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Health & Safety Executive

# OFFSHORE TECHNOLOGY REPORT - OTO 93 026

# STATISTICS OF WAVE BREAKING IN THE SOUTHERN NORTH SEA

by

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## SUMMARY

This study estimates the number of breaking waves in one year at locations in shallow parts of the southern North Sea.

The sources of wave data used are taken from wave measurements, hindcasts and visual observations. The annual occurrence of breaking waves is computed from the "scatter diagram" of wave height and wave period. The probability of wave breaking then follows from the theoretical work of Battjes & Janssen (1978).

Conclusions and recommendations for future work are presented.

## 1. INTRODUCTION

The purpose of this study is to estimate the annual number of breaking waves at certain locations in the southern North Sea due to the influence of shallow water. The area bounded in the north by latitude 55°N and in the south by the Straits of Dover is considered.

At present there are no observations of the probability of occurrence of wave breaking due to shallow water in this area. Observational methods are still in their early development (for example, Longuet-Higgins & Smith (1983), Holthuijsen & Herbers (1986)) and these few observations have concentrated on wave breaking in deep water. Two recent reviews of wave breaking in deep water have been made by Srokosz (1990) and Banner & Peregrine (1993). A review of wave breaking in shallow water is given in Peregrine (1983).

Wave data obtained from measurements, hindcasts and visual observations are used in this study. The annual occurrence of wave heights and periods (the "scatter diagram") at each location or for each area is then used to estimate the number of breaking waves in one year based on the shallow water criterion given by Battjes & Stive (1985) and the probability of wave breaking following the theory of Battjes & Janssen (1978). For a recent review of breaker height criteria the reader is referred to Southgate (1993).

The results derived in this study will supplement present information given in the HSE "Offshore Installations : Guidance on design, construction and certification" Fourth Edition, January 1990, Section 11, paragraph 11.4.4 (Shallow water effects) and the corresponding Appendix A11.4.4.

## 2. METHOD OF CALCULATION OF BREAKING WAVE STATISTICS

### 2.1 THEORY

The wave height at which breaking starts to occur for a given water depth, bed slope and wave characteristics, is taken from the work of Battjes & Stive (1985). It is usual to express the breaker height $H_b$ as a function of water depth d by $H_b = \gamma d$.

Battjes and Stive have carried out a comprehensive study of random wave breaking in both laboratory and field experiments. They found that



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$$\gamma = 0.5 + 0.4\tanh(33s_o) \quad (1)$$

where $s_o$ is the deep-water wave steepness given by

$$s_o = H_{rms}(\text{offshore})/L_o(\text{offshore})$$

$L_o$ is the wavelength corresponding to the peak spectral wave period (i.e. $L_o = gT_o^2/2\pi$ ).

The probability of wave breaking follows the theory of Battjes & Janssen (1978). The Rayleigh distribution of wave heights is taken to represent the distribution of wave heights :

$$P(H) = \frac{2H}{H_{rms}^2} \cdot \exp(-H^2/H_{rms}^2)$$

Then, in shallow water, this distribution is truncated at the breaker height $H_b$. Battjes & Janssen assume that all broken waves have a wave height given by $H_b$, thus resulting in a probability distribution truncated at $H_b$ to represent unbroken waves but with a delta function at $H_b$ to represent the broken waves. Battjes and Janssen then show that the probability of occurrence of broken waves, Q, is related to $H_{rms}$ and $H_b$ by

$$\frac{1 - Q}{-\ln Q} = \left(\frac{H_{rms}}{H_b}\right)^2 \quad (2)$$

Given values of $H_{rms}$ and $H_b$, then equation (2) can be solved for Q by an iterative procedure.

Table 1 gives the values of Q for particular values of $a \equiv (H_{rms}/H_b)^2$.

It is not at present possible to comment on the relative occurrence of spilling and plunging breakers in shallow water although it is generally believed that plunging breakers occur more frequently.

2.2 PROCEDURE

The wave data to be described in the next section consist of the probability of occurrence of values of significant wave height, $H_s$, and peak spectral period, $T_o$, or the mean zero crossing period, $T_z$. (i.e. the "Scatter Diagram").

