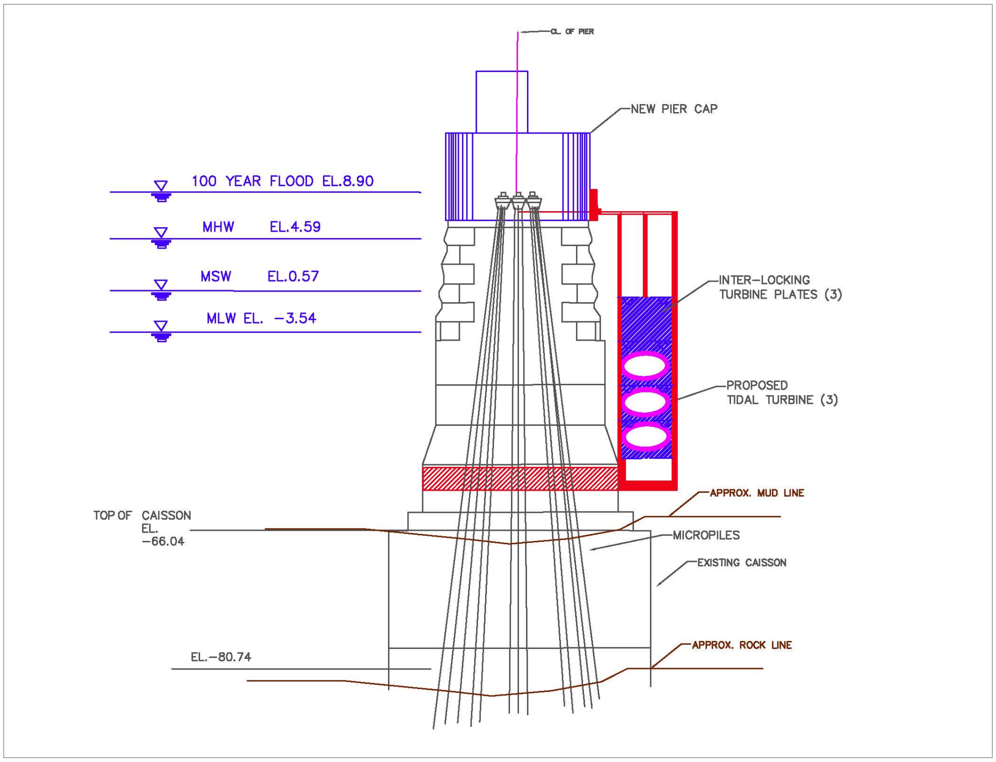


Figure 7: Initial pier mounting concept with collar.

To anchor back to the pier, a steel plate 2 inch thick and 2 feet in depth will provide a connection between the support structure and the pier cap. This provides a surface to connect the support structure to the pier structure. For the modular encasement to perform as designed, steel channels of C-shaped steel must be provided within the support structure to that the wheels on the encasement can move freely up and down. In turn the channels provide a track for the modular encasements to move up and down for maintenance purposes. The sizes of the channels will be C15X50 (15” wide and 50lb/ft.). This provides a track thickness of 12.125”, according to AISC Table 1-5, which would be more than enough space for a wheel to move up and down.

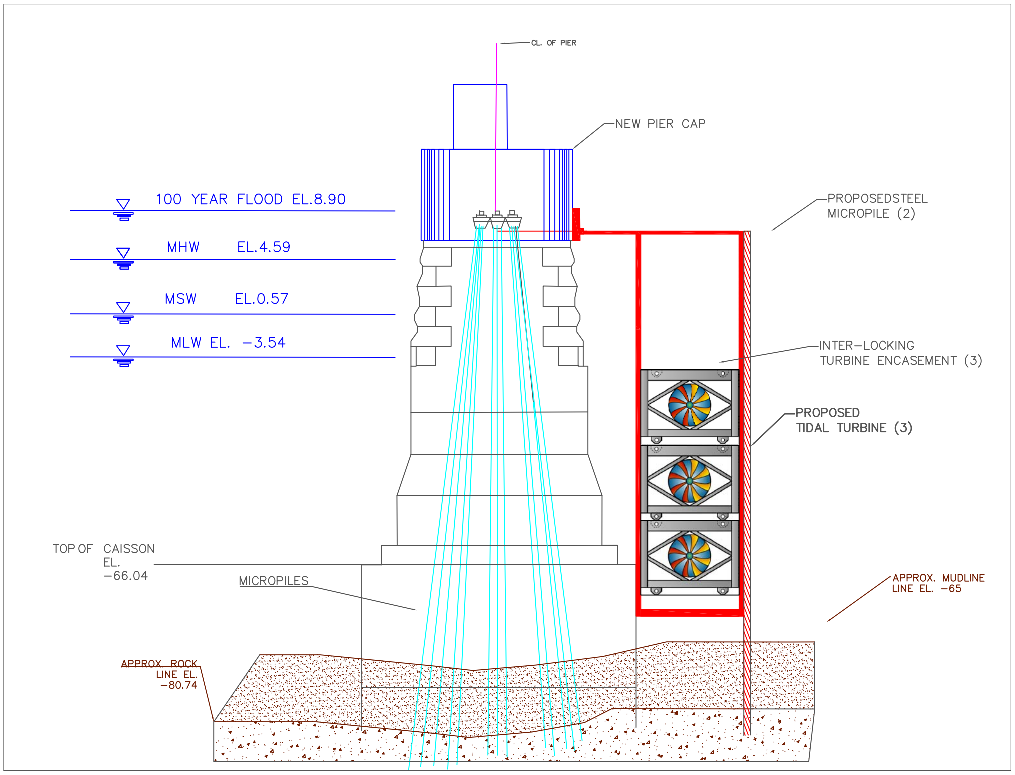


Figure 8: Proposed structure side elevation with steel pilings.

