Rig safety is vital

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With offshore drilling rigs moving into deeper waters and rougher areas of the world, it is reasonable to expect the rigs to encounter more severe environmental conditions. The methods of formulating the environmental design criteria for today's rigs, however, are questionable. Traditionally, the rig design criteria are determined by calculating the statistical extremes of wind, wave, and current forces independently. These loads are then combined and used in the design of the unit without regard to their occurrence in time, direction, or space.

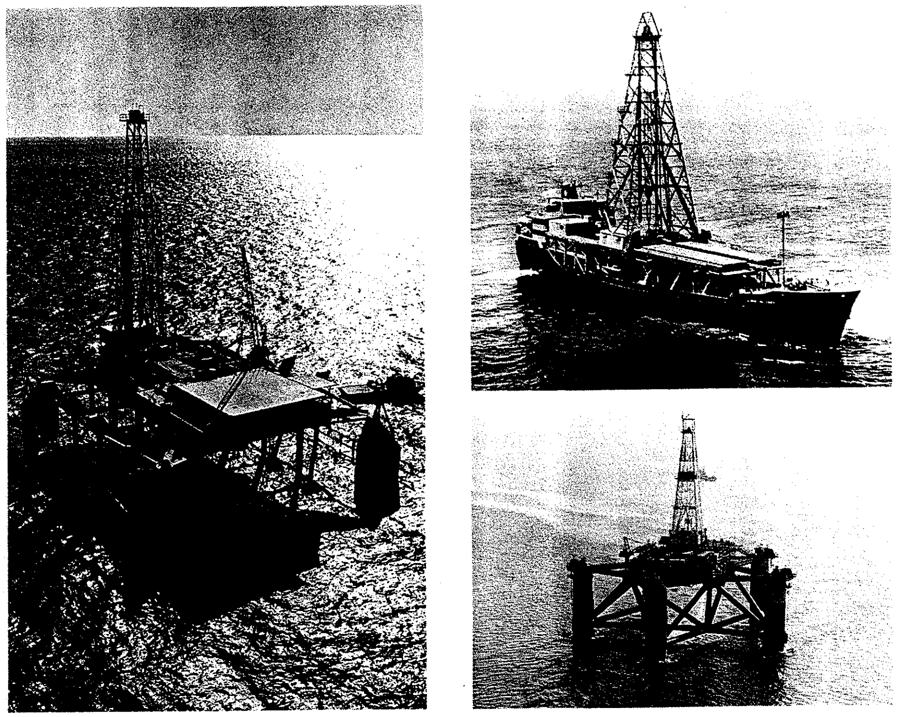
The element of arbitrariness in selection and application of design criteria and its effect on capital cost should thus be examined. It is unlikely that the proposed extreme wave, peak wind, and maximum combined current will occur simultaneously in the same space and direction. Building a rig to survive these combined criteria or to brave a higher factor of safety also greatly increases the cost of the rig. Thus it may be economically advisable to accept a lower safety factor in the design of the rig but to spend more on the safety of the crew.

The safety factors for offshore mobile drilling units are determined by many sources, including governmental agencies, insurance companies as well as insurance history, and past practice. The resulting "Rules" are then administered by several classification societies and governmental regulatory agencies. A detailed list of these organizations and their major publications is presented in Table 1.

The rules have established general design requirements for safety and survival of existing mobile drilling rigs. Typically the criteria might involve 115 mph winds simultaneous with 60 ft waves. Depending on the type of rig, this condition could be equivalent to 80 mph winds with 75 ft waves. However, the cost of such a rig could possibly be reduced by $10 million if greater risk on its loss were accepted, up to a level of risk equal to past recorded losses.

In order to maintain the level of safety for rig personnel implied by the rules, an expenditure of perhaps $1 million in emergency life support systems would still mean a capital saving of about $9 million. Therefore, in establishing design guidelines for offshore rigs it would be helpful to accurately determine the probability of combined wind, wave, and current as well as other combined environmental conditions for particular situations.

The design of today's rigs thus requires a rational alternative to more accurately reflect the typical char-



Drillships, jackups, semisubmersibles, all may face hostile environments.

acteristics of the environment. This article outlines some probable circumstances in which combined environmental loads produce unduly extreme conditions. The risk of operating an offshore mobile rig or a fixed platform can be determined through procedures described herein. With such risk criteria, the operator of the unit can then evaluate whether or not the risk in the given environment is acceptable.

Risk concept of design

The risk concept of design (1) is an alternative to the traditional use of safety factors which represents the arbitrary selection of design criteria recurrence periods. The newer and more extreme risk criteria must be considered in light of existing conditions. Balanced risk enables a particular design to be evaluated relative to other normally existing or normally accepted risks.

