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Analysis of Wave Heights in the North Sea 1965-68

as reported by Oil Rigs operating in Blocks 21 (57°N-58°N, 0° - 1°E)

42-44, 47-49 (53°N-55°N, 0° - 3°E)

53 (52°N-53°N, 2°E- 3°E)

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This memorandum also incorporates an analysis of Wind Speeds reported by the same Oil Rigs during 1965-68.

This investigation was prompted by the discovery of an anomalous second peak in the frequency of observations of wave heights in a previous analysis. The table of 'Monthly and Annual Frequencies and Percentage Frequencies of Observations of wave heights from Oil Rigs in the North Sea - Period 1965 - 1968' is included (Table 1). In this previous analysis, the wave heights are grouped as follows:-

0-1 ft, 2-3, 4-5, 6-7, 8-10, 11-13, 14-16, 17-19 ft etc.

as can be seen. Using these ranges, a double peak appears in the frequency distributions of some of the months, i.e. the frequency of observations in the 8-10 ft range often exceeds the frequency of observations in the 6-7 ft range, the first and larger peak in the distribution occurring in either the

4-5 ft range (winter months) or the

2-3 ft range (summer months)

The double peak is not evident in the figures for the summer months (MAY-AUGUST). Since the mean wave height varied from about 3 ft to 6 ft over the year the second peak, in the 8-10 ft range, seemed anomalous, and its origin was investigated.

Details of the Analysis

1) All the observations were re-analysed, and regrouped in individual single-value ranges i.e. in ranges 0, 1, 2, 3, ... 40 ft. (Where possible this was done by going back to some original working papers, which were compiled during the previous analysis).

This was done for each month of each year in the period 1965 - 1968, and totalled for the whole period. These results, showing the frequency distribution using the single value ranges, have been tabulated and are available, but are not included in this memo. (The table for the whole period 1965 - 1968 is included - table 2). A histogram (2) is shown for these reults.

The first peaks occur at a value of 4 ft (13.5%)

the frequency decreases at 5 ft (11.5%)

and 6 ft (9.7%); at 7 ft (4.8%) the frequency is anomalously low, and at 8 ft (6.9%) it rises again, falling at 9 ft (2.4%), rising again at 10 ft (4.8%)

falling at 11 ft(0.8%), rising again at 12 ft (3.2%)

The reason for these irregularities is obviously that the observers on the oil rigs are tending, naturally, to throw the wave height values to the even numbers of feet (this is particularly evident from 6 ft to 14 ft). For example, if the actual wave height is 7 ft, the observer will, on most occasions, report 6 or 8 ft, or if it is 9 ft, he will report 8 or 10 ft more often than he will report 9 ft, although a common observation is "8 - 10 ft". In the analysis, this 8 - 10 ft report was taken as a 9 ft report; whenever a range of wave height was given, the average was taken; if the average was not a whole number of feet, the nearest whole number of feet above the average was taken.

e.g. 15 - 20 ft taken as 18 ft.

4 - 5 ft taken as 5 ft.

The values of wave height which were comparatively infrequently reported were

7 ft, 9, 11, 13, 17, 19, 21, 23, 27 ft etc.

From the histogram (2) it can be estimated that.-

(i) on about 25% of occasions when actual wave ht is 7 ft, it is reported as 6 or 8 ft

(ii) on about 50% of occasions when actual wave ht is 9 ft, it is reported as 8 or 10 ft.

(iii) on about 75% of occasions when actual wave ht is 11 ft, it is reported as 10 or 12 ft.

The reason for the double peak found in the original analysis (table 1) now becomes clear. In that analysis, as already described, the ranges taken are 0 - 1 ft, 2 - 3, 4 - 5, 6 - 7, 8 - 10, 11 - 13 ft etc. In the range 6 - 7 ft only one of the two possible values, 6 ft or 7 ft, is commonly reported, i.e. 6 ft, whereas in the 8 - 10 ft range there are two values which are commonly reported, i.e. 8 ft and 10 ft, so that the frequency of observations in the 8 - 10 ft range may well exceed that in the 6 - 7 ft range, provided that there are sufficient observations above 6 ft or so. (Over the summer months, only 12.5% of the observations exceed 6 ft, and this number of observations is insufficient to produce a marked double peak).

2) It was decided to regroup the wave heights as follows:-

0 - 1 ft, 2 - 3, 4 - 5, 6 - 7, 8 - 9, 10 - 11, 12 - 13, 14 - 15 ft (all 2 ft ranges) 16 - 18 ft (3 ft range), 19 - 22, 23 - 26 ft (4 ft ranges) 27 - 31, 32 - 36, 37 - 41 ft (5 ft ranges).