4.1.2 Sizing of Modular Encasement

Rough estimates of member sizes were compiled in accordance to the American Institute of Steel Construction Manual 14th Edition [11]. It was decided that there would be a total of six encasements, with two modular encasements supporting each of the three turbines. Each encasement would be comprised of 8 members, 4 exterior and 4 inner modular members. The 4 interior members are modular in the event of a change in turbine. The four exterior members will be square tube steel members that will be 16.4 ft long (5m). In accordance to Table 1-12 of the AISC Steel Manual, each square tube will be a HSS 8X8X1/2” member (8” by 8” in dimension with a thickness) and a weight per foot of these members is 48.85 lb/ft. The four interior members will be comprised of double angle steel that will be 6.5 feet (2m). According to Table 1-7 of the AISC Steel Manual, each angle will be

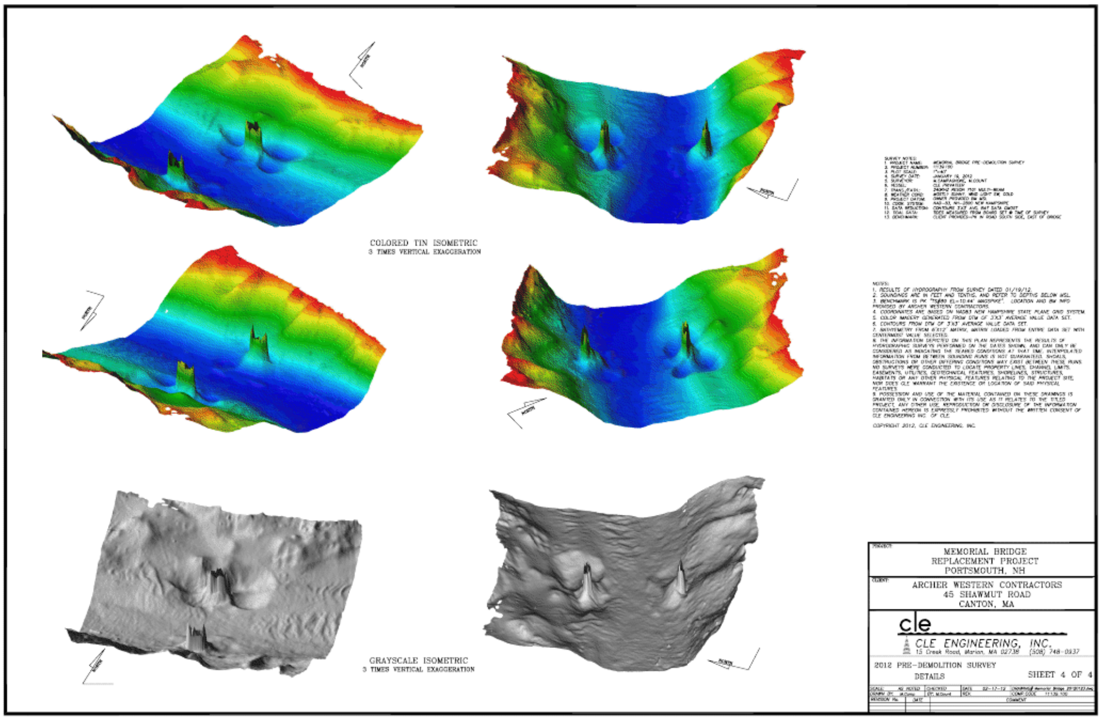


Figure 9: 3-Dimensional bathymetric survey of the Memorial Bridge site.

L6X6X1/2" (6" by 6" in dimension and 1/2" in thickness) and a weight per foot of 19.6 lb/ft. Since it was proposed to use double angles the unit weight per foot would double to 39.2 lb/ft.

The following calculations were performed to obtain the weight of the 6 encasements.

$$ExteriorMembers = 4 * [16.4' * 48.85lb/ft] = 3,204.5lbs, \tag{8}$$

$$InteriorMembers = 4 * [6.5' * 39.2lb/ft] = 1,037.9lbs, \tag{9}$$

$$6Casements = 6 * [3,204.5 + 1,037.9] = 25,454.4lbs \tag{10}$$

The weight of the turbines must also be included to obtain the true weight that the support structure will be holding. Since each turbine is roughly 3,000 lbs., with an array of three, the total weight will be 9,000 lbs.

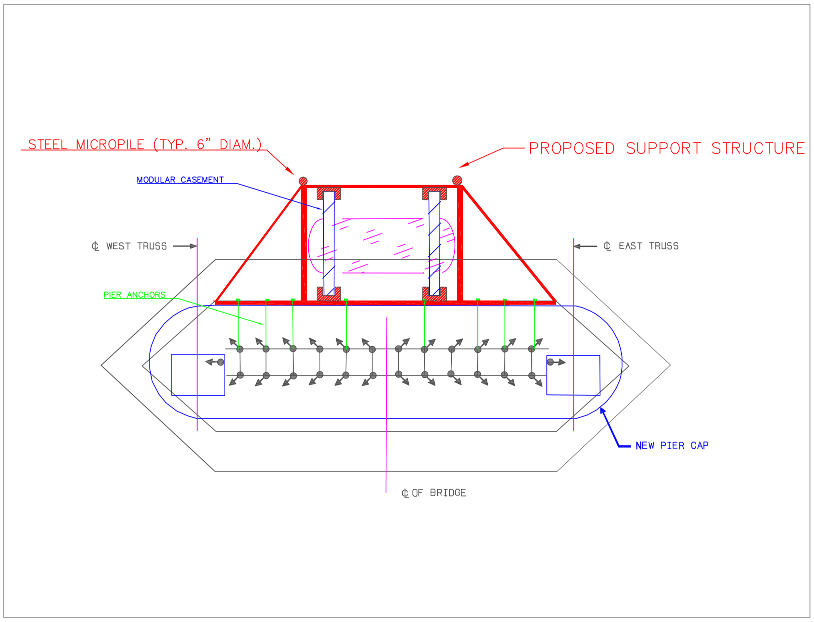
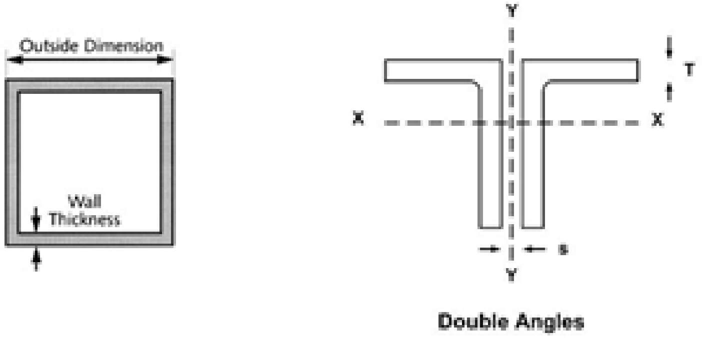


Figure 10: Proposed structure plan view highlighting material selection



(a) Square Tube HSS 8X8X1/2” (b) Double Angle 6X6X1/2”