Using readily available literature we find that the average size of the offshore mobile drilling rig fleet has been about 150 rigs over the past 24 years. There have also been 37 total rig losses out of 92 rig accidents (2) during this time interval. Using these figures, a rig casualty probability of $\frac{37}{(24)(150)}$ or $\frac{1}{97}$ means there is one chance in 97 that any particular rig will be lost in a year. This represents about three times the normally accepted shipping losses for the same period (3, 4). It should, however, be emphasized that this is the probability of loss of the rig, not loss of human life. The probability of loss of human life has historically been much smaller.

In 10 of the 92 rig accidents cited above there were a total of 77 crew fatalities. Assuming a crew of 40 men per rig per tour and two tours per month, this gives a crew fatality probability of $\frac{17}{(24)(150)(40)(2)}$ or 3,740, i.e. one chance in 3,740 that a crew fatality will occur on a particular rig in a one year time interval. While it is agreed that rig safety for personnel should be improved, the fatalities are presently about half as much as in other working environments which have a fatality probability of $\frac{1}{1{,}950}$ (Table 2). This means that working on an offshore rig is about as safe as working on the average onshore job and is half as safe as living in one's own home. On this basis, working offshore represents about the same danger as driving down a freeway.

Joint occurrence

For this joint occurrence study and to illustrate the principles behind risk design, a storm model is assumed. In the model, waves exceeding 60 ft (maximum waves) will occur at random during a four hour period, T_p. Peak winds are assumed to occur at random in a 20 hour period, T_c, which includes the four hour period in which the maximum waves occur. Discrete time intervals, T_i, are taken as the period for one storm wave to pass through and in some way affect a part of the rig or platform. A 60 ft wave having a steepness of 10 (wave length divided by wave height) passes through a 200 ft long platform in about 20 seconds. Thus, the number of intervals, N_i, of 20 second duration in the 4 hour storm period (3,600 seconds) are:

$$N_i = \frac{T_i}{T_i} = \frac{4\,(3{,}600)}{20} = 720$$

A particular wave may or may not pass through the structure in the four hour period so the possible events are $2N_i$-1. If a wave does pass through the structure in the four hour period it can lead, lag behind, or be coincident with the basic time interval, T_i. Thus, the probability of encounter of a particular wave, P_w, in a particular time interval is:

$$P_w = \frac{3}{2N_i - 1} = \frac{3}{2(720)-1} = \frac{1}{480}$$

The peak storm wind period, T_a, is usually taken as one minute. The probability that a particular storm wind will occur, P_a, during a particular time interval, T_i, in the four hour period, T_p, is:

$$P_a = \frac{(T_p)}{(T_c)}\,\frac{(T_a)}{(T_i N_i)} = \frac{(T_p)(T_a)}{(T_c)(T_p)} = \frac{T_a}{T_c} = \frac{1}{20(60)} = \frac{1}{1{,}200}$$

The useful rig life for an offshore mobile exploratory rig is normally assumed to be 20 years. The encounter probability, P_s, of a 100 year storm in the 20 year period is then:

$$P_s = \frac{20}{100} = 0.2$$

Let P_t be the probability that a particular wave will have a particular period. This can be determined from Figure 1 since the wave length, L, can be computed from $L = 5.12\,\tau^2$ where τ is the wave period. The steepness, s, is defined as $s = \frac{L}{H}$ where H is the wave height. Thus, waves of high steepness (15 or greater) occur 80% of the total time as shown in Figure 1.

The tidal current could also be at any angle with the wind direction. P_c is the probability that the current will be coincident with the wind direction. For conservative purposes, it can be assumed that the current is either with or against the wind so that a value of 0.5 can be used for P_c.

There is a very remote possibility that the peak 1 minute wind and the maximum storm wave would occur exactly at the same location and at the same time on a mobile rig or fixed platform. This is particularly questionable when considering that a storm can cover an area of several hundred miles in width. No information seems to be available in the literature on the subject, so for preliminary purposes we assume a conservative value of 0.25 for the probability of coincident location, P_L. This is a good estimate since storm models (5) show that the maximum wave heights usually occur in quadrant 4 of a storm (Figure 2).

The joint probability, P_j, of simultaneous wind, wave, and tidal current coinciding cumulatively in a 20 year period is then:

$$P_j = (P_L P_c P_t P_s P_W N_W)\ (P_a N_a),$$

where N_w and N_a are the possible occurrences of particular waves and winds, respectively. These numbers can be obtained for the North Sea from Figures 3 and 4.

Using the above assumptions, the joint probability is then reduced to $P_j = (3.47 \times 10^{-8})\ (N_w\ N_a)$, for wave steepness greater than 15.

