Hydraulics Research
Wallingford

WAVE PREDICTION IN RESERVOIRS - COMPARISON OF AVAILABLE METHODS

Report EX 1809
October 1988

Registered Office: Hydraulics Research Limited,
Wallingford, Oxfordshire OX10 8BA.
Telephone: 0491 35381. Telex: 848552

Wave prediction in reservoirs: Comparison of available methods,
Report EX 1809,
Hydraulics Research Ltd, Wallingford,
October 1988.

ABSTRACT

Most wave prediction methods have been based on measurements carried out in oceanic and coastal waters, with fetch lengths and fetch widths very different from those found in most UK reservoirs. Several attempts have been made by various researchers to devise methods of wave prediction in reservoirs, but few comparisons with measured data are available.

This report describes studies carried out to compare the results of six different wave prediction methods with measured wave heights in two Scottish reservoirs. Wind and wave conditions had been measured in Megget Reservoir for a previous study, but similar measurements in Loch Glascarnoch were commissioned especially for this project. All measurements were carried out by HR's Field Studies Section.

None of the six wave prediction methods which were examined gave particularly good agreement with the measured wave heights for all windspeeds and wind directions in both reservoirs. Of the methods examined, the Donelan/JONSWAP method was probably the best: it gave fairly good agreement for a wide range of wind directions, and any errors in predicted wave heights were almost always conservative.

The studies described in this report were funded by the Department of the Environment under research contract PECD 7/7/187, and formed a part of the research on reservoir safety recommended by the Department's Reservoir Safety Committee. The study was directed by Mr M W Owen, Research Manager of the Coastal Engineering Group, Maritime Engineering Department.

NOTATION

E	Wave energy
$E_i(f)$	Component of the wave energy/frequency spectrum
F	Fetch length
$\hat{F}$	Dimensionless fetch length (gF/U^2)
F_e	Effective fetch length
F_i	Fetch length measured along a direction Θ_i
F_φ	Fetch length measured along the predominant wave direction
g	Acceleration due to gravity
H_s	Significant wave height
$\hat{H}$	Dimensionless wave height gH_s/U^2
n	Directional spreading exponent
T_p	Wave period at the peak of the wave energy/frequency spectrum
$\hat{T}_p$	Dimensionless peak wave period gT_p/U
T_z	Mean zero-crossing wave period
$\hat{T}_z$	Dimensionless mean wave period, gT_z/U
U	Wind speed (usually at a height of 10m above water level)
Θ	Angle between wind direction and fetch direction
Θ_i	Fetch direction
Θ_w	Wind direction
φ	Predominant wave direction

WAVE PREDICTION IN RESERVOIRS - COMPARISON OF AVAILABLE METHODS

CONTENTS

CONTENTS (CONT'D)

CONTENTS (CONT'D)

FIGURES (CONT'D)

TABLES

APPENDIX

1 INTRODUCTION

The generation of waves on any body of water depends on the strength of the wind, the length of time for which it has been blowing (duration), the distance over the water for which it has been acting (fetch), and the depth of water. Most of the research effort on the measurement and prediction of waves has been devoted to oceanic and coastal waters, with long wide fetches and typical durations of several hours or even days. Inland reservoirs are however very different: fetch lengths are typically only a few kilometres, the width of the reservoir is frequently small compared to its length, and wave conditions are often governed by high wind speeds acting for very short durations, typically less than one hour. In addition, reservoirs are frequently constructed in deep valleys in upland areas, where the local topography can significantly affect both the wind speed and direction over the reservoir.

Bearing all these factors in mind, it would be very surprising if wave prediction methods developed for coastal and oceanic waters could be applied without modification to the estimation of waves in reservoirs. A limited amount of work has therefore been undertaken by various researchers to derive methods of modifying the wave prediction techniques used for open waters. Most of these modified methods have been reviewed in an earlier report on wave prediction in reservoirs (Ref 1). In this present report the wave predictions obtained by six different methods have been compared with measured wind and wave data obtained from two reservoirs in Scotland.

Details of Megget Reservoir and Loch Glascarnoch are given in Chapter 2 of this report, together with an account of the wind and wave measurement programmes in each. Chapter 3 describes the preliminary analysis of the data collected at both reservoirs, and in Chapter 4 the six methods used for wave prediction are described briefly. In Chapters 5 and 6 the predictions obtained are compared with the measured data. Finally Chapter 7 contains a discussion of the results, and draws some conclusions and recommendations from the study.

This report forms part of a research project on waves in reservoirs, commissioned by the Reservoirs Safety Committee of the Department of the Environment. The research includes not only the prediction of waves in reservoirs, but also the design of the protection against wave attack on the upstream face of dams.

2 WIND AND WAVE MEASUREMENTS

Wind and wave measurements have been carried out by Hydraulics Research Limited's Field Studies Team at Megget Reservoir and at Loch Glascarnoch reservoir, both in Scotland. The measurements at Megget were carried out on behalf of R H Cuthbertson and Partners, Consulting Engineers for the reservoir, whereas those at Loch Glascarnoch were obtained specifically for this research project on waves in reservoirs.

2.1 Megget Reservoir

Megget Reservoir lies on the River Tweed approximately 50km south of Edinburgh, and was officially opened in 1983 by Lothian Regional Council to meet an increasing water demand in the Edinburgh and Midlothian area. The reservoir is approximately rectangular, with a length of 3.5km and a width of 600m (Fig 1) and has a normal water level of 334m OD. The upstream face of the dam has a slope of 1 to 1.5, and is protected from wave attack by riprap rock armour layers. At the time of its design in the late 1970s, standard wave prediction techniques suggested that the reservoir would have an annual extreme significant wave height of a little over half a metre. However, visual observations on the reservoir since its completion indicated wave heights much larger than originally expected. This discrepancy could have been due either to inadequacies in the wave prediction methods used, or to unusually high winds in the immediate vicinity of the reservoir, or to the presence of a large reflected wave component from the upstream face of the dam. Because these larger waves could have serious implications for the design of the slope protection on the upstream face of the dam the consulting engineers for the reservoir commissioned Hydraulics Research to carry out wind and wave measurements at the site for a 12-month period, and by combining the results with other available wind data, to derive revised estimates of extreme wave heights.

Wind and wave recording was carried out from 23 April 1985 to 7 May 1986: the positions of the instruments are shown in Figure 1. For wave measurements a standard Datawell waverider buoy was used, deployed in about 35-40m of water about 250m west of the dam. For wind measurements the instrumentation consisted of a Didcot Instruments anemometer and wind direction sensor, both modified to include heating elements to prevent icing during winter. The equipment was mounted on a mast extending from the roof of a building on top of the draw off and overflow tower. This placed the equipment at 10-15m above the water surface (depending on the reservoir level at the time), and 5m above the dam crest.

In view of the short wind fetches involved in Megget Reservoir, a wind record was obtained every 15 minutes: wave records of 8 minutes 20 seconds duration were also obtained every 15 minutes, but only when the 15 minute average windspeed exceeded 10m/s. At this very exposed location, windspeeds greater than this occurred for about 16% of the time during the deployment period.

The data from the wind recorder was analysed on site to give the mean wind speeds and directions over 15 minutes and over 60 minutes, and the results transferred by magnetic tape to the mainframe computer at HR. The data from the wave recorder was logged on magnetic tape, and transferred to HR for analysis. Here the significant wave height and mean wave period were calculated for each record by the method of spectral analysis.

2.2 Loch Glascarnoch

Loch Glascarnoch is located in the North of Scotland, approximately 40km north west of Inverness. The reservoir and dam was designed by Sir Alexander Gibb and Partners, and construction was completed in 1957. The reservoir is owned by the North of Scotland Hydro Electric Board, and is used to generate electricity. The reservoir is approximately rectangular in plan, with a length of 7km and an average width of 740m (Fig 2). The normal water level is 252m OD. From the dam, the main axis of the reservoir is aligned roughly in a north westerly direction. The dam itself has a vertical upstream face consisting of dressed masonry blocks. The reservoir is located alongside the main road to Ullapool, and NSHEB staff have on several occasions noticed severe wave action at the dam, accompanied by a significant volume of spray overtopping.

Loch Glascarnoch was selected as the site for further measurements after a fairly extensive search amongst UK reservoirs and lakes. The main selection criteria were as follows:-

a) Length/width ratio about 10 or greater.
b) Length 4km or greater.
c) Fairly straightforward plan shape.
d) Main axis of reservoir aligned broadly with the prevailing wind direction.
e) Preferably located in a windy area, eg uplands.

Criterion (a) was to give a rather different ratio of Megget Reservoir (length/width about 6). It was decided to examine a greater length/width ratio because it was thought that there were few difficulties in predicting wave heights in relatively short and wide reservoirs. Criterion (b) would insure wave periods generally longer than 2 seconds, which is towards the lower limit of the sensitivity of the waverider buoys being used for wave measurements. Criteria (d) and (e) were hopefully to ensure that reasonably strong winds and hence large waves would occur in what was planned to be a fairly short deployment of the wind and wave instrumentation.

The initial search was carried out mainly by reference to the register of dams in the UK, prepared by the British National Committee on Large Dams (Ref 2), supplemented by information from Ordnance Survey maps at a scale of 1:25,000. A shortlist of about 20 reservoirs and lakes was identified.

Inevitably, most of these were located in Scotland or the north of England. A series of more practical criteria was then introduced to narrow the choice of sites:-

f) Suitable structure for mounting wind recording instrumentation.
g) Suitable building for housing the data receiving station, ideally with electrical power available.

h) Reasonable road access to the downwind end of the reservoir where the instrumentation would be deployed.

i) Local staff available and willing to perform routine maintenance.

Since the finally selected reservoir was likely to be some considerable distance away from Wallingford, criterion (i) was essential. The other criteria, while not essential, would have been very costly and/or inconvenient if not satisfied. Most of these practical considerations could only be discovered by direct discussions with the owners of the various reservoirs, and since about half of those on the shortlist were owned by NSHEB discussions were held first with them. Whilst in Scotland on other business, a member of HR's staff visited the Chief Engineer of NSHEB in Edinburgh, and with his staff went through the requirements and the list of reservoirs. As a result of these discussions Loch Glascarnoch was selected, and considerable assistance was received from the local staff of the North of Scotland Hydro Electric Board in deploying the equipment, and in carrying out the routine maintenance.

Wind and wave recording was carried out initially from 11 February 1987 to 20 May 1987, which it was hoped would give sufficient measurements of large waves for comparison with waves measured under similar windspeeds at Megget Reservoir. Both the waverider buoy and the anemometer were identical to those used on Megget Reservoir, and they were deployed at the positions shown in Figure 2. The waverider buoy was located in about 24 metres of water, about 760m metres west of the vertical faced dam. The anemometer was mounted on a mast extending from the railing of the access bridge leading to the draw off tower located on the south side of the loch. This placed the anemometer at 12 - 17m above the water surface (depending on the water level), and about 300m away from the waverider buoy.

Although the waverider buoy and anemometer were unchanged, the method of use and the data analysis procedures were changed.

A wind record was obtained every 15 minutes and when the average value over this period exceeded 8m/s (within the sector 220-340°N) the wave rider buoy logger was triggered. Waves were then recorded for 8 minutes 32 seconds every 15 minutes until the mean wind speed or direction dropped. During a second deployment in the winter of 87/88 (12 December 87 - 13 April 88) the wind speed and direction was recorded continuously and the wave buoy logger was triggered to record for 8 minutes 32 seconds every 1½ hours regardless of wind conditions.

During the first deployment only the ¼ hourly mean wind speed and direction were calculated at the site, with all other analysis being carried out at HR. During the second deployment both this wind analysis and a wave data analysis were carried out at the site with significant wave heights and mean wave periods being calculated from both a wave counting and spectral analysis. In all cases data was stored on magnetic tape cartridge for transfer to the HR main frame computer.

3 PRELIMINARY DATA ANALYSIS

3.1 Waverider Buoy accuracy

The waverider buoys used in both the Megget Reservoir and in Loch Glascarnoch are manufactured by Datawell B.V., Holland. The manufacturer's literature points out that the accuracy of the buoy decreases markedly for mean wave periods less than about 2 seconds. In many of the records obtained from the two reservoirs the indicated wave period fell below this threshold. After the completion of the measurements in Loch Glascarnoch the waverider buoy was therefore tested in a very large wave tank at Hydraulics Research. Tests were carried out at a range of wave periods and wave heights. The wave heights recorded by the waverider buoy were then compared with those measured by a standard laboratory twin-wire wave gauge, to derive a function describing the wave height correction factor to be applied at each wave period. Since these tests were carried out at fixed wave periods with regular waves the measured wave energy/wave frequency spectra for 16 representative sets of measurements from Megget reservoir were examined. For each spectrum, the wave energy at each wave frequency was corrected by the correction function just described: the complete spectrum was then re-assembled and the corrected value of significant wave height was calculated. The percentage error in wave height was then noted, and in general it was found to depend both on the wave period and the wave height, as shown by Figure 3. In theory, the error contours drawn on this Figure could have been used to correct all the wave measurements collected on both reservoirs. However, since almost all of the wave data had already been analysed, to apply this correction would have been very expensive. In view of this problem, it was decided to abandon all measurements having a mean period of less than 2.1 seconds. Figure 3 shows that all the remaining measurements would have a wave height error of less than 5%.

3.2 Megget data

The application of the wave period threshold of 2.1 seconds resulted in about half of the available wave data being abandoned, but this still left a considerable volume of data for analysis (2375 records).

The analysis of the Megget data which had been carried out in 1986 (Ref 3) had shown that the waverider buoy was almost certainly picking up wave energy reflected from the dam face. The main evidence for this was from the scatter diagram of wave height and wave period, reproduced here as Figure 4. This diagram shows the number of occasions when a given wave height and wave period occurred simultaneously. By drawing onto the diagram the contours of equal wave steepness (wave height/wave length) it could be seen that the largest waves had a steepness in excess of 0.08. Theoretical factors and measurements of ocean wave records lead one to expect a maximum wave steepness of about 0.065. Comparison of these two values indicated the presence of reflected waves with heights of about 23% (0.08/0.065-1) of the incident waves. The available literature on wave reflection suggests that for a 1 to 1.5 rock slope a reflection coefficient of about 30-40% would be expected for 2 second waves, slightly higher values than the data suggested. The difference between the measured and expected values was probably due to the position of the waverider buoy relative to the dam face. In the subsequent analysis of the wave data, it was assumed that the reflected wave heights ranged from 20% for 1.7s waves to 30% for 2.7s waves: these reflected waves were subtracted from the measured waves to give the heights of the incident waves arriving at the waverider buoy, and travelling towards the dam. It is the incident waves which are important in designing the slope protection on the dam face, and it is also the incident waves which are calculated by any of the available prediction methods. The same correction factor for wave reflections was therefore used for the data being considered in the present research project.

When the wind data at Megget was analysed in 1986 it was also found that windspeeds were very much higher than expected, due to the rather exposed location and to the relatively deep valley in which the reservoir is placed (see Fig 1). One anomaly which was never satisfactorily resolved was that the measured wind directions appeared to differ consistently by about 10-15° compared with those measured routinely at other anemograph stations in the locality. Furthermore, much better correlations between wind speed and wave height were obtained if the measured wind directions were corrected by this amount. For use in this present research project the corrected wind directions have been used throughout.

After abandoning records with wave periods less than 2.1 seconds, and after applying correction factors for wave reflections and for wind direction, all the resulting data was divided into subsets according to the mean hourly wind direction. Direction intervals of 10° were used, centred on 005°, 015°, 025° etc. For each data subset a scatter table was then prepared, showing the number of occasions when a given significant wave height occurred simultaneously with a given mean-hourly windspeed, for the selected mean hourly wind direction. These scatter tables are reproduced in this report as Tables 1-14, and on each table the mean value of the significant wave height for each windspeed is also listed. It is interesting to note from these Tables that there is a considerable scatter in the wave heights associated with a given windspeed and wind direction. This scatter is partly due to the stochastic nature of waves, whereby no two relatively short duration measurements of the same wave field can be expected to give identical results. However it is probably mainly due to the variations in windspeed and wind direction during the hour-long period over which the mean wind conditions are calculated. No prediction method can estimate the magnitude of the wave height variations, but it should be possible to predict the mean wave height for any given mean hourly windspeed and direction.

3.3 Glascarnoch data

Because of the very few occasions on which strong windspeeds occurred during the periods of deployment of the wind and wave recording equipment at Glascarnoch, the total number of records obtained was rather low. After abandoning those measurements showing mean wave periods less than 2.1 seconds, a total of only 432 records was left for detailed analysis.

The remaining wave measurements were plotted as a scatter diagram showing the number of occasions when a given wave height and a given wave period occurred simultaneously, Figure 5. By drawing onto this diagram the contours of equal wave steepness it was seen that some of the recorded waves had a steepness in excess of 0.08, against a maximum expected steepness of 0.065. The scatter diagram thus indicated the presence of reflected waves with heights up to about 40% of the incident waves. For a vertical dam face a reflection coefficient very close to one would be expected, implying that almost all the wave energy incident upon the dam face would be reflected back from it. Because the significant wave height of a given wave train is proportional to the square root of the energy of the waves, this implies a reflected wave height of about 41.4% of the incident wave height. This agrees well with the maximum of the reflected waves measured at Glascarnoch. However the measurements show that the reflected waves are present only for the shorter wave periods caused by the lower windspeeds, and disappear at the longer wave periods caused by the higher windspeeds. The waverider buoy is located at 760m from the dam face and it seems likely that the waves reflected at the dam are unable to travel this distance against the stronger winds. In the subsequent analysis of the data it was assumed that the reflected waves varied from 41% for 2.1 second waves to zero for 3.3 second waves: these reflected waves were then subtracted from the measured waves to give the heights of the incident waves arriving at the waverider buoy.

After abandoning records with wave periods less than 2.1 seconds, and after applying correction factors for wave reflections, all the resulting data was divided into subsets according to wind direction. Direction intervals of 10° were used, centred on 285, 295, 305°N etc. For each data subset a scatter table was then prepared, showing the number of occasions when a given significant wave height occurred simultaneously with a given windspeed, for the selected wind direction. These scatter tables are reproduced in this report as Tables 15-20. On each table the mean value of the significant wave height at each windspeed is also listed.

4 PREDICTION METHODS TESTED

The significant wave heights obtained for a given windspeed and wind direction were compared with several different wave prediction methods, which are now briefly described. Further details of most of these methods are given in the literature review published at the beginning of this research project (Ref 1).

4.1 SMB/Saville method

The SMB wave prediction curves were originally produced in 1947 for forecasting wave heights and periods in oceans and coastal waters. The curves were revised in 1952, and soon afterwards (1954) Saville published a method for using the SMB prediction curves to forecast wave heights and periods in reservoirs (Ref 4). The method relied upon the replacement of the direct fetch length (measured along the wind direction) by an effective fetch over a range of directions spanning the wind direction. The effective fetch length is actually defined as

$$F_e = \frac{\sum F_i \cos^2 (\Theta_i - \Theta_w)}{\sum \cos (\Theta_i - \Theta_w)}$$

where the summation is over the range $\left|\Theta_i - \Theta_w\right| \leq 45°$ and

F_e = effective fetch

F_i = fetch length along the ith radial

Θ_w = wind direction

Θ_i = direction of the ith radial

The effective fetch length as defined above was derived on a purely empirical basis in order to achieve good agreement between the 1952 SMB wave prediction curves and an extensive series of wind and wave measurements carried out in reservoirs in the USA between 1952 and 1954. Nevertheless the concept of effective fetch became firmly established in all standard reference books from the mid 1950's until the mid 1970's, where it was always quoted in conjunction with the SMB wave prediction curves. These curves however were themselves revised further in 1976, which has caused some confusion. For example, the wave prediction method quoted in the Institution of Civil Engineers Guide to Reservoir Safety (Ref 5), published in 1978, is based on the 1952 and not the 1976 version of the SMB curves. At fetch lengths typical of reservoirs differences of up to about 10% can occur between the wave heights predicted by the two versions at the same windspeed.

In this present study, the 1976 SMB wave prediction formulae have been used,

$$\hat{H} = 0.283 \tanh [0.0125 \hat{F}^{0.42}]$$

$$\text{and } \hat{T}_z = 7.54 \tanh [0.077 \hat{F}^{0.25}]$$

where the dimensionless wave height H, dimensionless period T_z, and dimensionless fetch length F are defined as:-

$$\hat{H} = g H_s/U^2$$
$$\hat{T}_z = g T_z/U$$
$$\hat{F} = g F/U^2$$

4.2 JONSWAP methods

4.2.1 General JONSWAP formulae

The JONSWAP method was first published in 1973, (Ref 6) and this or other very similar methods due to Mitsuyasu or to Lin have now become almost universally adopted for predicting wave conditions in oceanic and coastal waters. The basic equations predict the complete shape of the wave energy/wave frequency spectrum. However these basic equations can be integrated numerically to give the significant wave height and peak period. Different authors achieve slightly different numerical constants in their integrated equations, but those used at Hydraulics Research are as follows:-

$$\hat{H} = 0.00178\ \hat{F}^{0.5}$$

and $$\hat{T}_p = 0.352\ \hat{F}^{0.3}$$

where $\hat{T}_p = g\ T_p/U$

With a typical JONSWAP spectrum of wave energy the mean zero-crossing and the peak wave periods are related by the expression $T_z = 0.87\ T_p$.

The JONSWAP prediction formulae were derived from measurements in the open sea, and there has been considerable discussion about the fetch length which should be used when predicting wave conditions in enclosed waters such as reservoirs. For comparison with the wave measurements in Megget and Glascarnoch reservoirs three different definitions of fetch length have been used, as described below.

4.2.2 Direct fetch

The fetch length was measured as the simple distance from the waverider buoy location to the edge of the reservoir in the direction of the mean hourly wind.

4.2.3 Seymour's effective fetch

Soon after the publication of the JONSWAP formulae, Seymour (Ref 7) proposed an alternative to Saville's definition of effective fetch. Seymour's proposals are based on the commonly-held belief that wave energy normally has a directional distribution which is proportional to $\cos^2\Theta$, where Θ is the deviation angle from the predominant wave direction. Seymour's basic formula then becomes

$$E = \frac{2}{\pi}\sum E_i \cos^2 (\Theta_i - \Theta_w) \Delta\Theta$$

from which the significant wave height is given by

$$H_s = 4\sqrt{E}$$

In Seymour's formula, E_i is the wave energy generated along a direction Θ_i by a wind speed U acting over a fetch length F_i, and $\Delta\Theta$ is the directional increment. The summation is carried out over the range $|\Theta_i - \Theta_w| \leq 90°$. The wave energy E_i is calculated by the JONSWAP formula, and the combined method is sometimes referred to as the JON(SWAP) SEY(MOUR) wave prediction method. It should be noted that since Seymour's method is based on a weighted average of wave energies (rather than fetch lengths as in Saville's method) this calculation has to be repeated for each different windspeed.

Recently there has been some discussion about whether the directional spread of wave energy is as broad as the function $\cos^2\Theta$ suggests (90% of the energy within about ±50°). There is general agreement that a function of the form $\cos^n\Theta$ is appropriate, but values of n up to 30 have been suggested (90% of the energy within about ±15°). As well as the standard Seymour method, the very narrow $\cos^{30}\Theta$ distribution was therefore also used in the comparisons with the measured data.

4.3 Donelan methods

4.3.1 Original method

In 1980 Donelan published a further alternative definition of effective fetch, based on the argument that the fetch length should be measured along the wave direction, not along the wind direction (Ref 8). However, the wind speed to be used in the wave prediction formula should then be the component along the wave direction. Donelan further argued that the predominant wave direction was that which produces the maximum value of T_p. Donelan actually used his own unique wave prediction formulae, which can be written as

$$\hat{H} = 0.00366\ \hat{F}^{0.38}$$
$$\hat{T}_p = 0.541\ \hat{F}^{0.23}$$

Re-arrangement of the second of these equations shows that the maximum value of T_p is achieved when

the product $[\cos(\Theta_w - \varphi)]^{0.54}\ F\varphi^{0.23}$ reaches a maximum within the range $|\Theta_w - \varphi| \leq 90°$ where φ is the predominant wave direction, and F_φ is the fetch length measured along that direction. For any irregular shoreline, and a given wind direction, the value of φ satisfying this condition can only be determined by trial and error. However, since the product is independent of wind speed, the calculations have to be performed only once for each wind direction (see Appendix).