Figure 11: Material Dimensions

$$6Casements(w/turbines) = 25454.4lbs + 9,000lbs = 34,454.4lbs \tag{11}$$

Since this calculation is an estimate, it should be assumed that a factor of 15% should be applied for good measure

$$6Casements(w/turbines)+15\% = (25454.4lbs+9,000lbs)*1.15\% = 39,622.56lbs \tag{12}$$

4.2 Environmental Considerations

4.2.1 Environmental Constraints

Several environmental constraints were brought to attention during the discussions of the structure design and implementation including marine life and sediment disturbance. Marine life was looked at closely in terms of the impact the turbine would have if implemented into the design of the bridge. Free Flow Power provided data on turbines used for hydrokinetic power generation on the Mississippi River and gave insight on how their turbines affected marine life and assured the turbine would not impact the surrounding ecosystem. The Free Flow Power website also shows experts testing this theory by injecting fish into a tank with a tube and showing the fish swimming around the turbine. The turbine itself only spins to about one and a half times the speed of the current and would not pose a threat to the marine life. The Piscataqua River is the third fastest navigable river in the world where the current can get upwards of 2 meters per second, or around 4 knots. These conditions make it unsuitable for any type of marine breeding to take place around the pier and turbine area. Another area concerning the effect on marine life is what effect vibrations would have on the marine life specifically concerning the endangered Atlantic Sturgeon. The turbine is believed to not have a very high vibration frequency and testing would require deployment of the turbine into the water. The Piscataqua River serves as a major throughway for boat traffic and the area is home to the Portsmouth Naval Shipyard as well as Badger and Seavey's Islands. With the combination of boats, industry, and domestic use, addition of the turbine should not have any effect in terms of vibration frequency.

In compliance with the National Marine Fishery Service, the sediment on the bottom of the river could only be touched from the month of November to March if the project were to interfere with any wildlife habitat. In the first stages, the design of the structure would not touch the bottom to avoid any sediment disturbance. The purpose of not touching the bottom and disturbing the sediment was to avoid any pollution caused from moving the sediment around. The area around the Memorial Bridge includes many industrial sections along the river. The sediment around the bridge could contain pollutants from these places which have settled over time and disturbing them could have adverse effects on the marine life. After meeting with the NHDOT, Bob Landry assured that this would not be a problem and suggested that a design incorporating the use of micropiles would be more suitable to the needs of the structure.

4.2.2 Permitting

Aside from NEPA permitting, several other permits were required in order for the implementation of the turbine to be possible. The Army Corps of Engineers, the U.S. Coast Guard, and the Federal Energy Regulatory Commission all have permits which were extremely relevant to this project. Most of these permits entail other regulations within them which would be deemed relevant to this project.

ACOE Permit The Army Corps of Engineers requires permitting for construction of most structures on any port, harbor, canal, or navigable river. This is required in accordance with several other regulations including the Rivers and Harbor Act, the Clean Water Act, and the Marine Protection, Research, and Sanctuaries Act. Since the turbine would be implemented onto a structure over the Piscataqua River, the ACOE permit applies and is a must for the project to go through. Permitting is also required for any dredging in water and the only time dredging may occur is during installation of the micropile.

FERC Permit The Federal Energy Regulation Committee permit is required for all hydrokinetic projects on navigable waters generating water from a U.S. water source. The main purpose of this permit is to regulate the amount of energy produced if the energy were to be fed back into the main power grid. This project plans to keep all energy generated on the bridge and avoid having to feed power back into the electricity grid. Therefore this project may qualify towards a verdant exemption from the FERC permit. This would allow for an exemption from the FERC permit, sometimes called a Verdant Exemption, only if the power generated is kept on the bridge. Currently, the General Sullivan and Little Bay Bridges have FERC permits from the 2008 hydropower project and are the only bridges in the State of New Hampshire to have them.

USCG Permit The United States Coast Guard oversees all construction, reconstruction, and modifications of bridges and other structures along U.S. water ways and therefore requires permitting for these types of projects. Regulations from several other acts apply to the USCG permit including the General Bridge Act of 1946 and the Rivers and Harbors Act of 1899. The Homeland Security Act is also taken into account giving the Coast Guard its duty to protect structures near navigable water ways. This project is considered a modification to the bridge and would require a USCG permit to work around the bridge pier without repercussions from the Coast Guard.

We hope to do more with the increased latitude the state has given us in pursuing this project.

4.3 Future Work

Tidal Current Analysis To increase understanding of the tidal currents at our site, it would be a great asset to collect transect data over full tidal cycles at short intervals between measurements. This would potentially allow for one to correlate the NOAA time series data with the river transects. This information would allow for a clear picture for turbine placement out of the center stream, as well as allowing for stronger predictions of the available power and energy.

Turbine Selection For this project to be viable, it would be necessary to garner interest from companies looking to build and test turbines. Opening lines of communication, and outreach to companies with viable turbine models is needed to further this project from proposal to reality.

Structure Design Further considerations for the structure design include studying the effects of the structure in current, as well as minimizing the effects on fluid flow entering the turbines.

Environmental Concerns Permitting must be pursued and officially applied for before the turbine support structure can be implemented.

5 Memorial Bridge Hydrokinetic Generation Project Proposal

Problem Statement Tidal energy is a resource that is quickly becoming recognized as the most available and most reliable source of renewable energy. In New Hampshire we are able to take advantage of a unique situation: The Memorial Bridge in Portsmouth, NH spans the third fastest navigable river in the world and the tidal driven flow of the river is the ideal location to generate hydrokinetic power. The power generated from a turbine array mounted to the bridge pier on the Portsmouth side of the bridge would generate enough power to light navigation, aviation, and street lights as well as the aesthetic lights proposed by the townspeople. The power generated could also be incorporated into a structural health monitoring system for long-term bridge management. The additional benefits to the bridge structure and traveling public include continuous lighting and monitoring that will increase the safety, security, and sustainability of not only the Memorial Bridge but also create an incubator for tidal energy technology to change the future of bridge engineering.

Objectives The objective of this project is ultimately to generate power from tidal energy. However, this project also provides a research platform for companies and researchers developing turbines that would benefit from testing in a consistent, bi-directional flow. The design of the structure and casements to house the turbines creates a situation where turbines can be retracted as new ones are manufactured or as spots are taken for testing. The structure will become an incubator for this technology that allows for companies to test their newly developed turbines over longer periods of time in a structure that can be modified to house them. This is still an area that is being actively researched both in the turbines and in the technique used to store the power generated with the turbines. Being at the forefront of the research is an opportunity for New Hampshire to increase its presence in the field of renewable energy and sustainability.

