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Wave Measurement in Iceland

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ABSTRACT

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The Research Section of the Icelandic Harbour Authority (IHA) is responsible for collecting data for the design, construction and maintenance of harbours in Iceland. To fulfill these requirement, the IHA runs 9 accelerometer buoys and 5 pressure guages with various types of computers for data analyses. The research section also runs a hydraulic laboratory with irregular wave generators and other facilities for wave distubance tests with moored ships and stability tests of rubble mound breakwaters. Field observation of ship behavior at berth has been undertaken with the Icelandic system for measuring ship movements. This paper summarizes wave measurement in Iceland, the locations of recordings and experiences as well as offshore hindcast data, and closes with a desciption of a specific example of wave recordings. During the last few years the wave measurement program has focused on collecting simultaneous wave data both offshore and inshore near harbours to secure data on tidal range, long period waves, wave setup, surges and wind waves.

ADDITIONAL INDEX WORDS: *Wave measurement, wave recording, wave analysis, wave hindcasting, wave distrubance, ship movements.*

INTRODUCTION

The importance of fishery for Iceland is best described by the fact that more than 70 percent of the country's exports are fishery products. Iceland has about 70 harbours mostly serving the fishing fleet. They are spread along the entire coastline, with the exception of the sandy region along the south coast. The fishing fleet consists of almost 1,000 ships of 10-1,000 brt and about 1,500 fishing boats under 10 brt. Most Icelandic harbours are small, especially in relation to the wavelength they are exposed to, (breakwater length versus wavelength).

Most Icelandic harbours are located in relatively protected waters, like fiords. But even so the wave penetration from the ocean may still be considerable, necessitating protective works such as breakwaters. In many harbours the wave action causes long period waves, a wave set-up inside the surf zone and a sediment transport on sandy coasts. To investigate the behavior of long waves in a fiord a research project was undertaken in 1964, based on a grant from the Office of Naval Research at the University of Florida. The results of the investigation are described in another research paper (DORRESTEIN *et al.*, 1971). Surges and wave action often cause movements of ships exceeding the acceptable limits for loading, unloading and mooring.

The Research Section of the Icelandic Harbour Authority (IHA) has been running hydraulic model tests since 1973 and since 1977 with irregular waves. Usually a model of 1:60 is used to undertake both three dimensional wave disturbance tests with moored ships and stability tests of rubble mound breakwaters, conventional and bermed type (FAIRWEATHER, 1987). A selection of measured wave data is reproduced in the model. THe application of irregular waves in wave disturbance models and stability tests necessitates better knowledge of prototype wave climate, prototype ship movements and quarry material.

To improve the knowledge of ship movements, instruments have been developed that enable the recording of all ship movements including surge, sway, heave, roll, yaw and pitch. The instruments are operated from a truck parked on the quay at the shipside. The ship movements are measured by mounting a straight wire to the ship and measuring five angles as well as the length of the wire. A wind-direction meter is mounted on top of the ship and four loadcells measure the tension in the mooring lines. A pressure cell is installed

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underneath the ship and a Waverider outside the harbour. Each channel is scanned twice a second for a total of 2,048 samples and stored on a tape cassette in an HP 9825 desk computer, (VIGGOSSON *et al.*, 1984). The ship measurement is a part of a Nordic research project "Ship Movements in Harbours" which started in 1981 and finished in 1986. The purpose of the project was to establish criteria for acceptable ship movements in harbours, to be used in the design process for new installations and in assessment of existing harbours. The results of the research project are summarized in the final report "Ship Movements in Harbours" (Viggósson et al 1987). The nordic countries involved were Denmark, the Faroe Islands, Iceland, Norway and Sweden. The field observations of ship behaviour at berth in Iceland are described in a research paper (Viggósson, 1987). The purpose of measuring waves offshore, outside and inside the harbours simultaneously, is to establish the wave energy transfer functions between these three locations. These transfer functions are estimated by comparing rms and spectrum values at the same time. The transfer functions between waves and a moored ship are estimated by using the ship's instruments. Directional wave spectrum-refraction analyses have also been used to estimate the offshore-inshore energy transfer functions. A refraction analysis is used to evaluate the size and direction of models for wave disturbance tests.

DESCRIPTION OF WAVE MEASUREMENT

From 1957 to 1967 wave data was collected in four harbours with pressure gauges of the Am Mark IV type. The first Waverider buoy was installed in 1969. The Waverider system is an accelerometer-type instrument with a transmitting unit in a buoy of spherical shape, anchored at sea. On shore the receiver system consists of a chart and tape-recorder. The system is described elsewhere (VERHAGEN *et al.*, 1976; van BREUGEL, 1978). In 1973 two pressure gauges of the Ospos type were installed. The Ospos recorder is selfcontained and can be left unattended for about four weeks. They are either placed on the sea bottom or suspended from an anchor. The first Icelandic pressure cells were developed the same year. The gauge produces a continuous record of the pressure at

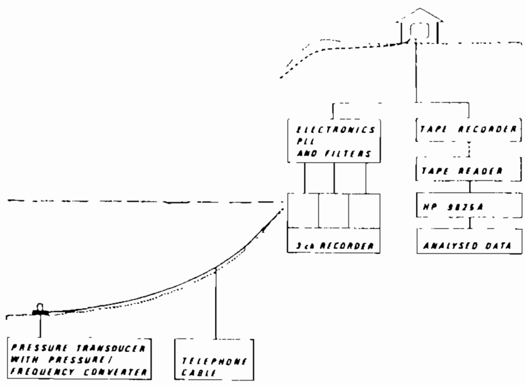

Figure 1. The IHA pressure gauge system.

some fixed position beneath the water surface. The amplitude of the pressure pulses generated by waves attenuates with depth. Short waves attenuate more than the long waves.

