COMHAIRLE NAN EILEAN SIAR
ASSETS AND RESOURCES

BREVIG HARBOUR

SAND DREDGING AND ROCK REMOVAL

FEASIBILITY REPORT

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REPORT

CONTENTS

REVISIONS

Rev.	Date	DESCRIPTION	SIGNATURE
-	18-09-25	DRAFT	Angus M Gillies

PREPARED BY Angus M Gillies BEng, MSc, MICE,CEng		
DATE 18/09/25		
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EXECUTIVE SUMMARY

This report covers the investigation of the effect of rock outcrops located near the entrance to Brevig Harbour to wave and swell propagation and the proposed mitigation of these effects by removal of the harbour entrance rock outcrops. The harbour is currently subjected to turbulent wave action within the inner harbour due to wave rebound from rock outcrops at the harbour entrance. The harbour also has reduced accessibility at low tides due to sand and silt build-up within the entrance channel .

Initial surveys and test sample extraction of the sand was carried out by CainTech Ltd within the harbour area. Testing carried out by James Hutton Ltd showed that no significant contaminants were contained within the sand samples but that the sand was noted to be very odorous.

The two options considered for rock and sand dredging and disposal were either land based excavators with material disposal to reclamation areas and storage bunds or fixed barge with excavators and sea disposal using shuttle barges. Following initial consultation with SEPA and Marine Scotland and cost estimates for both options the most feasible option was the sea disposal method.

The initial modelling undertaken by JBA showed rock removal was beneficial in reducing inner harbour wave oscillations and that the wave heights would not be increased by wave action from alternative south westerly wind and swell directions. JBA then developed the phase 1 report using mesh refinement and sensitivity analysis to assess five different modelling scenarios for rock removal and dredging against a baseline. This subsequent modelling did not show a clear difference or improvement between the different mitigation scenarios. Sand dredging alone presented the only clear reduction in wave height in the harbour compared to the baseline. The JBA report concludes that the additional benefit of rock and dredging should be weighed up against the environmental impacts, cost and irreversibility of rock removal.

The recommendation is to only dredge the harbour and channel entrance to -1.6m below Chart Datum and dispose of the dredged material at the sea disposal site off Arnish Point subject to Marine Scotland Licence approval.

GENERAL PROJECT DETAILS

1.0 INTRODUCTION

Comhairle nan Eilean Siar (CNES) Piers and Harbour propose to assess the feasibility of dredging and removing rock at the Brevig Harbour, Isle of Lewis to enhance this location's tidal accessibility and function as a fishing vessel harbour. The works comprise extraction of rock, removal of rock outcrops adjacent to the harbour entrance and dredging of sand from the inner harbour.

2.0 SURVEY AND CONTAMINATION TESTING

Initial requirements were for the harbour to be surveyed and the inner harbour sand to be tested for contamination.

For assessment of the harbour area Wallace Stone instructed Caintech Ltd to undertake:

i. A Bathymetric survey of the harbour location as outlined in red in the Fig 1.0
ii. Extract three grab samples from the inner harbour for contamination testing in accordance with Marine Scotland's testing schedule Doc 003 Appendix B – pre-disposed sampling guidance.

Fig 1.0
Harbour Location and Survey Extents

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2.1 Survey Findings

Canitech carried out the survey and sampling on the 21st of September 2024 with sample analysis carried out by James Hutton Ltd. The survey data and sample testing results are included in Appendix A.

Survey noted some scour below the concrete breakwater on the right hand side of the harbour entrance which may be attributable to wash from boat props entering the harbour. They also noted the samples extracted from the harbour as being very odorous. Most likely the sampled sand contains a high level of organic material from discarded fish.

Sample testing carried out by James Hutton showed no breaches of schedule contaminant levels and conclude that the dredged material is clean enough to go to licenced sea disposal site.

3.0 EXISTING HARBOUR CONDITIONS

Brevig Harbour was built in 1996 on the site of an existing local harbour by Contractor Balfour Beatty to a design specification by Crouch Hogg Waterman. The original specification included a harbour breakwater to prevent wave and swells entering the harbour mouth, however as this breakwater was not built the Harbour suffered from extreme wave action within the inner harbour during southerly directional swells. Harbour was amended to the current configuration to mitigate the wave action but was not completely successful in reducing the inner harbour turbulence to a satisfactory level. The element which has been alluded to cause wave action rebounding into the harbour is the rock outcrop in front of the navigation light which is exposed at low tide level. The rebound wave action can be so severe it has resulted in an unacceptable level of turbulence in the harbour for boats and fishing vessels.

Photo 1.0
Harbour Entrance Low Tide with Rock Outcrop Exposed

Appendix B contains an original drawing arrangement showing cross sections and construction detail.

The second concern with Brevig relates to the continued sand built up within the harbour entrance and the inner bay. Turbulent action from the wave action at the harbour entrance rock outcrops is believed to be causing sand and sediment build up to be transferring into the harbour entrance and building up to the point that some vessels can no longer enter the harbour except at certain tide levels.

Photo 2.0
Harbour Entrance High Tide with Rock Outcrop Submerged

4.0 MITIGATION METHODS – WAVE TURBULENCE

This current study has looked into methods of mitigation wave action by means of removing the harbour entrance rock and dredging the harbour of sand build up. The rock is a conglomerate rock type (Photo 3.0) which is soft and easily breaks up when disturbed. The rock type can be easily removed using excavators or dredging buckets. Rock of this type will break up into it's constituent components (silt and cobbles) and would need to be disposed either out at sea or within a bunded structure on land.

Photo 3.0
Conglomerate rock type

Other removal methods such as plough dredging were given consideration but it is thought that the harbour is too confined for this to be a feasible option.

5.0 ROCK AND SAND DISPOSAL OPTIONS

The most suitable disposal methods for the harbour material are:

1) Disposal of dredged material (soft sediments and rock) to a dredge disposal site

The closest site is just south of Arnish Point and has been used as a disposal site for other construction projects. Initial correspondence with Marine Scotland has indicated that Arnish Point is available for the deposition of dredged sand and removed rock material. For this option, CNES would submit, along with the marine licence application, a Best Practicable Environmental Option report which also considers other potential uses for the material and why sea deposit is the best option.

2) Disposal of dredged material (soft sediments and rock) on land or reclamation coastal area

To meet the requirements of Marine Scotland (bunded storage/reclamation below MHWS) the area identified would have to allow for drainage and the exposed face protected with an armour stone surround. This option would require consideration if the works fall within any of the categories within schedule 2 of The Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017, in particular, 1(e)/2(b)/10(m), and possible submission for a screening request to Marine Scotland to determine if the works are an EIA project. Also note that the reclamation area would be subject to consultation with Crown Estates.

The soft sand materials could be stored on land above MHWS but would have to meet any requirement set by SEPA. Most likely this would mean the bunding and draining the sand. Possibility would be that the sand could be re-purposed as land restoration material and avoid the requirement for landfill tax. Initial correspondence with SEPA has indicated that onsite storage or re-use options would be treated unfavourably:

1. Dredging spoil (EWC Ref 17 05 06) can be used in Paragraph 7, 9 and 19 waste exemptions (see guidance at Activities exempt from waste management licensing | Scottish Environment Protection Agency (SEPA)). Without specific details relating to the site(s) of proposed application then it would not be permitted. Furthermore, sand is not generally acceptable for use in Para 7 and 9 waste exemptions.
2. If the sand is ‘highly odorous’, as described, it is unlikely to be suitable for storage at the proposed location.
3. The rock could potentially be used for construction, maintenance or improvement of the dock under a Paragraph 19 exemption (see above guidance) but incorporating the rock into the shoreline would not be considered a suitable use.

6.0 HARBOUR WAVE MODELLING ANALYSIS

6.1 Wave Analysis

JBA were commissioned by CNES to carryout an assessment of the effects of wave action on the harbour from two different wave and swell directions and assess the potential benefits of removing the rock outcrops at the harbour mouth. The assessment was requested to ascertain whether:

i. Rock removal would have any overall beneficial effects on the inner harbour turbulence.
ii. Whether under certain wind wave directions the rock removal may have an adverse effect and lead to increased harbour turbulence.

JBA conducted a number of Hydrodynamic simulations using computational fluid dynamics (CFD) based on shallow water equations. Initial assessments comprising of two different wave conditions based on observed data and video evidence. The analysis was carried out with and without rock outcrop removal under two incident wave directions: (i) south easterly swell and (ii) south westerly wind waves.

I. Under the assumption made for wind and wave direction the initial results showed that the absence of the rock outcrop resulted in a slight reduction in the significant wave height within the harbour.

II. The removal of rock did not show that the harbour turbulence may be increased from certain wind directional waves and swells.

Further sensitivity analysis was carried out to determine the incoming wave directions relative to the harbour. Comparison of the computational modelling to actual events indicated that the incoming wave directions were slightly different. Recommendations were for a review of inputs and development of a more appropriate representative model of swell events.

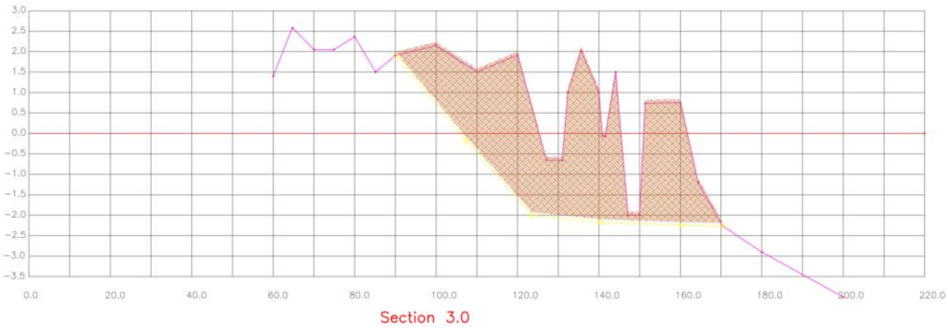
JBA Report – Initial Modelling Results is contained within Appendix C.

6.2 Further Modelling

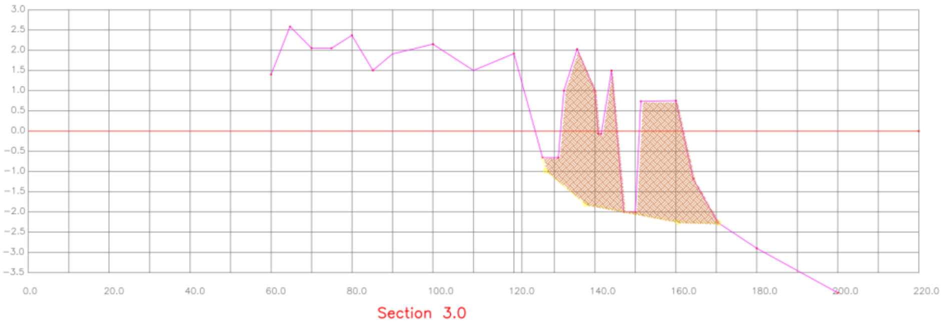
For the next stages in the modelling exercise JBA were requested to provide modelling of the various options using a refined model for two different rock extraction formations and inclusion of dredged harbour or an undredged harbour:

Alignment profile 1 was based on an extended rock extraction profile from the harbour entrance gently sloped back to existing formation level to form a beach profile which would dissipate incoming wave energy. Alignment profile 2 was based on a reduced excavation profile with a steeper shoreline boundary which may not totally dissipate incoming wave energy:

1. Rock removal Alignment 1 without dredging.
2. Rock removal Alignment 1 with dredging.
3. Rock removal Alignment 2 without dredging.
4. Rock removal Alignment 2 with dredging.
5. Dredging only



Alignment 1 Section 3.0



Alignment 2 Section 3.0

Typical Cross Sections through Areas 1and 2

*Also requested was some indication or assessment of whether rock removal would lead to reduced sediment build up within the harbour and some assessment of the effects of high and low water levels.

JBA Report – Brevig Harbour Modelling Phase 2 is contained in Appendix D.

The report assessed the effects of the five scenarios listed and compared the result for:

i. Net sediment transfer
ii. Impact of rock removal

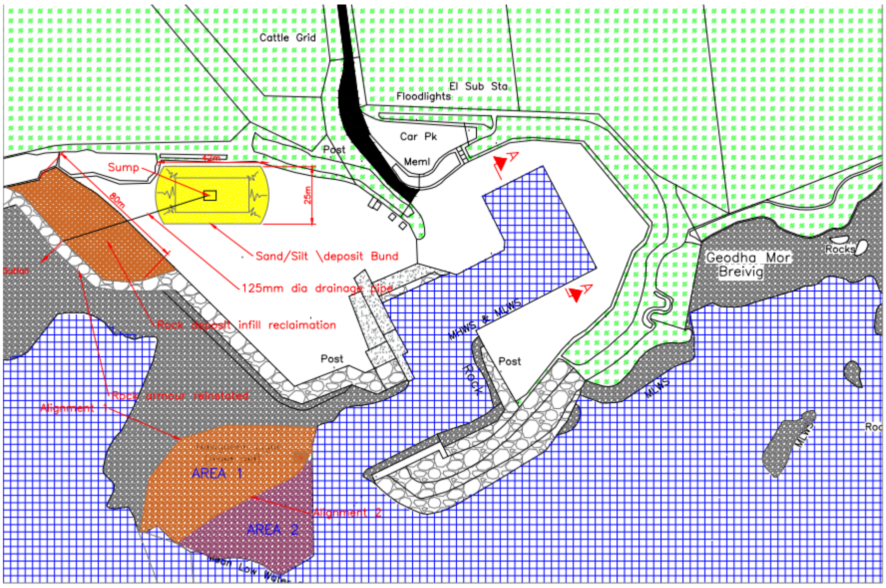
For sediment transfer the analysis results did not show any benefit in the rock removal. Sediment transportation was limited and harbour self dredging capacity was not demonstrated. Analysis did not show any clear differences or improvements between the different mitigation scenarios tested (rock removal/dredging/rock removal and dredging) – all showed that sediment transfer oriented outside the harbour and that the silting may be more attributable to tidal or other swell events.

For rock removal the larger area of rock removal (Alignment 1.0) had a greater effect on the reduction of wave oscillations (HmO) within the harbour. The reduced rock removal option (Alignment 2.0) did not show any benefit in terms of harbour oscillations or sediment transport. The final comparison between combined rock and sand removal (Alignment 2) did not show a clear reduction in harbour oscillations compared to dredging alone.

Sand dredging alone showed significant reduction in the inner harbour wave oscillations but only marginal impact on bedload sediment transfer. The additional benefit of combining dredging with rock removal was shown to be limited and may not be considered as the most cost effective option.

Appendix E contains a General Arrangement of the proposed excavation areas and rock excavation extents. The storage bund is shown for dredged sand to shoreside and a reclamation area to the north of the harbour carpark for rock with an armour stone surround.

The alignments and areas are shown in an extract of Drg 7(10C 30) 000 below.



Brevig Harbour Plan
Rock Removal Areas 1 and 2

7.0 COSTINGS AND QUANTITIES

For areas 1 and 2 the arrangement will require removal and reinstatement of the navigation light founded at the harbour entrance shown in Photo 1.0. Excavation extents for Area 2 only removes the rock headland and leaves the navigation light outcrop in place to reduce the project cost.

Sand within the channel and the harbour are to be dredged to -1.6m below Chart Datum.

7.1 Land bund Storage Options

The sand bund and rock reclamation locations shown are indicative and may be moved to more suitable locations in accordance with consultation with SEPA and Marine Scotland.

Land storage options will be subject to SEPA and Marine Scotland licence processes. Both statutory bodies have indicated that this option may require an additional assessment for the environmental and economic impact before a licence will be granted.

Costing exercise was conducted using typical rates for rock and sand removal and disposal. Contingencies have been added to the following costs to account for additional fees associated with disposal methods and licence applications.

Costings of materials dredged or excavated are as follows:

Rock extraction area	Extent of Alignment	Dredged Sand Cu.m	Conglomerate Rock Cu.m	Cost Estimate
Area 1+2*	Alignment 1	2,800	10,000	**£1,800,000**
Area 2	Alignment 2	2,800	3,200	**£800,000**
Sand Dredge Only	Inner Harbour and Channel	2,800	-	**£350,000**

The quantities sheets for each of the above options are contained within Appendix F. The method is based on excavation of the inner harbour and rock areas using long reach excavator based on land and quayside with material disposed using conventional lorries to designated bund or reclamation areas.

7.2 Sea Disposal Option

The alternative disposal option is for all the materials to be disposed of using barges at a designated site off Arnish point. The disposal runs using the barges will need considerable time between runs and will most likely need two number barges shuttling back and forth to maintain the cost effectiveness of the excavator barge.

Sea Disposal Location

The costing of this option was undertaken using information provided by Coastworks Marine.

Rock extraction area	Extent of Alignment	Dredged Sand Cu.m	Conglomerate Rock Cu.m	Cost Estimate
Area 1+2*	Alignment 1	2,800	10,000	**£700,000**
Area 2	Alignment 2	2,800	3,200	**£470,000**
Sand Dredge Only	Inner Harbour and Channel	2,800	-	**£370,000**

Marine Scotland have requested environmental best practice report on this option prior to a Marine licence being granted. Marine Scotland have also indicated that they may not accept the sampling analysis results as the sampling exercise was not undertaken with prior consultation with Marine Scotland.

8.0 CONCLUSIONS

The extensive analysis and modelling conducted by JBA has shown that there is only marginal benefit in removing the existing rock outcrop from the harbour entrance and therefore this proposal is not currently considered to be a cost effective solution to reducing inner harbour wave oscillations. The analysis also shows little effect in rock removal to allow the harbour to become self dredging given the time period considered for sediment transfer. Sand dredging alone showed significant reduction in the inner harbour wave oscillations but only marginal impact on sediment transfer.

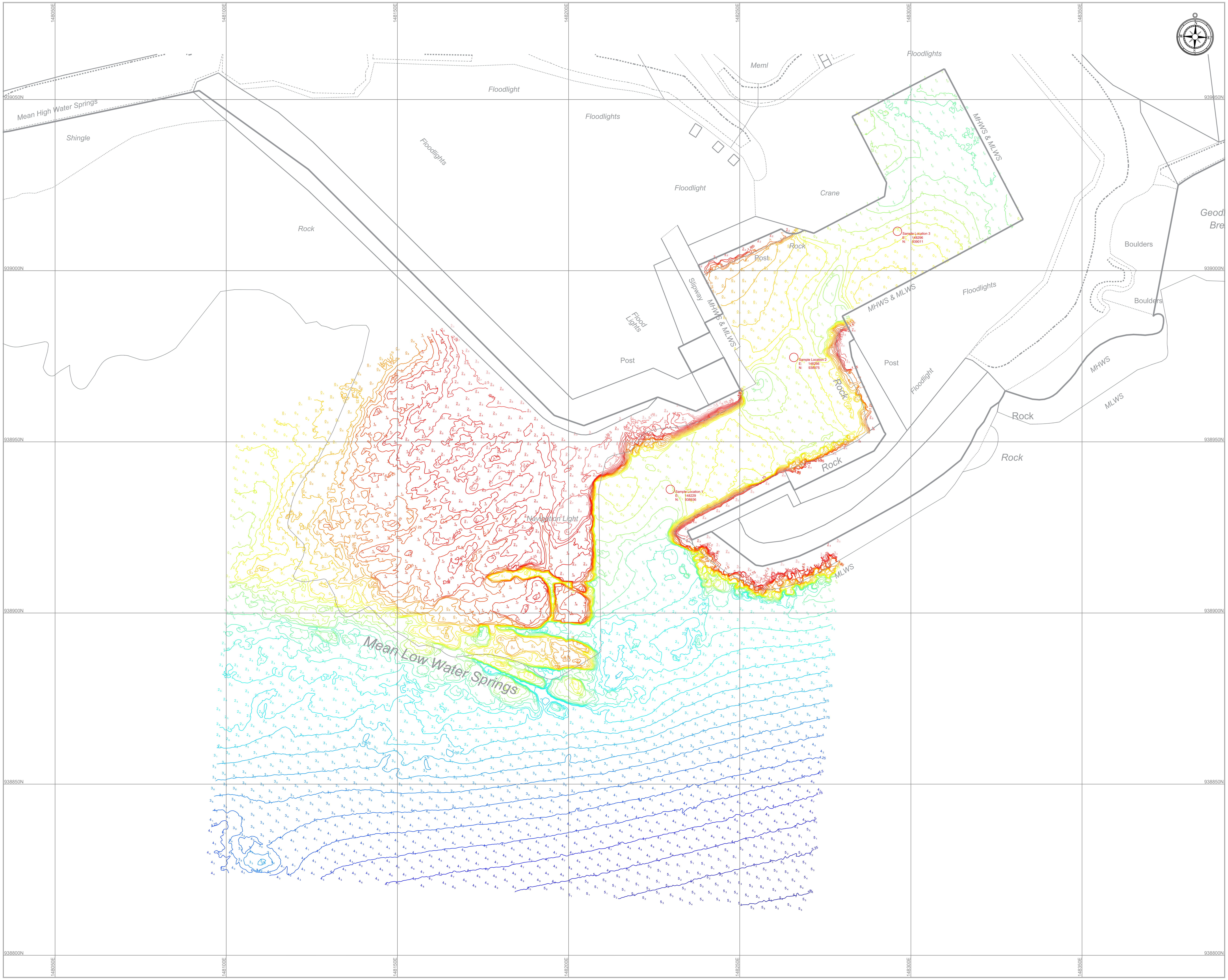
Initial consultations have taken place with SEPA and Marine Scotland with regards to the feasibility of the approaches described in this report. Significant concerns have been raised at the development stage with regards to land storage or reclamation storage for the excavated and dredged materials.

