EXECUTIVE SUMMARY

This Environmental Specification contains a rather large and varied amount of very detailed information related to environmental criteria for the development of the Mobile Offshore Base (MOB). It is indeed expected that, because of the highly specific technical nature of some subjects, parts of it may be outside the expertise of some readers. It is therefore the intent of this Executive Summary together with Chapters 1 and 2 to provide some "bottom line" description of the work performed in developing this document and its content. However, for specific information geared toward design application, the reader must read the main chapters (3 through 6) of the document.

GENERAL

Bechtel National, Inc., herein referred to as BNI, executed the work reported in this document as part of Delivery Order 22, Environmental Specification, of Contract No. N47408-93-D-7001. The objective of the overall work of this delivery order was to develop a two-part Environmental Specification, namely, a Qualitative and a Quantitative Environmental Specification. This specification will eventually form part of the overall classification process in the development of the MOB.

The ultimate aim of this project was to determine appropriate design environmental events and their combinations reflecting the various performance requirements presently envisioned for the MOB. Based on various analyses performed to date on different MOB candidate concepts, it is believed that environmental combinations that are not necessarily the maximum components of any one event may very well yield maximum structural responses, different ones for different MOB components; therefore, joint probabilities of the various parameters of wind, wave and current need to be quantified.

The work was executed by BNI with the assistance of the following expert consultants and contractors:

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This is a two-volume document. The first volume contains the main text of the Specification while the second contains a series of appendices including the electronic data, computer programs developed and supporting documentation.

After some introductory information on MOB operational requirements and general characteristics, as well as on how environmental forces may affect it, this report first presents the Qualitative Environmental Specification (Chapter 5). It offers primarily a general description of the atmospheric and oceanic environment viewed as critical to the MOB and that it will likely experience during the various phases of its life. Atmospheric and ocean flows, phenomenological description of environmental components, sources of environmental data and statistical description of environmental components are addressed.

Following that, the Quantitative Environmental Specification (Chapter 6) is presented. It offers the historical winds, waves and currents at the four sites where it is currently assumed that the MOB may be deployed and at those through which it may navigate while in transit route.

Hindcast “raw” environmental data are provided and are augmented by the inclusion of environmental effects not present in the raw data. Uncertainties inherent in the data are estimated. A statistical software, MOBENV, developed during this work to specifically establish a numerical process to access, manipulate and study the raw data by future designers wishing to get a general idea of several inter-related aspects of the environment, is also presented.

Following that, a brief study of wind, wave and current events and their dependence on global typhoon descriptors is included. Lastly, the Quantitative Environmental

Specification presents some recommendations based on knowledge gained from the work performed to date and deemed important for the development of the MOB to be offered as points of awareness, and for future consideration by the Government.

Since a number of environmental concepts and terms introduced and discussed in this Specification may not be of general knowledge to some within the potential engineering audience that might use this document, a Glossary is provided at the end of the document.

Because of the large number of algebraic symbols and abbreviations used, a List of Symbols and List of Abbreviations are also provided at the end of the document.

MOB OPERATIONAL REQUIREMENTS AND GENERAL CHARACTERISTICS

Current concepts for the MOB mostly consist of three to five individually-built modules that, for aircraft operations, are connected in-line, either by physical connectors or by computer controlled dynamic positioning thrusters. The modules may transit to the deployment site riding high on their lower hulls, and, then, be ballasted down for greater stability for operations.

For the purpose of the development of this Specification, the MOB is currently assumed, as specified by the Government, to spend most of its 40-year life (70%) operating either in the North Atlantic Ocean, the Northwest Pacific, the Sea of Japan, or the Arabian Sea. It is envisioned that it will be disconnected about as long as it will be connected. For the remainder of its life, it is assumed to be either laid up (25%) or in transit (5%).

Due to the MOB's great length (5,000 ft), certain issues related to environmental loading that are not normally considered in typical marine structure design, are uniquely important. The principal one is the phasing of waves from point to point along the vessel. The times at which crests of essentially broadside waves reach the vessel may vary significantly along its length, an effect normally ignored in such analyses of semisubmersibles. Few ocean data appear to presently exist to assist designers in resolving this issue.

Furthermore, for large steep waves, nonlinear effects may result in water particle kinematics, crest speeds, and wavelengths that are different from linear results. This can result in errors in relative phasing of wave forces at points along the MOB if linear analysis is used. To account for this effect, studies should be made to determine the importance of nonlinear wave kinematics.

