Back to
Papers

The Derivation of Environmental Design Conditions for Goodwyn 'A' Platform

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SUMMARY An overview is presented of the scope and methodology of investigations undertaken by Woodside Offshore Petroleum Pty Ltd for the review of environmental design conditions in support of the Goodwyn 'A' Project on Australia's North West Shelf. Emphasis is given to the diversity of Australian expertise employed in the review and the considerable success attained within the relatively short project schedule.

1. INTRODUCTION

The Goodwyn 'A' platform, currently in detailed design phase, will become the second offshore production facility for the North West Shelf Development Project when it comes on-stream in 1993. The new platform (GWA) will be located approximately 130km NW of Dampier and 23km WSW of the existing North Rankin 'A' platform (NRA) in a water depth of 131m (refer Figure 1).

The review of environmental conditions began in mid-1987 after the Joint Venture Participants announced the go-ahead for preliminary engineering design of the platform. Final project approval was given in April 1989. The total cost of the GWA project is expected to be A$1.63 billion, out of a total cost of A$12 billion for the North West Shelf Development Project.

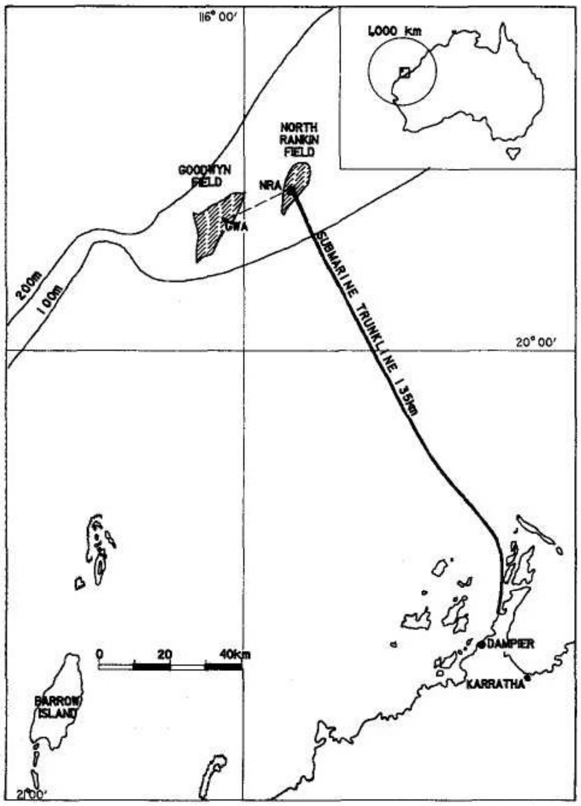

Figure 1: Project locality plan

2. BASIS FOR THE REVIEW

Environmental design conditions for the North West Shelf (NWS) region of relevance to Woodside activities had not been formally revised since 1979 when the NRA criteria were established. This earlier work relied heavily on overseas input and experience at the time. Although GWA is not geographically remote from NRA there were important and compelling reasons for an update of all major criteria, as follows:

- NRA criteria relied heavily on hindcast data with only a limited set of measurements being available at the time. An additional 8 years of data (approx. 30 instrument years) had become available for analysis;
- The additional data had resulted in an increased understanding of the oceanographic conditions, thereby allowing a less conservative approach to be adopted for establishing the design conditions than had been necessary for NRA;
- Numerical hindcast and data analysis techniques had improved significantly over this period;
- A greater level of detail was required, and criteria needed to be extended to cover ultimate limit state conditions (2,000 yr return periods and beyond);
- Finally, there was a need for a more complete and integrated set of criteria which would form the basis for design of future company facilities, both onshore and offshore.

3. SCOPE

The review of the environmental design conditions covered all major aspects of the design, including:

- Tropical cyclone generated winds, waves, currents and storm surge for return periods up to 10,000 yr;
- Non-cyclonic winds, waves and currents for return periods up to 50 yr;
- Operational meteorological and oceanographic conditions;
- Wind and wave conditions for tow routes from ports in Australia, Japan, Korea, Singapore, Malaysia and Indonesia;
- Wind and current boundary layer profiles;
- Surge plus tide joint distributions.

The priority assigned to each of these areas was determined by the requirements of the relatively short project schedule and the fact that structural design was proceeding in parallel with the review. An interim specification based largely on the NRA design criteria was prepared initially for use in the preliminary structural design. Revisions to the specification were issued as the results of successive phases of the investigation became available, with nine major revisions being issued prior to the commencement of detailed structural design.

