A Ferry and Ferry Port on the Exposed South Coast of Iceland

A proposal for a practical solution for transport between Vestmannaeyjar and mainland Iceland

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Abstract
The Icelandic Maritime Administration has been assigned by Althingi (the Parliament of Iceland) to undertake a survey and feasibility study for a ferry and ferry port facility at Bakkafjara on the open south coast. The purpose of this paper is to evaluate the possibilities for an alternative ferry solution to the present one by proposing a ferry port on the sandy shore at Bakkafjara some 5.4 nautical miles from Vestmannaeyjar and thereby increase the frequency of transport to Vestmannaeyjar. The IMA has currently presented two possible solutions for a ferry facility. One is on the shore and the other is an island ferry harbour. Extensive research is still needed before a definite conclusion can be made regarding the possible construction of the ferry harbour and this work has to be carried out in respect to the fact that at the exposed sandy south coast of Iceland experiences some of the highest wave activity on earth has been recorded.

Introduction
Vestmannaeyjar Harbour is a large fishing and transportation port, benefiting from the fact that no other harbour exists on the entire south coast of Iceland between Hornafjordur and Thorlakshofn. At present airborne transport to Vestmannaeyjar is either a 20 minutes flight from Reykjavík or a mere 6 minute flight from Bakkafjara. The passenger and car ferry Herjolfur makes the trip from Thorlakshofn to Heimaey in 2:45 hours in optimum weather conditions.

Objective
The main objective is to improve the frequency of sea transport to Vestmannaeyjar and shorten the travel period for passengers, cars and cargo. Three alternative solutions are now being discussed to fulfil this goal:

- *Replacing the existing ferry, Herjolfur:* The existing ferry is 3.354 GRT in size, 70.5 m long and 16.0 m beam with a regular service speed of 15 – 16 nautical miles per hour. The distance between Vestmannaeyjar Harbour and Thorlakshofn harbour is about 40 miles. The ferry has a capacity of 524 passengers and 70 private cars or 6 trucks and 35 private cars. The Herjolfur is 12 years old and it is expected that she will be in service some additional 3 year more or until 2008.

- *An undersea road tunnel from the mainland to Vestmannaeyjar:* The proposed tunnel will be 18 km long and will reach down some 200 to 300 m under water surface in the bedrock. Today, the longest undersea road tunnel is in Japan, some 6 km long.

- *A new ferry to Bakkafjara Coast:* As an alternative to improve the ferry connection between the Icelandic mainland and Vestmannaeyjar is to build a new ferry port at Bakkafjara, which is located on the sandy south coast, at the shortest sailing distance between mainland Iceland and Vestmannaeyjar, about 5.4 nautical miles.

The paper will investigate the possible options for a ferry harbour solution at Bakkafjara by discussing issues related to wave climate and sediment transport and the morphological evaluation to be considered before the planning and construction of a proposed ferry harbour.

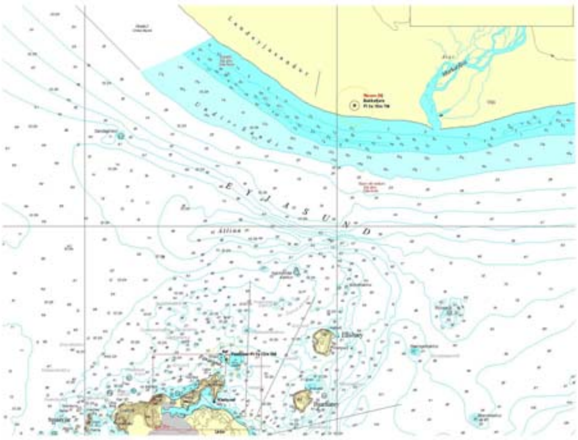


Figure 1. The shortest distance between Vestmannaeyjar and the sandy cost of Bakkafjara is about 5.4 nautical miles.

Overall Transport Pattern and Historic Morphological Response

As a general background for assessing the impact of the ferry harbour on the sediment transport, and, conversely, the effects of the transport on the structures, it is of value to determine the general sediment transport pattern in the area and associated historic morphological evolution. The basis for such an assessment is typically beach profile measurements, shoreline mappings, bottom topography surveys, and aerial photographs.

Aerial photos from the area around Bakkafjara, Figure 2, were available with varying coverage from 1954, 1960, 1971, 1976, 1989, 1996, and 2000. These photos show the dynamic behaviour of the river mouth, Markarfljót River, east of Bakkafjara, where the location of the river mouth seems to display a cyclic pattern in time. In 1954 the river mouth was somewhat east of where it was in year 2000. Subsequently, the mouth migrated to the west and in the beginning of the 1970's the location was at its most westward point, after which the mouth changed direction and migrated eastwards. In 1996 the river mouth approximately returned to its 1954 position indicating that a full cycle was completed in about 40 years. The migration of the river mouth does affect the transport pattern and associated erosion and accumulation of material in the vicinity of the mouth.