A number of different disposal methods were considered and costed. The most economical and feasible disposal method has been shown to be disposal at sea using barges. The shore rock excavation and dredging could be undertaken using excavator on barges with disposal using two shuttle barges to a site off Arnish point. The method will be subject to Marine Scotland licencing and may require an options report to be produced to show that this is the most cost effective/environmentally sustainable disposal method.

This report considers sand dredging alone to be the most cost effective solution to excessive turbulence within the inner harbour at Brevig. Although the initial analysis report also show that the risk of intensifying the wave action (following rock removal from the harbour entrance) within the inner harbour from south westerly wind and swell directions is not a significant risk the benefits of combined rock removal and sand dredging were not realised in the second phase analysis. The preferred method of dredging would be using excavators on barges with disposal to designated site off Arnish point. The dredging process should be identified as a regular maintenance event and should be carried out at four to five year intervals.

APPENDIX A

Bathymetric Survey and Test Results



Survey Parameters & Equipment	
Survey Vessel:	'Highlander'
Positioning System:	Aplanix Pos MV
GPS Correction Source:	TopNet Ntrip
Echosounder:	Norbit iWBMS
Motion Compensator:	Aplanix Wavemaster 2
Positioning System Spheroid & Datum:	ETRS89
Grid System:	National Grid of Great Britain
Geoid Model:	OSGM15
Transformation Parameters:	OSTN15
Spheroid:	Airy
Semi Major Axis:	6378137
Flattening:	298.257222101
Vertical Datum - Topographic:	-
Vertical Datum - Hydrographic:	Chart Datum
Distance Unit:	Metre
Chart Datum from Vorf Admiralty data service - 2.57m below OS Datum	
The Datum was established using Trimble VRS Now NTrip	

Depth Chart

-3.750	1.750
-3.500	2.000
-3.250	2.250
-3.000	2.500
-2.750	2.750
-2.500	3.000
-2.250	3.250
-2.000	3.500
-1.750	3.750
-1.500	4.000
-1.250	4.250
-1.000	4.500
-0.750	4.750
-0.500	5.000
-0.250	5.250
0.000	5.500
0.250	5.750
0.500	6.000
0.750	6.250
1.000	6.500
1.250	6.750
1.500	7.000

Meters
15 0 15 30
1:500

Notes:

1. Bathymetric Survey limits were supplied, data is set to Chart Datum.
2. Horizontal and vertical datums were referenced to control stations on site.

Height in metres above Chart Datum

MHWS	MHWN	MLWN	MLWS

Control Station Coordinates

STN	Easting	Northing	Height

Site Layout:

Bathymetric Survey

Brevig Harbour
21st September 2024

CainTech

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IV15 9HA

Drawn By:	Checked By:	Surveyed By	Surveyed Date:
JM	GCN	JM	21/09/2024

Drawing Status:

- ☐ FOR APPROVAL
- ■ FOR ISSUE
- ☐ FOR DISCUSSION
- ☐ DRAFT STATUS

Drawing Date: 25/09/2024

Drawing Scale: 1 : 500 @ A1

Drawing No: CTCH-5961-01

- Levels are in metres and are to Chart Datum (2.57m Below OS)
- Co-ordinates are to National Grid. (GPS Network)

Our Job Ref: J5961

Rev: –

A1 Do Not Scale (If in Doubt Ask)

James Hutton Limited
ANALYTICAL LABORATORY SERVICES
Assured Analytical Excellence

Analytical Report

on Various Analyses in Harbour Sediment Samples

For:
Jim Main
Caintech
Suite A2, Etive House
Beechwood Business Park
Inverness
IV2 3BW

REPORT AUTHOR

REPORT AUTHORISER & ISSUE DATE

[Redacted]

Douglas Kindness, BSc (Hons)
Analytical Chemist

[Redacted]

Job and Sample Information:	
Client Order No/Reference:	JM25092402
Date Sample(s) Received:	01/10/2024
Hutton ID	**Client sample ID**
1420141	Brevig Sample 1
1420142	Brevig Sample 2
1420143	Brevig Sample 3

Methods

Methods	Accreditation Reference	Date Analysis Completed
As, Cd, Cr, Cu, Hg, Ni, Pb, Zn by ICP-MS	Not Applicable	20/11/2024
Harbour sediments - Poly aromatic hydrocarbons	Not Applicable	31/10/2024
Harbour sediments PCB (ICES 7)	Not Applicable	31/10/2024
Harbour sediment - tributyltin	Not Applicable	31/10/2024
Harbour sediment - Total hydrocarbons	Not Applicable	30/10/2024

Results

Table 1. Concentration (mg/kg) of Polyaromatic Hydrocarbons (PAH's).

	Concentration (mg/kg)		
Client ID	**Brevig Sample 1**	**Brevig Sample 2**	**Brevig Sample 3**
Hutton ID	**1420141**	**1420142**	**1420143**
Naphthalene	0.002	0.003	0.008
Acenaphthylene	0.001	0.001	0.001
Acenaphthene	0.002	0.002	0.002
Fluorene	0.001	0.001	0.002
Phenanthrene	0.001	0.003	0.008
Anthracene	0.002	0.002	0.002
Fluoranthene	0.005	0.011	0.027
Pyrene	0.002	0.004	0.011
Benz[a]anthracene	0.009	0.010	0.016
Chrysene	0.005	0.005	0.008
Benzo(b)fluoranthene	0.008	0.009	0.013
Benzo(k)fluoranthene	0.002	0.002	0.003
Benzo(a)pyrene	0.004	0.004	0.007
Indeno(1,2,2-cd) pyrene	0.007	0.007	0.009
Dibenzo(a,h)anthracene	0.009	0.009	0.009
Benzo(g,h,i)perylene	0.004	0.004	0.005

No Breach of AL1 or AL2 specifications

Table 2. Concentration (mg/kg) of Polychlorinated Biphenyls (PCB's).

		Concentration PCB's (mg/kg)						
Client ID	**Hutton ID**	**PCB28**	**PCB52**	**PCB101**	**PCB118**	**PCB138**	**PCB153**	**PCB180**
Brevig Sample 1	**1420141**	0.0002	<0.0001	0.0002	0.0002	<0.0001	0.0002	0.0002
Brevig Sample 2	**1420142**	<0.0001	0.0001	0.0001	<0.0001	0.0001	0.0001	<0.0001
Brevig Sample 3	**1420143**	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 3. Concentration (mg/kg) of Tributyl Tin (PCB's).

Client ID	Hutton ID	Concentration of TBT (mg/kg)
Brevig Sample 1	**1420141**	< 0.0001
Brevig Sample 2	**1420142**	< 0.0001
Brevig Sample 3	**1420143**	< 0.0001

Table 4. Concentration (mg/kg) of Total Petroleum Hydrocarbons (TPH).

Client ID	Hutton ID	Concentration of TPH (mg/kg)
Brevig Sample 1	**1420141**	<0.01
Brevig Sample 2	**1420142**	<0.01
Brevig Sample 3	**1420143**	<0.01

No Breach of AL1 or AL2 specifications

Table 5. Concentration (mg/kg) of Metals by ICP-MS

		Concentration Metals (mg/kg)							
Client ID	**Hutton ID**	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Brevig Sample 1	**1420141**	1.29	0.09	9.95	3.84	<0.1	5.53	1.76	12.48
Brevig Sample 2	**1420142**	2.12	0.09	12.74	5.71	<0.1	6.47	2.34	17.68
Brevig Sample 3	**1420143**	1.80	0.08	14.20	7.17	<0.1	7.49	2.94	27.15

No Breach of AL1 or AL2 specifications

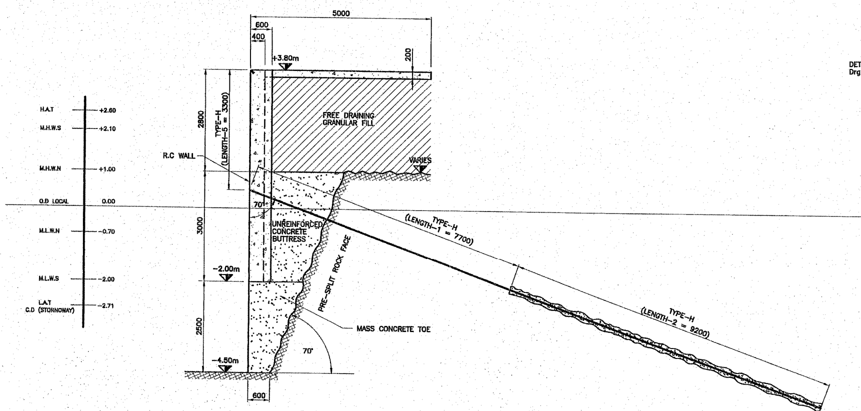
Note:

Samples will be stored for a period of eight weeks following completion of analysis and acceptance of analytical report(s) at no extra cost after which samples will be disposed of unless a specific instruction is given (with the sample analysis request/order) to store the sample beyond this period. Extended storage charges will apply.

END OF REPORT

APPENDIX B

Existing Structural General Arrangement



SECTION C – C

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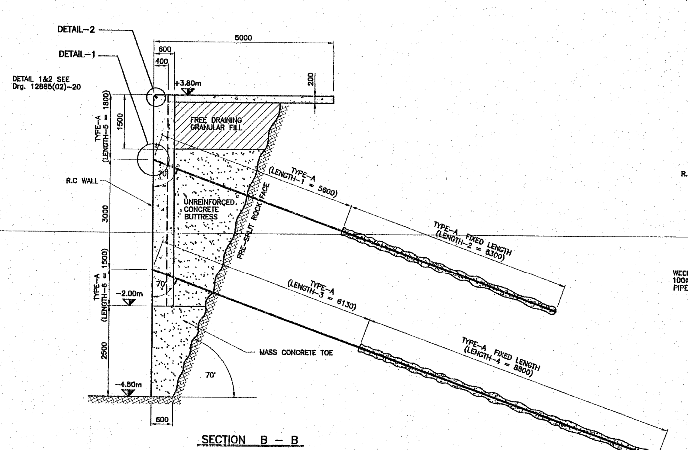

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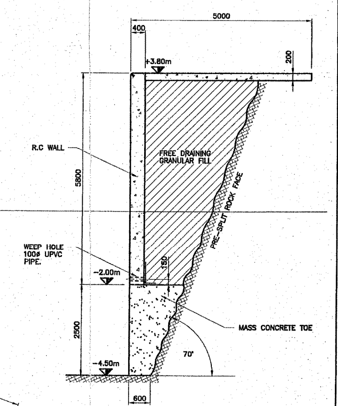


SECTION A – A

1:50

GENERAL NOTES

1) This drawing is to be read in conjunction with the relevant specification and all other relevant drawings issued by the Engineer.

2) All dimensions and levels to be checked on site and the Engineer notified of any discrepancies prior to commencement of work.

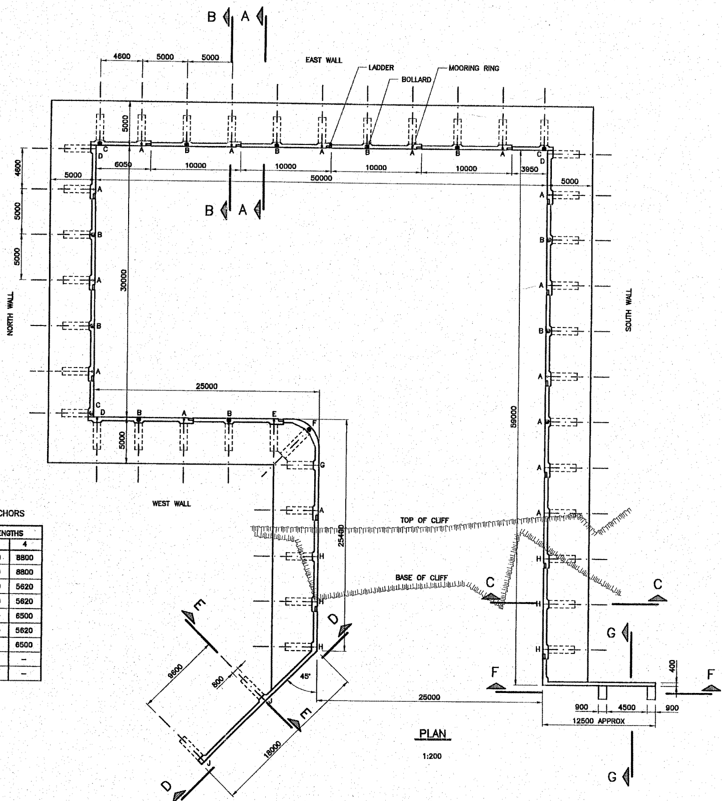
3 ALL DIMENSIONS SHOWN ARE IN MILLIMETRES.

4 ALL LEVELS SHOWN ARE IN METRES TO O.D LOCAL

5 ALL CONCRETE TO BE TYPE 40/20 UNLESS NOTED OTHERWISE.

6 ALL EXPOSED CORNERS HAVE A 50 x 50mm CHAMFER.

8 THIS DRAWING TO BE READ IN CONJUNCTION WITH Drg. Nos. 12885(02)-20



PLAN

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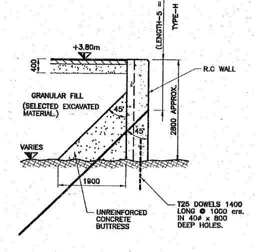

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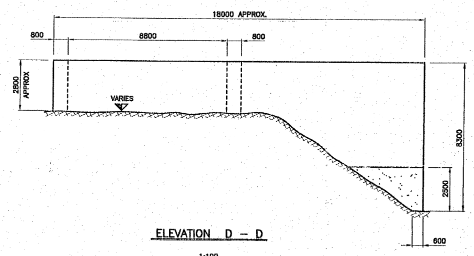

ELEVATION D – D

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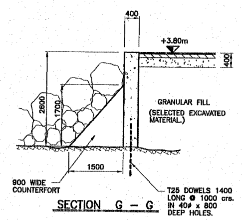

SECTION G – G

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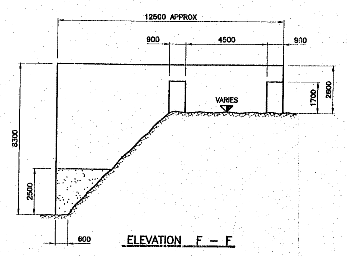


ELEVATION F – F

1:100

TOP ANCHORS

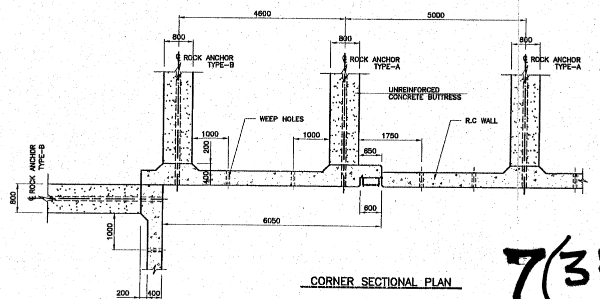
TYPE	No.	LENGTHS 1	LENGTHS 2
A	12	5600	6300
B	11	6300	7400
C	3	5300	6600
D	3	4900	3900
E	1	6300	6500
F	1	4900	3900
G	1	6300	6500
H	1	7700	9200
J	1	6300	6500

BOTTOM ANCHORS

TYPE	No.	LENGTHS 3	LENGTHS 4
A	12	6130	8800
B	11	6130	8800
C	3	5340	5620
D	3	5340	5620
E	1	6300	6500
F	1	5340	5620
G	1	6300	6500
H	–	–	–
J	–	–	–

TYPE	LENGTHS 5	LENGTHS 6
A	1800	1500
B	1800	1500
C	1800	1500
D	1800	1500
E	1800	1500
F	1800	1500
G	1800	1800
H	3300	–
J	1400	–

ROCK ANCHOR LENGTHS



CORNER SECTIONAL PLAN

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REV	DETAILS	BY	DATE

AMENDMENTS

ARCHITECT CLIENT: COMHAIRLE NAN EILEAN WESTERN ISLES ISLANDS COUNCIL

PROJECT: BREVIG HARBOUR

ELEMENT: QUAY WALLS

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DRAWING TITLE: PLAN AND SECTIONS

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I.J.McQ		
DATE December 1993	DATE	DATE
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REVISION		

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APPENDIX C

Wave Modelling Initial Results Report

JBA consulting

Brevig harbour Modelling

Draft

June 2025

Prepared for:
Comhairle Nan Eilean Siar

www.jbaconsulting.com

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Contract

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JBA Project Code	2025s0267

This report describes work commissioned by Comhairle Nan Eilean Siar by an instruction dated 20/02/2025. The Client's representative for the contract was Angus Gillies. Azin Lamei Florian Bellafont of JBA Consulting carried out this work.

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The methodology adopted and the sources of information used by JBA in providing its services are outlined in this Report. The work described in this Report was undertaken between March and June in 2025 and is based on the conditions encountered and the information available during the said period. The scope of this Report and the services are accordingly factually limited by these circumstances.

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Executive Summary

This study investigates the effect of an outcrop located near the entrance of Brevig Harbour on wave propagation and its interaction with harbour. Hydrodynamic simulations were performed using computational fluid dynamics (CFD) based on shallow waters equations within a domain including the harbour and its surrounding area, extending to a water depth of approximately 14m.

For a given wave height and wave period, simulations were carried out with and without the outcrop, and two assumed incident wave directions, representing south-westerly wind waves and south-easterly swell. The incoming wave directions for wind-waves and swell are identified such that under wind-waves, the incoming waves approach directly toward the harbour entrance while the swell approaches the south wall of the harbour.

Under these assumed wave directions, the effect of outcrop removal on significant wave height distribution under wind-waves and swell is studied. The results showed that, under these representative incoming wave directions, the absence of the outcrop resulted in a reduction in the significant wave height within the harbour.

Next, as a sensitivity analysis, spectral wave modelling was carried out over a larger computational domain for water depths up to 62m to determine the incoming wave directions relative to the harbour in swell events. Simulations were performed for two measured swell events in January 2025. The results indicated that the actual incoming wave directions are slightly different compared with the assumed directions in CFD computational domain. Therefore, it is essential to review the wave directions inputs in CFD calculations according to the findings in wave spectral modelling for an appropriate representation of swell events in Brevig Harbour.

1 Introduction

The harbour at Brevig (Isle of Lewis) suffers from wave excitation and amplification because of broken waves propagating into the inner harbour. Comhairle nan Eilean Siar commissioned JBA to assess the potential benefit of the removal of rock outcrops at the mouth on wave energy within the harbour. This report summarises the modelling work undertaken that focuses on incoming swell and wind-waves and their propagation within the harbour.

Two different wave conditions were assessed and, for each, an incident wave direction was assumed based on observed impacts and exposure of the mouth. Numerical wave modelling within the shallow water framework was carried out to evaluate the influence the rock outcrop has on wave energy in the harbour for the two wave conditions. To determine this, analysis comparing the distribution of significant wave height (Hs) with and without the outcrop was undertaken.

Figure 1-1 Schematic map of Isle of Lewis showing the location of Brevig Harbour.

This report begins with a description of the bathymetry developed for the simulations conducted in this study. Section 2 presents the CFD model setup and results for the two wave conditions relative to the harbour. Section 3 presents some sensitivity analysis to better understand wave direction during northeasterly swell events. Finally, Section 4 provides concluding remarks and outlines the limitations of this study.

1.1 Bathymetry

The following data sources are used to describe the bathymetry within the harbour, in its vicinity and in deep water:

- LiDAR data, provided by Scottish Government (2012), with a spatial resolution of 1m, are used to represent the elevation of Brevig Harbour and the nearshore zones within the domain, down to a minimum elevation of -1.4mODN (Ordinance Datum Newlyn).
- Bathymetric contours provided by Comhairle, used to define the outcrop zone and the bed elevation within the harbour, based on data obtained on 03/03/2025.
- Bed elevations below -1.4mODN are derived from bathymetric data with a resolution of 24.75m × 24.75m, purchased from EMAPSITE (2025).

All bathymetric and topographic data are references to Ordinance Datum Newlyn.

2 REEF3D Modelling

2.1 Modelling approach

Computational Fluid Dynamics (CFD) modelling has been widely applied in coastal engineering to obtain a better understanding of wave propagation, particularly in nearshore and harbour environments where complex interactions with coastal structures and bathymetry significantly influence wave behaviour. In this study, wave interactions within the harbour and its energy distribution are studied by use of an open-source CFD solver, REEF3D, see Bihs et al. (2016).