It is difficult to understand why the predominant wave direction should necessarily coincide with that giving the maximum value of T_p, rather than the maximum value of wave energy E or wave height H_s (= $4\sqrt{E}$). If this was the case, re-arranging the first equation would give the product $\cos(\Theta_w-\varphi)^{1.24}\ F_{\varphi}^{\ 0.38}$ to be maximised. This alternative definition was examined briefly for the Megget data, but the predominant wave direction was very little different from that calculated by maximising T_p. For comparison with the measured data, Donelan's original assumption of maximising T_p was therefore used.

4.3.2 Donelan/JONSWAP method

Donelan's original method of wave prediction used his own wave prediction formulae, which are significantly different from almost all other modern formulae. Donelan's basic concept of measuring the fetch length along the wave direction rather than the wind direction was therefore combined with standard JONSWAP formulae, and compared with the measured data. Using the JONSWAP formula, T_p is maximised when the product $\cos(\Theta_w-\varphi)^{0.4}\ F_{\varphi}^{\ 0.3}$ reaches its peak within the range $|\Theta_w-\varphi| \le 90°$. (Maximising H_s would depend on the product $\cos(\Theta_w-\varphi)\ F^{0.5}$).

5 COMPARISONS AT MEGGET RESERVOIR

5.1 Basis of comparison

As described in the previous section, the measured wave data was compared with the results obtained from 6 wave prediction methods, namely:-

(a)	SMB/Saville	(SMB/S)
(b)	JONSWAP straight fetch	(JONSWAP/SF)
(c)	JONSEY $\cos^2\Theta$ distribution	(JONSEY/2)
(d)	JONSEY $\cos^{30}\Theta$ distribution	(JONSEY/30)
(e)	Donelan's original method	(DONELAN)
(f)	Donelan/JONSWAP method	(DON/JON)

For the Megget data, tables 1-14 include the mean value of significant wave height for each wind speed and for each wind direction. The 6 wave prediction methods listed above were therefore used to calculate significant wave heights for the same values of windspeed and direction shown in those tables. For each wave prediction method, plots were then prepared showing the comparison between measured and calculated wave heights a) for a range of directions at given windspeeds, b) for a range of windspeeds at given directions. With windspeed increments of 2m/s, and direction intervals of 10°, a large number of such plots were produced. For this report, a representative sample of these plots has been selected, and also plots have been combined to allow some comparison between the accuracies of different prediction methods.

5.2 Effect of wind direction

Comparisons between the measured and predicted wave heights for different wind directions are shown in Figures 6 to 11 at standard windspeeds of 14 and 22m/s. All the prediction methods tested gave maximum wave heights occurring at wind directions within the range 235° to 245°N, very close to the axis of the reservoir which has an orientation of 240°N. The measured wave heights however do not show such a peak at either of the standard windspeeds shown, nor at any of the other windspeeds examined during the study. For a given windspeed, the largest wave heights tend to occur for wind directions between 175 and 215°N. The reason for this is not at all clear: one possible reason may be the fact that although the reservoir is aligned at 240°N for most of its length, the upstream end is at a different alignment, with the last kilometre or so curving through 220°N and eventually

180°N (Fig 1). It is possible that waves generated in this arm of the reservoir for a wind direction of 195° for example may be able to propagate around the corner and into the main portion of the reservoir, whereas at a wind direction of say 240° waves generated in the upstream arm may be dissipated on the south eastern shore.

5.2.1 SMB/Saville method

Figures 6 and 7 show the predictions using this method, and the comparisons with the measured data, at windspeeds of 14 and 22m/s respectively. Both Figures show a slight overprediction of wave height for winds blowing along the reservoir axis, with an error of about 5%. The predicted wave heights are much more symmetrical about the reservoir axis than are the measured waves, and thus the predictions are greater than measured for more northerly wave directions, and are less than measured for more southerly winds.

5.2.2 JONSWAP methods

Figures 8 and 9 show comparisons with measured data at windspeeds of 14 and 22m/s respectively, for the three different JONSWAP methods, namely JONSWAP/SF, JONSEY/2, and JONSEY/30 (see Section 5.1). From these diagrams it is clear that the original Seymour method (JONSEY/2) seriously underpredicts the wave heights for all windspeeds and directions. JONSEY/2 is based on a wide angular spread of wave energy which gives 90% of the wave energy within about 50° of the wind direction. If this angular spread is reduced considerably to about ±15° (JONSEY/30) then the agreement between measured and calculated waves is much better, with about 3% underprediction for wind directions close to the reservoir axis. However the under-prediction at other wind directions is rather larger. If the direct or straight line fetch is taken as the basis for predictions (JONSWAP/SF) the results at medium windspeeds (14m/s) are very similar to JONSEY/30, but at higher windspeeds there is an overprediction by about 15% for wind directions close to the reservoir axis, with significant under prediction for other wind directions.

5.2.3 Donelan methods

Figures 10 and 11 show comparisons with the measured data at windspeeds of 14 and 22m/s respectively, for the two different Donelan methods, namely DONELAN and DON/JON (see Section 5.1). The original DONELAN method considerably overpredicts wave heights for most wind directions, except in the region of 210°N where measured wave heights are larger than would have been expected. If the Donelan wave forecasting formulae are replaced by the JONSWAP formulae (DON/JON), then the overprediction is considerably reduced, especially at the higher windspeed. Again the best agreement is obtained at wind directions of about 210°N.

5.3 Effect of windspeed

Comparisons between the measured and predicted wave heights for different windspeeds are shown in Figures 12 to 20 for wind directions of 245° (close to the alignment of the main axis of the reservoir - 240°N), and 215° and 285°N. Not all comparisons are included in this report, only those which serve to amplify or to clarify the observations noted from the comparisons of the different methods when examining the effects of wind direction.

5.3.1 SMB/Saville method

Figure 12 shows the comparison between measured and predicted wave height at a wind direction of 245°N. Generally the lines of predicted and measured waves are very nearly parallel, but with the predicted wave heights about 0.03m greater than measured. For wind directions of 215° an 285°N (Figs 13 and 14) the agreement is much worse, mainly because predicted wave heights are fairly symmetrical about the direction of the reservoir's main axis whereas the measured data has a pronounced skewness. Consequently wave heights are underpredicted at 215°N, and over predicted at 285°N.

5.3.2 JONSWAP methods

Figure 15 shows the comparison between the measured and predicted wave heights for a wind direction of 245°N, and for the three different JONSWAP prediction methods tested (JONSWAP/SF, JONSEY/2 and JONSEY/30). In general, JONSEY/2 gives a considerable underprediction of wave heights at all windspeeds, with increasing error both in absolute and percentage terms at the higher windspeeds. On the other hand, JONSWAP/SF overpredicts wave heights at almost all windspeeds, on average by about 0.09m. JONSEY/30 gives much better agreement with the measured data, although there appears to be some tendency to underpredict slightly the wave heights at very high windspeeds. This tendency is probably exaggerated by the relatively high waves measured at a windspeed of 28m/s, but even if this data point is dismissed the underlying trend is still present.

Figures 16 and 17 show the comparisons at 215°N and 285°N. At 215°N, all three methods give very similar results, with considerable underprediction of the wave heights measured at this wind direction. At 285°N, JONSWAP/SF and JONSEY/30 give almost identical underpredictions, whereas JONSEY/2 happens to give fairly good agreement, although this is probably largely coincidence.

5.3.3 Donelan methods

Figure 18 shows the comparison between the measured and predicted wave heights for a wind direction of 245° for the two different Donelan methods employed, namely DONELAN and DON/JON. Both Donelan methods show a very considerable overprediction of wave heights, with the original DONELAN method giving increased errors at large windspeeds. At 215°N, Figure 19, both Donelan methods give better agreement than any of the other methods tests. At 285°N, Figure 20, the Donelan methods give a substantial overprediction of wave heights.

5.4 Discussion

Probably the most surprising feature of the wave measurements obtained in Megget Reservoir was that for a given windspeed the largest waves were not caused by winds blowing along the reservoir's main axis aligned at about 240°N. For wind directions of about 175-215°N the waves were significantly larger. None of the wave prediction methods which were tested could reproduce this feature, and for a given windspeed all gave maximum wave heights for wind directions close to 240°N.

For winds blowing close to 240°N, the SMB/Saville method gave reasonably good agreement, which is perhaps not surprising since this method was very extensively tested and calibrated against wind and wave measurements in US reservoirs. However, this method uses rather old wave prediction formulae, and many people have argued that with the modern JONSWAP formulae Saville's effective fetch concept is not necessary, and a straight fetch should be used. This argument is not borne out by the Megget data where the JONSWAP/SF method significantly overpredicts wave heights.

Both Saville's and Seymour's concept of effective fetch are based on a $\cos^2\Theta$ distribution of wave energy, with the fetch length based on a weighted average over about ±45°. The method of weighting differs between the two methods, but the JONSEY/2 method shows a substantial underprediction of wave height. The JONSEY/30 method, which uses Seymour's basic concept, but with a $\cos^{30}\Theta$ wave energy distribution, gives much better agreement with the measured data. With this method, the fetch length is a weighted average over about ±15°. Both of the Donelan methods which were tested gave significant overpredictions of wave height.

6 COMPARISONS AT LOCH GLASCARNOCH

6.1 Basis of comparison

After completing the comparisons between measured and predicted wave heights at Megget Reservoir, it was decided that only 4 methods of prediction should be used in the comparisons with the Loch Glascarnoch wind and wave data. These 4 methods were

(a)	SMB/Saville	(SMB/S)
(b)	JONSWAP straight fetch	(JONSWAP/SF)
(c)	JONSEY $\cos^{30}\Theta$ distribution	(JONSEY/30)
(d)	Donelan/JONSWAP method	(DON/JON)

For the Loch Glascarnoch data, Tables 15-20 show the mean value of significant wave height for each wind speed and each wind direction. The four wave prediction formulae were first used to calculate significant wave heights for the same values of windspeed and wind direction as used in these tables. However, because Loch Glascarnoch is rather narrow, the longest fetch exists only over a very narrow range of directions (296-304°N). For windspeeds of 295, 305, 315°N etc it was found that some of the prediction methods completely ignored this long fetch. The predictions were therefore repeated at wind directions of 290, 300, 310°N etc.

For each wave prediction method, plots were then prepared showing the comparison between measured and calculated wave height
(a) for a range of directions at given windspeeds
(b) for a range of windspeeds at given directions.

A large number of plots were produced, but only a representative selection are included in this report.

6.2 Effect of wind direction

Comparisons between measured and predicted wave heights for different wind directions are shown in Figures 22 to 29 at standard windspeeds of 8 and 14m/s. All the prediction methods produce maximum values of significant wave height at about 300°N, close to the alignment of the reservoir (303°N). The measured data shows little consistency in the direction of the wind causing the largest waves.

6.2.1 SMB/Saville methods

Comparisons of the measured wave heights and those predicted using this method are shown in Figures 22 and 23 for windspeeds, of 8 and 14m/s respectively. At both windspeeds and for almost all wave directions the predictions are noticeably lower than the measured wave heights.

6.2.2 JONSWAP methods

Figures 24 and 25 show comparisons with measured data at windspeeds of 8 and 14m/s respectively for predictions made using the JONSWAP/SF method, while Figures 26 and 27 show the comparison with JONSEY/30 predictions. The straight fetch method (JONSWAP/SF) gives fairly good agreement at both windspeeds when the wind direction is closely aligned with the axis of the reservoir (about 300°N). However for all other wind directions there is a serious underestimate of wave heights. The JONSEY/30 method on the other hand gives substantial underpredictions for all windspeeds and wind directions.

6.2.3 Donelan/JONSWAP methods

Figures 28 and 29 show wave height predictions produced by the DON/JON methods, compared with measured significant wave heights, at windspeeds of 8 and 14m/s respectively. At the lower windspeed, the agreement between measured and predicted wave heights is fairly good for all directions. At the higher windspeed the DON/JON method tends to overpredict the measured wave height for most directions.

6.3 Effect of wind speed

Although comparisons between the measured and predicted wave heights for different windspeeds were drawn for several different wind directions, only those for a wind direction of 300°N, close to the alignment of the axis of the reservoir, are reproduced here. Figures 30 to 33 show the comparison between the measured wave heights and predicted heights for the SMB/S, JONSWAP/SF, JONSEY/30 and DON/JON methods respectively. As expected from the wind direction plots discussed earlier, poor agreement is observed at all windspeeds for both the SMB/S and JONSEY/30 methods. The agreement for the JONSWAP/SF is fairly good, but this is rather deceptive because the predicted wave heights fall off very sharply for wind directions only about 5° away from the reservoir alignment. The agreement for the DON/JON method is also quite good, as it is also for quite a wide range of directions.

6.4 Discussion

Because Loch Glascarnoch is rather long and narrow, wave heights would be expected to peak for wind directions directly along the axis of the reservoir, and to fall away for other wind directions. The measured wave data is not entirely consistent, but it appears to show almost constant wave heights over a fairly large range of wind directions especially at lower windspeeds. Of the four prediction methods examined, the DON/JON method was the only one which gave a similar behaviour. The DON/JON method gives a heavy weighting to the fetch length which corresponds to the wave direction rather than the wind direction: in a long narrow reservoir the Donelan method will almost always give a wave direction close to the alignment of the main axis of the reservoir. Consequently, although the longer fetch lengths in Loch Glascarnoch exist only over a very narrow range of directions (296 to 304°N), the Donelan method is biased heavily towards this fetch length for a fairly wide range of directions. In direct contrast, any straight fetch method bases its predictions on the largest fetch lengths only for wind directions of about 295-305°N, and completely ignores that fetch for other wind directions. Consequently the predicted wave heights decrease very sharply for directions only slightly outside the range of the longest fetches.

Both the SMB/S and the JONSEY/30 methods are based on a weighted average of fetch lengths, with the heaviest weighting being given to the fetch length corresponding to the wind directions. The SMB/S takes a weighting over about ±45° from the wind direction, compared to about ±15° for the JONSEY/30 method. In a long narrow reservoir the effective fetch lengths determined by these methods of averaging would be very different: the fact that they tend to give rather similar results for winds acting along the axis of Loch Glascarnoch is presumably due to the counterbalancing differences in the SMB and JONSWAP wave prediction formulae used.

7 DISCUSSION OF OVERALL RESULTS

7.1 Comparison of reservoirs

The comparisons which have been made between the wave height predictions and measurements have yielded quite different results for the two reservoirs. Before discussing these results further, it is probably worthwhile recalling the differences between the two reservoirs. Megget reservoir has a maximum fetch length of 3850 metres from the location of the wave rider buoy, occurring along the direction 243°N. However at directions outside the range 232 to 251°N the fetch length is reduced to less than half the maximum. At Glascarnoch the maximum fetch length is greater (6345 metres at 303°N) but the range of directions having long fetches is smaller, with fetch lengths reducing to less than half the maximum for directions outside the range 296-304°N.

In Megget Reservoir, the wave rider buoy was 250m from the riprap protected sloping face of the dam, and there was evidence of waves reflecting off the dam face and reaching the waverider buoy. The measured wave steepness suggested that the measured wave heights should be reduced by about 20% on average, which was done. The waverider buoy in Loch Glascarnoch was 760m from the vertical faced dressed-stone dam, but there was evidence of significant wave reflections reaching the waverider buoy for shorter wave periods. Deductions ranging from 41% for 2.1s waves to 0% for 3.3 second waves were therefore made to this measured data.

The waverider buoy in Megget Reservoir was deployed for just over 12 months: after omitting those periods when wind speeds were less than 10m/s, and after abandoning those records with mean zero-crossing wave periods of less than 2.1 seconds, a total of 2375 mean-hourly records of wind and wave conditions was available for analysis. These covered quite a wide range of wind directions, and with maximum windspeeds up to 30m/s. The Glascarnoch buoy was deployed for a shorter period, amounting to 8 months in total. After allowing for storms which were missed because of malfunctions of the equipment, and after omitting those records with mean wave periods of less than 2.1 seconds, a total of 426 mean-hourly records of wind and wave conditions was available. This is much less than at Megget, and the range of windspeeds was also much less, with a maximum windspeed of only 18m/s.

Analysis of the wave heights and wind directions at Megget Reservoir yielded the very surprising results that for a given windspeed wave heights did not reach a maximum for wind directions along the axis of the reservoir (243°N), but for winds from about 175-215°N. In this matter the Glascarnoch data was not very consistent, but it appeared to show very little dependence of wave height on wind direction, at least not within the range of directions which were recorded (±25° of the reservoir axis).

7.2 Directional variation in wave heights

For a given windspeed, all 6 wave prediction methods which were examined produced maximum wave heights for wind directions close to the alignment of the main axis, for both reservoirs. In both reservoirs also the rate at which predicted wave heights reduced as the wind direction moved away from the main reservoir alignment depended very much on the fetch-averaging techniques used by the different prediction methods. As would be expected, the rate of reduction was quite slow for fetch-averaging techniques based essentially on a $\cos^2\Theta$ distribution of wave energy about the wind direction (SMB/Saville, JONSEY/2), which implies a weighted averaging procedure over about ±45°. The rate of reduction is also quite slow for the Donelan/JONSWAP method, which also depends on a type of $\cos^2\Theta$ function. At the opposite extreme, the method based on the straight fetch measured along the wind direction (JONSWAP/Straight fetch) gives a very rapid reduction as the wind direction moves away from the central axis. The method based on the $\cos^{30}\Theta$ distribution (JONSEY/30) also gives quite a rapid reduction, with the original Donelan method giving a slower reduction.

Although the measured wave data from the two reservoirs is not particularly conclusive, it appears that wave heights in long narrow reservoirs do not in fact depend very strongly on wind direction, at least for directions within about ±30°-40° from the central axis. This suggests that the ideal prediction method will probably be based on something like a $\cos^2\Theta$ wave energy distribution, rather than the much narrower $\cos^{30}\Theta$ or straight fetch assumptions. This would appear to rule out methods similar to JONSWAP/SF or JONSEY/30 which have been examined in this study.

7.3 Estimation of wave heights

The various methods examined which use some form of $\cos^2\Theta$ function are SMB/Saville, the original JONSWAP/Seymour method, and Donelan's method. In the SMB/Saville method, the fetch lengths are measured over directions within 45° of the wind direction, and a weighted fetch length is calculated. This fetch length is then introduced into the SMB wave prediction formula. The weighting method is such that even for winds blowing along the central axis, the effective fetch in a long narrow reservoir is less than half the reservoir's length, the exact ratio depending on the length/width ratio of the reservoir. However some people have argued recently that the SMB wave prediction formulae greatly exaggerate wave heights at fetch lengths typical of reservoirs, since the formulae were developed from measurements in the open oceans with long fetch lengths. Certainly, in comparison with the JONSWAP formulae, for the same windspeed and fetch length the SMB formulae give wave heights varying between about 15 and 65% larger for fetch lengths typical of reservoirs (Fig 1, Ref 1). It is therefore argued that Saville's effective fetch concept for reservoirs, giving effective fetches noticeably shorter than the real fetch (for winds along the reservoir axis) is simply a correction factor to compensate for the basic inaccuracy of the SMB formulae. If this is indeed the case, then the SMB/Saville method would not necessarily be expected to give good agreement with measured data for all fetch lengths, fetch length/width ratios, and windspeeds. Thus, although it may have worked well for the 3 American reservoirs where it was calibrated, it would not necessarily work well for reservoirs of different size or shape.

For the Megget Reservoir, the agreement between measured and predicted wave heights, using the SMB/Saville method, is actually quite good - better than any of the other methods in fact. However for Loch Glascarnoch, which is both longer and relatively narrower, the SMB/Saville method seriously under-predicts wave heights, perhaps over-correcting for the exaggerated predictions of the SMB formulae.

In the original JONSWAP/SEYMOUR method, the wave energy is calculated along each fetch direction within 90° of the wind direction, using the component of windspeed along that fetch direction as input to the JONSWAP wave prediction formulae. The total wave energy is then obtained from a weighted summation of the individual fetch wave energies. The effective fetch length which can be deduced from this method varies with the windspeed, but again for long narrow reservoirs is typically less than about 70% of the reservoir length, even for winds blowing along the central axis. The JONSWAP/Seymour method was originally calibrated against measurements in coastal inlets. However the measurements in both Megget and Glascarnoch Reservoir, which both have a larger fetch length/fetch width ratio than the coastal inlets, show that the JONSWAP/Seymour method seriously underpredicts wave heights in reservoirs.

In the Donelan method, the fetch length is always measured along the wave direction, not along the wind direction, and the wind speed component along the wave direction is used in any wave prediction formulae. In a long narrow reservoir, Donelan's method of calculation is such that the wave direction is very close to the central axis of the reservoir for all wind directions within about ±80° of the axis. For winds blowing directly along the axis, this means that the full windspeed U and the maximum fetch length F_m are used for wave predictions. For winds blowing at an angle to the axis, the maximum fetch length and $U\cos\Theta$ are used, where Θ is the angle between wave direction and wind direction.

The Glascarnoch measurements showed fairly good agreement between the measured wave heights and the predictions made by the Donelan/JONSWAP method. Donelan's original method was not examined in detail at Glascarnoch, but would have given predicted wave heights slightly higher than the Donelan/JONSWAP method for winds along the reservoir axis, and slightly lower for wind directions well away from the axis.

The measurements in Megget Reservoir showed that the original Donelan method, using Donelan's own prediction formulae, grossly overpredicted the measured wave heights. Using Donelan's concept with the JONSWAP wave prediction formulae gave better agreement, though there was still a significant overprediction, typically about 25%.

8 CONCLUSIONS

Six different methods have been used in a comparison of predicted wave heights and measured wave heights obtained in an earlier study of Megget Reservoir. In addition, wind and wave measurements were carried out specifically for this study in Loch Glascarnoch reservoir, and compared with predictions. Loch Glascarnoch is about twice as long as Megget Reservoir, but about the same width.

Analysis of the wave heights and wind directions at Megget Reservoir yielded the very surprising results that for a given windspeed wave heights did not reach a maximum for wind directions along the reservoir axis, but for winds about 30-60° off the main alignment. The Glascarnoch data was not very consistent in this respect, but it did not appear to show much dependence of wave height on wind direction, at least not within the range of directions recorded.

For a given windspeed, all six wave prediction methods which were examined produced maximum wave heights for wind directions close to the alignment of the main axis, for both reservoirs. The rate at which the predicted wave height reduced for other wind directions depended very much on the fetch-averaging techniques used by the different prediction methods. Compared with the measured variations of wave height with wave direction, it seems very likely that the ideal prediction method would be based on something like a $\cos^2\theta$ wave energy distribution about some central wave direction.

None of the six wave prediction methods which were examined gave particularly good agreement with the measured wave height for all windspeeds and directions in both reservoirs. In Megget Reservoir the original SMB/Saville method gave the best agreement of the methods examined, but the same method seriously underestimated wave heights in Loch Glascarnoch. In Loch Glascarnoch, the modified Donelan/JONSWAP method gave the best agreement, but this method significantly overestimated wave heights in Megget Reservoir.

The main conclusion of this study must therefore be that none of the available wave prediction methods can be relied upon to produce accurate estimates of the wave heights in reservoirs of similar size and shape to Megget Reservoir and Loch Glascarnoch. Of the methods which have been examined in this study, the Donelan/JONSWAP method is probably the best: it gives fairly good agreement for a wide range of wind directions, and any errors in predicted wave heights are likely to be on the high side, leading to a safe design.

9 REFERENCES

1. WAVE PREDICTION IN RESERVOIRS: A Literature Review, Report No EX 1527, Hydraulics Research Ltd, Wallingford, February 1987.

2. DAMS IN THE UK 1963-1983, British National Committee on Large Dams, London, 1983.

3. WIND AND WAVE MEASUREMENTS AT MEGGET RESERVOIR, Report No EX 1477, Hydraulics Research Ltd, Wallingford, 1986.

4. SAVILLE T, The effect of fetch width on wave generation, Tech Memo No 70, US Army Corps of Engineers, Beach Erosion Board, December 1954.

5. FLOODS AND RESERVOIRS SAFETY, AN ENGINEERING GUIDE, Institution of Civil Engineers, London, 1978.

6. HASSELMANN K et al, Measurements of wind wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP) Deutsche Hydrographische Institute, Hamburg, 1973.

7. SEYMOUR R J, Estimating wave generation on restricted fetches, Proc Am Soc Civ Engrs, Vol 103, No WW2, May 1977.

8. DONELAN M A, Similarity theory applied to the forecasting of wave heights, periods and directions, Proc Canadian Coastal Conf, Nat Research Council, Canada, 1980.