To design a MOB, a set of design cases must be first identified. Each design case is for the MOB in a particular configuration (e.g. connected, ballasted down, in undamaged condition) and with a particular response being considered (e.g. longitudinal tension in a module-to-module connector). By selecting a criterion for the response (say, 100-year return period), a set of environmental parameters (wind, wave, current, internal wave) can be identified that result in a response for this return period. This defines the one or more seastates corresponding to this design case.

These seastates will depend on the detailed characteristics of a particular MOB configuration and concept, and so cannot be determined until the exact MOB design

concept is known. They will, therefore, have to be specified in the specific design phase and were beyond the scope of this particular project. The Quantitative Environmental Specification, is thus a primarily statistical description of atmospheric and oceanic conditions, and a "recipe" of how to use these descriptors to specify detailed environmental conditions for the design. Hence, it provides the process needed to determine whatever the particular concept-specific environmental design parameters may be.

QUALITATIVE ENVIRONMENTAL SPECIFICATION

Atmospheric and ocean flows, phenomenological description of environmental components, possible sources of environmental data and statistical description of environmental components are addressed. Statistical description of environmental components and fatigue environment issues is also discussed.

Atmospheric and Ocean Flows

As an introduction to the Qualitative Environmental Specification, a general background of atmospheric flows (winds) and ocean flows (currents) is first presented in Chapter 5 of this report. There are major atmospheric flows that generate related ocean flows that occur all year long with more or less the same strengths. At any site, these are well known, and the MOB must be driven against these in order not to drift away continually. Their scale is very much larger than the MOB so the modules will not tend to be separated by these currents and winds. An example of this phenomenon is the Gulf Stream.

On top of these flows are secondary winds, that, while not as constant as the previous flows, can blow with great constancy for periods of many months. In the Arabian Sea and the Northwest Pacific, these are represented by monsoons, resulting in correspondingly steady wave and current conditions.

At the next level down are tropical cyclones (the most intense of which are called hurricanes in the Atlantic and typhoons in the Northwest Pacific), and extra-tropical storms. Hurricanes develop only in certain areas of the world. They move quickly, and can generate waves up to about 36 m. Extra-tropical storms have a smaller spatial scale than hurricanes, but are capable of high wind velocities, and can intensify explosively. They can generate surface currents that move in a circular trajectory with a frequency (inertial frequency) $f_I = (\sin l)/12$ in cycles per hour, where l is the latitude.

The final class of atmospheric flows are winds that may be generated quite locally and may be affected by landforms.

In this report, this general introduction of atmospheric and ocean flows is followed by a phenomenological description of environmental components such as wind, currents, wind waves and internal waves. A brief summary of some key related issues follows.

Wind

Wind speeds are continually changing in time about a mean value associated with a given period of time. The wind spectrum, giving the energy at each frequency, typically increases monotonically towards zero frequency, showing that slowly changing variations are greater than the more rapid ones. The MOB, due to its high mass, will hardly respond to the higher frequencies. However, it will respond more to the lower frequencies and to the steady mean component. A mooring system may have to resist all such motions, but a dynamic positioning (thrusters controlled by computers) may be only required to resist the mean force, allowing the system to wander backwards and forwards in the ocean with the cyclic components.

Wind characteristics can be categorized by mean speed profile, integral scales of turbulence, turbulence spectra and turbulence spatial cross-spectra. The mean wind speed profile describes how the wind varies with elevation and a logarithmic function of elevation is often found to be an appropriate representation. Horizontal spatial variations can be significant over a 1-km scale for local storms and over larger distances for hurricanes. Integral scales of turbulence are measures of spatial dimensions of turbulent eddies. For high wind speeds, this scale is about 1/5 of a mile, closer to the length of individual modules than the length of a MOB, suggesting that the variation of the wind speed along the MOB may need to be considered.

When wind speed is averaged over shorter and shorter times, an increase in the maximum mean speed is seen. However, for averaging times of as low as 1 minute, the increase is only 25% from that for 6 hours. Typical spectra for hurricane and non-hurricane winds are given in the report, with formulae for cross-spectral densities and coherence functions that describe the relative strength and phases of the wind for points separated in space. Peak wind speeds appear to follow reverse Weibull distributions.

Currents

Currents also have both time-varying and constant components. Just as for wind forces, it may not be necessary for a dynamically positioned MOB to be driven against cyclic forces, as it may be allowed to move backwards and forwards many miles. Only the constant component needs to be resisted, in order to keep to a mean position.