Societal Need A safe, secure, and sustainable bridge will hugely benefit the people of Portsmouth as well as the rest of New Hampshire and the world. This project will harvest energy independent of the weather, meaning that even if there is inclement weather, which could cause power outages, this bridge will still be well-lit and ensure safe travel across, over, and around the bridge. This renewable power will also make aesthetic lighting proposed by the public possible and thereby addressing public concerns from local interest groups and public meetings. Another proposed use for the power being generated was that of a structural health monitoring system that will extend the life of the bridge and make maintenance more effective and proactive. In the near future renewable resources will become more important and having an available tidal resource is going to be invaluable. Tapping into this now will create opportunities for research and discoveries making them available locally. This will also further New Hampshire's Renewable Portfolio Standards and Goals to reach 23.8 percent renewable energy by 2025 (FERC).

Approach This proposed project deployment will be integrated with the ongoing construction of the new Memorial Bridge. The structure will encase three turbines held in modular casements. The modular tidal turbine support structure is designed to allow of ease of maintenance and turbines can be easily retracted for deployment of new technology. With a permanent deployment, a new structure would have to be constructed in order to support and array of three turbines. After consulting with Archer Western Contractors (AWC) along with the NH DOT, the idea of anchoring a support structure into the micropiles of the pier to increase stability and rigidity was proposed as well as two steel piles to provide stability for the structure. Minor sediment disturbance would come from the piles and this route of stability would be more feasible for AWC. The two 6" diameter steel piles would be drilled 10 feet into the bedrock. With the aid of the bathymetry around the bridge, it is feasible to take the route of using a steel pile. This pile would be drilled during the time period allocated for pier modification by AWC. The support structure would be comprised of multiple steel members that will be welded in order to support its self-weight and the weight of the turbines as can be seen in Figure 12 and Figure 13.

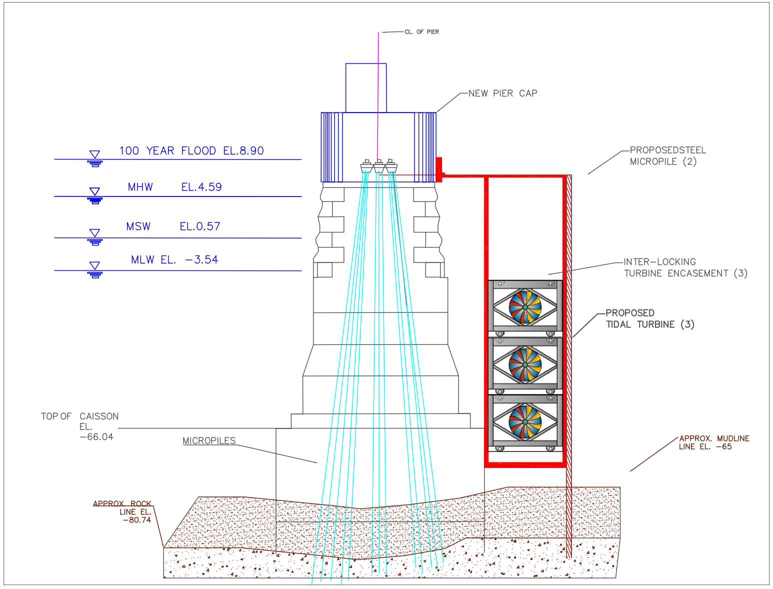


Figure 12: Front Elevation of Proposed Structure with 3 Turbine Casements

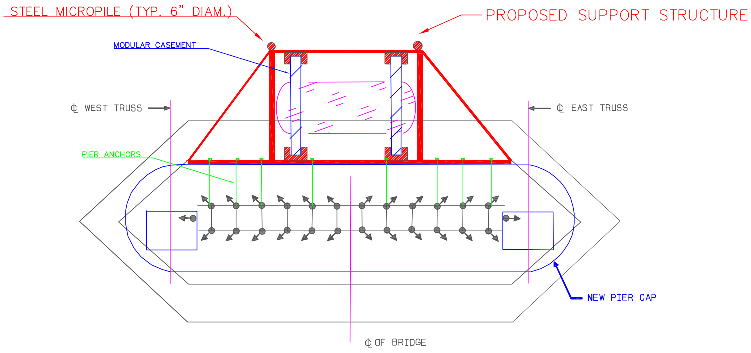


Figure 13: Top View of Proposed Structure

The deployment will follow a general schedule as shown below. This is dependent on the turbines selected to go into the structure and the change in design needed for the casements.

Off Site Task/Requirements *Task proposed to be performed prior to Archer Western Pier 2 Retrofit*

- Alleviate any remaining permit constraints
- Final sizing and design of support structure and critical members
- Final sizing and design of modular encasement
  - Critical based on selection of turbine selection
- Contractor approval of method of implementation to Pier 2 structure
  - Proposed anchoring to new micropiles
- Final Design of Steel micropile
  - Proposed 6” diameter steel pile, drilled and grouted
- Pre-Construction Meeting

On Site Task/Requirements *Task proposed to be performed during Archer Western Pier 2 Retrofit*

- Site Investigation,
  - For required permitting and site preparation
- Anchoring of steel plate members to pier.
  - Proposed anchoring to new micro-piles in Pier 2
- Implementation of proposed steel micro-piles
  - Required Drilling and grouting
  - Base on Contractor Design, will take advantage of Contractor’s experience and methods

- Installation of support structure
- Inspection and Load Testing
    - Required prior to installing turbine array
- Implantation of Turbine Array
    - Testing

Outcome and Expected Significance Implementing this structure on the bridge is going to be a step ahead in the realm of renewable energy.The power generated will provide energy for all of the lights (aviation, navigation, and traffic) on the bridge as well as a possible health monitoring system. The sustainability of the bridge will increase, as will the life of the bridge since the health monitoring system will enable proactive maintenance of the bridge. Tidal energy is clean and renewable, providing some independence from fossil fuel energy sources. As the technology increases we foresee the power generated becoming greater and therefore the reach of the power will go beyond just lights on the bridge. Such integration will enhance sustainability rapidly by providing clean and renewable energy sources for both existing and new infrastructure. This deployment will also lead to job creation as companies interested in tidal energy will come to this area to test and research tidal turbines and ways to generate power using tidal energy.