General application

Carrying through with the mathematics indicated above, Table 3 gives the criteria for 60 to 75 ft wave heights and 80 to 120 mph wind velocities in the middle North Sea (about 57° latitude). The results show that the chance is only 3.94×10^{-8} or about 1 in 25 million that 75 ft waves (with steepness greater than 15) coinciding with 120 mph winds and tidal current will occur in 20 years. The table also shows, for example, that the probability of joint occurrence of 70 ft waves and 80 mph winds is about the same as the probability of simultaneous occurrence of 60 ft waves and 100 mph winds. However, these two load combinations might produce the same or considerably different safety factors in design, depending on exposed wind areas, air gap, etc.

TABLE 1

Classification Societies

Name, Address	Major Publications, "Rules" Pertinent to Offshore Mobile Drilling Units
American Bureau of Shipping 45 Broad Street New York, New York 10004 U.S.A.	"Rules for Building and Classing Offshore Mobile Drilling Units 1973" "Rules for Building and Classing Steel Vessels 1974"
Bureau Veritas 58, bis Rue Paul—Valliant—Couturier 92300 Levallois-Perret, France	
Det Norske Veritas Grenseveien 92 Oslo 6, Norway	"Rules for the Construction and Classification of Mobile Offshore Units 1973" "Principles for Classification of Offshore Drilling Platforms 1973" "Rules for the Construction and Classification of Steel Ships 1970"
Germanischer Lloyd 1 Berlin 19 Heerstrasse 32 Germany	
Lloyd's Register of Shipping 71 Fenchurch Street London EC3M 4BS, U.K.	"Rules for the Construction and Classification of Mobile Offshore Units 1972" "Rules and Regulations for the Construction and Classification of Steel Ships 1974"
	Major Publications, "Rules" Pertinent to Offshore Mobile Drilling Units

A schematic of the data in Table 3 is given in Table 4 to illustrate risk design. If the conditions of shaded Area A in Table 4 are met by the given design, then additional conditions such as those indicated by shaded areas B, C, and D might also be met as a consequence. The probability of severe environments occurring which are not met by the design criteria is then the total probability of 8.30×10^{-4} less the probability of design criteria indicated by areas A through D, 7.06×10^{-4}, which results in 1.24×10^{-4}. This means that in a 20 year period the given design criteria of A through D would be insufficient to withstand expected environmental loads only one chance out of 8,000 or 0.012% of the time.

Finite risks

As a case example, we will examine the risks involved for a jackup design. The ETA Europe Class jackup is a deep water, high variables capacity rig specially designed for severe environmental conditions. Two such units are scheduled for delivery in June and November of 1976 for operation in the North Sea in up to 350 ft of water.

The 507 ft long legs are designed for maximum conditions of 75 ft waves and 125 mph winds at 260 ft water depths and for slightly less severe criteria in 350 ft water depths. These conditions are substantially more severe than ever expected by a jackup.

The rigs are designed to meet the requirements specified by Det norske Veritas (DNV) in the latest "Rules for the Construction and Classification of Offshore Mobile Drilling Units," 1975, and are the first jackups to be built to DNV classification.

Nippon Kaiji Kyokai
(Japanese Marine Corporation)
17-26 Akasaka 2-chome
Minato-ku
Tokoyo 107, Japan

Registro Italiano
Via Corsica 12
16128 Genoa, Italy

Governmental Regulatory Agencies

Sjofartsdirektoratet (Norwegian
Maritime Directorate)
P.O. Box 8123
Oslo 1, Norway

U.S. Coast Guard
Washington, D.C. 20591 U.S.A.

Occupational Safety and Health
Administration
U.S. Department of Labor
Washington, D.C. 20210 U.S.A.

U.K. Department of Energy
(formerly Department of Trade and
Industry)
Petroleum Production Division
Thames House South
Millbank
London SW1P 4QJ, U.K.

"Guidance on the Design and Construction of Offshore Installations 1974"
"Offshore Installations (Construction and Survey) Regulations 1974"
"Mineral Workings (Offshore Installations) Act 1971, Proposals for Construction and Survey Regulations," October 1972.

"Mineral Workings (Offshore Installations) Act 1971, Environmental Factors Relating to the Design and Use of Installations," October 1972.

From the above finite risk approach discussion, it is clear that various combinations of environmental loads can be encountered and the rig should therefore be designed accordingly. Design envelopes of environmental loads on station have been calculated for the ETA Europe Class jackup. Figure 6 depicts the allowable wave height versus allowable wind velocity for zero current, for a 1.5 knot current running against the wind, and for a 1.5 knot current running with the wind.