4. METHODOLOGY OVERVIEW

A joint deterministic and stochastic (JDS) methodology was adopted in preference to the more traditional "hindcast" approach. An overview of the JDS approach is given in Figure 2, followed by brief summaries of its major components. Detailed descriptions are presented in Section 5.

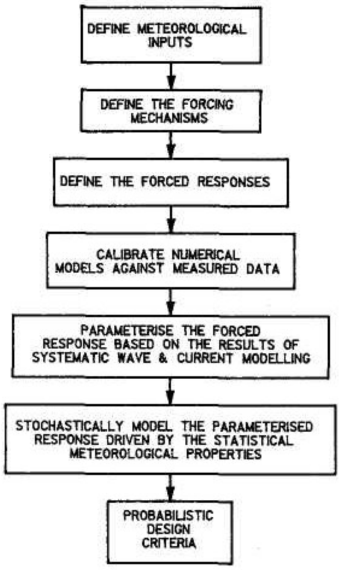

Figure 2: Overview of the joint deterministic and stochastic methodology

4.1 Definition of Event Statistics

For any ocean environment the dominant inputs are essentially meteorological in nature. By classifying these inputs in terms of discrete physical events it is possible to build up relatively accurate statistics which describe the meteorological environment.

4.2 Establishing Forcing Mechanisms

Meteorological forcing is transferred to the ocean surface by way of surface shear or pressure gradients which can be approximated in the case of tropical cyclones by relatively simple empirical models.

4.3 Defining of Forced Responses

For more complex parameters numerical models of wave and current dynamics are used to accurately predict the ocean response through the many complex hydrodynamic interactions.

4.4 Calibration of Models

Measured data are essential in confirming the accuracy of any numerical modelling and in fine tuning forcing mechanisms to allow confident application to extreme conditions.

4.5 Parameterisation of the Forced Response

Complex model behaviour is simplified through systematic wave and current modelling to extract a parameterised response which still retains the essential spatial and temporal characteristics. This is only necessary where it is impractical to run the full deterministic models in the stochastic modelling owing to time constraints.

4.6 Stochastic Modelling

This final step brings together the (generally) parameterised forced responses into a statistical framework by simulating an extended period of time driven directly by the statistical properties of the meteorological inputs. Frequency distributions of the individual and joint parameter responses are maintained throughout the simulation period (typically 100,000 years), and these are analysed to yield a set of mutually consistent probabilistic design conditions which are directly amenable to further joint probability analyses.

4.7 The Selection of the JDS Approach

Several factors contributed to the selection of the JDS approach in preference to the hindcast technique, not the least being its ability to provide the type of multi-site predictive capability needed for future NWS projects. Other reasons included the availability of several basic software tools well adapted to the method and the overall flexibility offered by the approach. The JDS method brings together the predictive deterministic power of sophisticated numerical modelling with the probabilistic base provided by numerical simulation using Monte Carlo techniques. Unlike hindcast studies, less reliance is placed on extreme value analysis and its consequent subjectivity which can have a high impact on the end result. The JDS method offers the benefit of statistical predictions based on significantly larger data sets. This is because emphasis is not solely placed on defining outputs but rather the inputs to physically based "mechanical" models of the environment under study. The outputs are then available in a statistical framework with all possible detail retained, enabling extremely long range predictions to be supportable.

5. DETAILED ANALYSES

5.1 Tropical Cyclone Statistics

The primary source of storm data was the Australian Bureau of Meteorology. To ensure reliable statistics the data set was limited to post 1959/60 when satellite imagery was introduced. A spatial limit of a 1000km radius of GWA was also imposed, this being the practical limit of influence (especially wave effects) from tropical cyclones (refer Figure 1).

Storm parameters considered were intensity (minimum central pressure), ambient pressure, radius to maximum winds, track and speed, life span, temporal (frequency of occurrence) and spatial distributions throughout the region. The radius to maximum wind estimates were prepared by Woodside, based on analyses of all available synoptic charts, satellite imagery and especially radar data. The majority of storm tracks could be relatively easily schematised as either a straightline path essentially parallel or perpendicular to the coast, or a dual-legged (recurving) path in which the storm initially moves parallel to the coast prior to turning and crossing the coast. This allowed compilation of spatial statistics such as origin and proximity to GWA. Frequency of occurrence statistics were parameterised in terms of a track-dependent Poisson distribution and intensity statistics as a track-dependent Gumbel distribution. Following a specialist study by Holland, a lower limit of 860 hPa central pressure was applied for the storm intensity. All other storm statistics were treated directly as cumulative distributions.