A Fall Semester

A.1 Initial Proposal

Objective To determine if there is sufficient tidal energy present to provide the Memorial Bridge in Portsmouth, NH with enough energy to power the lights and center span lift while remaining stable and functional.

Approach This project has been broken into four major tasks. The first task includes determining the present state of the bridge and tidal currents. To do this we will refer to the NOAA survey in 2007 for the tidal current data. The amount of power required to operate the center span lift and to keep the lights on in all weather will be calculated. The second task involves taking initial measurements using the Acoustic Doppler Current Profiler (ADCP) which will be deployed for a full lunar tidal month. We will also be looking at the bridge loads and dynamics at this time. The first and second tasks will be completed by Thanksgiving and will be followed by a full report of what has been accomplished. The third task is analysis of the initial measurements that were taken as well as planning for deployment of the Gorlov turbine that has been previously studied by a UNH graduate student and has data already collected for us to use as comparison. This planning will involve the design of a deployment structure for the turbine. The fourth task is the deployment of the sensors for the bridge and the Gorlov turbine. Once the turbine has been deployed the loads on the bridge and bridge structure will be assessed and the output of the turbine will be measured so that efficiency calculations can be made.

Equipment ADCP, sensors for the bridge, use of boats for deployment and measurements, material for deployment structure for the turbine, Gorlov turbine.

A.1.1 Turbine Suspension Plans

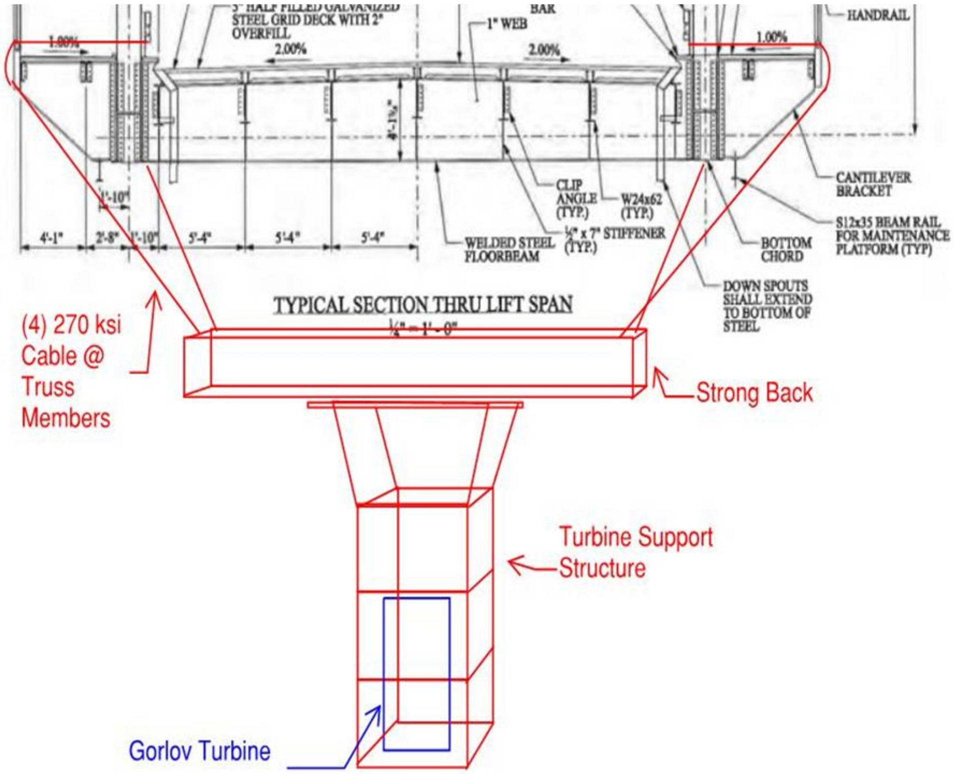


Figure 14: The original deployment plan for suspending a single turbine from underneath the Portsmouth side flanking span, with the intention of measuring tidal resource and induced bridge stresses using a Gorlov (Vertical Axis Helical Turbine)