The dotted lines in Figure 6 show that for equal risk the rig can withstand any combination of waves up to 85 ft heights with any wind velocity up to 130 mph when the current is in the opposite direction of the wind. When the wave heights are 60, 65, 70, and 75 ft, the allowable wind velocities are 126, 119, 111, and 102 mph, respectively, with the wind and current taken in the same direction.

Keeping the DNV safety factors constant, the only combined environmental load excluded with this rig then is area E as shown in Table 5. The shaded area represents acceptable design criteria. Area E, however, has a risk probability of 6.29×10^{-7} or one out of about 1½ million. Assuming that the rig is adequately designed for wave steepness greater or less than 15, area F in Table 5 is then 1.57×10^{-7} or one out of about 6.4 million. The total probability of design exceedance for areas E and F is therefore 7.86×10^{-7}, compared to a total probability of 8.30×10^{-4} for combined environmental conditions in 20 years as shown in Table 3.

Finally, these numbers can be expressed in a more readily understandable way. The probability of 8.30×10^{-4} or a chance of about one in 1,200 means that in a 20 year period various combinations of environmental criteria given in Tables 4 and 5 will occur at specific times. The combined loads will average a total of about 6.02 days in the 20 year period. Thus, the probability that design limits will be exceeded is only 7.86×10^{-7} (areas E and F) or one chance in 1.2 million. This probability represents a total of about 8 minutes during the 20 year period.

These critical 8 minutes, however, should be examined more closely. The rules require that the maximum stress shall not exceed 84% of the yield strength of the materials, which is the design standard of the ETA Europe Class jackup. If the most extreme combined environmental loads of 75 ft waves and 110 mph winds are acting concurrently in the same direction as the 1.5 knot currents, then the ETA Europe Class jackup will experience combined stresses that are on the order of 10-15% greater than design stress. This condition, however, will still be below the yield strength. In fact, the combined stresses would be 94.9% of yield. As another example, if combined loads of 75 ft waves and 125 mph winds are acting with 1.5 knot currents, the rig experiences combined stresses that are about 20% greater than design criteria, or only slightly greater than the yield strength. From other calculations, the factor of safety against loss of the rig from overturning is then reduced from 1.50 to 1.33.

Comparative risk

Taking another approach, the adoption of current rules will imply that the safety of the jackup, i.e., the probability against loss, will be substantially greater than that corresponding with the past record of offshore drilling units. This point is explained in the following discussion. As shown previously, the calculated 20 year joint probability for the middle North Sea is $3.47 \times 10^{-8}\ N_wN_a$ for all steepnesses. With the annual rig risk calculated as 1/97, the 20 year joint probability of loss from all causes is 20/97. All causes include loss due to environmental criteria, blowouts, ship collisions, sabotage, acts of God, revolution, etc. As a matter of interest, let us consider the effect of ignoring all risks except severe storm conditions and determine the savings possible as a result of this.

Calculating the above assumption so

TABLE 2

Annual Risk Comparisons

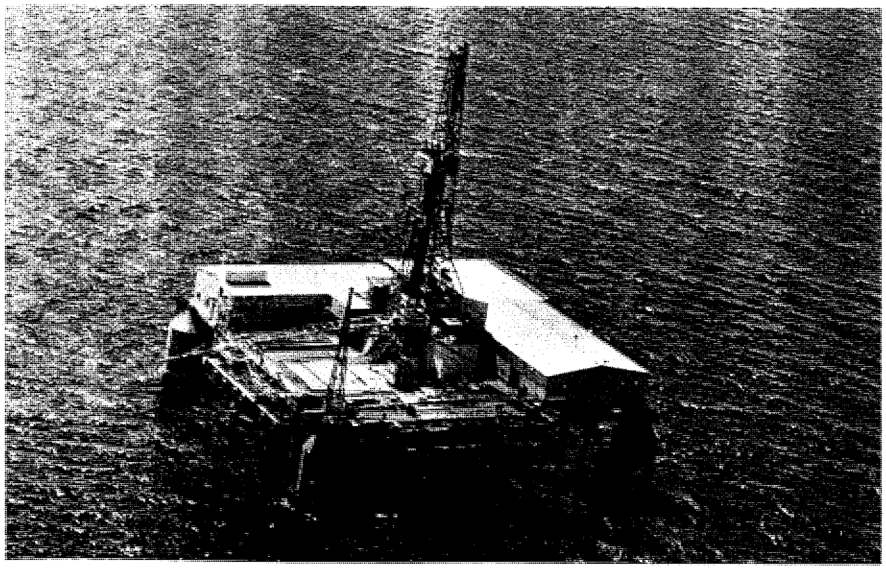
Probability	
$\frac{1}{1,950}$	Accidental Work Fatalities
$\frac{1}{3,750}$	Accidental Auto Fatalities
$\frac{1}{6,700}$	Accidental Home Fatalities
$\frac{1}{10,000}$	Accidental Public Fatalities
$\frac{1}{970}$	Cumulative Accident Risk
$\frac{1}{3,740}$	24 year Average Crew Fatalities (offshore drilling rigs)
$\frac{1}{333}$	1971 U.S. Flag Ship Losses
$\frac{1}{97}$	24 year Average Mobile Drilling Rig Casualties