REEF3D is based on the Reynolds-Averaged Navier–Stokes (RANS) equations, employing high-order numerical schemes in both space and time. In this study, the two-dimensional depth-averaged solver within a shallow water framework, REEF3D::SFLOW is applied. SFLOW solver uses a quadratic pressure approximation to account for non-hydrostatic pressure effects, improving the accuracy of wave propagation modelling over complex bathymetries. For more details, see Wang et al. (2020).

Simulations are performed for regular (2^{nd} Stokes) waves, for a duration of 1800s. During post-processing of the numerical output, the initial 300s, i.e. the transient response is discarded.

2.2 Model domain

The computational domain in REEF3D is located in the nearshore area close to the harbour and, as shown in Figure 2-1, extends to a maximum water depth of 13.14 m at its offshore boundary. The rectangular domain is rotated for 50° in counter clock-wise with respect to the eastings direction, such that the bottom-left side of the domain aligns approximately normal to the harbour entrance, while the bottom right-hand boundary extends approximately parallel to the harbour's southern outer wall, see Figure 2-1. The orientation of the computational domain enables an approximate representation of two incoming wave directions within the domain, namely south-westerly wind-waves and south-easterly swell.

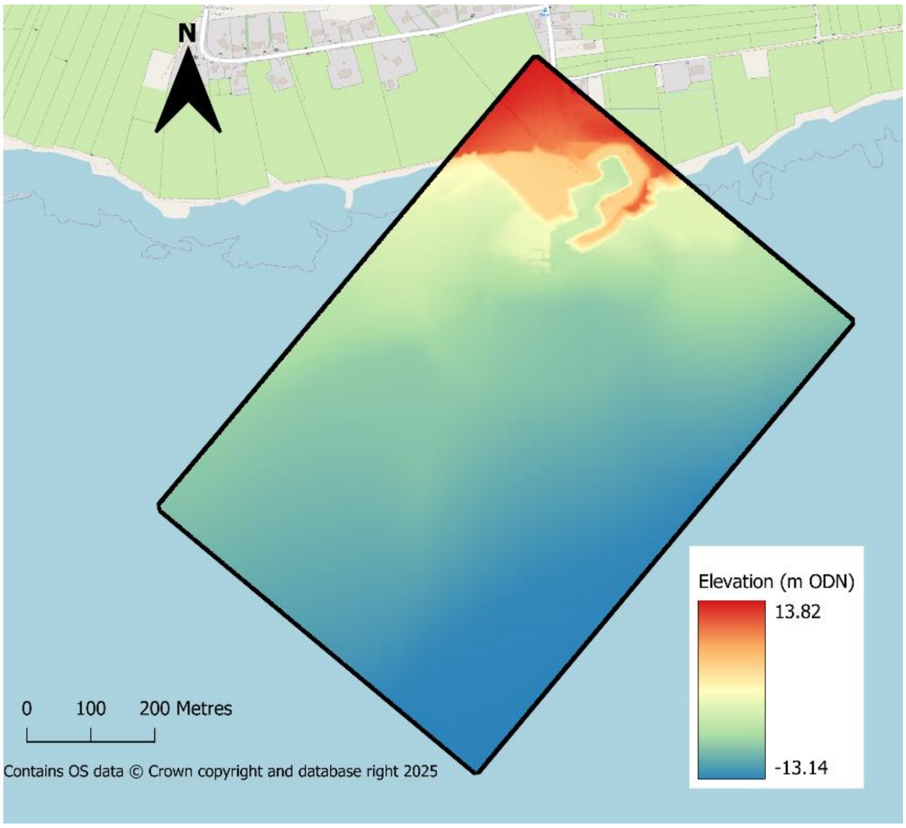
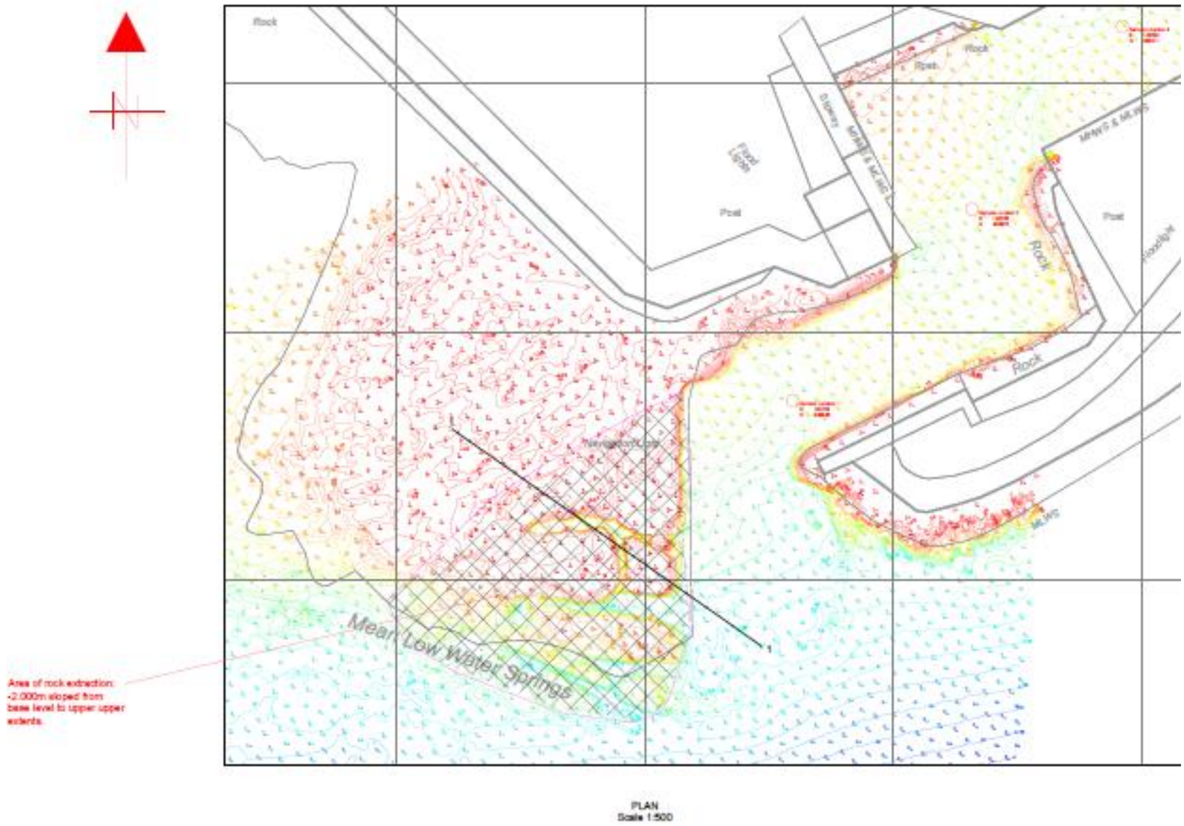


Figure 2-1 Developed computational domain and the corresponding bathymetry for REEF3D simulations.

To model the bathymetry of the outcrop zone, when the outcrop is removed, a proposed rock level profile provided by the Comhairle was applied, see Figure 2-2. The profile demonstrates an approximately linear decrease in bed level from 0.05mCD (Chart Datum) to -2mCD. In the REEF3D computational domain, a similar profile is implemented within the outcrop zoned such that the bed elevation decreases linearly from the left-hand side to the right-hand of the zone. Figure 2-3 shows the modified bathymetry near the harbour with the outcrop removed, following a bed level profile consistent with the profile provided.



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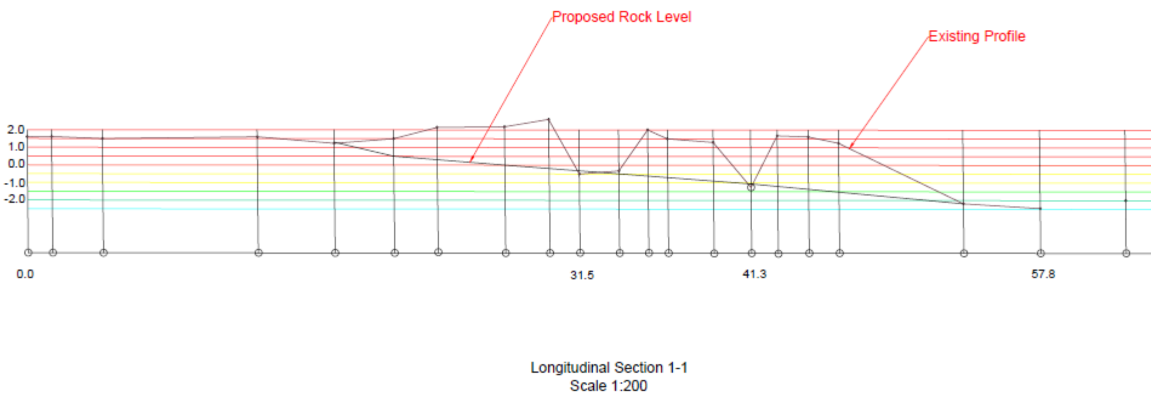
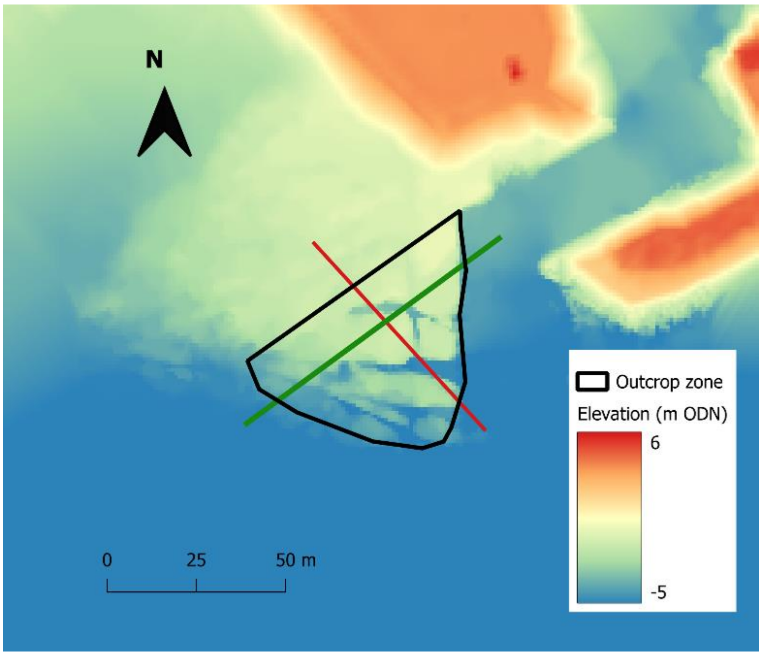


(b)

Figure 2-2 (a) Bathymetry contours, the black line represents the cross section where the outcrop level is compared with the proposed profile in the absence of the outcrop, and (b) comparison of the bed profile with and in the absence of the outcrop, courtesy of both drawings by the Comhairle.



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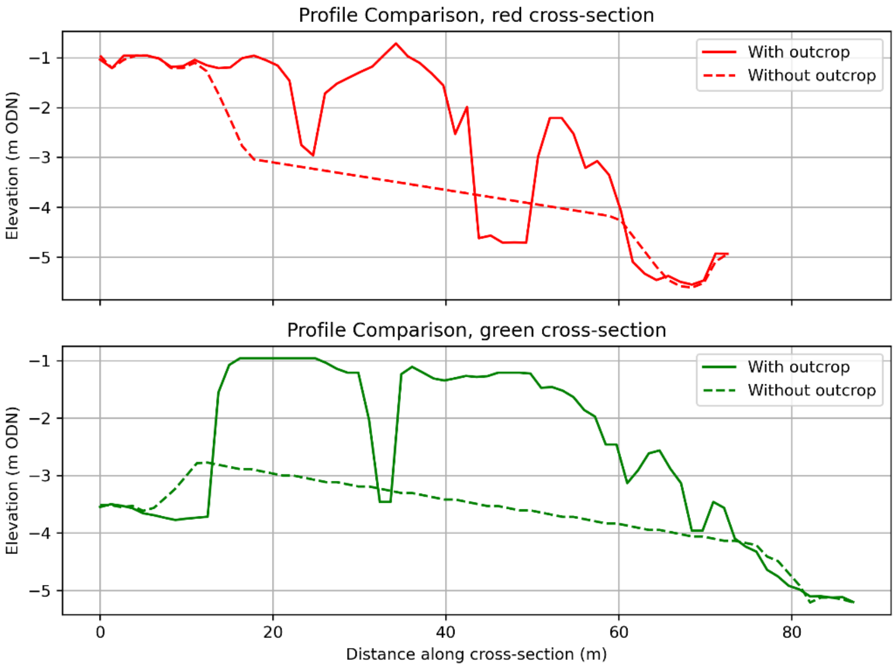


(b)

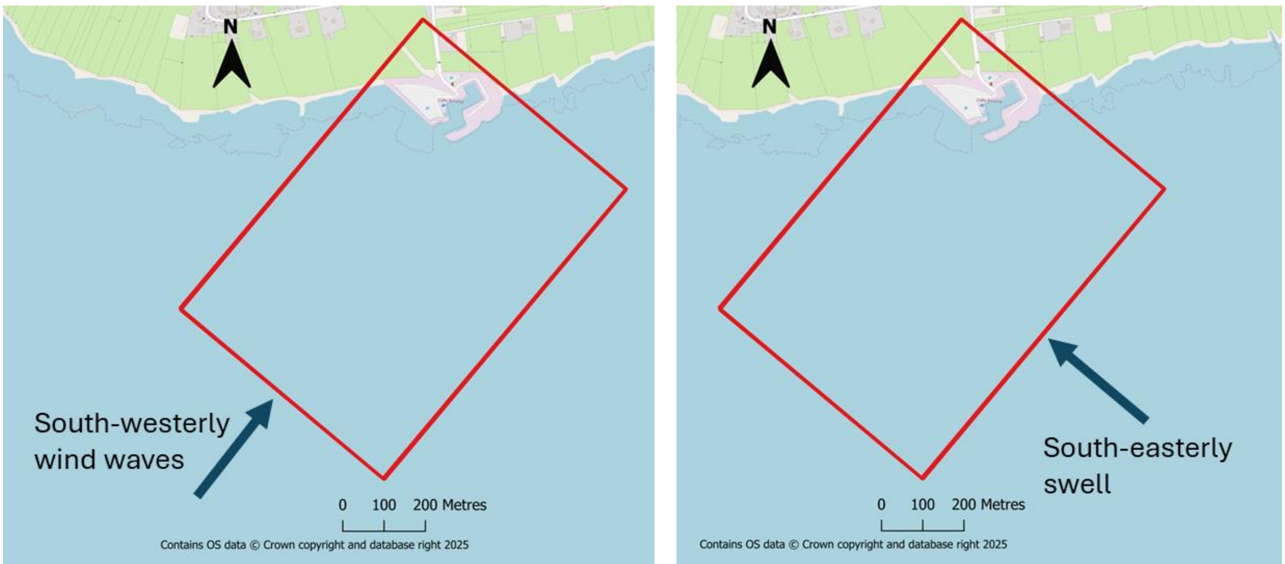
Figure 2-3 (a) Bathymetry within the harbour and at its vicinity, when outcrop is present, (b) comparison of the bed profile with and in the absence of the outcrop in the developed computational domain for the two cross-sections over the outcrop zone.

2.3 Model boundary conditions

REEF3D simulations are carried out using hindcast data obtained from Copernicus Marine Service (2024) at a nearshore gauge located at latitude 58.25° N and longitude 6.28° W, close to the harbour on 06/02/2025 at 10:00 AM. At this date and time, the recorded wave height and wave period were 1.2m and 5.4s, respectively. This date corresponds to an event during which wave height amplification was documented in the harbour by Comhairle. Nevertheless, no free surface elevations within the harbour are provided for calibration of the developed model in REEF3D. The water level was fixed at MHWS at Stornoway, 2.15mODN and each wave condition is simulated for two scenarios: with the outcrop present and with the outcrop removed.

Initially, four simulations were carried out in REEF3D for incident regular waves with two incoming wave directions, representing (i) south-easterly swell and (ii) south-westerly wind waves, see Figure 2-4. Shown in (a), it is assumed that the incoming wind-waves propagate directly towards the entrance of the harbour. Modelling this wave direction allows investigation of whether the removal of the outcrop results in an increase in significant wave height within the harbour. Moreover, with the assumed direction of the incoming swell, i.e. normal to south wall of the harbour, the effect of the harbour structure and the outcrop at the entrance on wave diffraction within the harbour can be investigated.

Next, to better represent the influence of the outcrop on wave propagation and resonance within the harbour, two more simulations were carried out where the water level is fixed at the highest point of the outcrop zone, -1mODN. Similar to the previous cases, wave period and the incoming wave height are 5.4s and 1.2m, respectively.



(a) (b)

Figure 2-4 Schematic of the numerical domain and the incoming wave direction representing (a) south-westerly wind-waves, and (b) south-easterly swell.

Table 2-1 summarises the REEF3D::SFLOW simulations and their environmental conditions. Results are presented in section 2.6.

Table 2-1 Simulations carried out in REEF3D::SFLOW, together with the corresponding outcrop bathymetry and incoming wave conditions.

Cases	Incoming waves	Direction (°,nautical convention)	T_p (s)	H (m)	Outcrop
Water level: MHWS					
1	South-westerly wind-waves	220°	5.4s	1.2m	Present
2	South-westerly wind-waves	220°			Removed
3	South-easterly swell	130°			Present
4	South-easterly swell	130°			Removed
Water level: Highest point of the outcrop zone					
5	South-easterly swell	130°	5.4s	1.2m	Present
6	South-easterly swell	130°			Removed

2.4 Model mesh

A uniform mesh with 1m resolution in both the longitudinal and transverse directions of the computational domain is generated. Based on the incoming wave conditions on 06/02/2025, the wavelength at the offshore side of the domain is approximately 33.21m, resulting in a resolution of approximately 33 elements per wavelength in that region which is in line with the recommendations of Jin (2020) and Pakozdi et al. (2021) for wave modelling simulations using REEF3D.

It should be noted that no mesh sensitivity analysis was performed for this setup. However, the current mesh resolution is considered sufficient to assess the relative effect of outcrop on the wave field within the harbour. Using a finer mesh within the harbour could improve the accuracy of the simulated surface elevation in the harbour should the quantification of wave parameters be of need in future phases.

2.5 Analysis

The wave propagation and its energy within the harbour is investigated by determining and comparing the following parameters at several gauges shown in Figure 2-5,

- Total significant wave height and the component due to long waves are determined at gauges within the harbour and compared for the two wave directions, with and without the outcrop.

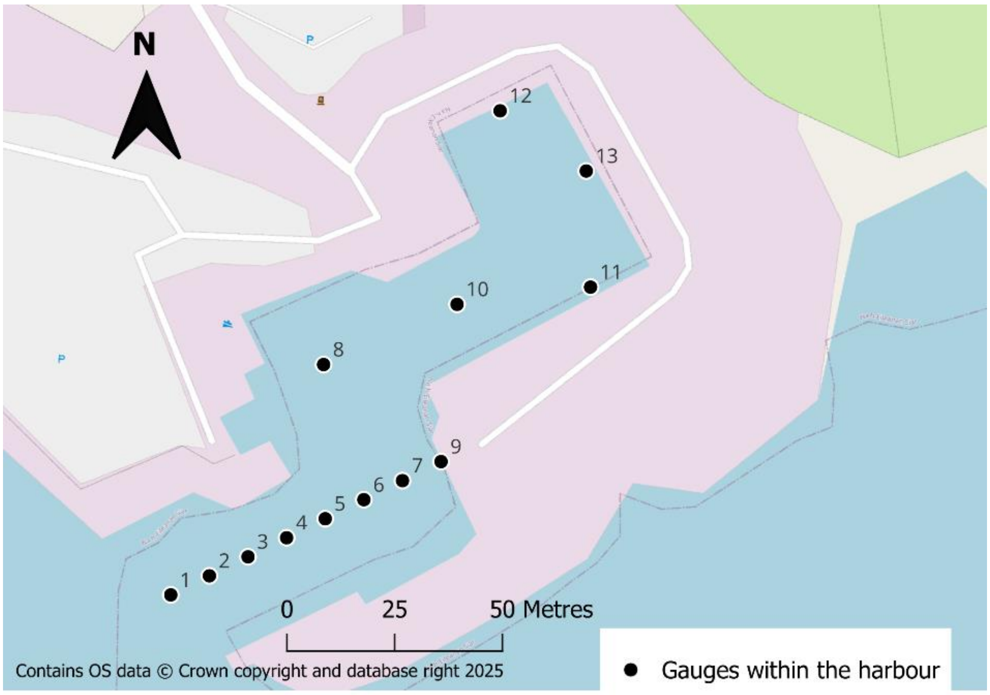


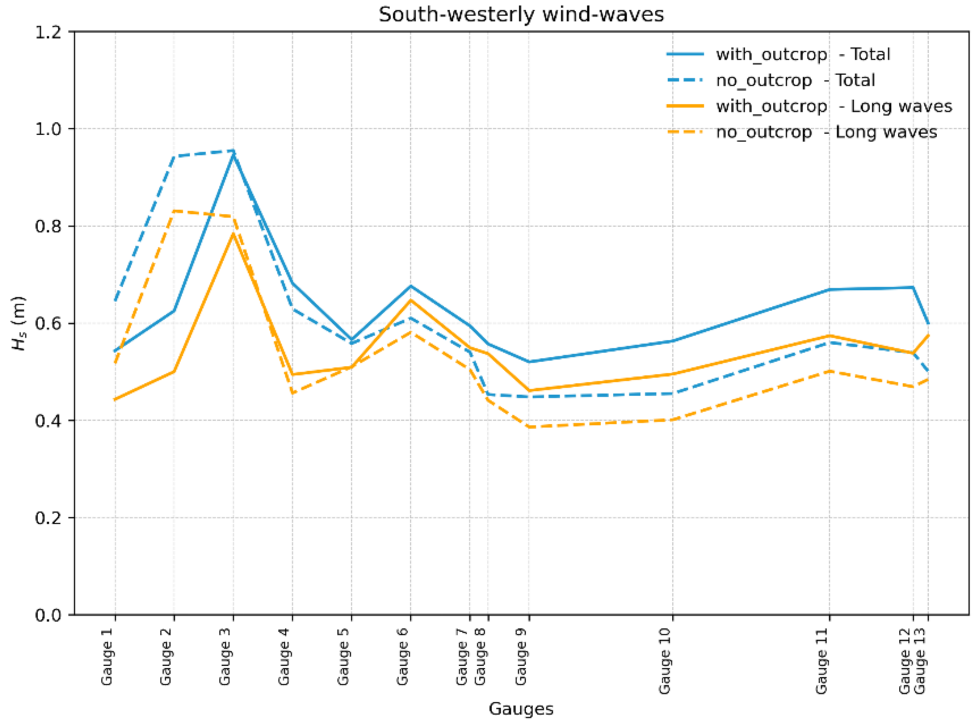
Figure 2-5 Schematic of the computational domain, representing the location of the gauges within the harbour.

