Title	**Tidal and River Energy Converter Debris Impact Load and Cable Snag Risk Quantification**
DSA Document	DSA-MRC-FTSA
Revision	B
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Status	Release
Prepared for	Marine Renewables Canada
Client reference/project	
DSA project	MRC-FTSA
Last revised	2016-06-07
Pages (incl. cover)	26

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DYNAMIC SYSTEMS ANALYSIS

Revision History

Revision	Date	Description	Revisions by	Checked by
A	2016-04-08	Issued for SMC/TC114 completion	Colin Wilson	Ryan Nicoll
B	2016-06-07	Tug/barge size sensitivity analysis, future work section, and misc. clarifications added	Colin Wilson	Ryan Nicoll

Executive Summary

Tidal and river energy converters can be placed in regions with marine traffic and also floating debris. This introduces significant challenges for the structural and mooring design of these systems to handle both tug and barge towline snag and dynamic impact loading from logs, ice, or other debris.

Dynamics Systems Analysis Ltd (DSA) was tasked with assessing debris impact loads and towline snag effects on floating turbine systems and related technologies, such as floating debris diverters. To better understand these systems, the work presented was carried out in three phases of numerical dynamic analysis:

1. Tug and barge navigation through tidal channel in proximity to a hypothetical tidal farm site to assess likelihood of collision
2. Floating submerged turbine platform towline snag to qualitatively refine a snag resistant design
3. Floating platform debris impact for verification from field test data

The results of the work completed in these phases is intended to inform marine renewable energy standard development by providing indications of loads in debris impact and snag scenarios as well as guidance on how to make floating tidal systems snag resistant. The analysis of tug and barge traffic also provides some reference for assessing potential operating depth and clearance requirements from marine traffic zones to reduce snag risk. All time domain simulation analysis were completed using ProteusDS.

The first phase of analysis was designed to model the barge traffic through Discovery Passage on the east coast of Vancouver Island. Data on a range of tug, barge, and towline configurations were provided by SRM Projects and was used as the basis for establishing a representative tug and barge system to assess in more detail. This system is characteristic of a container barge traveling to Alaska from Seattle and back through the passage. Additional sensitivity studies were completed to examine the effect of lower towing capacity tugs and varied towline lengths. The depth of the towline throughout the transit was monitored to gain an understanding of the risk involved with deploying a submerged turbine in this high traffic area. In order to accurately model this system, hydrodynamically modelled local tidal currents and bathymetry data were supplied by SRM Projects and Cascadia Coast Research Ltd. In addition, a piloting control scheme was developed to ensure the tug and barge follow desired navigation waypoints through the passage. The maximum towline depth observed was 62.4m when the tug and barge system travelled south. The associated maximum lateral tug standard deviation from the waypoints, or intended path through the channel, was 93m. These are extreme results that were produced by the shortest towlines and also smallest tugs investigated. Small tugs spent more time navigating laterally across the channel to maintain the desired track, allowing the barge to drift and catch up to the tug. Short towlines allowed the less time for the barge to catch up to the tug and either pull it off course or increase catenary depth, particularly with small tugs. Increasing towline length also showed some correlation with increased catenary sag. In contrast to these more extreme results, a more reasonable scenario with medium capacity tug with moderate towline length produced a catenary depth of 16.6m and maximum lateral deviation of 12.2m. The lateral deviation from path is of the tug and not the barge. These results give an indication of the dynamic model capabilities in evaluating potential lateral deviation from a controlled channel for this type of tug and barge system when gauging marine traffic proximity to a hypothetical tidal farm.

The second phase of analysis utilised a submerged floating turbine platform designed by MAVI Innovations Inc (MAVI). Using the supplied geometry and mass values, the system was reconstructed in simulation and steady mooring response verified against expected analytical values. The platform was subjected to a snag load scenario by a passing catenary line to mimic a

worst-case scenario of a tug and barge interaction with a submerged floating turbine. Several frame designs were tested to provide some insight on design features that would alleviate snagging. Key results are that convex slopes should be used on the top portion of the frame to prevent the line from catching on the hull. In addition, careful assessment of the center of gravity and mooring connection point is needed to ensure the platform can easily tip to allow the line to pass.

The third and final phase of analysis focused on debris impact of floating platforms used for river and tidal turbine systems. In partnership with Alaska Hydrokinetic Energy Research Center (AHERC) via the University of Alaska, field data of impact loads from debris on a floating platform was provided and used for verification of similar impacts in ProteusDS. Field tests showed mooring tension peaked at approximately 30kN during debris impact and DSA used this measured data to compare against a similar floating platform configuration in simulation. Due limited information available, only a qualitative comparison to the field data was conducted. In addition to this, a numerical sensitivity study was completed using various floating debris configurations, masses, and flow speeds to assess the change in impact loads. Generally, the larger the mass and the larger the flow speed, the larger the impact forces. However, the geometry and buoyancy of the debris has a strong effect as well: marginally buoyant but large and heavy structures were easily submerged and rolled off the platform with significantly reduced impact loads.

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1 Introduction

1.1 Overview

Floating debris is a hazard to tidal and river energy converters. In addition, marine traffic and tidal and river energy converters are hazards to one another. These hazards can introduces significant challenges for safety as well as the structural and mooring design of these systems in order to handle potential tug and barge towline snagging or dynamic impact loading from logs, ice, or other debris.

Dynamics Systems Analysis Ltd (DSA) was tasked with assessing debris impact loads and towline snag effects on floating turbine systems and related technologies. The work presented here was completed with critical information provided in partnership with MAVI Technologies, SRM Projects, and the Alaska Hydrokinetic Energy Research Center (AHERC) at the University of Alaska.

A key aspect of the research project was to develop contact effects to model towline snag and debris impact and incorporate it into the marine dynamics analysis program ProteusDS. This analysis tool was then used to investigate a number of scenarios to assess the risk of marine traffic and debris hazards. The results of the analysis completed is intended to inform marine renewable energy standard development by providing indications of loads in debris impact and towline snag scenarios as well as guidance on how to make tidal systems snag resistant. The analysis of tug and barge traffic also provides some reference for assessing potential operating depth, clearance from marine traffic zones to reduce snag risk, and potential lateral deviation from the intended transit path.

1.2 Objectives

To better understand these risks and loads associated with tug and barge towlines and debris impact, a research program was completed to develop functionality to investigate contact effects between floating systems and towlines. These tools were then used to complete three phases of numerical analysis:

1. Marine traffic dynamics: tug and barge navigation through tidal channel in proximity to a hypothetical tidal farm site to assess snagging risk
2. Turbine and towline snag dynamics: floating submerged turbine platform towline snag for the assessment of snag resistance platform designs
3. Debris impact: floating platform debris impact to verify the numerical model with field test data

The load cases considered are not intended to be exhaustive. The results are intended to provide some basis and guidance for marine renewable standards development such as but not limited to structural and mooring design.

1.3 Project Type

Project classification is indicated in Table 1.