B Updated Structure Plans

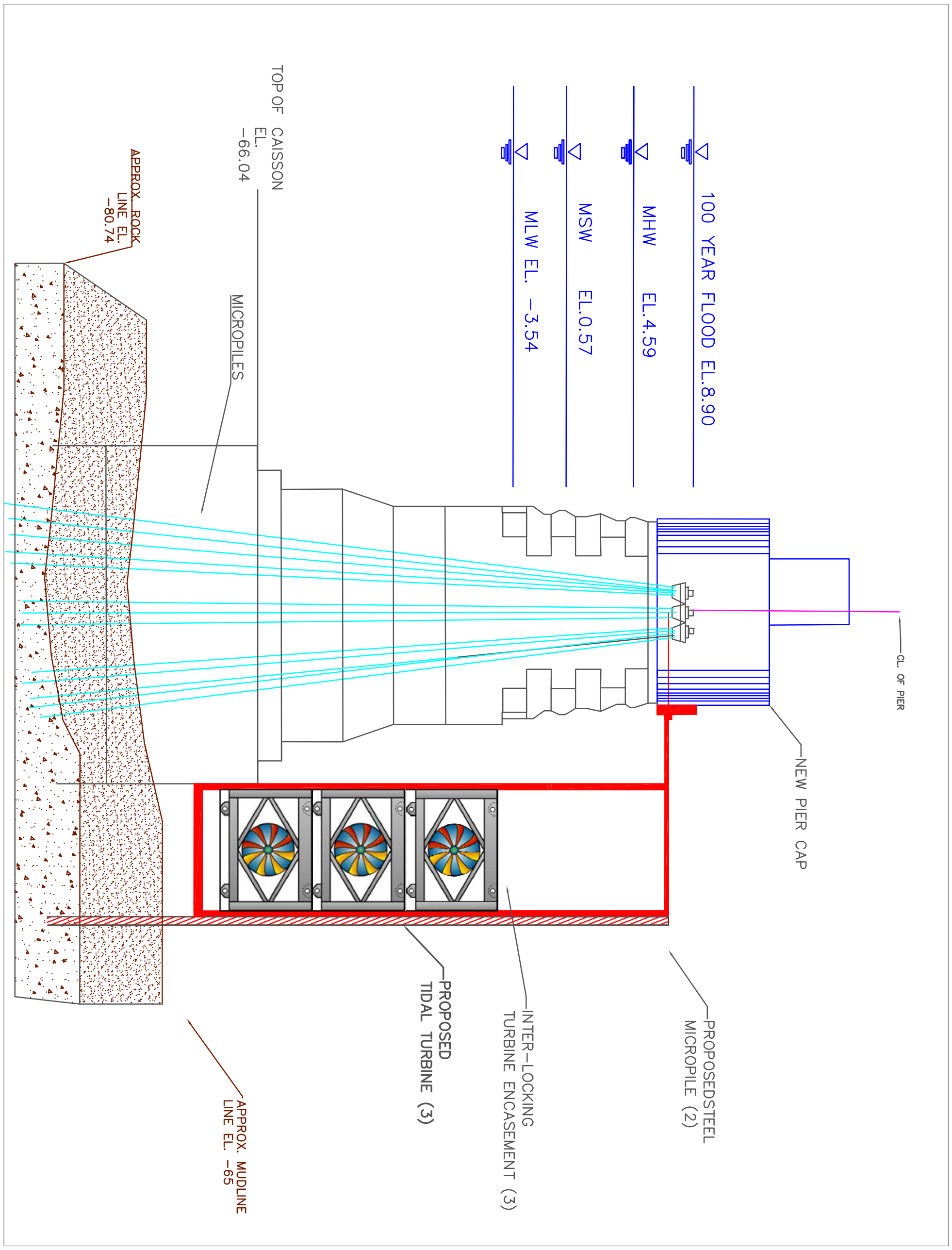


Figure 15: Proposed Structure: Front Elevation

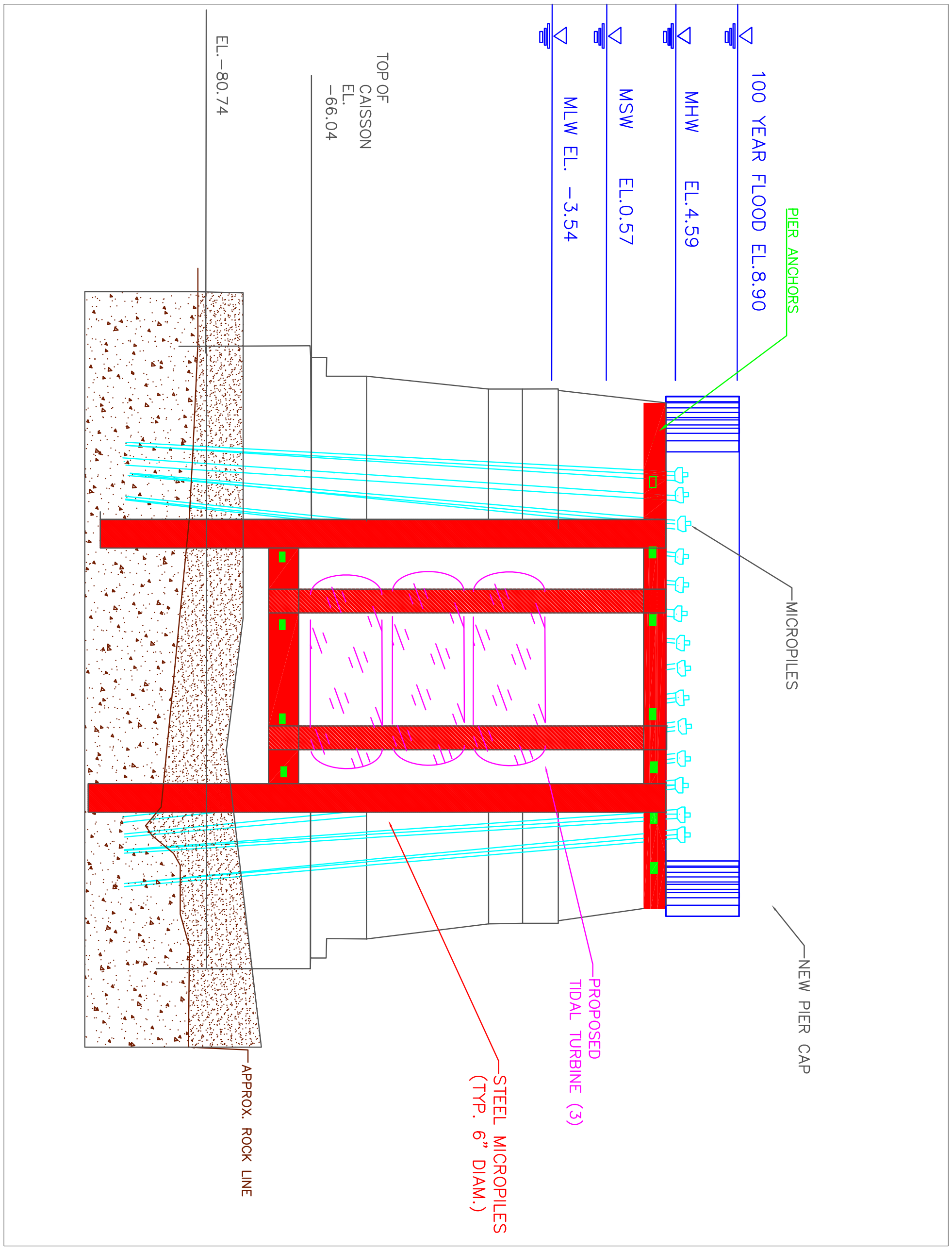


Figure 16: Proposed Structure: Side Elevation

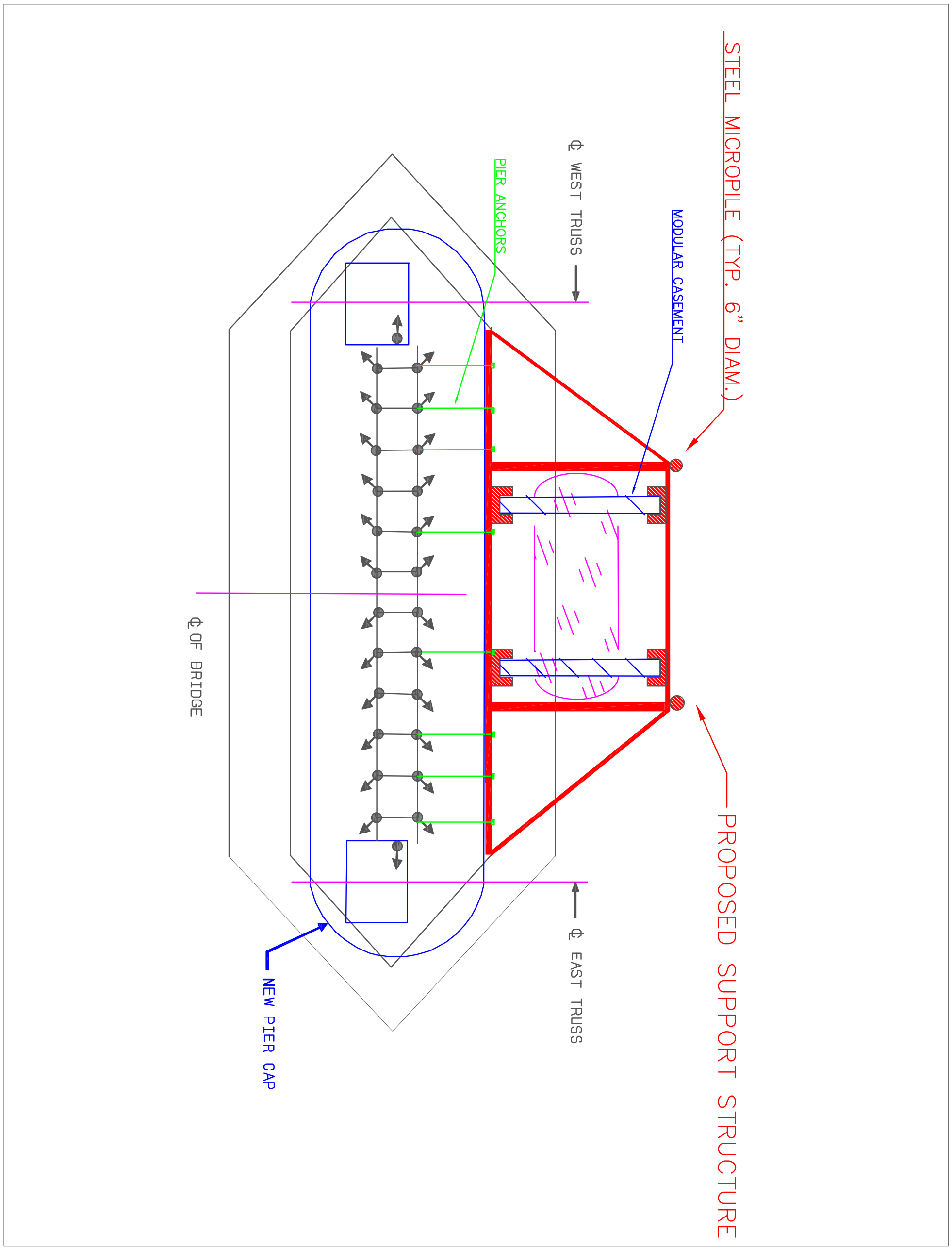


Figure 17: Proposed Structure: Plan View