- A map of the total significant wave height distribution within the harbour is generated. This distribution, calculated over the computational domain in REEF3D, corresponds to the final time step of the simulation at t = 1800s. Additionally, for each incoming wave direction, the difference in significant wave height distributions, with and without the outcrop is computed. This comparison enables us to assess the effect of the outcrop on the spatial distribution of significant wave height under two wave conditions and the two water levels.
- Power spectral density (PSD) is studied at two gauges within the harbour. The PSD demonstrates the frequency range in which the wave energy is concentrated, hence identifying the dominant wave components contributing to the wave energy at the harbour. This analysis helps identify wave frequencies that might result into resonances within the harbour and potentially resonant motions in floating bodies, such as moored boats within the harbour.

2.6 Results

2.6.1 Water level at MHWS

The total significant wave height, together with those components due to the long waves at gauges within the harbour (see Figure 2-5) for south-westerly wind-waves and south-easterly swell are presented in Figure 2-6(a) and (b), respectively. Additionally, distribution of the total significant wave height, H_s for both incoming wave directions within the harbour are shown in Figure 2-7 (a), (b) and (c) and Figure 2-8(a), (b) and (c), respectively.



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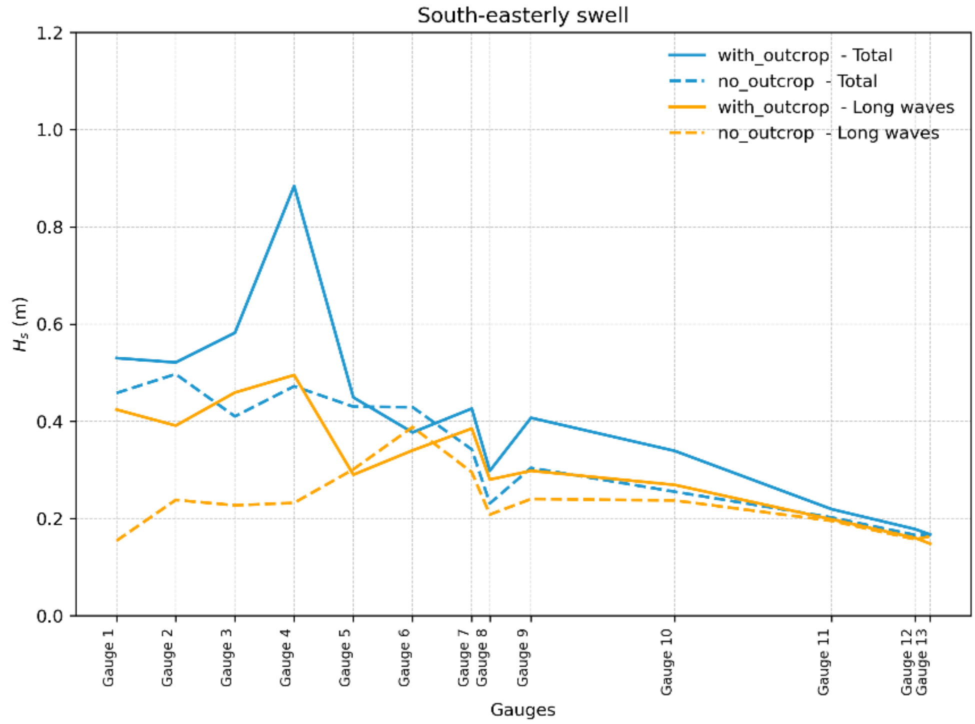


(b)

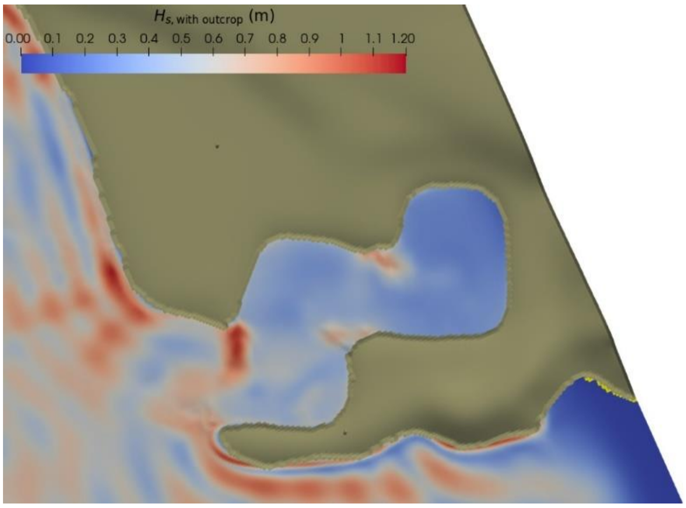
Figure 2-6 Comparison of total significant wave height and long wave component contributions at gauges within the harbour, due to (a) south-westerly wind-waves and (b) south-easterly swell and water level at MHWS, with and without the outcrop.

As shown in Figure 2-6(a), the effect of the outcrop is more pronounced at Gauges 7 to 13, where the significant wave height, H_s decreases in the absence of the outcrop. In contrast, for south-easterly swell, the presence of the outcrop has a greater influence on H_s at gauges located in the outer part of the harbour (Gauges 1 to 6).

Distribution of H_s within the harbour, presented in Figure 2-7 (a) and (b) for south-westerly incident wind waves, shows that the outcrop is approximately aligned with the incoming wave direction, and results in the reflection of wave energy back into the harbour. Consequently, a local increase in H_s is observed at the harbour entrance. In contrast, in the absence of the outcrop, higher H_s are seen near the north wall of the harbour entrance, leading to a lower H_s distribution within the harbour compared to the scenario with the outcrop, as shown in Figure 2-7 (a). This effect is further illustrated in Figure 2-7(c), which presents the difference in computed H_s between the scenarios with and without the outcrop.

Regarding H_s distribution due to south-easterly swell, as shown in Figure 2-8, diffracted waves from the south wall of the harbour and the outcrop result in higher H_s values, particularly along the outer side of the south wall and locally at the harbour entrance next to the outcrop. However, as shown in Figure 2-8(b), when the outcrop is removed, the H_s distribution in the vicinity of the south wall and the harbour entrance decreases.

This is further demonstrated in Figure 2-8. (c), which presents the relative difference in significant wave height between the scenarios with and without the outcrop.



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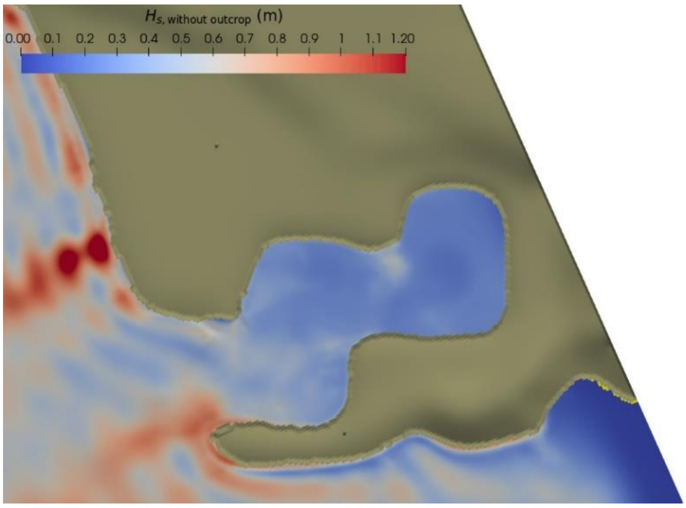

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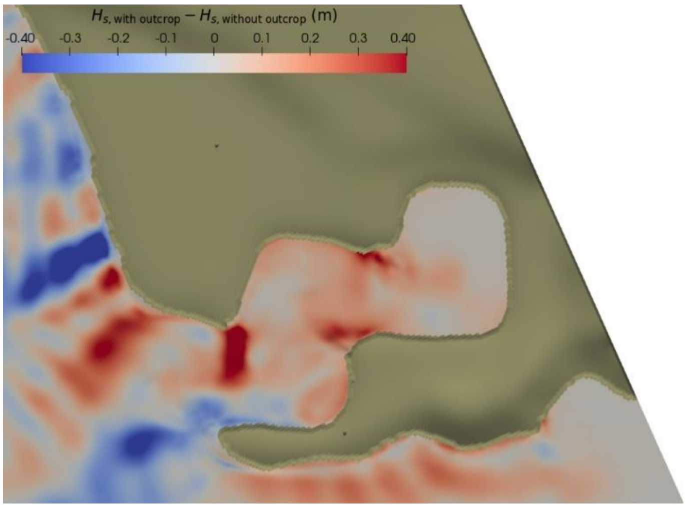
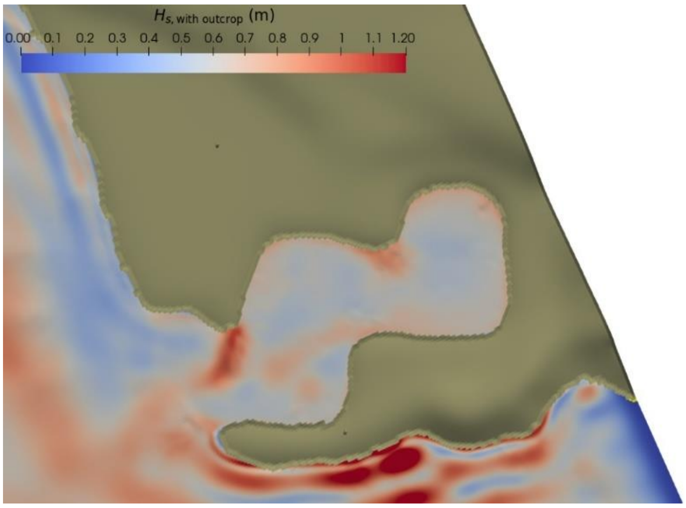


(c)

Figure 2-7 Maps of the significant wave height distribution within the harbour under south-westerly wind-waves and a water level at the MHWS (a) with the outcrop present, (b) with the outcrop removed, and (c) the difference between (a) and (b).



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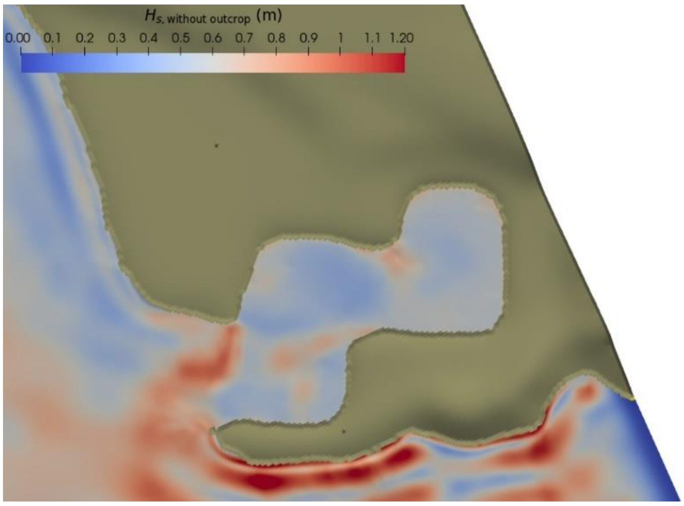

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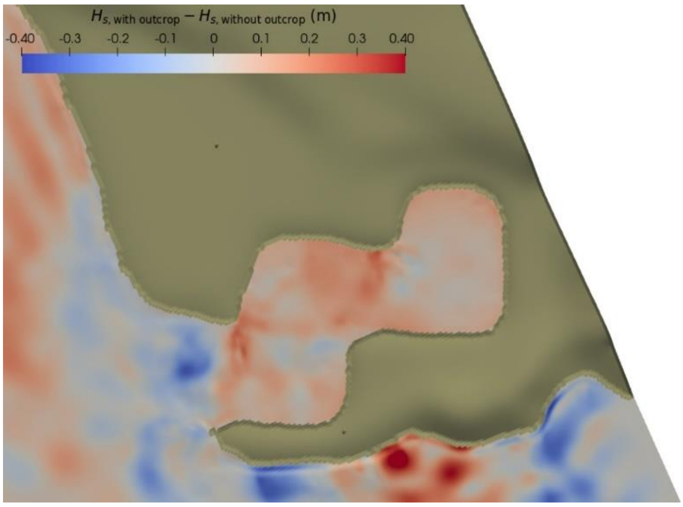
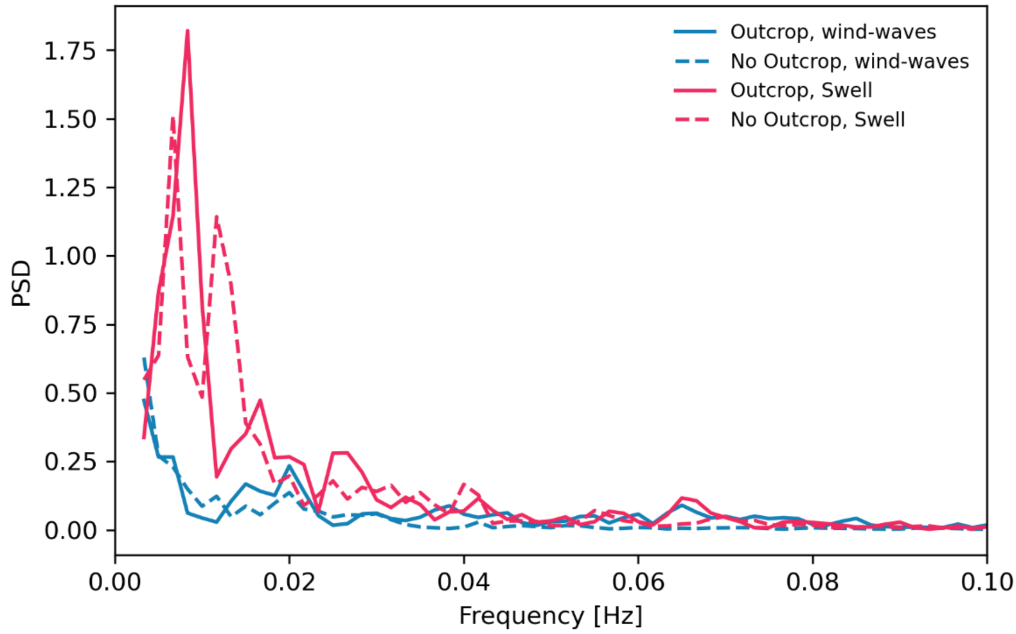


(c)

Figure 2-8 Maps of the significant wave height distribution within the harbour under south-easterly swell and the MHWS (a) with the outcrop present, (b) with the outcrop removed, and (c) the difference between (a) and (b).

Finally, the spectral energy distribution across wave frequencies for south-westerly wind waves and south-easterly swell, under two scenarios, with and without the outcrop, at Gauges 5 and 13 are shown in Figure 2-9(a) and (b), respectively. In both cases, the spectral energy associated with wind waves is significantly lower than that of swell. This confirms observations that incoming swell results in detrimental oscillations within the harbour.

The dominant energy concentration is seen for wave frequencies smaller than approximately 0.015Hz, which corresponds to long waves and may be as a result of harbour resonance modes. Furthermore, a larger peak is observed at Gauge 13, located further inside the harbour compared with Gauge 5 (see Figure 2-5 for gauge locations). The results also show that the removal of the outcrop leads to a reduction in spectral energy at both gauges, indicating that when the outcrop is removed the resonance within the harbour may be slightly reduced.



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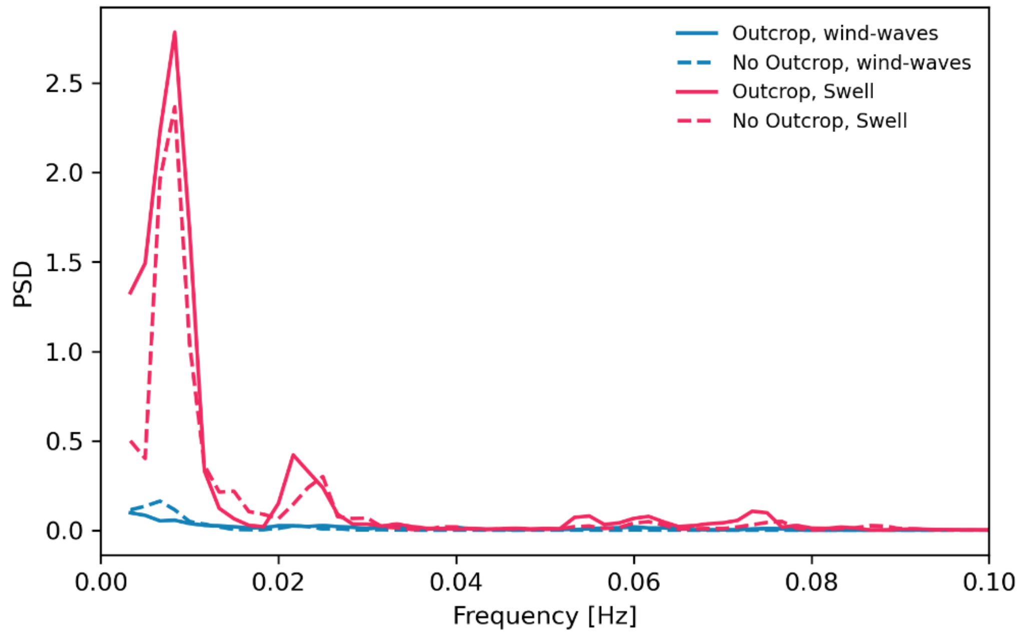


(b)

Figure 2-9 Comparison of the computed PSD due to wind waves and swell, with and without the outcrop, at (a) Gauge 5 and (b) Gauge 13.

2.6.2 Water level at the highest point of the outcrop

The simulations presented here are based on a lower water level compared to those in Section 2.6.1, demonstrating the effect of the outcrop in wave height amplifications in the harbour.

Figure 2-10 presents the computed total significant wave height and its long-wave component due to the south-easterly swell, and the water level at the highest point of the outcrop, at gauges inside the harbour. In general, it is shown that both the total H_s and its long-wave component are reduced in the absence of the outcrop at most gauges, except at Gauge 10. Furthermore, Gauge 9 experiences the lowest significant wave height among all gauges within the harbour.