	Project Type	Description
☒	Feasibility	Assessing concepts where feasibility and core engineering challenges have not been identified. None of the primary risks are known. Concepts are to be tested to validate proceeding to concept study or FEED stages.
☐	Concept study / Pre-FEED	Analysis and simulation of concepts to identify feasibility, produce ideas, and assess pros and cons of implementing those ideas. Typically the purpose of the project will be to assess wide array of concepts, assess risks, identify costs, and loosely dimension system components for budgetary purposes.
☐	FEED	Support of the development of an initial design which includes ensuring that components meet safety factor requirements and that the concepts developed meet safety or classification requirements.
☐	Detailed design support and finalized analysis	Supporting the detailed design though analyses which have been finalized to the degree that the results may be used for construction. All model inputs are to be documented.
☐	EPC support	Supporting engineering, procurement and construction contractors in the implementation of detailed design plans. Tasks may include installation analysis, operability assessment or risk mitigation.
☐	Owner / operator life cycle support	Tasks may include operational support, operability assessment, risk mitigation, decommissioning studies.

Table 1: Project classification

2 Inputs and Setup

2.1 Overview

This section reviews input parameters fundamental to the project. Various currents and current profiles were used but ocean waves were not considered in the analysis.

2.2 Environmental Conditions

2.2.1 Marine traffic dynamics

The hydrodynamic data for Discovery Passage was supplied to DSA by Cascadia Coastal Research. This included a detailed bathymetry height map and temporal and spatial varying current data. The maximum flood (Northern) and ebb (Southern) tide currents were used in the simulation as a worst case scenario approach. These portions of the tidal cycle are shown in Figure 1 with a single sample point normalized to indicate flow direction in the channel. As tug and barge traffic generally do not navigate in opposing currents, the analysis was completed with the tug and barge following the current in all cases. By incorporating the spatial and time varying flow, the forces on the tug and barge system due to hull drag and resistance are incorporated in the navigation simulation.

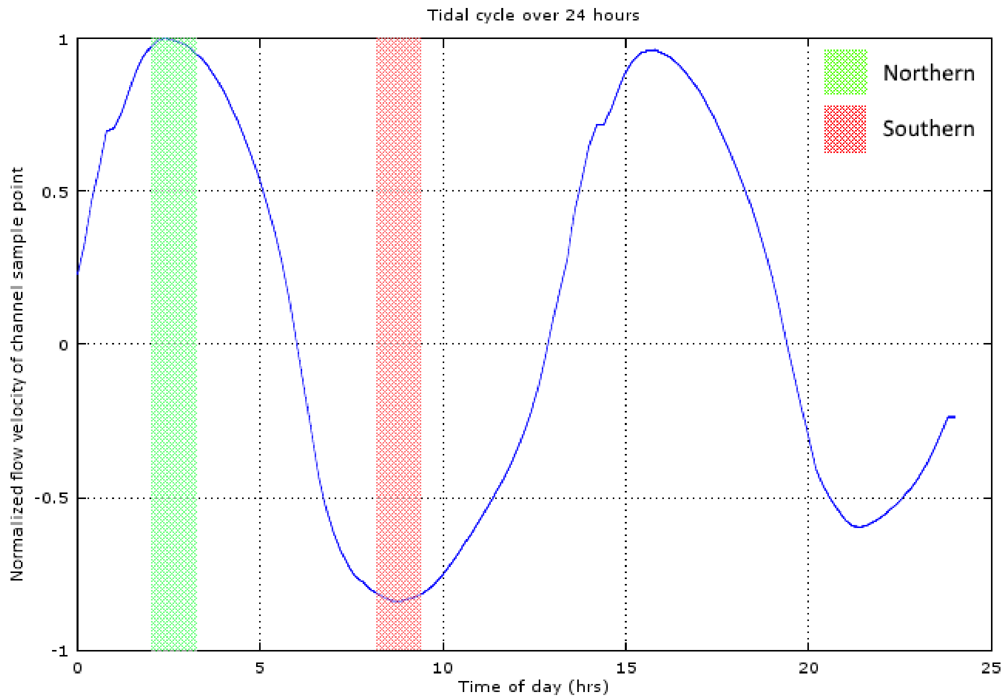

Figure 1: A 24 hour tidal cycle with chosen flood and ebb periods

2.2.2 Towline and turbine snag dynamics

A continuous uniform 2m/s current was used for the platform and towline snag assessment. This was used as a representative flow speed during turbine operation as it relates to a typical operational flow rate for the turbine design and typical flow rates in Discovery Channel.

2.2.3 Debris impact

Continuous uniform current profiles were used in the debris impact simulations including validation with AHERC data. The flow speeds considered included 1, 2.5, and 5 m/s.

2.3 Simulation Inputs

2.3.1 Marine traffic dynamics

The tug and barge system used for this assessment were modeled after Seattle-based Alaska bound container barges. These were selected as they are the largest vessels of this type travelling through Discovery Passage as well as the length and mass of the towing arrangement based on data provided by SRM Projects [2]. The larger size also means larger drag forces from tidal currents and more challenging navigation from the momentum of the system. The maximum depth of the towline will occur when a connected tug and barge surge close together due to influence of currents and navigation through the channel. It is expected that longer and heavier towing materials will maximize the sag relative to smaller systems. Furthermore, limited information was available on smaller local tug and barge systems.

The tug and barge were modeled as rectangular rigid bodies shown in Figure 2 and outlined in Table 2. This approximation was made to simplify the problem as the dominating effect on navigation in the channel is the hull drag and resistance, thrust capacity, and mass of the tug, barge, and towline. No wind or waves were considered in the problem and the detailed seakeeping motions of the tug were not required, so a more accurate hull shape for the tug was not necessary.

The towing system was initially modeled with two 30m, 70mm chain bridles and a 250m, 70mm chain towline. A chain towline is a conservative measure as the greater weight creates a larger catenary depth. The line lengths for these systems may range from 183 to 311m and this was used as a representative length [2]. Axial elasticity of chain is usually higher than wire rope, but this will not produce any difference in response as the catenary form dominates the dynamic reaction loads from the towline. Additional sensitivity simulations were completed using various lengths of 2 3/8in wire rope for the main towline. The properties of the tow system are shown in Table 3 based on data provided by SRM Projects [2].

The tug was driven by a waypoint controller that applied surge and yaw forces to steer the tug vessel along several paths. The controller maximum force limit, indicating the navigation capacity of the system or bollard pull, was initially set to 2MN or 200 tonnes. Preliminary analysis showed this was a reasonable limiting capacity to use given the size of the tug and barge system. This is merely the maximum available bollard pull and does not represent average load the controller uses. Additional sensitivity runs were completed using various maximum force limits, representing the capabilities of smaller tugs. Note that the tow line remained fixed length and no dynamic tension control was used on the towline. No relative speed control was used to match velocity between the tug and the barge. This means that based on the currents in the channel, the barge may drift and catch up to the tug, which is following a course through the channel at a target speed.

The waypoint control algorithm is illustrated in Figure 3.

