CHAPTER 26

STABILITY OF DESIGN WAVE ESTIMATES

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ABSTRACT

Design wave heights are estimated for the Atlantic coasts of Southern Africa and the Iberian peninsula using the best available recorded data sets from the more exposed sites along these coasts. By spatial integration of the available data for a region and relaxing conditions with respect to independent sampling, stable estimates of design wave heights are obtained. Clear patterns are found in which the predicted design wave heights are strongly correlated with latitude. The recommendations of the IAHR committee on methods for design wave estimation are discussed and reservations are expressed about their recommendation to use only one method for design wave estimation.

INTRODUCTION

The estimation of design wave heights from recorded data is a subject that has received attention from many designers, engineers, statisticians and scientists in the past. Standard procedures for these estimates have however not been established and a variety of methods are presently being used. An international committee appointed by the IAHR, published a recommended procedure for design wave estimation in 1994 (Mathiesen et al, 1994). The committee recommended that only one method should be used. This method fits a three parameter Weibull distribution to data selected by means of a peaks over threshold (POT) sampling method.

This paper describes an alternative approach to design wave estimation favoured by the authors for areas such as the Atlantic ocean off South Africa and the Iberian peninsula. These areas are free of cyclones and similar storm events occur with great regularity during the winter months. Clear patterns in parameters such as the mean and standard deviation of the recorded wave heights exist in these areas. By using the method of moments to fit an Extreme 1 distribution to a total sample from the winter months, stable design wave estimates are obtained. Using this method, a very

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interesting pattern in design wave heights emerges which is compatible with the known weather patterns in the area. Design waves estimated by this method are often much higher than with the method recommended by the IAHR committee.

In this paper an overview of the weather systems responsible for generating large waves in the Atlantic is given. Patterns in recorded wave heights are described and the knowledge of the weather and wave patterns are used to estimate design waves. The results obtained are discussed and compared with the results from studies by the IAHR committee

WAVE CLIMATE OF THE STUDY AREAS

The Atlantic coastlines off South Africa and the Iberian peninsula are free of cyclones as illustrated in Figure 1

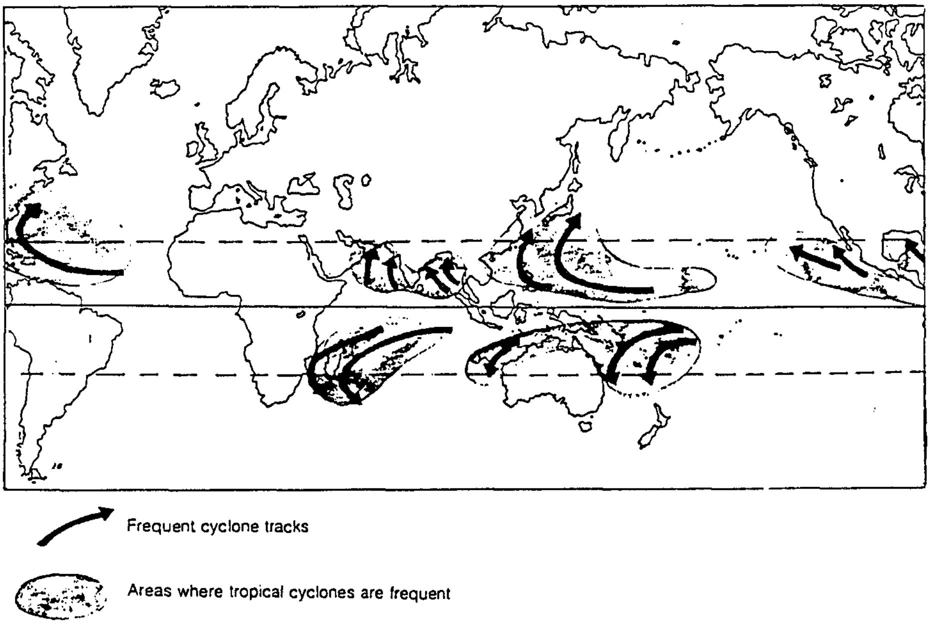

Figure 1: Frequent cyclone tracks of the world

(*Hurry* and *van Heerden*, 1982)

All major wave events in these areas are caused by large frontal systems which occur with great regularity during the winter months. Because of the size of the frontal systems and the speed at which they move on their path from west to east towards and past the coastline, similar wave heights are recorded over large coastal areas during major wave events. This is illustrated in Figure 2 for the South African coast for a few events during August 1980.