C ADCP Reference

Figure 18: Reference of data collected near the Memorial Bridge

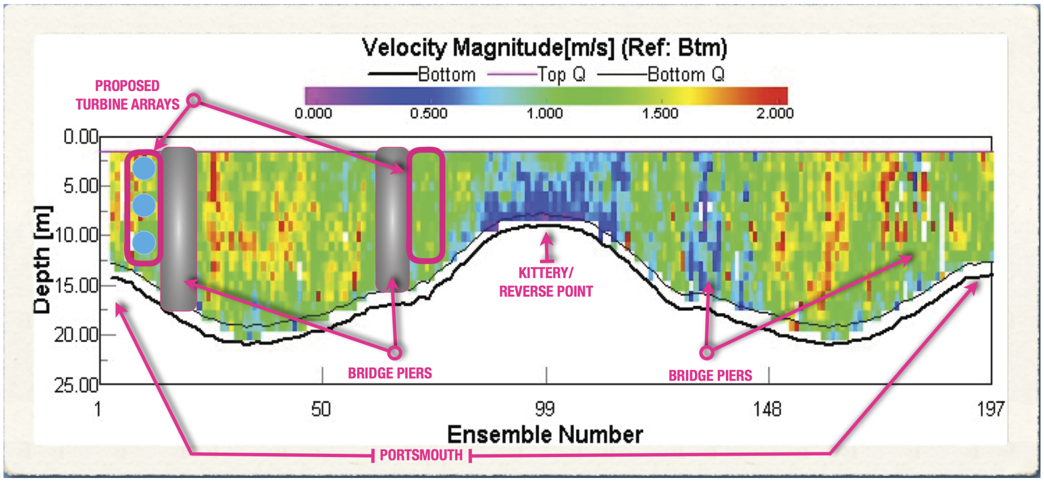


Figure 19: A marked transect taken from along the Memorial Bridge, highlighting physical features of the geography, as well as proposed turbine array placement