TABLE 3

Probability of 20 Year Combined Environment

Steepness Greater Than 15

Wind Speed, mph:	80-90	90-100	100-110	110-120
Wave Height, ft				
60-65	1.72×10^{-4}	5.00×10^{-5}	1.38×10^{-5}	2.78×10^{-6}
65-70	4.73×10^{-5}	1.37×10^{-5}	3.82×10^{-6}	7.63×10^{-7}
70-75	1.51×10^{-5}	4.37×10^{-6}	1.21×10^{-6}	2.43×10^{-7}
75+	4.30×10^{-6}	1.25×10^{-6}	3.47×10^{-7}	3.94×10^{-8}
Accumulative	2.38×10^{-4}	6.93×10^{-5}	1.92×10^{-5}	3.83×10^{-6}
Subtotal	3.31×10^{-4} for steepness greater than 15			
Subtotal	8.27×10^{-5} for steepness less than 15			
Total	4.15×10^{-4} for all steepnesses and one tidal current direction			
Grand Total	$8{:}30 \times 10^{-4}$ for all steepnesses and both tidal current directions			



Many safety factors are built into the giant semisubmersibles used for drilling.

that $20/97 = 4.33 \times 10^{-8}\ N_w N_a$ and using Figures 3 and 4, any number of weather combinations can be determined, such as 50 foot waves with 55 mph wind and no current in 260 ft water depth. The ETA Europe Class jackup has a 3.02 factor of safety against overturning with these environmental criteria.

If one next considers the relative costs of meeting a design code based on safety factors (such as the rules) versus taking a risk equal to previous overall performance, then the tradeoffs are as follows. The ETA Europe Class jackup, for example, is designed for 75 ft waves and 125 mph winds with an overturning factor of safety of 1.5 in 260 ft water depths. However, the 20 year risk or joint probability is one in 13 million that 75 mph waves and 125 mph winds will occur simultaneously (1.5 safety factor). The risk with 75 ft waves and say 180 mph winds (1.0 safety factor) is one in 12 billion.

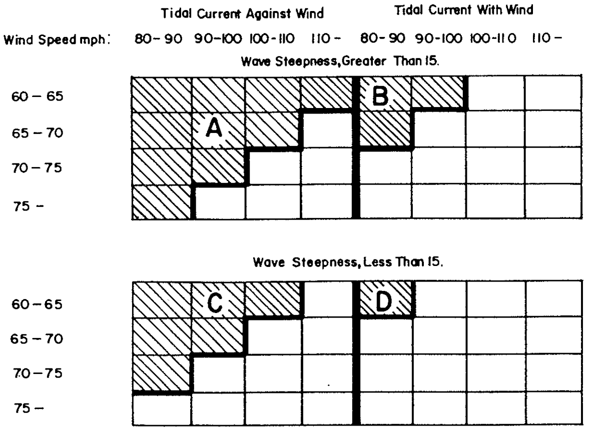
Using the safety factor approach, we find that where there is a safety factor of 15 and a risk of rig loss of one in 13 million, the total rig cost is estimated at about $35 million. Using the risk analysis approach, when there is a safety factor of 1.0 and the environmental risk is taken as equal to the total previous risk of 20/97, then the total rig cost is estimated at about $22 million.

In order to compensate for the higher risk to human life that the risk analysis approach indicates, it would be financially advantageous and wiser to spend say one or two million dollars on emergency life support systems (survival capsules, devices to preserve life in storms) and thus save $11 or $12 million overall. This then may translate into operating procedures. Specifically, if extreme weather is expected, if a blowout occurs, or a ship collides with the rig, use of a "foolproof" method of removing personnel could be advantageous. The cost of such a system might prove to be more attractive than paying a large initial penalty by making the rig working environment safer overall when it is already safer than most other work environments. The consequence of building stronger and larger rigs to protect against risk to human life rather than the risk for the property alone is significant—an increase of $10 to $20 million per rig.