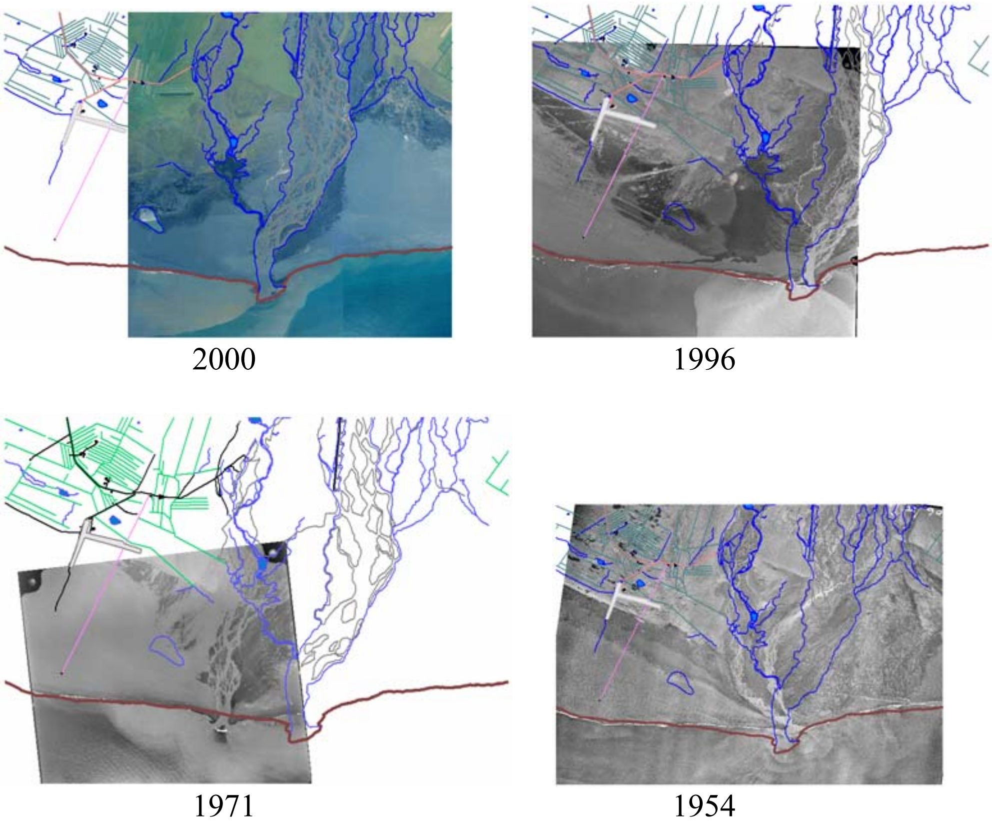


Figure 2. Aerial photos from the area around Bakkafjara

Possible influence of normal and hazard flooding in Markarfljot River

Depending on the area influenced by the river mouth, some effects on the transport pattern and morphological evolution in the vicinity of the planned harbour could be possible. Thus, this area of influence should be investigated and its consequences for the sediment transport and morphological change should be estimated. Another issue to be considered regarding the river is the sediment discharge and its characteristics. This work has not yet been carried out. Neither has the work of Eliasson (2005) on a possible hazard flood of 300,000 m^3/sec in the Markarfljot River yet been considered.

Bathymetric surveys

Bathymetric surveys were carried out in the area in 1973, 2002, 2003, and 2004 and in May 2005. Although the coverage is uneven in time, important information on the morphological evolution is available from these surveys.

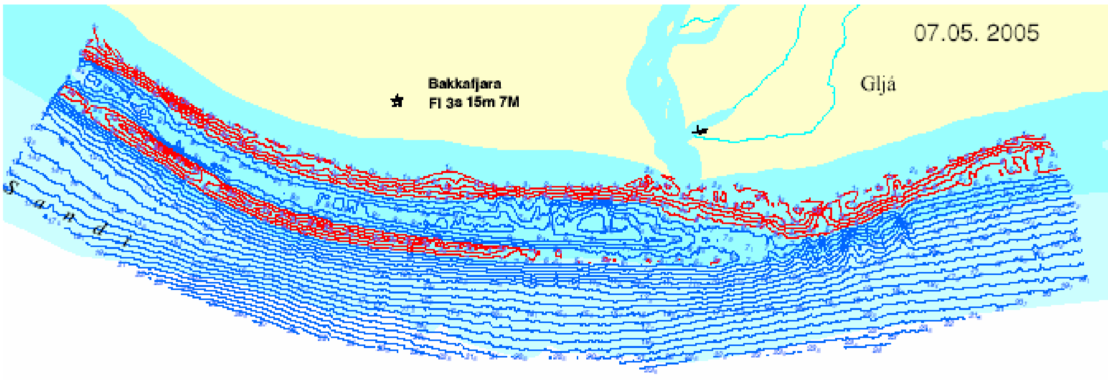


Figure 3. Bathymetric surveys at Bakkafjara in 2002. Red colour indicates below – 6 m.

Comparison between the 2002 and 1973 bathymetric surveys indicates an overall seaward transport of sediment, probably associated with offshore movement of the bar. The bathymetric changes 2002-2003 and 2003-2004 provide less clear pictures of the evolution, partly because of the short time interval between the surveys. However, the former change indicates a general, slight accumulation of material, especially in the near shore area, whereas the latter change indicates the opposite. The surveys do not provide much information on the response close to the shoreline or up in the dry area. In shallow water (2-5 m), the surveyed profile lines seem to indicate a fluctuating behaviour in the western part of the area, whereas erosion prevails further to the east until the river mouth is encountered. In the vicinity of the river mouth some accumulation is observed, especially on the eastern side.

Long-shore Bar Development

The profile surveys show a distinct alongshore bar in a large part of the area west of the river mouth, Figure 4-5 (Larson 2005). Rough estimates of the bar properties based on the surveys are: a crest depth of 5 m, a bar height of 5 m, and a bar length of 400 m. The bar moved offshore along most of the shoreline with an average movement of about 100 m between 1973 and 2004, yielding an average speed of more than 3 m/yr. However, it is expected that the offshore migration of the bar takes place during severe storm events, implying that the migration is not continuous in time but confined to occasional events. The historic movements of the bar varies somewhat alongshore with smaller displacement in the western part of the surveyed area, Figure 5 (section 5), somewhat larger displacements in the middle of the area, Figure 5 (section 9B), and little or no movement along the other profile lines, Figure 5 (section 20) to the east. In fact, for many of the profiles surveyed along lines to the east, a distinct bar is not always present, but the profile shape exhibits a more gradual decrease in depth with distance offshore.

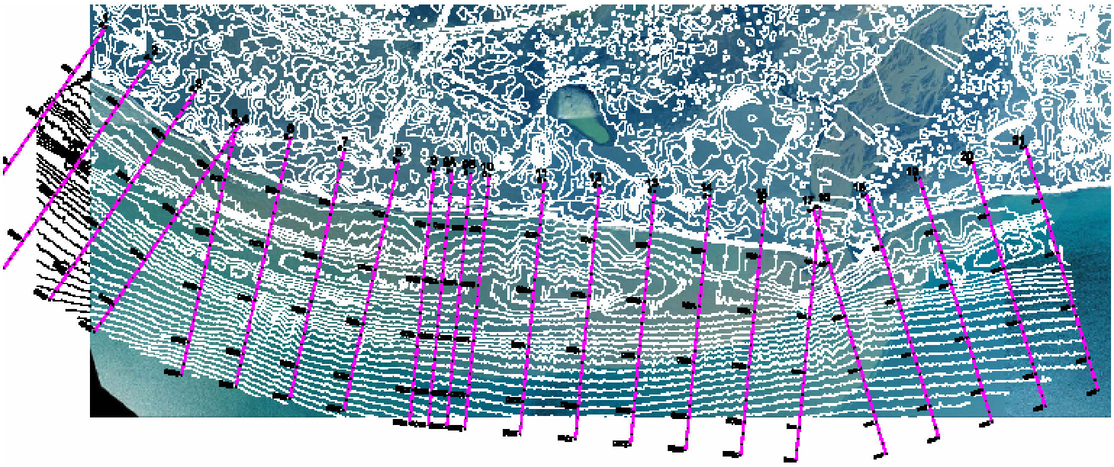


Figure 4. The bathymetry south of Bakkafjara as measured in 2002. The aerial photograph in the background is from 2002

