Report submitted to

Port Glasgow Yacht Club and
Municipality of West Elgin

Project title:

Feasibility Study of Steel Crib Offshore Breakwaters
Port Glasgow, Ontario

2018 Aerial Photo © Mapbox

DRAFT

Riggs Engineering Ltd.
1240 Commissioner's Road West
Suite 205
London, Ontario
N6K 1C7

September 11, 2018

DRAFT

Table of Contents

List of Figures

List of Tables

Executive summary

The scope of this is to evaluate the feasibility of using steel crib offshore breakwaters for the purpose of reducing the incoming wave energy at the Port Glasgow marina. Presently, marina users report difficulties in navigating through the entrance and using two eastern launching ramps during periods of rough weather, thereby limiting the use of the marina's facilities. Previous work undertaken by others has identified remedial options to reduce the incoming wave energy at the marina, which included extending and encapsulating the existing piers. Previous proposal recommended using armour stone in the remedial works. Cost estimates of the of the previously recommended option revealed extremely high costs, which were ultimately deemed uneconomical.

Subsequently, Riggs Engineering has provided an alternative that, if proven feasible, would be significantly more economical while providing a reduction in wave agitation at the marina entrance and its basin compared to present conditions. The alternative offered by Riggs Engineering included placement of steel crib breakwaters offshore of the marina entrance. The breakwaters would consist of individual steel crib units, 4.9 m (16 ft) wide and 12.2 m (40 ft) long, and filled with stone. Cost constraints by the marina owners allow for placement of five or six steel crib units. The offshore breakwater(s) would be constructed by linking together a number of units to ultimately produce sheltering for the wave energy currently reaching the marina. What is presently unknown is the orientation (or configuration) of the steel crib breakwaters that would offer the most protection for marina's end users.

This report therefore focuses on determining the best configuration for the offshore breakwaters. A total of nine different steel crib offshore breakwater configurations were tested using numerical modeling. The numerical analysis was used to quantify the degree of wave sheltering in response to different offshore breakwater configurations, and evaluating ease of navigating through the marina entrance. Each configuration was evaluated using two different wave directions (from the south, and from the southwest), shown to be dominant at the project site. Subjective criteria were used to rank the alternative configurations that took into account reduction in wave energy at the marina entrance and in the marina basin. The recommended configuration included two offshore breakwaters to be placed offshore of the existing west pier, as it received best compromise in reducing wave agitation and having high navigability ranking.

Note that work carried out in this report does not deal with issues required for purposes of regulatory permitting of the proposed works. A separate sediment transport assessment, including determining impacts of the proposed works on Lake Erie's up- and downdrift sediment movement patterns, will require to be undertaken should the marina owners wish to proceed with regulatory approvals. Note that previous design completed in 2009 was approved by the Ministry of Natural Resources on the basis of the marina operators using the updrift beach to extract sand from the littoral system. We anticipate that similar logic would be applied regarding the steel crib breakwaters as well.

1 Introduction

Port Glasgow is a small community on the north shore of Lake Erie, located within the boundary of Municipality of West Elgin, in the Province of Ontario. The marina at Port Glasgow is co-owned by the Port Glasgow Yacht Club and the Municipality of West Elgin. Dock capacity of the marina is 80 berths, with exactly 55 boat docks located on municipal lands, and 25 docks on the lands owned by the club. There are two launching ramps located east of the marina basin, and a third launching ramp on the west side of the main basin. Figure 1 shows the site plan of the marina.

Figure 1: Port Glasgow marina site plan

The harbour entrance at Port Glasgow consists of two piers, referred to as east and west Piers. Each of the two piers are approximately 85 m long and 6 m wide. Depending on erosion and accretion conditions of the surrounding shoreline, the existing piers extend between 30-40 m into the lake. Sandy beaches are located on either side of the marina, with the beach southwest of the marina used for aggregate extraction. The aggregate extraction operation annually removes sand deposited by Lake Erie's littoral drift, which limits sand deposition in the marina's entrance channel.

1.1 Background information

Previous investigations completed in 2009 identified that two eastern launching ramps at the marina are unusable during periods of rough weather (Monteith Brown, 2012). The recommended option from the 2009 study was to increase the usability of the marina by extending and rehabilitating the existing east and west piers. The option recommended was to encapsulate and extend the existing west pier with a shore connected rubble mound breakwater, and to encapsulate the existing east pier in the similar manner. The cost estimates of the encapsulation and breakwater extension alternative proved too onerous for the marina owners, and were ultimately never implemented.

Riggs Engineering subsequently offered an alternative design that could increase the navigability in rough weather, with a significantly reduced construction cost. The alternative design included a proposal to place steel crib offshore breakwaters to improve navigability at the marina entrance, and improve berth tranquility inside the marina basin. Rather that using armour stone breakwaters which are costly, the alternative proposal uses steel frame crib structures filled with stone. The benefit of the steel crib structures is that they are much more cost effective than fixed armour stone breakwaters. The steel crib structures would be made up of individual units 4.9 m (16 ft) wide and 12.2 m (40 ft) long. Imposed cost constraints by the marina owners have restricted the number of steel crib units to five or six, but not more. New steel crib breakwater(s) would be assembled by positioning a number of units in series to achieve desired lengths, which would offer increased level of protection to the marina entrance and main basin compared to present conditions. The offshore breakwater would block a portion of the incoming wave energy. What is presently not known is what is the best and most appropriate configuration of the offshore breakwaters (within the specified length range) to be placed in front of the entrance. Determining the configuration of the offshore breakwaters forms the scope of this study.

1.2 Study scope

The main objective of this study is to find out an appropriate placement of individual steel crib breakwater units so that they can improve berth tranquility and navigation through the marina entrance in rough weather. In this feasibility study the aim will be to demonstrate if placing in front of the marina entrance five or six steel crib offshore breakwater units would be able to increase navigability and basin tranquility in rough weather. The work carried out is a desktop study that uses numerical analysis to simulate the effectiveness of a number of different configurations of the proposed steel crib offshore breakwaters using five and six individual steel crib units. Based on the results of the numerical analysis and our own engineering judgment we will be able to offer comments regarding the feasibility of the proposed.

The scope of this study is to determine the feasibility of using the steel crib offshore breakwaters at Port Glasgow using criteria related to navigability and berth tranquility inside the marina basin. Note that regulatory permitting requirements for proposed works are more onerous, and typically require a separate coastal impact assessment. Such an assessment is required to carry out analyses and comment how the placement of the breakwaters will change the coastal sediment transport processes in the lake. The general criteria for regulatory approvals are to assess, using scientific and engineering principles, that anticipated effects of the proposed on the neighbouring shoreline and/or Lake’s Erie’s littoral system in general. Should the feasibility of the proposed offshore steel crib breakwaters be proved to be viable, a separate coastal impact assessment will be required at a later date as part of the regulatory approvals.

Note that the previous design of the encapsulation and extension carried out in 2009 was submitted to the Ministry of Natural Resources for approval. We understand that regulatory approvals were obtained for the 2009 design on the basis that the marina owners carry out sand extraction on the updrift beach, which has the effect of removing the littoral drift from the system that would otherwise pass by the marina entrance. Removing the littoral drift through sand extraction therefore governs the littoral transport. If the littoral sediment is removed before reaching the marina, the orientation of the breakwaters at the entrance are thus not anticipated to have adverse effect on the littoral system. We anticipate that similar logic would be applied in regulatory approvals for the steel crib breakwaters as well.

2 Evaluation criteria and options

2.1 Evaluation criteria

The evaluation criteria proposed to evaluate the feasibility are based on improving the navigability of the entrance during rough weather, and improving berth tranquility inside the marina basin. A number of different configurations of the offshore steel crib breakwaters will be evaluated in our study, with wave height inside the marina basin and through the entrance being the governing criteria. Our analyses will provide a comparison of how each option reduces wave agitation through the entrance and at the marina basin. Therefore, wave height will form the main criteria in this feasibility study.

For the purposes of this work we have selected to evaluate each alternative option using two dominant storms: a storm from the east, and a storm from the southwest. Subsequent analysis will show these as dominant directions, accounting for majority of storms at Port Glasgow. Given the governing conditions at the project site, it may be possible that some configurations will perform well for one dominant direction, but not for the other. A separate evaluation will be provided for each dominant direction.

The favoured option is thus defined in this feasibility study as one that reduces most, regardless of the storm direction, the wave agitation through the entrance and at the marina basin, which is also easy to navigate through. A criterion of navigability through the marina entrance is used in our evaluation of options, as the proposed steel crib breakwaters must be placed such that marina users would be able to navigate through. An option that blocks the entrance and reduces wave agitation in the channel and marina basin would not receive favourable rating unless it could be demonstrated that marina users could navigate safely through the obstacles. Reduction of wave agitation through the entrance and in the marina basin form the criteria, as well as the navigability of the proposed.

2.2 Offshore breakwater alternatives

The steel crib offshore breakwaters are envisioned to consist of individual units 4.9 m (16 ft) wide and 12.2 m (40 ft) long. Each offshore breakwater will be assembled by linking a string of individual units together. For this study, we have considered a number of five and six unit alternatives, including options for one single, and two distinct breakwaters. Originally we have proposed three configurations for analysis. Upon completing initial analysis, we have also included a number of additional options that include slight modification (and refinement) of the options originally proposed.

The final set of alternatives includes the following: 1, 2, 2a, 2b, 3, 3a, 3a modified, 3b, and 3b modified. The alternatives are presented graphically in Figures 2 to 10. Each of the alternative configurations of the steel crib breakwaters are evaluated numerically. Details on the numerical analysis are presented next.