The rules for the classification and safety of offshore rigs are revised peri-

TABLE 4

Design Joint Probabiliy of Combined Environment Over Rig Life

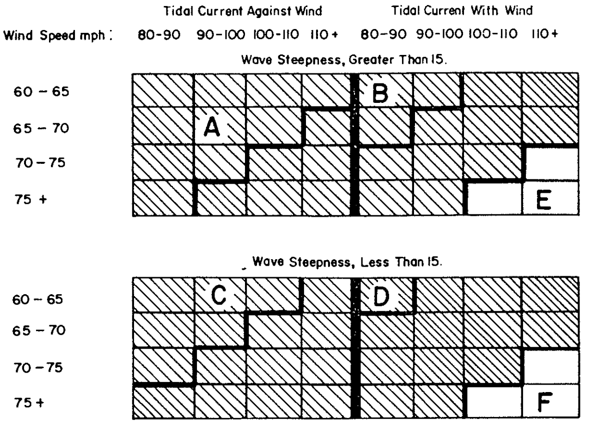


Area:	A	B	C	D	Total
Probability	3.27×10^{-4}	2.69×10^{-4}	7.80×10^{-5}	4.30×10^{-5}	7.06×10^{-4}

Note: This means that if design conditions represented by shaded area A above are satisfied, then with the risk analysis theory, the conditions indicated by shaded areas B, C, and D might also be satisfied.

TABLE 5

Design Joint Probability of Combined Environment Over Rig Life



Area:	A	B	C	D	Total
Probability	3.27×10^{-4}	2.69×10^{-4}	7.80×10^{-5}	4.30×10^{-5}	7.06×10^{-4}

Note: Shaded areas represent criteria for which the ETA Europe Class jack-up design is sufficient.

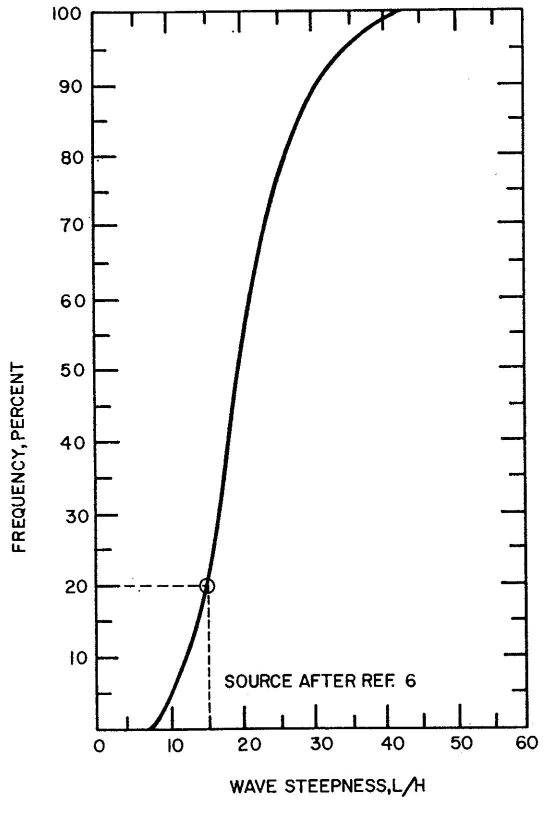
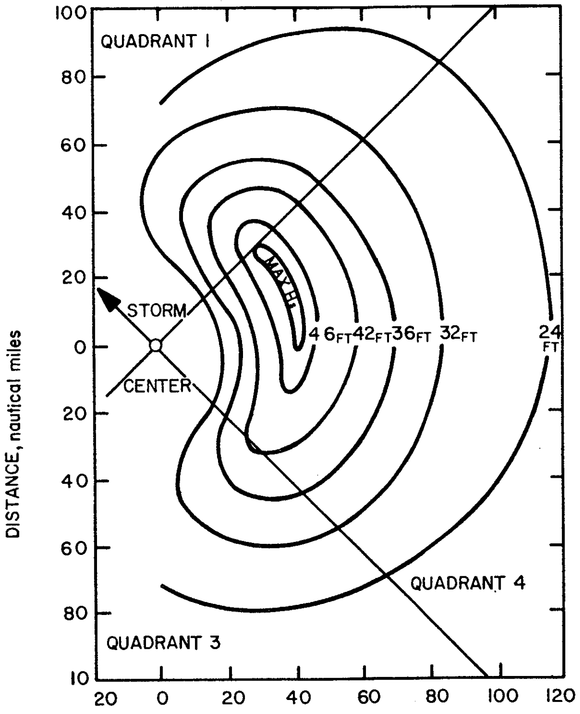


FIG. I CUMULATIVE FREQUENCY DISTRIBUTION OF WAVE STEEPNESS FOR NORTH ATLANTIC



TYPICAL TROPICAL STORM MODEL SHOWING SIGNIFICANT WAVE HEIGHT DISTRIBUTION FIG.2

odically. Many of the organizations are currently reviewing the design criteria requirements for offshore mobile drilling units for potential readjustments. A reassessment of the rules might possibly allow for significant initial investment savings through the use of the risk analysis approach.