The following relations were used :

$$H_{rms} = H_s/\sqrt{2} \quad \text{and} \quad T_o = 1.28T_z.$$

Equation (1) was first computed for the value of $\gamma$ and hence $H_b$. Q was then calculated from equation (2). Finally, the total number of breaking waves in 1 year, $N_b$, was calculated by summing the contributions for each cell of the "scatter diagram" by taking into account the probability of occurrence of particular combinations of wave height and period.

## 3. SOURCES OF WAVE DATA FOR THE SOUTHERN NORTH SEA

The sources to be considered in the analysis for wave breaking in the southern North Sea have been taken from three kinds of data : wave measurements, hindcast data from numerical wave models and visual observations.

### 3.1 WAVE MEASUREMENTS

The scatter diagrams for wave analyses made by the Institute of Oceanographic Sciences and its predecessor, the National Institute of Oceanography, were used for Dowsing, Galloper and Tongue. Confidential data from West Sole were kindly supplied by BP. The measurements at Dowsing, Galloper and Tongue were made with the Shipborne Wave Recorder (SBWR). Data at West Sole were obtained from a Baylor Wavestaff.

The positions of the stations are given in the following table and are shown in Figure 1 :

| Station | Position lat., long. | Depth of water m |
|---|---|---|
| Dowsing | 53.6°N,0.8°E | 26 |
| Galloper | 51.7°N,2.0°E | 29 |
| Tongue | 51.5°N,1.4°E | 13 |
| West Sole | 53.7°N,1.1°E | 24 |

### 3.2 HINDCAST DATA

Wave hindcast data (ANEP,1987) from the Second Generation wave model, HYPAS, were used at four grid points within the southern North Sea. The statistical data given in ANEP (1987) cover the years 1968-1983 and were hindcast from information from synoptic weather charts reported every six hours. The wave model HYPAS uses information on wind-generated shallow water waves and includes shallow water wave damping on swell.

The positions of the four grid points are given in the following table and in Figure 1 :

| Grid Point | Position lat., long. | Depth of water m |
|---|---|---|
| 3 | 53.11°N,1.14°E | 8 |
| 5 | 54.52°N,2.94°E | 31 |
| 8 | 53.41°N,5.28°E | 5 |
| 10 | 54.74°N,7.27°E | 31 |

### 3.3 VISUAL OBSERVATIONS

Data from visual observations have been compiled by Korevaar (1989) at the KNMI. The data are based on observations made from voluntary observing ships over the period 1961-1980. Data from this source in the southern North Sea are shown for the 8 areas denoted by reference numbers 19-26 inclusive in Figure 1.

## 4. CALCULATIONS OF STATISTICS

### 4.1 RESULTS

The calculations of the total number of breaking waves in 1 year, $N_b$, are shown in Tables 2,3 and 4 for wave measurements, hindcast data and visual observations respectively.

For the wave measurement sites given in Section 3.1, it was found that wave breaking due to shallow water could not occur for the depths of water at these stations. This is probably due to the choice of a measurement station where it is not desirable to have active wave breaking at the site of a wave recorder. It was therefore decided to calculate the statistics for an assumed nearshore position with depth 10m. Tables 2 show the results.

For the hindcast data, wave breaking due to shallow water occurred at Grid Points 3 and 8. But the depths of water at Grid Points 5 and 10 were too great and an assumed nearshore position with depth 10m was taken. (The wave direction, which is available for the hindcast data, was used in estimating the probability of occurrence of wave height and period). Tables 3 show the results. The variation of $N_b$ with wave period is shown for these data.

For the visual observations, it was found that the areas shown in Figure 1 covered too large a range of depths for any "typical" depth to be chosen. It was decided to make the calculations for a nominal depth of 10m except for area 20 where no depth was less than 10m.