Figure 2: Option 1 configuration

Figure 3: Option 2 configuration

Figure 4: Option 2a configuration

Figure 5: Option 2b configuration

Figure 6: Option 3 configuration

Figure 7: Option 3a configuration

Figure 8: Option 3a modified configuration

Figure 9: Option 3b configuration

Figure 10: Option 3b modified configuration

3 Numerical analysis

This section of the report presents the summary of the numerical analysis used in this feasibility study. It includes numerical modeling of wave propagation using two different numerical wave models: one to propagate the lake generated waves from offshore to the harbour entrance, and one to characterize waves at the local scale (including effects of local structures). The text that follows documents data and its processing, development of numerical models, description of initial and boundary conditions, as well as modeling results.

3.1 Data used

3.1.1 Aerial imagery

The aerial imagery used in this project includes data used from the South Western Ontario Orthorectification Project 2015 (SWOOP2015), as well as satellite imagery data available from Google. The SWOOP2015 imagery was used to digitally trace the shoreline at the project site, which was used in subsequent modeling.

3.1.2 Bathymetry

The bathymetry data (below water topography of the lake bed) used in this work included contours from a bathymetric survey carried out in 2007 by Riggs Engineering on behalf of the Port Glasgow Yacht Club. An assumption in the modeling was that the marina entrance and main basin are at elevation 1.0 m below chart datum. Outside of the immediate boundary of the harbour, we have used the National Oceanic and Atmospheric Administration (NOAA) 1 m contours for Lake Erie, which were produced for the entire lake.

3.1.3 Waves

For wave data we have used the hindcast (historical reconstruction of past wave climate) constructed by the US Army Corps of Engineers for Lake Erie through their Wave Information Study (WIS) program. The WIS hindcast for Lake Erie is available at output nodes spaced approximately 2 km for the entire perimeter of the lake. For the present feasibility study we have obtained hourly wave data from the WIS hindcast node ST92163 (closest to Port Glasgow), which includes significant wave height, peak wave period, and wave direction for years 1979-2014. The WIS hindcast node ST92163 is located approximately 8 km offshore of Port Glasgow, at about the 17 m depth contour.

3.1.4 Water levels

Water level data was obtained from the document titled Technical Guide for Great Lakes St. Lawrence River Shorelines, published by Ministry of Natural Resources (MNR, 2001). A summary of the MNR (2001) data, extracted for Port Talbot is provided in Table 1. For all of the work in this feasibility study we have assumed the Lake Erie water levels to be at elevation 1.7 m above chart datum, which equates to the 25-yr return period. As this is a feasibility study looking at navigation and berth tranquility criteria, use of 25-yr water level is deemed appropriate.

Table 1: Water level statistics at Port Glasgow, MNR (2001)

Return Period [yr]	Water Level [m, IGLD55]	Water Level [m, IGLD85]	Water Level [m, Chart Datum]	Water Level [m, CGVD28:78]
2	174.49	174.66	1.16	174.69
5	174.75	174.92	1.42	174.95
10	174.89	175.06	1.56	175.09
25	175.03	175.20	1.70	175.23
50	175.12	175.29	1.79	175.32
100	175.20	175.37	1.87	175.40

Notes:
CD = Chart Datum
IGLD = International Great Lakes Datum
CGVD28:78 = Canadian Geodetic Vertical Datum 1928, 1978 adjustment
Lake Erie Chart Datum = 173.5 m IGLD85

3.2 Data analysis

3.2.1 Statistical wave magnitudes

Data analysis was carried on WIS hindcast node ST92163 data to characterize the wave climate offshore of Port Glasgow. The WIS data was used to group wave data into bins on a 16 directional compass, thus producing a time series for each of the 16 compass directions. Each wave direction time series was used to extract the largest annual value of significant wave height, and then used to fit a Gumbel statistical distribution to the extracted data. The results of the statistical distributions assign to each direction band a series of values representing return intervals ranging from 2-yr to 100-yr.

Identical data analysis is prepared using all data in the WIS record (all year), as well as data filtered to include only the boating season (estimated between May 15 – Oct 15). Table 2 shows the wave statistics for the all year time series, while Table 3 depicts the statistics from the boating season.

3.2.2 Durational statistics

We have also carried out statistics on the WIS data for the hindcast node ST92163 to characterize the duration of time waves occur from a particular direction. Our results are shown in Table 4 for all year, and in Table 5 for the boating season (May 15 – Oct 15). Our analysis shows that regardless of season, the dominant directions of waves offshore at Port Glasgow are from the east, south-southwest, and southwest. For the purposes of the analyses in this feasibility assessment, we have selected to use the waves from the east, and waves from the southwest directions.

Table 2: WIS node ST92163 wave magnitude statistics, all year

Dir band	Wave dir	Wave dir	Significant Wave Height, Hm0 [m] return period					
[-]	[-]	(Az deg)	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
1	N	0	1.38	1.73	1.96	2.26	2.48	2.69
2	NNE	22.5	1.19	1.62	1.90	2.26	2.52	2.78
3	NE	45	1.40	1.85	2.14	2.51	2.79	3.06
4	ENE	67.5	1.97	2.52	2.88	3.34	3.68	4.01
5	E	90	3.08	3.70	4.10	4.61	4.99	5.37
6	ESE	112.5	2.15	2.73	3.12	3.61	3.97	4.33
7	SE	135	2.18	2.65	2.97	3.37	3.67	3.96
8	SSE	157.5	2.48	2.96	3.28	3.67	3.97	4.26
9	S	180	2.81	3.25	3.53	3.89	4.16	4.42
10	SSW	202.5	3.53	4.18	4.62	5.16	5.56	5.96
11	SW	225	3.68	4.21	4.56	5.01	5.34	5.66
12	WSW	247.5	2.29	2.64	2.88	3.17	3.39	3.61
13	W	270	1.74	2.01	2.19	2.41	2.58	2.74
14	WNW	292.5	1.46	1.72	1.90	2.11	2.27	2.43
15	NW	315	1.40	1.65	1.81	2.02	2.17	2.32
16	NNW	337.5	1.38	1.67	1.86	2.10	2.28	2.45

Table 3: WIS node ST92163 wave magnitude statistics, May 15-Oct 15

Dir band	Wave dir	Wave dir	Significant Wave Height, Hm0 [m] return period					
[-]	[-]	(Az deg)	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
1	N	0	0.78	0.96	1.07	1.22	1.32	1.43
2	NNE	22.5	0.68	0.85	0.96	1.10	1.21	1.31
3	NE	45	0.81	1.10	1.29	1.52	1.70	1.88
4	ENE	67.5	1.13	1.55	1.83	2.18	2.44	2.69
5	E	90	1.70	2.32	2.73	3.25	3.63	4.01
6	ESE	112.5	1.04	1.40	1.63	1.93	2.15	2.37
7	SE	135	1.03	1.43	1.69	2.02	2.26	2.50
8	SSE	157.5	1.33	1.76	2.05	2.41	2.68	2.95
9	S	180	1.86	2.26	2.53	2.86	3.11	3.36
10	SSW	202.5	2.32	2.84	3.18	3.62	3.94	4.26
11	SW	225	2.13	2.67	3.03	3.48	3.81	4.15
12	WSW	247.5	1.30	1.56	1.73	1.95	2.11	2.27
13	W	270	1.01	1.28	1.46	1.69	1.86	2.03
14	WNW	292.5	0.89	1.12	1.27	1.45	1.59	1.73
15	NW	315	0.81	1.00	1.13	1.30	1.42	1.54
16	NNW	337.5	0.81	1.02	1.16	1.34	1.47	1.60

Table 4: WIS node ST92163 wave duration statistics, all year

Dir band	Wave dir	Wave dir	Count	Perc
[-]	[-]	(Az deg)	[hrs]	[%]
1	N	0	10130	3.51
2	NNE	22.5	8329	2.89
3	NE	45	9130	3.17
4	ENE	67.5	11782	4.09
5	E	90	36976	12.83
6	ESE	112.5	12516	4.34
7	SE	135	8785	3.05
8	SSE	157.5	9552	3.31
9	S	180	17850	6.19
10	SSW	202.5	59587	20.67
11	SW	225	53699	18.63
12	WSW	247.5	15870	5.51
13	W	270	10332	3.58
14	WNW	292.5	7059	2.45
15	NW	315	7045	2.44
16	NNW	337.5	9637	3.34

Table 5: WIS node ST92163 wave duration statistics, May 15- Oct 15

Dir band	Wave dir	Wave dir	Count	Perc
[-]	[-]	(Az deg)	[hrs]	[%]
1	N	0	4756	3.57
2	NNE	22.5	4131	3.10
3	NE	45	4891	3.68
4	ENE	67.5	5624	4.23
5	E	90	18829	14.15
6	ESE	112.5	6961	5.23
7	SE	135	4662	3.50
8	SSE	157.5	4898	3.68
9	S	180	9208	6.92
10	SSW	202.5	32380	24.34
11	SW	225	21461	16.13
12	WSW	247.5	4291	3.22
13	W	270	2598	1.95
14	WNW	292.5	2067	1.55
15	NW	315	2405	1.81
16	NNW	337.5	3894	2.93

3.3 Numerical modeling

Characterization of site specific wave climate is required to assess the feasibility of the steel crib offshore breakwaters at Port Glasgow. Two different wave modeling tools are used to capture wave characteristics for global and local conditions.