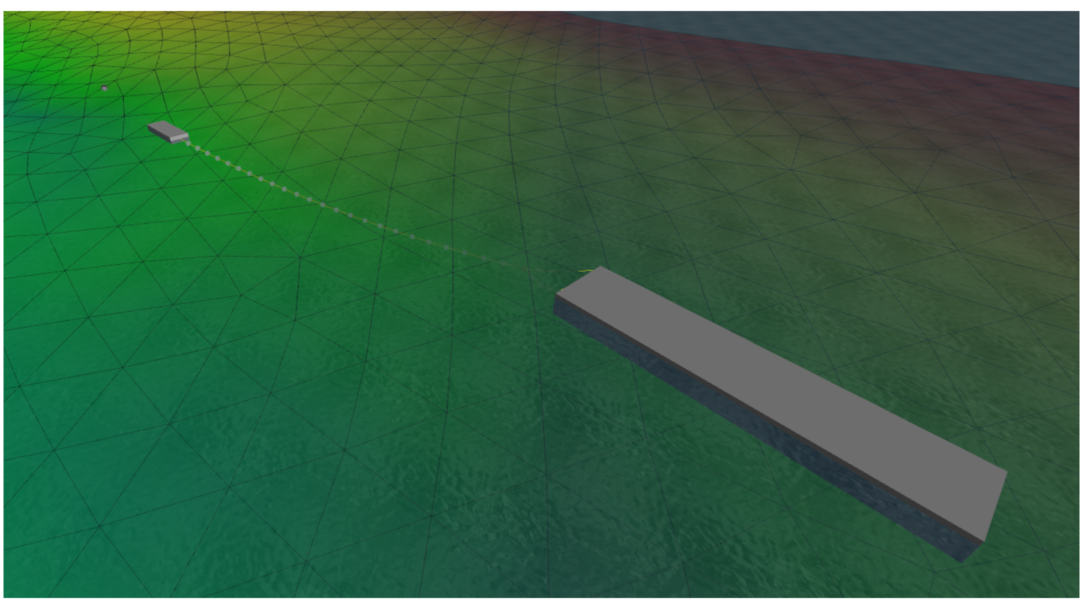

Figure 2: Tug and barge system showing bathymetry and finite element towline mesh

Vessel	Mass (kg)	Length (m))	Width (m)	height (m)
Generic tug	1.5e6	40	18	4
Barge	2.8e7	130	30	10

Table 2: Towed barge properties

Component	Material	Diameter (mm)	Mass (kg/m)	EA (N)	Length (m)
Bridle	Chain	70	107.3	3.9e8	30x2
Tug line	Chain	70	107.3	3.9e8	250
Tug line	Wire rope	60	15.5	2.0e8	various

Table 3: Towline properties

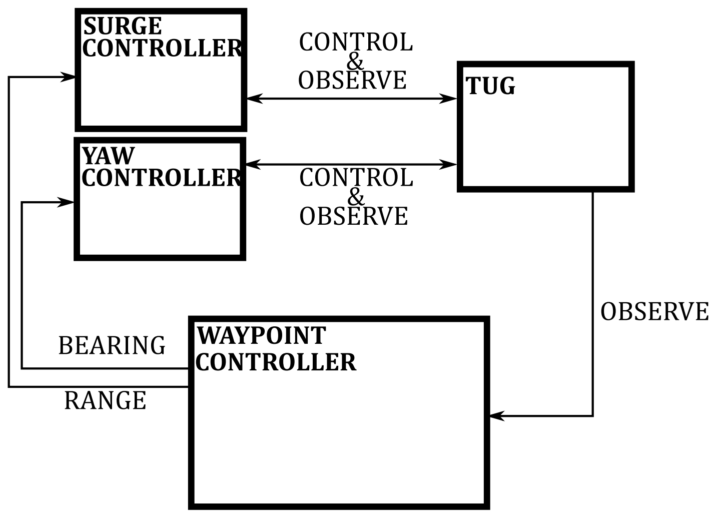

Figure 3: Waypoint controller schematic

2.3.2 Turbine and towline snag dynamics

The geometry of the submerged floating MAVI turbine platform was approximated using simple cuboid shapes as shown in Figure 4 with mass and dimensions reported in Table 4 and Table 5 [3]. The mooring was modeled using three shots ($\sim$90m) of 30mm chain at each anchor location with the remaining mooring length of 120m with 12mm Amsteel Blue (Dyneema) fiber rope. The mooring material properties are reported in Table 6. The MAVI submerged turbine platform was settled at a depth of $\sim$13m in total water depth of 75m. The anchors located 212m to the north and south. The turbine thrust load is absorbed by the mooring system and uplift on anchors is a limiting factor in design of these systems, which is alleviated by increasing mooring scope. This was selected as a reasonable starting point that also considered the available space at the hypothetical turbine location in Discovery Passage.

An initial snag analysis was completed using the approximated hull geometry. Refined hull geometry based on the geometry specified was also used as seen in Figure 5. In addition to this, a conceptual hull design was generated based on the results of the initial snag analysis. This geometry is shown in Figure 6. The surfaces of frame above the mooring connection points are designed to allow any lines in the water to pass over the platform. Furthermore, MAVI innovations supplied an updated platform model shown in Figure 7.

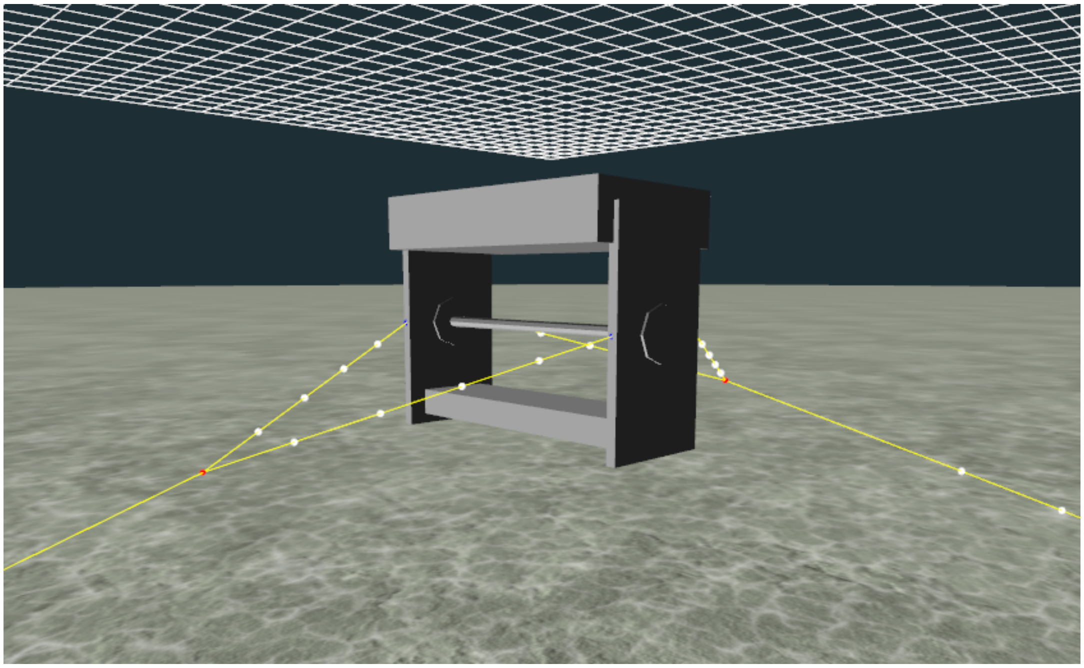

Figure 4: Submerged turbine platform with approximate hull geometry for contact effects