By using these ranges, it was possible to smooth out most of the anomalies caused by the subjective reporting of wave heights. (In almost all cases the observations were made by the observer looking at the wave height against a "leg" of the oil rig which is graduated in feet.)

The results are presented in a tabulated form

(i) Monthly and Annual frequencies and Percentage frequencies of observations of wave height from oil rigs in the North Sea 1965-68 (also mean monthly and annual wave heights). Table 3

(ii) Seasonal Frequencies (and percentage frequencies) of Wave height observations 1965-68 Table 4

(Year divided into two main seasons

a) JANUARY to APRIL and SEPTEMBER to DECEMBER

b) MAY to AUGUST)

Table 4 includes mean seasonal wave heights.

Also available, but not included in this memo are:-

(iii) Table of monthly and annual cumulative percentage frequencies of wave heights 1965-68. (Ranges 0 - 1, 2 - 3, 4 - 5 ft etc.)

(iv) Table of monthly and annual reverse cumulative percentage frequencies 1965-68 (Ranges 0, 1, 2, 3 ..... 40 ft).

(This simply gives the percentage of wave height observations which are equal to or exceed any particular value of wave height).

The results from this table are summarised in Table 5. This gives the percentage of observations equal to or greater than 5, 10, 15, 20, 25, 30, 35, 40 ft. (for easy reference) (a) for each month, (b) for the two seasons, and (c) for the year (period 1965-68).

(v) Monthly and Annual percentage frequencies of observations of wave heights in the North Sea 1965-68. (Using single value ranges 0, 1, 2, 3 ..... 40 ft).

(vi) Monthly frequencies of wave height observations for 1965.

(vii) Monthly frequencies of wave height observations for 1966.

(viii) Monthly frequencies of wave height observations for 1967.

(ix) Monthly frequencies of wave height observations for 1968.

(x) Table of seasonal frequencies and percentage frequencies of wave height observation in the North Sea 1965-68. (also reverse cumulative percentage frequencies) (Using single value ranges 0, 1, 2, 3 ..... 40 ft).

A table showing the percentage frequencies of wave height observations greater than or equal to 10, 15, 20, 25 ft in the roughest and mildest months (for any one month). (Table 6) e.g. In the roughest January of the four Januaries, Jan '65, Jan '66, Jan '67 and Jan '68, 9% of the observations of wave height were equal to or greater than 15 ft, whereas in the mildest January of the four, only 0.7% of the observations were greater than or equal to 15 ft.

Summary of Histograms included

(i) Wave height frequencies 1965-68
(single value categories 0, 1, 2, ... 40 ft) .....(2)

(ii) Wave height frequencies 1965-68
(categories 0-1, 2-3, 4-5, 6-7, 8-9 .....37-41 ft) .....(3)

(iii) Wave height frequencies 1965-68

Season JAN - APRIL and SEPT - DEC ..... (4a)

(iv) Wave height frequencies 1965-68

Season MAY - AUGUST ..... (4b)

(v) Wave height frequencies 1965-68

Each Month JAN - DEC

The mean monthly and annual wave heights (also shown in Table 3) are: (all values in feet).

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
6.7	5.9	6.6	5.1	4.2	3.3	.6	4.1	4.6	5.9	6.2	6.6	5.5 ft.

showing January, March and December to be the roughest months and June and July to be the mildest. This is also illustrated in table 5, which shows, for example, the percentage frequency of wave heights greater than or equal to 10 ft to be (for each month over 1965-68 period).

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
21.9%	17.0	21.9	13.3	4.7	3.0	2.4	3.5	12.2	17.4	17.3	29.4	14.7%

Dividing the year into the two seasons, the mean seasonal wave heights are:-

JAN - APRIL and SEPT - DEC	MAY - AUG
6.2 ft.	3.9 ft.

and the percentage frequency of wave heights greater than or equal to 10 ft -

JAN - APRIL and SEPT - DEC	MAY - AUG
19.5%	3.4%

It should be pointed out that the observations of wave heights (9,157 in all) are taken from all the oil rigs which were reporting wave heights during the period 1965-68 The rigs, in that period, were in positions in blocks 21, 42, 43, 44, 47, 48, 49 and 53. The observations for block 21 were not separately analysed for the 4 years, except for 1968, for purpose of comparison with observations for the same year in block 49 (49-26).

3) Wave Height Comparison (1968) between Blocks 21 and 49

The positions chosen to represent the extremes in mean annual wave height were 49.26 (within 30 miles of coast to the SW) and 21.11/21.26 (nearest coastline is 80 miles to the West).