Tidal currents in the open ocean are generally less than 10 cm/sec, increasing significantly in some coastal regions. Currents at inertial frequencies can reach 1 m/sec, while equilibrium wind-driven currents are often assumed to be about 3% of the wind speed. Geostrophic flows (driven by atmospheric pressure gradients) can reach 3 m/sec. Both

tidal and inertial flows revolve around all directions of the compass during their respective cycles.

In the open ocean, currents are predominantly wind-driven and geostrophic, and, as a result of the scale of the atmospheric disturbances, mostly have scales of 10 km or larger. Small eddies could reverse flow directions in perhaps 5 km, and similar gradients could be expected of other currents near landmasses. The location of the Loop current in the Gulf of Mexico moves and gives rise to energetic eddies with diameters of several tens of km.

Wind Waves

Waves are normally specified by a spectrum, giving the energy of the waves at a range of frequencies. However, more detailed description is required to actually specify the water particle motions and, hence, the wave forces used in design.

One of two methods is normally used for design of marine structures subjected to waves. Diffraction programs are used with large members (whose dimensions are not small relative to the lengths of the waves), as in the MOB. However, these programs generally ignore nonlinear effects. The wave force equation (Morison equation) can include nonlinearities but fails to recognize effects from the large size of the members. For some conditions, it may be necessary to include both nonlinearities and large-member effects in order to perform accurate analyses.

A commonly seen effect of nonlinearities in waves is the narrow crests and broad troughs seen, for instance, in the surf zone of a beach. Buoys commonly measure surface elevation changes from waves, but these buoys have the disadvantage of moving horizontally with the waves and reducing the apparent degree of nonlinearities in the waves (steep crests, flat troughs). Wave staffs on fixed platforms do not have this failing, but are, of course, not so widely distributed in the oceans. Radar methods are now being increasingly used, particularly from satellites.

Wave spectra can be divided broadly into wind-driven waves and swell (generated away from the region though which they are passing). Wind-driven waves can be further subdivided into those whose characteristics are limited by a short fetch (the region over which the wind blows to generate the waves), and fully-developed seas (where the fetch is long enough that no further changes in wave characteristics take place). Spectra have been suggested that accurately model the seas, using as input the wave age (ratio of speed of wave propagation at spectral peak to wind speed). Directional spreading is generally much less in swell than in wind-driven seas, and is considerable in seas resulting from the rapidly changing winds in hurricanes.

Formulae for statistics of crest heights are presented as well as estimated joint probabilities of wave heights and periods. The grouping of high waves in an irregular sea can be studied by the number of successive waves exceeding a selected height.

Spatial coherence refers to the ability to predict the wave history at one point from that at another. As an example, at two points perpendicular to the direction of wave travel the

wave histories may not be the same, contrary to the simple theory of long-crested waves. This issue has not yet been well studied in the ocean.

A similar effect applies with two points parallel to the direction of wave propagation. Examples are also given in this report of the deficiencies in predicting wave characteristics, by the use of linear theory, at a downstream location several wavelengths from a point where the wave characteristics are known. Linear theory assumes that all wave components travel at speeds related to their individual frequencies, while, in fact, many wave components are bound to other components traveling at the same speed. To achieve adequate accuracy, it may require nonlinear wave theory. In real ocean conditions, this may mean nonlinear irregular directional theory, which is currently state of the art, and not widely used.

Internal Waves

Internal waves exist below the water surface and propagate because of the differences in densities that exist in different layers of the ocean, resulting from temperature stratification. This layering is generally present in the top 30 m. They can be generated by natural processes in the ocean or by driving a ship through such water, in which case the ship experiences anomalous drag due to the generation of internal waves.

Internal solitary waves consist of single wave crests, inverted below the water surface. They have crest widths of the order of 0.5 - 1 km and velocities around 0.5 m/sec. If they travel in a direction with a component in the direction of the MOB's longitudinal axis, they will try to separate the modules, because the crest width is much less than the length of the MOB, and, therefore, the water particle velocities vary along the length of the structure.

Linear internal waves have cycles at the tidal or inertial periods, but the crest widths are very much larger than the length of the MOB, so the principal effect is to move a floating body backwards and forwards distances of the order of 5 km.

Possible Sources of Environmental Data

Following the phenomenological description of environmental components, possible sources of environmental data are addressed. Climatologies provide large-scale coverage (often only monthly means) of surface meteorological data such as air temperature, wind speeds, etc. Meteorological centers, both public and private, collect data as often as four times a day, with 1^0 or 2^0 resolution in position. They can provide raw data or analyzed data. Examples of such centers are:

- The European Centre for Medium Range Weather Forecasts (ECMWF)
- The U. S. National Center for Environmental Predictions (NCEP)
- The U. S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC)

Wind data from these sources can be used to drive hindcasting models to estimate both current and wave characteristics. In this way, the correct relationships between wind

(speed and direction), wave (height, period and direction) and current (speed and direction) can be found. Government and private organizations provide these modeling capabilities.