TABLES.

Table 1 - Megget Reservoir recorded wave heights 175 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 170-179 Deg N

WAVE HEIGHT BANDS Hs (m)						
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						
1.0-1.099						
0.95-0.999						
0.9-0.949						
0.85-0.899						
0.8-0.849						
0.75-0.799						
0.7-0.749						
0.65-0.699						
0.6-0.649			1			
0.55-0.599			2			
0.5-0.549			4			
0.45-0.499			4			
0.4-0.449			1			
0.35-0.399						
0.3-0.349						
0.25-0.299						
0.2-0.249						
0.15-0.199						
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average Values	ERR	ERR	0.52	ERR	ERR	ERR

Table 2 - Megget Reservoir recorded wave heights 185 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 180-189 Deg N

WAVE HEIGHT BANDS Hs (m)						
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						
1.0-1.099						
0.95-0.999						
0.9-0.949						
0.85-0.899						
0.8-0.849						
0.75-0.799						
0.7-0.749				1		
0.65-0.699				3		
0.6-0.649		1	3	2		
0.55-0.599		3	8	2		
0.5-0.549		3	14			
0.45-0.499		9	6			
0.4-0.449		5	3			
0.35-0.399		7	1			
0.3-0.349		2				
0.25-0.299						
0.2-0.249						
0.15-0.199						
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average	ERR	0.45	0.5[illegible]	0.64	ERR	ERR

Table 5 - Megget Reservoir recorded wave heights 195 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 190-199 Deg N

WAVE HEIGHT BANDS Hs (m)						
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						
1.0-1.099						
0.95-0.999					3	
0.9-0.949					1	
0.85-0.899						
0.8-0.849			1	3		
0.75-0.799				10	3	
0.7-0.749			2	15	1	
0.65-0.699			9	23		
0.6-0.649			26	18		
0.55-0.599			32	17		
0.5-0.549			32	7	1	
0.45-0.499			38	5	1	
0.4-0.449			20	1		
0.35-0.399			19			
0.3-0.349			1			
0.25-0.299			1			
0.2-0.249						
0.15-0.199						
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average Values	ERR	ERR	0.52	0.65	0.79	ERR

Table 4 - Megget Reservoir recorded wave heights 205 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 200-209 Deg N

WAVE HEIGHT BANDS Hs (m)							
1.5-1.599							
1.4-1.499							
1.3-1.399							
1.2-1.299							
1.1-1.199							
1.0-1.099							
0.95-0.999				1	2	2	3
0.9-0.949					6	2	1
0.85-0.899				3	8	1	
0.8-0.849				1	3	1	
0.75-0.799			1	7	8	1	
0.7-0.749		1		13	7	1	
0.65-0.699		1	7	29	7		
0.6-0.649		1	10	27	2		
0.55-0.599		2	13	17	1		
0.5-0.549		14	17	9			
0.45-0.499		32	20	3			
0.4-0.449		61	10	1			
0.35-0.399		35	3	1			
0.3-0.349		16	1				
0.25-0.299		2					
0.2-0.249		2					
0.15-0.199							
0.1-0.149							
0.05-0.099							
0-0.049							
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9	21-22.9
Average	ERR	0.43	0.53	0.65	0.79	0.88	0.96

MEGGET Recorded Wind Data
Adjusted data Directions 210-219 Deg N

WAVE HEIGHT BANDS Hs (m)							
1.5-1.599							
1.4-1.499							
1.3-1.399							
1.2-1.299							
1.1-1.199							1
1.0-1.099						1	3
0.95-0.999						3	13
0.9-0.949					1	3	4
0.85-0.899				2	1	3	3
0.8-0.849				6	9	5	
0.75-0.799				4	8	1	
0.7-0.749				5	11		
0.65-0.699				10	13		
0.6-0.649			5	14	3		
0.55-0.599		6	18	15			
0.5-0.549		14	45	2			
0.45-0.499		57	39	1	1		
0.4-0.449		70	19	2			
0.35-0.399		36	11				
0.3-0.349		18	2				
0.25-0.299		13					
0.2-0.249		2					
0.15-0.199							
0.1-0.149							
0.05-0.099							
0-0.049							
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9	21-22.9
Average Values	ERR	0.42	0.49	0.65	0.73	0.89	0.97

Table 6 - Megget Reservoir recorded wave heights 225 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 220-229 Deg N

WAVE HEIGHT BANDS Hs (m)						
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						1
1.0-1.099					1	3
0.95-0.999					2	
0.9-0.949					1	
0.85-0.899					4	
0.8-0.849				1		
0.75-0.799				1		
0.7-0.749				4		
0.65-0.699			1	3		
0.6-0.649			2	11	2	
0.55-0.599			6	4	2	
0.5-0.549			20	7	2	
0.45-0.499			15	3	2	
0.4-0.449			16			
0.35-0.399			15	1		
0.3-0.349			6			
0.25-0.299						
0.2-0.249						
0.15-0.199						
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average	ERR	ERR	0.46	0.61	0.74	1.08

Table 7 - Megget Reservoir recorded wave heights 235 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 230-239 Deg N

WAVE HEIGHT BANDS Hs (m)								
1.5-1.599								
1.4-1.499								
1.3-1.399								
1.2-1.299								
1.1-1.199								
1.0-1.099							1	
0.95-0.999							2	3
0.9-0.949								
0.85-0.899					4	1	1	
0.8-0.849					2	3	5	1
0.75-0.799				2	5	7	3	
0.7-0.749				4	11	3		
0.65-0.699			2	8	11	3		
0.6-0.649			4	14	15	7		
0.55-0.599			7	20	14	6		
0.5-0.549			13	15	5			
0.45-0.499			16	22	2			
0.4-0.449			19	9				
0.35-0.399			11	5	1			
0.3-0.349			6	1				
0.25-0.299			1					
0.2-0.249								
0.15-0.199								
0.1-0.149								
0.05-0.099								
0-0.049								
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9	21-22.9	23-24.9
Average Values	ERR	ERR	0.46	0.54	0.65	0.69	0.86	0.94

Table 8 - Megget Reservoir recorded wave heights 245 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 240-249 Deg N

WAVE HEIGHT BANDS Hs (m) \ Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9	21-22.9	23-24.9	25-26.9	27-28.9	29-30.9
1.5-1.599											
1.4-1.499											1
1.3-1.399										2	
1.2-1.299										1	1
1.1-1.199									1	1	1
1.0-1.099							1		2		
0.95-0.999							2	5	2		
0.9-0.949					1		3	6	3		1
0.85-0.899						2	7	7			
0.8-0.849					1	1	12	8			
0.75-0.799					1	7	4	4			
0.7-0.749				1	6	7	3	3			
0.65-0.699				5	11	8	4				
0.6-0.649				7	16	7	3				
0.55-0.599				22	7	1					
0.5-0.549				31	9	3					
0.45-0.499				45	8						
0.4-0.449				22	2						
0.35-0.399				2							
0.3-0.349											
0.25-0.299											
0.2-0.249											
0.15-0.199											
0.1-0.149											
0.05-0.099											
0-0.049											
Average Values	ERR	ERR	ERR	0.51	0.61	0.69	0.81	0.86	1.00	1.28	1.19

Table 9 - Megget Reservoir recorded wave heights 255 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 250-259 Deg N

WAVE HEIGHT BANDS Hs (m)							
1.5-1.599							
1.4-1.499							
1.3-1.399							
1.2-1.299							
1.1-1.199							
1.0-1.099							
0.95-0.999							1
0.9-0.949							2
0.85-0.899				1			1
0.8-0.849						1	
0.75-0.799						3	1
0.7-0.749				1	3	8	2
0.65-0.699				2	7	6	
0.6-0.649				3	6	4	1
0.55-0.599				3	6	3	
0.5-0.549				2	2	3	
0.45-0.499				7	3		
0.4-0.449				15			
0.35-0.399				5			
0.3-0.349							
0.25-0.299							
0.2-0.249							
0.15-0.199							
0.1-0.149							
0.05-0.099							
0-0.049							
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9	21-22.9
Average Values	ERR	ERR	ERR	0.49	0.61	0.67	0.82

Table 10 - Megget Reservoir recorded wave heights 265 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 260-269 Deg N

WAVE HEIGHT BANDS Hs (m)						
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						
1.0-1.099						
0.95-0.999						
0.9-0.949						
0.85-0.899						
0.8-0.849						
0.75-0.799						
0.7-0.749						
0.65-0.699						
0.6-0.649						
0.55-0.599						
0.5-0.549						
0.45-0.499						
0.4-0.449						
0.35-0.399					12	
0.3-0.349					46	
0.25-0.299					18	
0.2-0.249						
0.15-0.199					11	
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average	ERR	ERR	ERR	ERR	0.30	ERR

Table 11 - Megget Reservoir recorded wave heights 275 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 270-279 Deg N

WAVE HEIGHT BANDS Hs (m)						
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						
1.0-1.099						
0.95-0.999						
0.9-0.949						
0.85-0.899						
0.8-0.849						
0.75-0.799						
0.7-0.749						
0.65-0.699						
0.6-0.649						
0.55-0.599						
0.5-0.549						
0.45-0.499						
0.4-0.449						
0.35-0.399						
0.3-0.349						
0.25-0.299			3			
0.2-0.249						
0.15-0.199			1			
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average Values	ERR	ERR	0.25	ERR	ERR	ERR

Table 12 - Megget Reservoir recorded wave heights 285 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 280-289 Deg N

WAVE HEIGHT BANDS Hs (m)								
1.5-1.599								
1.4-1.499								
1.3-1.399								
1.2-1.299								
1.1-1.199								
1.0-1.099								
0.95-0.999								
0.9-0.949								
0.85-0.899								
0.8-0.849								
0.75-0.799								
0.7-0.749								
0.65-0.699								
0.6-0.649								
0.55-0.599								
0.5-0.549								
0.45-0.499						3		1
0.4-0.449					4		1	3
0.35-0.399						16		
0.3-0.349						1	3	
0.25-0.299					1	4		
0.2-0.249					4			
0.15-0.199					3			
0.1-0.149								
0.05-0.099								
0-0.049								
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9	21-22.9	23-24.9
Average Values	ERR	ERR	ERR	ERR	0.28	0.37	0.35	0.44

MEGGET Recorded Wind Data
Adjusted data Directions 290-299 Deg N

WAVE HEIGHT BANDS Hs (m)						
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						
1.0-1.099						
0.95-0.999						
0.9-0.949						
0.85-0.899						
0.8-0.849						
0.75-0.799						
0.7-0.749						
0.65-0.699						
0.6-0.649						
0.55-0.599						
0.5-0.549						
0.45-0.499						
0.4-0.449					3	1
0.35-0.399				3	1	
0.3-0.349				1		3
0.25-0.299				3		
0.2-0.249				5		
0.15-0.199						
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average Values	ERR	ERR	ERR	0.28	0.41	0.35

Table 14 - Megget Reservoir recorded wave heights 305 Deg N

MEGGET Recorded Wind Data
Adjusted data Directions 300-309 Deg N

WAVE HEIGHT BANDS Hs (m)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
1.5-1.599						
1.4-1.499						
1.3-1.399						
1.2-1.299						
1.1-1.199						
1.0-1.099						
0.95-0.999						
0.9-0.949						
0.85-0.899						
0.8-0.849						
0.75-0.799						
0.7-0.749						
0.65-0.699						
0.6-0.649						
0.55-0.599						
0.5-0.549						
0.45-0.499						
0.4-0.449						
0.35-0.399						
0.3-0.349						
0.25-0.299						
0.2-0.249			4			
0.15-0.199						
0.1-0.149						
0.05-0.099						
0-0.049						
Wind Speed Values (m/s)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19-20.9
Average Values	ERR	ERR	0.23	ERR	ERR	ERR

Table 15 - Loch Glascarnoch recorded wave heights 285 Deg N

GLASCARNOCH Recorded Wind Data
Adjusted data Directions 280-289 Deg N

WAVE HEIGHT BANDS Hs (m)									
1.5-1.599									
1.4-1.499									
1.3-1.399									
1.2-1.299									
1.1-1.199									
1.0-1.099									
0.9-0.999									1
0.8-0.899				1		1		3	
0.7-0.799							1		
0.6-0.699			1	3	2		1		
0.5-0.599			1	4	4	2			
0.4-0.499			2	4	1	1			
0.3-0.399			7	3	2				
0.2-0.299			1	2					
0.1-0.199			1						
0-0.099									
Wind Speed Values (m/s)	1-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9
Average Values	ERR	ERR	0.38	0.49	0.52	0.60	0.70	0.85	0.95

Table 16 - Loch Glascarnoch recorded wave heights 295 Deg N

GLASCARNOCH Recorded Wind Data
Adjusted data Directions 290-299 Deg N

WAVE HEIGHT BANDS Hs (m)							
1.5-1.599							
1.4-1.499							
1.3-1.399							
1.2-1.299							
1.1-1.199							
1.0-1.099							
0.9-0.999							
0.8-0.899						1	
0.7-0.799						2	2
0.6-0.699						1	
0.5-0.599				1			2
0.4-0.499				3			1
0.3-0.399				14	6		
0.2-0.299				4			
0.1-0.199							
0-0.099							
Wind Speed Values (m/s)	1-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9
Average Values	ERR	ERR	ERR	0.35	0.35	0.75	0.61

Table 17 - Loch Glascarnoch recorded wave heights 305 Deg N

GLASCARNOCH Recorded Wind Data
Adjusted data Directions 300-309 Deg N

WAVE HEIGHT BANDS Hs (m)								
1.5-1.599								
1.4-1.499								
1.3-1.399								
1.2-1.299								
1.1-1.199								
1.0-1.099								
0.9-0.999								1
0.8-0.899							1	
0.7-0.799		1					1	
0.6-0.699			1		3	1	1	
0.5-0.599		2	1			2	2	
0.4-0.499	1	5	3		4	6	1	
0.3-0.399	1	5	9		9			
0.2-0.299	6	5	2		1			
0.1-0.199			1					
0-0.099								
Wind Speed Values (m/s)	1-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9
Average Values	0.29	0.39	0.37	ERR	0.42	0.49	0.63	0.95

Table 18 - Loch Glascarnoch recorded wave heights 315 Deg N

GLASCARNOCH Recorded Wind Data
Adjusted data   Directions   310-319 Deg N

WAVE HEIGHT BANDS Hs (m)							
1.5-1.599							
1.4-1.499							
1.3-1.399							
1.2-1.299							
1.1-1.199							
1.0-1.099							
0.9-0.999							
0.8-0.899						1	1
0.7-0.799			1	1		2	3
0.6-0.699			1	1		6	2
0.5-0.599		1	3	4			
0.4-0.499		1	2				
0.3-0.399		1	6	4			
0.2-0.299		2					
0.1-0.199							
0-0.099							
Wind Speed Values (m/s)	1-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9
Average Values	ERR	0.37	0.47	0.50	ERR	0.69	0.73

Table 19 - Loch Glascarnoch recorded wave heights 325 Deg N

GLASCARNOCH Recorded Wind Data
Adjusted data Directions 320-329 Deg N

WAVE HEIGHT BANDS Hs (m)							
1.5-1.599							
1.4-1.499							
1.3-1.399							
1.2-1.299							
1.1-1.199							
1.0-1.099							
0.9-0.999							
0.8-0.899							
0.7-0.799				1			
0.6-0.699			1			1	
0.5-0.599			1	1			
0.4-0.499						2	4
0.3-0.399			3	1		13	
0.2-0.299	3			1		1	
0.1-0.199							
0-0.099							
Wind Speed Values (m/s)	1-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9
Average Values	0.25	ERR	0.45	0.48	ERR	0.37	0.45

Table 20 - Loch Glascarnoch recorded wave heights 335 Deg N

GLASCARNOCH Recorded Wind Data
Adjusted data — Directions 330-339 Deg N

WAVE HEIGHT BANDS Hs (m)								
1.5-1.599								
1.4-1.499								
1.3-1.399								
1.2-1.299								
1.1-1.199								
1.0-1.099								
0.9-0.999								
0.8-0.899								
0.7-0.799								
0.6-0.699								
0.5-0.599				1		3	24	7
0.4-0.499						28	46	7
0.3-0.399				12	13	23	6	2
0.2-0.299			2	10	4			
0.1-0.199								
0-0.099								
Wind Speed Values (m/s)	1-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9
Average Values	ERR	ERR	0.25	0.32	0.33	0.41	0.47	0.48

FIGURES.