The purpose of developing the pressure cells was to record simultaneously wind waves, long period waves, and tidal variation. However, the recording of tidal range is not accurate as the gauge measures the differential pressure inside and outside the cell. Figure 1 shows schematically the Icelandic pressure gauge system. Inside the cell there is a pressure transducer with a pressure/frequency converter. A telephone cable connects the cell to the shore. Onshore the system contains a phase lock loop, high and low pass filters, three channel pen-recorder and tape recorder. A printout from the pen-recorder is shown on Figure 2. This system was used until 1985. During the first years of wave measurements many problems were experienced. From 1969 to 1973 10 Waverider buoys were installed, but only two buoys worked satisfactorily. Six times the mooring system was damaged and the accelerometers twice. Three buoys were lost. After 1975 the offshore mooring system was modified, based on experience from Norway,(HOUMB *et al.*, 1974). Inshore, at water depth less than 30 m, IHA has developed its own mooring system. From 1975 to 1984 29 Waverider buoys were installed. One buoy was lost due to a fault in the rubber cord and one has experienced damage of an accelerometer. Vessels have on three occasioms damaged the accelerometers by collision. To reduce the hazard of spinning caused by passing ships, a triangle is

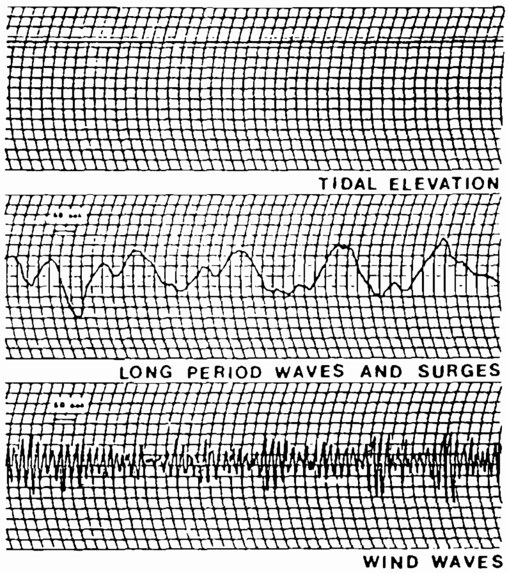

Figure 2. A printout from the three channel pen-recorder of a pressure gauge.

installed on the buoy. From 1977 to 1978 the greatest problem with wave recordings was the amount of radio interference. The reason for this interference was the special circumstances caused by the high sunspot activity. By changing the carrier frequency of the transmitting unit of the buoy from ca. 27,7 mH_z to ca. 30 mH_z the problem was minimized.

RECORDING OF DATA

From 1978 waves have been recorded on tape cassettes with Memodyne dataloggers, but since 1986 they have gradually been replaced by PC - computers. This has made it possible to perform some of the analyses on site. The analysis is stored on diskettes along with the timeserie. The PC-computers are also used to control the new DIWAR - receivers from Datawell. Waves are recorded 17.1 minutes every three hours at weather observation time. The sampling is 2 times per second and the capacity of the recording media corresponds to about one week's recording. Often the signals from two Waveriders are recorded by one receiver. Until 1985 wave data recording had been undertaken at 34 locations by Waveriders and at 19 locations by pressure guages. Figures 3 and 4 show

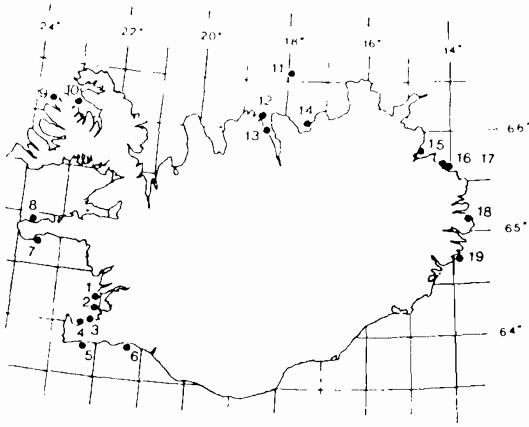

Figure 3. Installation points of Waverider buoys until 1985.

the installations of Waveriders and pressure gauges around Iceland until 1985. Since then Waveriders have been installed at 9 new locations.

ANALYSIS OF DATA

From 1978 the analysis was performed on a Hewlett Packard (Hp 9825) desktop computer and later it was replaced by a Hp 1000 with capability for much more comprehensive analysis. When the PC's were installed at the measuring sites the full analysis was transformed to XT and AT computers (1986). The next step will be to centralize the wave measurements such, that a central computer will call each site

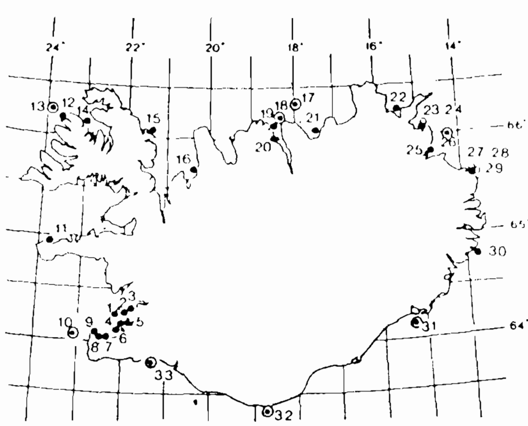

Figure 4. Installation points of pressure gauges until 1985.

through the public telephone network and gathre data either in real time or once a day.

