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Design environmental criteria – what are the consequences of exceedance?

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SYNOPSIS

It is standard practice in the offshore industry to design structures to withstand the loads imposed by site-specific environmental extremes which have a very low frequency of occurrence. Typically, extremes which have an average return period of once in 50 years are chosen. The selection of 50 years as the return period is somewhat arbitrary and during the life of a structure there is a very low probability that it will, in fact, experience environmental conditions which exceed the design conditions, ie conditions which have a return period which is greater than once in 50 years. If a structure is exposed to the environment for a period of 25 years there is a 39% chance that it will experience the 50-year extremes during that exposure and there is a 22% chance that it will experience the 100-year extremes during the same period of exposure. These percentages are dependent on the laws of probability and are the same for all locations in the world. Therefore all structures designed using the 50-year extreme environmental conditions have equal probability of experiencing the 100-year extremes for any given exposure period. What is most certainly not the same for each location worldwide is the difference in environmental loadings between the 50-year and 100-year extremes. This paper will expand on this topic and will highlight those areas of the world where the potential problem is most serious.

INTRODUCTION

Offshore platform distribution

Since the beginnings of the offshore oil industry in the 1950s there has been a constant growth in the number of offshore platforms emplaced on the continental shelves around the world. Initially these were mainly in shallow inshore waters but, as technology advanced, there was a progressive move into deeper and more distant waters. Today it is estimated that something in the region of 6000–6500 offshore platforms exist worldwide.[1,2] These are distributed as follows:

1.	Gulf of Mexico	4800
2.	North America (other)	44
3.	South America	170
4.	Europe	250+
5.	Africa	80
6.	Middle East	500
7.	Far East and Communist Bloc	500

Although decommissioning of the older platforms is now taking place the total number in commission continues to increase as more and more new fields are brought on stream.

Design criteria

No matter what the size of a platform, or the characteristics of the area in which it is to be emplaced, there is one overriding factor which must dominate the design of the platform. That is that it must be designed such that it can withstand the worst weather conditions which it is ever likely to experience without suffering catastrophic failure.

The need for compromise

Theoretically it is possible to design every platform to be so massive that survival can be guaranteed and, therefore, the local environment can be ignored. The cost penalties resulting from such an approach would, of course, be massive making it totally unrealistic. From the point of view of cost the operator wants to keep the size and strength of a platform to a minimum while, at the same time, from the point of view of safety some minimum acceptable level of size and strength has to be determined, which is consistent with the maximum environmental forces likely to be experienced by the platform during its lifetime. The decision as to which environmental forces should be chosen for this purpose is somewhat arbitrary but in many cases the '50-year storm' is used, although the '100-year storm' is also commonly used.

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CALCULATION OF DESIGN ENVIRONMENTAL CRITERIA

Definition of '50-year storm'

By definition the '50-year storm' is a combination of wind, wave and current conditions which, on average, will be reached or exceeded only once every 50 years. Because the '50-year

Table I: Percentage increase in force exerted by extreme winds in some areas where the increase is relatively small as return period increases

	100 year extreme over 10 year extreme	*100 year extreme over 50 year extreme*
Gabon	22	< 3
North East Brazil	10	< 3
Northern North Sea	26	4
Southern North Sea	23	5
South West Africa	28	6
South Borneo	29	6
Colombia	37	6
South California	26	6
Red Sea	23	7
Gulf of Thailand	44	7
Java Sea	32	7
Halmahera/Ceram	23	7
Tierra del Fuego	30	7
Campos Basin	40	7

Table II: Percentage increase in force exerted by extreme winds in some areas where the increase is relatively large as return period increases

	100 year extreme over 10 year extreme	*100 year extreme over 50 year extreme*
North Borneo	130	49
Bombay High	220	34
Louisiana	98	29
Blake Plateau	125	28
Bonaparte Gulf	174	27
Texas	137	25
Ganges Delta	129	23
Yellow Sea	106	21
Australian NW Shelf	135	20
Pearl River Basin	76	20

storm' refers to the joint occurrence of certain extreme values of wind, wave and current there are, in fact, many different combinations each of which can be classed as the '50-year storm'.

Until very recently measurement campaigns have treated wind, wave and current separately and, so, long-time series of joint occurrence measurements do not exist. This makes it impossible to calculate true '50-year storm' figures. Almost by default, what is in common use as the '50-year storm' for design purposes is actually the combination of the 50-year extremes of wind, wave and current, each calculated separately then assumed to occur simultaneously. Clearly this means that the design criteria used are actually more severe than a true '50-year storm' though by how much is impossible to calculate, especially as this will vary from location to location. Nevertheless it is a method which appears to produce credible design criteria. To the best of the author's knowledge no platform has suffered catastrophic damage solely due to the weather. On the other hand there are sufficient weather-related 'incidents' to suggest that the degree of over-design is probably not all that great.