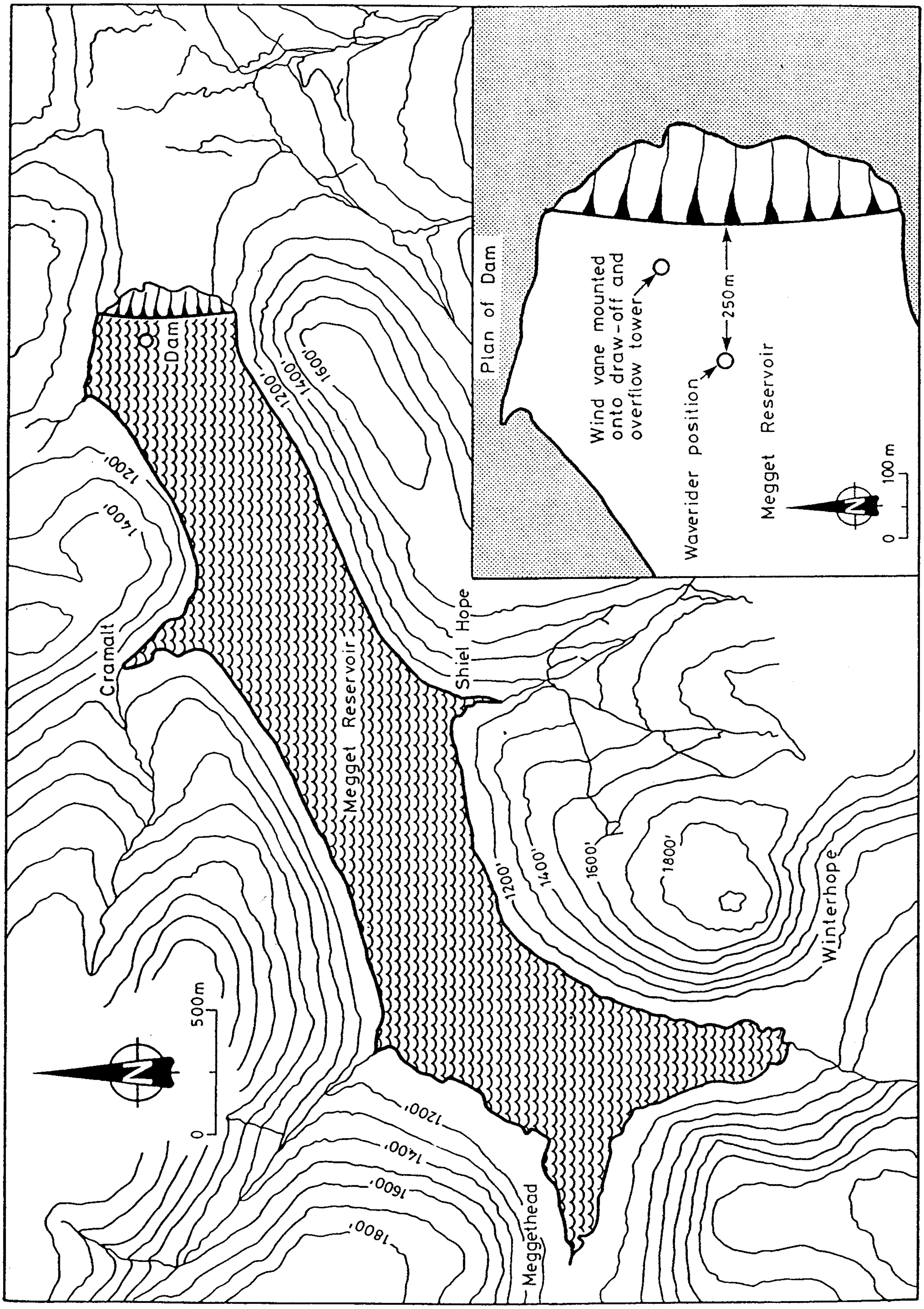

Fig 1 Megget Reservoir

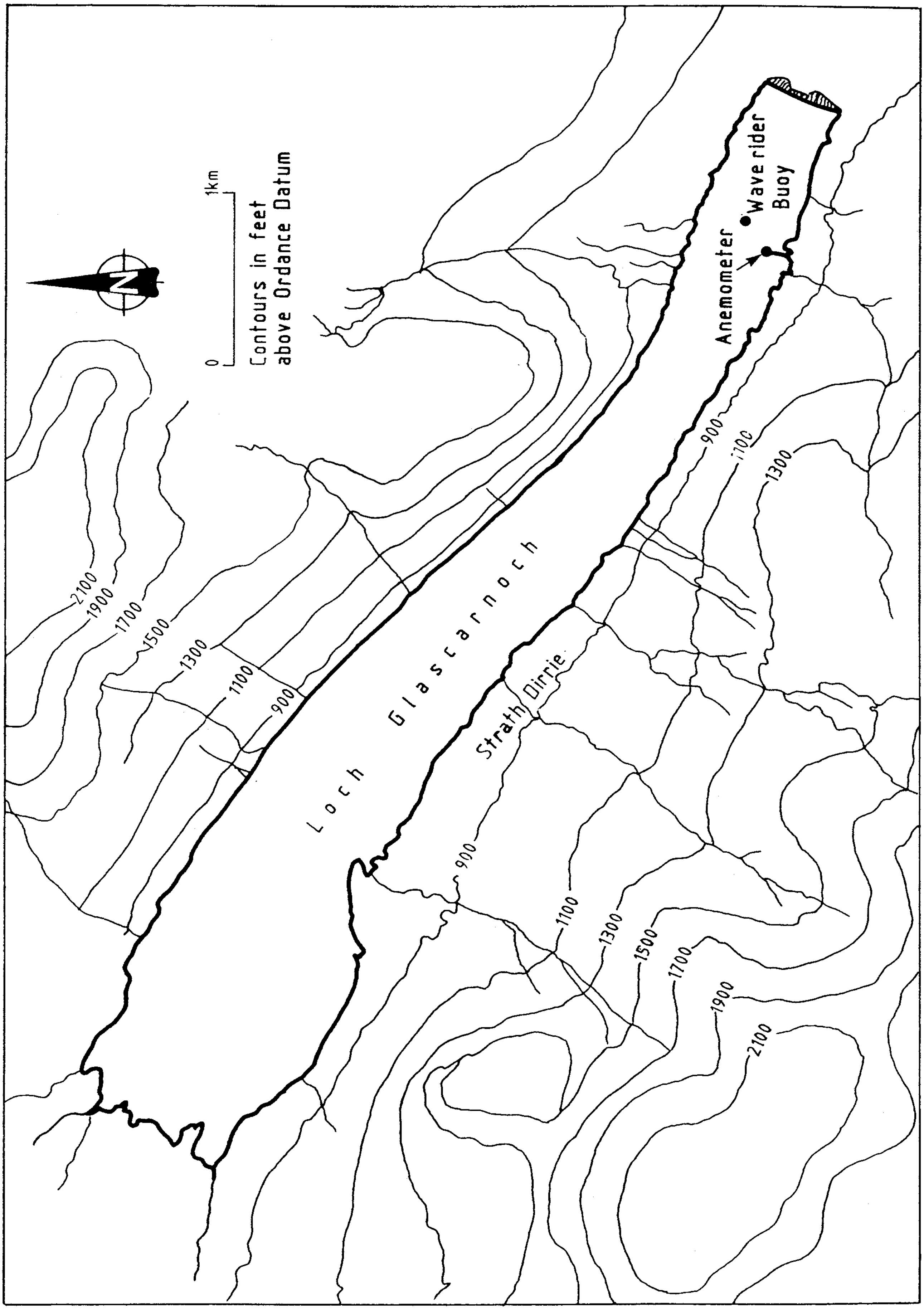

Fig 2 Loch Glascarnoch

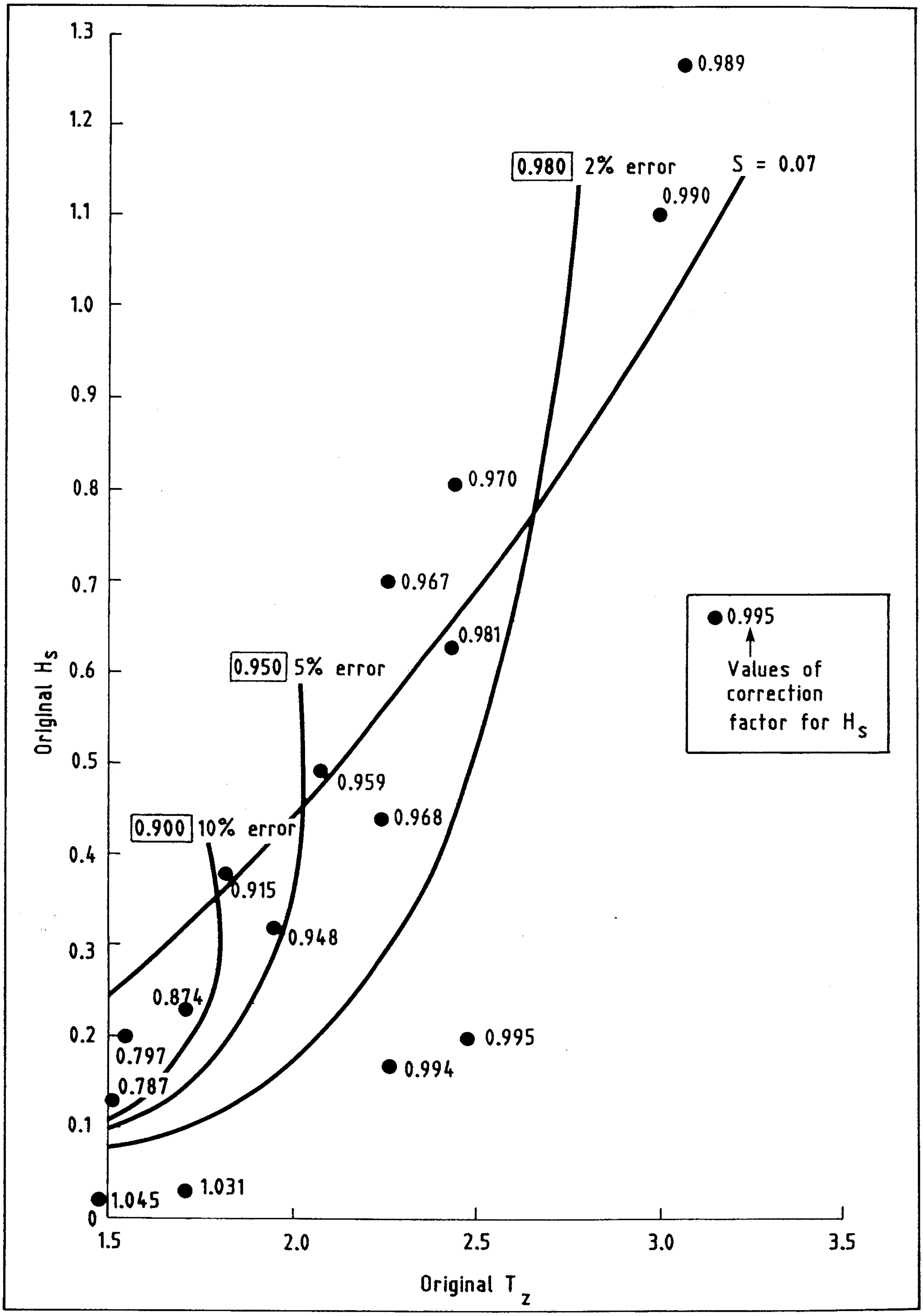

Fig 3 Waverider buoy correction factors

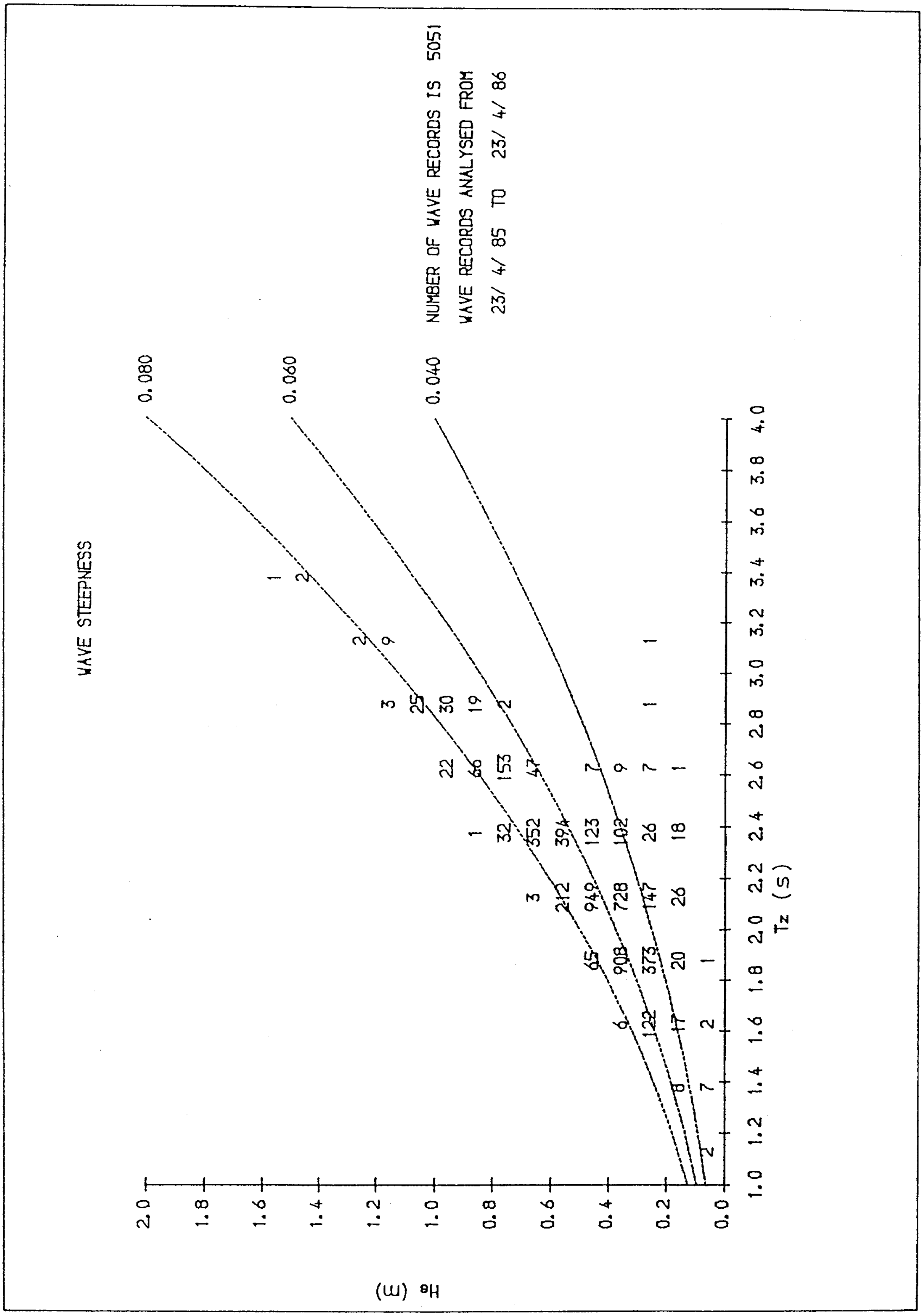

Fig 4 Megget Reservoir. Scatter diagram of wave heights and periods

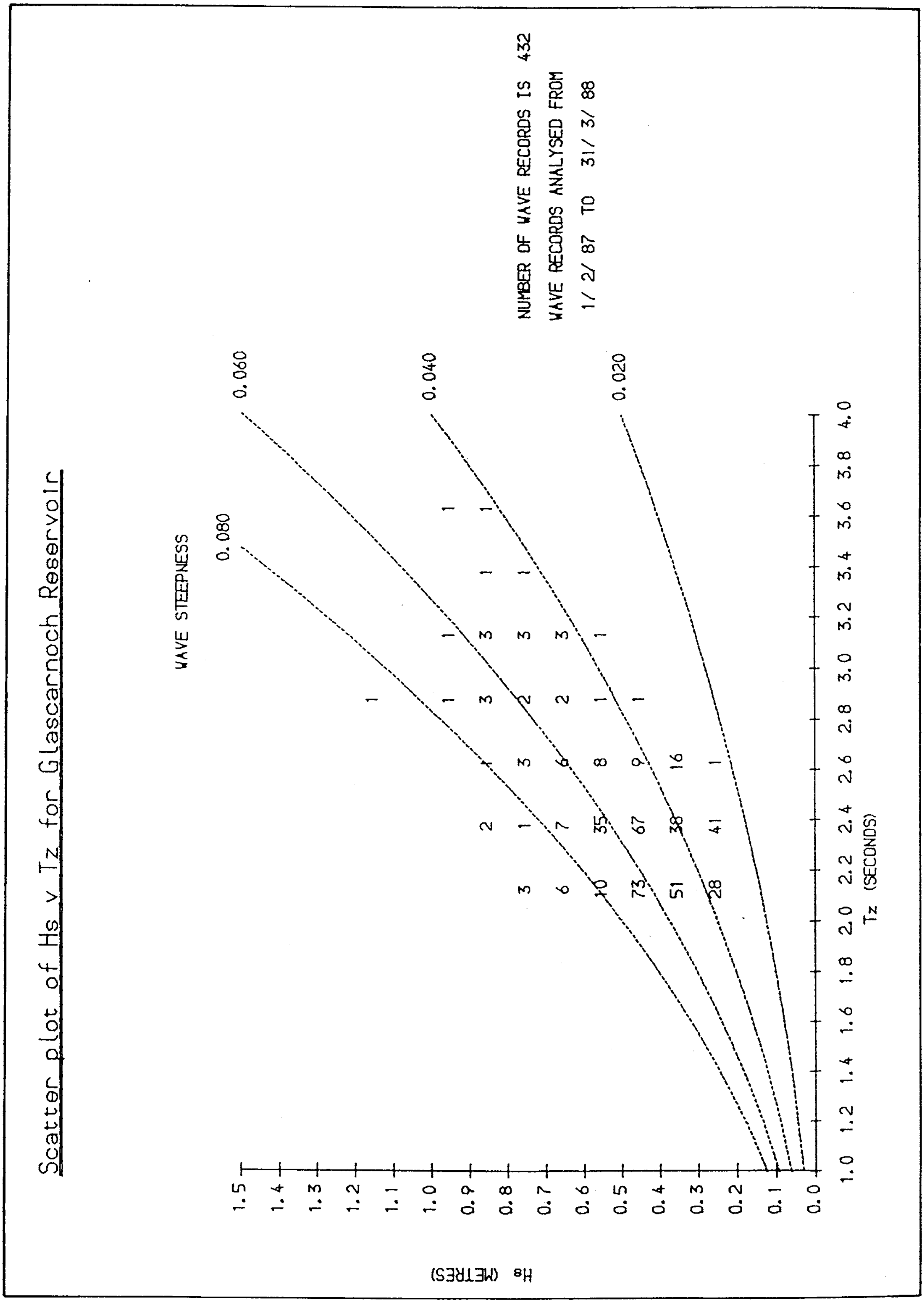

Fig 5 Glascarnoch scatter diagram of wave heights and periods

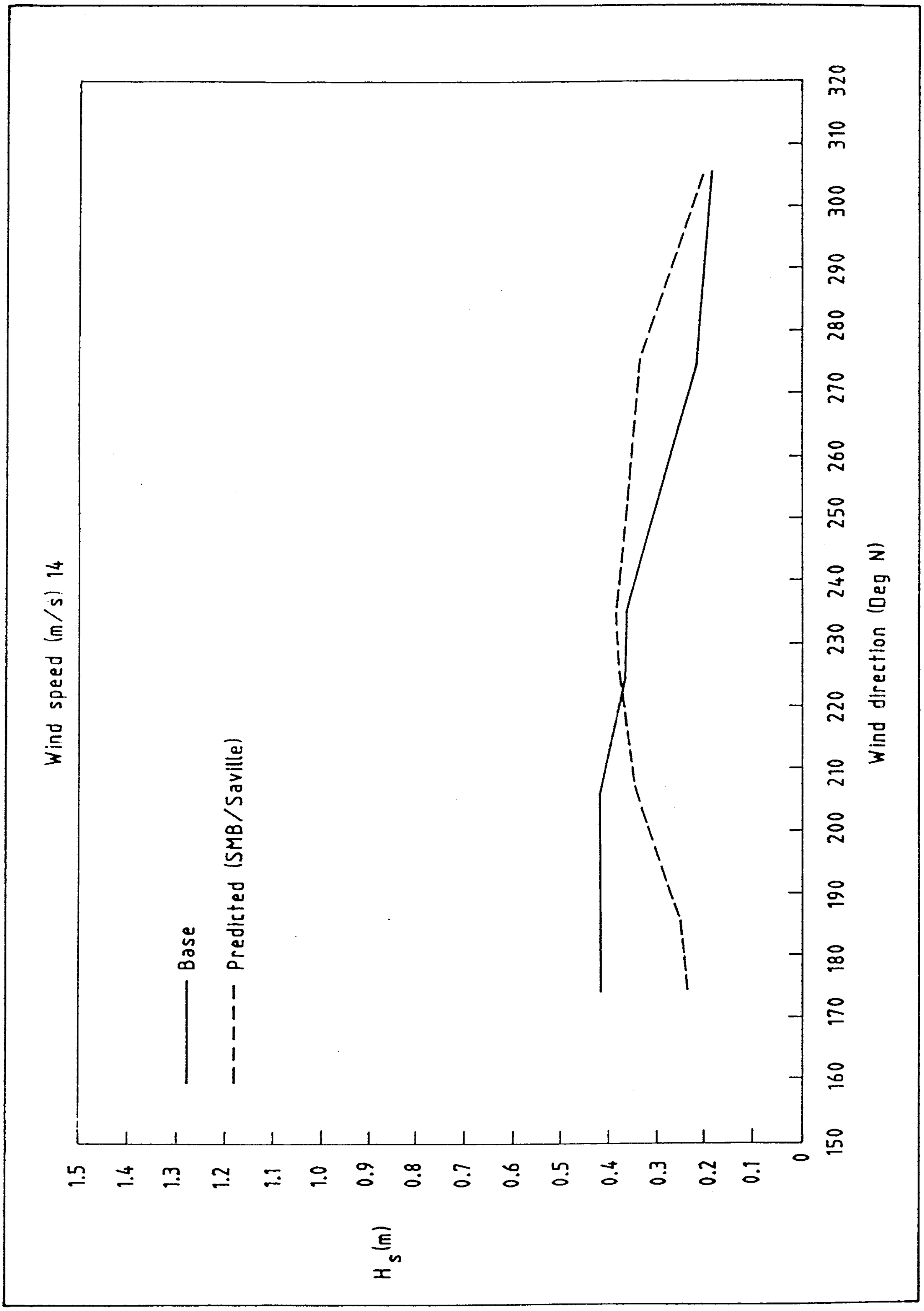

Fig 6   Megget wave heights at fixed windspeeds - SMB/Saville method

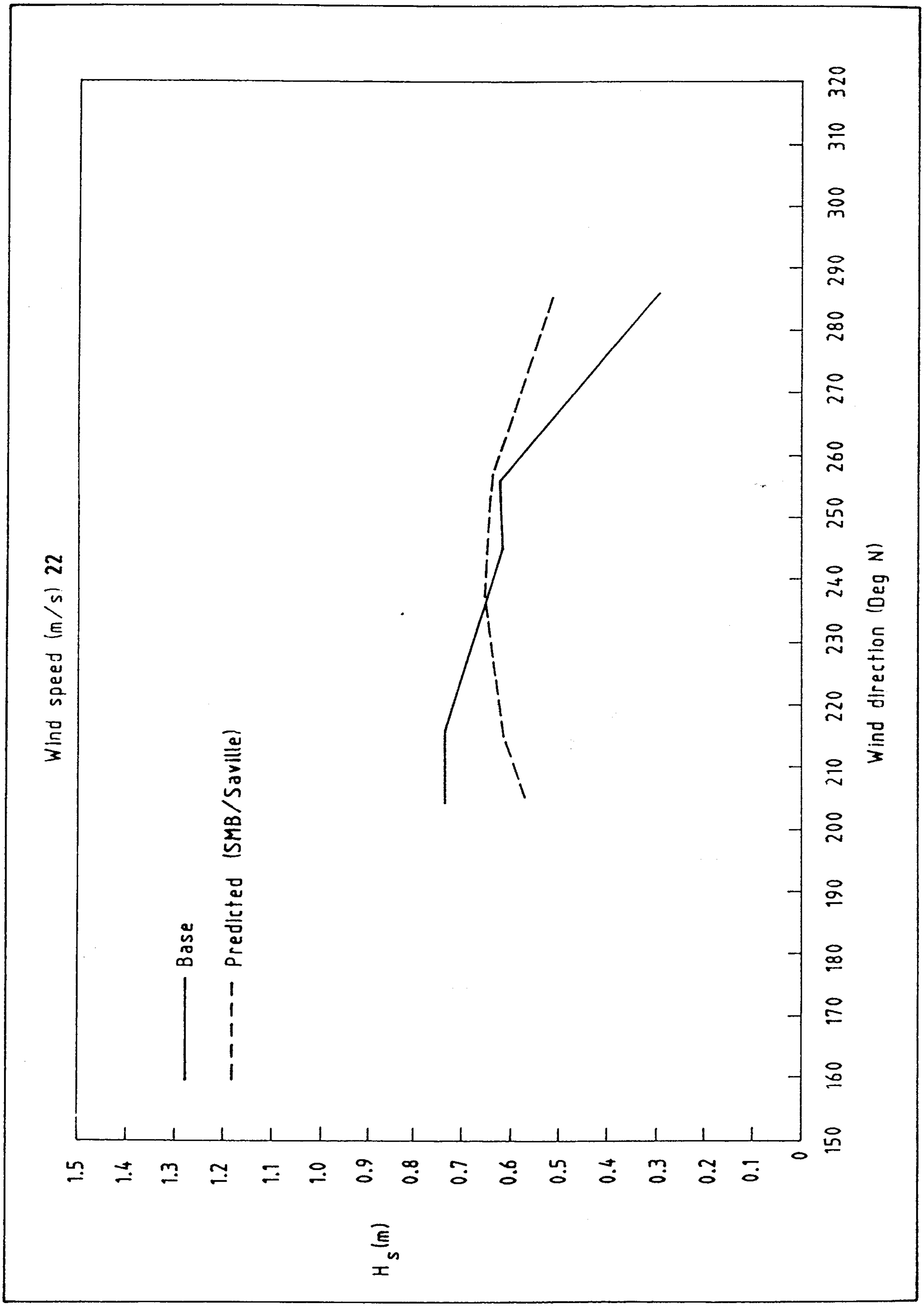