Platform part	X dimension	Y dimension	Z dimension	Drag coeff.
Top duct	3.36	6.40	1.16	0.77
Bottom duct	1.70	6.40	0.58	0.91
End plate	2.50	0.22	4.82	0.58

Table 4: Submerged turbine platform dimensions

Mass (kg)	Ixx (kg*m2)	Iyy (kg*m2)	Izz (kg*m2)
23815	1.21e5	3.88e4	3.46e4

Table 5: Submerged turbine platform mass and inertia

Material	Diameter (mm)	Mass (kg/m)	EA (N)
Chain	30	18.18	7.5e7
Amsteel Blue	12	0.09	4.7e6

Table 6: Submerged turbine mooring parameters

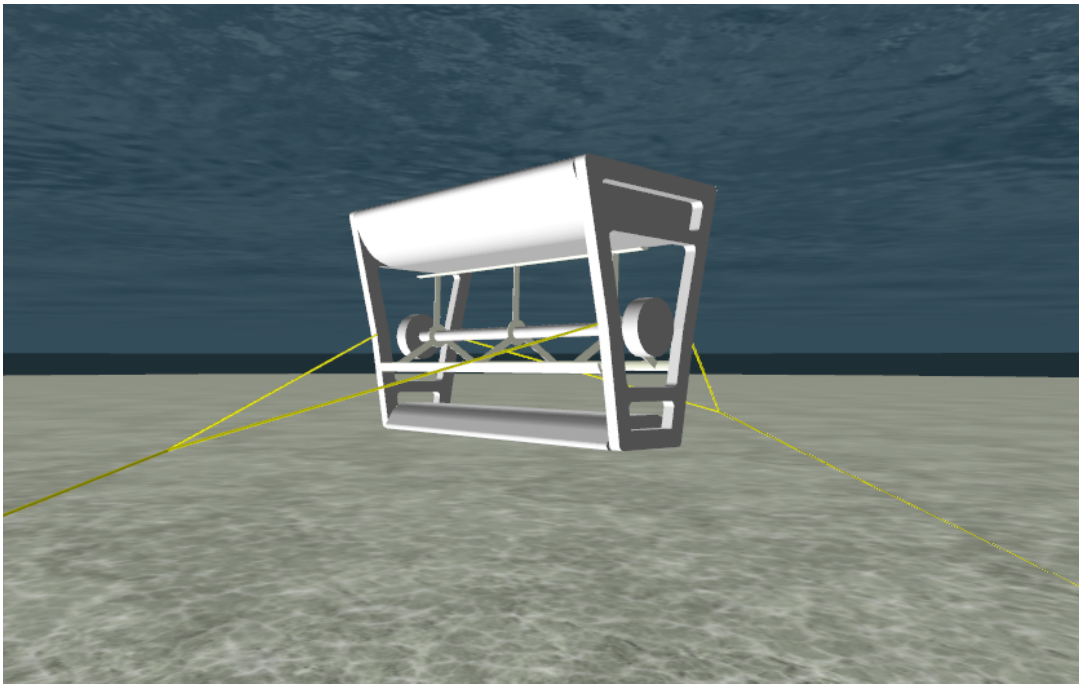

Figure 5: Submerged turbine platform using the specified hull geometry for contact effects