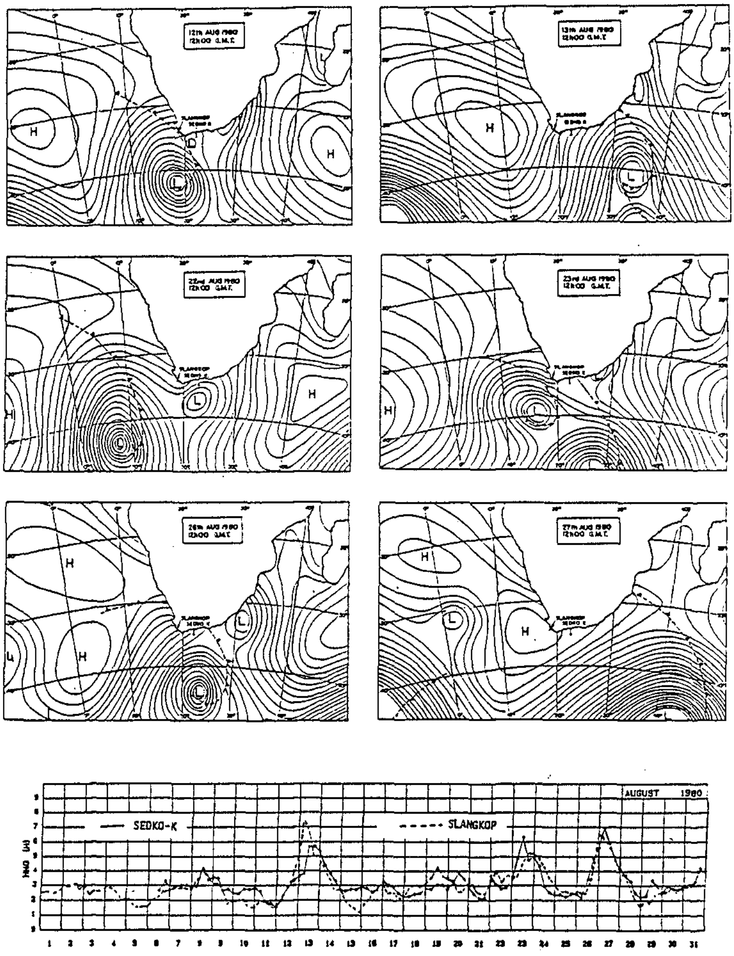

Figure 2: Waves recorded during August 1980

The similarity in wave heights recorded at two stations 300 km apart is apparent from this figure. Not only are the wave heights during major wave events similar over large areas, but the mean and standard deviation of the recorded wave heights over longer periods also show a remarkable similarity. In Figure 3 this similarity for 3 stations off the Iberian peninsula is illustrated.

The seasonal variation in wave height is also apparent from Figure 3. Extreme events can therefore be expected to occur in the winter months. In Figure 4 a comparison is made of the mean and standard deviation of the wave heights recorded in winter at a number of stations in the north Atlantic.

A clear pattern of increasing wave height with latitude is evident as can be expected due to the increasing intensity of the frontal systems at higher latitudes. A similar pattern is evident along the South African Atlantic coast.