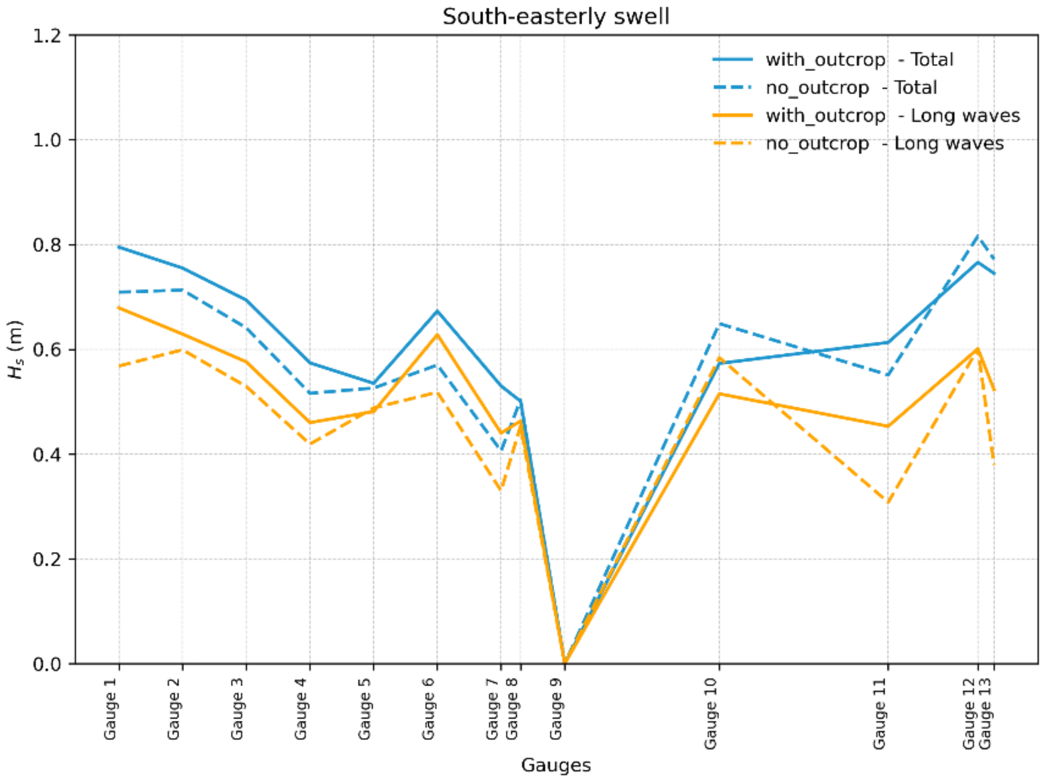
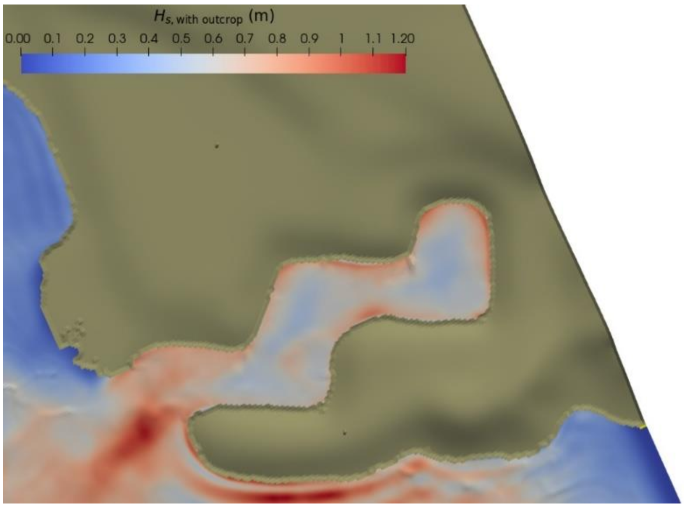


Figure 2-10 Comparison of the total significant wave height and long wave component contributions at gauges within the harbour, due to south-easterly swell and water level at highest point of the outcrop, with and without the presence of the outcrop.

The distribution of significant wave height H_s within the harbour for cases with and without the outcrop, together with their relative difference, is shown in Figure 2-11(a), (b), and (c), respectively. As discussed in Section 2.6.1, the presence of the outcrop leads to an increased H_s distribution along the outer side of the harbour's south wall and near the harbour entrance adjacent to the outcrop.

At this lower water level, which corresponds to the highest point of the outcrop, the computed H_s at the harbour entrance is greater than that observed under MHWS conditions in Figure 2-8 (a). The reduction in local significant wave height within the harbour when the outcrop is removed is shown in both Figure 2-11(b) and (c) for this water level.

Finally, comparing the difference in significant wave height distribution between simulations with and without the outcrop, for the two water levels MHWS and the highest point of the outcrop (shown in Figure 2-8(c) and Figure 2-11(c), respectively), it can be seen with the lower water level (i.e., at the highest point of the outcrop), the presence of the outcrop results in a larger increase in significant wave height at the entrance of the harbour compared to the MHWS condition.



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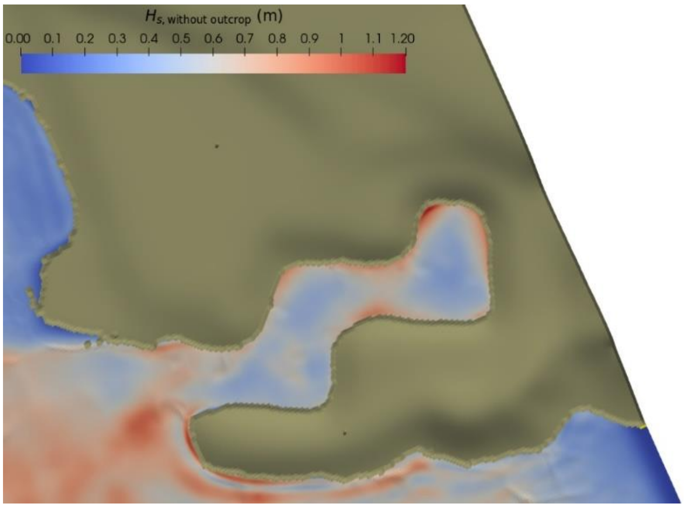

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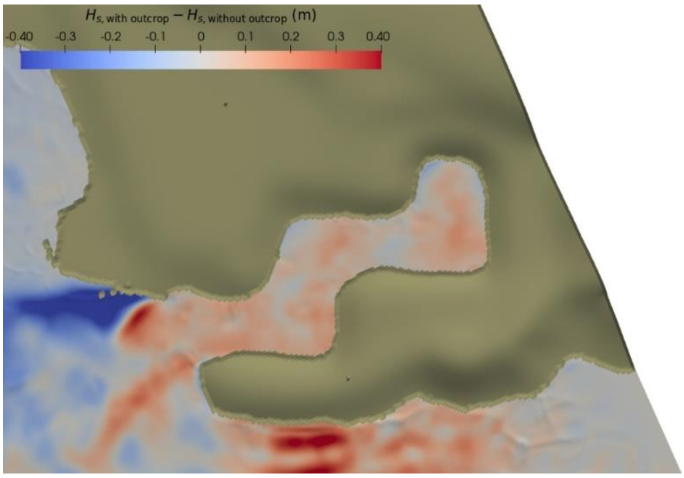

(c)

Figure 2-11 Maps of the significant wave height distribution within the harbour under south-easterly swell conditions and a water level at the highest point of the outcrop zone (a) with the outcrop present, (b) with the outcrop removed, and (c) the difference between (a) and (b).

3 SWAN modelling

SWAN (Simulating WAves Nearshore) is a spectral wave model developed to compute the generation, propagation, and transformation of wave energy from deep waters to coastal regions (SWAN, 2024). Discussed in previous section, REEF3D simulations were performed using two approximate, assumed wave angles nearshore representing the incoming wind-waves and swell to the Brevig Harbour. However, with spectral modelling in SWAN given the offshore data for swell events, it is possible to investigate the accuracy of those assumptions made in REEF3D.

To model the incoming wave propagation from deep water, a larger computational domain compared with REEF3D, was developed, see Figure 3-1. The developed domain in SWAN extends to minimum bed level of approximately -62mODN.

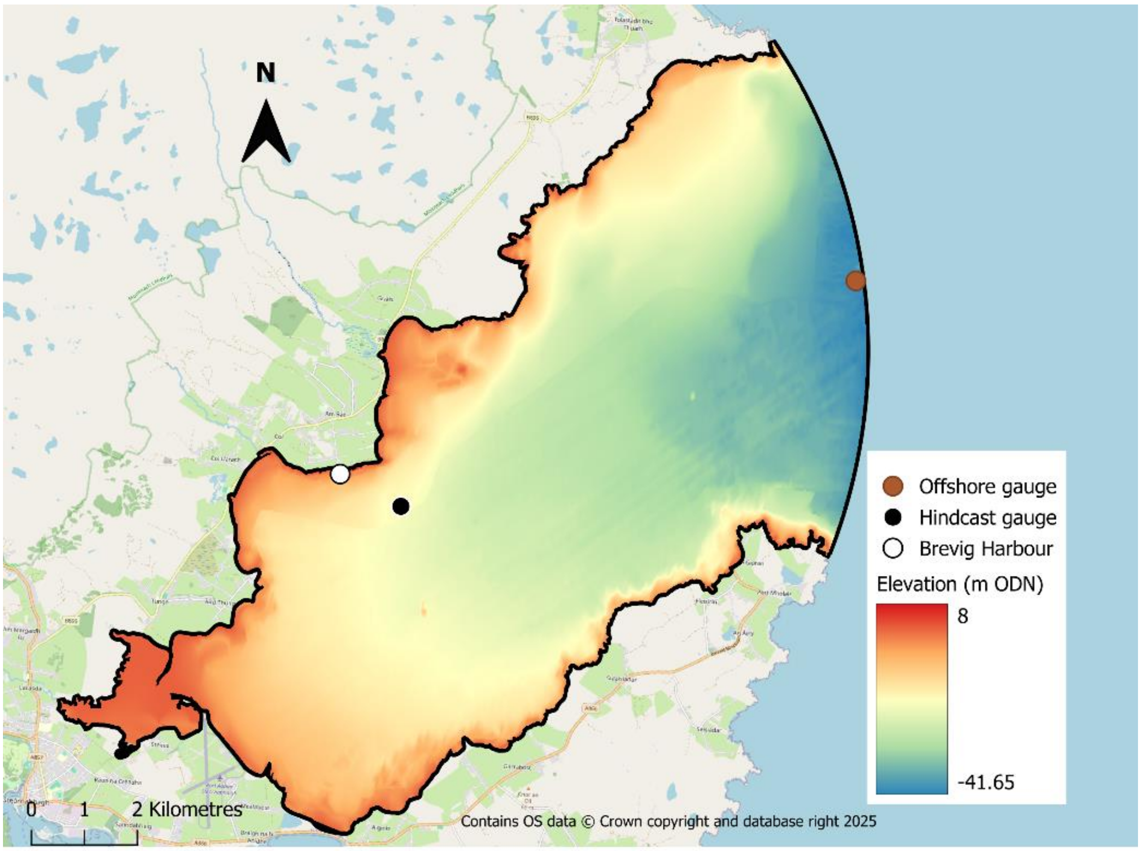

Figure 3-1 Map of the developed computational domain and its corresponding bed elevation for SWAN modelling.

SWAN simulations were carried out for two swell events on 07/01/2025 at 21:00 and 10/01/2025 at 00:00. The resulting wave fields in the vicinity of the REEF3D computational domain were analysed. By comparing the computed wave directions from SWAN with the wave directions applied in the REEF3D model, we assessed whether the incoming waves in the REEF3D represent the swell conditions accurately.

Table 3-1 presents the incoming wave and wind conditions applied at the offshore boundary of the domain in the SWAN simulations. The wave and wind conditions were obtained from Copernicus Marine Service (2024) and Weather Underground (2025), respectively. Furthermore, the water level is assumed to be constant, computed as the average of the MHWS level at 2.15mODN and the highest point of the outcrop at –1mODN, resulting in a water level of 0.575mODN

Table 3-1 Incoming wave and wind conditions at the offshore boundary of the model domain in SWAN simulations.

Event	07/01/2025 21:00	10/01/2025 00:00
Offshore wave height (m)	3.18	1.89
Offshore peak wave period (s)	12.1	10.1
Offshore wave direction (Nautical convention)	28.0°	32.5°
Wind speed (m/s)	6.7	6.7
Wind direction (Nautical convention)	22.5°	22.5°
Water level (m ODN)	0.575	0.575

3.1 Model mesh

The computational domain for SWAN simulations is discretised into a finite number of Delaunay triangular elements. This mesh type is an optimal choice for complex geometries such as coastlines and allows for local refinement in zones of interest within the domain. In this case, the mesh resolution starts at 50m at the shorelines at left-hand side of the domain and increases linearly to 200m offshore, where the element size remains constant, see Figure 3-2.

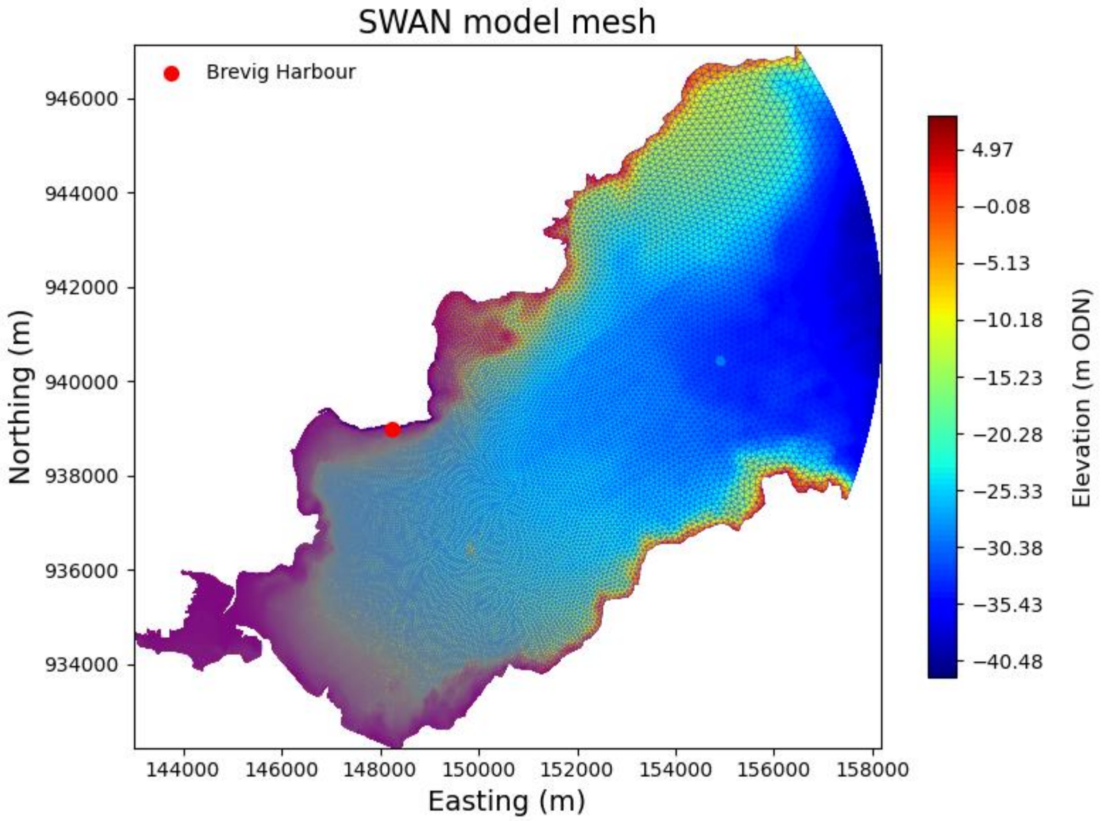

Figure 3-2 Generated model mesh for SWAN simulations.

3.2 Results and discussion

Figure 3-3(a) and (b) show the computed wave field in the region surrounding Brevig Harbour, including the computational domain used for REEF3D simulations. The computed wave directions are with respect to the nautical coordinate system (where waves are measured clockwise from North).

As shown for both events in Figure 3-3, the incident wave direction at the bottom right-hand boundary of the REEF3D domain is approximately between 65° and 90°. To investigate this further, a point near this boundary was selected, represented as a red marker in Figure 3-3. The power spectral density (PSD) computed at this location, is plotted as a function of wave frequency (Hz) and direction (in nautical convention) in Figure 3-4, for the two swell events. The results show that the highest spectral energy occurs for wave directions between 60° and 90°.

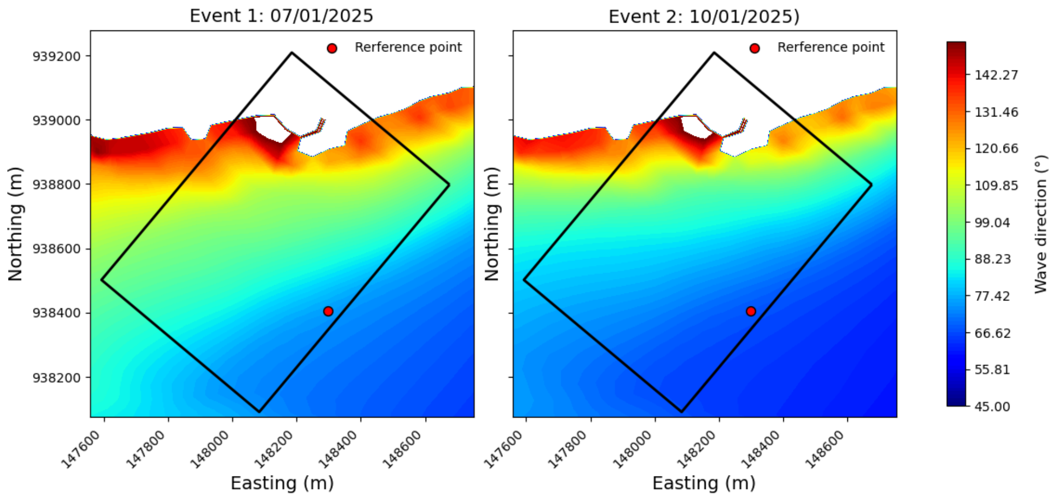

Figure 3-3 Wave direction distribution computed by SWAN near Brevig Harbour, focusing on the area overlapping with the REEF3D computational domain: (a) Event 1, 07/01/2025, (b) Event 2, 10/01/2025.

As discussed earlier, the REEF3D computational domain is oriented at an angle of 50° relative to the easting direction. Hence, the incoming swell direction assumed in REEF3D computational domain is 130° in nautical convection. Shown in Figure 3-4, little to no energy is observed at this wave direction, i.e. 130° in nautical convention. As shown in Figure 3-3 and Figure 3-4, the computed wave direction by SWAN near the bottom right-hand side of the REEF3D domain approaches this boundary at an angle between 15° and 40°, indicating an inconsistency between the assumed angle for incoming swell in REEF3D and the computed swell direction by SWAN.

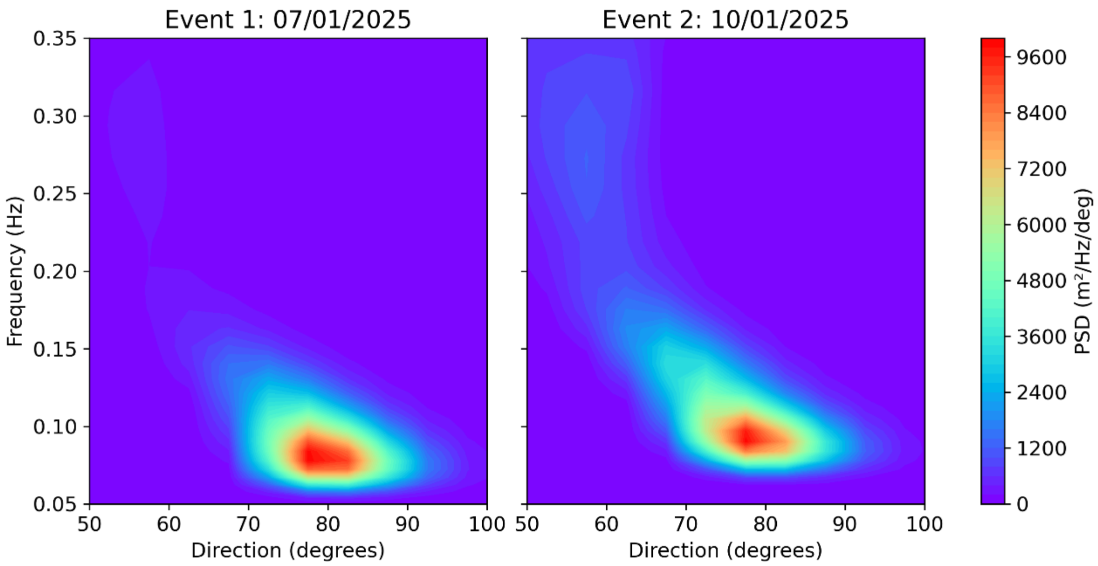

Figure 3-4 Contour plot of PSD computed by SWAN at the reference point within the REEF3D domain, see Figure 3-3**Error! Reference source not found.**, as a function of wave frequency (Hz) and direction (°) in nautical convention for (a) Event 1, 07/01/2025, (b) Event

2, 10/01/2025.

Consequently, to better represent swell conditions in REEF3D simulations, the computational domain should be rotated such that incident waves approach the offshore boundary of the REEF3D model domain (i.e., the bottom right-hand side) perpendicularly. This shall be investigated further in the following stages of the project.