The analysis is shown in Figure 5. Most of the parameters are defined according to IAHR and PIANC's "List of Sea State Parameters" (1986). Following is an explanation of the parameters in Fig 5:

Observation place/time (VE for the Westman Islands, time of observation year, month, day, hour); Err (number of errors defined as elevation exceeding 1,5 * H_{4rms} from mean level); Mean (mean value of time series); H_{4rms} (4 times the rms-value); T_p (spectral peak period); $H_{1/3}$ (zero downcrossing significant wave height, average of the highest onethird zero downcrossing wave heights); T_z (zero downcrossing wave period); H_{maxD} (maximum zero downcrossing wave height); H_{maxU} (maximum zero upcrossing wave height); Y_{max} (zero crossing wave crest height); Y_{min} (zero crossing wave trough excursion); $H_{s3,10}$ (estimate of significant wave height for waves with period between 3 and 10 seconds); $T_{p3,10}$ (spectral peak period between 3 and 10 seconds); $H_{s10,25}$ $T_{p10,25}$ (wave height and period as before, for waves with period between 10 and 25 seconds); Arason (maximum areal fo wave over mean level,m elevation multiplied with time). To distinguish between local and offshore waves inside fjords, $H_{s3,10}$, $T_{p3,10}$, $H_{s10,25}$ and $T_{p10,25}$ are evaluated. The purpose of the Arason-parameter is to estimate the volume of flow above mean level, propagating into the permeable part of the breakwater.

Figure 6 shows a monthly summary of the significant wave height (4 RMS) and the zero crossing period (T_z) for the offshore Gardskagi buoy located 64°5'N 23°12'W, 8 miles from Gardskagi lighthouse (at water depth 85 m). The figure also shows simultaneous weather observations of wind velocity and direction from the nearest weather observation station at Keflavik Airport. The wind velocitv is defined by maximum wind gustiness, maximum 10 min average and 10 min average at the observation time.

Figure 7 shows a summary of the significant wave height and the zero crossing period for Bolungarvik harbour during the winter 1982 - 1983. The spectrum is computed using the fast fourier transform (FFT) with 2,048 values (Figure 8). Figure 9 shows a summary of wave recordings offshore and highest measured significant wave heights.

WAVE HINDCASTING

Since 1972 the Norwegian Meteorological Institute (NMI) has operated a wave hindcasting model. In a number of cases the computed wave data has been compared with actual field observations. Comparisons have led to the conclusion that there are no apparent systematic errors in the way the model develops wave energy (HALAND *et al.*, 1980). The calculation is performed for intersection points of a regular square grid with a mesh-width of 150 km. Small scale variations, however, seem to be a little smooth due to the resolution of the grid. There are limitations for using this hindcast data. Where the grid points are located less than one mesh-width from land the waves generated by offshore wind are not representative. The

Observation place/time	Err	Mean	H_{4rms} m	T_p sec	$H_{1/3}$ m	T_z sec	H_{maxD} m	H_{maxU} m	Y_{max} m	Y_{min} m	H_{s310} m	T_{p310} sec	H_{s1025} m	T_{p1025} sec	Arason m-sec
VE.88010703	0	0.25	1.66	11.1	1.59	7.4	2.23	2.77	1.47	1.30	1.31	6.9	1.00	11.1	3.46
VE.88010706	0	0.25	1.46	11.1	1.43	5.9	2.23	2.12	1.42	1.29	1.13	7.8	0.85	11.1	2.87
VE.88010709	0	0.25	2.45	6.0	2.38	5.8	4.13	4.07	2.01	2.46	2.28	6.0	0.79	11.1	3.59
VE.88010712	0	0.25	3.73	7.8	3.69	6.6	6.32	6.59	4.07	2.97	3.63	7.8	0.72	13.5	7.40
VE.88010718	0	0.25	5.26	11.1	5.10	8.5	7.30	8.28	3.84	-4.56	3.47	7.3	3.92	11.1	11.13
VE.88010721	0	0.25	5.10	13.5	5.01	8.9	6.88	7.39	3.75	4.10	2.92	7.3	4.15	13.5	11.77
VE.88010800	0	0.25	5.52	13.5	5.35	8.4	7.33	7.99	4.09	4.24	4.10	8.8	3.65	13.5	11.37
VE.88010803	0	0.25	5.35	12.2	5.19	9.4	7.57	7.58	4.13	4.46	2.95	8.8	4.43	12.2	12.10
VE.88010806	0	0.25	5.36	12.2	5.24	9.4	7.52	6.97	3.64	3.88	2.77	8.8	4.56	12.2	11.06
VE.88010809	11	0.39	11.04	0.0	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0.00
VE.88010812	0	0.25	9.03	13.5	8.82	9.8	14.46	13.29	7.67	6.79	4.18	6.9	7.98	13.5	26.15
VE.88010815	0	0.25	9.07	13.5	8.60	10.4	12.41	12.54	6.38	6.32	4.06	9.5	8.08	13.5	24.44
VE.88010818	0	0.26	7.78	13.5	7.50	10.4	12.02	11.66	6.33	7.19	3.77	8.3	6.79	13.5	20.46
VE.88010821	0	0.24	6.88	12.2	6.73	10.1	11.78	10.36	6.40	5.38	3.29	7.8	6.02	12.2	20.86
VE.88010900	0	0.24	4.89	10.2	4.98	10.2	7.00	7.46	3.82	3.74	2.77	7.3	4.00	10.2	13.42
VE.88010903	0	0.25	5.42	15.1	5.25	9.5	7.73	7.12	4.30	4.06	2.62	8.8	4.72	15.1	14.50
VE.88010906	0	0.25	4.47	15.1	4.21	8.5	7.08	7.28	4.10	4.06	2.66	6.6	3.56	15.1	15.81
VE.88010909	0	0.25	4.59	15.1	4.51	9.1	7.25	6.55	3.41	4.22	2.88	7.8	3.55	15.1	11.58
VE.88010912	0	0.26	4.08	15.1	3.97	8.6	5.67	6.35	3.31	3.04	2.79	9.5	2.94	15.1	10.83
VE.88010915	0	0.25	3.81	9.5	3.64	7.9	5.12	5.86	3.03	3.40	2.83	9.5	2.50	15.1	9.59
VE.88010918	0	0.25	4.00	15.1	3.74	7.5	5.89	5.86	3.33	3.07	2.84	9.5	2.77	15.1	10.00
VE.88010921	0	0.25	3.60	15.1	3.50	8.8	4.74	4.83	2.40	2.89	2.13	6.0	2.87	15.1	8.61