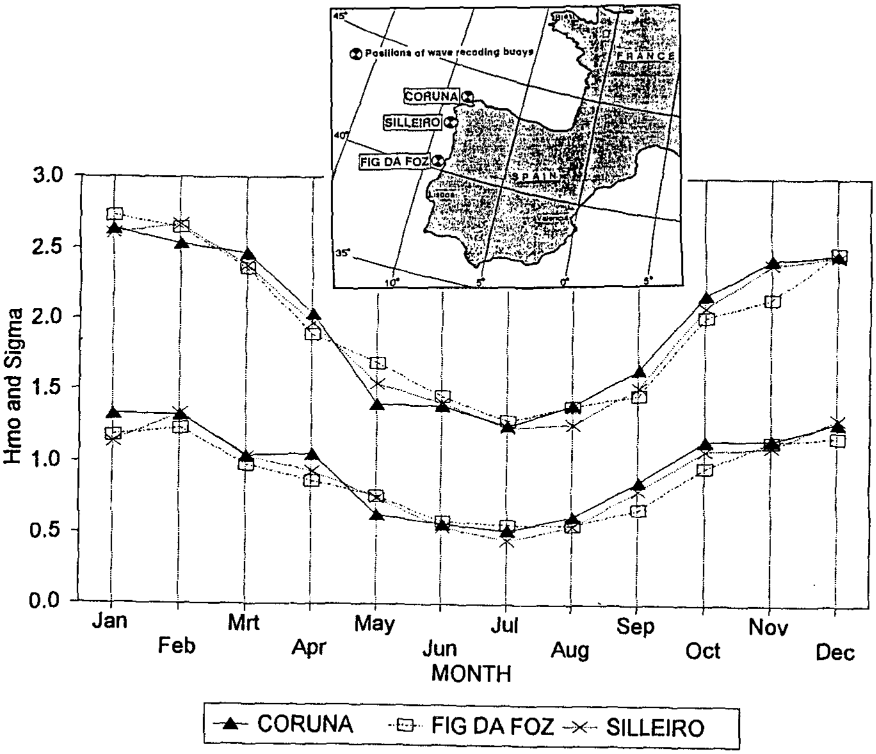

Figure 3: Mean and standard deviation of Hmo - Iberian Peninsula

The similarity in extreme and average wave conditions recorded along these coasts, together with the knowledge of the weather systems, lead to the following conclusions related to design wave estimation:

- Extreme waves are invariably caused by similar frontal systems and the extreme wave heights at exposed coastal stations must belong to the same extreme distribution.

- Due to the absence of cyclones and the seasonal variation in wave heights, identical data would be ensured if only data from the stormy winter months are selected

- The paths of the frontal systems are such that their intensity increase towards the higher latitudes. An increase in design wave heights should therefore occur with increasing latitude. Recording stations at similar latitudes should have similar design wave heights.