State-of-the-art instrumentation now enables joint measurements of wind, wave and current to be made. Also, major hindcast projects such as NESS will provide joint occurrence statistics. This means that we are approaching the stage where, for some locations, the calculation of true '50-year storm' conditions will be possible. The industry is pressing for this to be done as it would, of course, reduce costs through reduction in the design criteria used. Before these reductions are made very careful consideration needs to be given as to whether or not too much safety is being eroded away by the change of method.

Present methods

As mentioned above, the standard practice today is to treat wind, wave and current independently. The requirement is to calculate the 50-year extremes of each for a precise location. Ideally the input data should be a continuous time-series of measurements of at least 20 years duration from the precise location. In practice this never exists and the metocean specialist has to make do with whatever relevant data he can find. This may be measured data from a location some distance away, perhaps a long distance. The time covered by the measured data may be anything from a few months to a few years, but seldom longer than that and almost certainly not long enough to capture the true long-term climate.

Very often no measured data exist and the global archive which has been built up from weather observations reported by ships of passage is used. This does not provide site-specific information. Instead it gives information relating to an area which often cannot be directly related to the location for which the design criteria are required.

In areas affected by tropical cyclones the practice today is to use numerical modelling in a way which combines the actual tracks and intensities of historical storms with an 'ideal' two-dimensional tropical cyclone model.

In a few areas no relevant information of any kind can be found, and the metocean specialist then has to rely very much on experience in order to correlate his location of interest with some other part of the world which has a similar climate and for which an acceptable data set exists.

Having obtained whatever datasets he can find the metocean specialist then has to use that data to arrive at his estimate of the 50-year extremes. This is normally done by fitting all or some of the data to some statistical distribution such as Weibull or Fisher-Tippett. The distribution used and the way it is applied depends on the dataset and, to some extent, the whim of the specialist. There is no sound argument in favour of any one method and a considerable amount of subjective interpretation goes into the calculation. The 50-year extremes which are produced fall into the category of 'best estimate' but there is potential for significant error. For most locations around the world an honest metocean specialist would probably claim no better accuracy than ± 20%. Indeed, in the supporting documentation to the new draft of the UK Department of Energy Guidance Notes,[3] it is stated by the Institute of Oceanographic Sciences (IOS) that the contours of 50-year extremes of significant wave height in the North Sea are accurate to only ± 20% generally. Near to where there is a reliable long-time series of measured data IOS suggest an accuracy of ± 10%. Provided that metocean specialists, calculating the design criteria, aim to provide a genuine best-estimate and do not add a factor for safety, then it is reasonable to assume that approximately half of the 50-year extremes provided will be underestimates and half will be overestimates.

Errors in environmental loading calculation

When presented with a set of 50-year extremes for a location a designer takes them at face value and accepts them as the best estimate available using the existing database. As it is not

Table III: Percentage increase in force exerted by extreme waves in some areas where the increase is relatively small as return period increases

	100 year extreme over 10 year extreme	*100 year extreme over 50 year extreme*
Gulf of Thailand	26	4
Nigeria	24	7
North East Brazil	35	7
Colombia	32	7
North California	28	7
Central North Sea	32	8
Ivory Coast	38	8
South West Africa	38	8
Southern Red Sea	33	8
St Helena Bay/ Cape of Good Hope	39	9
South Borneo	33	9
Halmahera/Ceram	33	9

Table IV: Percentage increase in force exerted by extreme waves in some areas where the increase in wave heights is relatively large as return period increases

	100 year extreme over 10 year extreme	*100 year extreme over 50 year extreme*
Bombay High	55	37
North Borneo	80	30
Louisiana	145	21
Yellow Sea	62	20
Blake Plateau	111	19
Tierra del Fuego	88	17
Bonaparte Gulf	59	16
Venezuela	89	16
Australian N W Shelf	86	15
Pearl River Basin	59	15

possible to design to a range of values no account can be taken of the fact that the envelope of error is ± 20%.

If the calculated 50-year extremes are overestimates then there is no concern from a safety point of view, although the over-design would have cost implications for the operator. On those occasions where the calculated 50-year extremes are, in fact, underestimates safety factors are eroded. Bearing in mind that the forces exerted on platforms by wind and wave are in proportion to the square of the wind speed and wave height, respectively, then a 20% underestimate in the calculation of 50-year extremes is very significant. It equates to a 44% underestimate in the environmental forces which should be used in the design. In the author's experience many engineers involved in design are unaware of this potential underestimate and are horrified when confronted by it.