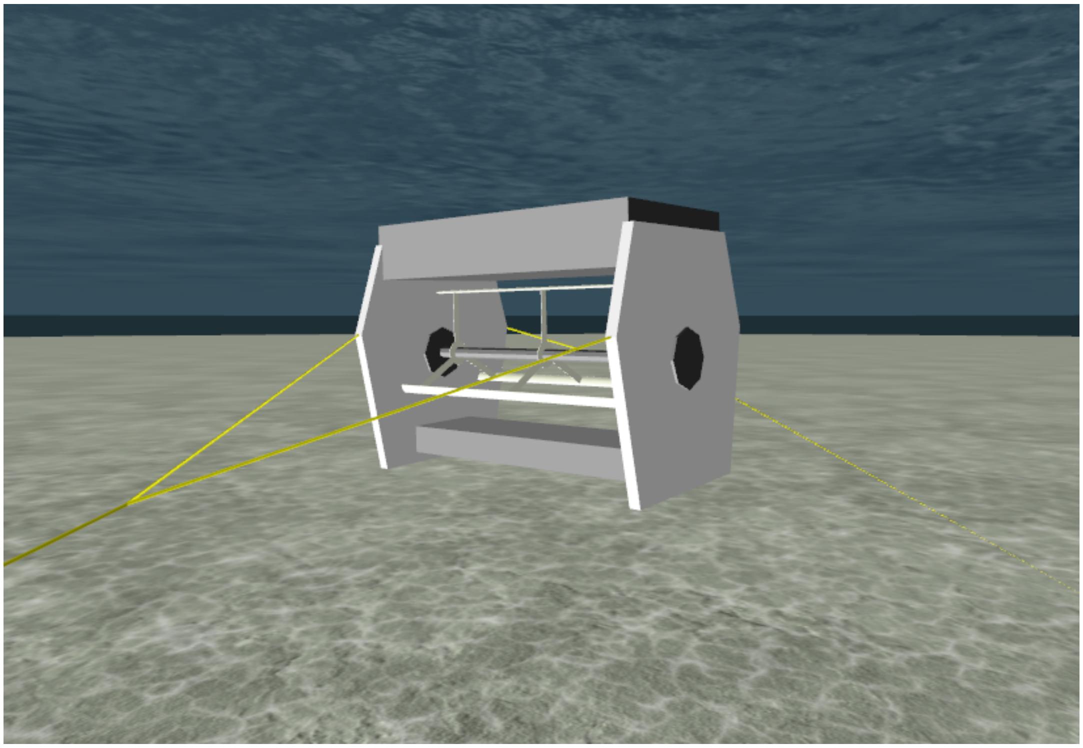

Figure 6: Conceptual submerged turbine platform design

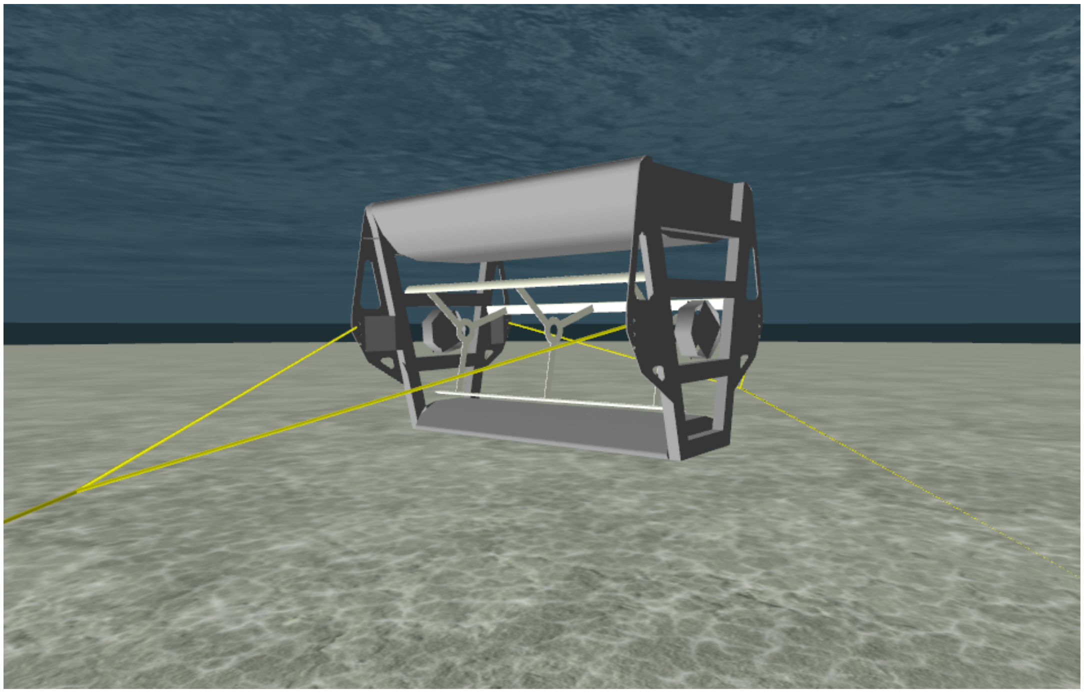

Figure 7: Updated submerged turbine platform design

2.3.3 Debris impact

AHERC provided basic parameters for the River Debris Diverter Platform (RDDP). The platform was modeled as rigid body with a freely rotating wheel connected by revolute joint at the bow. A single leg mooring was used to hold the platform. An image of the platform can be seen in Figure 8. The dimensions of the platform as well as the properties of the mooring are shown in Table 7 and Table 8, respectively. The platform was placed in several current velocities with various objects floating downstream into the system. Two shapes of debris were assessed, cylinders (to approximate logs) and spheres (to approximate root balls or ice). The dimensions and properties of the debris are shown in Table 9. Only the RDDP was modeled as this corresponded to the field test data provided by AHERC and so no additional structure or turbine was incorporated.

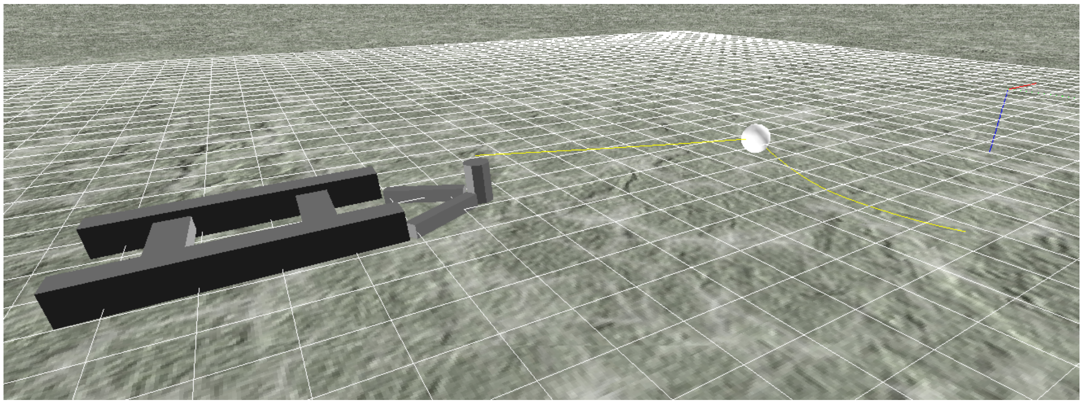

Figure 8: Approximation of RDDP platform

Platform part	X dimension	Y dimension	Z dimension	Drag coeff.
Pontoon	8.5	1	1	1
Center frame	4	1	0.5	1
Fore frame	3	0.5	0.5	1
Spinner	1	1	1.5	1

Table 7: RDDP platform dimensions

Material	Diameter (mm)	Mass (kg/m)	EA (N)
Chain	22	9.78	4.0e7
Amsteel Blue	25.4	0.32	1.5e7

Table 8: RDDP mooring parameters

Object	Length (m)	Diameter (m)	Mass (kg)
Cylinder	10	0.8	1000
Cylinder	10	0.8	2500
Cylinder	10	0.8	5000
Sphere	-	3	7250
Sphere	-	3	11600

Table 9: Debris properties

3 Results and Discussion

3.1 Overview

All results for the three phases of analysis are presented in this section. They are separated with headings depicting the individual systems.

3.2 Marine traffic dynamics

The tug and barge system was driven up and down Discovery Passage along four paths of navigation waypoints. The waypoint paths act as intended paths of the tug and barge system and the marine traffic simulation provides an indication of how much deviation away from the intended paths occur due to the tidal flow and tow dynamics. Information provided by SRM Projects indicated that tug and barge traffic generally prefer mid-channel, which appears to correspond to larger water depths and avoids Yaculta Bank [2]. The paths and border of a hypothetical turbine deployment area can be seen in Figure 9 [7]. The most pertinent regions of the paths are along the middle span of the navigation paths close to the hypothetical deployment area.