Fig 7 Megget wave heights at fixed windspeeds - SMB/Saville method

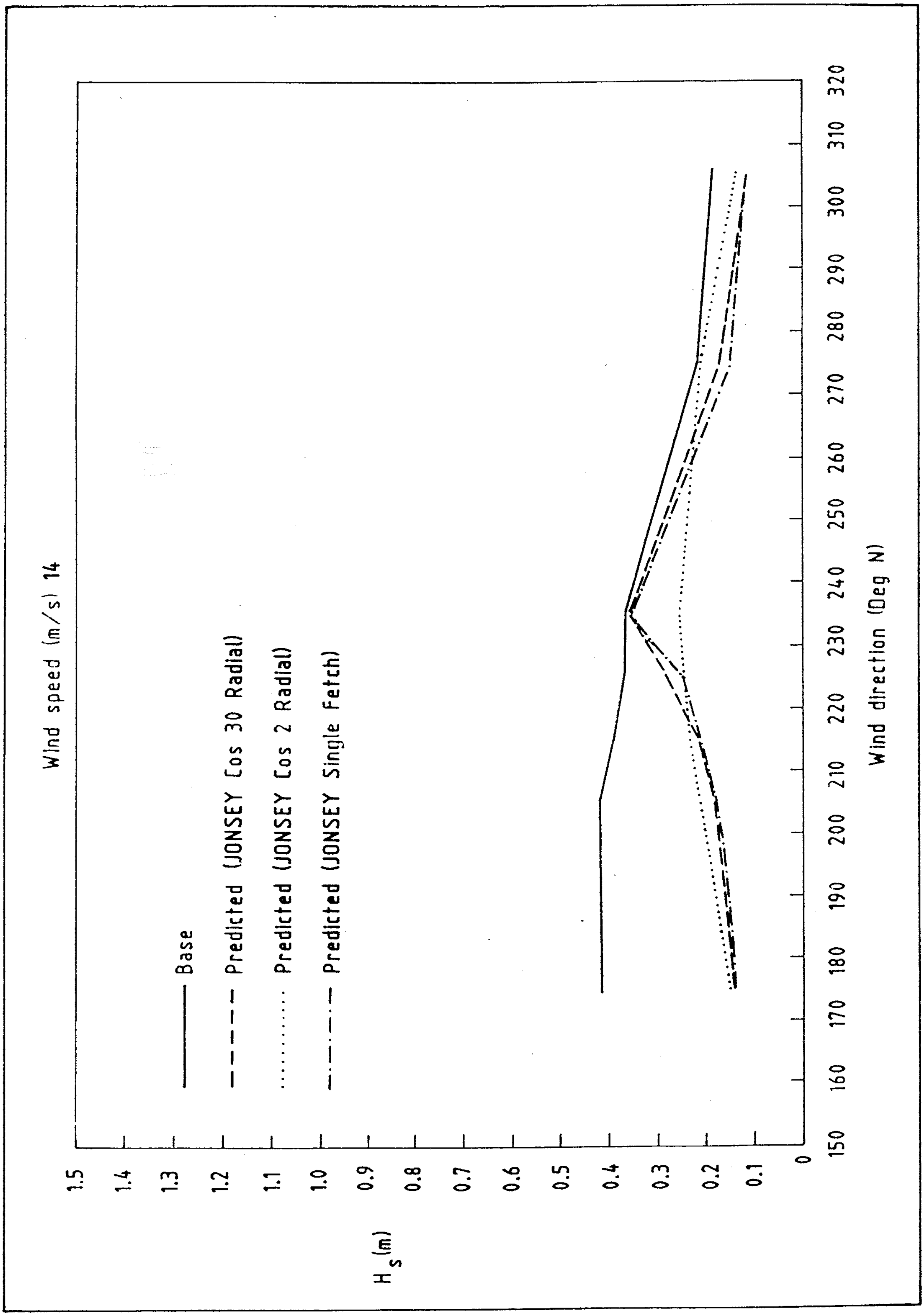

Fig 8 Megget wave heights at fixed windspeeds JONSWAP methods

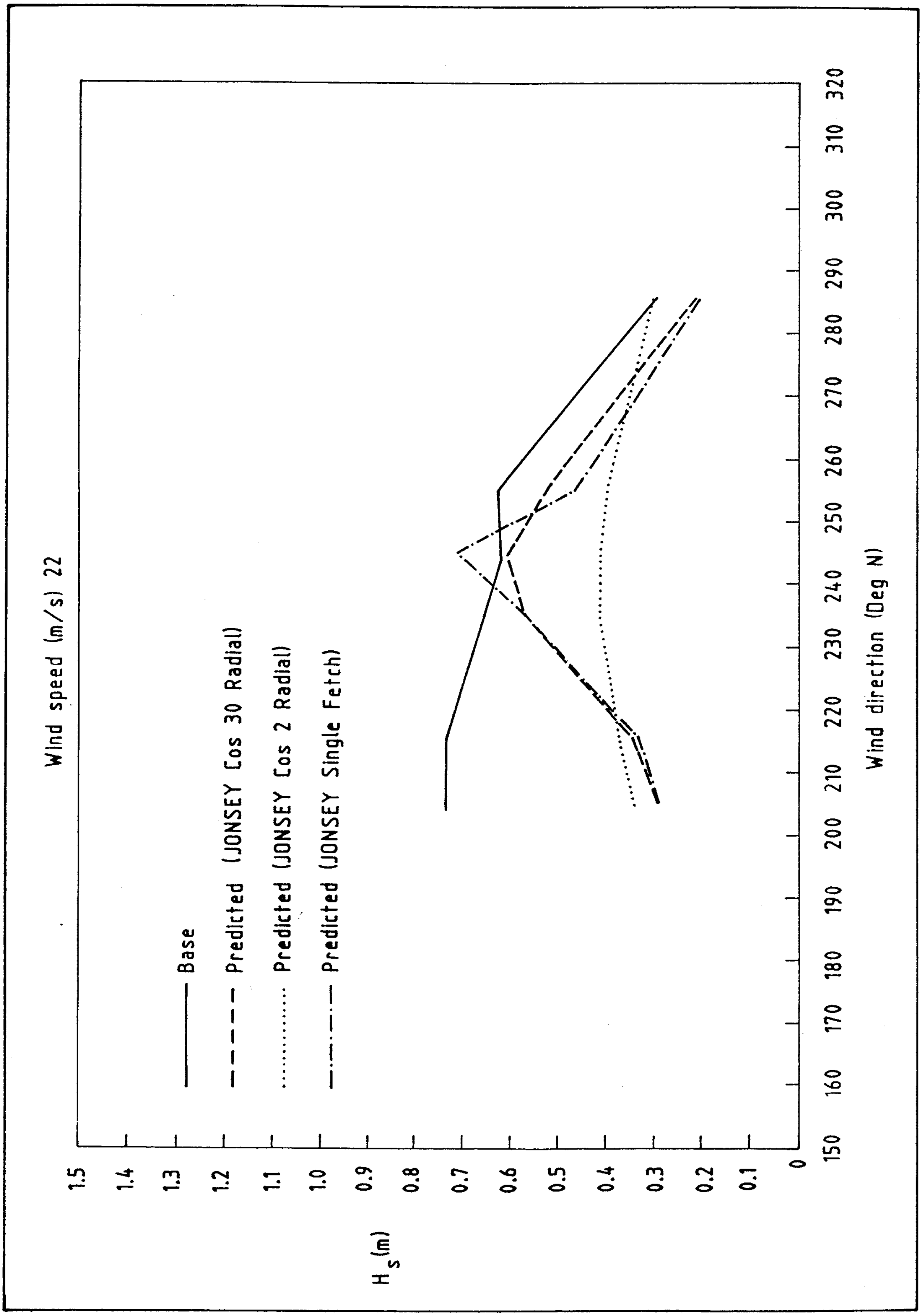

Fig 9 Megget wave heights at fixed windspeeds JONSWAP methods

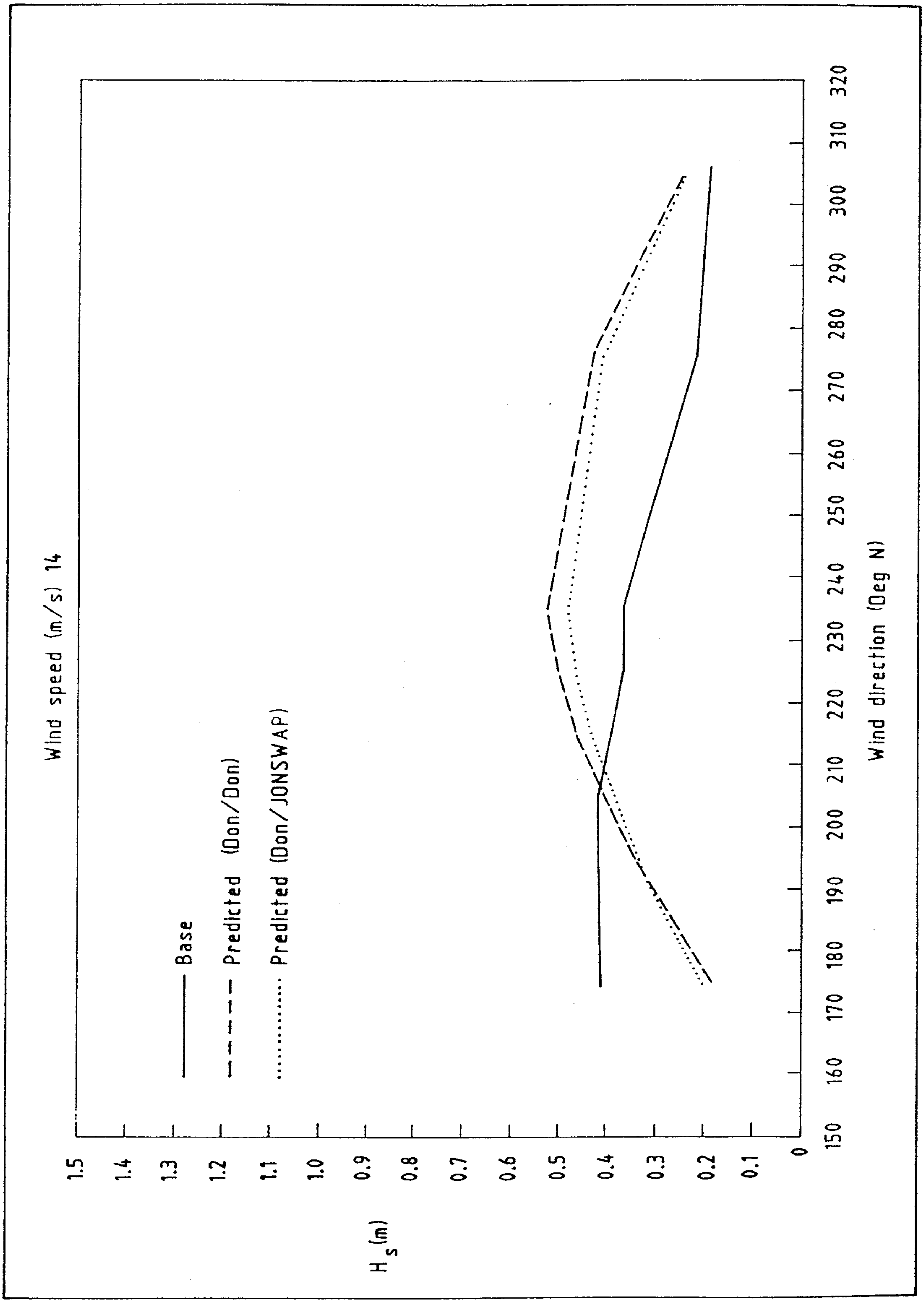

Fig 10 Megget wave heights at fixed windspeeds Donelan methods

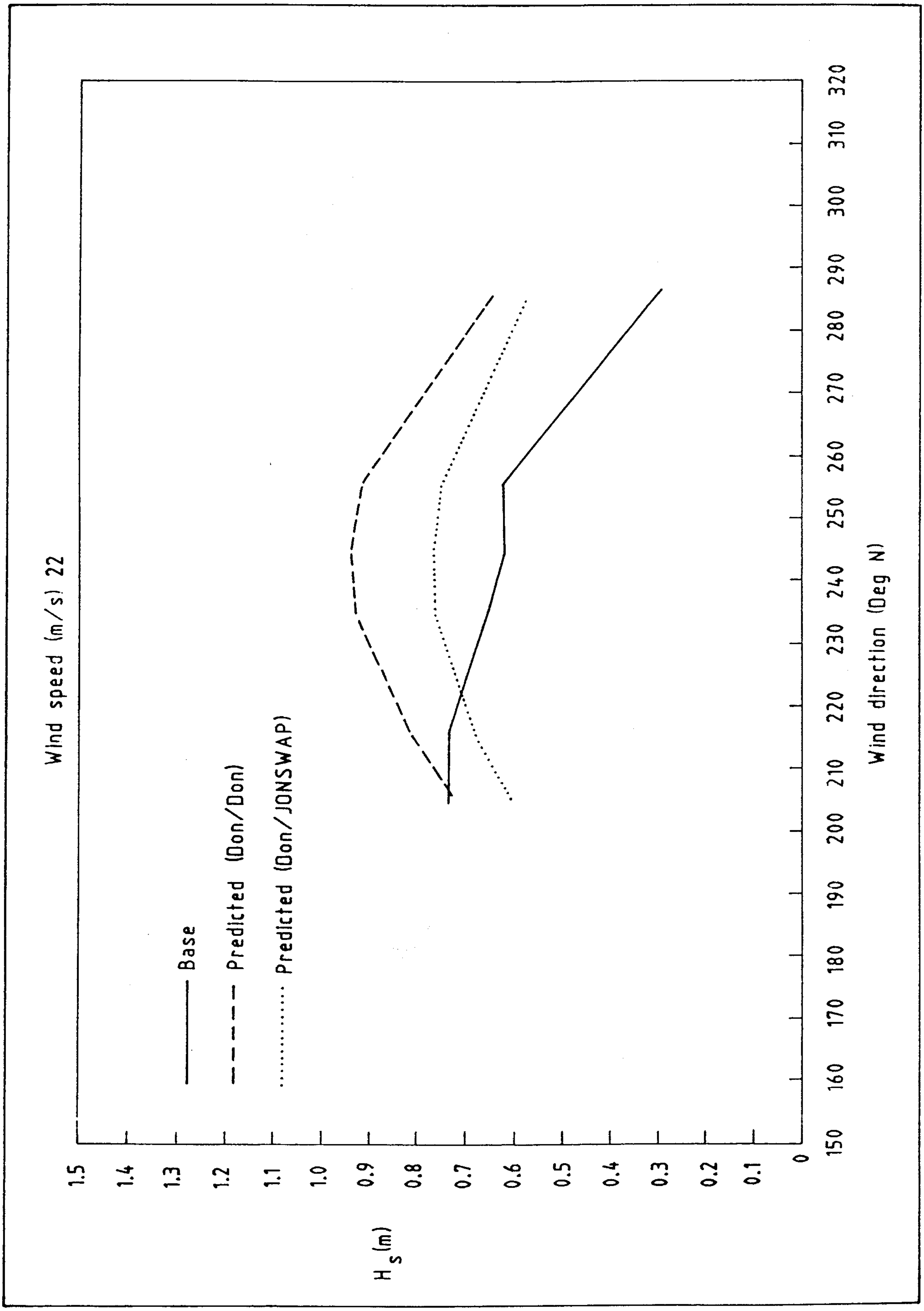

Fig 11 Megget wave heights at fixed windspeeds Donelan methods

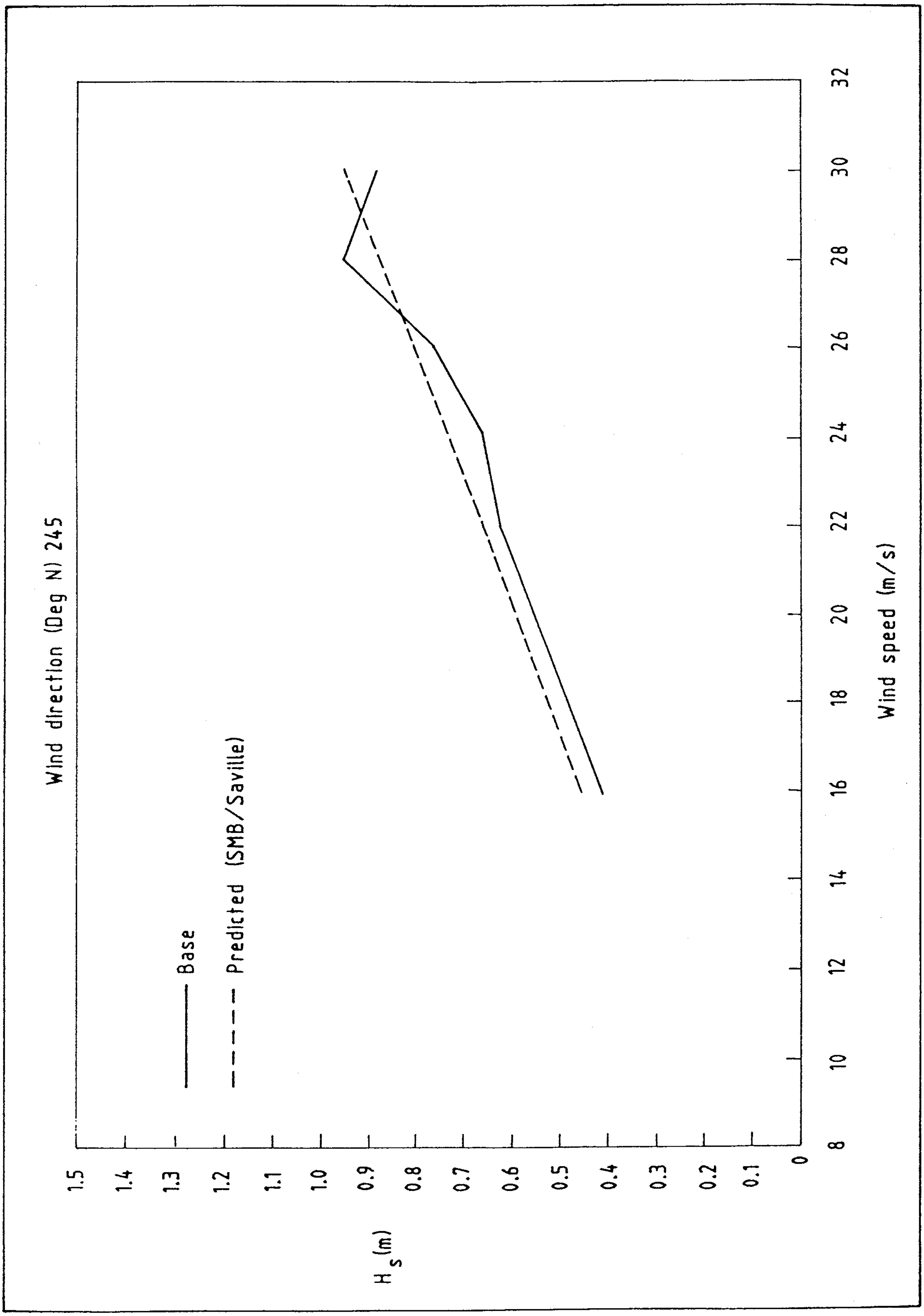

Fig 12 Megget wave heights at fixed wind directions SMB/Saville method