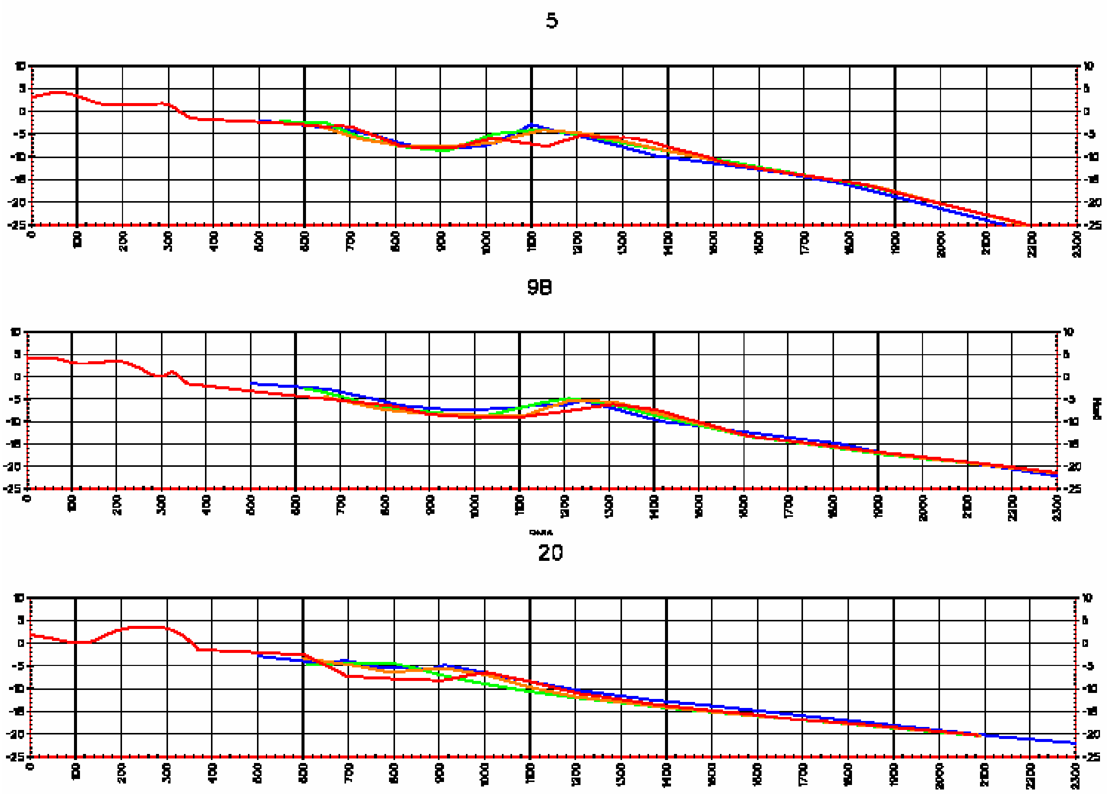


Figure 5. Bed elevations as measured in 1973, 2002, 2003 and 2004. The location of the lines is shown on fig. 4.

Bottom samplings

Figure 9 shows the three profiles, 500 m apart, where the bottom samplings were collected and the table 1 give $D_{50\%}$ and $D_{90\%}$ in mm. The material near the shore and in the through is coarse but the material offshore the bar is fine. Only one sample was taken at the bar, Sn 5, which indicates coarse material there.

Table 1. Bottom samplings

Nr.	$D_{50\%}$	$D_{90\%}$
2	0.36	0.63
3	0.35	0.71
4	0.43	1.00
5	0.32	0.50
6	0.17	0.23
7	0.16	0.23
8	0.15	0.24
10	0.35	0.80
11	0.32	0.48
12	0.47	2.28
13	0.17	0.24
14	0.16	0.24
15	0.15	0.23
17	0.36	0.60
18	0.32	0.47
19	0.35	0.50
20	0.19	0.40
21	0.16	0.23
22	0.15	0.23

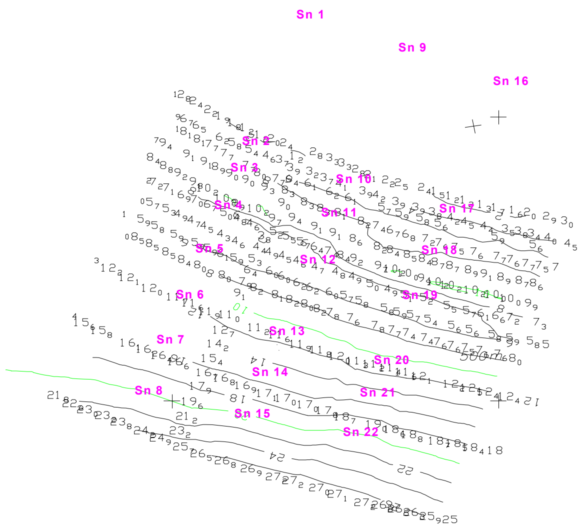


Figure 6. Location of bottom samplings.

Tide Levels

The tide evaluation is based on measured tides at Vestmannaeyjar Harbour. The estimated mean high water spring is 2.64 m, the mean sea level is 1.39 m and the mean low water spring is 0.13 m.

Wave measurements at Bakkafjara

Measured wave data offshore is available since 1988 from Surtsey (63°17,14 N, 20°20,70 W) at 130 m water depth. Wave measurement have been carried out at Bakkafjara Coast (63°,29 N, 20°,35 W) at 28 m water depth since October 2003.

The results of a statistical analysis fitting the data with a three parameter Weibull distribution is shown for Surtsey data (1988–2004) and Bakkafjara data (November 2003 to March 2005) in table 2 (Viggosson 2004).

Table 2. The long term wave statistics at Bakkafjara buoy and Surtsey offshore.

% of time	Return period,year	Hs (m)	Tp (s)	Hs (m)	Tp (s)
60		1.9	10	2.9	10
90		3.2	11	5.1	12
98		4.4	13	7.2	13
99		4.9	15	8.1	15
	1	6.8	16	11.7	16
	10	7.7	18	14.1	18
	100	8.5	20	16.4	20

Wave hindcast data are available from NMI for the year 1988 to 1993. ECMWF 0,5° wave data are available at two location 63°,6 N, 20°,0 W and 63°,6 N, 20°,5 W at Bakkafjara coast together with 1,5° ERA15 hindcast wave data (63°N,21,0°W) from 1979.

The long time wave statistics at Surtsey has been fitted to the NMI wave height data but the estimation of the wave direction offshore is based on the NMI wave data. This evaluation has been used for the last 10 years.

Table 3. Wave height and wave direction distribution at (63.5°N,21.5°W) based on NMI wave data and Surtsey wave measurements.

% of time	Return Period	135° SE	180° S	225° SW	270° W	All Dir.
90%			4.31	4.59	2.10	5.71
98%		4.63	6.83	6.88	5.24	7.82
99%		5.55	7.74	7.74	6.08	8.63
	1	9.16	11.23	11.03	8.86	12.19
	10	11.12	13.22	12.92	10.28	14.41
	100	12.94	15.00	14.64	11.55	16.51
		11.7%	30.0%	41.8%	16.5%	100%