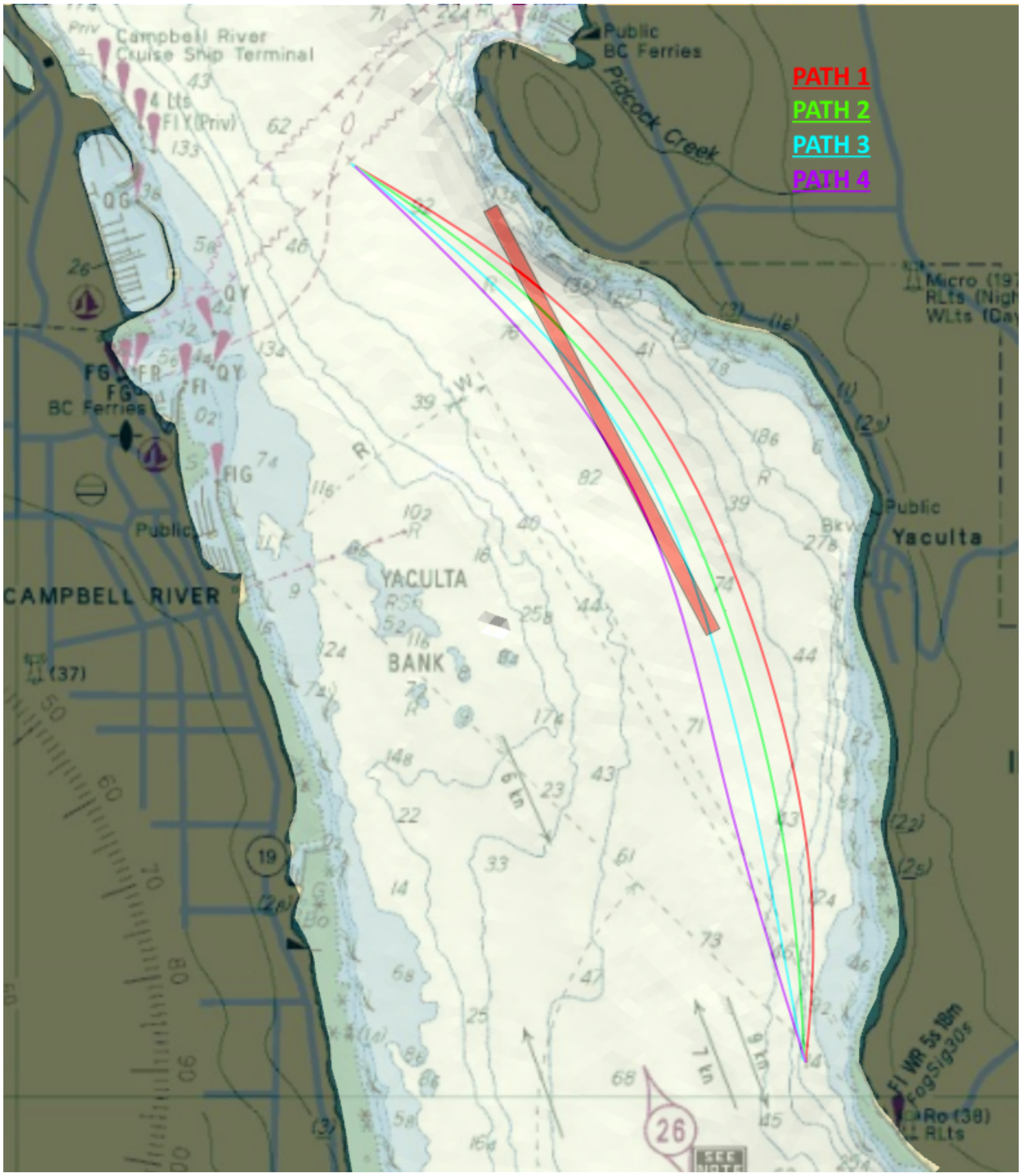

Figure 9: Tug and barge navigation waypoint paths along Discovery Passage

The tug and barge system was modeled traveling north and south along the shown paths. For each case, the maximum following current was used to induce maximum towline sag. The largest flow speed in the entire region during any transit was 4m/s or approximately 8knots; this is only a sample point and not the average flow through the channel. This part of the tidal cycle induces the largest drag loading on the barge pushing it closer toward the tug. The operational approach is conservative based on several factors. Firstly, when tug and barges enter passages or narrows, it is standard to shorten the towline [1]. Secondly, the tow speed would be minimized to reduce the risk of the barge catching up to the barge, typically 6knots in port areas [8] [4]. Another way that tug pilots would avoid the barge catching up is to only transit in slack tide

[1]. Finally, towing vessels should always leave sufficient reserve power for emergency maneuvers and be able to exceed the required bollard pull of the operation [5].

For each northern and southern transit, the maximum towline depth and standard deviation of the tug's distance from intended path are reported in Table 10 and Table 11. The greatest depth the towline reached was 14.9m. This was when the system was traveling north along Path 1. The lateral error from intended path was shown to be greater for the southern transits. This was due to the strictly north/south initial orientation of the tug. When starting the south bound transit, the tug had to make more corrections since the path had an eastern direction. In contrast, the north bound transits started with a more northern path. The level of deviation from intended path could be used as an indication of how much this type of system might deviate past a specified navigation channel limit.

Path	Max towline sag (m)	Tug lateral std dev from intended path (m)
1	14.9	10.3
2	10.8	15.9
3	10.8	18.4
4	11.0	18.7

Table 10: Tug and barge results for Northern travel

Path	Max towline sag (m)	Tug lateral std dev from intended path (m)
1	10.8	30.2
2	11.0	28.5
3	11.2	26.8
4	11.4	25.2

Table 11: Tug and barge results for Southern travel

3.2.1 Single path sensitivity study

Sensitivity studies on towline length and tug thrust capacity were completed to better understand the effect on navigation and catenary depth. The navigation way points for path 2 were used for these studies as shown in Figure 9. The tow line was modeled as a 2 3/8 inch wire rope connected to the same chain bridle system attached to the barge as previously simulated to more accurately represent typical line types used. The diameter of wire rope was chosen based on a factor of 2.5 of the bollard pull of the larger tug [6]. Two tug models were implemented with one representing a relatively small tug and one medium sized. The tug specifications are shown in Table 12. The barge remained the same displacement. The additional tug and barge runs are listed in Table 13. Notice the changing lengths of the tow line for both Northern and Southern routes. The pertinent results from the 12 additional runs are listed in Table 14. As the length of the tow line increased the potential for greater sag is increased. However, as shown in the results, with greater tug bollard pull capability the maximum tow line sag is mitigated when compared to the same tow line length by better control of the barge. An example of this can be seen when comparing Case 6 and Case 12.

Two of the twelve additional runs were unable to complete for various reasons. In case 2, the combination of the short tow line, smaller tug, and initial tight turn were enough to send the barge off track and overcome the tug's bollard pull capacity. In case 11, the tow line was so long that the barge drifted off course too far and ran aground. The maximum towline sag when considering only the transits that completed was 62.4m. This occurred in the case with the 250m long towline southern configuration. In this case, the small tug spends more time navigating laterally in the channel to follow the desired waypoints, which allows the barge to drift with the current and catch up. The maximum tug path deviation was 93m which happened on the same transit as the maximum towline sag.

The smallest tug appears to be in certain cases unable to control the barge. Extreme tow line lengths can cause problems if the barge swings wide and runs aground. Case 7 shows the most reasonable towing configuration as depicted by literature [8][4][1][5]. Using a shorter tow line (75m) and a more capable tug (medium sized) this specific transit configuration minimized tow line sag and tug deviation from the desired path with catenary depth of 16.6m and path deviation of 12.2m.

Relative size	Similar to	Bollard pull (MN)	Bollard pull (tonnes)	Displacement (tonnes)
Small	Seaspan Corsair	0.27	27	149
Medium	Seaspan Royal	0.93	93	975

Table 12: Tug sizes

Case #	Heading	Tow line length (m)	Tug size
1	North	75	Sm
2	South	75	Sm
3	North	250	Sm
4	South	250	Sm
5	North	400	Sm
6	South	400	Sm
7	North	75	Med
8	South	75	Med
9	North	250	Med
10	South	250	Med
11	North	400	Med
12	South	400	Med

Table 13: Sensitivity configurations

Case #	Max towline sag (m)	Tug lateral std dev from intended path (m)	Successful transit
1	21.3	22.9	Y
2	35.1	162.4	N
3	48.6	15.3	Y
4	62.4	93.7	Y
5	24.9	11.6	Y
6	29.8	28.4	Y
7	16.6	12.2	Y
8	14.9	12.4	Y
9	27.5	10.0	Y
10	20.3	19.6	Y
11	19.4	58.2	N
12	20.1	14.6	Y

Table 14: Tug and barge results for the additional simulations

3.3 Turbine and towline snag dynamics

MAVI provided a submerged turbine design based on their experience in developing floating turbine platform systems. As a verification step, the simulated static mooring configuration of the submerged floating turbine was compared to the analytical estimates based on buoyancy and drag supplied by MAVI. The comparison of results can be seen in Table 15. These results are for static condition with the turbine not operational. Once the simulation was verified with the expected loads, a snag loading scenario was created. To represent a worst case scenario, a horizontal line was dragged directly across the path of the turbine system. The four frame geometries tested for the tidal platform are listed below.