Both these positions yield a suffici ntly large number of observations (about 1000 for each) for the year 1968

Table of mean wave heights at 21.11/21.26 and 49.26 in 1968 (all values in feet)

position	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
21.11/21.26	8.8	6.2	8.0	6.4	5.9	3.2	4.5	4.1	5.5	-	-	11.0	6.3 ft.
49.26	5.6	4.8	5.2	3.4	3.6	2.9	3.8	4.5	6.4	5.2	7.0	8.5	5.3 ft.

Mean wave height for all positions in 1968 5.8 ft.

The generally higher mean wave heights at Block 21 are almost certainly due only to the greater fetch of wind over the sea for almost all directions of the wind. As will be shown later, the mean wind speeds at Block 21 over the period 1965-68 are in fact lower than those at Blocks 42-44/47-49.

It may well be worth doing the analyses of wave heights separately for block 21 and block 42-44/47-49, on the basis of the above figures. However it was thought that over the whole area of blocks 42-44/47-49 the mean conditions do not differ significantly enough from those at block 21, and that the analysis of all observations from all positions would be sufficiently representative of general conditions existing in blocks 21, 42-44, 47-49 (and 53).

It is estimated that the percentage of observations, for the period 1965-68, from Block 21 is 20%, and from Blocks 42-44/47-49, 53 is 80% (less than 1% of observations from Block 53).

4) Analysis of Wind Speed Observations

The observations of wind speed (no account taken of direction) were analysed for the period 1966-68. There were a total of 9998 observations for these 3 years, and since there were only about 400 observations for 1965, the 1966-68 analysis can be taken as being satisfactorily representative of the years 1965-68. (the period over which the wave heights were analysed).

The wind speeds have been analysed separately for block 21 and blocks 42-44/47-49, and tables compiled for:-

(i) Monthly and Annual frequencies of observations of Wind Speed from oil rigs - Block 21. (also mean monthly and annual wind speeds) 1966-68 (Table 7)

(ii) Monthly and Annual frequencies of observations of Wind Speed from oil rigs - Blocks 42-44/47-49. (also mean monthly and annual wind speeds) 1966-68. (Table 8)

(iii) Monthly and Annual frequencies and percentage frequencies of observations of Wind Speed from oil rigs in the North Sea - Blocks 21, 42-44/47-49, 53. (also mean monthly and nnual wind speeds) 1966-68. (Table 9)

Table 9 is a combination of Tables 7 and 8 and a few hundred observations from block 53. (a separate table of the wind speed analysis for block 53 is available but is not included in this memo).

(iv) Seasonal frequencies and percentage frequencies of observations of wind speed from oil rigs - Blocks 21, 42-44/47-49, 53. (also mean seasonal wind speeds) 1966-68. (Table 10)

This table includes comulative percentage frequencies.

(v) Percentages of wind speed observations greater than or equal to 20, 30, 40, 50, 60 knots. (Table 11)

Also available but not included in this memo:-

(i) Monthly frequencies of wind speed observation for 1966

(ii) Monthly frequencies of wind speed observation for 1967

(iii) Monthly frequencies of wind speed observation for 1968

(The mean wind speed for each year was evaluated and the results included in these tables) They are:-

Mean wind speed 1966 18.9 kt
Mean wind speed 1967 19.3 kt
Mean wind speed 1968 19.6 kt
} Mean wind speeds for all positions in blocks 21, 42-44/47-49, 53

The following table is a summary of mean monthly and annual winds at

a) Blocks 42-44/47-49

b) Block 21

c) All positions

over the period 1966-68 for purposes of comparison. The mean monthly and annual wave heights over the period 1965-68 are also shown.

Mean wind speed at	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
a) 42-44/47-49 (knots)	21.2	20.6	23.7	18.2	16.8	15.3	15.6	17.4	18.3	20.9	20.8	24.9	19.8
b) 21	21.1	20.5	22.8	16.7	16.6	14.1	14.0	14.5	15.9	-	-	24.5	17.6
c) all positions	21.2	20.5	23.5	17.9	16.8	14.9	14.8	16.3	17.3	21.3	20.6	24.4	19.3
Mean wave height, all positions (feet)	6.7	5.9	6.6	5.1	4.2	3.3	3.6	4.1	4.6	5.9	6.2	6.6	5.5

The mean annual wind speed at Block 21 (17.6 kt) is in fact the mean wind over the months JAN-SEPT, and DEC since no observations for OCT and NOV from Block 21 are available.