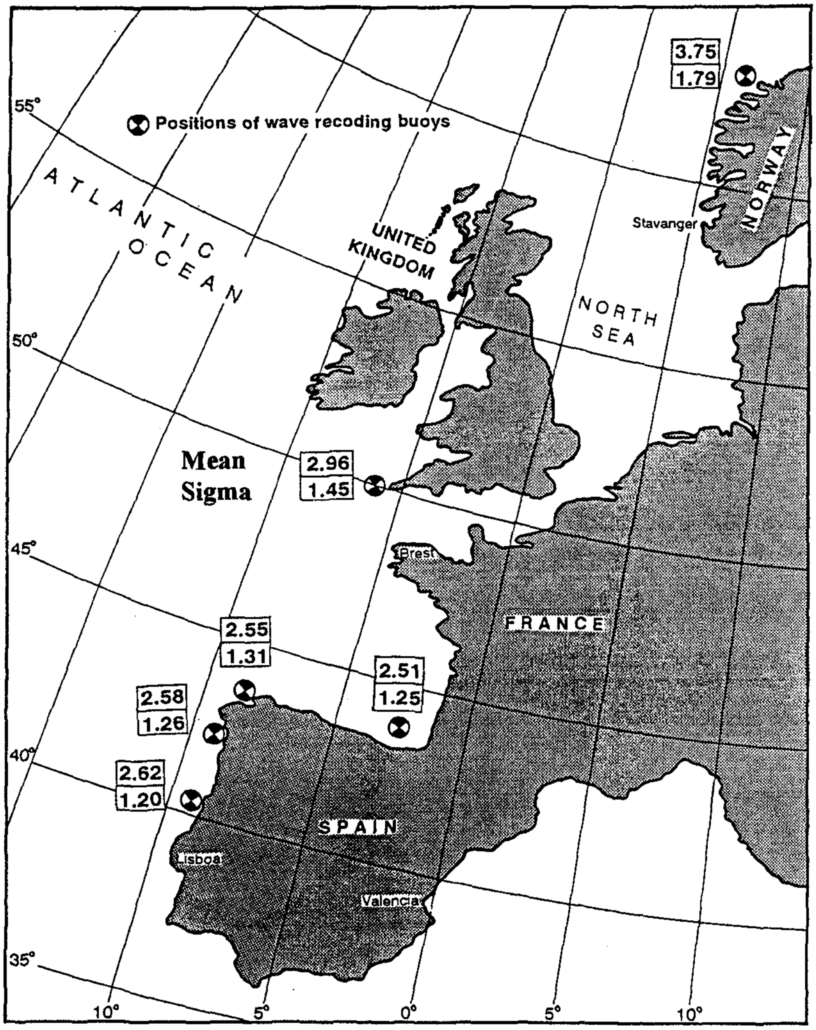

Figure 4: Mean and standard deviation of Hmo- European Atlantic

ESTIMATES BASED ON EXTREME 1 DISTRIBUTION AND TOTAL SAMPLE

The method preferred by the authors for estimating design wave heights, uses the method of moments to fit an Extreme 1 distribution to a total sample from the winter months. In this method the parameters of the distribution are based only on the mean ($\overline{H}mo$) and standard deviation (sigma) of the recorded wave heights in winter. The distribution is given by

($\overline{H}mo$) = A-B*ln(-ln p) with

B = 0.78*sigma and

A = ($\overline{H}mo$) - 0.5772*B

p = probability of non-exceedance of Hmo.

A graph of Hmo versus ln(-ln p) gives a straight line with slope B and a abscissa A as shown in Figure 5.

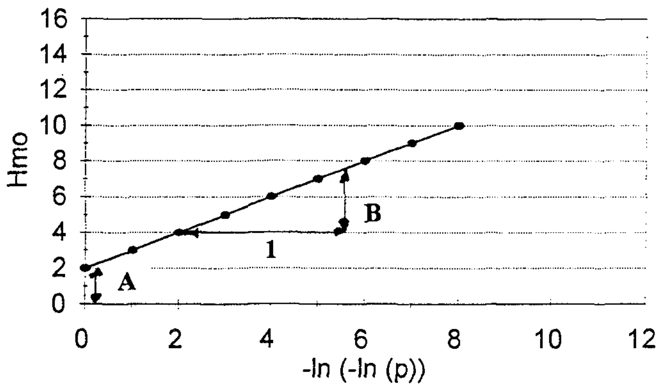

Figure 5: Extreme 1 distribution

This method makes maximum use of the available data as well as of the clear pattern that exists in the mean and standard deviations of the recorded wave heights

The fit of the data to the Extreme 1 distribution for all the stations along the South African west coast is shown in Figure 6.

The distribution generally fits the data well although deviations occur near the upper tail of the data. The deviations of the data at the upper tail are both above and below the fitted distribution. Although it will be possible to obtain a better fit at individual stations by employing a three parameter distribution, the overall fit is acceptable if the same distribution is used at all the stations along the coast. Inspection of the data shows that the stations where the data at the upper tail exceeds the fitted curves, included the more severe storms recorded on the coast. A downward deviation occur where these storms are not included in the data set. These deviations are considered to be due to variations in the wave climate and deficiencies in the data rather than variation in the underlying distributions. Too much emphasis on this upper tail will lead to unstable design wave estimates that vary haphazardly from station to station.