Figure 5. Analysis of wave measurements westman island.

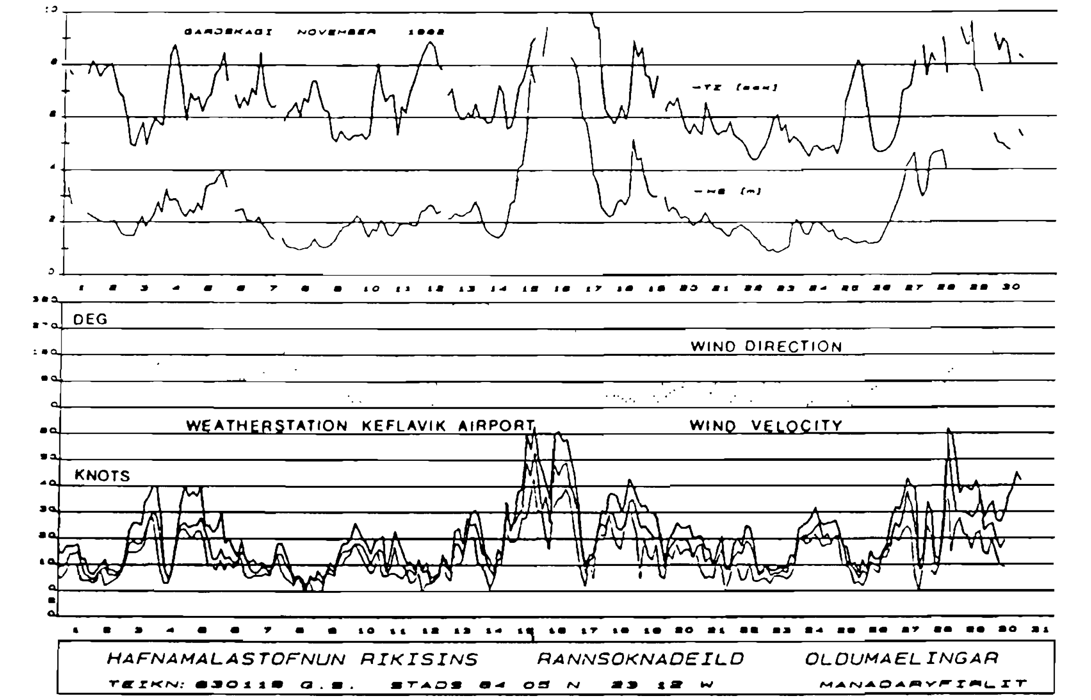

Figure 6. Monthly summary of wave recordings and weather observations.

boundary of sea-ice north of Iceland in the wave model is fixed with the shortest distance being 71 nautical miles. (The average distance to the sea ice from 1919 to 1943). This data has been analyzed and summarized in tables of significant wave heights versus wave periods and directions on a monthly, yearly, and five-yearly basis. The annual average significant wave-height is shown in Figure 10 for different wave directions, and the annual frequency of the significant wave height is shown on Figure 11. The long term wave statistic based on this five years' hindcasted data have been calculated according to Weibul distribution:

$$P_r(H_s < H) = 1\text{-exp}\,(-((H-H_o)/(H_c-H_o))^b)$$

Where H_o is equal to zero (two parameter Weibul distribution). Based on this data the significant wave heights for all direction are given in the following table. Based on this data, the significant wave heiqht with a return period of 10 and 100 years is 22 and 40 percent higher respectively than the wave height with a 1 year return period. Professor T. Karlsson (1973), has studied the problem of wave hindcasting around Iceland and has developed a computer model for this purpose. In the Thorlákshöfn harbour project in Iceland during 1973-1974, extreme wave statistics in deep water off Thorlákshöfn was needed. In 1974, he performed wave hindcasting based on ten of what were believed to be the most severe southerly storms during the period of 1963-1973. The statistical evaluation of the extreme wave conditions of the significant wave height for a southerly direction are H_{s10} = 12,1 m and H_{s100} = 13,7 m, for a return period of 10 and 100 years respectively. Based on the Thorlákshöfn wave measurement from 1976 the wave height is estimated: H_{s10} = 11,9 m and H_{s100} = 13,1 m (only a one year measurement, (G. VIGGÓSSON). The extreme wave heights for all directions based on NMI-data shown in Table 1 are 20-25 percent higher than the Thorlákshäfn hindcast data for a southerly direction and the measured wave data from 1976.