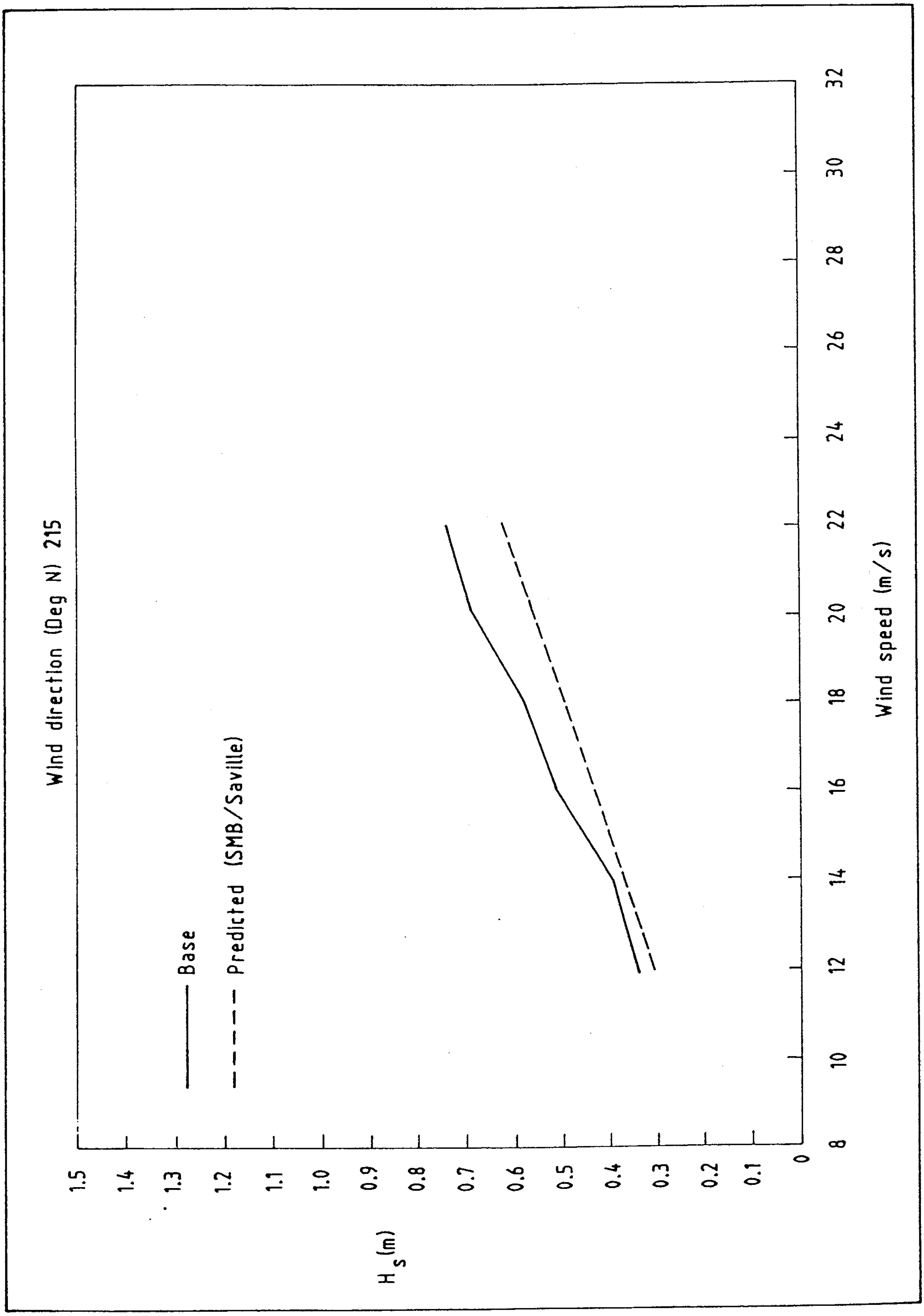

Fig 13 Megget wave heights at fixed wind directions SMB/Saville method

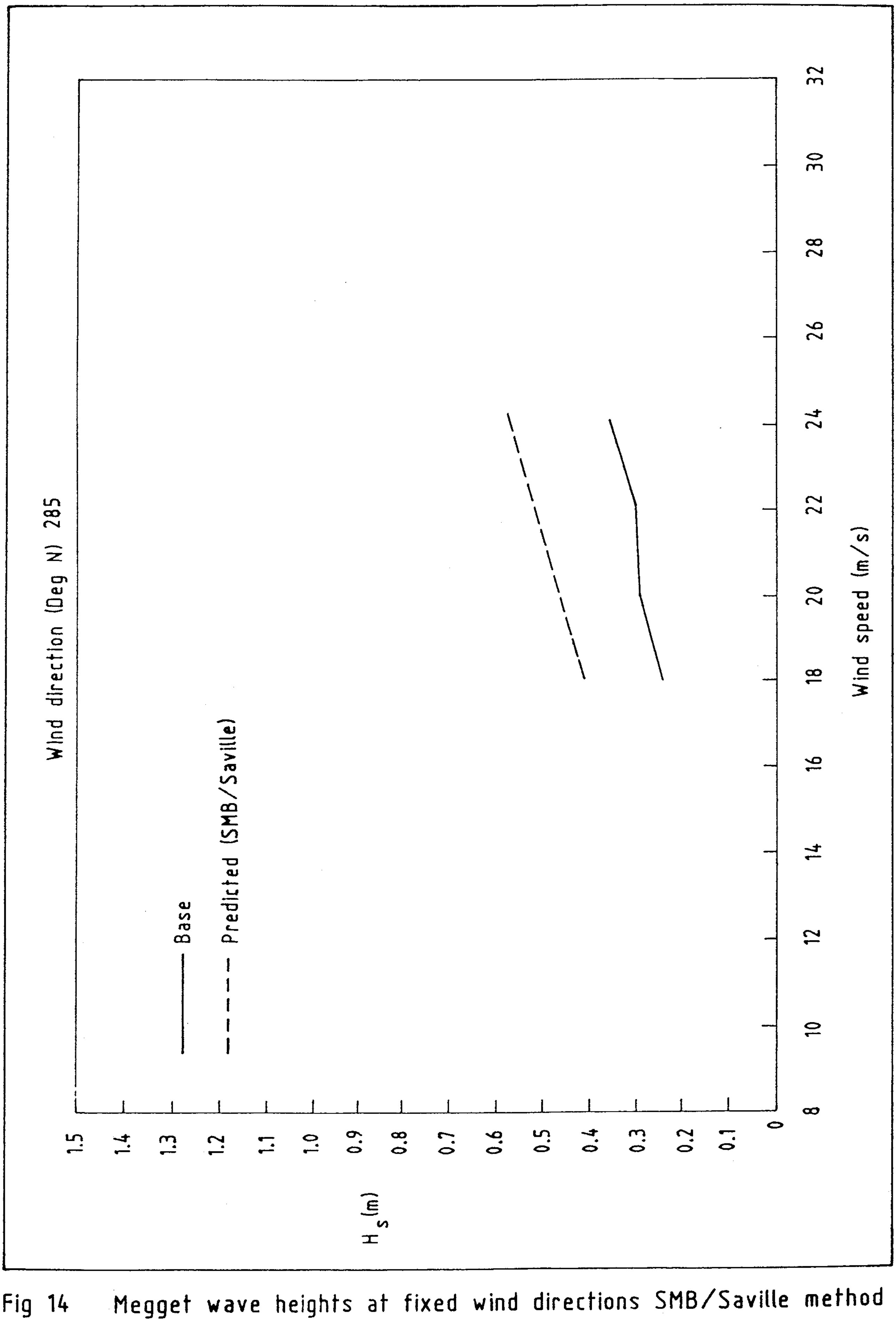

Fig 14 Megget wave heights at fixed wind directions SMB/Saville method

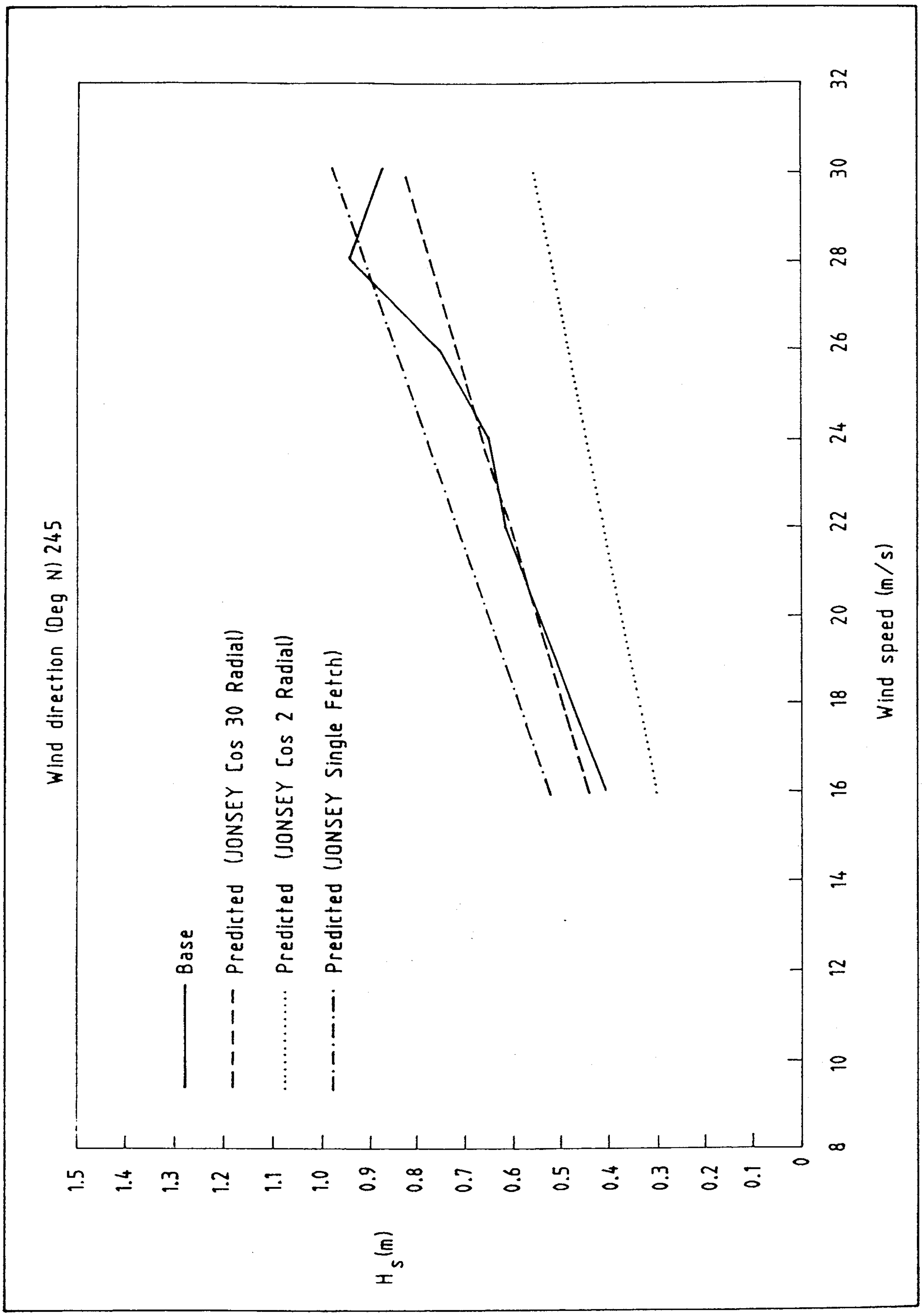

Fig 15 Megget wave heights at fixed wind directions. JONSWAP methods

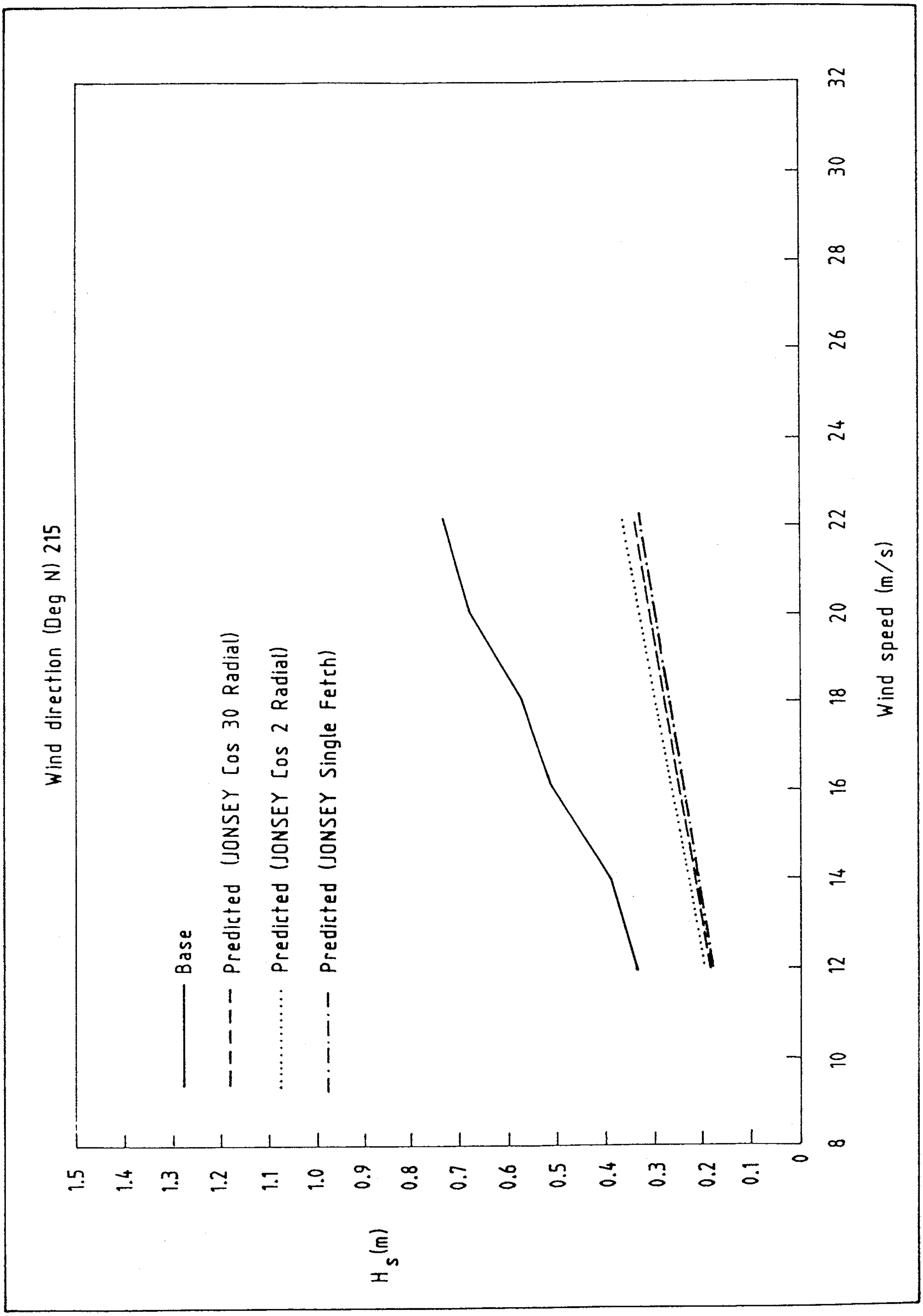

Fig 16 Megget wave heights at fixed wind directions JONSWAP methods

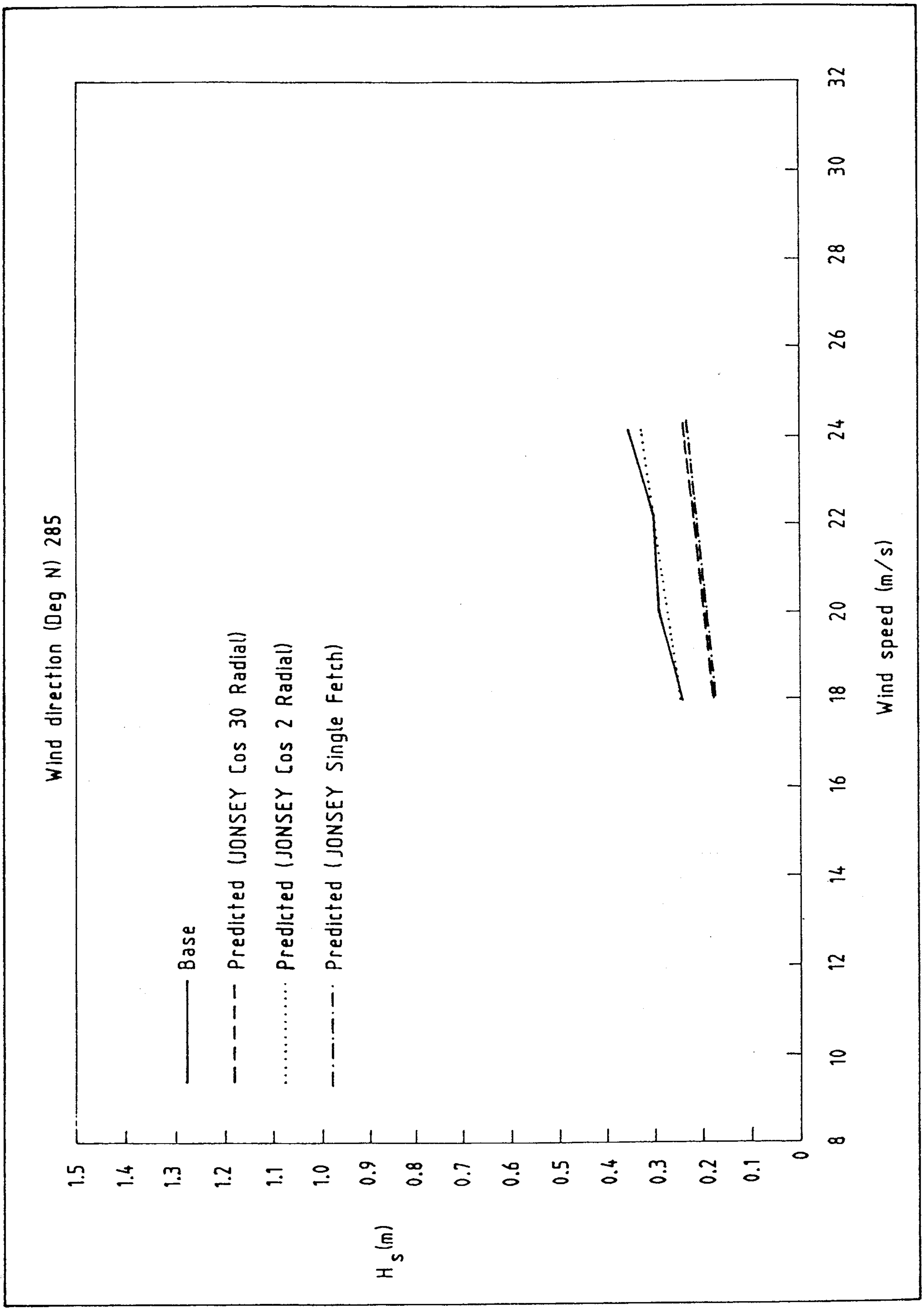

Fig 17 Megget wave heights at fixed wind directions JONSWAP methods.