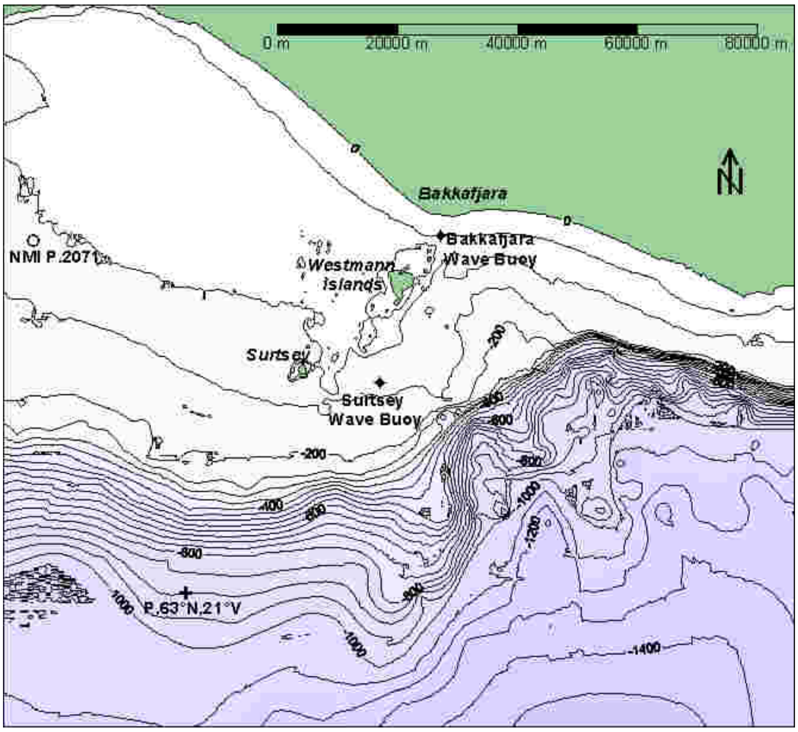


Figure 7. Location of wave buoys and hindcast wave data.

Wave refraction analysis

Wave refraction analysis has been carried out for Bakkafjara Coast for various directions from west to south-east and for frequency from 95% to 100 years return period. Figures 6 – 11 show typical results of the wave analysis for various wave directions. The arrows show the wave direction and the wave height decreases according to darker blue colour. These figures demonstrate the sheltering effects of the Vestmannaeyjar on the Bakkafjara shore. Based on wave refraction analysis an attempt has been made to reconstruct wave height time series for the wave buoy location at the Bakkafjara coast since 1979.

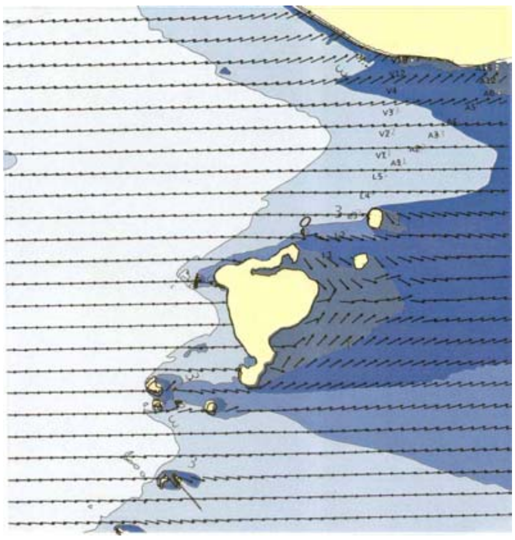


Fig. 8. Waves from west 98 % of the time

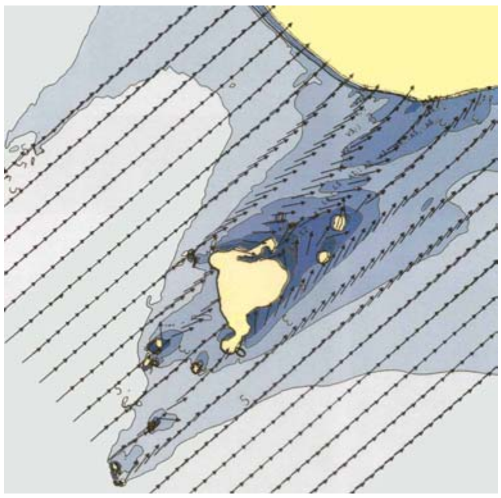
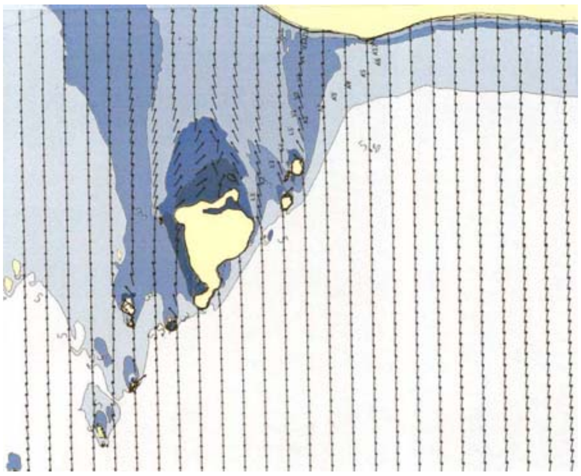


Fig.9. Waves from southwest 98 %

Hs = 5.2 m, Tz = 7.9 s

of the time Hs = 6.9 m, Tz = 9.3 s



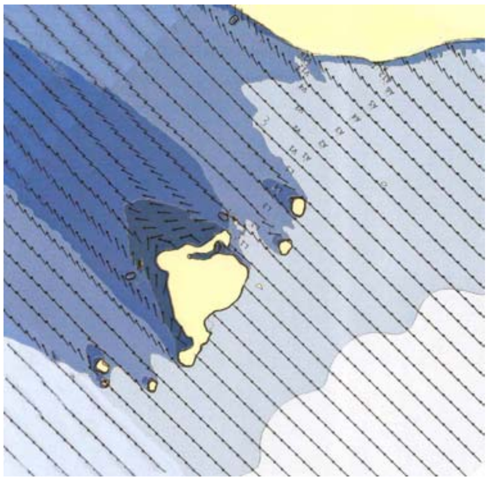


Fig. 10.Waves from south 98 % of the time Hs = 6.8 m, Tz = 9.3 s

Fig. 11. Waves from southeast 98 % Hs = 4.6 m, Tz = 7.7 s

Design wave condition off Bakkafjara

To minimize wave load on possible structures both outside and inside the sand bar, wave refraction analysis has been carried out for the design offshore significant wave height from SE, SW and W. The design offshore wave heights are based on highest measured and hindcasted wave height at the south coast of Iceland. For SW wave direction, highest measured wave was recorded at Surtsey on January 9th 1990: Hs = 16.7 m associated with average wave period which gives the highest inshore wave condition, Tz = 12.4, 13.4 and 14. 4 sec. For SE wave direction: Hs = 14.0 m and Tz = 12.8, 13.8 and 14.8 sec and for W wave direction: Hs = 14.0 m and Tz = 13.0 sec for SE direction. These calculated offshore wave heights are 10 – 20 % higher than 100-years wave given by the wave statistic in Table 3.

The preliminary design water level outside the sand bar is estimated to be 3.4 m based on 10 years wind and air pressure set up and the preliminary design water level inside the sandbar is estimated to be 4.3 m based on 10 years wind and air pressure set up and one year wave set up. Table 4 and Figure 12 give the preliminary wave conditions were the wave height are in minimum from south westerly and south easterly wave direction.