## 4.2 SENSITIVITY OF THE CALCULATIONS TO WATER DEPTH

The calculations of the number of breaking waves are very sensitive to the ratio of wave height to water depth as shown in Table 1. To obtain some indication of this sensitivity the calculations with wave measurements at Dowsing were repeated for water depths of 9m and 11m. The results are shown in the following table :

Influence of water depth on wave breaking

| $h_s$ (m) | $N_b$ Water depth (m) 9 | 10 | 11 |
|---|---|---|---|
| 4.75 | 97 | 38 | 14 |
| 4.25 | 116 | 35 | 9 |
| 3.75 | 58 | 13 | 3 |
| 3.25 | 26 | 4 | 0 |
| **Totals** | **297** | **90** | **26** |

## 5. CONCLUSIONS

Wave breaking due to shallow water in the southern North Sea is negligible for water depths greater than 20m. For the typical wave climate in this region most wave breaking takes place in depths less than 10m.

The total number of breaking waves in one year was found to be very sensitive to the water depth. For example, a change in water depth of + 1m at Dowsing caused the number of breaking waves in one year to vary by a factor of 4. The simple model described in this report is a first step in calculating wave breaking in the southern North Sea. The model does not consider the effect of currents on wave breaking nor the influence of tidal levels.

The results given in this report are a general indication of the annual number of breaking waves due to shallow water. There is at present no observational evidence to confirm these statistics. However the method can be used to evaluate wave breaking statistics at different sites for comparative design purposes.



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## 6. RECOMMENDATIONS

Accurate calculations of wave breaking in shallow water are needed to take into account the influence of surface currents and tidal levels. Coastal engineers (e.g. Southgate, 1989) have developed wave models which can account for these processes but these models need to be modified to predict breaking wave statistics on an annual basis.

The main requirement is the need for observational methods which can be used to quantify and collect breaking wave statistics. A review should be made of suitable techniques for use in coastal waters.

The existence of breaking waves is not included in extreme value estimation for shallow water waves as presently given in the "Guidance Notes". The methods discussed in the "Guidance Notes" are based on the use of the Fisher-Tippett I (FT-I) distribution for the estimate of the 50-year return value of $H_s$. It should be possible to use the Fisher-Tippett III distribution which has an upper bound. (The FT-I distribution is unbounded above). Then, by taking the upper bound equal to $H_b$, an estimate of the 50-year return value of $H_s$ can be obtained.

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## 8. NOMENCLATURE

- a = $(H_{rms}/H_b)^2$
- d = depth of water
- g = acceleration due to gravity
- $H_b$ = breaker height
- $H_{rms}$ = r.m.s. wave height
- $H_s$ = significant wave height
- $N_b$ = number of breaking waves in one year
- Lo = wavelength corresponding to the peak wave period
- Q = probability of occurrence of breaking waves
- so = deep-water wave steepness
- To = peak spectral wave period
- $T_z$ = mean zero-crossing wave period
- $\gamma$ = ratio of $H_b$ to d