Examples of such organizations are:

- The U. S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) (wind waves)
- The Naval Research Laboratory, Ocean Dynamics and Prediction Branch (ocean currents)
- Oceanweather, Inc. (wind waves)

Statistical Description of Environmental Components

The Qualitative Environmental Specification presents a statistical description of environmental components. To identify environmental conditions associated with design cases, the statistical distributions of the environmental parameters and, hence, of the responses of the MOB will have to be found. To facilitate this analysis, the environmental conditions are broken down into two levels: long term and short term.

The occurrence of storms and the variations of intensity within each storm are considered as long-term distributions. The variations within about a one-hour duration of free surface elevation, wind speed, etc., and, hence, structural response, are part of an essentially stationary process that can be called short-term. The short-term processes can be described by power spectral density functions, and the statistics of the short-term responses can be generated from knowledge of the characteristics of the structure.

Wind, wave and current are highly correlated, but the data may not be available for potentially required sites from measurements. Recourse can be taken to obtaining data from numerical models, driven by wind measurements. It is overly conservative to use maximum values (actually associated with a given return period) for all parameters. Therefore, a procedure is required to assess the joint probabilities of all parameters in order to determine the statistics of the MOB responses. This can be achieved through analytical or Monte Carlo methods.

In the analytical method, environmental parameter distributions are specified as analytical functions. The response function (depending on several environmental parameters) is also specified as an analytical function, perhaps by fitting to appropriate polynomials by regression analysis. The statistics of the response can then be determined analytically.

The Monte Carlo approach simulates the environmental events and exciting force time histories on a computer and solves for the structural response. This process is repeated a large number of times reflecting the statistical variation of the environmental events in the structural responses. From this ensemble of response time histories, one can calculate the required response statistics.

Fatigue

Fatigue, an important structural issue, is also discussed in the document. Fatigue damage accumulates from hundreds of thousands or millions of cycles of stress of smaller magnitude than the stress caused by the extreme sea conditions.

In the Northwest Pacific site, commonly occurring waves are small relative to the design level waves from hurricanes. Therefore, fatigue damage accumulation is likely to be low at this site. Furthermore, since it is assumed that the MOB will be in transit for a relatively short fraction of its life and is not likely to be subjected to extremely high waves during this phase, fatigue damage from transit is not expected to be high, although should be assessed during the course of the design.

On the other hand, the North Atlantic is annually subjected to a general background of high waves. These conditions will result in continuous growth of fatigue damage at this site. Since fatigue-causing waves are rather smaller than strength-level waves, their wavelengths may be a small fraction of the MOB length and uncertainties related to knowledge of wave coherence may lend extra uncertainty to the wave analyses.

QUANTITATIVE ENVIRONMENTAL SPECIFICATION

Locations for environmental data, hindcast data and related uncertainties, the statistical software developed to access and manipulate the data, and a study on wind, wave and current events and their possible dependence on global typhoon descriptors are addressed. Appropriate recommendations are made based on knowledge gained from the work performed.

Locations for Environmental Data

As mentioned earlier, four locations were selected by the Government for consideration in the Environmental Specification development as possible deployment sites. These were chosen as locations that combined the possibility of being potential tactical sites and having extremely severe environmental conditions. They are:

- the North Atlantic Ocean,
- the Northwest Pacific,
- the Sea of Japan, and
- the Arabian Sea.

Of the four, the North Atlantic and Northwest Pacific sites have clearly the strongest winds and highest waves. The data for the North Atlantic should thus be considered a primary site for design conditions. At the remaining three (tropical) deployment sites, typhoons create the most extreme conditions. The typhoons at the Northwest Pacific site are more intense than at the remaining two, and so, specific data are provided at this site to characterize a number of very strong typhoons. Since typhoons are not as severe at the

two remaining sites, these sites were considered secondary sites (environmentally speaking), and no specific typhoon data were developed.

In addition to these four deployment sites, data were collected for 21 other global sites representing possible regions for transit.