D Site Bathymetry

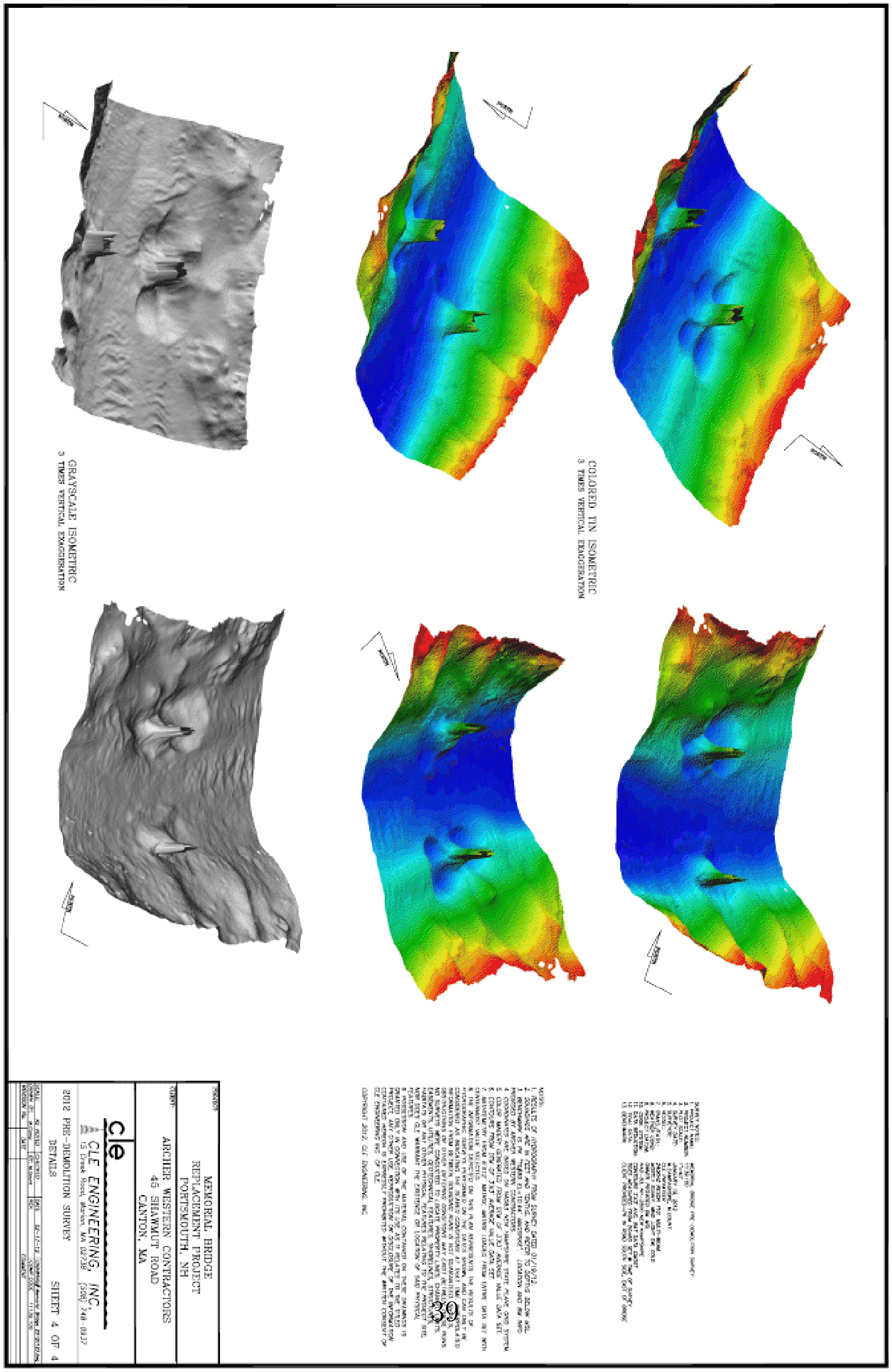


Figure 20: 3-Dimensional Bathymetry

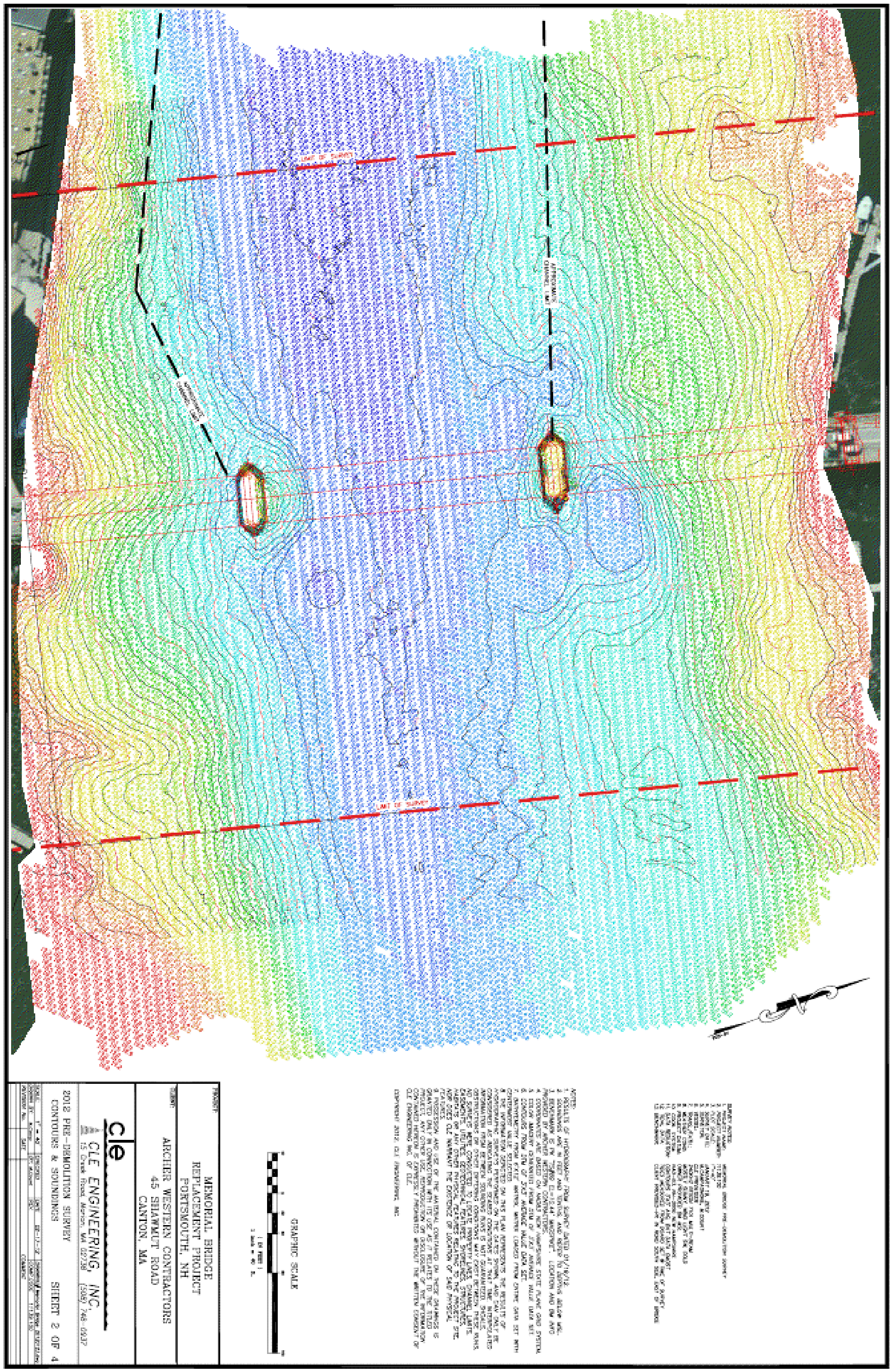


Figure 21: Top View Bathymetry

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