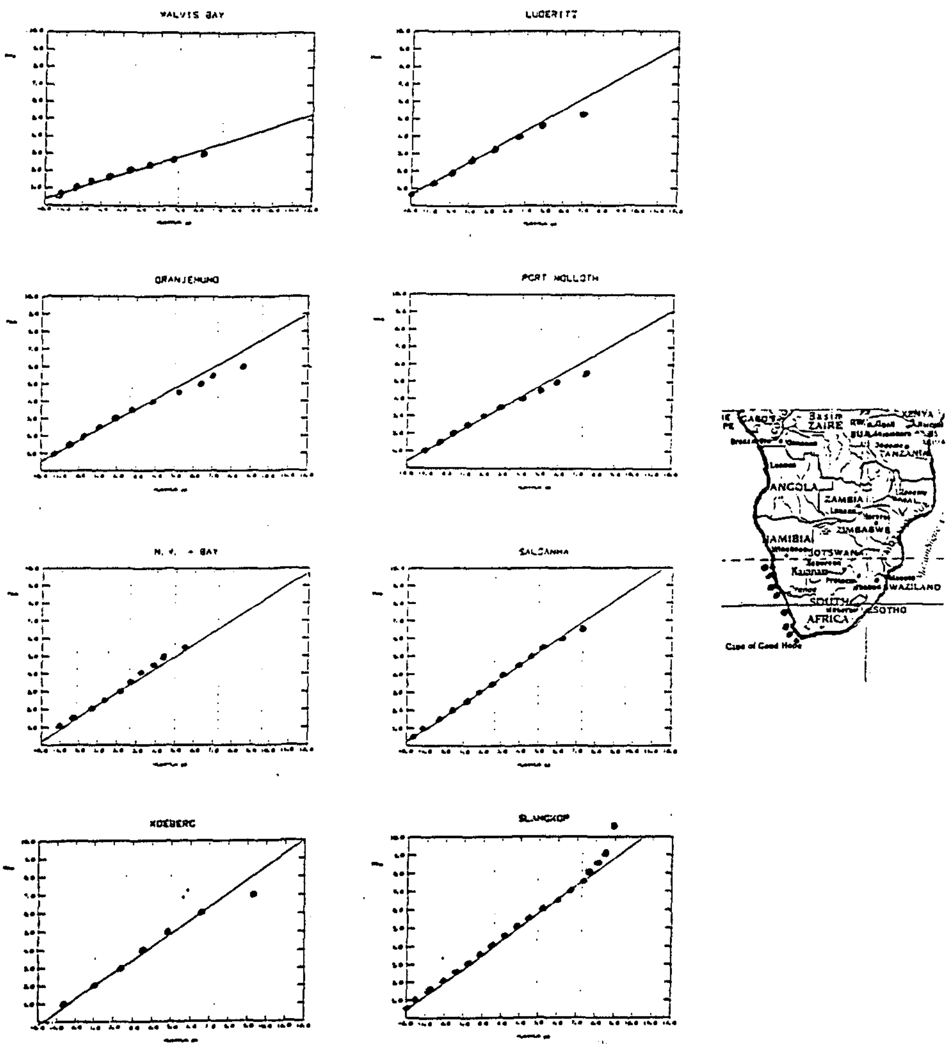

Figure 6: Extreme 1 fit to RSA data

The 100 year return period waves (Hmo) with a duration of 3 hours are shown in Figure 7 for the south and north Atlantic. Added to the data off the South African and Iberian Atlantic is data off the British isles and Norway.

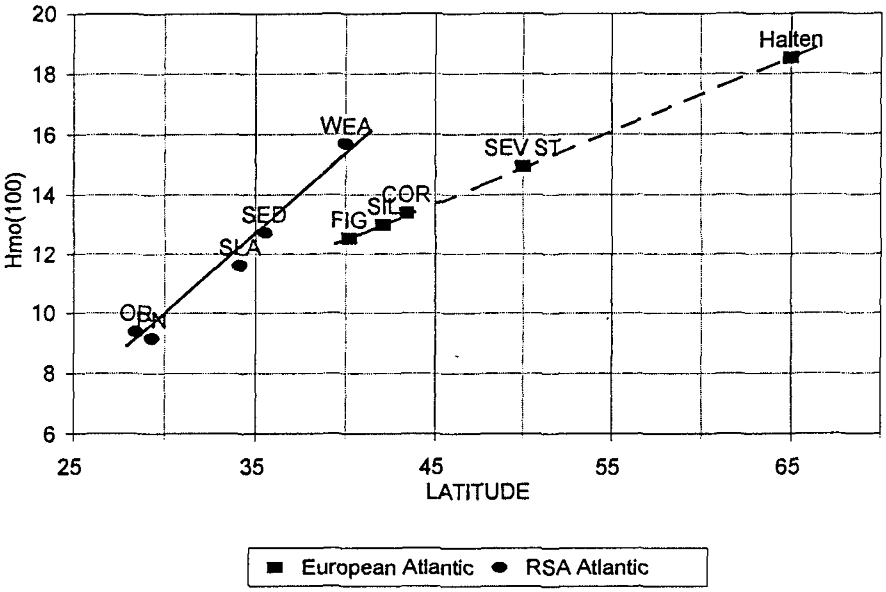

Figure 7: Design Hmo(100)- 3 hour duration

A strong correlation between the design waves and the latitude is evident from this figure.