## 9. FIGURE

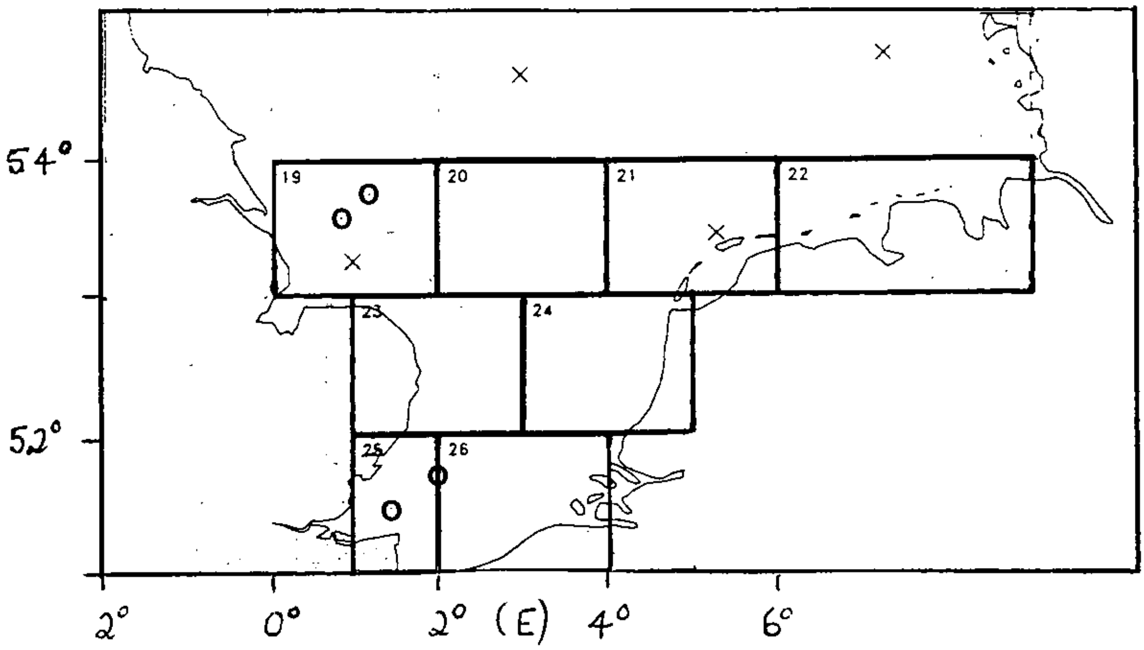


*Figure 1* : Wave measurement stations are shown by O. Hindcast grid points from ANEP (1987) are shown by X. Eight areas from Korevaar (1989) are indicated by the numbers in the top left corner of each area.

## 10. TABLES

### TABLE 1

Table of values of $a=(H_{rms}/H_b)^2$ and the probability of breaking waves, Q.

| a | Q |
|---|---|
| 1.000 | 1.000 |
| 0.975 | 0.950 |
| 0.950 | 0.902 |
| 0.900 | 0.807 |
| 0.85 | 0.716 |
| 0.80 | 0.629 |
| 0.75 | 0.546 |
| 0.70 | 0.467 |
| 0.65 | 0.324 |
| 0.55 | 0.261 |
| 0.50 | 0.203 |
| 0.45 | 0.152 |
| 0.40 | 0.107 |
| 0.35 | 0.0702 |
| 0.30 | 0.0409 |
| 0.25 | 0.0198 |
| 0.20 | 6.89E-03 |
| 0.15 | 1.28E-03 |
| 0.10 | 4.54E-05 |
| 0.05 | 2.06E-09 |

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## TABLE 2(a)

**Measured wave data at DOWSING**
Wave breaking at an inshore depth of 10m

| Hs (m) | Tz (s) | $N_b$ |
|---|---|---|
| 4.75 | 8.25 | 38 |
| 4.25 | 7.25 | 35 |
| 3.75 | 7.25 | 13 |
| 3.25 | 6.75 | 4 |
| | **Total =** | **90** |

## TABLE 2(b)

**Measured wave data at GALLOPER**
Wave breaking at an inshore depth of 10m

| Hs (m) | Tz (s) | $N_b$ |
|---|---|---|
| 5.18 | 6.5 | 22 |
| 5.03 | 6.5 | 8 |
| 4.88 | 7.0 | 40 |
| 4.73 | 6.5 | 4 |
| 4.57 | 6.0 | 12 |
| 4.42 | 6.0 | 16 |
| 4.27 | 6.0 | 28 |
| | **Total =** | **130** |

## TABLE 2(c)

**Measured wave data at TONGUE**
Wave breaking at an inshore depth of 5m

| Hs (m) | Tz (s) | $N_b$ |
|---|---|---|
| 2.44 | 6.0 | 205 |
| 2.29 | 6.0 | 137 |
| 2.13 | 6.0 | 78 |
| 1.98 | 5.2 | 23 |
| 1.83 | 5.0 | 20 |
| 1.68 | 4.5 | 5 |
| | **Total =** | **468** |

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TABLE 2(d)