Table 4 Preliminary design wave condition

Preliminary design wave condition			
Hs (m)	14	16.7	14
Tz (s)	13	12.4	10.8
Wave direction (°)	W	SW	SE
Water level (m)	3.4	3.4	3.4
	Hs	Hs	Hs
Bakkafjara wave buoy	6.80	5.39	8.99
N5		7.16	8.02
N4	7.13	7.05	7.08
N3	6.28	6.21	5.63
N2	3.22	3.28	3.02
N1	3.43	3.43	3.08
O5	6.43	6.21	7.53
O4	6.24	6.20	7.07
O3	5.32	5.42	5.37
O2	3.32	3.51	3.71
O1	3.17	3.30	3.21
P5	7.19	6.71	7.66
P4	6.51	6.49	7.67
P3	5.39	5.54	5.43
P2	3.73	3.84	3.67
P1	2.59	2.89	2.58

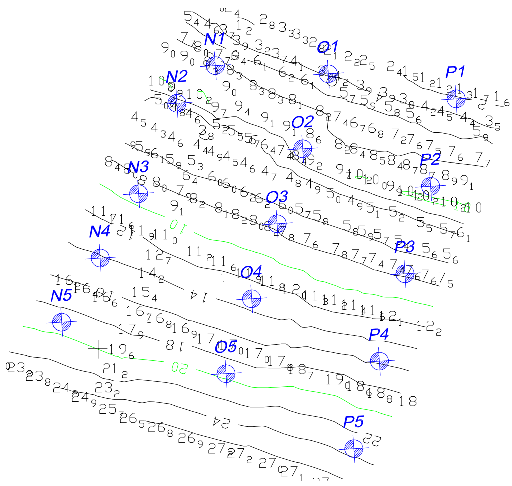


Figure 12. Location of the calculated wave heights

The preliminary results indicate that the design wave conditions for ferry harbour located offshore at the bar are Hs_{design} = 7.0 m along the section O and for a harbour located at the shore is Hs_{design} = 4.0 - 4.5 m along the shore some 1500 m east of section O.

Proposed ferry

The proposed ferry is expected to be about 45 m long with a beam of 12 m and a minimum draft of 3 to 3.5 m. The regular service speed will presumably be about 15 nautical miles per hour, thus the journey from Vestmannaeyjar to Bakkafjara should only last about half an hour in optimum weather conditions. The ferry will carry up to 400 passengers and 28 private cars or 3 trucks and 24 private cars. The scheduled around trip will be 2 hours with four trips per day during the summer months (732 trips) and two trips per day during the winter month (366 trips), depending on the traffic.

Proposed layout of the shore based ferry harbour and the sailing lane.

At the preliminary stage of the project it was decided to make a proposal for ferry harbour on the shore. A ferry port located there will be more cost effective in all respect than an island ferry harbour located offshore on the sand bar. The main disadvantage of the shore connected harbour will always be the crossing of the surf zone with passengers and cars in areas where the bar system can change during and after severe storms. Figure 13 shows the proposed layout at the shore at Bakkafjara, together with the proposed sailing lane. There are proposed two 500 m long parallel breakwaters, 100 m apart, with a berm at the breakwater head that reaches out to -7 to 8 m water depth. The breakwaters protect the 70 m wide sailing lane to the ferry facility. Along the shore two 350 m long shore protections are proposed. The total volume of quarry rocks needed for the construction of the ferry harbour at the shore is estimated to ca. 830,000 m^3 whereas the volume of large rocks between 20 - 30 tonne is estimated to ca. 30,000 m^3.

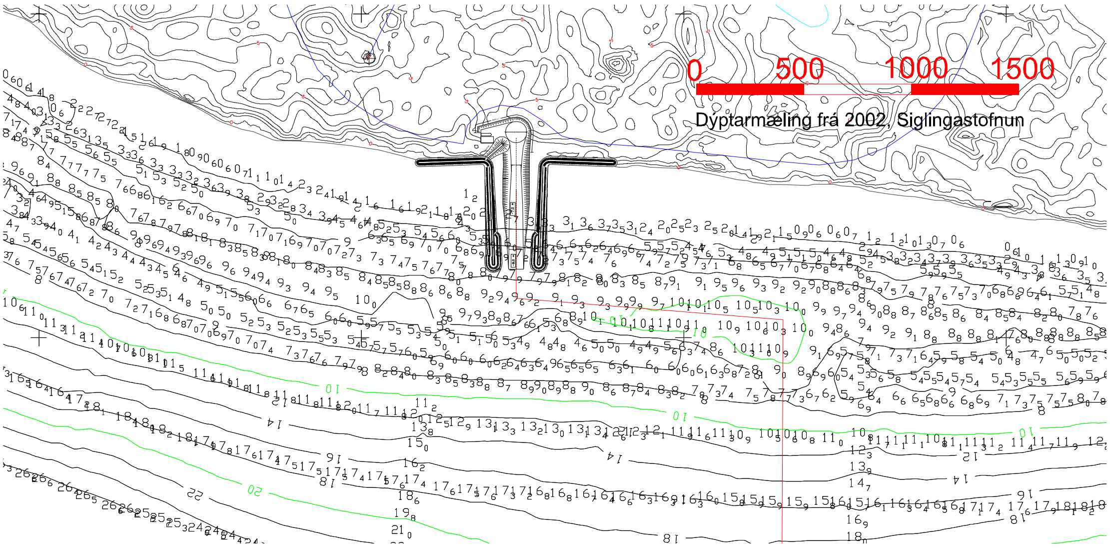


Figure 13. Proposed ferry harbour at Bakkafjara. Preliminary design.

The sailing lane

The minimum water depth when navigating through the surf zone is about 5.5 – 6.0 m for ferry with the draft of 3.0 – 3.5 m. According to the topographic survey the water depth along section D in 2002 was larger than 6.7 m over 750 m wide area, in 2003 larger then 6.5 m over 600 m and in 2004 larger than 6.4 m over 900 m wide area. The distance over the bar between 10 m water depth is from 150 to 300 m. When the ferry has crossed the bar she must turn 90° to the port side and sail some one nautical mile in a 100 to 200 m wide area with enough depth until she must turn 90° to the starboard into the entrance channel which will be approximately 700 m long to a 100 m turning area and then to the ferry facility. The navigational conditions in this proposal are in many aspects similar to the conditions in the tidal entrance to Hornafjordur and also in the entrance to Grindavik harbour. In Hornafjorduros the vessels have to cross the surf zone over the outer bar and then navigate inside the bar into the tidal entrance, either against the strong tidal current or following the current. Based on experiences of the navigational conditions off the entrances of these harbours, safe navigation through the surf zone is possible for 30 to 50 m long fishing vessels up to significant wave height of 3.5 m when the wave heights are measured just outside the surf zone. These fishing vessels, however, navigate in much higher waves and it is common to navigate in up to 4 to 6 m wave height depending on the wave and current directions and strength.