1. Block geometry
2. Specified frame
3. Conceptual frame
4. Updated frame

The block frame uses the cuboid hull components used to represent flotation, ballast, and basic frame components. The specified frame geometry is the minimal structural frame designed by MAVI to contain the turbine components, flotation, and ballast. The conceptual frame adds additional components to help shed the snagging line. The updated frame design was the latest iteration produced by MAVI that takes into account the lessons learned throughout the previous analysis cases.

The resulting maximum mooring line tension and tidal platform pitch induced in each snag scenario for each frame style can be seen in Table 16. As expected, the block frame exhibited the greatest platform pitch. The lip at the top of the frame catches the snag line. However, the initial MAVI specified frame gave the maximum mooring tension. This was due to the concave shape the bridle lines made with the structure and its alignment with the platform's center of gravity. The amount of force required to pitch the tidal platform was maximized since the snagging line gets caught in that point. The vertical faces of the block frame allowed the snag line to release earlier than the specified frame design.

The conceptual frame design was generated to address these effects. The outer frames of the structure were made to be convex and tapered to the top and bottom. In addition, the mooring bridle connection point was moved up so that the snagging line does not get caught in line with the center of gravity of the platform. These changes were enough to reduce the peak mooring load and pitch magnitude when compared to the previous systems. An example of the relative pitch for each platform design can be seen in Figure 10.

This indicates how simple design modifications can make a significant difference in the platform motion and mooring loads in a snag event. The lessons learned from the previous three platform configurations enabled MAVI Innovations to supply an additional frame geometry for assessment. The resulting maximum anchor line tension and platform pitch when collided with a horizontal snagging line are reported in Table 16. The latest frame geometry yielded a slightly larger maximum anchor line tension that the conceptual design but a reduced maximum pitch. An illustration from the simulation results of the updated platform in contact with the snag line can be seen in Figure 11. The amount of tension and pitch was sensitive to the relative height of the platform compared to the snag line. By lowering the platform, the possibility of the snag line getting caught is significantly reduced.

Net forces	Analytical value (kN)	Simulated value (kN)	Error (%)
Vertical	79.4	81.7	1.4
Horizontal	46.7	48.8	2.2

Table 15: Predicted and simulated turbine platform static mooring loads in static configuration

Configuration	Max mooring tension (kN)	Max platform pitch (deg)
Block frame	668	85
Specified frame	758	34
Conceptual frame	322	25
Updated frame	429	20

Table 16: Simulated turbine platform dynamic behavior

In summary, key aspects of improving snag performance of floating turbine platforms indicated by the work are:

1. Ensure no concave faces are present; faces should be swept back to allow the line to pass over
2. Move bridle connection points as high above platform center of mass as possible
3. Lower platform center of mass as much as possible

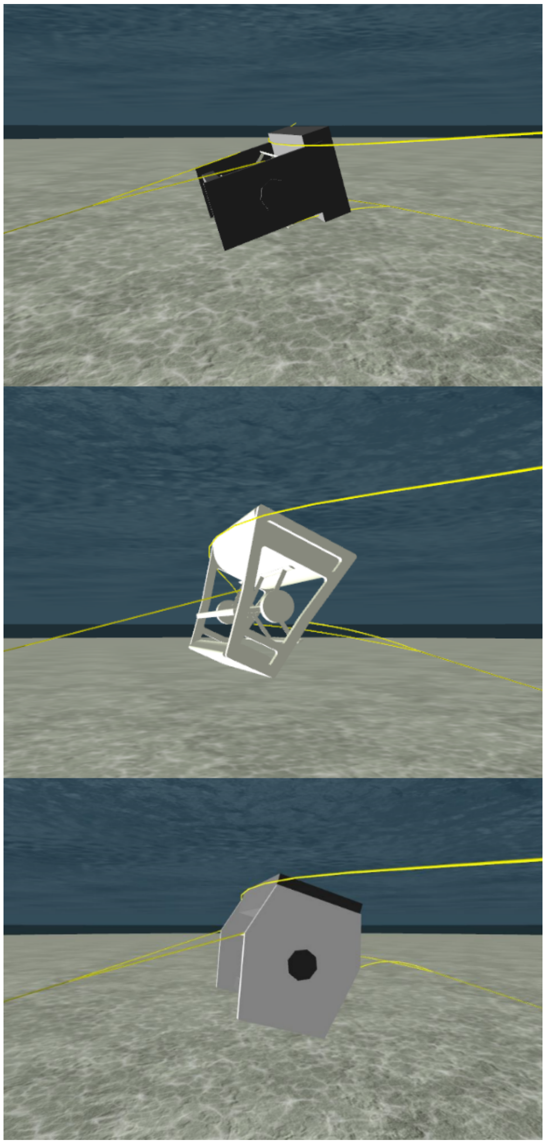

Figure 10: Snag dynamics for each frame design

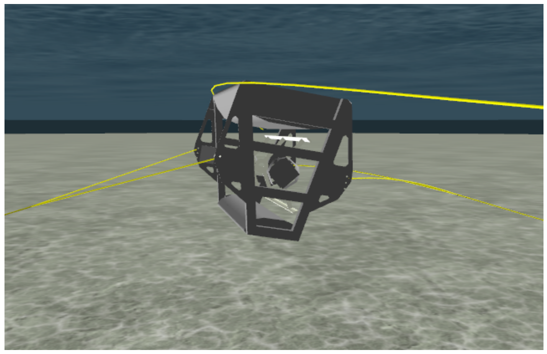

Figure 11: Updated platform snag

3.4 Debris impact

The RDDP was subjected to debris impact from several types of floating objects in a river environment. The dynamic mooring tensions caused by the collisions are reported in Table 17 and Table 18. Increased current speed increased impact magnitudes and mooring tensions. In addition, as the mass of the objects increased, the mooring tensions generally increased as well. Contrary to the general behavior, the 5000kg log showed a slight decrease in mooring tensions during a collision when compared to the 2500kg case. This was because the log was almost neutrally buoyant such that it was able to slide underneath the platform where as the 2500kg case the log had to deflect around the platform. The captured impact data from an instrumented deployment by AHERC is shown in Figure 12. With a peak measured impact load of approximately 30kN, this matches reasonably well to the simulated 2500kg log in 2.5m/s current case. Additionally, the mean mooring line tensions also matched fairly well when no impact is recorded, 2.5kN measured and 2.7kN simulated. With limited data on the actual corresponding debris impact measured by AHERC, this still serves as a qualitative reference for the sensitivity study. Furthermore, the general behavior shown in the demonstration video of a floating log impact provided by AHERC match that of the 2500kg log case. An example of the simulation can be seen in Figure 13.