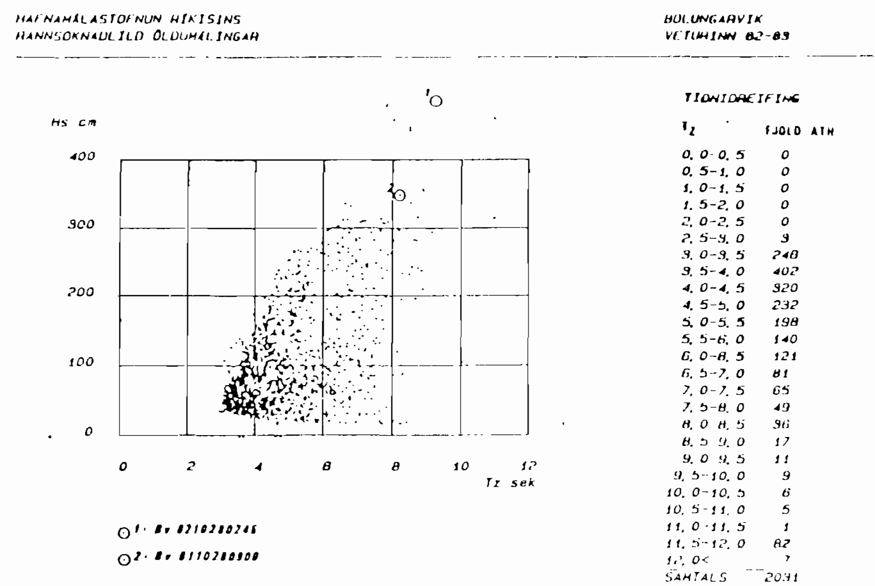

Figure 7. Summary of wave recordings during the winter 1982-1983 outside Bolungarvík harbour. Wave heights versus zero-crossing periods. (Recordings 1 and 2 were selected in wave disturbance tests).

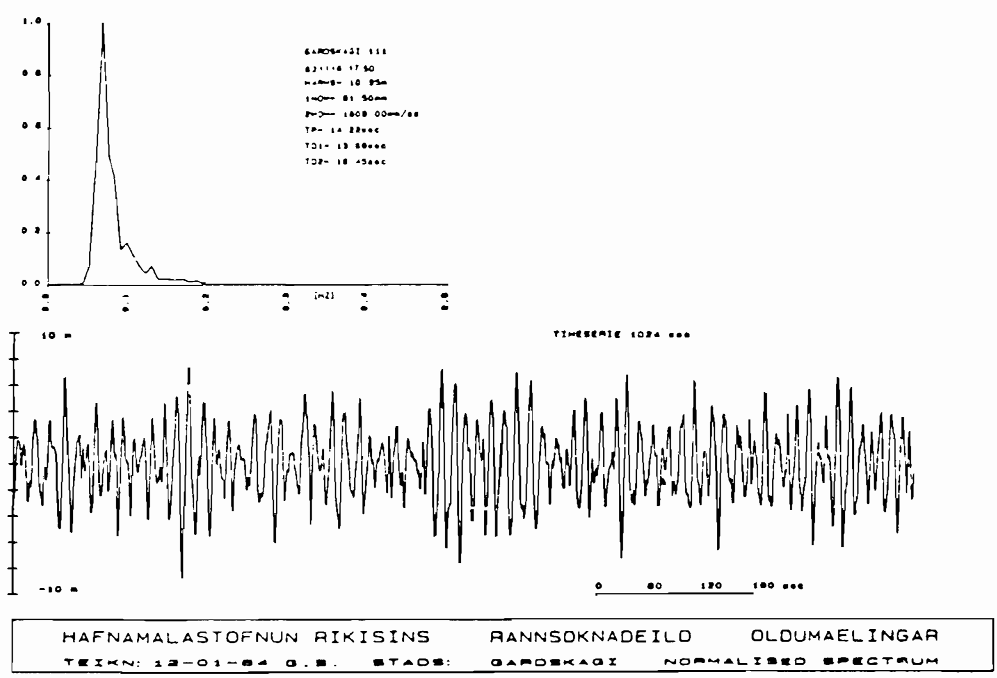

Figure 8. Spectral analysis of wave recordings.

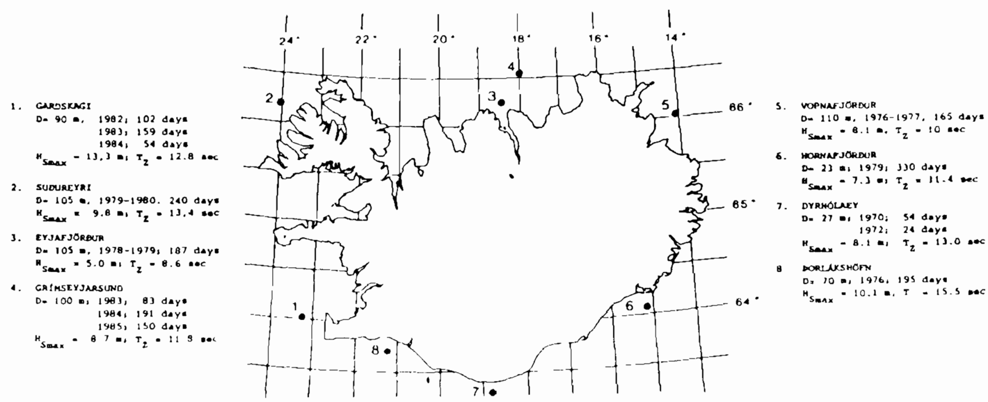

Figure 9. Summary of wave recordings offshore and highest measured significant wave heights.