Both phase averaging and phase resolving wave models are used in this study. The former is used to obtain lake wide wave fields, while the later is used to capture relevant processes of waves propagating through marina entrance.

Phase averaging wave models are best suited for estimation of wave climate over long distances and are most appropriate in capturing how deep water waves propagate to the coast. The evolution of the wave spectrum in phase averaging models is described by means of the spectrum action balance equation. Phase resolving models on the other hand are best for cases where local wave properties vary strongly within short distances (in the order of magnitude of the wavelength or less), such as wave propagation in harbours, around breakwaters, or over reflecting surfaces such as vertical walls.

For the present study, phase averaged wave model TOMAWAC and phase resolving wave model ARTEMIS are used. Both wave models are part of the TELEMAC (2018) suite of numerical solvers, a state of the art finite element numerical modeling code. Numerical models part of the TELEMAC suite have been originally developed at the National Hydraulics Laboratory of the Research and Development Division of the French Electricity Board, Electricité de France (EDF). Presently, the TELEMAC suite of models are entirely in open source and maintained by a consortium of established research organizations specializing in hydraulic and coastal research. TOMAWAC and ARTEMIS coastal models are briefly described next.

The TOMAWAC model is an open source phase averaging wave model which solves the wave spectral action balance equation. The model captures the effects of spatial wave propagation, refraction, shoaling, generation, dissipation and nonlinear wave-wave interactions. TOMAWAC has been developed specifically to capture wave transformation from offshore to nearshore waters. Processes of wave breaking, bottom friction and (simplified) diffraction effects are included in all simulations carried out in this work.

ARTEMIS is an open source phase resolving wave model which solves the Elliptic Mild Slope equations using the finite element method using TELEMAC's libraries and suite of solvers. Main applications of the ARTEMIS model deals with wave agitation in harbours and small bays where the following phenomena are captured:

- wave reflection by an obstacle,
- wave diffraction behind an obstacle,
- wave refraction by bottom variation,
- regular waves,
- mono-directional or multi-directional random waves,

- bottom friction,
- bathymetric breaking, and
- dissipation by breaking and/or bottom friction.

As with all phase resolving wave models, wave refraction by currents is not captured.

3.3.1 Wave propagation from offshore to harbour entrance

A TOMAWAC wave propagation model was set up for the Lake Erie domain extending from the WIS hindcast node (approximately 8 km offshore) to the marina entrance at Port Glasgow. Alongshore length of the model included approximately 10 km on either side of Port Glasgow. We have used the shoreline traced from the SWOOP2015 product. The NOAA bathymetry for Lake Erie (available at 1 m contours) was used in wave propagation modeling.

The TOMAWAC numerical model grid was developed using a triangular mesh. NOAA bathymetry was used to assign bottom elevations to the triangular mesh. Table 6 shows the boundary conditions (obtained from our analysis of the WIS hindcast) used in the wave propagation modeling. For the purposes of analysis in this report we have used a 25-yr water level, in combination with a 2-yr wave during the boating season. More comprehensive analysis may require additional cases, but for the purposes of the present feasibility study, we believe the identified cases are sufficient.

Table 6: TOMAWAC boundary conditions (8 km offshore)

Parameter	E waves	SW waves	Notes
WL [m, CD]	1.70	1.70	Water level with respect to Lake Erie Chart Datum
Hm0 [m]	1.50	2.10	Significant wave height, obtained from WIS
Tp [sec]	5.50	6.00	Peak wave period, obtained from WIS
Dir [Az deg]	90.00	225.00	Wave direction, obtained from WIS

The finite element method was used in TOMAWAC to solve the spectral action balance equation, and thus obtain spatial distribution of significant wave height, peak wave period, and wave direction. The results from the TOMAWAC simulations are presented in Figure 11 (east waves) and Figure 12 (southwest waves). Wave characteristics, extracted in front of the Port Glasgow marina entrance are shown in Table 7.

Table 7: TOMAWAC wave propagation results (250 m offshore)

Parameter	E waves	SW waves	Notes
WL [m, CD]	1.70	1.70	Water level with respect to Lake Erie Chart Datum
Hm0 [m]	0.76	1.36	Significant wave height, obtained from TOMAWAC
Tp [sec]	5.50	6.00	Peak wave period, obtained from TOMAWAC
Dir [Az deg]	107.70	1.00	Wave direction, obtained from TOMAWAC

Results reported in Table 7 are used to force the phase resolving model ARTEMIS.

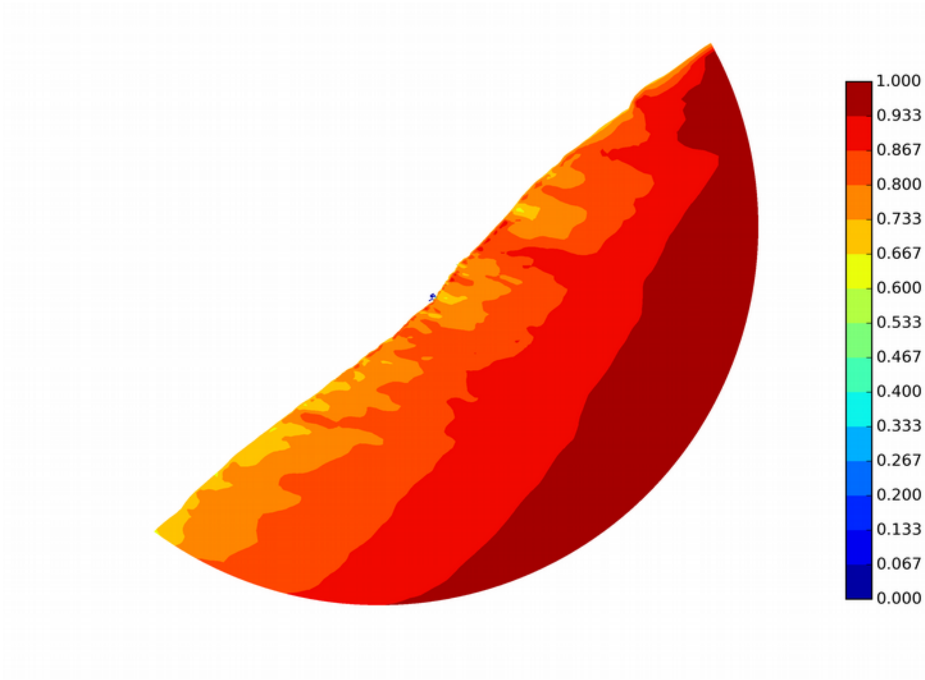

Figure 11: TOMAWAC simulation result, east waves, Hm0 [m]

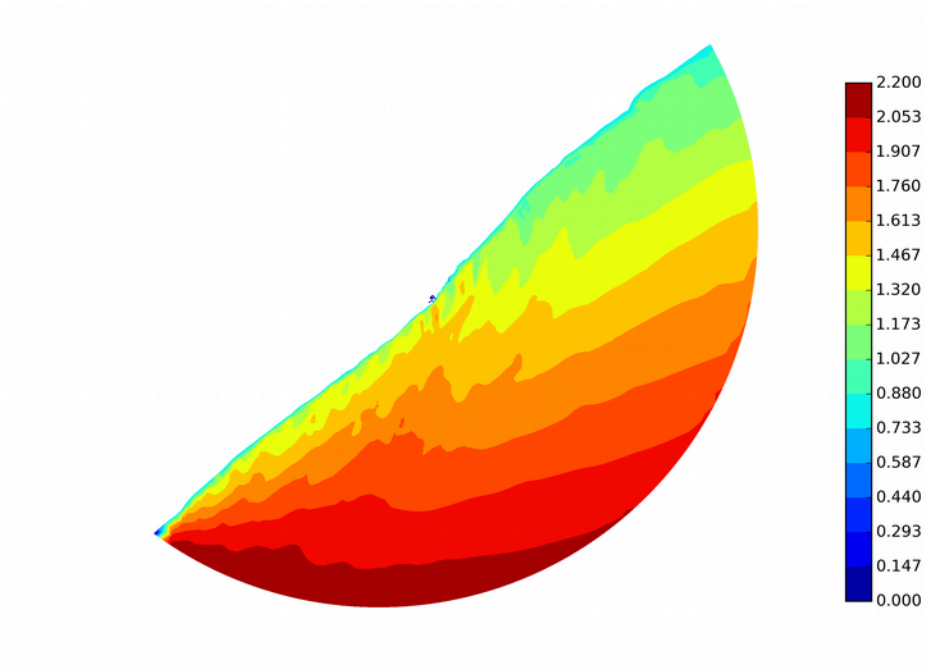

Figure 12: TOMAWAC simulation result, southwest waves, Hm0 [m]

3.3.2 Wave propagation through the harbour entrance

An ARTEMIS phase resolving numerical model was set up for the purpose of evaluating proposed alternative configurations of the steel crib offshore breakwaters at Port Glasgow. The model was set up for a domain that extends approximately 250 m offshore of the marina to the shoreline, and about 250 m of shoreline on either side of Port Glasgow. The shoreline traced from the SWOOP 2015 product was used in the modeling. Bathymetry surveyed in 2007 was used in the modeling.

The ARTEMIS numerical grid was developed using a triangular mesh, having an element area constraint of 6.25 m^2. Such a fine mesh resolution is required to ensure the numerics are able to resolve the detailed coastal processes that are required to be captured in the modeling. The 2007 surveyed bathymetry was used to assign bottom elevation values to each node in the numerical model. Wave characteristics 250 m offshore of the marina entrance obtained from TOMAWAC simulations were used as the boundary condition to the ARTEMIS model, as detailed in Table 7.