4 Concluding remarks

4.1 Conclusion

Computational fluid dynamics (CFD) modelling using shallow water framework was carried out to investigate the effect of the outcrop on the wave field and wave height amplification within Brevig Harbour. This study focused on two primary wave conditions affecting the harbour, (i) swell and (ii) wind-waves. Swell was assumed to propagate from the south of the harbour to study whether the removal of the outcrop would influence the distribution of significant wave heights inside the harbour. For wind wave condition, waves were considered approaching approximately towards the harbour entrance, to ensure that the removal of the outcrop would not result into increased significant wave height distribution within the harbour under incoming wind-waves. Numerical modelling of the wave propagation and its interaction with Brevig Harbour was simulated using the REEF3D::SFLOW model assuming that the water level is fixed at MHWS at Stornoway. Comparison of significant wave height distributions for cases with and without the outcrop showed that the removal of the outcrop results into a reduction in significant wave height within the harbour.

Under wind-wave conditions, large significant wave heights are observed at near the northern wall of the harbour and its entrance. With outcrop removed, the significant wave height reduces significantly upstream of the outcrop zone and at the entrance of the harbour. Regarding the incoming swell, a higher significant wave height distribution is observed next to the south wall of the harbour, which is reduced in the absence of the outcrop. Comparing the changes in significant wave height distribution between the two wave conditions, a larger reduction is observed under swell conditions when the outcrop is removed.

This outcome was confirmed by additional simulations at a lower water level than MHWS, corresponding to the highest point of the outcrop zone, and incoming swell condition, which also showed a similar decrease in significant wave height when outcrop is removed.

4.2 Limitations

This study presents a qualitative analysis of wave field changes within Brevig Harbour. It is important to note that the modelling conducted in REEF3D and SWAN has not been calibrated or validated, as no gauge measurements are available within the domain. Absolute values are therefore not recommended for use in decision making.

Nevertheless, conclusions can be drawn from the comparative analysis of the numerical results for cases with and without the outcrop. Finally, no sensitivity analysis on the numerical setup and the mesh resolution generated for SWAN and REEF3D modelling have been carried out.

4.3 Recommendations and further work

In the video recorded by Comhairle nan Eilean Siar on 10/01/2025, wave propagation and breaking within Brevig Harbour are observed. Before entering the harbour, the waves break as they pass over the outcrop. As they approach the harbour entrance, the waves experience a second wave breaking event due to their interaction with decreasing bed level and harbour structure. Following this, the waves diffract into the inner harbour and lose energy as they interact with and reflect off the harbour walls along their course. A similar wave interaction with the harbour is observed in the REEF3D simulations, particularly with water level at highest point of the outcrop. However, to accurately capture the complex wave dynamics in the harbour, mesh sensitivity tests should be performed to determine an appropriate resolution such that the complex wave dynamics within the harbour are presented appropriately. This will ensure the numerical model represents the event appropriately. With this mesh refinement, the model can be used to investigate other wave conditions and their propagation pattern within the harbour.

Furthermore, regarding the current computational domain used in REEF3D, future modelling could consider a smaller domain focused on the harbour and its immediate surroundings. This would allow for a finer mesh resolution in the area of interest, but a more efficient and potentially less computationally demanding simulations in REEF3D.

Finally, a preliminary sensitivity analysis was carried out by use of SWAN on wave direction distribution in shallow waters near Brevig Harbour, particularly within the zone covered by the REEF3D simulations. The results indicated that the assumed wave direction representing swell events in the REEF3D model should be reviewed.

To gain a better understanding of wave direction distribution at the vicinity and within the harbour, a parametric study on the effect of incoming wave direction is recommended. REEF3D simulations can be performed for a range of wave directions to identify the conditions that lead to increased wave breaking within the harbour.

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APPENDIX D

JBA BREVIG HARBOUR MODELLING (PHASE 2)

Brevig harbour Modelling (Phase 2)

Draft

October 2025

Prepared for:

Comhairle Nan Eilean Siar

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Contract

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This report describes work commissioned by Comhairle Nan Eilean Siar by an instruction dated 03/10/2025. The Client's representative for the contract was Angus Gillies. Ramtin Sabeti, and Florian Bellafont of JBA Consulting carried out this work.

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Executive Summary

This study focuses on reproducing the wave event of 10 January 2025 at Brevig Harbour, subsequently employing this model to evaluate mitigation strategies for outcrop removal near the harbour entrance and sand dredging within the harbour. The REEF 3D model developed in Phase 1 serves as the foundation for this analysis, alongside results from SWAN modelling that define the input wave conditions (wave height, period and direction).

A series of sensitivity analyses was conducted, varying mesh resolution and the extent of the computational domain. The resulting setup was used to simulate five mitigation scenarios provided by the client: rock removal in two distinct alignment configurations, sand dredging, and a combined rock-excavation and sand-dredging scheme. In lieu of fully coupled sediment-transport modelling, wave results were post-processed using established bedload sediment transport equations such Meyer-Peter & Müller to create first order estimates of bedload transport rate.

Sediment transport analysis does not show clear differences or improvements between the different mitigation scenarios tested. All of them, including baseline, show a net sediment transport oriented outside the harbour, which is in contradiction with the reported issue of sediment accumulation within the harbour. This means that the event selected – low-energy incoming swells with low water levels (no tidal effects) – may not be the type of event leading to harbour silting.

Sand dredging-only provides a clear reduction of the wave height in the harbour compared to the baseline. The additional benefit of rock removal, whether with or without sand dredging, is limited under the considered wave conditions and water level, and should be weighed against the costs, environmental impacts, and irreversibility of the solution (extracted rock cannot be put back in place).

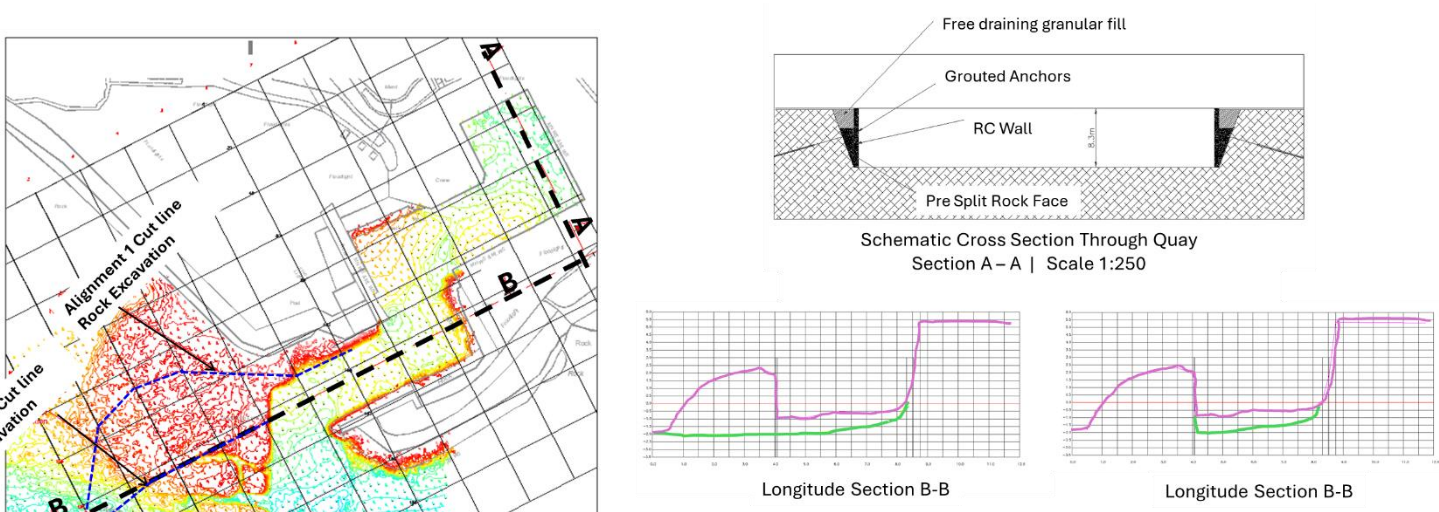
Only a narrow set of wave conditions and water level, which only focuses on wave effect not the tide, has been considered. A hydrodynamic model, such as TELEMAC-2D or Delft3D, that represents tidal effects should be considered for studying sediment transport patterns in more details.

1 Introduction

This phase 2 study focuses on the event that occurred on 10 January 2025, for which the client has shared a video. An incoming wave appears to be reflected by the rock outcrop toward the harbour entrance, breaks, and evolves into a bore. The water level is close to the outcrop level; the weather seems windy from the video's sound with no rain; offshore waves look small; harbour oscillations look acceptable for harbour operations.

At the start of the project, it was assumed that the rock outcrop had a detrimental effect, as it favours wave reflection, guiding waves towards the inner harbour, leading to increased harbour oscillations and sediment accumulation. Phase 2 aims to study whether altering the rock outcrop geometry can reduce harbour oscillations and/or sediment accumulation in the harbour.

Building on the REEF 3D and SWAN models from the previous phase of this project (JBA, 2025), this study provides insights into the impact of various mitigation scenarios across two primary alignments proposed by the client (Figure 1-1) on wave propagation around and within the harbour, and sediment transport patterns. A mitigation scenario refers to a combination of sand dredging within the harbour and/or excavation of a portion of the outcrop rock (alignment).



Alignment 1	
Excavation	Cubic metre
Rock	9826
Sand	2722

Alignment 2	
Excavation	Cubic metre
Rock	3190
Sand	2722

Figure 1-1: Overview of mitigation scenarios, including excavation details for the two proposed alignments.

The subsequent sections present the sensitivity analyses which were conducted on the model extent and mesh resolution, as well as the model boundary conditions, leading to the final setup of the baseline model. Following this, the proposed alignments are introduced, and the results of the simulations for these scenarios are discussed, culminating in a conclusion.

2 REEF3D Modelling

2.1 Modelling approach

The SFLOW solver of REEF3D, in keeping with the previous phase, is employed for the simulations in this phase. The duration of the simulation has been reduced to 800 seconds, with simulations conducted for regular (2^{nd} Stokes) waves over this duration. In post-processing, the first 50 seconds of the numerical output are discarded to eliminate transient response effects.

2.2 Sensitivity tests on model domain and cell size

A total of seven sensitivity tests were carried out to identify the optimal model extent and mesh resolution. These tests included three variations in model extents, expanding the maximum horizontal extent (x_{max}) from 278m to 620m and the maximum vertical extent (y_{max}) from 300m to 400m, details of these three tests are provided below:

1) x_{max} = 278m, y_{max} = 300m
2) x_{max} = 302m, y_{max} = 331m
3) x_{max} = 620m, y_{max} = 400m

In terms of cell size, four tests were conducted using grid resolutions of 0.25, 0.35, 0.50 and 0.75m.

The final baseline model selected for the next stage of the study features a mesh resolution of 0.35m, with x_{max} set at 620m and y_{max} at 400m (Figure 2-1). This configuration was chosen for its reasonable simulation time of approximately 8 hours, compared to 20 hours with the 0.25m mesh size. The model extent was rotated by 22° anticlockwise so the mesh cells align with the harbour entrance orientation; the incoming waves, perpendicular to the input boundary, have a direction of 158 degrees (Nautical convention).

Additionally, the selected model extent satisfies the recommended distance of 1 to 2 wavelengths (λ) for wave generation before reaching the 151 probes located inside and in close proximity to the harbour. The designated probes are configured to record time series data for water surface elevation, in addition to measuring the depth-averaged velocity components.

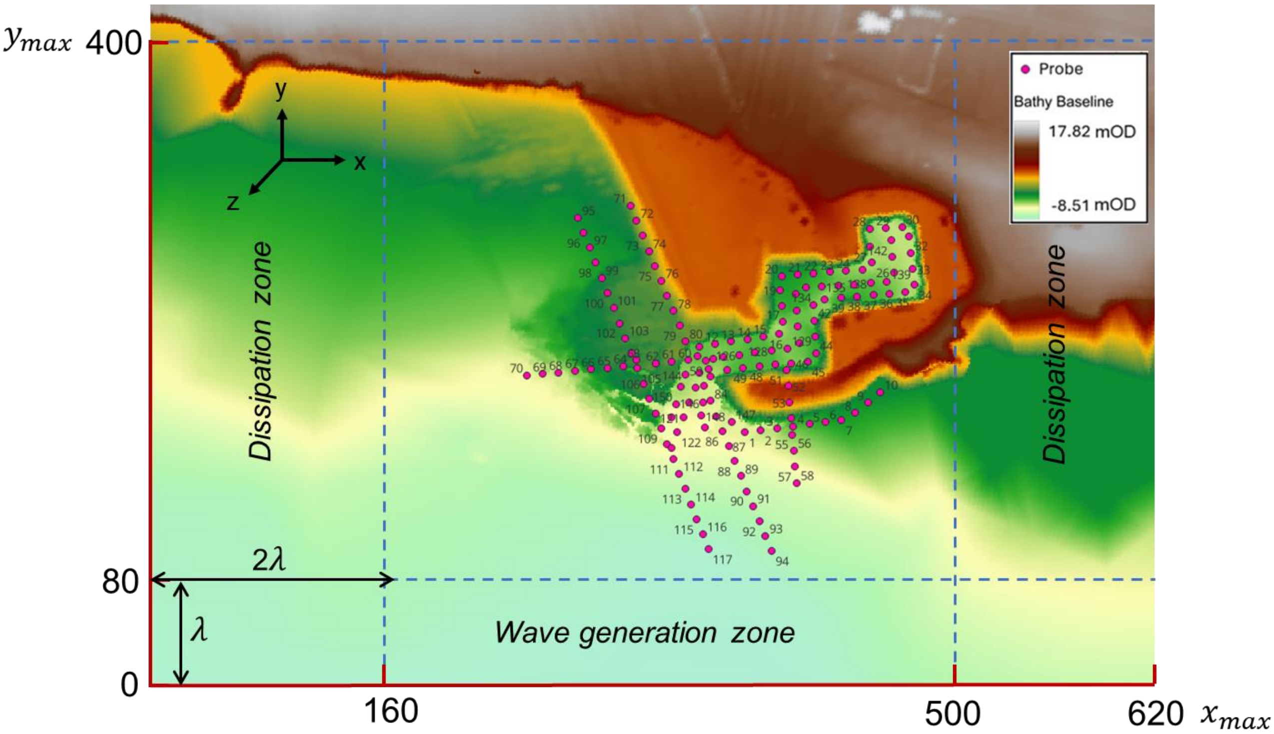


Figure 2-14 Baseline model configuration showing the model extent and probe locations. The total number of probes is 151.

2.3 Model boundary conditions

The developed REEF 3D model from the previous phase has been updated to reflect the new model extent, with water levels at the outcrop set as follows:

- Maximum Outcrop level = -1mODN
- Minimum elevation of Bathymetry = -8.51mODN
- Water Level = -1mODN

In terms of wave input conditions, wave heights and periods are derived from the developed SWAN model, which simulated the event of 10 January 2025, while wavelengths are determined based on the dispersion relation, which is solved using the Newton–Raphson iteration method. It is important to note that the wave height is calculated using the average of significant wave results from the SWAN model in the wave generation zone (Figure 2-2).

- Wave height (H): 0.30m
- Wave period (T): 10s
- Wavelength (λ): 80m
- Wave direction: 100 degrees (Nautical convention)

Considering the wave characteristics and a water depth of 7.22m, calculated from the average bed level in the wave generation zone, the type of wave is determined to be Stokes 2nd order based on the wave theories categories.

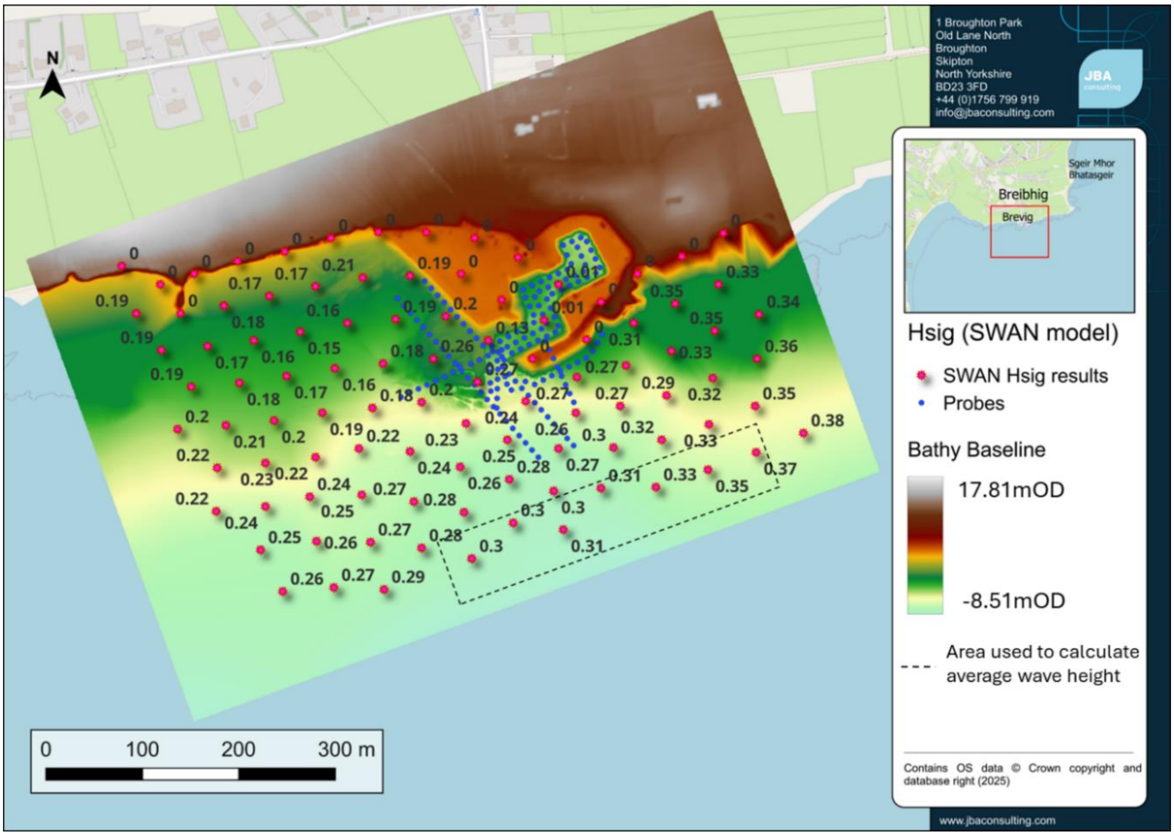


Figure 2-2 Significant wave height results from the SWAN model, showing significant wave heights within the model domain. The dashed-lined area outlined is used to calculate the average wave height.

2.4 Proposed mitigations (Alignments 1 and 2)

To assess the impact of rock removal and sand dredging on wave generation and bedload sediment transport rates, using the two alignments proposed by the client, a total of five scenarios were developed. The scenarios SC-1 and SC-3 are based on Alignment 1 (Table 2-1), which encompasses a higher volume of rock excavations (9,826m^3). SC-1 evaluates the impact of rock removal, SC-2 assesses the effects of sand dredging alone, while SC-3 combines both SC-1 and SC-2. The second set is focused on Alignment 2, which involves a lower volume of rock excavations (3,190m^3). SC-4 examines the impact of rock removal only, whereas SC-5 incorporates both sand dredging and rock removal.

Table 2-1 Summary of mitigation scenarios based on Alignments 1 and 2.

Run	Status	Run time (h)	Rock outcrop	Dredging
SC-0	Done	8.60	Baseline	No
SC-1	Done	11.6	Alignment-1	No
SC-2	Done	8.10	Baseline	Yes
SC-3	Done	9.30	Alignment -1	Yes
SC-4	Done	7.90	Alignment -2	No
SC-5	Done	8.60	Alignment -2	Yes

To implement the proposed Alignments 1 and 2 in the model, the bathymetry created in Phase 1 was modified. Based on the cross-sections provided by the client, which include five cross-sections for rock removal for each alignment and seven for sand removal, the elevations for the excavations and dredgings were extracted. These elevations, along with the transformed x and y coordinates to the British National Grid, were used to create a point layer in QGIS specific to each scenario. Using the Triangulation tool in QGIS, a raster was then generated from these points for each scenario and prioritised alongside the baseline bathymetry raster. A series of slight modifications were made to create a smooth transition between the two rasters using RASMapper of HEC-RAS v6.6.

All simulations for the five scenarios and the baseline model recorded results from the 151 defined probes. To focus on crucial locations for the wave height parameter, a selection of probes ranging from probe 126 to probe 140 was chosen for comparison of wave heights between the baseline model and the five scenarios. This subset encompasses both the interior of the harbour and its entrance (Figure 2-3).