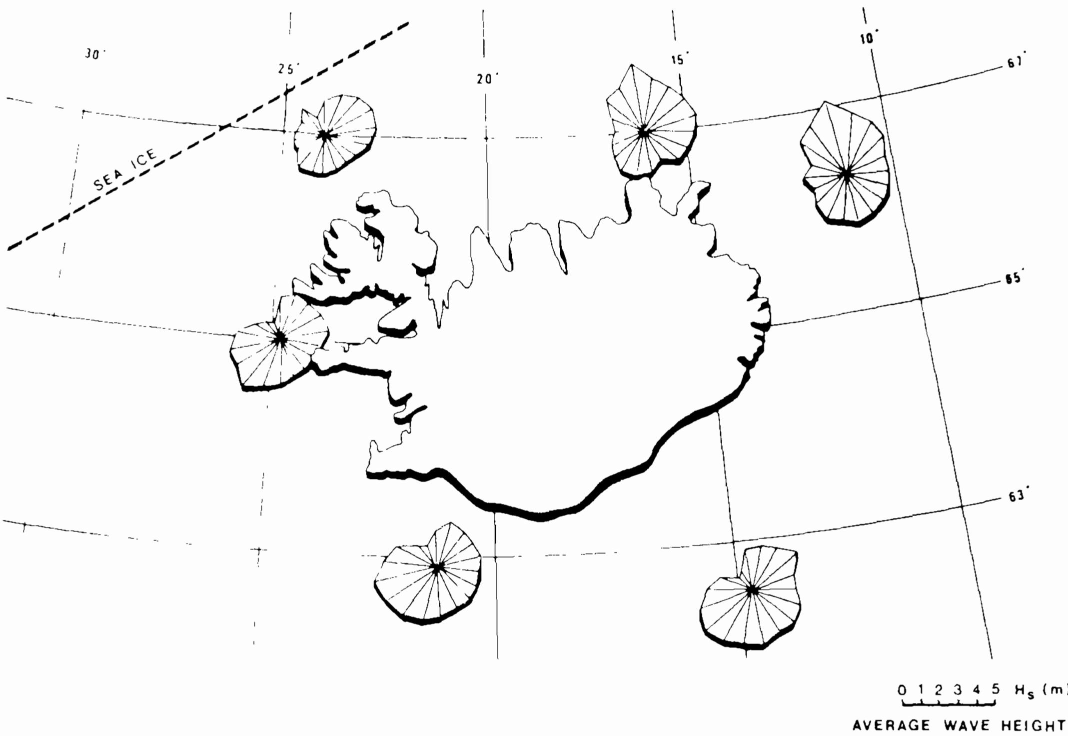

Figure 10. Annual average wave heights of different wave directions at six locations around Iceland.

SPECIFIC EXAMPLE ON WAVE RECORDING AT BAKKAFJÖRDUR

The port facilities at Bakkafjördur consistet of a small concrete pier serving fishing boats. The pier is located (Figure 12) in a small fiord inside the bay of Bakkafjördur exposed to local and offshore waves, an area that was to undergo

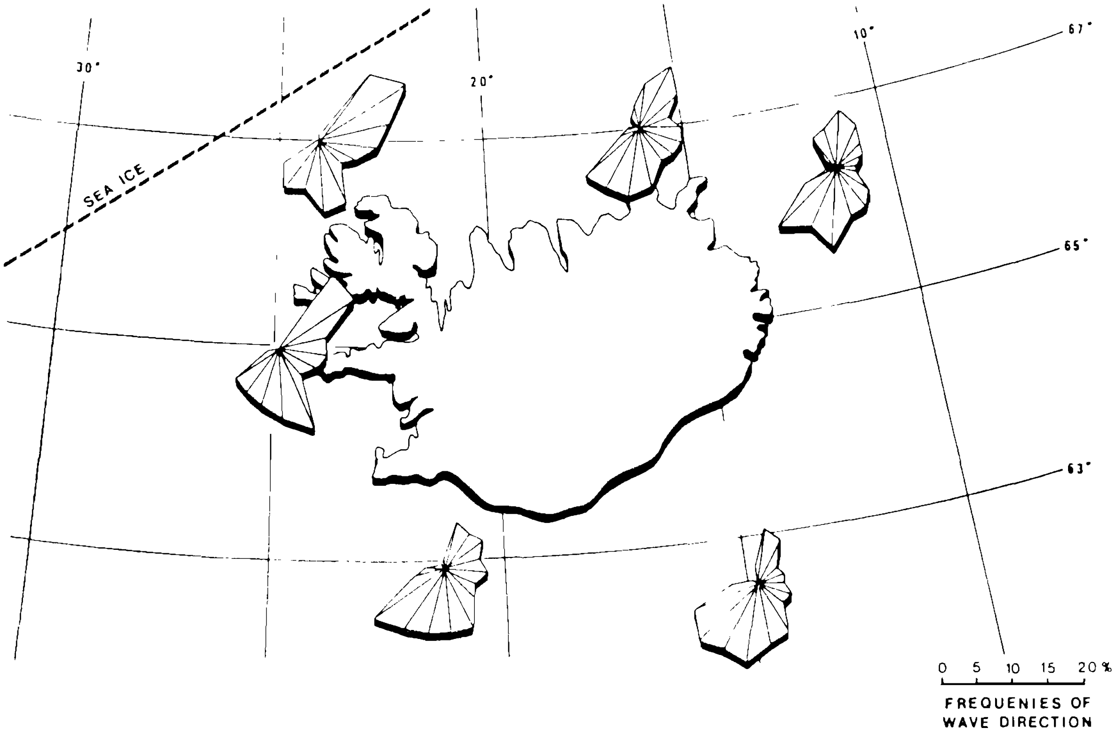

Figure 11. Annual frequency of wave directions at six locations around Iceland.