We have simulated the existing conditions (no offshore breakwaters), together with nine configurations of the offshore steel crib breakwaters. Each configuration was simulated for waves propagating from the east, and from the southwest, as detailed previously.

In developing the ARTEMIS numerical model careful consideration was given to assigning properties to different types of shoreline within the domain. Beaches on either side of the marina were assigned absorbing properties, as they tend to absorb (rather than reflect) wave energy. Sheet pile walls, however, were modeled as reflective objects, as they tend bounce of vertical structures without much absorption. The proposed steel cribs were also assigned fairly reflective properties, as it is anticipated they too would tend to reflect the incoming wave energy, rather than absorbing energy.

The results from the ARTEMIS wave propagation modeling are summarized in Figures 13 to 22 for east waves, and in Figures 23 to 32 for southwest waves.

The computed wave field is displayed as a colour coded plot of the wave height, with the red depicting wave agitation (i.e., higher wave magnitudes), and blue depicting calms (i.e., low wave magnitudes). When evaluating effectiveness of option, options for which the wave field is colour coded with blue within the region of interest (such as the entrance channel and the marina basin) is preferable.

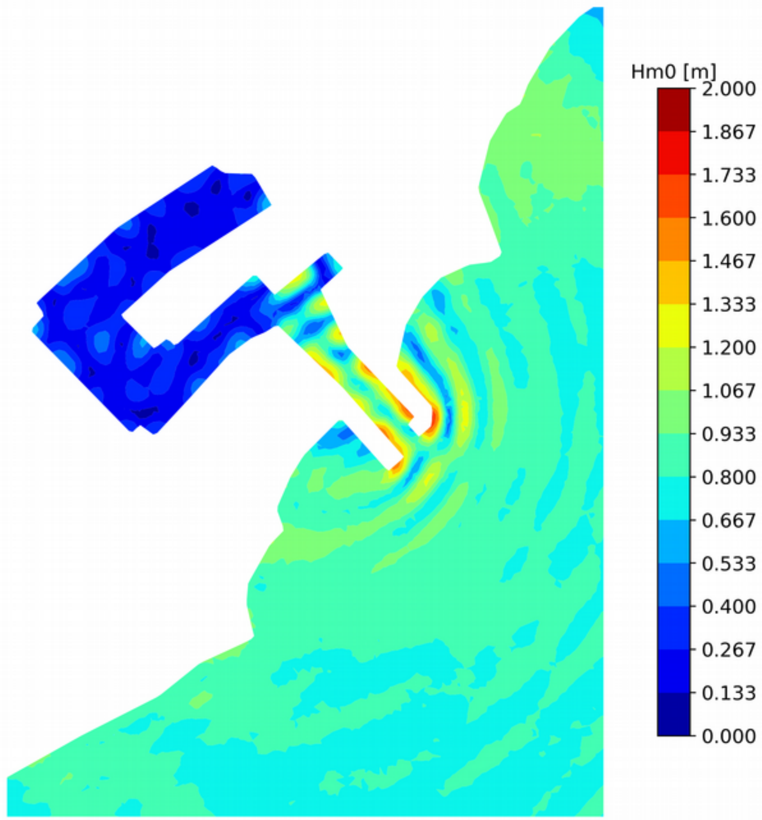

Figure 13: ARTEMIS result, existing conditions, east waves

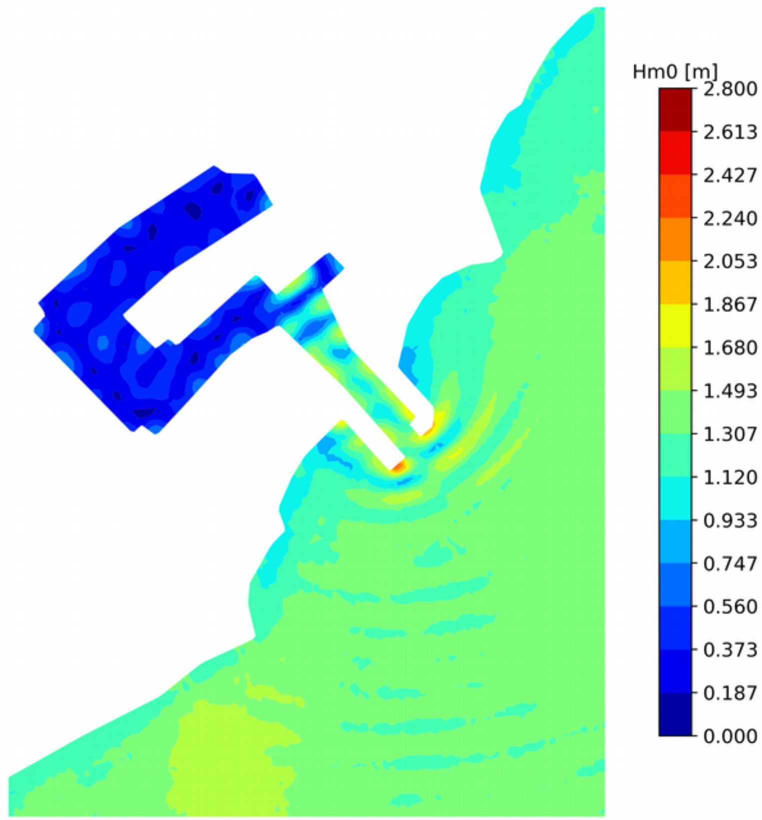

Figure 14: ARTEMIS result, existing conditions, southwest waves

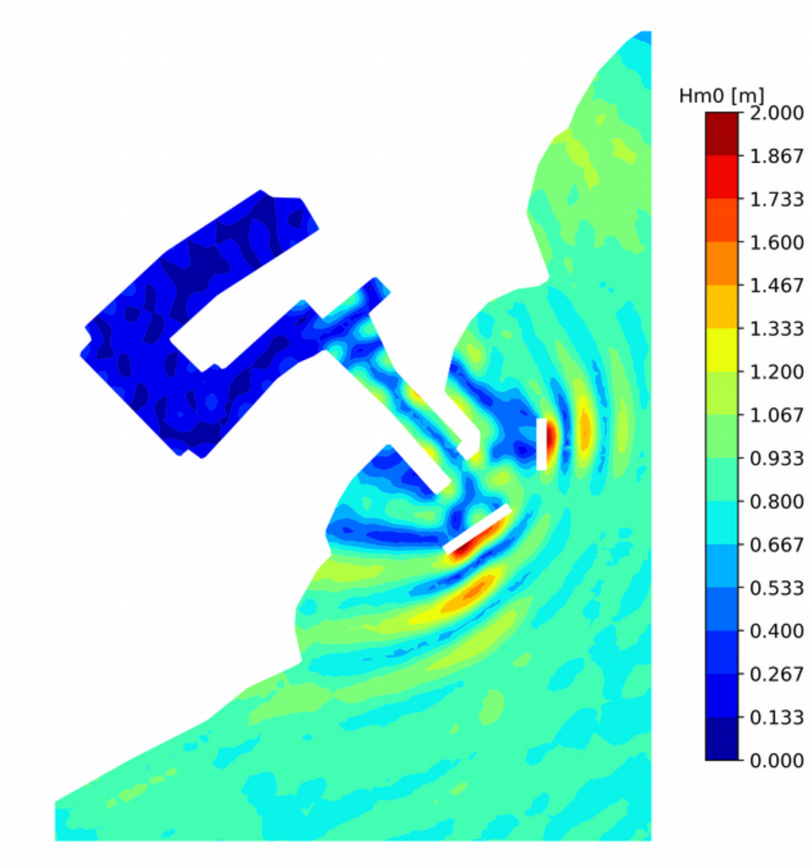

Figure 15: ARTEMIS result, option 1, east waves

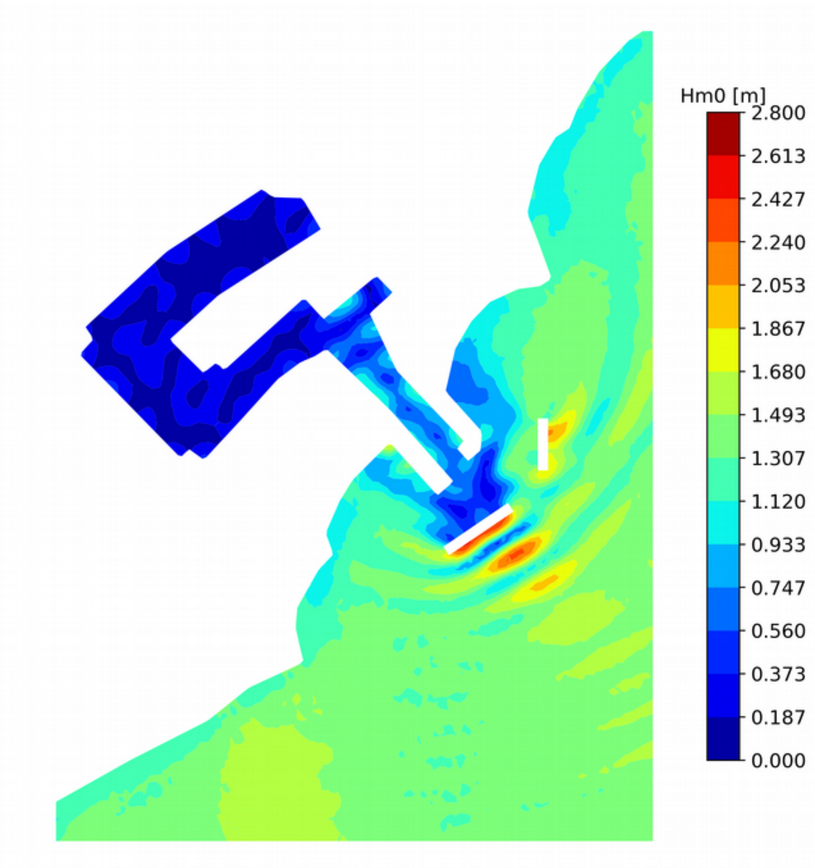

Figure 16: ARTEMIS result, option 1, southwest waves

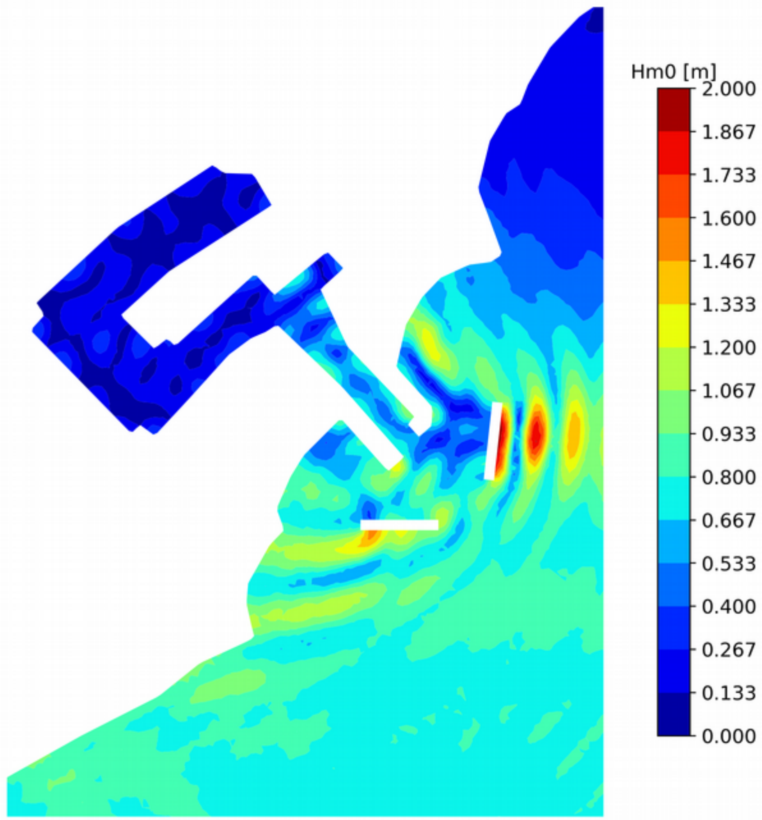

Figure 17: ARTEMIS result, option 2, east waves

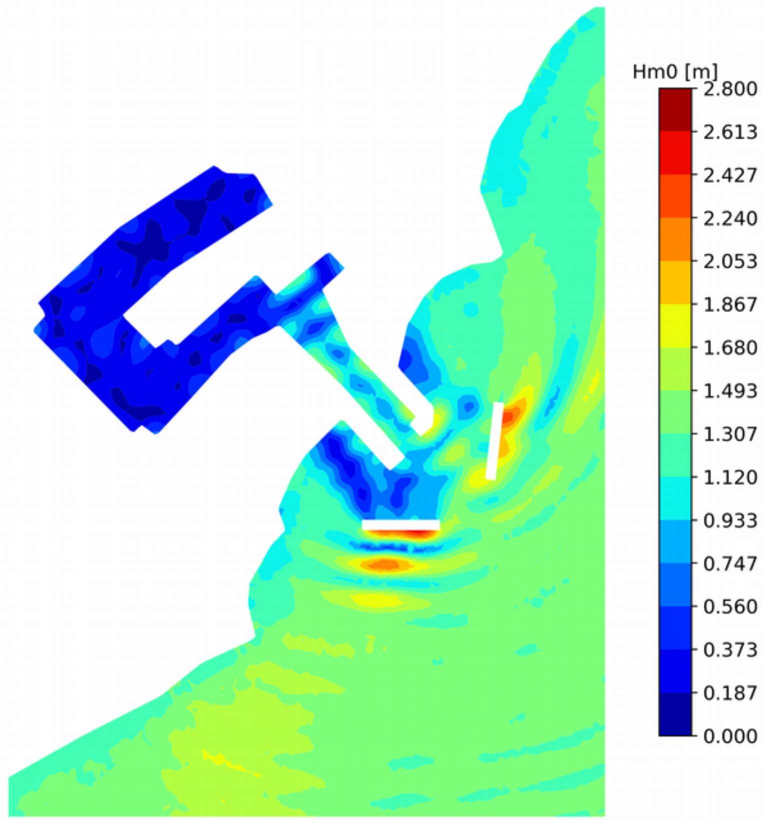

Figure 18: ARTEMIS result, option 2, southwest waves

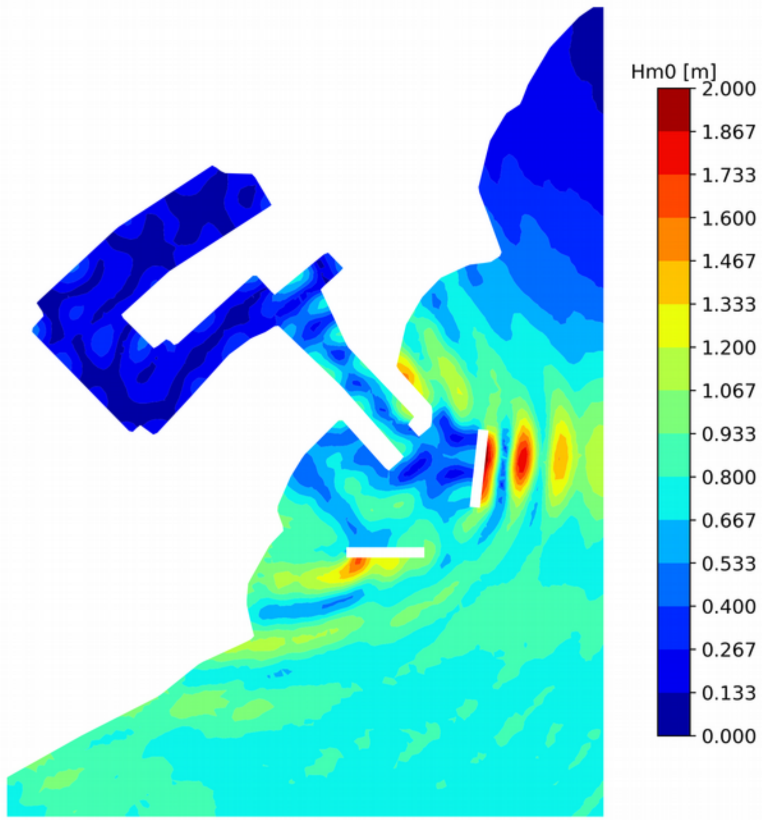

Figure 19: ARTEMIS result, option 2a, east waves

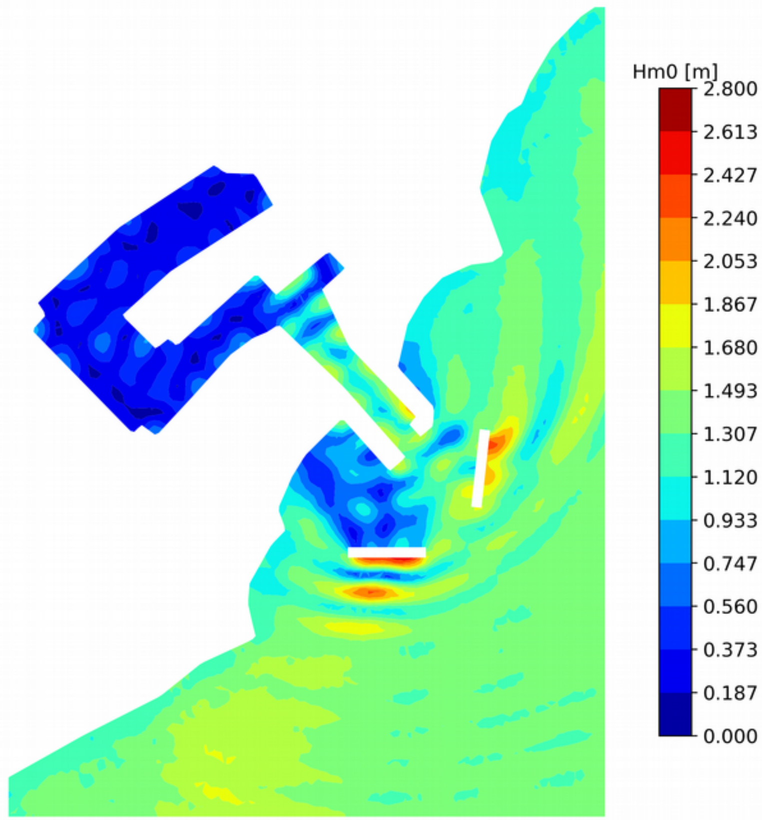

Figure 20: ARTEMIS result, option 2a, southwest waves

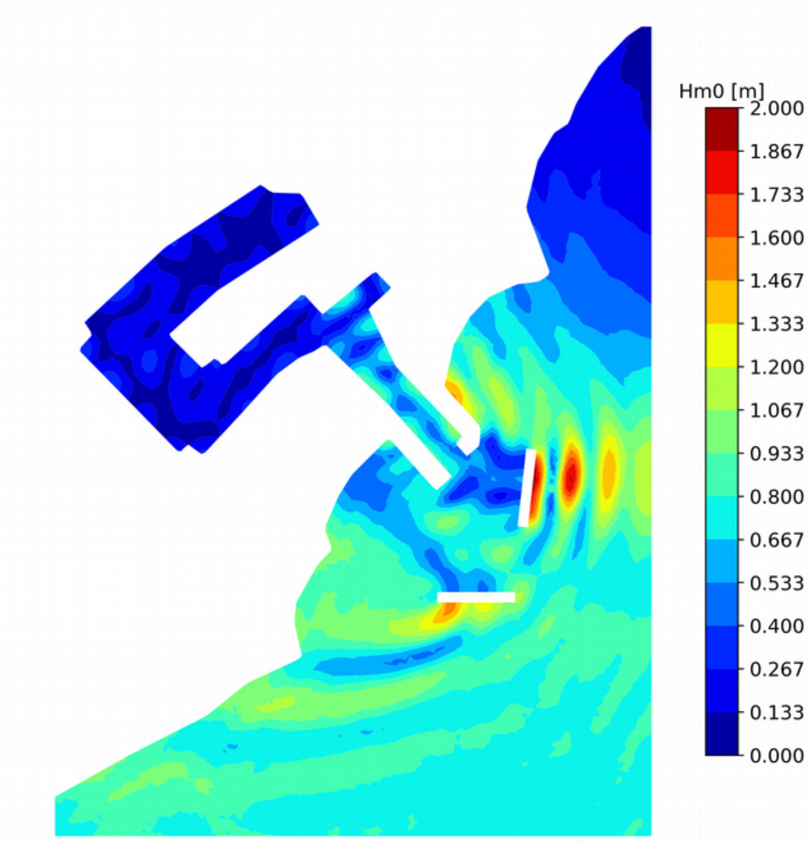

Figure 21: ARTEMIS result, option 2b, east waves

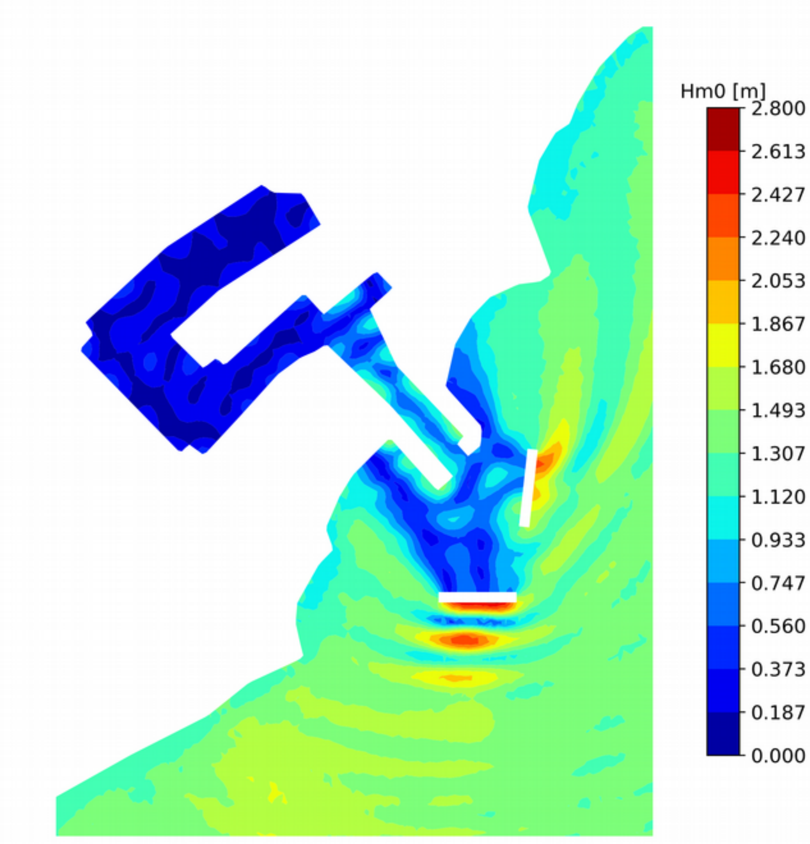

Figure 22: ARTEMIS result, option 2b, southwest waves

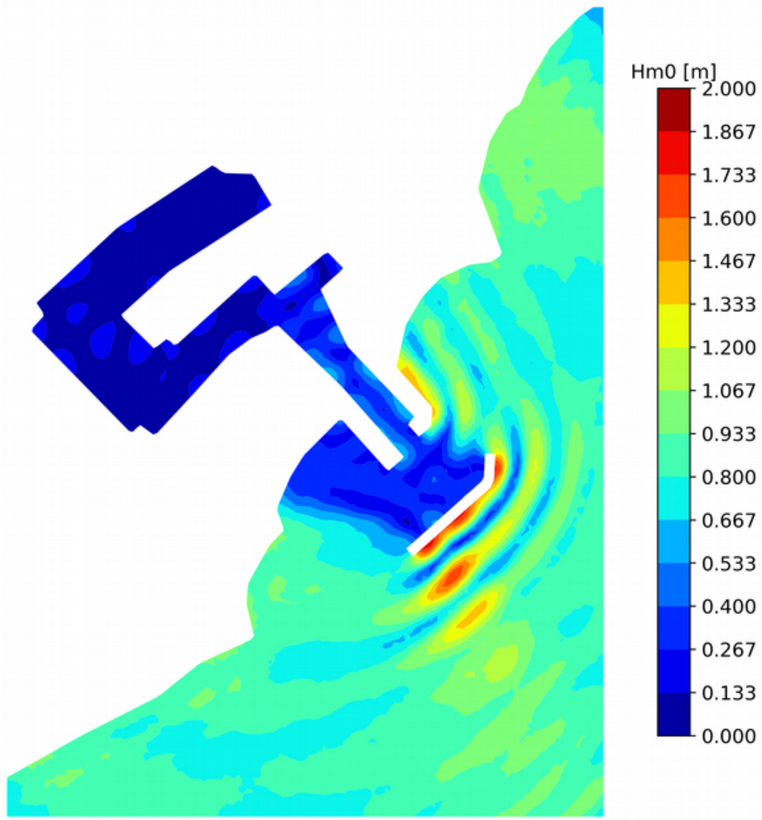