The resulting set of storm statistics formed a comprehensive summary of the major features of these severe weather events over the entire NWS region with particular spatial reference to GWA.

5.2 Wind and Pressure Models

Initially a modified National Hurricane Research Project (NHRP) wind and pressure model was used. This was later replaced by the Holland (1) hurricane model, which was found to provide more accurate predictions of measured wind records for the more intense storms. The data set used for calibration was limited to the NWS region and included NRA, Port Hedland and other coastal and offshore sites such as Automatic Weather Stations. A total of 23 wind records from 17 storms were used with peak 10-minute mean winds ranging from 17 to 56m/s. Storm records with winds less than 17m/s were generally unsatisfactory for calibration purposes due to contamination from other regional influences not directly attributable to the tropical cyclone in question.

An important aspect of model calibration, and ultimately selection of design wind conditions, was the specification of the over-water atmospheric boundary layer profile applicable to tropical cyclone conditions. Based on recommendations from Holland and Holmes (2), the 10 m level to gradient height wind speed ratio was set at 0.7. The work by Holmes also included an assessment of turbulence intensity leading to the definition of gust relationships for the various wind averaging periods required viz 10 min, 1 min and 3 s.

For calibration purposes, the Holland model's shape parameter ('B') was adjusted to minimise the discrepancy between measured and modelled data. This was achieved in an objective manner using error indicators based on peak, bias and scatter criteria. Nearly all of the 23 cases yielded good matching between model and data for acceptable values of the 'B' parameter. Peak error was less than 4% for 21 of the cases, with a bias (defined as the mean error over the half peak duration) less than 12% in 19 cases. Figure 3(a) shows a typical result from the wind model calibration, shown here in the case of TC Victor as recorded at NRA.

In order to minimise the number of free parameters to be considered, the overall sensitivity of the calibration result to 'B' was carefully assessed with the conclusion that adoption of a single value could be justified. An average 'B' value was therefore established and carried forward into the wave and current production modelling stages and the stochastic simulation.

5.3 Wave Modelling

This task covered two distinct elements of work: numerical modelling to estimate integral based parameters such as the significant wave height Hs and associated period Tz, followed by estimation of discrete wave parameters such as Hmax and its associated period THmax. Both types of parameters were required for various aspects of the substructure design. In addition, design storm wave hydrographs (time series of significant wave height), wave counts and directional spectral analyses were derived.

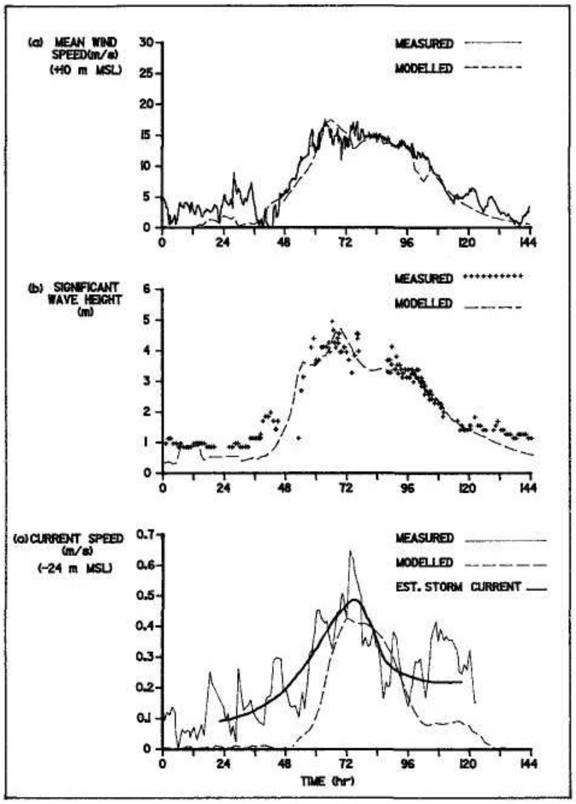

Figure 3: Comparison of measured and modelled storm responses at North Rankin 'A', for TC Victor;
(a) 10-minute mean wind speed (+10 m MSL);
(b) significant wave height;
(c) mean current speed (-24 m MSL);
(Elapsed times measured relative to 1800 GMT, 2-3-86).

5.3.1 Numerical Spectral Wave Modelling

The second generation discrete spectral numerical wave model by Sobey and Young (3) was applied inhouse, using the Holland wind field model as input. Several bathymetric computational grids were defined, ranging from the 'A' grid at 1620 by 1296km and 54km resolution, down to the 'B3' grid at 108 by 108km and 10.8km resolution. Simulations were staged through one or more grids depending on storm track proximity to the GWA site.