It may well be that the safety factors built in through the use of the individual 50-year extremes of wind, wave and current, respectively, are compensating for the potential under-design resulting from those occasions when the calculated 50-year extremes are underestimates.

Even with the improvement in ways of measuring wind, wave and current, and with the development of major hindcast projects, it seems unlikely that we shall see much reduction in the ± 20% envelope of error in calculated 50-year extremes. Great caution will therefore have to be used in introducing true '50-year storm' joint occurrence extremes if too much of the safety factor is not to be eroded away.

SETTING THE SAFETY FACTOR

Why the 50-year storm?

As mentioned earlier in this paper the '50-year storm' is commonly used for offshore design purposes while the '100-year storm' is used in some countries. There is nothing particularly significant about the selection of either of these storms. Both have been selected somewhat arbitrarily in the belief that they set adequate safety factors. It is, however, important to be aware that if a platform is designed to, say, the 50-year storm this does not mean that it cannot experience more severe conditions during its lifetime. Even if then it has been possible to calculate the 50-year storm with great accuracy the platform may encounter the 1000-year storm during its lifetime.

With around 6000 platforms in commission there are approximately 6000 platform-years being accumulated annually. Simple statistics suggest that it would, therefore, not be unreasonable to expect one or more platforms to experience a 1000-year storm every year. Such a suggestion is false, due to the fact that the platforms tend to be grouped in a relatively small number of offshore 'basins'. There are perhaps about 20 major offshore oil basins around the world so we are, therefore, accumulating something like 20 basin-years per year. This means that over a period of 50 years 1000 basin-years will accumulate. Statistics show that in a 1000 year exposure there is a 63% chance of reaching or exceeding the 1000-year storm. Looked at in this way the 1000-year storm is by no means merely theoretical. It seems quite likely to occur somewhere during the life of the offshore industry. When it does occur it is likely to affect many platforms because of the way in which they are grouped together in various parts of the world.

Risk variation from location to location

The typical life of an offshore platform is 25 years though some are planned for a much longer life. If a platform is designed to the 50-year storm and is exposed for a period of 25 years the probability that it will experience conditions equal to or more severe than the 50-year storm is 40%. Similarly, the probability that it will encounter the 100-year storm is 22%. These percentage probabilities are not location specific and apply anywhere in the world. If given only casual thought this might suggest that the risk of damage from a 100-year storm to a platform designed to the 50-year storm is the same anywhere in the world. This, of course, is not so as it depends on the difference between the severity of the 50-year and 100-year storms at any particular location.

In some parts of the world the difference between the 50-year storm and the 100-year storm is small while in others it is quite substantial. This variation from one part of the world to another becomes even more marked if the 10-year storm is also considered. This inclusion of the 10-year storm is relevant as many of the critical construction phases of a platform are designed to the 10-year storm.

Looking first of all at winds, Table I gives a list of some areas of the world where there is a relatively small difference between the 50-year extreme and the 100-year extreme. The table shows the force exerted by the 100-year extreme wind expressed as a percentage increase over the force exerted by the 10-year extreme and over the force exerted by the 50-year extreme. These forces are proportional to the square of the actual wind speeds.

Table I is a very interesting grouping of regions. It includes very benign climates such as in Gabon and South Borneo and very severe ones such as around Tierra del Fuego and the

Northern North Sea. The common factor to them all is that there is not much year to year variation. The benign areas are benign every year while the severe areas are severe every year. In such areas platforms designed for the 50-year extreme wind should have no difficulty in coping with the 100-year extreme. An operation designed for the 10-year extreme wind might well become somewhat hazardous should the 100-year extreme be encountered.

Going to the other end of the spectrum, Table II highlights some areas where there is a relatively large difference between the 50-year and 100-year extreme winds.

The areas listed in Table II are scattered across many parts of the world but one very significant common factor is that they all experience tropical cyclones from time to time.

Turning now to waves, Table III shows some areas of the world where the increase in wave height from 50-year extreme to 100-year extreme is relatively small.

Table III gives a list of areas with a similar mix to those contained in Table I, ie some benign tropical areas not effected by tropical cyclones and some mid-latitude severe weather areas. Once again the common factor is that there is little variation in weather from year to year.

The final table in this set (Table IV) shows areas of the world where there is a relatively large increase in wave height from the 50-year extreme to the 100-year extreme.