Mass (kg)	1 m/s	2.5 m/s	5 m/s
1000	3.5	16.2	46.1
2500	5.1	30.1	154.9
5000	3.7	44.5	103.8

Table 17: Cylinder collision mooring tensions (kN)

Submergence	1 m/s	2.5 m/s
50%	7	10
80%	40	38

Table 18: Sphere collision mooring tensions (kN)

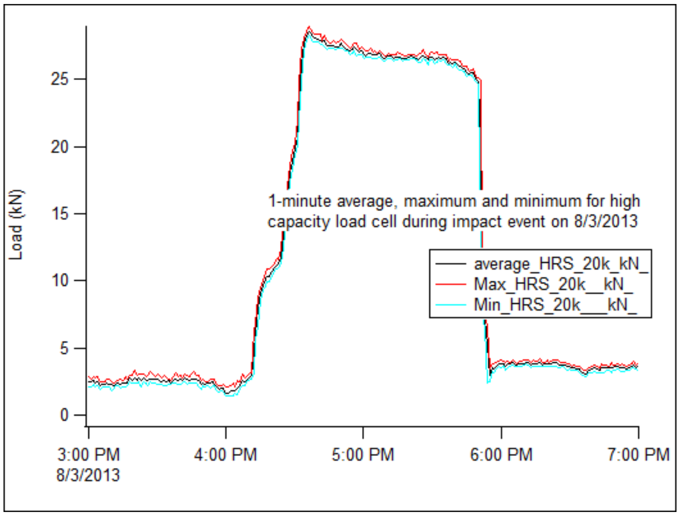

Figure 12: AHERC collision load cell data

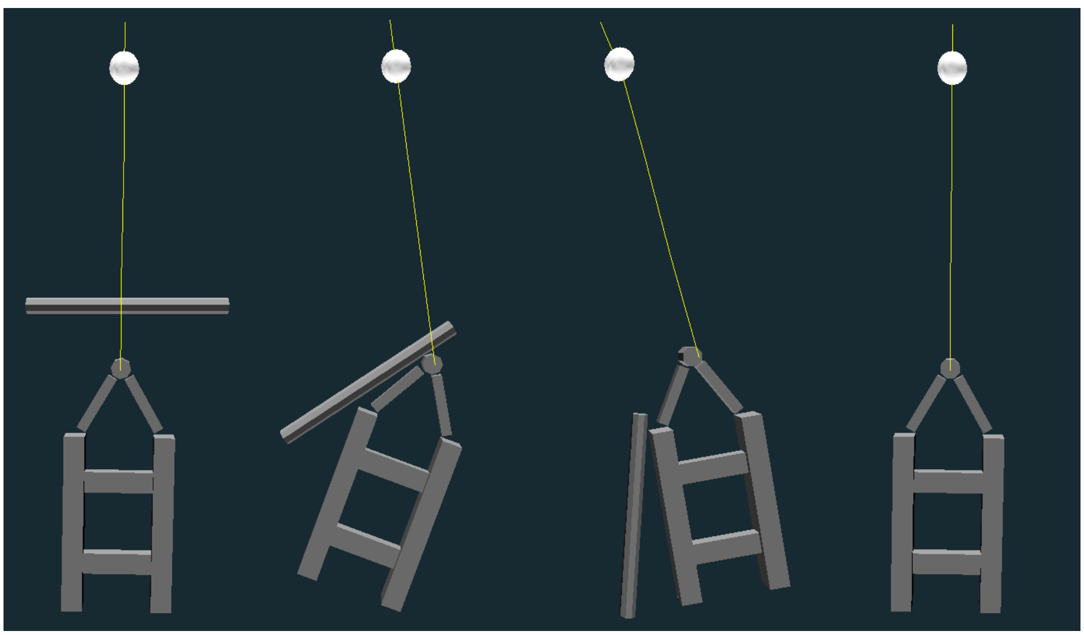

Figure 13: Log impact stages

4 Conclusions

The purpose of this research program was to provide information to evaluate risk of marine traffic to tidal turbines and to quantify loads during snag and debris impact events. A key aspect of this project was to develop the contact effects necessary to simulate towline snag and debris impacts. The load cases considered are not intended to be exhaustive. Simulations were completed using realistic tidal flow data, bathymetry, vessel and towline parameters to assess maximum line depth and lateral motion away from intended paths in a real marine traffic corridor that could contain tidal devices in the future. A tug and barge system was modeled traveling north and south through Discovery Passage on the east coast of Vancouver Island. The tug was driven through four paths using defined waypoints. For each transit, a following tidal flow current was used to induce the greatest sag of the towline. The maximum flow speed present in the channel was 4m/s or approximately 8knots. Initially, the towline was assumed to be chain, which was conservative as the heavier weight increases catenary sag. Using a maximum bollard pull limit of 2MN (200 tonnes) with the tug navigation control, the maximum towline sag was observed at 14.9m. In addition, the standard deviation of the tug's lateral offset from the waypoint path was monitored. The greatest standard deviation from the waypoint path was approximately 30m. Furthermore, additional simulations were executed examining varied tug bollard pull and tow line length. Both smaller vessels and excessively long tow lines caused problems in navigation through the channel. Both situations are not recommended for operating procedure when navigating narrow channels with tidal currents. Two of the 12 cases were unable to complete due to the barge overcoming the tug's capacity for control or the barge running aground. The new maximum sag was 62.4m due to the barge the tug and the new maximum lateral tug path error was 93.7m, from the cases that actually completed, from the barge pulling smaller capacity tugs off course. The moderately powered tug with shortened towline produced a catenary depth of 16.6m with lateral offset of 12.2m.

A tidal and river turbine developer, MAVI, provided realistic design parameters for a submerged floating turbine platform as an input to additional numerical simulations used to quantify the dynamics, motions, and resulting loads from a worst-case snag scenario. The snag scenario was conducted on four frame configurations including a simple approximation using rectangular blocks, using the actual geometry specified by MAVI, a conceptual frame design based on the results of the test results on the first two configurations, and an updated geometry supplied MAVI. In order to minimize the amount of platform pitch that was created during a snag event, the platform frame must be smooth with no concave sections. Also, to minimize line tensions, and ultimately stress on the system, the snag line needs to be able to slide up and over the platform easily. This means that the snag line must be able to slide above the center of gravity of the platform. The updated frame design showed reduced mooring tension and maximum platform pitch in the snag scenario.

Finally, a sensitivity study on a debris diverter device was completed to assess impact forces and mooring loads in a river environment. Parameters for the platform and data on measured from real impacts provided by AHERC was useful as a qualitative validation of the debris impacts. The debris diverter was modeled in a constant current representing a river environment. Floating debris was added in various shapes and sizes, including cylinders and spheres, to assess the impact loads. Cylinders were used to represent logs and spheres were used to represent root balls or ice. Supplied data from AHERC showed the numerical results were reasonable and videos of log impacts show the same characteristic dynamic response throughout the collisions. The AHERC reported mooring tensions peaking at approximately 30kN where the simulated showed a 30.1kN mooring tension when struck with a 2500kg log in 2.5m/s current.

5 Future work

Based on the work completed, considerations for additional analysis were compiled. The impact of wind on the tug and barge navigation analysis could be considered: additional drag loading from the wind could impact the tug's ability to control the barge and stay on course. Also, it would be beneficial to understand the implications of increasing the number of waypoints used to describe the desired target transit path. Furthermore, currently only the lateral deviation of the tug was tracked; however, the lateral deviation of the barge should also be considered.

With more design iterations and discussion, the submerged turbine platform snagging cases can also be updated. As the problem becomes more refined, better understanding of what is needed to mitigate damage to both the platform and snagging line can be achieved. This could include implementing a local spatially varying current speed and headings instead of the constant current used as well as completing a study on the impact of mooring bridle connection configuration.

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