Model calibration was confirmed by comparison with 19 separate waverider data sets from 17 storms recorded by Woodside since 1973. Storm records were selected only where peak Hs exceeded 2.5m, to avoid substantial contamination from background conditions. The maximum significant wave height records available were recorded during the 1988/89 season, namely TC Ilona (7.7m) and TC Orson (10.5m at time of instrument failure, estimated as two hours before peak conditions). Reasonably consistent model hindcasts were obtained without resort to tuning of the model parameters, and discrepancies between measured and predicted results could generally be rectified by relatively small and justifiable adjustments to storm parameters such as track, radius to maximum winds or the Holland 'B' value.

Using similar error criteria to that applied to winds, wave modelling yielded peak errors for Hs less than 15% in all but one case, eight being less than 5% in error. Bias in Hs was within 15% for all but five storms and within 10% for eight storms. Other parameters were also well predicted: Tz at time of maximum Hs being on average only 2.8% higher than measured and Tp being 6.4% higher. Figure 3(b) illustrates a typical wave modelling result, again showing TC Victor recorded at NRA.

5.3.2 Wave Statistics

Because of the importance attached to accurate determination of the design maximum wave heights, which affect platform deck height, and the associated periods, specialist studies by Sobey (4) and Bea (5) were commissioned. Sobey's work provided the framework for detailed wave statistical analysis and firmly established the need for special attention to wave hydrograph shape, which directly contributes to the probabilty distribution of individual wave heights within a storm. Analysis techniques after Forristall (6) and others were assessed against the theoretical base of Rayleigh; the former method proving the most accurate in modelling NWS conditions, with a mean underprediction of Hmax/Hs(max) of about 4%. The wave height distributions were subsequently incorporated into post-processing of results from the Young numerical model, thus yielding the additional deterministic parameter Hmax.

5.4 Surge and Tide Modelling

Estimates of design stillwater levels at GWA were based on consideration of the relative (joint) contributions of both astronomical tide and storm surge. The semi-diurnal harmonic tidal constituents were used to generate time histories of water level throughout the duration of stochastically modelled tropical cyclones, while the time varying storm surge component was simply approximated by the deepwater inverted barometer effect based on the radially symmetric Holland pressure profile. Linear superposition of the two water level components was applied, and the statistics of water level exceedence determined.

5.5 Current Modelling

The definition of design currents was one of the most challenging aspects of the criteria review. Measurements collected by Woodside over several years had already highlighted the complexity of NWS current dynamics, especially the occurrence of baroclinic currents, or "internal waves", which propagate essentially orthogonally to the shelf break. The currents caused by these phenomena, although transient, can be as high as 1 m/s, and the exact interaction between these baroclinic effects and the tropical cyclone wind forced currents is poorly understood.

Although numerical modelling was deemed to be essential in attempting to quantify the current regime under extreme conditions, it was far from clear as to the most appropriate method of attack in the limited time available. A state-of-the-art review of numerical current modelling formulation and Australian capabilities was prepared by Bode and Samarasinghe (7) (James Cook University), and this formed the basis for a 2-day Modelling Workshop held in early 1988. Representatives from several major numerical modelling groups in Australia participated, including the CSIRO (Fandry,Craig), University of Western Australia (Zelt), Curtin University of Technology (Hearn), Australian Defence Force Academy (Holloway) and James Cook University (Bode,Stark). The workshop was coordinated by Steedman Ltd, whose staff also participated. The aim of the workshop was to define the technical options which would offer the most practical means of completing the work within the timescale and to an acceptable degree of accuracy. These efforts culminated in a joint development being established with Steedman Ltd as technical project manager utilising the numerical model of Fandry, with additional specialist studies of baroclinic effects by Holloway and the bottom boundary layer by Bode.

The 3-D finite difference based numerical hydrodynamic model embodied a 10-layer Sigma depth coordinate system, a constant eddy viscosity and a capability to represent stratification (although this was ultimately not used). The model domain extended from North West Cape in the south to Broome in the north and 600km seawards at a resolution of 10km. The Holland wind and pressure field model was again used as input. The current model calibration relied on a relatively sparse set of recorded data from only eight storms. The results for TC Victor are shown in Figure 3(c). Dr. G. Forristall of Shell Development Company provided a specialist review role for this work.

Parallel work delineated the influence of the baroclinic wave activity, barotropic tides, drift currents and the near-bottom boundary layer.