The list of areas in Table IV is very similar to that contained in Table II, ie there is a dominance of areas affected by tropical cyclones. One interesting inclusion is Tierra del Fuego. This is probably due to the fact that, although the area experiences very strong winds every year, the wave heights are generally restricted by fetch due to the dominant wind direction being westerly, while very strong winds from an easterly point occur only infrequently. This is likely to result in a very marked year to year variation in the maximum wave height.

When studying Tables I–IV the following points should be borne in mind:

1. Not all possible areas of the world have been studied in the preparation of this paper and there may be some additional areas which would have justified inclusion in the Tables had they been studied.
2. The figures given refer to typical deep water locations in the more severe parts of the areas examined. They are not intended to refer to any specific location and the figures for waves will be unrepresentative of some locations, particularly in shallower water.
3. The figures are based on studies carried out by the Environmental Studies Department of Noble Denton Weather Services Limited. They have been calculated as described in the section on the calculation of design environmental criteria in this paper and are subject to the inherent errors as the author has described. They represent state-of-the-art calculations.

GEOGRAPHICAL VARIATIONS

The relatively 'safe' areas

Tables I–IV show that there are certain types of climate in which the extreme environmental forces do not increase rapidly as the return period under consideration is lengthened. In general these areas are tropical regions, which do not experience tropical cyclones, and temperate latitude areas in both the northern and southern hemispheres. In the tropical regions which fit this pattern the weather is generally benign throughout the year with little change to this pattern from one year to the next. The temperate latitude areas which fit the pattern have a generally disturbed weather pattern and experience severe stormy conditions every year.

The 'not-so-safe' areas

Tables I–IV quite clearly show that areas affected by tropical cyclones are areas where environmental forces increase rapidly as extremes for longer return periods are calculated. The problem is obviously common to all areas subject to tropical cyclones, though some areas are certainly worse than others. It is most unlikely that the particular examples studied will have thrown up the worst possible cases. These are likely to be in near-equatorial regions on the equatorial edge of the areas affected by tropical cyclones.

To help put this whole problem into perspective Fig 1 shows those areas of the world which are affected by tropical cyclones from time to time. All tropical oceans are at least partially affected, with the exception of the south Atlantic Ocean where no tropical cyclone has ever been recorded. All the areas indicated will have a larger than average difference between the 50-year extremes and the 100-year extremes, but the areas where this difference is likely to be most marked are those areas labelled 'Intermittent' on the equatorward edge of each affected area. In the context of the offshore oil industry this means the following areas:

1. north coast of South America from Venezuela and Trinidad to Colombia;
2. the Caribbean coasts of Panama, Costa Rica and Nicaragua;
3. north Australia from Cape York Peninsula to King Sound;
4. the Celebes Sea, north Borneo and the South China Sea between 5°N and 10°N;
5. the Gulf of Thailand;
6. Sri Lanka and the east coast of India south of Madras;
7. the west coast of India;
8. Burma and the Andaman Sea;

One particularly interesting point which comes out of Tables I–IV is that south Borneo is one of the lowest risk areas while north Borneo is one of the highest risk areas, yet they are very close together. The reason for this is that south Borneo is in the benign equatorial belt just south of the extreme southern limit of the NW Pacific typhoon area while north Borneo is just inside the southern limit.

These areas on the equatorial edge of the tropical cyclone areas are particularly difficult when it comes to calculation of the 50-year extremes. Because they are visited by tropical cyclones only very infrequently the available database is very inadequate. The potential for a significant underestimate or overestimate of 50-year extremes is considerable. Combining this higher than average potential for error, in calculation of extremes, with the fact that in such areas the rate of increase in environmental forces with lengthening return period is highest, then it can be seen that these areas probably have the greatest potential for significant under-design.

In most years the weather is very benign throughout the year but on very rare occasions, perhaps once or twice a century, along comes a major tropical cyclone which brings newspaper headlines such as:

'Freak storm smashes oil rigs'

or

'Worst storm in living memory strikes coast'

The implication behind such headlines is that the storm was unprecedented and could not be anticipated. The fact that it was perhaps 25, 50 or 75 years since the previous occurrence does