Table 1. *Long term wave heights, statistics, hindcasted NMI-data, 1972–1977*

Location	H_{s1} (m)	H_{s10} (m)	H_{s100} (m)
65,0 °N, 24,5° W	11,4	14,0	16,0
67,0 °N, 24,5° W	10,6	13,0	15,0
67,0 °N, 16,0° W	11,2	13,7	15,8
66,4 °N, 11,3° W	11,7	14,4	16,4
62,6 °N, 14,8° W	13,0	15,6	18,0
63,8 °N, 21,2° W	11,8	14,5	16,5

H_{s1}, H_{s10}, and H_{s100} are wave heights with return periods of 1,10 and 100 years respectively.

the improvement of port facilities. Soundings to 60 m water depth indicate lower wave heights closer in at a site near the bottom of the fiord. Refraction analysis also indicates lower wave action. Two Waveriders were installed in 1980. The outer Waverider was 400 m north of the pier at 17 m water depth and the inner Waverider at 2,1 km closer in at 12 m water depth. The highest wave situations measured during the winter 1980-81 were:

September 1980 $H_{sH} = 3{,}19$ m $T_{pH} = 11{,}4$ sec
$H_{sF} = 2{,}80$ m $T_{pF} = 11{,}8$ sec
October 1980 $H_{sH} = 4{,}05$ m $T_{pH} = 15{,}2$ sec
$H_{sF} = 2{,}87$ m $T_{pF} = 9{,}7$ sec

Where subscripts H and F refer to the outer and inner buoys respectively. The wave situation in October 1980, was estimated with a return frequency of one year, but the other in September 1980 with a return frequency of about 10 times per year.

Figure 13 shows the significant wave heights and peak periods during the two storms. The trend is similar, except in October 1980 where H_s is about one meter higher and T_{po} is also much higher. Differences are noticeable in the October situation as the peak energy top of the inner spectrum often almost disappears. In Figure 14 there is a plotting of H_{sF}/H_{sH} versus T_{pH} and T_{pF}/T_{pH} versus T_{pH}. The relationship of H_{sF}/H_{sH} decreases with an increase in T_{pH} and the relationship of T_{pF}/T_{pH} decreases almost line-

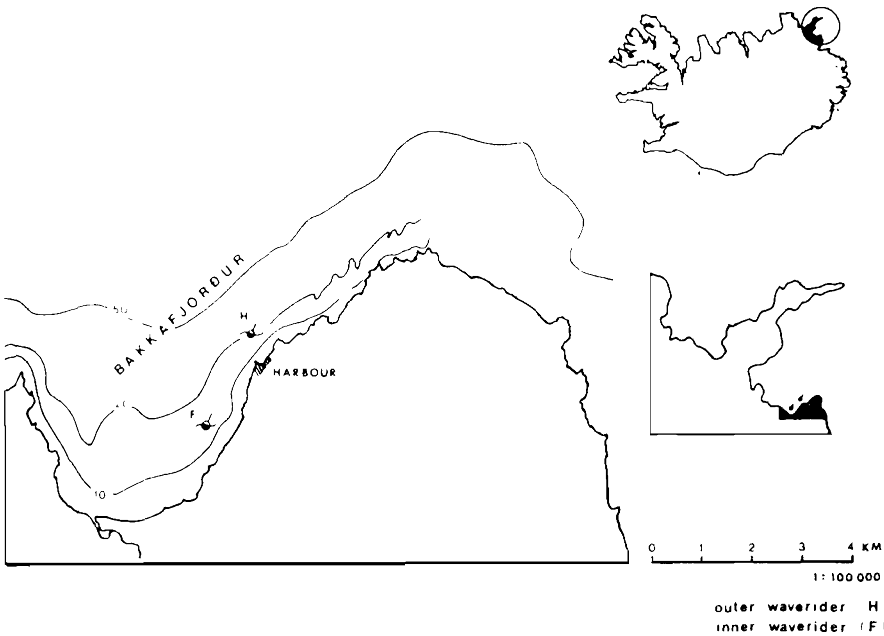

Figure 12. Location of Bakkafjördur.

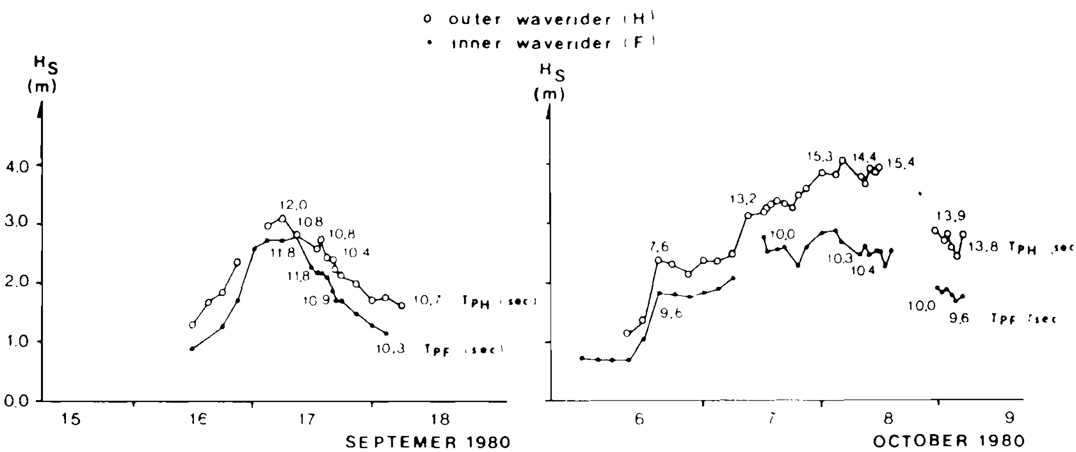

Figure 13. Wave recordings of two storms at Bakkafjördur.

arly with an increase inT_{pH} with T_{pF}/T_{pH} = 1,0 at T_{pH} = 11,0 sec. This specific example shows that a wave situation along the coast can change significantly within a small distance.