Environmental Data

Following is a summary description of the raw wind, wind wave, internal wave and current data supplied in this Specification. It is followed by a discussion pertaining to the inclusion of other environmental effects not inherent in the raw hindcast data and associated uncertainties. This, in turn, is followed by the specification of the actual environmental data at the four deployment sites and transit routes:

Wind Data

After studying various possible sources for wind data outlined in the Qualitative Environmental Specification, it was decided to use, for most sites, those from a government climatology known as the NCEP/NCAR CDAS/Reanalysis Project. (National Centers for Environmental Prediction; National Center for Atmospheric Research; Climate Data Assimilation System).

This data set provides wind speeds and directions at 6-hour intervals at locations covering the surface of the earth. It has been collected from a wide selection of land surface, ship, rawinsonde (balloon), pibal (also balloon), aircraft, satellite and other measurements and assimilated with a numerical simulation model, which is driven by atmospheric dynamics. These data were provided to the project by Oceanweather, Inc., (subcontracted to BNI) in CD-ROM format. They reflect a period of 23 years, from 1974 through 1996.

The Northwest Pacific site is subjected to several typhoons a year, some of which result in extreme conditions. Climatologies do not adequately capture the details of typhoons, because enough instruments necessary to provide good detail are never present in the relatively small region of high winds. Therefore, wind field models were created of 25 intense typhoons that passed close to the site. These analyses, performed by Oceanweather, Inc., used measured or estimated parameters, such as the pressure at the center of the typhoon, maximum wind speed, track, etc. Wind speeds and directions are provided at a number of points surrounding the deployment site.

Wind Wave Data

From our research on studies of available wave data, it was decided that the best data set that could be obtained for a number of deep ocean sites was from hindcasts. A major reason for choosing hindcasting is that, while wind data have been measured for many decades at large numbers of sites around the world and in the oceans, there are relatively few long-term sets of measurements of waves, especially if directional information is desired. By using hindcast data, corresponding wind and wave information can be obtained that gives full correlation between these two metocean items.

Oceanweather, Inc. was contracted to provide wave data from their global wave hindcast for the 23-year period between 1974 and 1996. The model from which these were obtained was driven by winds from the NCEP/NCAR CDAS/Reanalysis Project. These data are at 6-hour intervals, like the wind that drove the model, therefore are consistent. They include significant wave heights, peak spectral periods, directions of a set of wave trains chosen to represent the directional waves present, and information on the frequency distribution.

For the same reasons mentioned for winds, there are few measurements of waves in typhoons, and those that exist are very sensitive to location relative to the typhoon track. Wind climatologies do not capture the details of the typhoons, so waves hindcast from these winds cannot be accurate. Therefore, it was decided for the Northwest Pacific site, to use dedicated typhoon wave hindcasts to estimate the waves during the 25 typhoons for which wind fields were developed. These analyses were run by Oceanweather, Inc.

Data provided at a number of points surrounding the site include significant wave heights, peak spectral periods, and directions of a set of wave trains chosen to represent the directional waves present, and information on the frequency distribution.

Internal Wave Data

The internal wave data represent a detailed description of the kinematics of the water particles as an internal wave passes for some of the larger internal waves that have been measured. Due to the relatively little data available, no long-term statistics could be provided to be used in a rigorous risk analysis. Instead, the characteristics of a large internal wave are provided that can be used in the design.

Current Data

Compared with the number of measurements of wind and waves, there are very few long-term measurements of currents in the open ocean. It was, therefore, found necessary once more to go to hindcasting in order to obtain the best possible information. Currents were divided into three categories: The first was global circulation from global wind fields, the second was local currents from local winds, and the third was from tides.

The Oceanography Division of the Naval Research Laboratory (NRL) provided the global current data from modeling of all the oceans of the world, driven by winds from a global

climatology. These data were provided by NRL at 3.05-day intervals for the years 1979-1996, and consist of current direction and speed for the upper layer of the current model. These data were interpolated and reorganized by BNI so that the time intervals are exactly 3 days which is a more appropriate time interval.

Since the time scale of the data from this model is relatively large, currents with periods less than 3 days were not included. However significant components of ocean currents have such periods. These were modeled in a separate hindcast. For the currents driven by the global winds, BNI did this modeling from differential equations of equilibrium provided by Dr. Robert Weller. This hindcasting was carried out for the global data, using the NCEP/NCAR CDAS/Reanalysis Project. For typhoons at the Northwest Pacific site, the typhoon wind fields developed by Oceanweather, Inc. were used, and the analysis was performed using a modified version of the program PWP from Dr. Jim Price of Woods Hole Oceanographic Institution. Current directions and speeds are provided for the global data and for the typhoons at steps of 1 hour.