Figure 23: ARTEMIS result, option 3, east waves

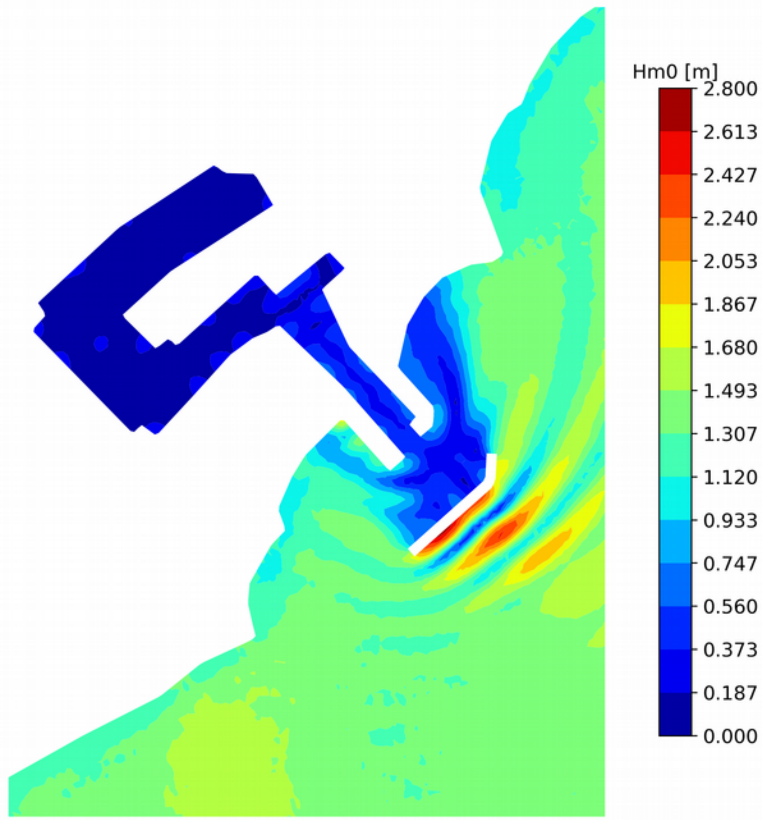

Figure 24: ARTEMIS result, option 3, southwest waves

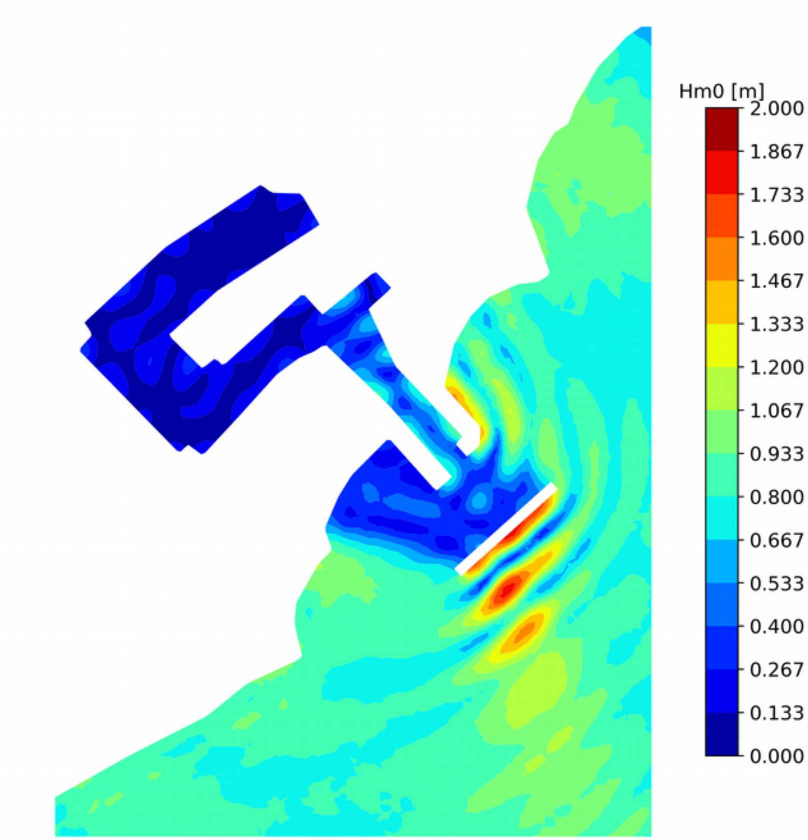

Figure 25: ARTEMIS result, option 3a, east waves

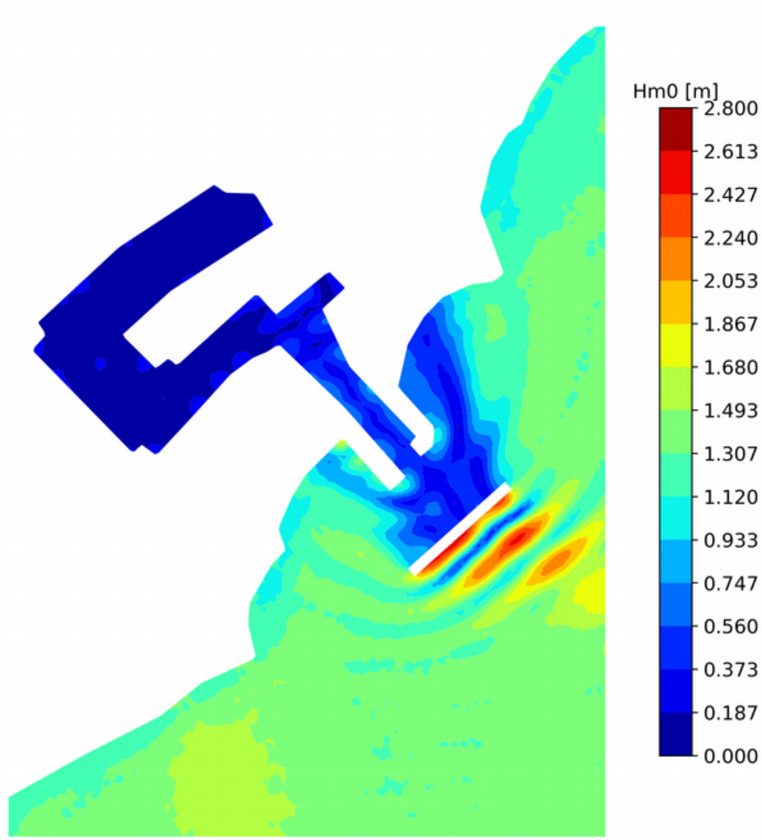

Figure 26: ARTEMIS result, option 3a, southwest waves

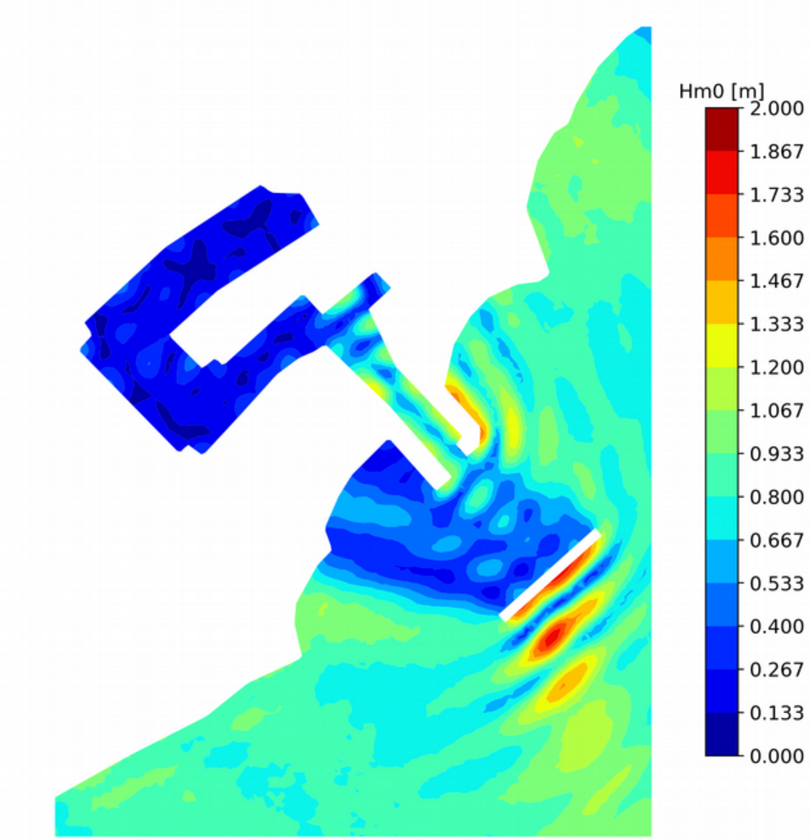

Figure 27: ARTEMIS result, option 3a modified, east waves

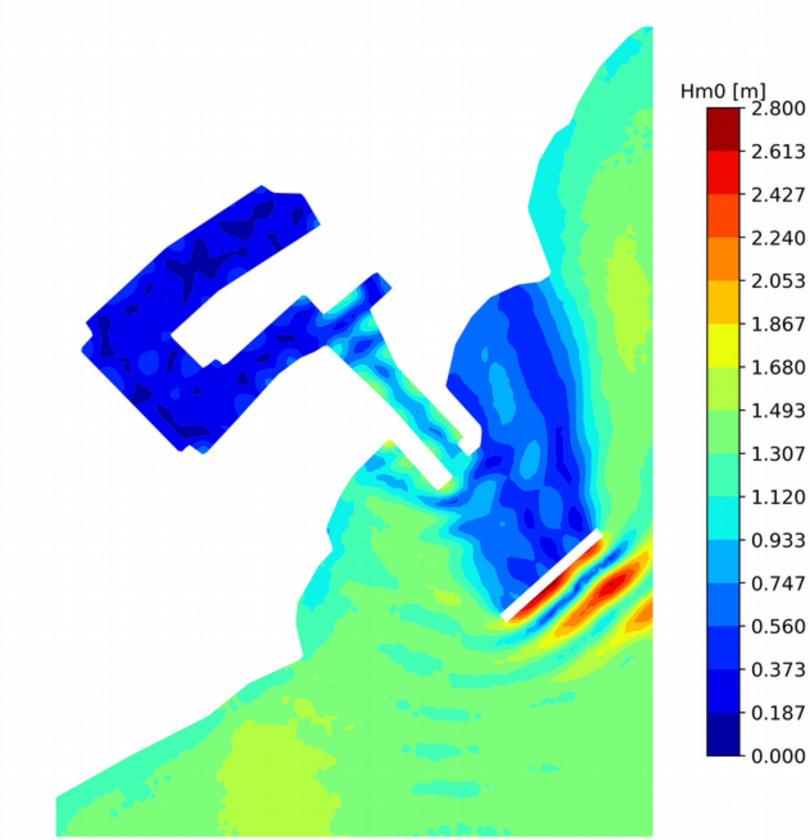

Figure 28: ARTEMIS result, option 3a modified, southwest waves

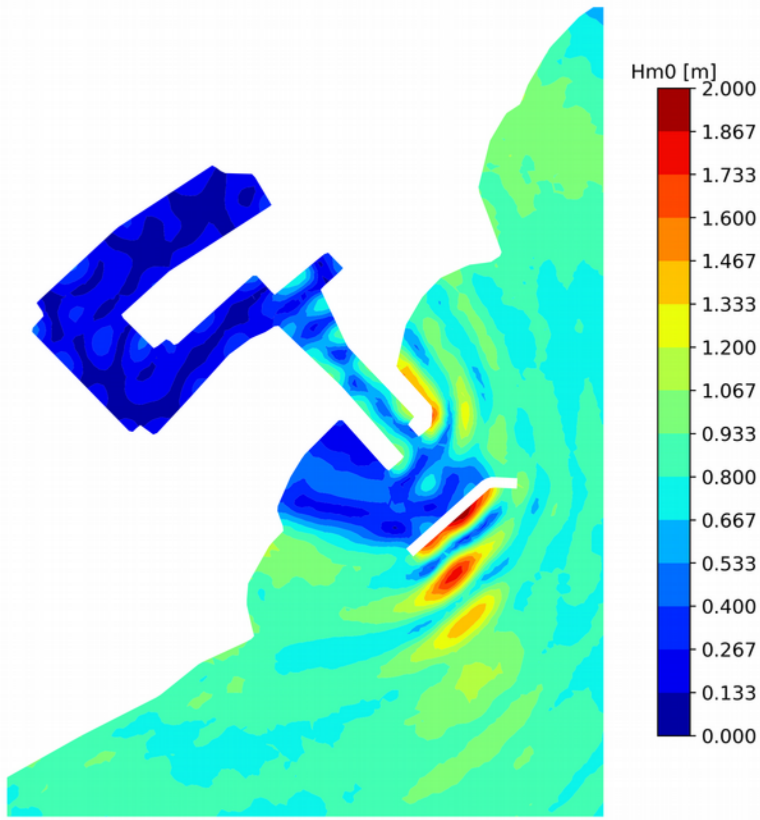

Figure 29: ARTEMIS result, option 3b, east waves

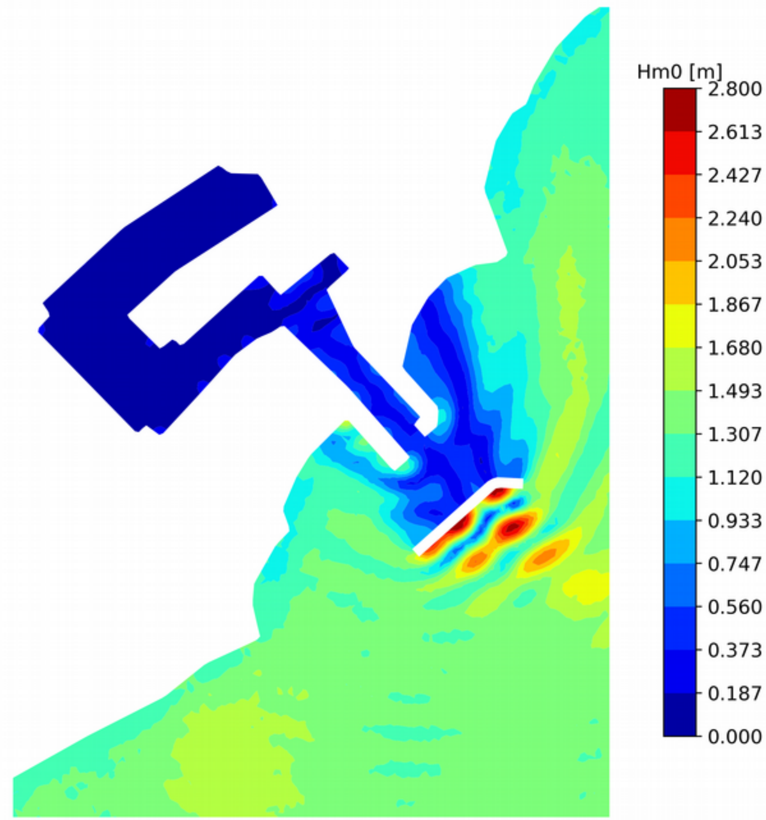

Figure 30: ARTEMIS result, option 3b, southwest waves

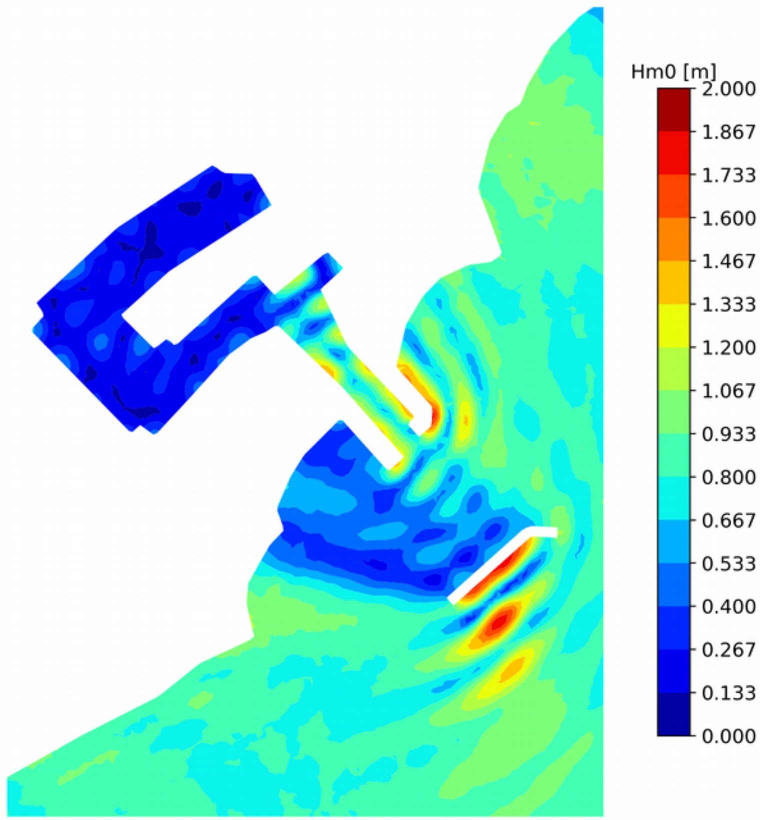

Figure 31: ARTEMIS result, option 3b modified, east waves

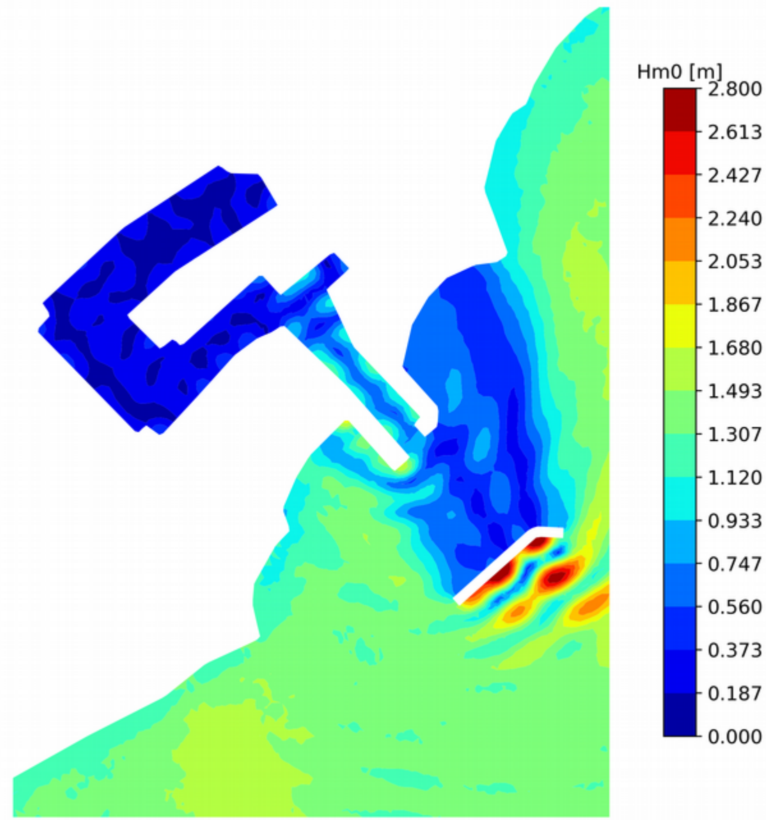

Figure 32: ARTEMIS result, option 3b modified, southwest waves

4 Evaluation of options

The results of the numerical modeling, presented in Section 3.3 form the basis of the evaluation of the nine alternative configuration evaluated in this report. The following subjective criteria is proposed to provide a ranking of the options presented.