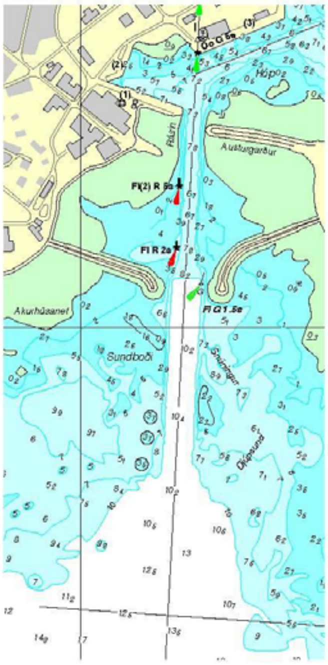


Figure 14. Grindavik entrance

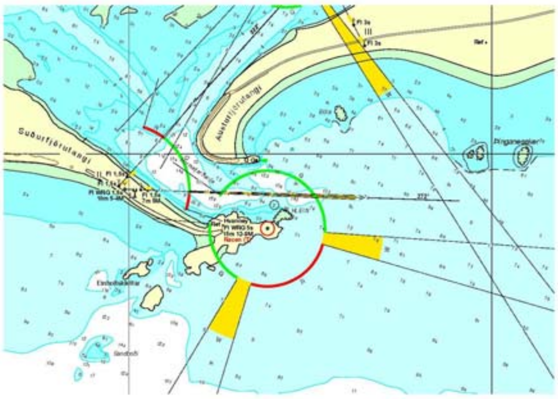
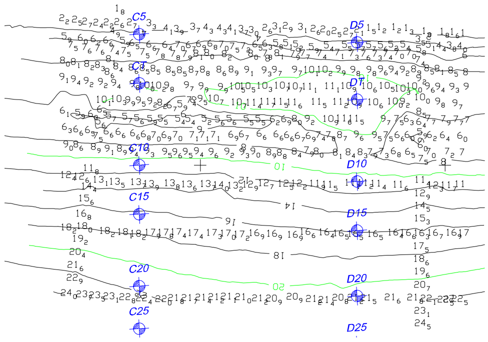


Figure 15. Hornafjorduros entrance

According to the refraction analysis the wave heights along section D are given in table 4 when the significant wave height at the Bakkafjara wave buoy location just outside the bar is 3.5 m.

Table 5 Wave height along section D when Hs = 3.5 m at the Bakkafjara wave buoy.

	4.1	3.2	3.1	3.5
	W	SW	S	SE
D25	3.1	3.0	3.5	3.6
D20	2.9	3.0	3.5	3.6
D15	3.0	3.4	3.5	3.5
D10	2.9	3.8	3.9	3.5
DT	2.6	3.7	3.4	3.0
CT	2.7	3.4	3.1	3.1



As shown in the table 5 the wave height at 10 m water depth inside the bar can reach 3.9 m in southerly direction. If, however, the wave height 3.5 m at the bar is used as criteria, then the Hs may reach 4.1 m in W direction, 3.2 m from SW, 3.1 m from S and 3.5 m from SE.

Due to the sheltering effect of Vestmannaeyjar the best possible sailing lane with respect to the wave height and wave direction can be optimized to minimize the inconvenience for the passengers and the crew. The ferry will be specially designed for sailing through the surf zone, taking into account the strength of the wave induced current and breaking waves. The vertical acceleration in head sea will be minimized by the design of the ferry and the bulge bow, cutwater and the location of the passenger salon. Different design criteria for safe navigation will be established for the ferry carrying fishermen, passengers, tourists, cars and trucks.

When evaluating the conditions for a safe navigation of the ferry all relevant modern navigation equipment will be applied, such as navigational aids and an online camera showing the surf zone, automatic weather station at the shore, wave buoy just outside the sand bar, monitoring equipments for topographic surveys of the bars and the surroundings of the harbour.

An estimation of the down time for the ferry based on different wave height criteria just outside the bar has been evaluated based on data from Bakkafjara wave buoy for the year 2004. Using the wave height criteria of 2.5 m for the tourist season, June to August, some 14 trips have to be cancelled but none for wave height 3.5 m for the period June - August. For safe navigation of 3.5 m approximately 7 trips will have to be cancelled during the summer months and about 34 trips during the winter months. For 4.0 m wave height about 6 trips will have to be cancelled during the summer and 23 trips during the winter season.

Sariöz 2005 et al. has evaluated the habitability of passenger vessels based on ISO criteria of vertical acceleration in open sea for 50 m long motor yacht similar to the proposed ferry for Bakkafjara. The sea keeping performance assessment procedure starts with prediction of the hydrodynamic response characteristics of the vessel for a range of speed and heading values. The magnitude of the motions in the sea can then be predicted, utilizing wave spectra representative of the selected operational sea area. Finally, the habitability of the vessel can then be estimated, based on the probability of ship motions remaining within acceptable limits. The acceleration levels are selected in accordance with levels described by the ISO 2631 standard for different exposure times. Based on this standard about 10 % of the passengers will get seasick when the RMS vertical acceleration is 0.5 m/s^2 (approximately 0.05g significant) for an exposure period of 2 hours and 1 m/s^2 for 0.5 hours in the frequency range 0.1 to 0.315 Hz. For a 2 hour exposure the criteria for vertical acceleration for fishermen is 0.15 g.

These criteria will always be fulfilled when the ferry sails in following, quartering and beam sea from Vestmannaeyjar to Bakkafjara Coast. When sailing from Bakkafjara to Vestmannaeyjar the ferry will first encounter beam sea and then head sea where the vertical acceleration can exceed the above criteria for at least 10 to 15 minutes when crossing over the bar. The vertical acceleration of the ferry in head sea can be reduced by choosing appropriate sailing lane and by reducing the speed of the ferry.

Next autumn, field measurements of the surf area will be carried out with an appropriately equipped fishing vessel of the same size as the proposed ferry. Both the wave height outside the surf zone and the motions of the vessel, especially the vertical acceleration, will be monitored when crossing the surf zone in different wave conditions. The obtained data will then been compared with results from field surveys of the vertical acceleration of the vessel when sailing through the entrance to Grindavik harbour during breaking waves. Thus the experience gained from navigating through the surf zone into Grindavik harbour can be utilized to assess the implications gathered when crossing the bar in Bakkafjara.

The proposed island ferry harbour offshore the bar

Because of the obvious problems connected with the crossing of the breaker a second proposal was introduced where the entrance to the port is located offshore on the sandbar outside the general surf zone. This location would minimize the risk of intensive breaking of waves at the ferry port entrance. Both proposals will suffer from siltation of suspended material into the harbour to some extent. Placing the harbour away from the shoreline would mean that it will be necessary to build a bridge to connect the island ferry harbour to the shore. Even if the harbour is located in deeper water some effects on the littoral system, as well as effects on the harbour from sand drift, are expected.

The layout of the proposed island ferry harbour is shown on Figure 16. The berm breakwater reaches out to 14 m water depth. The proposed preliminary cross sections are shown in Figure 18. The total volume of quarry rocks needed to construct the ferry island harbour and the road connection to the shore is estimated to ca. 1,450,000 m^3 whereas the quantity of large rocks between 20 - 30 tonne is estimated to ca. 74,000 m^3. The bridge is estimated to be ca. 410 m long.