CONCLUSION

The Research Section of the Icelandic Harbour Authority is responsible for collecting wave data for the design, construction and maintenance of harbours. To fulfill these requirements the IHA runs accelerometer buoys and 5 pressure gauges, with various types of computers for data analyses. The section also runs a hydraulic laboratory with an irregular wave generator and other facilities for wave disturbance tests with moored ships

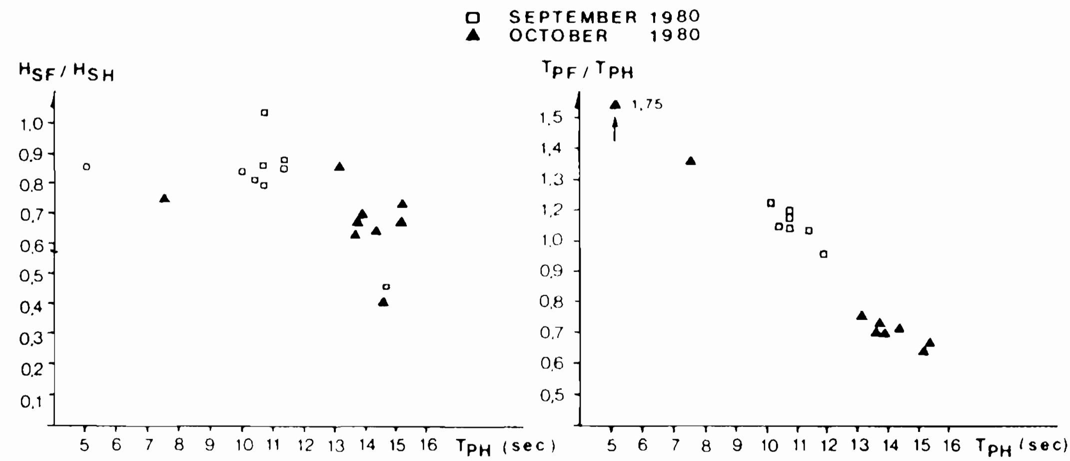

Figure 14. Relationship between significant wave heights and peak periods versus period at outer waverider.

and stability tests on rubble mound breakwaters.

To improve the knowledge of ship movements, instruments have been developed enabling recording of these movements, including surge sway, heave, roll, yaw and pitch and mooring forces. External forces like wind and waves are also recorded. To establish the relationship between offshore and inshore wave characteristics, the wave measurement program has during the last few years focused on collecting wave data simultaneously at many locations shorter distances apart. The example of wave recording at Bakkafjördur shows that wave conditions are very site specific. Unfortunately, the wave design conditions usually have to be evaluated on the basis of wave recordings over only one or two winter seasons. The experiences gained by comparing hindcasted and measured wave heights have been satisfactory. It can be stated that IHA has overcome most of the difficulties of wave recording, although measurements at sea are a very expensive and difficult task.

ACKNOWLEDGEMENTS

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□ RESUMEN □
La finalidad de la medina de oleaje en Islandia es obtener datos seguros y útiles para el diseuo, construcción y mantenimiento de Puertos. Desde 1969 la Autoridad Portuaria de Islandia ha trabajado con boyas Datawell (acelerómetros) y desde 1973 con sensores de presión, también Datawell, en condiciones normales 8 boyas y 5 sensores de presión. Durante los últimos auos el programa de medida de oleaje ha centrado su atención en la medida simultánea de oleaje en profundidades indefinidas y reducidas. Se instalaron sensores de presión en las dársenas para obtener datos de marea, ondas largas, sobreelevación por oleaje, marea meteorológica y oleaje. En este se resumen las medidas realizades en Islandia, una previsión en profundidades indefinidas y una descripción de un ejemplo concerto de registro de oleaje.—*Department of Water Sciences, University of Santander, Santander, Spain.*

□ RÉSUMÉ □
La measure des houles en Islande est destinée à la conception, la construction et la maintenance des ports. Depuis 1969, l'Islandic Harbourg Authority a fait fonctionner des bouées Datawell, et depuis 1973 différentes jauges de pression Datawell. Actuellement 8 bouées Datawell et 5 jauges de pression sont en service. Au cours des 5 dernières années, le programme de mesure a été centré sur la collecte simultanée des données au large et à proximité de la côte. Des transducteurs de pression ont été installés dans les ports afin d'ajuster ces données avec le marnage, les vagues à longue période, le retrait ou la montée dus à la mer du vent/ L'article résume les mesures de houle en Islande, localise les enregistrements et conclut par la description d'um exemple spécifique d'enregistrement de houle.—*Catherine Bressolier, EPHE, UA 910 CNRS, Montrouge, France.*

□ ZUSAMMENFASSUNG □
Das Ziel der Wellenmessung auf Island ist es, Datenmaterial zu erhalten, welches nüzlich für Gestaltung, Bau und Erhaltung der Häfen ist. Seit 1960 arbeitet die isländische Hafenbehörde (IHA) mit Datawell Bojen und seit 1973 mit verschiedenen Datawell Druckwasserstandanzeiger. Während der letzten Jahre konzentrierte sich das Wellenmessprogramm auf simultane Messungen "offshore" und "inshore" in Nähe der Häfen. Druckübermittler wurden in den Häfen installiert, um Daten z.b. über Tidenhub, langperiodische Wellen, Brandung und Wellenaufbau zu erhalten. Ausserdem wird neben den Lokalitäten de Wellenmessungen eine exemplarische Beschreibung einer Wellenmessung mitgeteilt.—*Ulrich Radtke, Geographisches Institut, Universität Düsseldorf, F.R.G.*