The 100 year wave as estimated here is compared to the largest waves recorded at various sites in the north Atlantic in Figure 8. The 100 year wave predicted at all the stations exceed the maximum recorded wave height by between 30 and 50 per cent. The maximum difference occur at Haltenbanken where the 100 year wave of 18.5 m exceeds the maximum recorded wave by 6m or nearly 50 per cent. This design wave seems extraordinarily high and is much higher than the 15.0 m predicted by the members of the IAHR committee using the same data (van Vledder,1993). The question obviously arises whether there should be a physical limit to the height a wave can reach. A wave height (Hs) of 17.4 m was recorded at the Weather Station India in the North Atlantic (Draper,1986), at a latitude lower than the Haltenbanken site, giving some credibility to this high design height. The probable reason for the large difference between the two methods of design wave estimation in the case of Haltenbanken lies in the difference in emphasis placed on the upper tail of the data by the two methods. This will be further discussed in the next section.

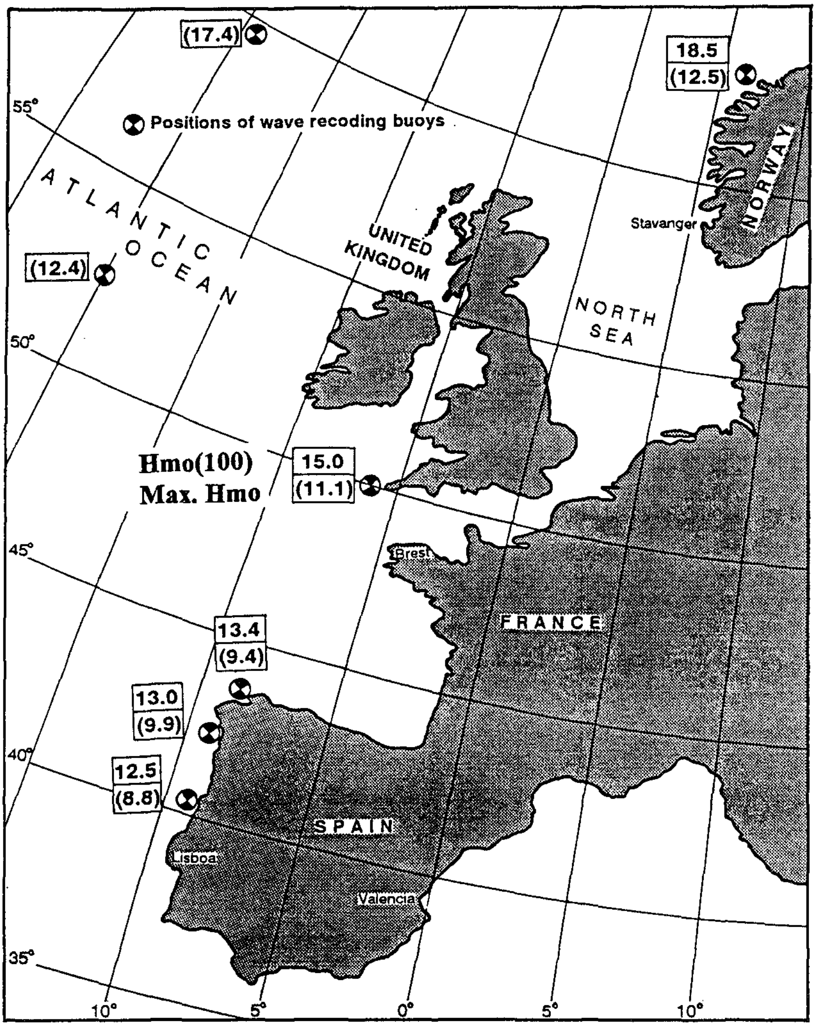

Figure 8: Hmo(100) and maximum Hmo recorded

ESTIMATES BASED ON 3 PARAMETER WEIBULL DISTRIBUTION AND POT SAMPLING

The method for design wave estimation recommended by the IAHR group, differ from the method described above. To ensure independent and identical data, a peaks over threshold sampling technique is used. The highest wave recorded between the up and down crossing of a chosen threshold (POT) is used as data. A three parameter Weibull distribution is fitted to the selected data. This method inherently places the emphasis on the upper tail of the data in that only the largest storms are included in the data and that the use of three parameters allows the fit to follow the data deviations at the upper tail.