The tidal current data were provided at the four deployment sites by Dr. L. Kantha, from a project run jointly between the University of Colorado, Mississippi State University and the U.S. Naval Oceanographic Office. Since tidal currents in the open ocean have little effect on transit operations, due to the short periods of their motions and relatively small magnitudes, no data were sought for the transit sites.

Inclusion of Environmental Effects not Present in the Hindcast Data

The wind, wind wave and current data give a set of concurrent information over a period of about 20 years from which joint statistics of any metocean parameters can be determined.

However, before these raw data are used in design studies, various additional information should be included in the wind and sea conditions. This includes expanding the provided raw data to include, for instance, the variation of wind speed with elevation above the ocean, wind turbulence, directional distribution of waves, etc. This information is provided in detail in Section 6.3.

In summary, these raw and expanded data can be used in the following way: In the proposed statistical method of design, a given response of the MOB is to be found for a particular set of metocean conditions. Then, from the statistics of these metocean conditions the statistics of the response can be found, and, hence, the reliability assessed. The analysis of the MOB for a given set of metocean conditions would be perhaps incomplete unless the additional information is used in this analysis. For instance, a certain response associated with a particular set of the 3 wave trains may be sought, given by significant height, peak spectral period and direction for each. By adding to the raw data the spectral shape and the directional distribution, the wave description is completed and the MOB can be analyzed using appropriate software.

Certain types of events, such as atmospheric and oceanic fronts, are not included at all in the raw wind, wave and current data above described. However, estimates of the

magnitude of these events are provided. No further information to the basic data needed to be provided for internal waves. The internal waves data provided are inherently complete and give all the information that is needed for design.

Uncertainty in Data

In order to reliably use the metocean data for design, a knowledge of their accuracy is most desirable. A section of the document is devoted to estimating the uncertainties in the wind, wave and current data. However, this is often quite difficult to do and hard statistical data are sometimes supplemented by estimates from experts.

Looking at global winds first, the accuracy of the mean of the 6-hour mean wind speeds may be as good as 5% and the standard deviation of the scatter of individual values is probably about 10% to 15%.

It is more difficult to estimate the uncertainty of the winds in the intense part of a typhoon, due to the almost total lack of such data. Uncertainties are estimated at 15% or 20%.

It is generally recognized that good wave hindcast models create wave fields whose accuracy depends largely on the winds that drive them. Estimates of the uncertainty are that the mean error in wave height is less than 0.5m in extra-tropical areas, and the scatter of individual values (standard deviation) is about 25%. The mean error in peak period is less than 0.5 sec, and the scatter is 35%.

Estimates of the global current accuracy suggest that the currents are probably biased about 35% low, with considerable scatter.

Summary of Environmental Data at Deployment Sites

A section of the main report and several appendices are devoted to summarizing the obtained environmental data at the deployment sites. The data give an overview of the operational and extreme conditions. This is not intended to be a definitive summary of the data in a “ready-to-use” format for design, as different MOB concepts will be sensitive to different metocean conditions and statistical combinations are necessary. This subject is addressed below.

Statistical Software

The raw environmental data from hindcasts can be thought of as providing a listing of the values of the environmental parameters (wind, waves and currents) at a number of times during periods of interest. Since these data include all parameters at each time point, they, in effect, provide a sufficient basis for any statistical analysis desired that uses these environmental parameters. Such statistics include joint probability density, as well as cumulative, marginal, conditional, extremal and directional distributions. Furthermore, with 23 years of global wind, wave and current data, supplemented by 25 sets of typhoon data, simply accessing the data presents a rather formidable task.

In order to be able to accomplish both accessing the data and performing statistical analyses, a program, called MOBENV (for MOB ENVironment), was developed by BNI. It was written in MATLAB largely because of its graphics capabilities. It allows a user not only to quickly read the various sets of data, but also determine various statistical single-variable or joint statistics.

The program can read any of the wind, wave or current data at a chosen site, from either the global or typhoon hindcasts producing tables and plots of the data themselves or can solve for user-prescribed distribution functions fitted to these data.

Considerable flexibility, too much to fully describe in this summary, is available in the way the global data can be extracted. For instance, a selected number of months during selected years can be requested. This would allow the user to study seasonal effects. If the whole set of years is selected, return periods associated with a given variable can be established.

Since, as described above, the global data at the Northwest Pacific site are known to be not very accurate during the passage of typhoons, an option was included to exclude data that may be significantly affected by typhoons in the region. When this option is used, the data that are recorded during close typhoons are separated from other periods of time. This empowers the user to be able to judge the contribution from the typhoons. Extreme conditions at this site should, however, be studied using the typhoon hindcasts.