The mean wind at blocks 42-44/47-49 over the months JAN-SEPT, and DEC is 19.3 kt, which is significantly greater than the mean wind over the same months at block 21. Part of the difference might be explained by the fact that the observations at block 21 are weighted towards the summer months (MAY-AUG) whereas those at blocks 42-44, 47-49 are weighted towards the winter months, but looking at the monthly means, these are

consistently higher at blocks 42-44/47-49 except for the month of December. Another point to bear in mind is that the analysis of wind speeds at Blocks 42-44/47-49 includes observations covering all 3 years 1966-68, whereas that at Block 21 includes observations from only 1967 and 1968 (no observations available for 1966); so that if 1966 had in general been significantly more windy than 1967-68, this would give a mean wind speed over 1966-68 greater than a mean wind speed over 1967-68. But this was not the case; as already stated the mean wind speed (for all positions) for a) 1966 is 18.9 kt

b) 1967 is 19.3 kt

c) 1968 is 19.6 kt

so that 1966 was in fact generally less windy than both 1967 and 1968. So it seems that the lower mean values of wind speed at block 21 are quite genuine, which is a little surprising, considering that block 21 is some 200 miles to the North of blocks 42-44/47-49 and would be nearer to the tracks of depressions in a majority of cases.

As already pointed out, although the mean wind speed at block 21 is lower, the mean wave heights there are higher than at blocks 42-44/47-49 due to the effect of greater fetch of wind over the sea for most directions of the wind, particularly for wind directions in the SW quadrant.

In this wind speed analysis, no account has been taken of the direction of the wind. In a previous analysis of the wind observations from North Sea oil rigs for 1966-67, both the wind speed and direction have been analysed. A brief attempt was made, during this analysis, to correlate wind speed and wave height for varying fetches, but the scatter of points in this correlation was excessive. By taking account of the duration of the wind, (this can be done by taking the mean wind speed over the previous 24 hours in cases where the rigs are reporting 4 times daily, but a change of wind direction over the previous 24 hours by more than 45 degrees, or 2 points on the 16 point compass, complicates matters) the scatter of points can be reduced, and an analysis on these lines, given the time, is recommended.

D. G. Hunter, in August 1967, made an analysis of the data available from the oil rig 'Transocean Two' for the period January to July 1967, during which time the rig was positioned at 49.26 (53°05'N, 02°06'E). A comparison was made between the observed values and the forecast values of wind speed and direction, and wave height. One of the interesting facts to emerge from this comparison was that there was a tendency for the forecast wave heights to exceed the observed wave heights. (In 51% of cases the forecast value exceeded the observed value by at least one foot, and in 28% of cases the observed value exceeded the forecast value by at least one foot). The forecast wind speeds, however, were not biased in this way to such a marked degree, although it is perhaps interesting to note that the forecast wind speed exceeded the observed value by 2 or more forces (on the Beaufort Scale) on 17.8% of occasions whereas it was 2 or more forces less than the observed value on only 5·7% of occasions. (The forecast value is within one force of the observed value on 76.5% of occasions).

The tendency to overestimate wave height in the forecast may well be completely attributable to the tendency to overestimate (to a much lesser degree) the forecast wind speed, since the forecast maximum wave height, H_m is given by

$$H_m = AW^{3/2}$$

where W is the forecast wind speed, and A is a constant dependent on fetch and duration of thewind; obviously any error in W will be exaggerated in H_m. The forecast significant wave height, H_s, defined as the mean height of the highest one third of waves, is then given by

$$H_m = 1.60\ H_s$$

a theoretical relationship, which has been found is approximately true in practice. Of course, the forecaster also makes use of the latest available wave height reports when preparing his forecast, and does not have to rely completely on the forecast winds.

It should also be stated that any comparison between forecast and observed wave heights is further complicated by the fact that it is not really known exactly what the reported wave height is, in relation to the "mean height of the highest one third of waves" H_s. If the observer records a wave height which is the height of the

largest wave he sees over a period of about one minute, then the wave height that he reports may well be greater than "the mean height of the highest one third of waves". If he gives a range of wave height, e.g. 8 - 10 ft as an observation, then by taking the mean, 9 ft in this case, we may have a value which is near to "the mean height of the highest one third of waves". It is thought that the error involved in any single observation generally exceeds any difference between the reported wave height and "the mean height of the highest one third of waves", but when a large number of observations is analysed, the mean of all the reported wave heights will almost certainly differ from the (theoretical) mean of all the "mean heights of the highest one third of waves".

In conclusion it should be stressed that the analysis of wave heights comprises only 4 years' data, and that of wind speed, only 3 years' data, so that the statistics are very much those of a sample rather than a population, and should be treated as such, particularly in the case of the monthly figures.

Error

Two wave height observations of 27 feet (for October 1967) were omitted in error from the analysis of wave heights. The two observations have, however, been included in the histogram for OCTOBER.

Other histograms included are:

(i) Frequency of wind speed observations 1965-68 ..... (5)

(ii) Frequency of wind speed observations
Season JAN-APR and SEP-DEC, 1965-68 ..... (6a)

(iii) Frequency of wind speed observations
Season MAY-AUG 1965-68 ..... (6b)