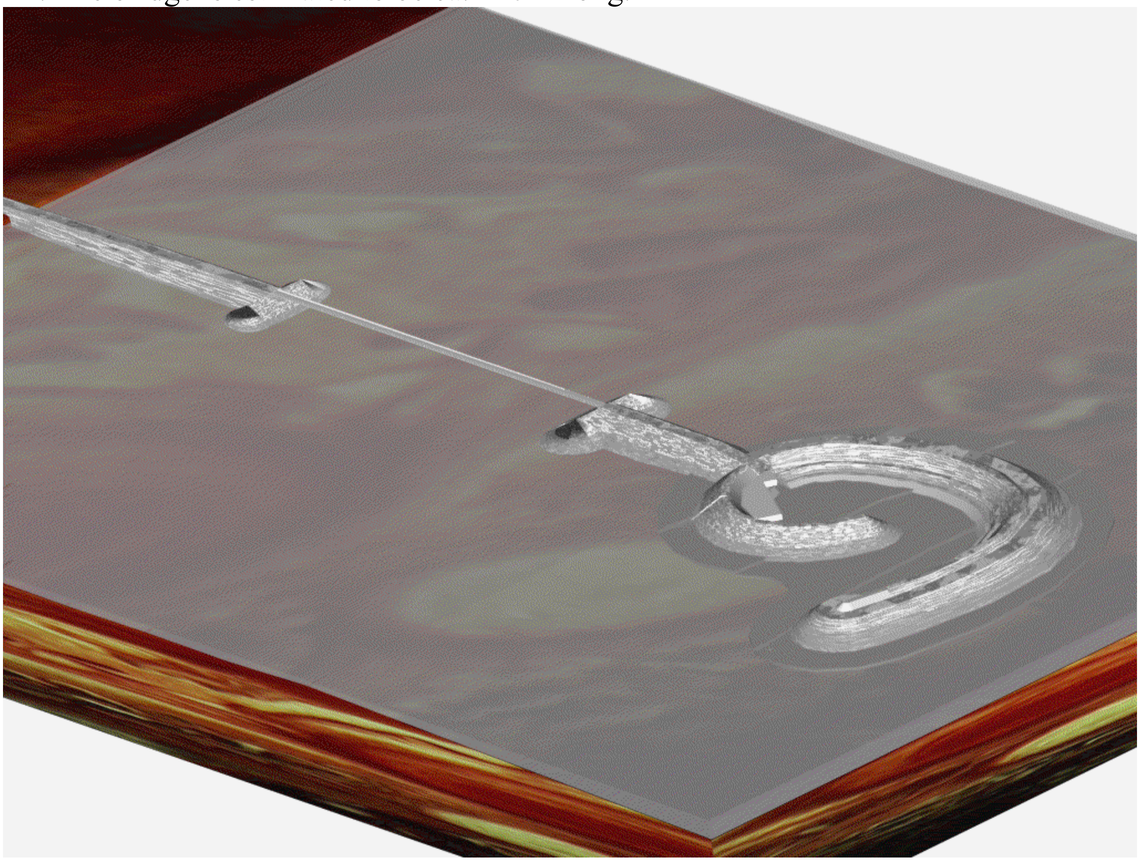


Figure 16. The proposed island ferry harbour offshore from the bar.

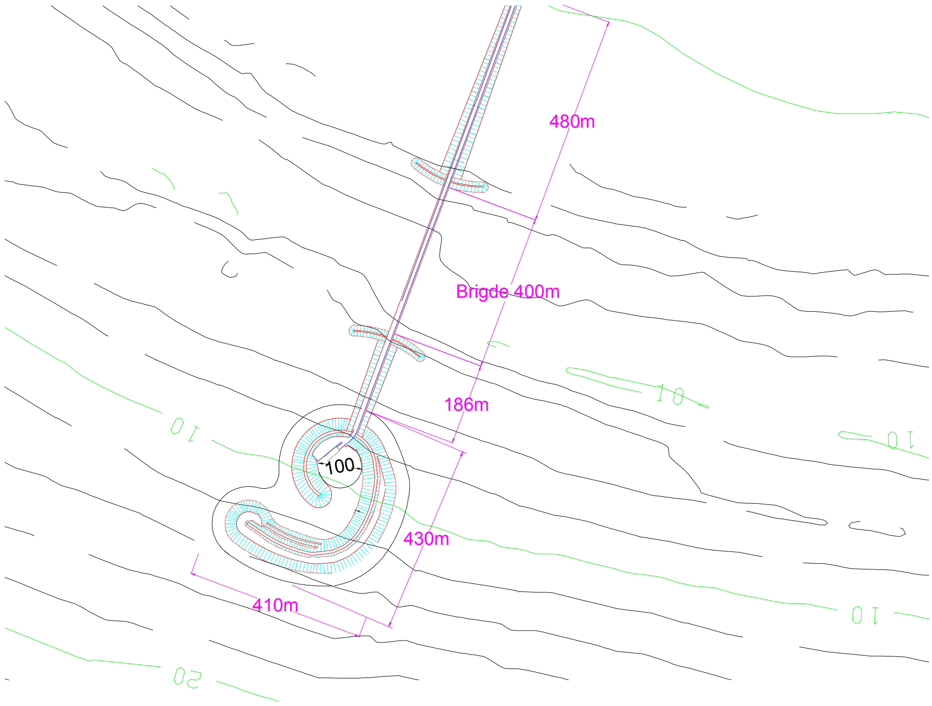


Figure 17**.** The proposed island ferry harbour offshore the bar.

The estimated final location of the ferry harbour on the shore will be near section O in Figure 17 and the offshore location will be based on evaluation on navigation condition for the ferry into the harbour and expected siltation into the harbour.

A quarry site for large rocks is available near the harbour at the town of Thorlakshöfn some 74 km west of Bakkafjara Coast and a quarry for smaller rocks is available some 20 km inland from the possible ferry port site. Gravel is available near the mouth of the Markarfljót River.

The quality of the rocks at the quarry in Thorlakshofn is excellent. Some 2,000,000 m^3 must be blasted in Thorlakshöfn to achieve the large rocks needed for the project. The predicted quarry yields are:

Class I:	(20 – 30 tons)	4 %
Class II:	(10 – 20 tons)	9 %
Class III:	(4 – 10 tons)	11 %
Class IV:	(1 – 4 tons)	15 %
Class V:	(0.1 – 1 tons)	24 %

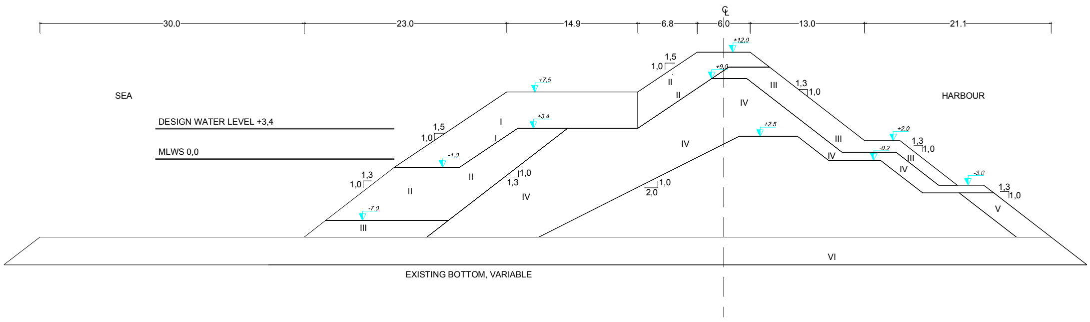


Figure 18. Bakkafjara berm breakwater. Class I: 20 -30 tons, Class II: 10 – 20, Class III: 4 – 10 tons, Class IV: 1 – 4 tons, Class V: 01 – 1 tons. Class VI: Scour protection of quarry run, 3 m tick. Hs, design = 7.0 m, a statistically stable berm design.