Meaning	Descriptor
Worst	Very Poor
	Poor
	OK
Best	Good

Table 8 provides an evaluation of the nine options based on the above descriptors, for both east and southwest winds.

Table 8: Evaluation of breakwater options

	East Winds		Southwest Winds		Navigation
Option	Channel	Basin	Channel	Basin	Channel
1	Poor	Poor	OK	OK	OK
2	Poor	Poor	Very Poor	OK	OK
2a	OK	OK	Very Poor	OK	OK
2b	OK	OK	OK	Good	OK
3	Good	Good	Good	Good	Very Poor
3a	OK	Poor	Good	Good	Very Poor
3a modified	Poor	Very Poor	Poor	Poor	OK
3b	Poor	OK	Good	Good	Very Poor
3b modified	Very Poor	OK	Good	OK	Good

5 Concluding remarks

Based on the evaluation of nine alternative configurations for the proposed steel crib offshore breakwater at Port Glasgow our work has identified option 2b as the preferred alternative. Option 2b consists of a two steel crib offshore breakwater. The recommended option received the best overall ranking in our evaluations as it showed best performance in reducing the wave energy compared to existing conditions, in addition to receiving a high evaluation on navigability through the proposed obstacles.

References

Monteith Brown (2012). Port Glasgow Yacht Club Marina Master Plan, prepared by Monteith Brown Planning Consultants, London, Ontario, November 2012.

TELEMAC (2018). Open TELEMAC, the mathematically superior suite of solvers, http://opentelemac.org/.

MNR (2001). Technical Guide for Great Lakes – St. Lawrence River Shorelines, Ministry of Natural Resources, Toronto, Ontario.

Closure

The factual data, findings, interpretations and conclusions made in this report have been prepared for the Port Glasgow Yacht Club and the Municipality of West Elgin for the purposes of evaluating feasibility of the steel crib offshore breakwaters. The present report is provided to answer specific questions identified in the scope of work, and therefore may not directly be applicable or transferable to other studies or projects. Riggs Engineering can not offer any warranty on the application and/or use of data, findings, interpretations and conclusions made in this report to any other future work. Should an individual, corporation or entity wish to use the content of this work, that individual, corporation or entity shall assume all the risk and carry all liability.

This report was prepared by Pat Prodanovic, Ph.D., P.Eng and Brian Riggs, P. Eng. of Riggs Engineering.