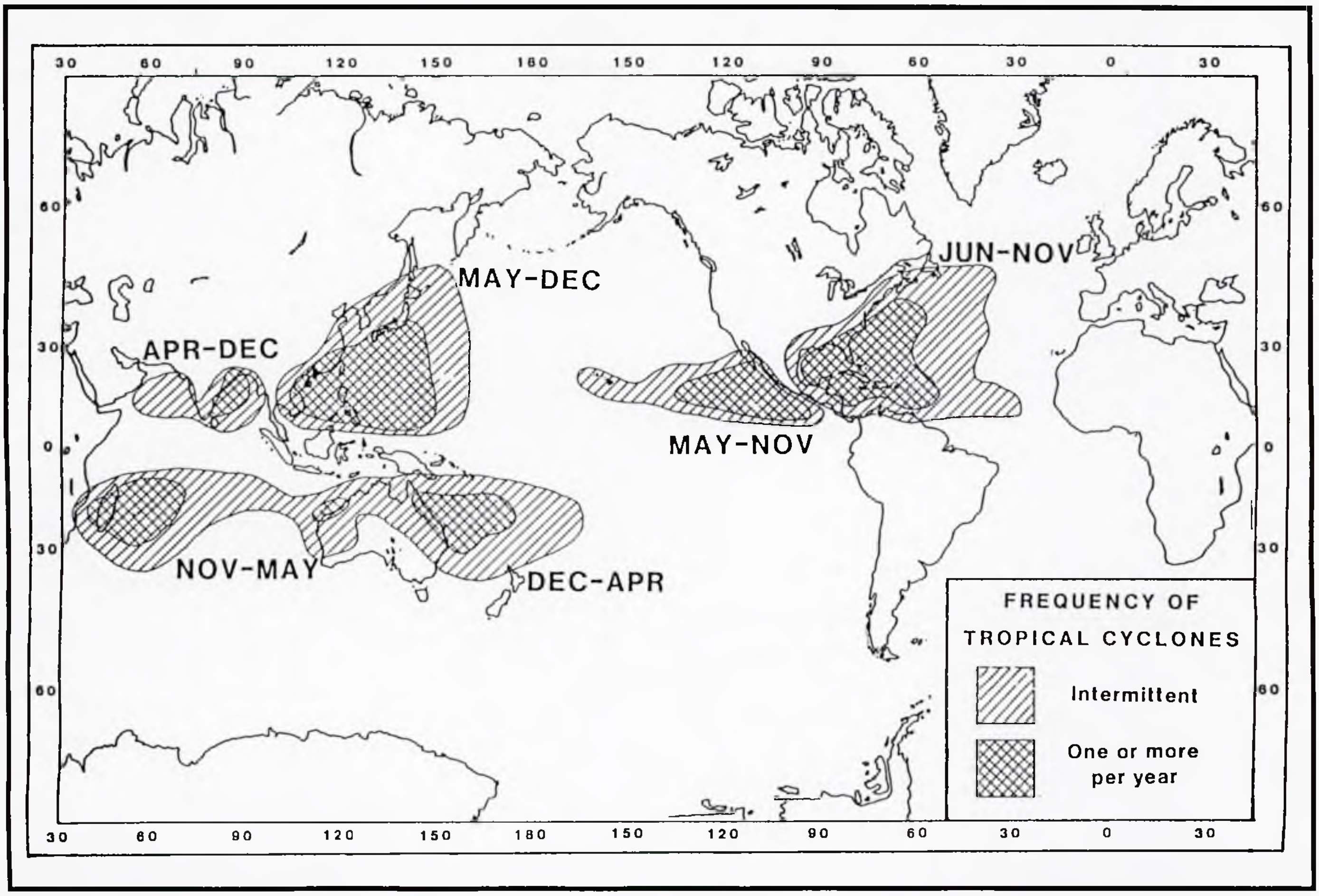

Fig 1: Map showing which areas of the world are subject to tropical cyclones: The main seasons are also indicated

not mean that it should not be expected to happen. There are undoubtedly some equatorial areas of the world which have not experienced a tropical cyclone this century yet have been devastated at some earlier time in history.

One event of which the author has personal experience is the minimal tropical storm which hit the waters of Brunei on Christmas Day in 1973. This coincided with a very strong surge of the NE monsoon and caused unprecedented sea conditions amongst the offshore oilfields. There was substantial damage though, fortunately, no casualties. This occurred in an area which was generally taken to be 'storm-free' as the offshore industry had not previously experienced a severe storm in the area.

CONCLUSIONS

It is inevitable that some platforms, during their lifetime, will experience weather conditions more severe than those which have been used as design criteria. In most cases the safety margins built into the design will ensure that this exceedance of the design criteria will not result in catastrophic failure. However, there must be a limit to the amount of exceedance which the safety factors will absorb. Beyond that limit damage will occur. The studies which have gone into the preparation of this paper show that gross exceedance of design criteria is much more likely to occur in near-equatorial regions, which are usually benign, than it is in those parts of the world where severe storms are a regular occurrence.

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