The preliminary plan is to transport the rocks from Thorlakshofn to Bakkafjara with four ca. 1000 m^3 barges in the period from the middle of Mars to the end of September. Each roundtrip will take 24 hours. Barges are expected to be in operation until the significant wave height reaches 2.5 m at Bakkafjara wave buoy. During the first summer the outer part of the berm breakwater, the road connection from the shore and preparations for the bridge will be completed. The second summer the breakwater will be completed together with the bridge and ferry facility. The construction will be completed in the third year.

Long-shore Sediment Transport

The long-shore sediment transport will affect, and be affected by the construction of the harbours in two different ways: infilling of the harbour basin and blocking of the alongshore drift by the bridge.

Harbour infilling

The water depth at the proposed site of the island ferry harbour is 14 m and the site lies outside the surf zone based on calculations of the local wave conditions derived from numerical simulations with the HISWA model. Most of the long-shore transport occurs in the surf zone, hence a placement of the harbour seaward of this zone will markedly reduce the rate of infilling. However, there will always be some drift outside the surf zone implying that maintenance dredging of the harbour basin will most likely be needed at regular intervals. The estimation of the frequency and amount of dredging will require mathematical modelling of local waves, currents, and sediment transport.

Since the harbour will be located in such deep water, extreme events will probably have a significant impact on the rate of infilling whereas the continuous transport of sediment into the harbour basin at “normal” wave conditions would be negligible. Preliminary estimate of the quantity of material necessary to be dredged from the harbour is some 30 – 50,000 m^3 per year on a regular basis and 100 – 200,000 m^3 after extreme events.

Blocking of transport by bridge
The bridge that connects the island harbour to land should be designed for minimum obstruction of the long-shore sediment transport. Even if the long-term net transport is not so pronounced for the area, short-term trends in the transport occur that may cause erosion and accretion of material if the transport is blocked. After the detailed design of the bridge is known model simulations could be employed to quantify the blocking effect and the possible impact on the shoreline and near shore areas. Preliminary design of the bridge: Two lanes, 8.5 m wide bridge way with leaf of 54+60+60+60+60+60+54 = 408 m. Each pier is made of steel sheets of 4 m height and 12 m breadth.

Long shore Bar Behaviour
Considering the expected balance that should develop between the long-term wave characteristics, especially the more extreme waves, and the bar shape, the offshore movement of the bar should decrease with time (Larson 2005). It may be difficult to exactly estimate how far offshore the bar will move, but a closer analysis of the long-term wave statistics; together with some simple profile modelling based on equilibrium concepts might provide a rough estimate.

Hybrid Model
The goal of the study is to improve the stability of the rubble mound breakwater and improve the navigational conditions in the entrance to the harbour as well as the wave agitations inside the harbour. Only a hybrid model is possible for complicated circumstances like the one at Bakkafjara. It is composed of field data, properly interpreted, including sediment budget, numerical and hydraulic models, both calibrated to the field data. In 2005 and 2006 both numerical and physical models of the ferry harbour will be evaluated to obtain further data to improve the design of solutions for the navigation condition, improvement of the wave agitations and the stability of the rubble mound.

Recommended further field measurements

- Systematic topographic soundings and bottom sand sampling.
- Beach profiles measurements both in the field and from aerial photographs.
- Installation of automatic weather station.
- Continuous wave measurements.
- Further wave refraction analysis.
- Improve wave forecasting at Bakkafjara.
- Monitoring vessel navigation through the surf zone and inside the bar during design wave and weather conditions.
- Aerial photographs of the breaking waves in the surf zone from aeroplane.
- Evaluation of the discharge and supply of material from Markarfljot River.
- Evaluation of a hazard flood of 150,000 to 300,000 m^3/sec from the glacier Katla.

Recommended model simulations

- In order to estimate the rate of sediment infilling and the effect of blocking by the bridge, numerical model simulations should be undertaken.
- A more complex model would describe both the alongshore and cross-shore variation in the sediment transport. The wave properties, current, and sediment transport rate should be calculated at each grid point.
- Depending on the availability of data and the complexity of the numerical model to be applied, it might be necessary to perform simulations only for a number of well-defined, representative cases. Since the infilling is most likely related to severe storms this may not be a serious restriction.
- Wave disturbance tests to investigate the navigational condition for the ferry when entering the harbour and safe mooring at berth.
- Wave stability tests of the berm breakwaters.
- Geotechnical investigations at the site.
- Quarry runs investigations.
- At the end, risk assessment has to be carried out for navigation of the ferry and for all items regarding the passengers, cars, crew, the ferry and all items of the facilities.
- Based on the risk assessment monitoring and warning systems have to be installed and rescue operations will have to be trained.

Conclusion

The Icelandic Maritime Administration has been assigned by Althingi (the Parliament of Iceland) to undertake a survey and feasibility study for a ferry and ferry port facility at Bakkafjara on the open south coast. The purpose of this paper is to evaluate the possibilities for an alternative ferry solution by proposing a ferry port at the sandy shore at Bakkafjara some 5.4 nautical miles from Vestmannaeyjar and thereby increase the frequency of transport to Vestmannaeyjar. The IMA has currently presented two possible solutions for a ferry facility. One is at the shore and the other is a island ferry harbour.

The expected size of the proposed ferry is about 45.0 m long, 12.0 m in breadth and with a minimum draft of 3.0 to 3.5 m. The service speed is expected to be about 15 nautical miles per hour and it will take about 0.5 hours under optimum weather conditions to sail from Vestmannaeyjar to Bakkafjara Coast. The ferry will carry up to 400 passengers and 28 private cars or 3 trucks and 24 private cars. The scheduled around trip will be 2 hours with four trips per day during the summer month (732 trips) and two trips per day during the winter month (366 trips), depending on the traffic.

An estimation of the down time for the ferry based of different wave height criteria just outside the bar has been evaluated based on data from Bakkafjara wave buoy for the year 2004. Using the wave height criteria of 2.5 m for the tourist season, June to August, some x trips have to be cancelled but none for wave height 3.5 m. For safe navigation of 3.5 m approximately 7 trips will have to be cancelled during the summer months and about 34 trips during the winter months.

Extensive research is still needed before a definite conclusion can be made regarding the possible construction of the ferry harbour and this work has to be carried out in respect to the fact that at the exposed sandy south coast of Iceland some of the highest wave activity on earth has been recorded.

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