With the South African data it was found that the two methods described above lead to similar design values in cases where a long data record is available and where the upper tail of the data follows the Extreme 1 distribution. With shorter data sets or in cases where a deviation from Extreme 1 distribution occur at the upper tail of the distribution, large differences occur between the two methods. Because of the emphasis on the upper tail by the IAHR method, much lower design wave heights are predicted when the data deviates downward at the upper tail. This is thought to be the reason for the large differences at Haltenbanken discussed in the previous section. Similarly the IAHR method will predict higher waves where the deviation is upward. The emphasis on the upper tail destroys the clear pattern in design waves illustrated in Figure 6. Copeiro (1978) already warned against placing too much emphasis on the upper tail of the distribution.

APPROPRIATE METHOD

Two methods have been presented which essentially differs in the procedure for data selection and in the choice of extreme value distributions. The question arises as to which procedure is most appropriate.

The advantages of using a total sample from the winter months and a simple two parameter Extreme 1 distribution in areas such as the open coasts of the South African and European Atlantic are:

- Maximum use is made of the available data.
- Design wave estimates are not sensitive to the upper tail of the data. The loss of data during storms and outliers in the data do not influence the estimates unduly.
- Estimates of design waves stabilise after a few years of data. This method is therefore ideal where short data records must be used.
- The Extreme 1 distribution fits the data well if all the data of an area is considered rather than data at individual recording stations
- Maximum use is made of clear spatial patterns that exist in the mean and standard deviation of the recorded wave heights

Criticisms against the method are:

- The data used are not independent. For areas such as the South African and Iberian Atlantic, where storms occur with great regularity, the use of correlated data do not seem to bias the estimates (Rossouw,1988). This method however will only work in areas where one can expect a strong correlation between mean and extreme conditions. It will not work in areas prone to cyclones, semi-protected areas where refraction, diffraction and other shallow water effects will influence the data or in areas where mixed distributions are present.

- The selection of the probability associated with a given return period requires a decision with respect to the duration of the storm peak. This in the opinion of the authors is an advantage since the significant wave height of one hour duration during the peak of the storm can be expected to be higher than the height for three hour duration. This is also the reason why an increase in the peak Hmo value can be expected if the recording interval is decreased. Rossouw and Medina (1995) show that the selection of the duration of storm peaks varying from 1 to 6 hours, although affecting the value of the design Hmo, does not influence the design Hmax values.

Advantages of the method recommended by the IAHR committee are as follows:

- The POT method of sampling should ensure independent and identical data.
- The use of a three parameter Weibull distribution allows a good fit to most data sets

Problems with this method are however:

- The POT method of sampling is sensitive to the level of the threshold that is chosen. This was illustrated by the IAHR committee in van Vledder et al (1993).
- There is a emphasis on the upper tail of the distribution. This emphasis increases with increasing threshold values
- The use of a 3 parameter distribution increases the emphasis on the upper tail of the distribution.
- The use of only one data point in each storm makes the method very sensitive to outliers in the data, loss of records near the peak of the storm, the recording interval, etc. Long data records are also required before stable design wave estimates are obtained.

It is concluded that both these methods have their merits. The method recommended by the IAHR committee is expected to be superior in cases where there is a danger of using non identical data. Such areas would be cyclone prone areas, semi protected areas such as inside bays where directionality plays a major role and where mixed systems are present.

The simple method favoured by the authors seem to be applicable to areas where storms of identical origin occur with great regularity. In such areas a correlation between the mean and extreme conditions should exist and the estimate of design waves based on mean wave heights seems reasonable.

For either method the integration of the data over space should help to add stability to the estimates. Knowledge of the generating systems should be incorporated in the integration process.

CONCLUSIONS

The recommendation of the IAHR committee to use only one method for design wave estimation seems unrealistic. Their recommended method will work well in areas where different systems are responsible for wave generation for example in areas where cyclones occur regularly. In areas such as the Iberian and South African Atlantic, the methods used by the authors are preferred, especially at stations with short recording histories. In areas such as the South African east coast where cyclones occur very irregularly, i.e only once every few years, neither these methods are applicable.

Clear patterns exist in the recorded wave data. This is to be expected taking into account the present knowledge of the weather systems over the oceans. Design wave estimates, especially over large bodies of open water, can be improved by the spatial integration of the available data. Efforts to do this in the South African and Iberian Atlantic produces promising results. A global approach and co-operation between the countries involved in wave recording, will enhance our knowledge of extreme wave events and will lead to better estimates of design wave conditions.

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