An option is also given to the user to expand the 25 typhoon hindcasts to account for the possibility of their moving in paths other than the historical ones. This effectively uses the intensity variation of the historical hindcasts and adds random track variations to give a more complete coverage of the typhoon characteristics, without resorting to running more typhoon hindcasts. A section in the report details the use of this option.

Another powerful option in the program allows the user to combine individual environmental variables into a new variable, using a user-defined function of these environmental variables. The program can then create histories (and, hence, statistics) of functions of the recorded environmental data, instead of the variables themselves. Thus, for instance, using a numerical hydrodynamic model of the MOB such as WAMIT, a user can run a series of waves of varying peak period and direction and estimate some peak response during a 6-hour period, for each such wave. Then, fitting a function to this response as a function of wave height, period, and direction, the response of the MOB can be simulated over 20 years, and the extreme response for, say, 100 years could be found.

One more example of the valuable use of MOBENV is in its ability to determine various statistics of environmental parameters associated with one specific variable. For instance, there may be interest in knowing the statistics of waves associated with a particular range of wind speeds (say 40 mph) that could be a factor in operations such as landing or take-off of aircraft. This capability is included.

Section 6.6 and Appendix E of the report describe in detail the basis and use of MOBENV together with analytical examples.

Wind, Wave and Current Events and their Dependence on Global Typhoon Descriptors

This study examined the characteristics of typhoons in the Northwestern Pacific.

The first part of the study was to see how well simple models of typhoon wind and wave fields matched more elaborate (and accurate) models, such as the model used in creating typhoon wind and wave data for this project. Cooper (1988) proposed and calibrated a wind and wave model that consisted of a few quite simple equations involving fundamental typhoon parameters such as radius to maximum wind, pressure deficit, forward speed, etc.

Using four of the hindcast typhoons, wind speed and direction, and wave height, period and direction at all grid points in a region around the central part of the storms were compared with values computed from the Cooper equations. It was found that the simple equations gave reasonable estimates of wind speed, and wave heights and periods, but not accurate enough for even preliminary design use. Directions were more poorly estimated, but some of the difference comes from the fact that the Oceanweather typhoon wind fields were superimposed on the existing global wind fields, while the simple model assumed no winds at a distance from the storm center.

The second part of the study attempted to relate the spatial variations of the wind, waves and currents in typhoons to the parameters that are used to describe the typhoons. Due to its great length, the MOB is expected to be more sensitive to horizontal variations of metocean variables than most marine structures, so an estimate was made of the maximum rate of change of wind speed, significant wave height and current speed, with respect to horizontal distance. At various times during the passage of a number of typhoons, the archived hindcast wind, wave and current data were examined over an area of the ocean covering up to 1000 km square. The rate of change with respect to distance of these variables was found over this area, and the maximum value was recorded over the area for each typhoon. Plots of the rates of change of these variables against the typhoon parameters used to characterize the typhoons showed little correlation, so it must be concluded that it is not easy to estimate the rates of change of these metocean variables from the typhoon parameters. However it was found that the variations horizontally of the wind and current are small compared to those from other metocean events such as ocean fronts and internal waves.

Recommendations

This Environmental Specification presents a solid foundation for design and input to the overall MOB Classification Guide. Nonetheless, as it is inherent to this kind of developmental work, new lessons have been learned by simply doing the work and additional advances in gathering of environmental data are continued to be made. Some of these are deemed important developments for the design of the MOB and are offered here as points of awareness and recommendations for consideration by the Government. It is believed that the recommended issues will further improve the determination of environmental criteria and their application. The reader is referred to Section 6.8 for the detailed description. They are summarized here (not in order of importance) for reference as follows:

Nonlinear Wave Effects on MOB

The higher seastates have considerable nonlinearities in the waves that cause, among other things, higher crests and shallower troughs. It is not clear how important these are in computing the response of a MOB. A study should be made of the effect on the response of one or more MOB concepts from the nonlinearities present in big waves. First, the changes in forces on a MOB would be studied using linear and then nonlinear regular waves. This would be followed by using irregular waves.

Additional Description of Wave Spectra for Deployment Studies

For this specification, seastates have been characterized by two or three wave trains in different directions. It would be presently possible to obtain more detailed description of the seastates with a spectrum defined by a number of frequencies and directions. Since the MOB concepts are probably all quite sensitive to frequency and directional content of the waves, this would increase the accuracy of the response calculations.