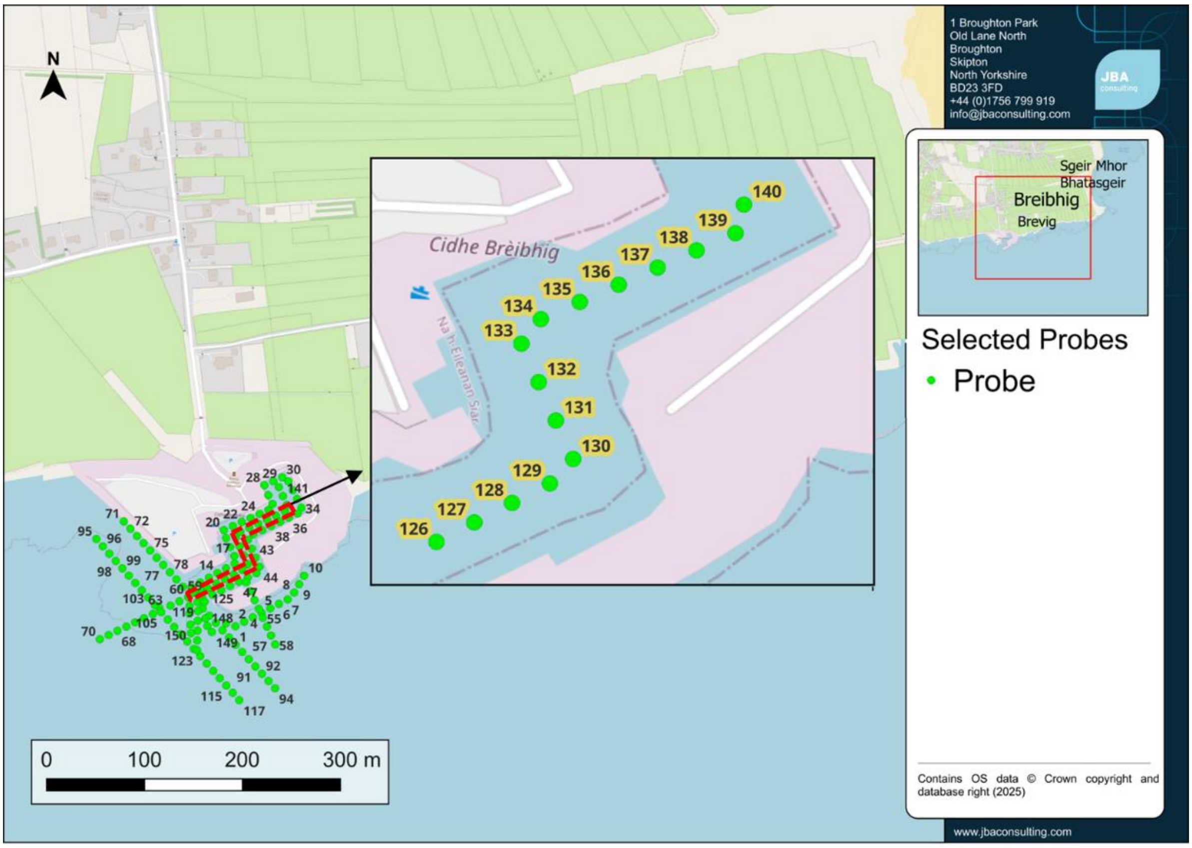


Figure 2-3 Locations of selected probes (126 to 140) for result analysis within the harbour and at its entrance.

2.5 Bedload transport rate

To quantify sediment transport dynamic, the bedload transport rate is calculated to reflect the amount of sediment being moved along the seabed in all five scenarios and baseline models. In this analysis, two key equations are employed to assess the bed shear stress and associated bedload transport rate. The bed shear stress is obtained using Manning's law, as follows:

$$\tau_b = \rho_w g n^2 U^2 h^{-1/3}$$

where, ρ_w = 1025kg/m^3 is the ocean water density; U is the depth-average velocity component from probes; n = 0.026 is the Manning coefficient, h= $SWL - z_{bed} + \eta$ is the water depth; SWL is the Still Water Level; z_{bed} is the bed elevation from bathymetry; η is the free surface elevation; and g = 9.81m/s^2 is the gravitation acceleration.

For bedload transport rate, the equation developed by Meyer-Peter & Müller (1948) is applied as follows:

$$Q_b = \phi_b \sqrt{g\,(\rho_s/\rho_w - 1)d^3}$$

where ϕ_b is the dimensionless bedload transport rate from Meyer-Peter & Müller equation; ρ_s = 2650kg/m^3 is the sediment density, and d is the grain size.

Using these equations, the net transport rate and its direction are determined, which are presented for a series of probes within the harbour and just outside, near the entrance, in the next section (Results). Details of the calculations, including all steps, are provided in the Appendix.

3 Results

The results of the simulations assessing the impact of proposed Alignments 1 and 2 across five scenarios are presented in Figure 3-1Figure 3-1. The length of the vectors indicates the magnitude of sediment transport, while the arrows depict the direction. The significant wave height (Hm0) is presented for the selected probes (Figure 2-3Figure 2-3). Table 3-1 lists the maximum net sediment transport rates for scenarios SC-0 to SC-5 within the assessment areas shown on the map (Figure 3-1). In the following sub-sections, scenarios that focus solely on rock removal are grouped together for better comparison, while those examining the effects of sand dredging are categorised in a separate set. The scenarios that involve a combination of rock removal and sand dredging are also included in their own category. All these sets are compared to the baseline model.

3.1 Net sediment transport rate

Sediment transport analysis (Figure 3-1Figure 3-1, top) does not show clear differences or improvements between the different mitigation scenarios tested. All of them, including baseline (SC-0), show a net sediment transport oriented towards the harbour exit, which is in contradiction with the reported issue of sediment accumulation within the harbour. This means that the event selected – low-energy incoming swells with low water levels (no tidal effects) – may not be the type of event leading to harbour silting.

The highest calculated net sediment transport rate is 1.2 m^3/h per m; the average one at the harbour entrance is 0.1 m^3/h per m. To put these numbers into perspective, the duration needed to move all the harbour sand outside, under the considered wave conditions and water level, would be about 130 days, calculated as follows:

- Average net transport rate: 0.1 m^3/h per m
- Angle between the harbour entrance orientation and net sediment transport vector: 53° (cos 53° ~ 0.6)
- Net transport rate in the direction of the harbour entrance: 0.06 m^3/h per m
- Harbour entrance width (excluding side effects): 15m
- Volume of sand: 2,722m^3
- Duration: ~130 days

This extrapolation is purely theoretical and intended for illustration, as it considers constant forcing and does not account for tidal effects or more energetic wave conditions.

Sediment transport is limited within the harbour and harbour self-dredging capacity is not demonstrated.

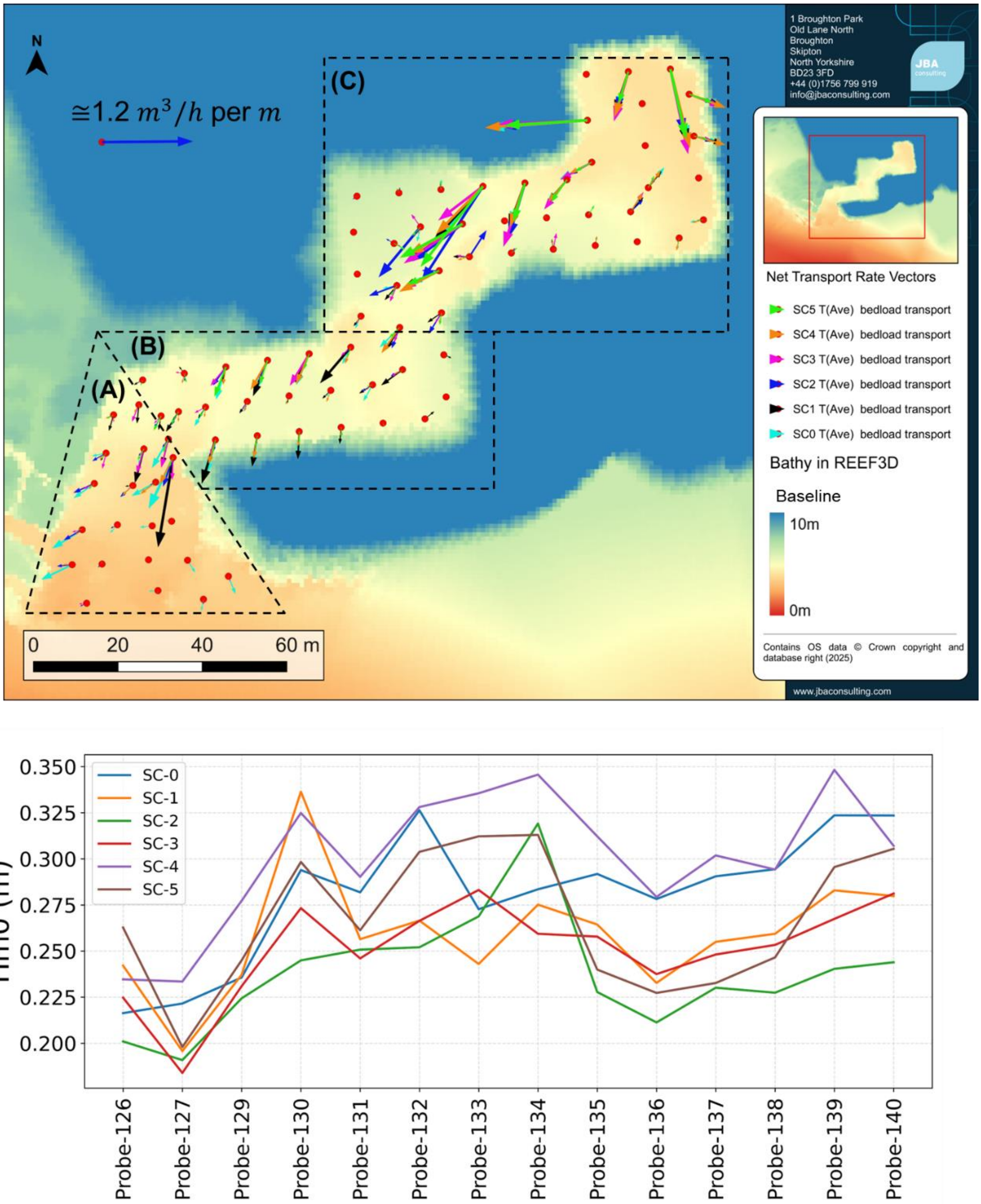


Figure 3-1 Overview of all scenarios: net transport vectors for each scenario presented above and Hm0 impact values displayed below. Selected areas for assessing maximum net sediment transport rates for scenarios SC-0 to SC-5: Area (A), just outside the harbour entrance; Area (B), inner harbour; Area (C), terminus end of the harbour.

Table 3-1 The selected areas for assessment of maximum net sediment transport rates for scenarios SC-0 to SC-5 within Areas (A), (B), (C), and for the combined area of A–C (Figure 3-1).

Scenario	Maximum net sediment transport rate (m^3/h per m)			
	Area (A)	Area (B)	Area (C)	Areas (A, B and C)
SC-0	0.62	0.38	1.07	1.07
SC-1	0.99	0.51	1.12	1.12
SC-2	0.33	0.24	1.23	1.23
SC-3	0.32	0.40	0.98	0.98
SC-4	0.32	0.37	1.12	1.12
SC-5	0.15	0.34	1.11	1.11

3.2 Impact of rock removal scenarios

In this section, Scenarios 1 and 4 (SC-1 and SC-4), designed to assess the impact of rock removal alone, are presented and compared against each other, as well as the baseline model (SC-0) as shown in Figure 3-2~~Figure 3-2~~. The vectors for SC-1 are larger than those for SC-4 (Figure 3-2~~Figure 3-2~~a, b and c), indicating that the greater volume of excavation in SC-1 results in a more pronounced positive impact on both Hm0 reduction and sediment transport.

The results indicate that SC-1, which involves a larger amount of excavation (approximately 10,000m^3), has a greater effect on the reduction of Hm0 compared to SC-4 (with an excavation of approximately 3,000m^3) and the baseline model (Figure 3-2~~Figure 3-2~~d). Moreover, Alignment 2 alone (SC-4) does not show any benefit in terms of both harbour oscillations and sediment transport compared to baseline.

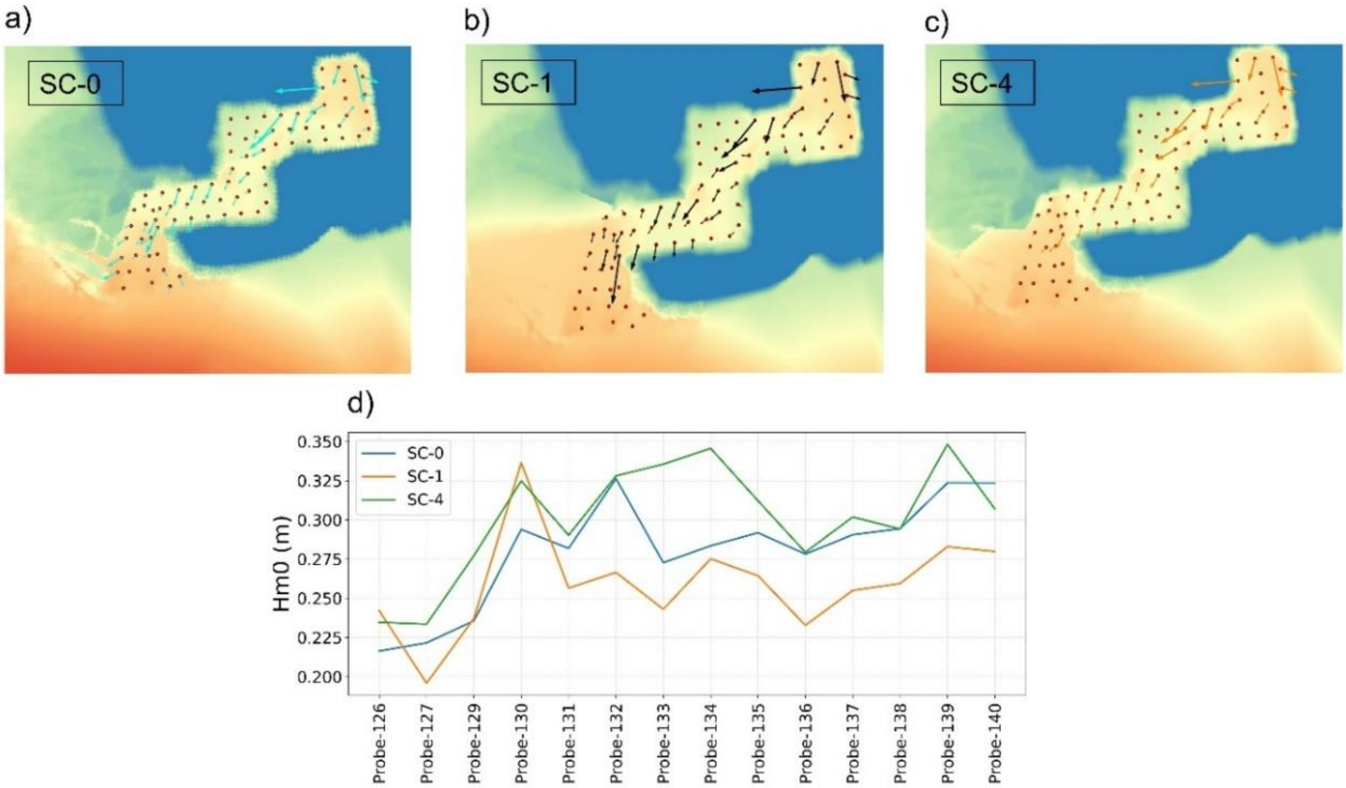


Figure 3-22 a), b), and c) impact of rock removal scenarios on bedload transport and d) Hm0

3.3 Impact of sand dredging scenarios

SC-2 is the only scenario that assesses the impact of sand dredging alone. The results indicate the effectiveness of the dredging in reducing Hm0 but there is only a marginal impact on the bedload transport rate compared to the baseline model (Figure 3-3).

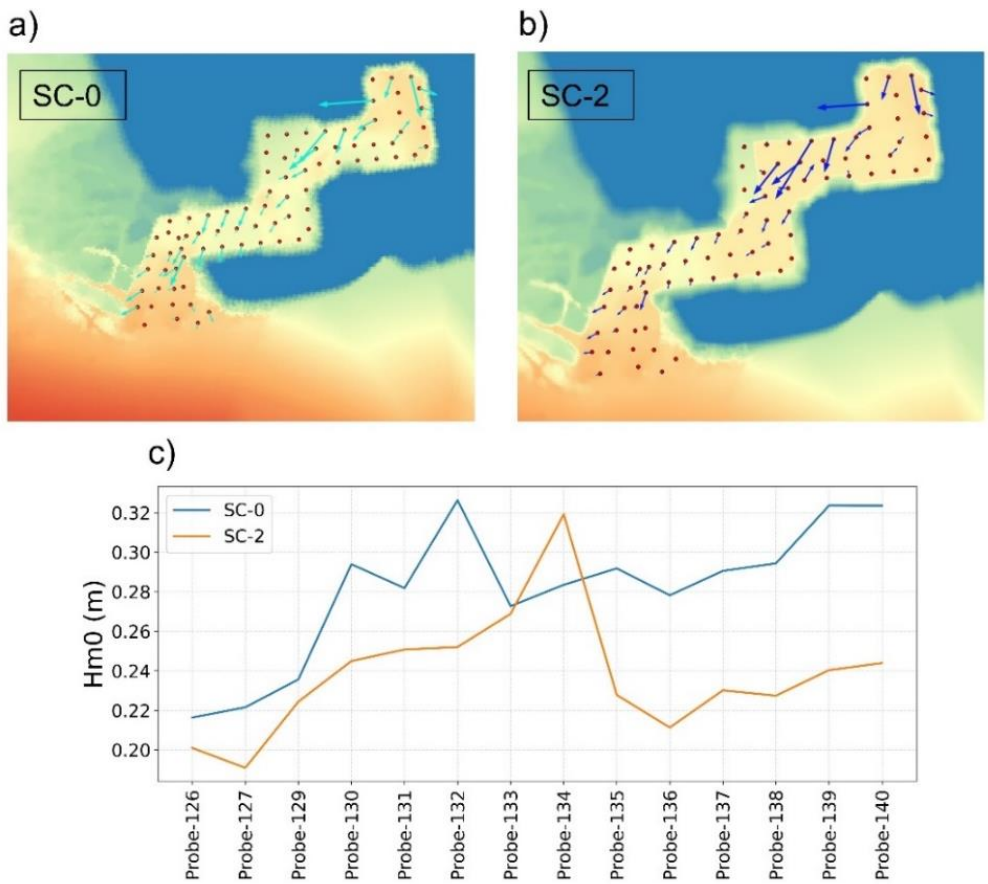


Figure 3-33 a), b) impact of sand dredging scenario on bedload transport and c) Hm0

3.4 Impact of Combined Rock Removal and Sand Dredging

The results of the simulations for Scenarios 3 and 5 (SC-3 and SC-5), designed to assess the combined impact of rock removal and sand dredging, are presented in Figure 3-Figure 3-4. While the differences in bedload transport rates between SC-3 and SC-5 are similar, SC-3 demonstrates better performance in reducing Hm0 at most locations.

Rock removal with sand dredging do not clearly reduce more harbour oscillations compared to sand dredging only (Figure 3-Figure 3-4, bottom), questioning the additional benefit of rock removal under the considered wave conditions and water level.

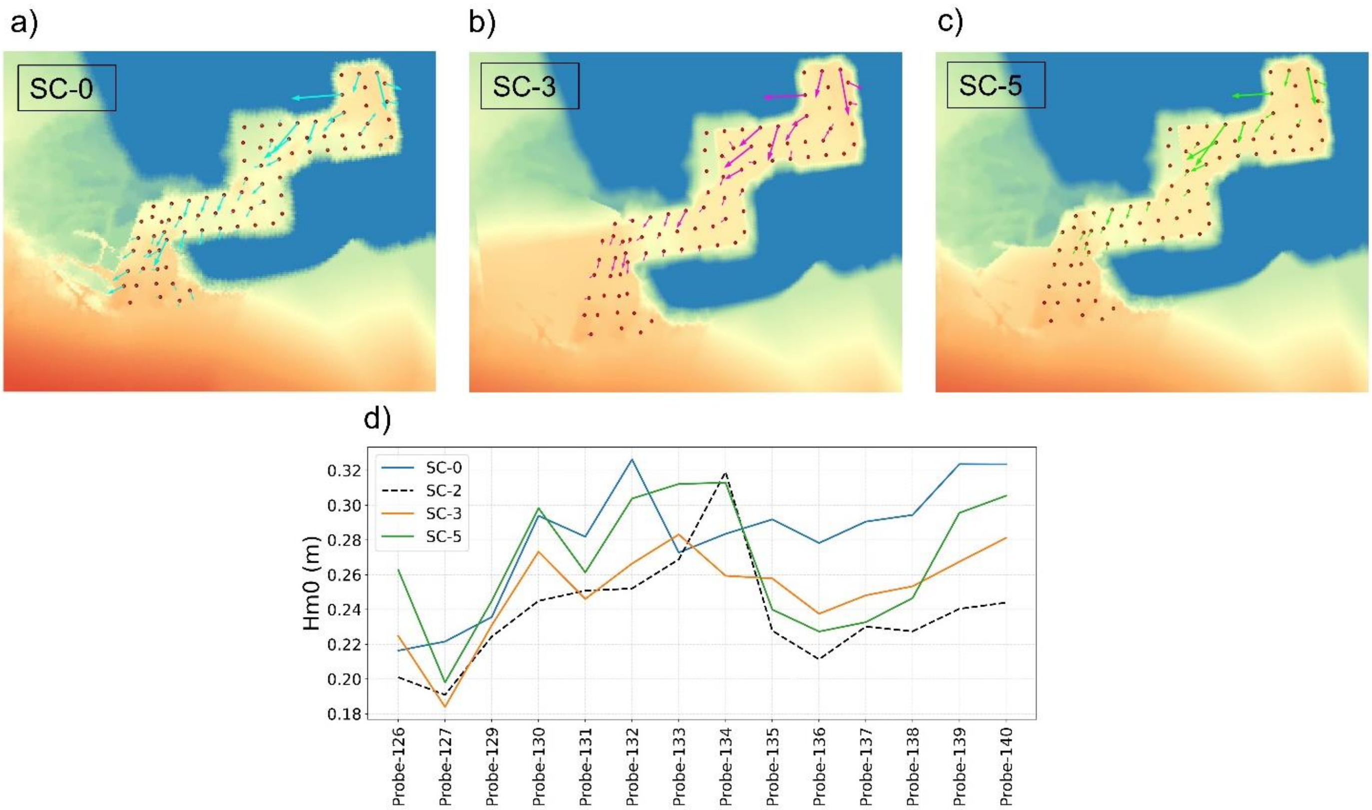


Figure 3-44 Impact of combined rock removal and sand dredging scenarios on bedload transport (a, b, c) and Hm0 for both the rock removal and sand dredging combination and the sole sand dredging scenario (d).