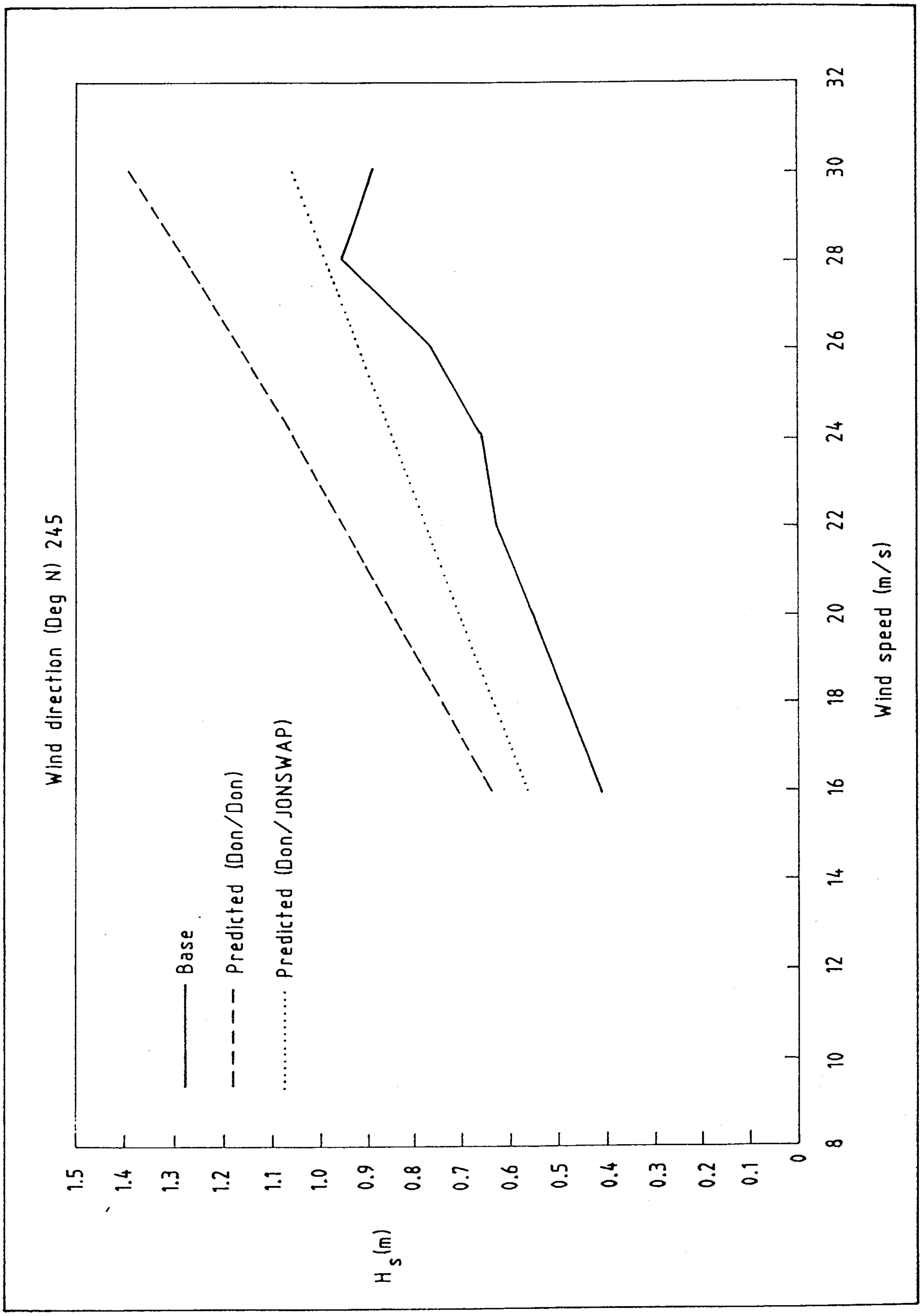

Fig 18 Megget wave heights at fixed wind directions Donelan methods

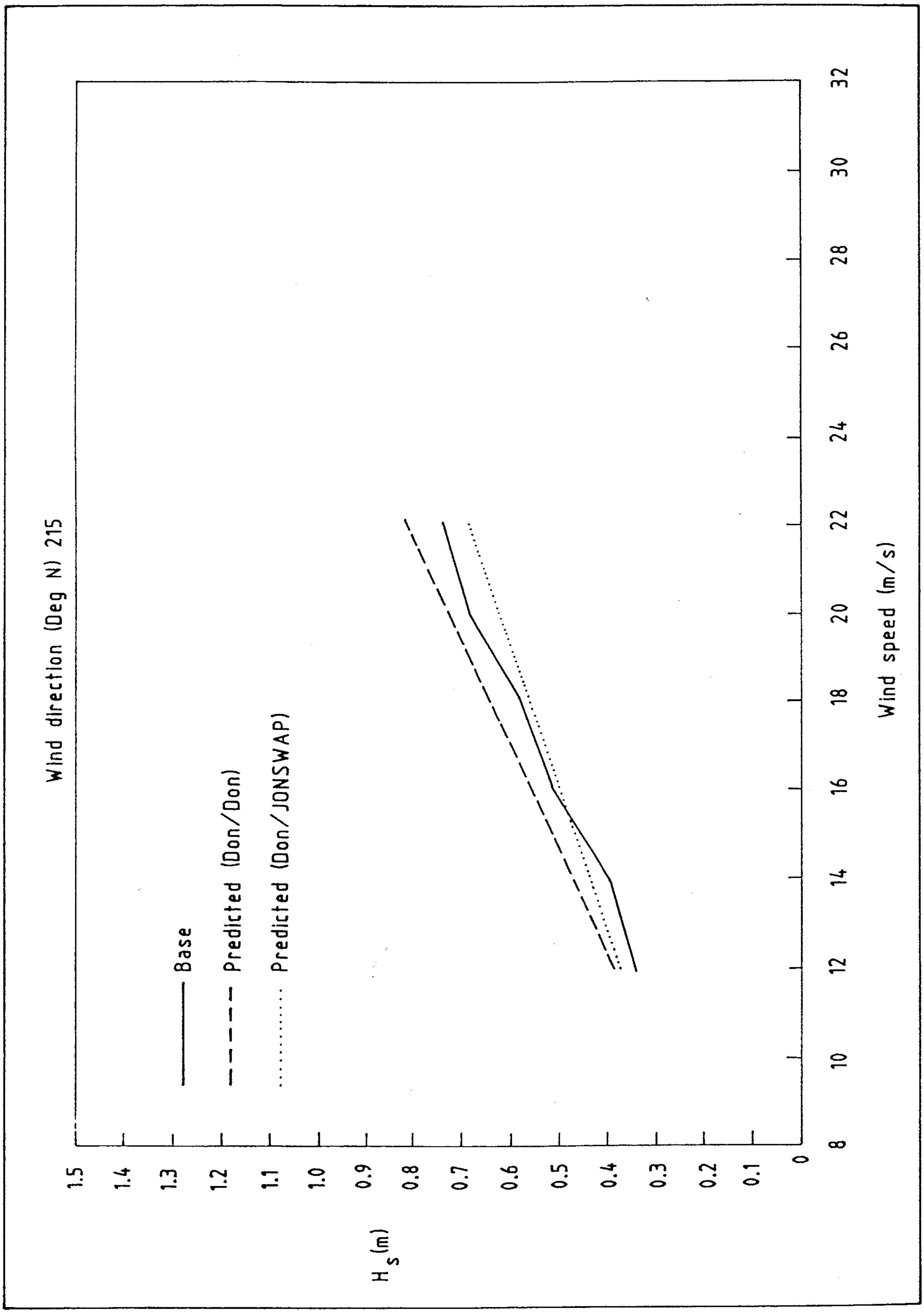

Fig 19 Megget wave heights at fixed wind directions Donelan methods

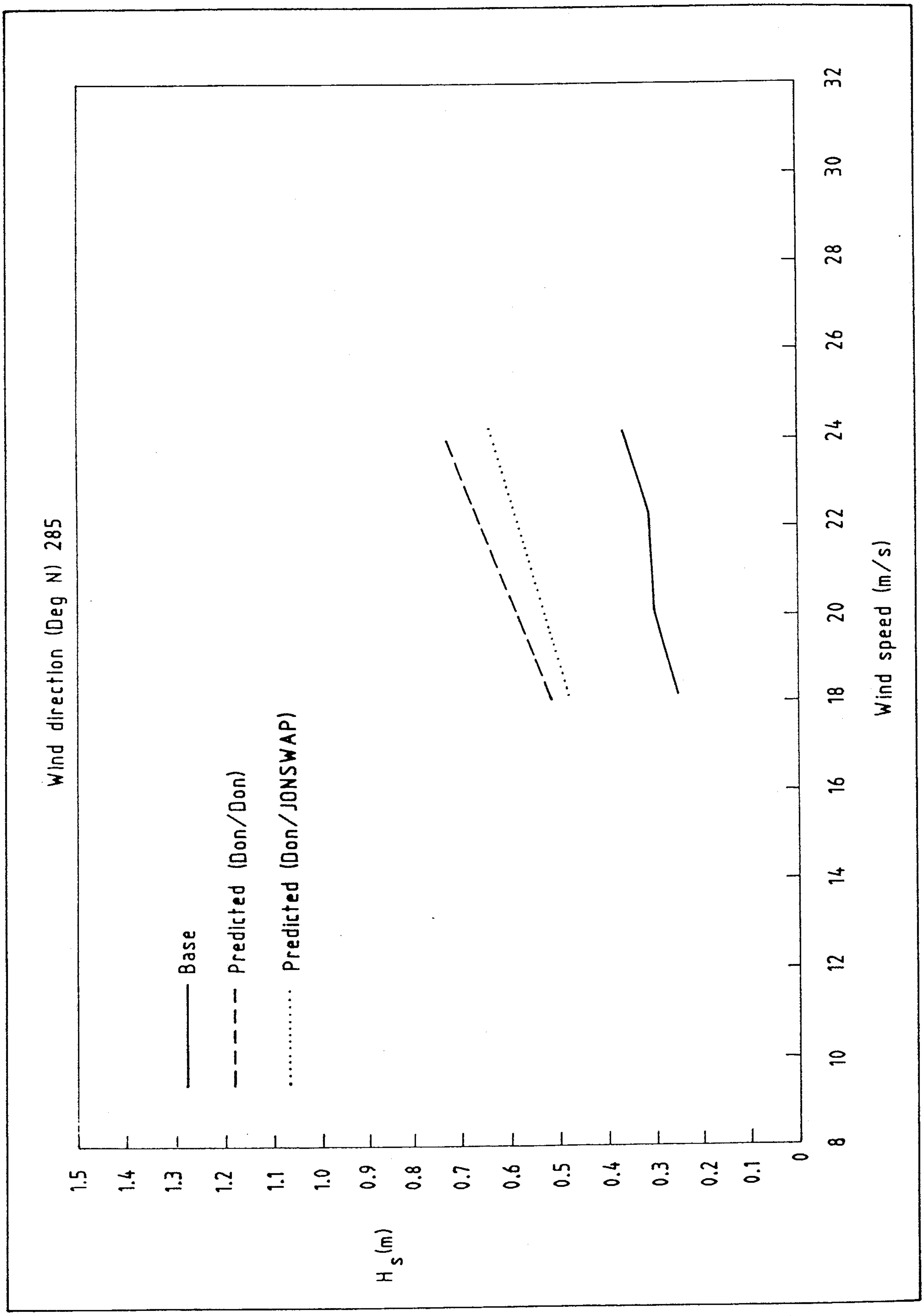

Fig 20 Megget wave heights at fixed wind directions Donelan methods

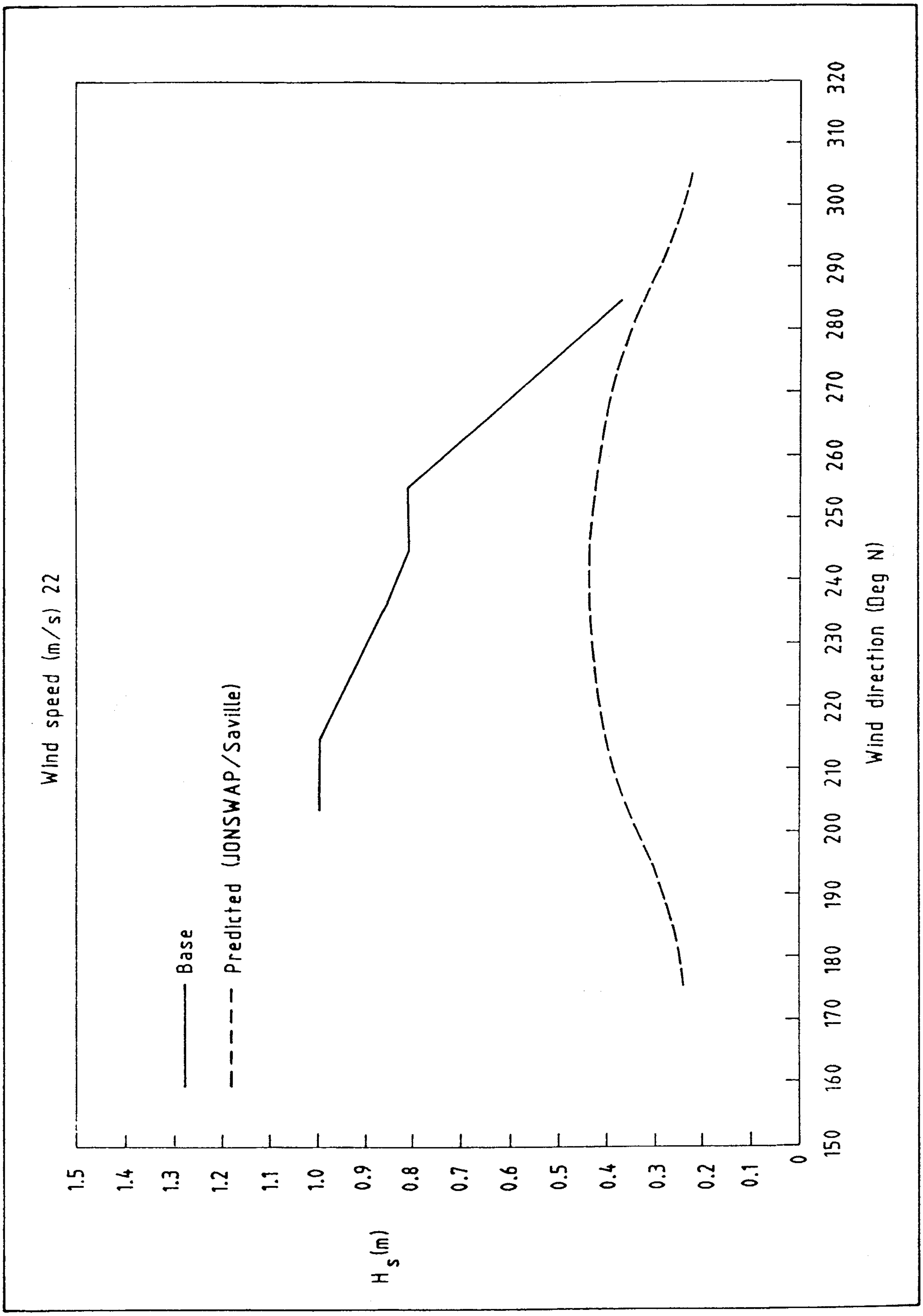

Fig 21 Megget wave heights at fixed wind directions JONSWAP/Saville method

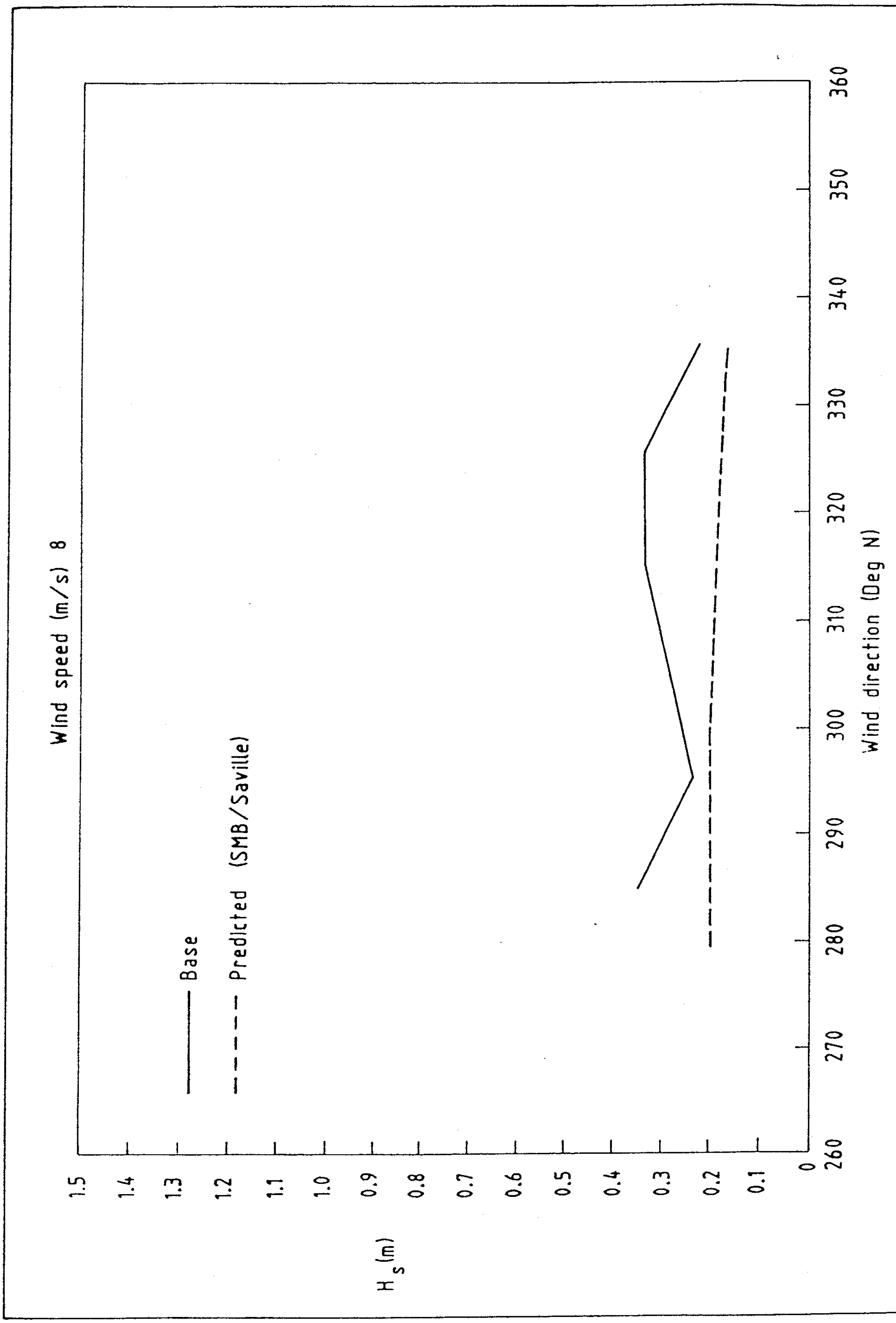

Fig 22 Glascarnoch wave heights at fixed windspeeds SMB/Saville meth

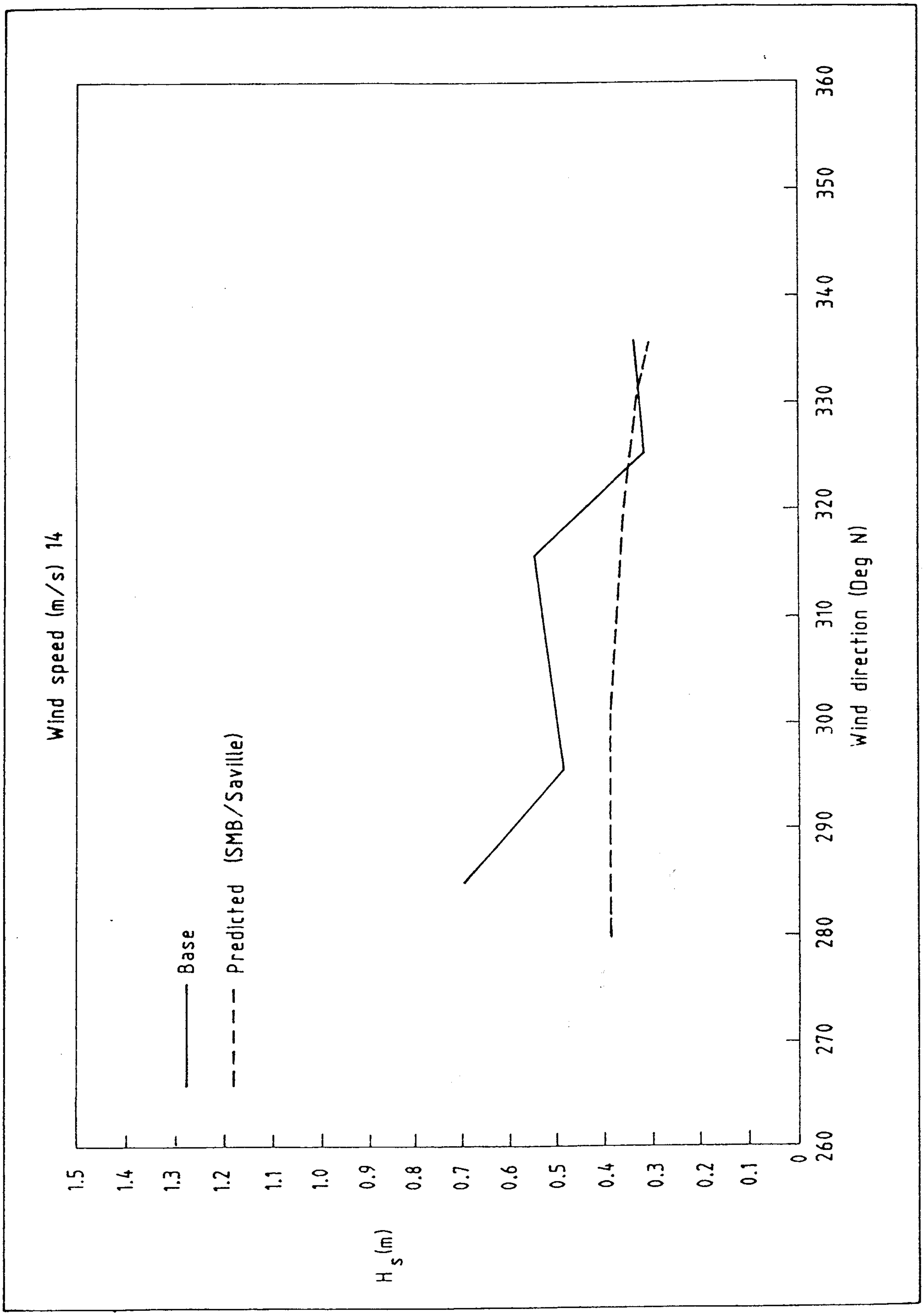

Fig 23 Glascarnoch wave heights at fixed windspeeds SMB/Saville method

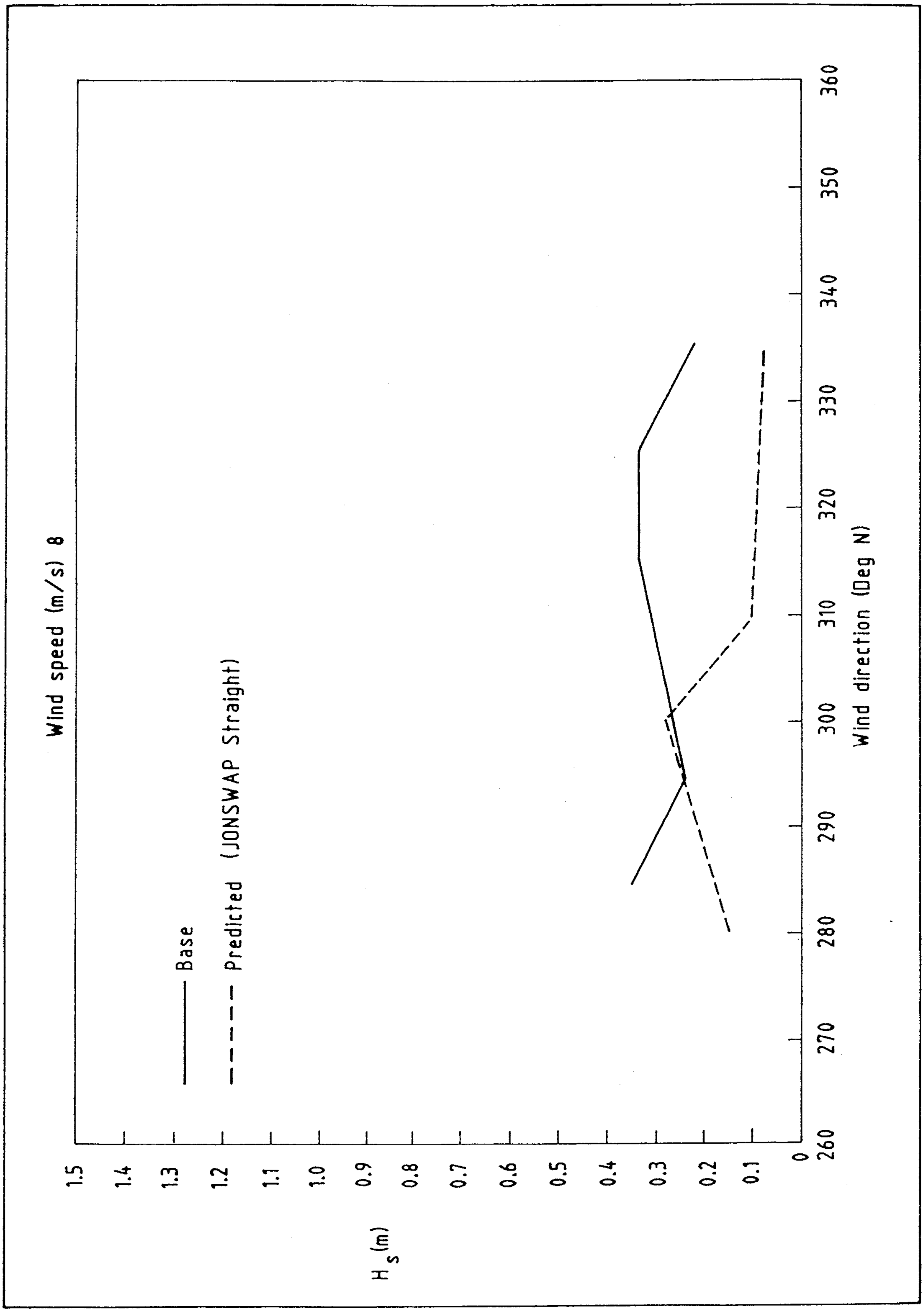

Fig 24 Glascarnoch wave heights at fixed windspeeds JONSWAP/Sf method

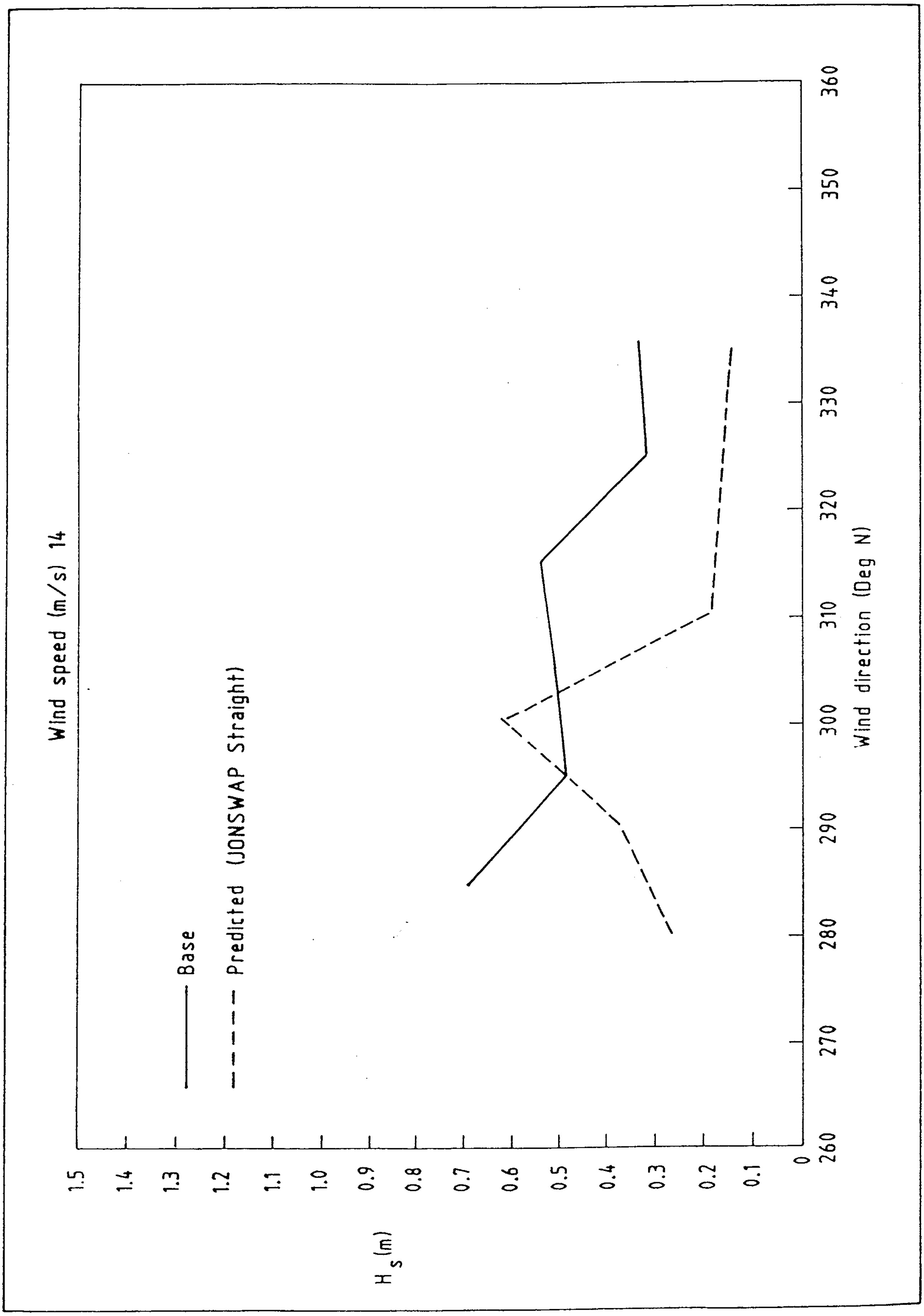

Fig 25. Glascarnoch wave heights at fixed windspeeds JONSWAP/Sf method

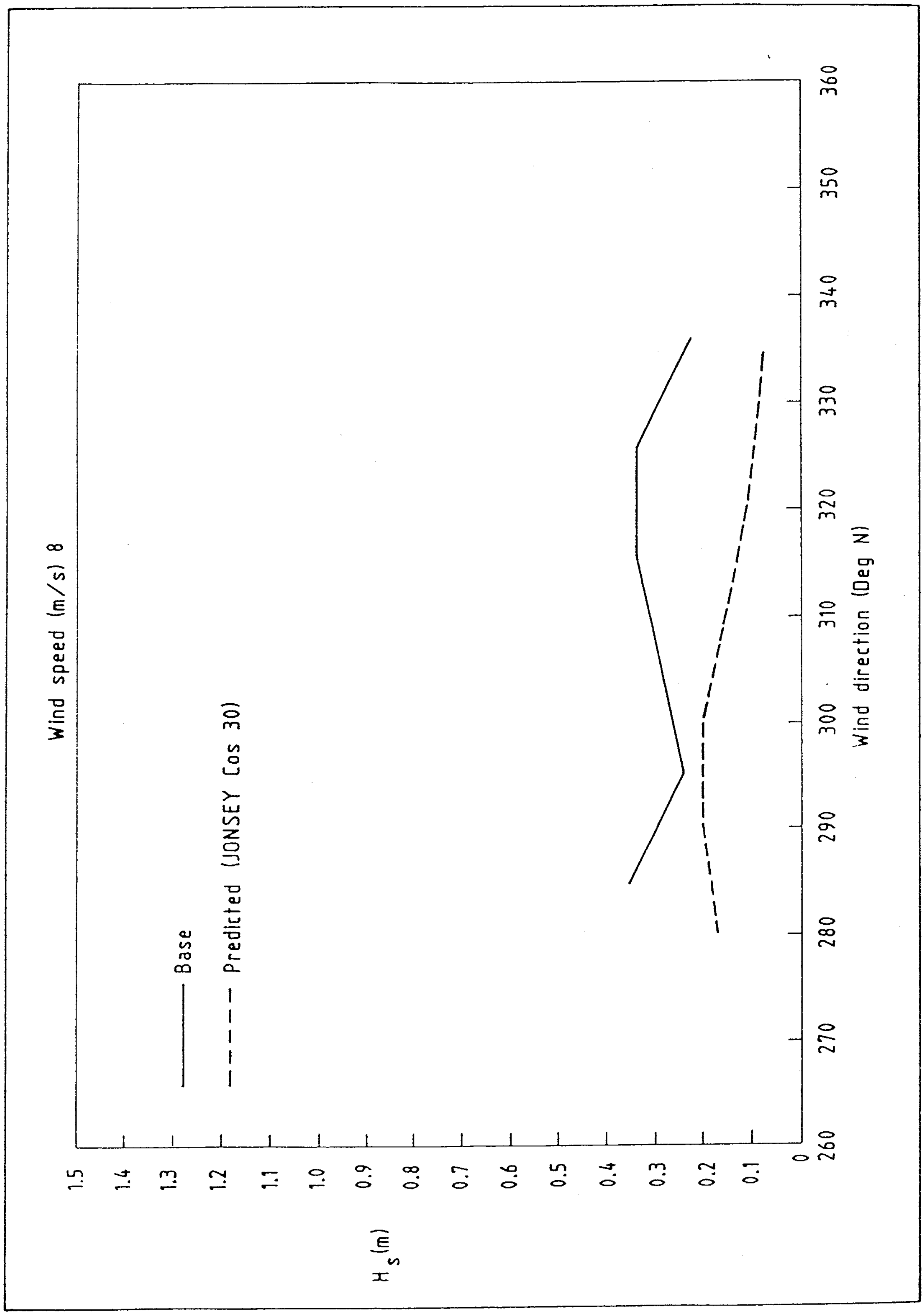

Fig 26 Glascarnoch wave heights at fixed windspeeds JONSEY/30 method

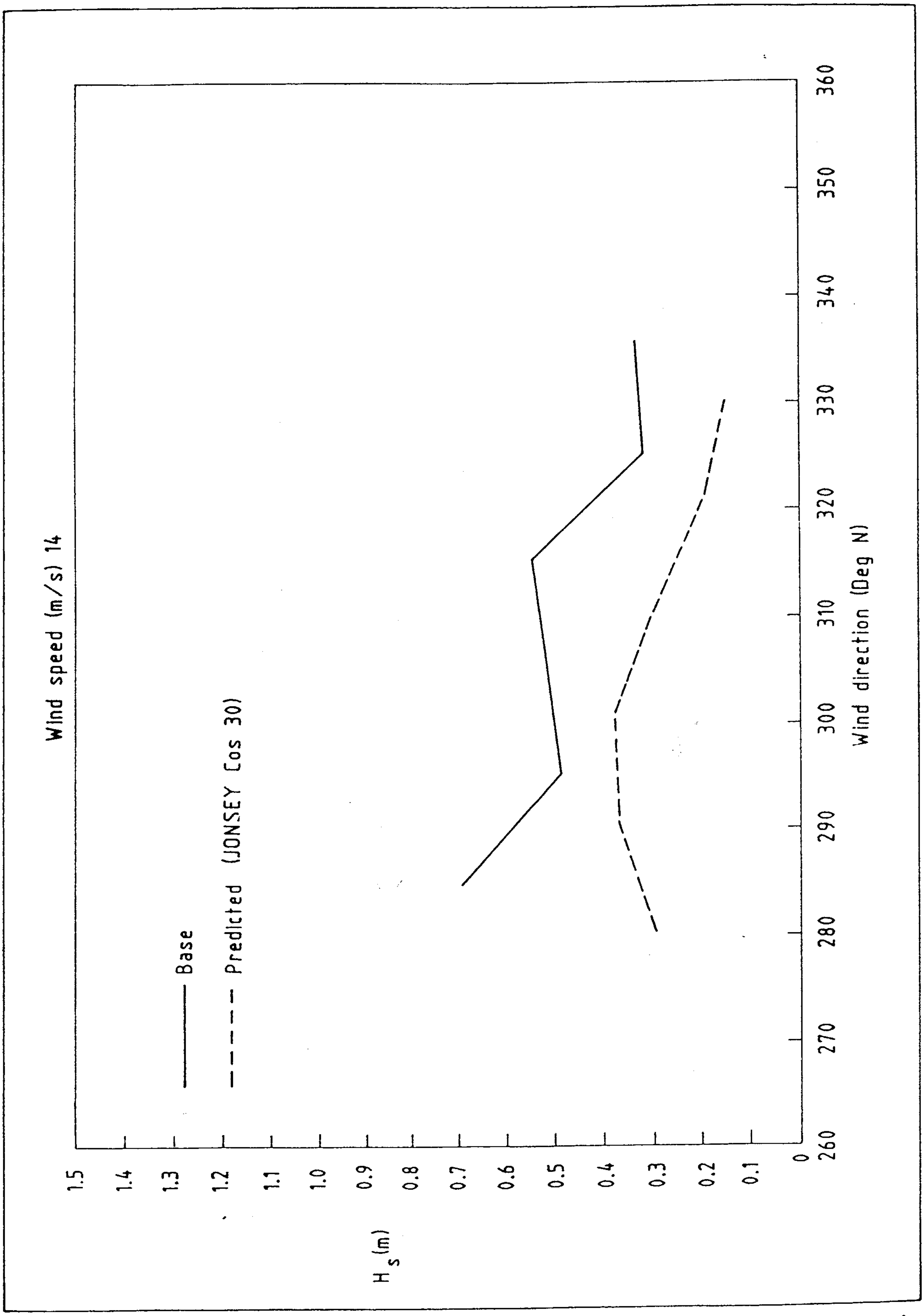

Fig 27 Glascarnoch wave heights at fixed windspeeds JONSEY/30 method

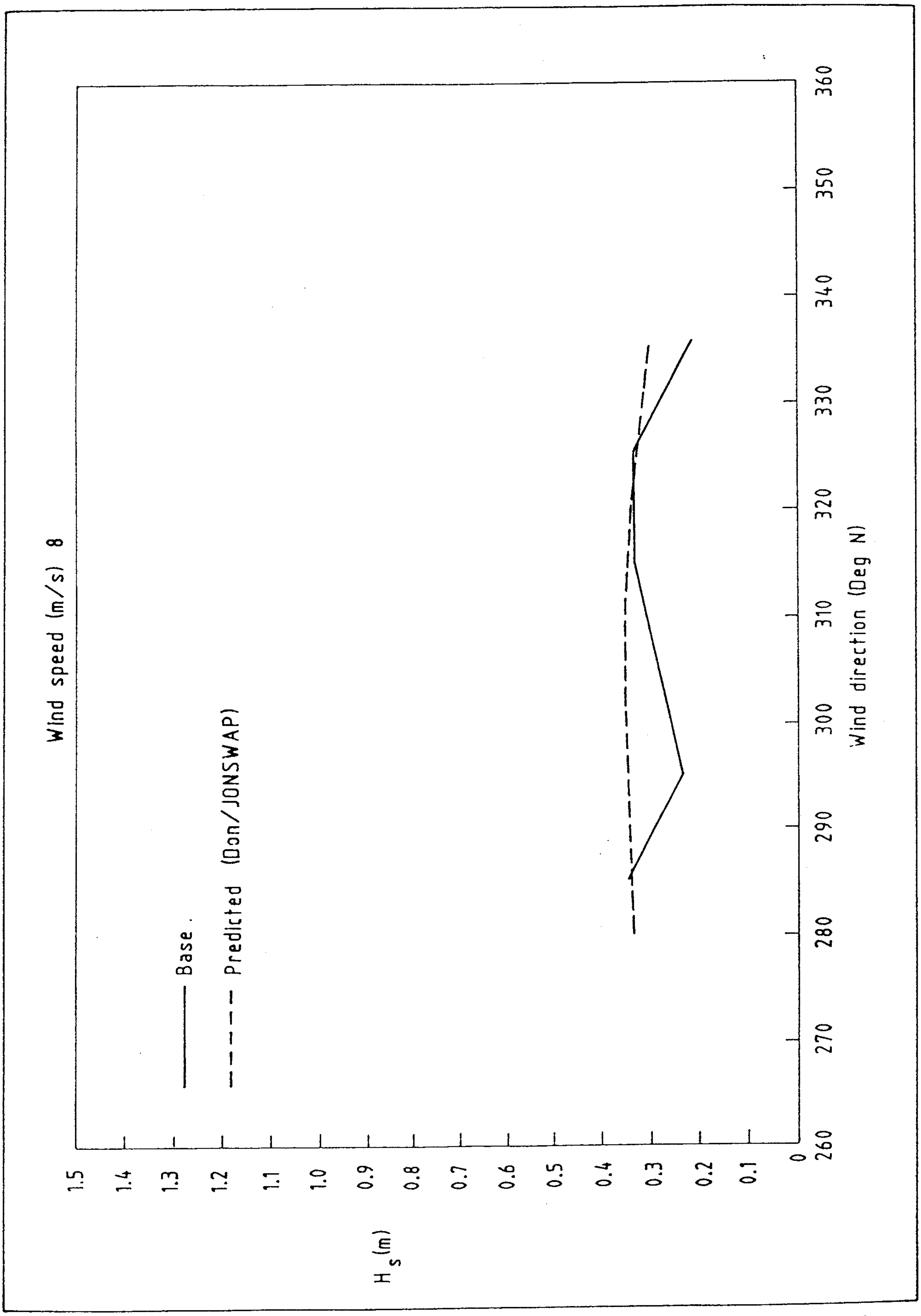

Fig 28 Glascarnoch wave heights at fixed windspeeds DON/JON method

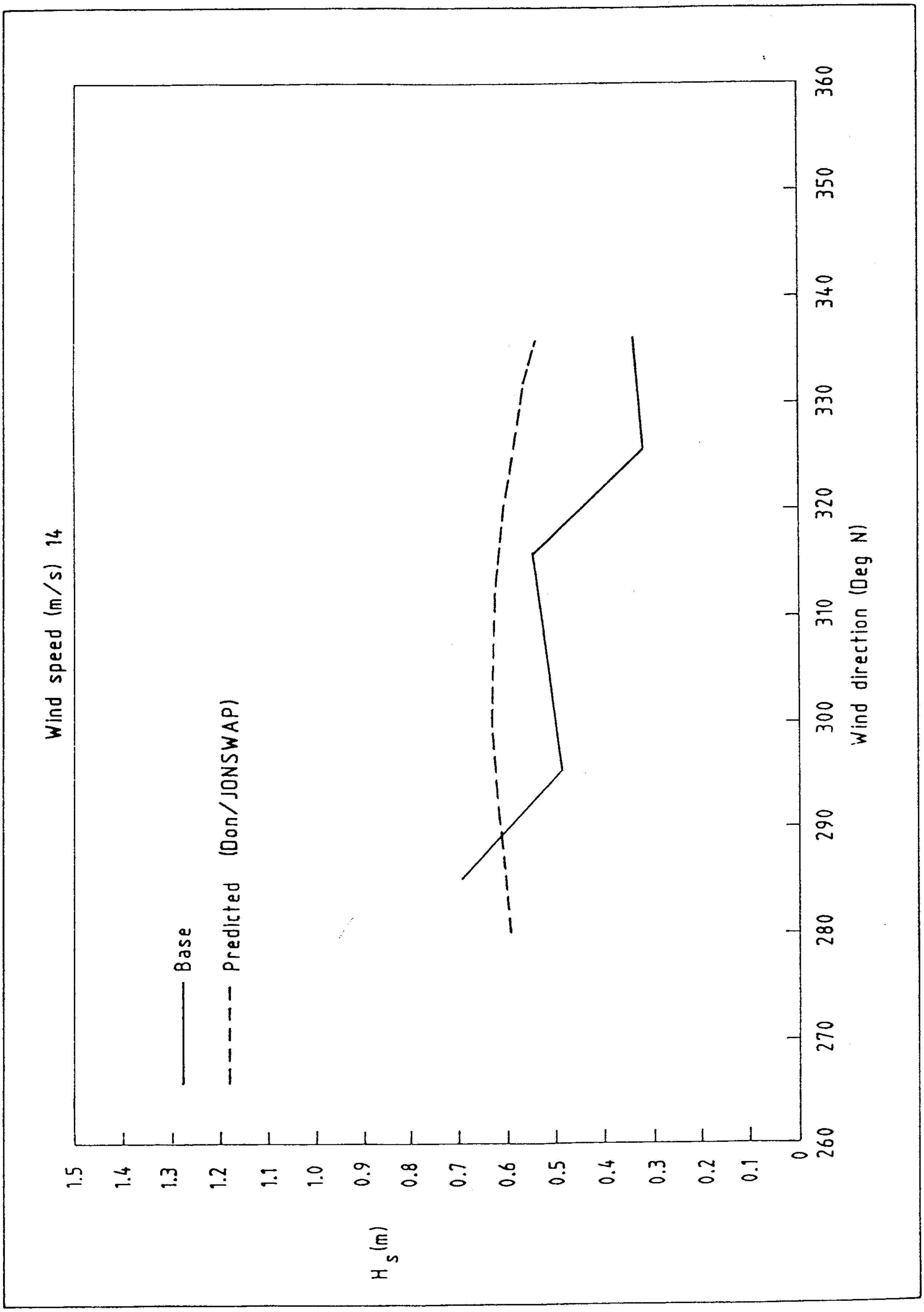

Fig 29 Glascarnoch wave heights at fixed windspeeds DON/JON method

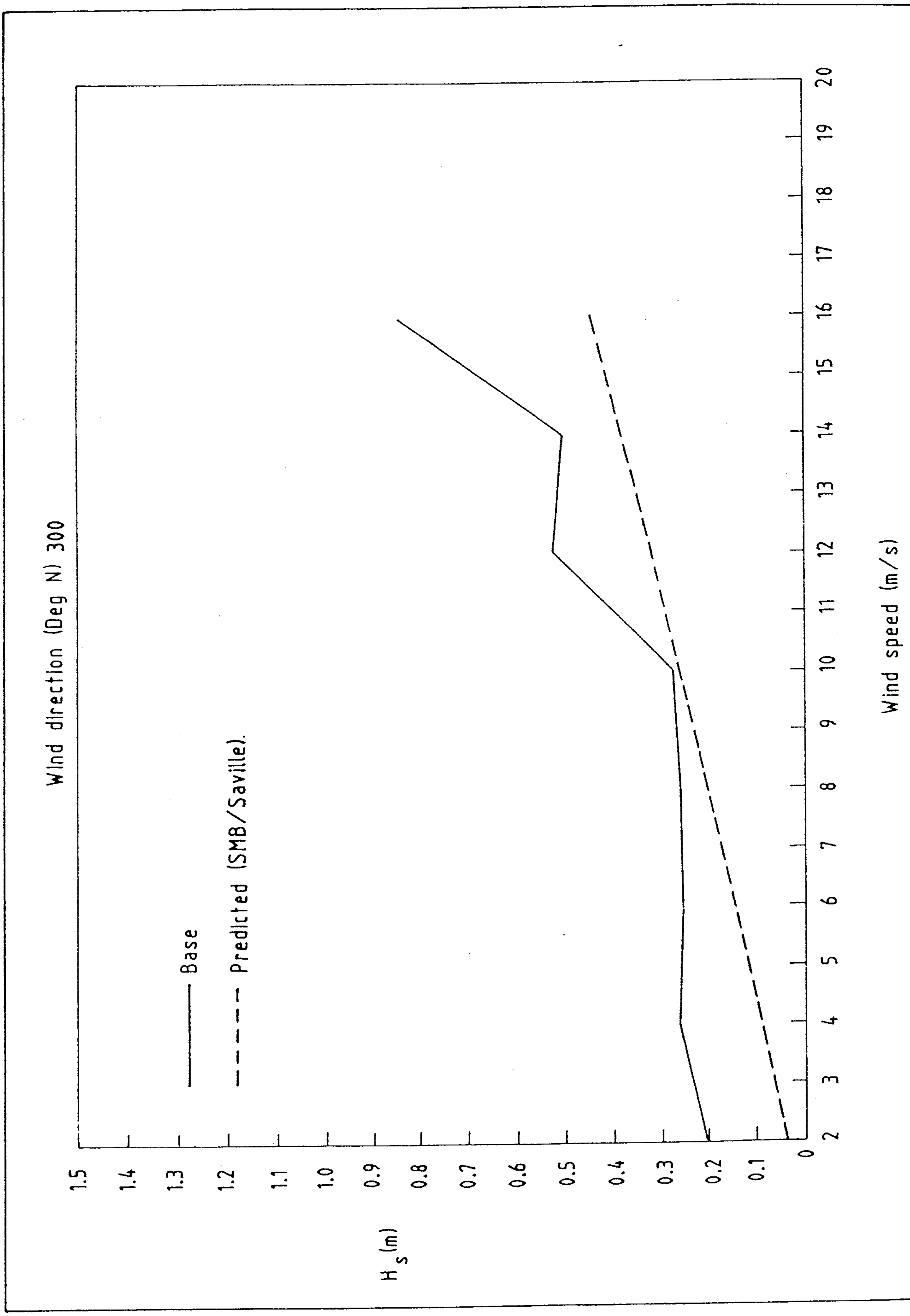

Fig 30 Glascarnoch wave height at 300°N, SMB/Saville method

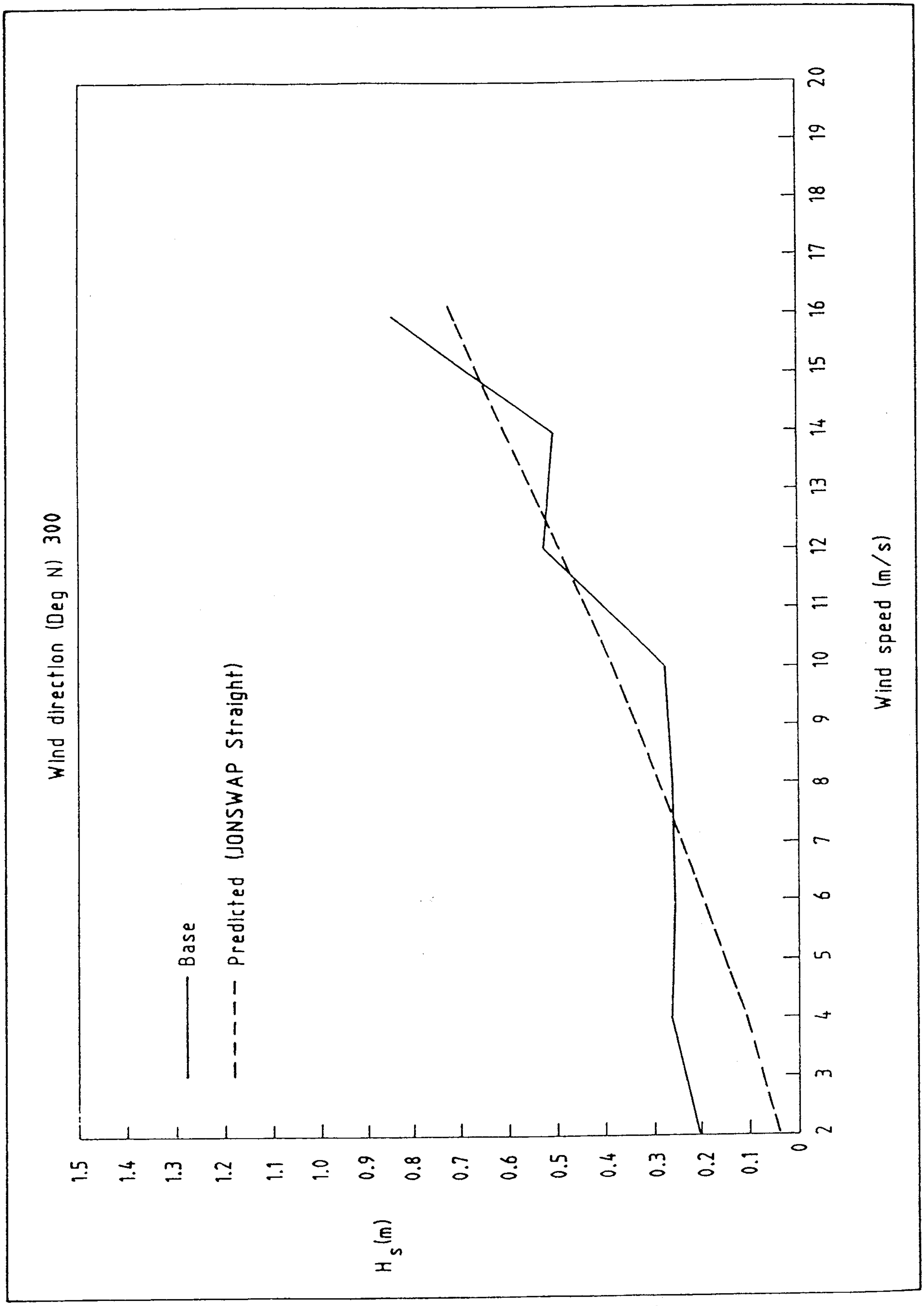

Fig 31 Glascarnoch wave height at 300°N, JONSWAP/Sf method

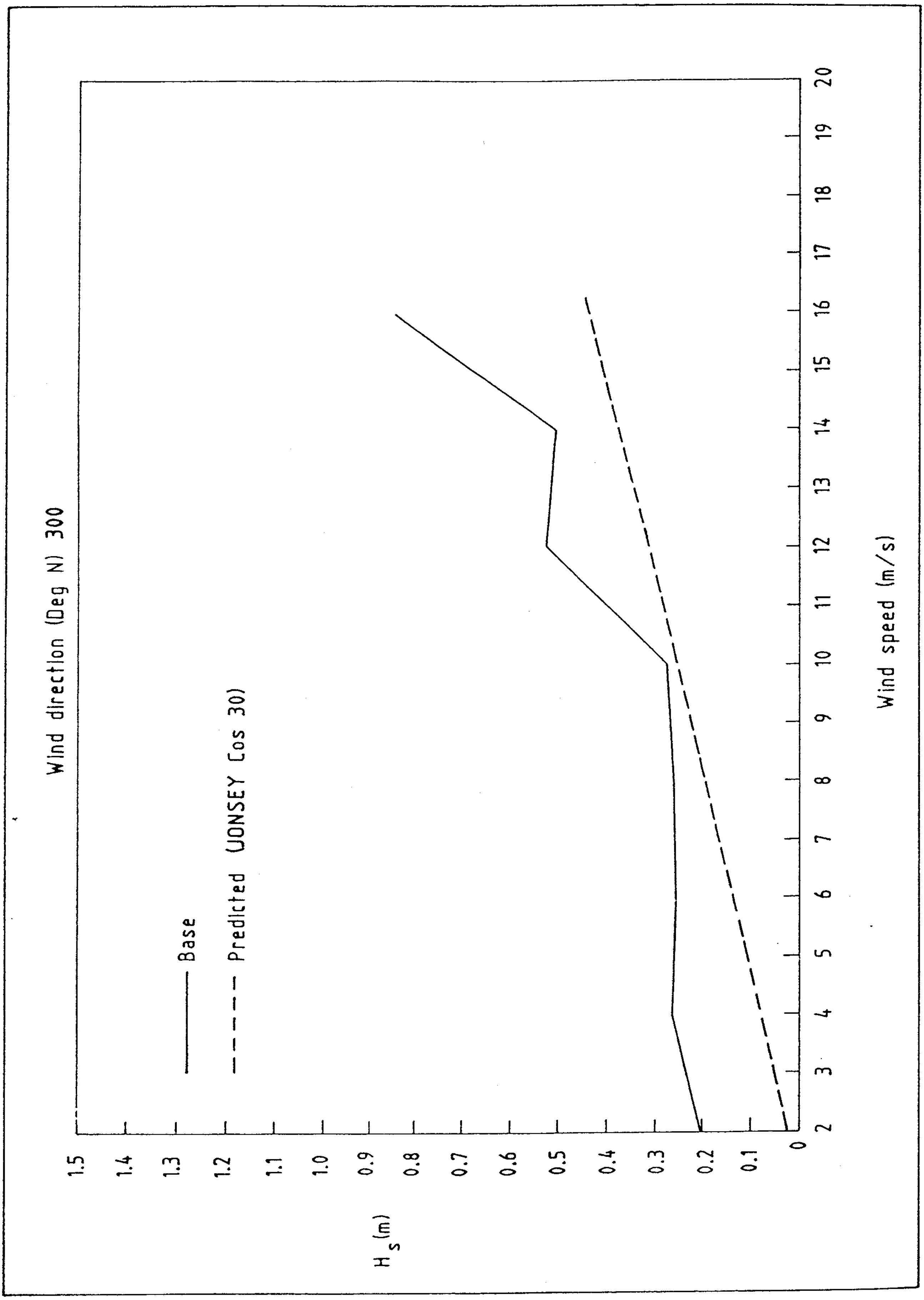

Fig 32 Glascarnoch wave height at 300°N, JONSEY/30 method

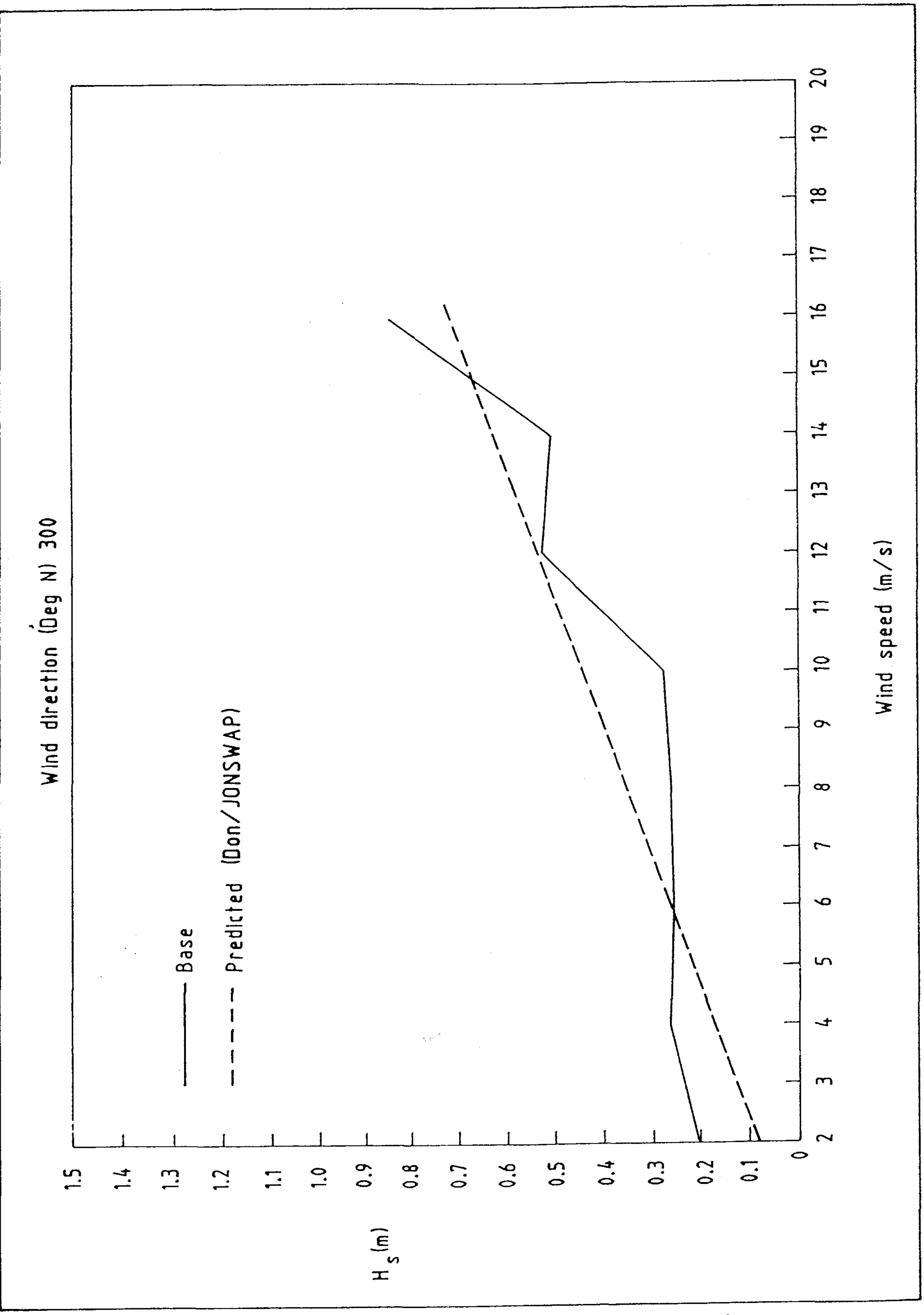

Fig 33 Giascarnoch wave height at 300°N, DON/JON method

APPENDIX.

Alternative definitions

It is not immediately obvious why the predominant wave direction should correspond to the maximum value of peak wave period, rather than the maximum wave energy (and hence wave height). In addition, Donelan's wave formulae differ from all other modern formulae, of which the JONSWAP formulae are probably the most widely used. The product which has to be maximised will differ depending on which alternative assumption is used, as follows:

$\cos(\Theta_w-\varphi)^{0.54}\ F_\varphi^{\ 0.23}$ (maximum T_p, Donelan formulae)

$\cos(\Theta_w-\varphi)^{0.40}\ F_\varphi^{\ 0.30}$ (maximum T_p, JONSWAP formulae)

$\cos(\Theta_w-\varphi)^{1.24}\ F_\varphi^{\ 0.38}$ (maximum H_s, Donelan formulae)

$\cos(\Theta_w-\varphi)^{1.00}\ F_\varphi^{\ 0.50}$ (maximum H_s, JONSWAP formulae)

In many situations the predominant wave directions will in fact be very similar whichever of these assumptions is used, but in this report the second assumption has been adopted throughout the calculations, ie maximising the peak period using the JONSWAP wave prediction formulae.