Conclusions

► Methods are now available to the operator and contractor which can more accurately evaluate the actual risk of operating a particular rig or platform in various environments, and thus fully ultilize the unit's operational capabilities.

► A lot of money is being spent on resisting environmental conditions

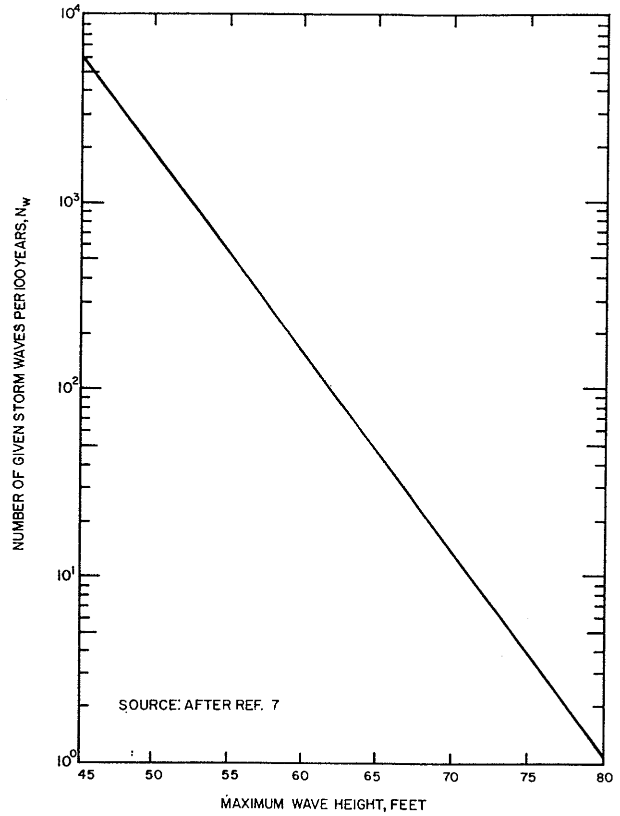


FIG.3 MAXIMUM WAVE HEIGHT OCCURRENCE IN MIDDLE NORTH SEA

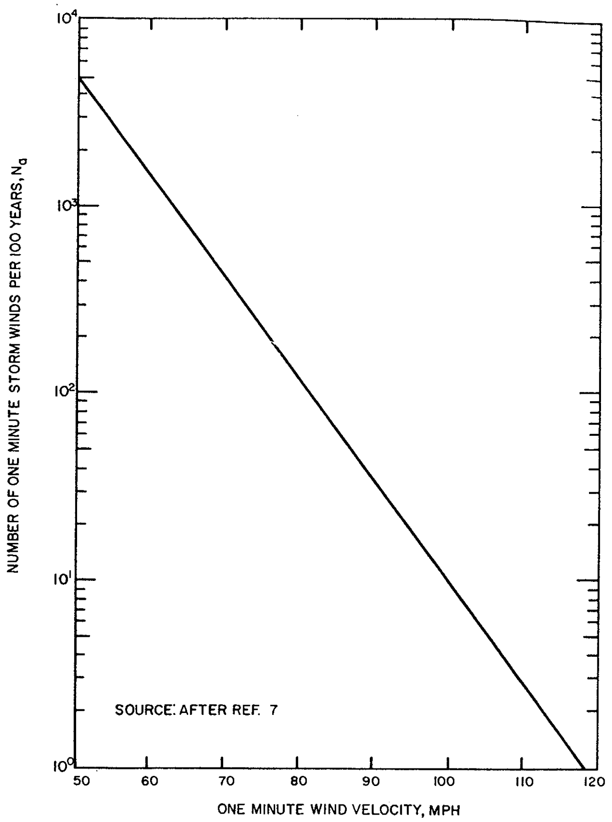
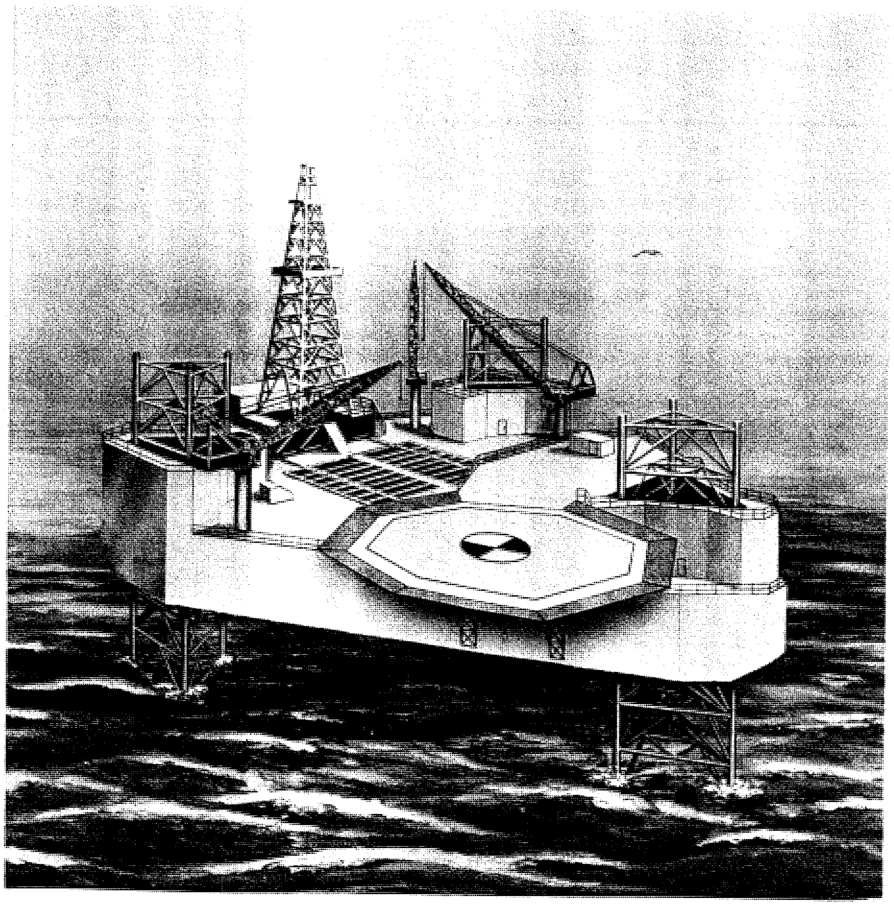