4 Conclusion

Phase 2 study focuses on the event that occurred on 10 January 2025. On a video of the event, an incoming wave appears to be reflected by the rock outcrop toward the harbour entrance, breaks, and evolves into a bore. At the start of the project, it was thought that the rock outcrop had a detrimental effect, as the reflected wave would lead to increased harbour oscillations and sediment accumulation under such wave forcing.

Different mitigation strategies (rock outcrop removal, harbour sand dredging or a combination of the two) were tested to reduce harbour oscillations, and limit sediment accumulation and ideally promote self-dredging. Two rock alignments (rock extraction volumes of about 3,000 and 10,000m^3) and one sand dredging option (~3,000m^3) were tested, leading to 5 runs in addition to the baseline.

Sediment transport analysis does not show clear differences or improvements between the different mitigation scenarios tested. All of them, including baseline, show a net sediment transport oriented outside the harbour, which is in contradiction with the reported issue of sediment accumulation within the harbour. This means that the event selected – low-energy incoming swells with low water levels (no tidal effects) – may not be the type of event leading to harbour silting.

Sand dredging-only provides a clear reduction of the wave height in the harbour compared to the baseline. The additional benefit of rock removal, whether with or without sand dredging, is limited under the considered wave conditions and water level, and should be weighed against the costs, environmental impacts, and irreversibility of the solution (extracted rock cannot be put back in place).

4.1 Recommendations and further work

Only a narrow set of wave conditions and water level, which only focuses on wave effect not the tide, have been considered. A hydrodynamic model, such as TELEMAC-2D or Delft3D, that represents tidal effects should be considered for studying sediment transport patterns in more detail. A better characterisation of the sediment (e.g. sediment size and type) would improve the prediction of sediment transport patterns.

Based on the model's results, sand dredging alone should be prioritised over rock extraction. Further work is needed to study the cost/benefit of the rock extraction solution.

5 References

Meyer-Peter, Eugen, and Robert Müller. "Formulas for bed-load transport." (1948).

JBA (2025) PES-JBA-XX-XX-RP-HM-0001-A1-C01-Brevig_harbour_modelling. Phase 1 report

Jin, Y. (2020). *Numerical Modelling of Wave Overtopping Response to Sea Level Rise with REEF3D::SFLOW* [master's Thesis]. Norwegian University of Science and Technology.

Appendix

Step-1: Calculation of bed shear stress (τ_b):

Bed shear stress (Manning "law")

$\tau_b = \rho_w g n^2 U^2 h^{-1/3}$

$h = SWL - z_{bed} + \eta$

$U = \sqrt{{U_m}^2 + {V_m}^2}$ is the current magnitude.

Manning Coefficient (n) = 0.026 for a sediment size of 0.001m

Ocean water density (ρ_w) = 1025kg/m^3

Step-2: Calculation of dimensional bedload transport rate (Q_b):

Bedload transport (Meyer-Peter & Müller, 1948)

$$\phi_b = \begin{cases} 8(\theta - \theta_{cr})^{3/2}, \theta > \theta_{cr} \\ 0, \quad otherwie \end{cases}$$

θ_{cr} = 0.047

$\theta = \frac{\tau_b}{(\rho_s - \rho_w) g d}$

$Q_b = \phi_b \sqrt{g\,(\rho_s/\rho_w - 1) d^3}$

Sediment density (ρ_s) = 2650kg/m^3

Sediment diameter size (d) = 0.001m

Step-3: Calculation of time average transport rate:

Bedload transport direction (α): supposed to be the same as the waves -> α = atan2(U_m, V_m)

Net transport rate (m^3/s per m) into components:

$q_{bx}(t) = Q_b(t)\cos(\frac{\alpha(t)\pi}{180})$ and $q_{by}(t) = Q_b(t)\cos(\frac{\alpha(t)\pi}{180})$

$$q_{bx} \approx \frac{1}{\Delta T} trapz\,(q_{bx}, t)$$

$$q_{by} \approx \frac{1}{\Delta T} trapz\,(q_{by}, t)$$

$\Delta T = t_{max} - t_{min}$

Net transport rate = $\sqrt{{q_{bx}}^2 + {q_{by}}^2}$

Net transport rate direction = atan2 (q_{bx}, q_{by})180/π

Time average transport rate (m^3/s per m) $\approx \frac{1}{\Delta T}\, trapz\,(Q_b(t),\, t)$

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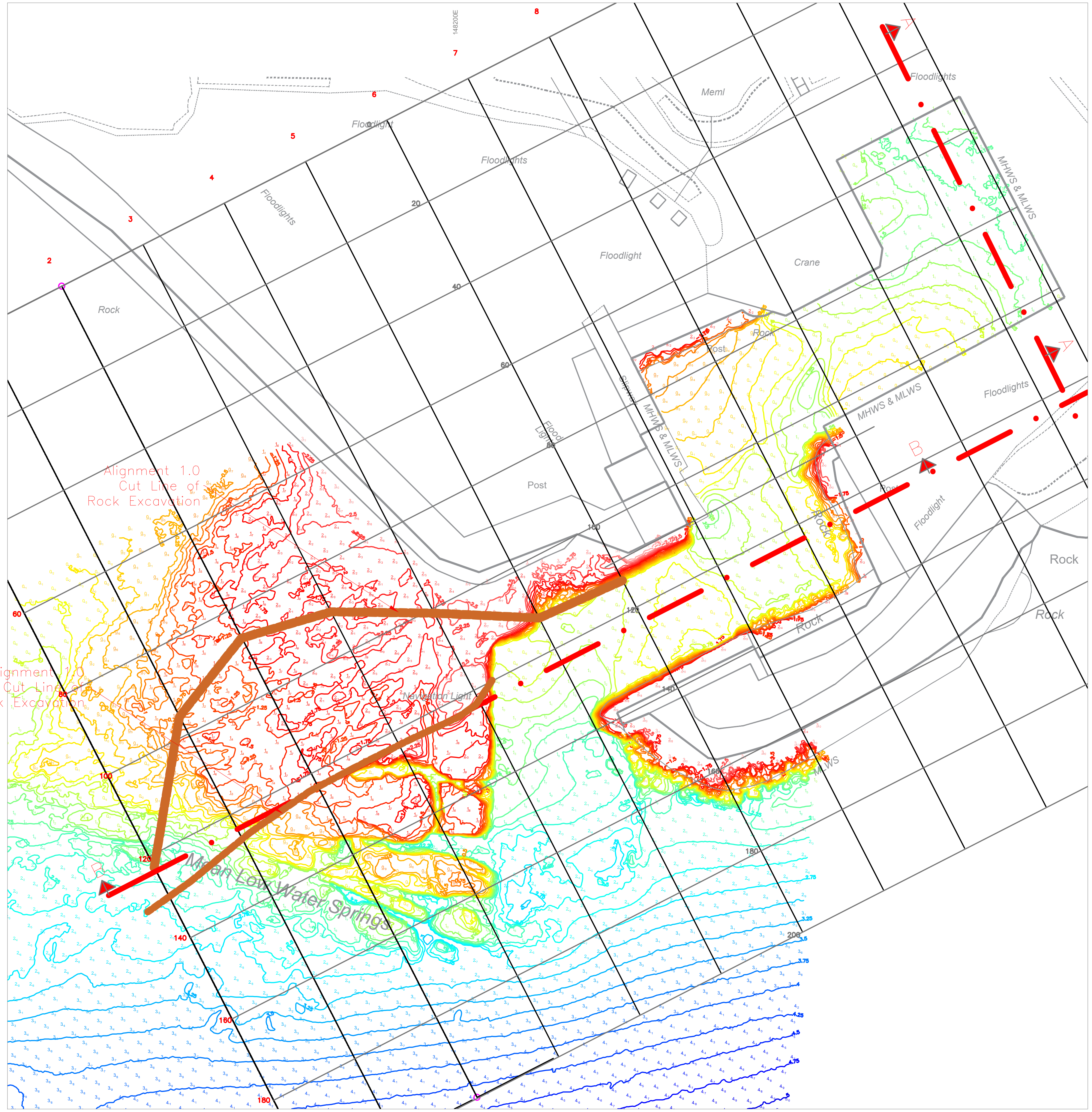
APPENDIX E

Drawing 7(10C 30) 000 Proposed Excavation Alignments

NOTES:

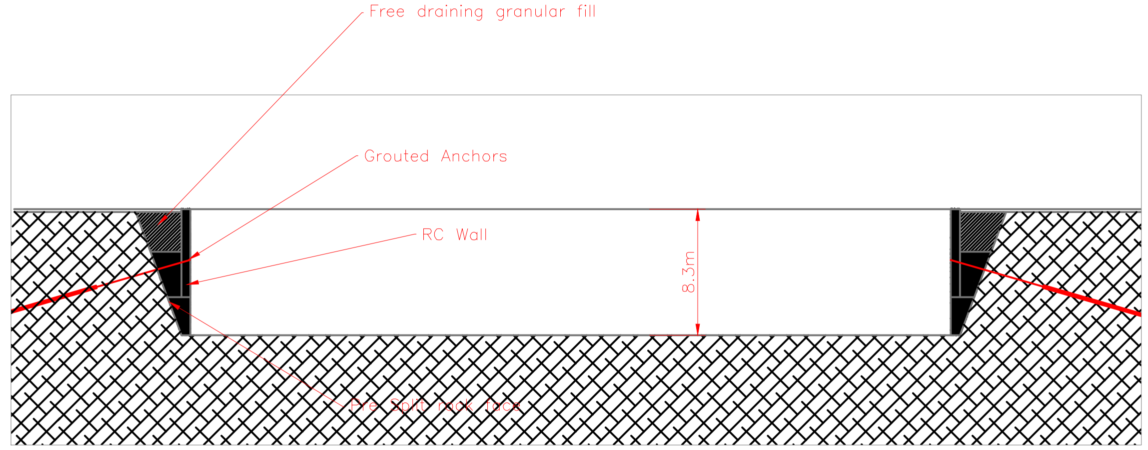
GENERAL NOTES

1. All dimensions are in mm U.N.O.
2. All levels shown in metres to Chart Datum.
3. Chart Dtaum −2.57m below OS Datum.



Plan of Harbour Entrance and Quay

Scale 1:500



Schematic Cross Section Through Quay
Section A – A
Scale 1:250

Alignment 1	
Excavation	Cubic metre
Rock	9826
Sand	2722

Alignment 2	
Excavation	Cubic metre
Rock	3190
Sand	2722

Brevig Harbour Location

rev	description	drawn	ckd	date

COMHAIRLE NAN EILEAN SIAR
FINANCE, RESOURCES AND ASSETS:
ROADS,BRIDGES AND LIGHTING

Project:
PIER AND HARBOURS
Brevig Harbour
Rock and Sand Dredging

Drawing:
Survey Plan
Rock Removal and Harbour Dredging

Project No: TBC

Scale: As Shown
Original Size: A1
Date: 28-04-25
Drawn: AMG
Checked: AMG

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PRELIMINARY

DRAWING No. 7 (10C 30) 001   Rev:

APPENDIX F

Quantities and Costings

Item No	Description	Quantity	Units	Rate	Amount
	Brevig Harbour – Long Reach				
	Alignment 1.0				
	(Disposal to local site adjacent to Harbour)				
	100 - Preliminaries				
1.1	Temporary Accommodation/welfare facilities	Item	1	20,000	20,000
1.2	On/off Mobilisation 40t excavator	Item	2	20,000	20,000
1.3	On/off Mobilisation long reach excavator	Item	2	70,000	140,000
	600 - Excavation				
6.1	Excavation of acceptable material in marine environment (Conglomerate).	9826	m^3	20.00	196,520
6.2	Excavation of unacceptable material in marine environment.(Harbour silts and sands)	2722	m^3	10.00	27,220
	Excavation in Hard Material				
6.3	Extra over exaction for excavation in hard material (Rock in marine environment).	9826	m^3	110.00	1,080,860
	Disposal of Material				
6.4	Disposal of acceptable material Class U1 to bunded local storage site (Conglomerate).	9826	m^3	25.00	245,650
6.5	Disposal of unacceptable material Class UA1 to bunded local storage site (Harbour Silts and Sands).	2722	m^3	20.00	54,440
	1700 – Structural Concrete				
17.1	Provision and placement of C40/50 concrete	14	m^3	400	5,600
17.2	Reinforcement	0.35	T	3000	1,050
17.3	Formwork	18	M^2	50	900
	1800 – Steelwork				
18.1	Provision and installation of navigation light	1	Item	10000	10,000
	Miscellaneous				
18.2	Removal of existing navigation light	1	Item	5000	5,000
		Total to Summary		1,806,380	

Item No	Description	Quantity	Units	Rate	Amount
	Brevig Harbour – Long Reach Alignment 2.0				
	(Disposal to local site adjacent to Harbour)				
	100 - Preliminaries				
1.1		Item	1	20,000	20,000
	Temporary Accommodation/welfare				
1.2	facilities	Item	2	20,000	20,000
1.3	On/off Mobilisation 40t excavator	Item	2	70,000	140,000
	On/off Mobilisation long reach excavator				
	600 - Excavation				
6.1	Excavation of acceptable material in marine environment (Conglomerate).	3190	m^3	20.00	63,800
6.2	Excavation of unacceptable material in marine environment.(Harbour silts and sands)	2722	m^3	10.00	27,220
	Excavation in Hard Material				
6.3	Extra over exaction for excavation in hard material (Rock in marine environment).	3190	m^3	110.00	350,900
	Disposal of Material				
6.4	Disposal of acceptable material Class U1 to bunded local storage site (Conglomerate).	3190	m^3	25.00	79,750
6.5	Disposal of unacceptable material Class UA1 to bunded local storage site (Harbour Silts and Sands).	2722	m^3	20.00	54,440
		Total to Summary		756,110	

Item No	Description	Quantity	Units	Rate	Amount
	Brevig Harbour – Long Reach Alignment 2.0 (Disposal to local site adjacent to Harbour)				
	100 - Preliminaries				
1.1		Item	1	20,000	20,000
	Temporary Accommodation/welfare				
1.2	facilities	Item	2	20,000	20,000
1.3	On/off Mobilisation 40t excavator	Item	2	70,000	140,000
	On/off Mobilisation long reach excavator				
	600 - Excavation				
6.1	Excavation of acceptable material in marine environment (Conglomerate).	-	m^3	20.00	-
6.2	Excavation of unacceptable material in marine environment.(Harbour silts and sands)	2722	m^3	10.00	27,220
	Excavation in Hard Material				
6.3	Extra over exaction for excavation in hard material (Rock in marine environment).	-	m^3	110.00	-
	Disposal of Material				
6.4	Disposal of acceptable material Class U1 to bunded local storage site (Conglomerate).	3190	m^3	25.00	79,750
6.5	Disposal of unacceptable material Class UA1 to bunded local storage site (Harbour Silts and Sands).	2722	m^3	20.00	54,440
		Total to Summary		341,410	

Alignment 1 (Sea Disposal)

Sand Dredge	2722	cu.m	6532.8	T		
Rock Excavation	9826	cu.m	11791.2	Bulked cu.m	23582.4	T
Travel to disposal site	45	km				
Travel speed barge	5	knots	9.26	km/hr		

Plant

		Rate					
Excavator	Doosan DX300 Long Reach	2500	£ per day				
Work Barge	20x9.6x1.72 Boxer Modular Pontoon	700	£ per day				
Split Hopper Barge	31.34x7.04x2.24 : 160cum/285t capacity	800	£ per day	160	capacity cu.m	285	capacity tonnes
Tug	Coastworker 195x6x2.3	3500	£ per day				
Total rate for Plant and Barges		7500	£ per day				

Mobilisation

Barges x 2	Split Hoppers	50000	per mobilisation
Works Barge	Boxer Modular	25000	per mobilisation
Excavator	Doosan DX300	50000	per mobilisation
Tug	Coastworker 195x6x2.3	15000	per mobilisation
Total Cost for Mobilisation		280000	£

Works Duration

Time to disposal site	10	Hrs	Return trip
Maximum No trips Sand	23	No	Based on tonnage
Maximum No trips Rock	83	No	Based on tonnage
Total number of days	53	No	

Excavation rate

Sand @ 1000 cu.m per day		3	days
Rock @ 500 cu.m per day		20	days
Total number of days		22	days
Works duration dictated by barge trip to disposal site		53	days
Total cost for Works duration		396253	
Miscellaneous Items	Navigation Light	23000	
Total Cost for Works including Mobilisation		699253	

Alignment 2 (Sea Disposal)

Sand Dredge	2722	cu.m	6532.8	T		
Rock Excavation	3190	cu.m	3828	Bulked cu.m	7656	T
Travel to disposal site	45	km				
Travel speed barge	5	knots	9.26	km/hr		

Plant

		Rate					
Excavator	Doosan DX300 Long Reach	2500	£ per day				
Work Barge	20x9.6x1.72 Boxer Modular Pontoon	700	£ per day				
Split Hopper Barge	31.34x7.04x2.24 : 160cum/285t capacity	800	£ per day	160	capacity cu.m	285	capacity tonnes
Tug	Coastworker 195x6x2.3	3500	£ per day				
Total rate for Plant and Barges		7500	£ per day				

Mobilisation

Barges x 2	Split Hoppers	50000	per mobilisation
Works Barge	Boxer Modular	25000	per mobilisation
Excavator	Doosan DX300	50000	per mobilisation
Tug	Coastworker 195x6x2.3	15000	per mobilisation
Total Cost for Mobilisation		280000	£

Works Duration

Time to disposal site	10	Hrs	Return trip
Maximum No trips Sand	23	No	Based on tonnage
Maximum No trips Rock	27	No	Based on tonnage
Total number of days	25	No	

Excavation rate

Sand @	1000	cu.m per day	3	days
Rock @	500	cu.m per day	6	days
Total number of days			9	days
Works duration dictated by barge trip to disposal site			25	days
Total cost for Works duration			186695	
Total Cost for Works including Mobilisation			466695	

Sand Dredge Only (Sea Disposal)

Sand Dredge	2722 cu.m	6532.8 T		
Rock Excavation	0 cu.m	0 Bulked cu.m	0 T	
Travel to disposal site	45 km			
Travel speed barge	5 knots	9.26 km/hr		

Plant

		Rate		
Excavator	Doosan DX300 Long Reach	2500 £ per day		
Work Barge	20x9.6x1.72 Boxer Modular Pontoon	700 £ per day		
Split Hopper Barge	31.34x7.04x2.24 : 160cum/285t capacity	800 £ per day	160 capacity cu.m	285 capacity tonnes
Tug	Coastworker 195x6x2.3	3500 £ per day		
Total rate for Plant and Barges		7500 £ per day		

Mobilisation

Barges x 2	Split Hoppers	50000 per mobilisation
Works Barge	Boxer Modular	25000 per mobilisation
Excavator	Doosan DX300	50000 per mobilisation
Tug	Coastworker 195x6x2.3	15000 per mobilisation
Total Cost for Mobilisation		280000 £

Works Duration

Time to disposal site	10 Hrs	Return trip
Maximum No trips Sand	23 No	Based on tonnage
Maximum No trips Rock	0 No	Based on tonnage
Total number of days	11 No	

Excavation rate

Sand @	1000 cu.m per day	3 days
Rock @	500 cu.m per day	0 days
Total number of days		3 days

Works duration dictated by barge trip to disposal site	11 days
Total cost for Works duration	85958
Total Cost for Works including Mobilisation	365958