**Measured wave data at WEST SOLE** ***(CONFIDENTIAL)***
Wave breaking at an inshore depth of 10m

| Hs (m) | Tz (s) | Nb |
|---|---|---|
| 7.25 | 8.5 | 702 |
| 6.75 | 8.0 | 320 |
| 6.25 | 8.0 | 389 |
| 5.75 | 8.5 | 361 |
| 5.25 | 8.0 | 203 |
| 4.75 | 8.0 | 136 |
| 4.25 | 7.5 | 80 |
| 3.75 | 7.0 | 23 |
| | **Total =** | **2214** |

TABLE 3(a)

**Data from Hindcast wave heights (ANEP,1987)**
Grid point 3. Depth at grid point = 8m

| Hs (m) | To (s) | Nb |
|---|---|---|
| 4.5 | 18.3 | 277 |
| 3.5 | 7.7 | 9 |
| " | 8.3 | 12 |
| " | 9.1 | 19 |
| " | 10.0 | 28 |
| " | 11.3 | 42 |
| " | 12.6 | 56 |
| " | 13.3 | 60 |
| " | 14.3 | 71 |
| | Sub-total = | 297 |
| 2.5 | 9.1 | 4 |
| " | 10.0 | 5 |
| | Sub-total = | 9 |
| | **Total =** | **583** |

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**TABLE 3(b)**

**Data from Hindcast wave heights (ANEP,1987)**
Grid point 5. Depth taken as 10m

| Hs (m) | To (s) | Nb |
|---|---|---|
| 6.5 | 12.5 | 352 |
| 5.5 | 10.0 | 356 |
| 4.5 | 9.1 | 101 |
| 3.5 | 8.3 | 7 |
| | **Total =** | **816** |

**TABLE 3(c)**

**Data from Hindcast wave heights (ANEP,1987)**
Grid point 8. Depth at grid point = 5m

| Hs (m) | To (s) | Nb |
|---|---|---|
| 4.5 | 10.0 | 2212 |
| 3.5 | 6.7 | 448 |
| " | 7.7 | 563 |
| " | 8.3 | 644 |
| " | 9.1 | 744 |
| " | 10.0 | 856 |
| " | 11.3 | 1020 |
| " | 12.5 | 1119 |
| " | 13.3 | 1187 |
| " | 14.3 | 1235 |
| | Sub-total = | 6629 |
| 2.5 | 5.7 | 798 |
| " | 6.7 | 1024 |
| " | 7.7 | 759 |
| " | 8.3 | 114 |
| " | 9.1 | 697 |
| " | 10.0 | 690 |
| " | 11.3 | 422 |
| " | 12.5 | 237 |
| | Sub-total = | 4741 |
| 1.5 | 8.3 | 18 |
| | 9.1 | 36 |
| " | 10.0 | 20 |
| " | 11.3 | 5 |
| " | 12.5 | 3 |
| | Sub-total = | 82 |
| | **Total =** | **13664** |

TABLE 3(d)

**Data from Hindcast wave heights (ANEP,1987)**
Grid point 10. Depth taken as 10m

| Hs (m) | To (s) | $N_b$ |
|---|---|---|
| 6.5 | 12.5 | 705 |
| 5.5 | 11.3 | 1339 |
| 4.5 | 10.0 | 716 |
| 3.5 | 8.3 | 24 |
| | **Total =** | **2784** |

**TABLE 4**

**Data from visual observations (Korevaar,1989)**

A depth of 10m was taken throughout these calculations since the areas concerned cover a wide range of depths none of which can be considered representative.

**TABLE 4(a)**

**Area 20**

A depth of 10m was taken throughout these calculations since the areas concerned cover a wide range of depths none of which can be considered representative.

**Area 24**

Data from Fig.94

| Hs (m) | $T_z$ (s) | $N_b$ |
|---|---|---|
| 6.0 | 9.0 | 620 |
| 4.0 | 8.0 | 165 |
| | **Total =** | **785** |

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**TABLE 4(b)**

Data from Fig.99 : Jan.1961-1980

| Area | Hs (m) | Tz (s) | Nb |
|---|---|---|---|
| 19 | 3.75 | 8.0 | 203 |
| 21 | " | " | 121 |
| 22 | " | " | 81 |
| 23 | " | " | 203 |
| 25 | " | " | 41 |
| 26 | " | " | 81 |

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