Refinement of Wind Data

The global wind data are provided at 6-hour intervals over about 20 years. Spectral formulae are recommended for determining the variation of wind speeds with time due to turbulence but may not be very accurate for periods over an hour, where the variations in wind speed are not due to turbulence. It would, therefore, be desirable to be able to simulate variations of wind speeds for certain MOB response calculations at between 1- and 6-hour spacing. To achieve this, wind records at sites in the oceans as near as possible to the four deployment sites would be sought, and spectra in this middle period range would be generated for various conditions. From this, specific recommendations for spectra for these sites would then be made.

Rarely Occurring Waves for Reliability Analysis

Reliability analyses will be recommended for MOB design in which the actual probability of failure will be estimated. Prudent design requires this probability of failure to be at the 10^{-4} to 10^{-5} level as it is most desirable to be able to specify seastates with return periods far greater than the usual 100-year values that are used with traditional working stress design or load and resistance factor design (LRFD). All seastates contribute in computing the estimated failure probability and estimates of seastates that occur at these same low probability levels are required for these calculations. Extrapolation of historical hindcasts to such low probabilities often leads to large statistical errors. Using a different approach, a larger number of storms can be simulated by varying the basic parameters that characterize a storm, individually, thus allowing seastates at much lower probabilities of occurrence to be produced by hindcasts. A joint-industry project is currently being assembled by the offshore oil industry to produce and study such rarely occurring seastates using the measured distributions of these typhoon parameters. It is recommended that the Government, perhaps through a contractor, participate in this joint industry project.

Correlation of Hindcast Data with Hurricane Bonnie Measurements

There is currently information available on this storm (August 24, 1998) including actual waves in hurricane Bonnie as measured from a NASA airplane. The data are significant because they are the very first measurements ever of the overall wave field associated with a hurricane. It is a great opportunity to study these real data and assess any correlation with the available hindcast data provided in this Environmental Specification**.** To assess the accuracy of the wave hindcast data, a hindcast could be commissioned to simulate hurricane Bonnie, in exactly the same manner the Northwest Pacific typhoons were hindcast. Data would be archived for a region of the ocean large enough to cover the swaths created by the NASA airplane. The wave data from the scanning radar altimeter (SRA) on the airplane would then be compared with those produced by the hindcast. As NASA plans to fly into and collect similar data from future hurricanes, this study would also establish the process for assessing future measured data.

MOBENV Enhancements

The program MOBENV is a valuable tool in examining the huge amount of data archived for this Specification and developing statistical information on them. In developing this tool, emphasis was put on the computational and operating aspects. Although the program is fully functional, the user interface can be improved as MATLAB, which was the application used for developing MOBENV supports a good graphical user interface (GUI). Thus, the program can be made to be menu-driven, instead of requiring the user to interact with the program in a prescribed sequence. This would broaden its application and ease-of-use.

Improved Global Data When Typhoons are in the Region.

A useful improvement to the hindcast data would be to attempt to improve the global hindcast at the Northwest Pacific site during times where the local weather is dominated by typhoons to make it more accurate, so that the statistics generated from the global model would be closer to reality during these periods of time. Two possible approaches are offered for consideration using either the hindcast data from the typhoons that occurred during the period of time covered by the global data or by substituting the wind, wave and current data during typhoons with data estimated from a simple parametric model such as the Cooper model that was evaluated in Section 6.7. The full set of 25 typhoons would first be used to tune the various parameters in the Cooper model, to conditions in the Northwest Pacific. This effort would result in having a reasonable model for predicting environmental conditions for all typhoons that occurred in this region. The global data during typhoons could then be removed and replaced by those predicted by the parametric model.

APPENDICES

A set of appendices is provided in Volume 2 augmenting the information in the main text of the report. They include:

- CD-ROMs containing the environment database
- Reports from Oceanweather, Inc. and Naval Research Laboratory on the hindcasts
- Formal descriptions of the data
- Listing and verification of the program used to predict local wind-driven currents
- The statistical analysis program MOBENV and examples of its use
- Studies by Dr. Robert Weller on comparing the wind and current data provided with measured data
- Studies by Dr. Mark Donelan summarizing the hindcast wave data
- Studies by Dr Robert Weller to estimate the mixed layer depth to be used in computing local wind-driven currents.

HOW TO USE THIS SPECIFICATION EFFECTIVELY

In addition to this Executive Summary, the reader is encouraged to also read Chapter 1 for important information on how this document is organized and can effectively be used. Such guidance is important due to the vast and varied amount of information provided.