APPENDIX

Calculation of predominant wave direction

In Donelan's method of wave prediction, the fetch length is defined along the wave direction rather than being based on the wind direction. Moreover, the windspeed to be used for wave prediction is the component along the wave direction. Wave conditions can therefore only be predicted if the predominant wave direction can be calculated.

According to Donelan, the predominant wave direction φ corresponding to a given wind direction Θ_w is that wave direction which gives the greatest value of T_p, the wave period at the peak of the energy spectrum. Using Donelan's own wave formulae, peak period is obtained from the expression

$$\hat{T}_p = 0.541\ \hat{F}^{0.23}$$

where $\hat{T}_p = gT/[U \cos(\Theta_w - \varphi)]$

$\hat{F} = gF_\varphi/[U^2 \cos^2(\Theta_w - \varphi)]$

F_φ = fetch length along the wave direction

Rearranging this expression gives

$$T_p = 0.541\ g^{-0.77}\ U^{0.54}\ \cos(\Theta_w - \varphi)^{0.54}\ F_\varphi^{\ 0.23}$$

For a given windspeed, the largest value of T_p is therefore obtained when the product $\cos(\Theta_w - \varphi)^{0.54}\ F_\varphi^{\ 0.23}$ reaches its maximum.

For an irregularly shaped fetch area the predominant wave direction can only be determined by trial and error. For a given wind direction, the various steps involved are as follows:

1. Mark out fetch rays from the wave prediction point for all directions within ±90° of the wind direction. Any angular spacing can be used, but about 5° would be suitable in most reservoir applications.

2. Measure off the fetch lengths along each ray. The angular spacing between rays need not be uniform: smaller increments can be used when fetch lengths are changing rapidly with direction, and larger increments where the fetch length is almost constant.

3. For each fetch ray within ±90° of the wind direction calculate the value of the required product [eg $\cos(\Theta_w-\varphi)^{0.54}\ F_{\varphi}^{0.23}$]. Identify the maximum value of this product, the fetch ray direction at which it occurs, and the fetch length at that direction. For the given wind direction, this fetch ray direction represents the predominant wave direction.

4. Repeat the calculations for different wind directions, and prepare a table showing the wind direction, predominant wave direction, and the fetch length corresponding to that wave direction.

Although tedious, these calculations are very straightforward, and can easily be accomplished on a personal computer. Note also that they have to be performed only once for each reservoir.