FIG.4 SEVERE WIND OCCURRENCE IN MIDDLE NORTH SEA



ETA Europe Class Jack-up. Two jack-ups of this design, the "Dyvi Beta" and the "Dyvi Gamma" are due for delivery from CFEM in Dunkerque, France for J. E. Dyvi of Oslo, Norway.

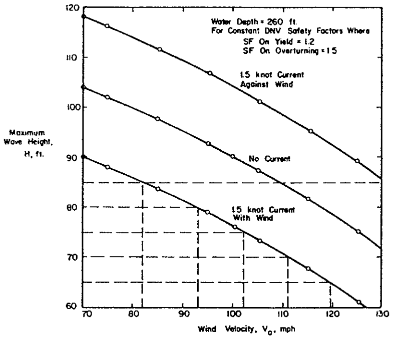


FIG. 6 ENVIRONMENTAL CRITERIA FOR ETA EUROPE CLASS JACK-UP

which are inconsistent with other risks, and this is costly protection.

► Reduction of this cost should be attempted and consideration given to spending more on other systems for safety of life and safety against other risks such as blowouts, collisions, fires. This is believed to be more economical overall.

► Large sums of money are being spent on constructing the rigs to counteract conditions which have been shown to produce the least losses. As these conditions become more severe, the cost becomes very much higher, much more so than in the past.

► In view of the results presented

above as well as from the results of other internal studies, it appears that more concentrated attention should be devoted to safety of rig personnel. With the considerable interest by operators, contractors, as well as insurance firms, it seems obvious that an industry study on improved safety could be very cost effective.

► Unless drastic changes are made in the trends of the rules which are becoming more stringent, or unless use of a Risk Analysis is made, the construction cost of offshore structures may escalate to such a degree that the growth of the industry may be severely inhibited. ☐

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Nomenclature

H = wave height, ft
L = wave length, ft
N_a = number of wind occurrences, numeric
N_i = number of time intervals, numeric
N_w = number of wave occurrences, numeric
P = probability, numeric
P_a = wind encounter probability, numeric
P_c = tidal current encounter probability, numeric
P_j = joint wind, wave, current probability, numeric
P_L = probability of coincident location
P_p = wind encounter probability in T_p, numeric
P_s = storm encounter probability, numeric
P_t = wave period encounter probability, numeric
P_w = wave encounter probability, numeric
T = wave period, sec.
T_a = individual wind duration, sec.
T_c = peak wind occurrence interval, hour
T_i = wave platform intersection time interval, sec.
T_p = duration of peak storm period, hour
T_r = return period, year

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