5.6 Stochastic Modelling

The model used in this study was a further development by Woodside of SATSIM (8), extensively used for coastal surge and tide estimation throughout Australia. Essentially the model is the vehicle for recombining in a statistical framework the various deterministic relationships previously established between tropical cyclone parameters and the resulting ocean and atmospheric outputs such as water level, winds and waves. The model itself is driven empirically by a probability source (random number generator) and therefore is of the "Monte-Carlo" type.

Figure 4 summarises the simulation procedure whereby the model first requires the specification of the various driving mechanisms; these being the statistical distributions of tropical cyclone parameters from Section 5.1. The (generally) parameterised output functions must also be supplied by way of astronomical tide constituents, or the complex wave and current response functions determined to apply at the site; the wind model can be applied directly. The model then simulates an extended period of time (100,000 years has been used as a standard) by sampling the assumed independent storm parameter distributions which advance the simulation in time on an event-by-event basis. Each discrete storm event produces an output response at the site, being a synthesised time history, and the sum total of all individual events builds to produce the estimated continuous frequency distributions of the particular parameters of interest. Joint distributions of the output can then be directly obtained. The model is self-checking to the point where it maintains a complete set of statistics of the simulated storm events which can be used to confirm that correct sampling of the input statistics has occurred.

One of the most powerful features of the model is the ability to test for sensitivity of any given input or output parameter in determining the final make-up of the extreme event time series. This was used to check sensitivity to the forms of parameterisation adopted when simplifying the complex real interactions in nature.

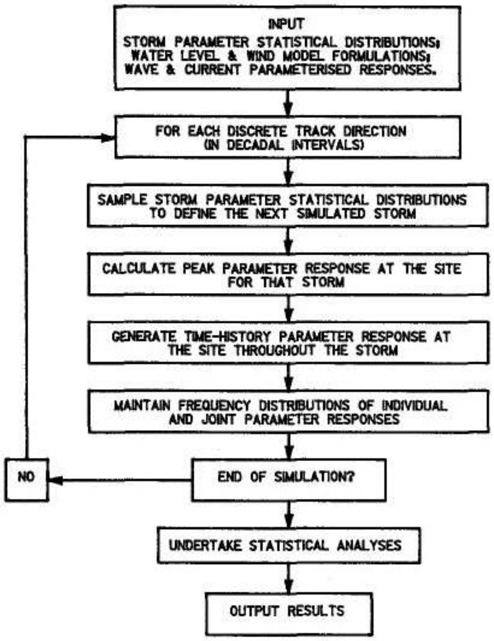

Figure 4: Statistical simulation methodology

6. CONCLUSIONS

An extensive review of NWS environmental design conditions was undertaken to provide the basis for detailed design of the Goodwyn 'A' platform. The review was undertaken primarily in-house by Woodside personnel with the assistance of various specialist Australian consultants and other researchers. In spite of the difficult timetable, state-of-the-art techniques were developed and applied to yield a comprehensive, integrated and consistent set of conditions in excess of normal industry standards.

Because of the immense investments dependent on these analyses it has been essential for this work to be critically reviewed against worldwide industry practice. The successful completion of such an extensive investigation requires access to a rich diversity of technical and managerial skills. Our work has confirmed that such skills are available in Australia and can be focussed to address these complex and challenging problems in the field of ocean engineering.

The benefit of the considerable past investment in offshore measurement programs by Woodside and its partners was fully realised in this investigation. The work has also highlighted the benefits that are available to the offshore industry by undertaking and maintaining oceanographic measurement programs. Only in this way will we amass the detailed knowledge required to more fully understand such complex phenomena and so achieve even further safety and economy in the design of offshore structures.

7. ACKNOWLEDGEMENTS

The above work was carried out under the general supervision of Robert Male, Civil Engineering Manager. Technical reviews carried out by C.J.Shaw (SIPM) and R.G.Bea (PMB Systems Inc.) are also gratefully acknowledged.

The authors wish to thank the management of Woodside Offshore Petroleum Pty Ltd and the North West Shelf Joint Venture Participants for permission to publish this paper. The six equal Participants in the LNG Phase of the project are Woodside Petroleum Ltd, BHP Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Asiatic Limited, Japan Australia LNG (MIMI) and Shell Development (Australia) Pty Ltd.

8. DEDICATION

The authors wish to make mention of the contribution to the above work both personally and in the broader sense by the late Professor Kevin Stark of James Cook University. His significant contribution to marine based research in Australia has been without peer and his guidance and vision will be sadly missed.

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