

## OTC 7685

### Development of a New Metocean Design Basis for the NW Shelf of Europe

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#### ABSTRACT

The paper discusses the development of a new metocean design basis for a deep water harsh environment off the NW shelf of Europe. The principal steps taken to achieve this, in an auditable and scientific manner, within the constraints of the available data, and short time scale, are described. The industry partnership approach, adopted to ensure early acceptance by all the relevant contributors, is outlined.

#### INTRODUCTION

This paper discusses the development of a new meteorological and oceanographic ("metocean") design basis for the first West of Shetland (WoS) Developments in quadrant 204 (see Fig. 1). This area is exposed to the full force of Atlantic storms which, together with the water depth and a complex ocean current regime, present unique challenges.

##### Location

In the general area, the sea bed slopes from the edge of the continental shelf (approx. 200 m), to the bottom of the Færoe-Shetland channel, where depths are 1000 m or more. The development location is in a water depth range of 375 m to 850 m, with the first field, "Foinaven", in 450 m to 500 m. For comparison, the deepest North Sea development in the UK sector is BP's Magnus, in 185 m.

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References and figures at end of paper.

Fig. 2 demonstrates the differences in metocean design criteria and illustrates the scale of the engineering challenge.

##### Data Sources

In the early 1970's, weatherships sponsored by the UK Offshore Operators Association (UKOOA) at "Fitzroy" (60°N, 4°W) measured wind and wave data. These were replaced later in the 70's by weather buoys at the "Foula" location, approx. 50 km to the ENE. In the 1980's, data was collected by the UKOOA data buoy DB3 in Block 206/6. During summer exploratory drilling, ocean current measurement campaigns by individual operators have also supported the drilling programmes in the area.

In addition to the measured wind and wave data, the North European Storm Study (NESS) provides data from computer models (ref. 1). The NESS dataset contains some 25 years of winter data, from 1964 to 1989, and provides output at 30 km intervals over the whole WoS area. Selected grid points and other data source locations are in Fig. 1.

##### Initial Design and Operational Criteria

Early metocean criteria for Foinaven, issued in late 1993, were based on proprietary work carried out for the North West Approaches Group (NWAG) in 1988. NWAG is an ongoing joint industry group, with the objective of exchanging and collecting metocean data for the WoS area. It was formed in 1986 and currently has 13 oil company members (chaired by BP), together with the UK Health and Safety Executive (HSE).

To reduce the period from discovery to development ("fast-track" project), requires considerable compression of the concept engineering, with design basis development in parallel with reservoir evaluation. The metocean design basis was, therefore, required considerably earlier than has been traditional practice. A decision on the metocean data gathering was made in late 1993 after concept engineering identified the feasibility of a floating production development on Foinaven.

A series of BP/Shell funded studies in early 1994 (involving a wider industry consultation), provided revised criteria for use in the initial design work at Foinaven. These included winds, waves, currents, water levels, air temperatures, sea temperatures, and snow and ice occurrence. These studies included all the available data, both public domain and proprietary to BP and NWAG, up to the end of May, 1994.

#### Involvement with Industry

These metocean studies had to meet all the design requirements for a major programme of subsea completions and a permanently moored Floating Production, Storage and Offloading (FPSO) vessel with up to 15 separate risers. To achieve this, an industry partnership was developed involving the Specialist Design Contractors, Certifying Authorities, Specialist Consultants and the BP/Shell Atlantic Frontier Programme (AFP) Metocean Team.

The first group workshop, with 13 individual participants, was held on the 17 March, 1994 to detail the methodology for the initial Design Basis. By 23 May, 1993 the second group workshop had 24 participants (now including the UK's HSE and Department of Trade and Industry) to review the scope of the Design Basis which was finalised by July, 1994.

On the core Foinaven Stage 1 Project, a smaller team has been established with 6 participants representing the Contractor, Certification, Operator and Independent Verification functions.

### **PRE-PROJECT DEVELOPMENT**

#### Overall Strategy

**With such a significant step into a new regime, the overall aim has been to follow a realistic approach to satisfy the Safety Criteria required by the UK Authorities.** In such an approach, a full understanding of all the uncertainties was required, in order to develop a satisfactory methodology for a probabilistic, risk-based, approach. This strategy incorporated a rigorous scientific basis, only limited by the available industry

resources within the time scale. Any uncertainties in the pre-project design values used by the contractors needed to be identified in parallel with the data gathering and final design basis work. Therefore, the contractor's designers and the Certification Authority were involved in the development of the metocean criteria in order to identify and confirm the required level of safety.

#### Background

The Færoe-Shetland Channel is one of the harshest open-ocean environments in the world, with persistent long period swells, complex current regime, and quickly changing weather conditions. In the past there has been some systematic metocean monitoring in the area, although no detailed Code or Regulatory Requirements are yet established. The most applicable published guidance for the UK sector is primarily based on fixed North Sea structures (ref. 2), or world-wide shipping (ref. 3). The approval cycle via the UK certification procedures, therefore, has to be integrated with the Design Basis development.

The significant technology steps for the project also have to address the specific requirements of an FPSO, where there is a different emphasis on several aspects of the metocean data. The main subjects considered were:

- Directionality - important for station keeping and offloading
- Current profile - important for riser loads
- Surface current drift - for environmental impact assessment
- Sea bed water temperature - wellhead and flowline specification
- Near sea bed currents - installation and design

A further consideration was that the planned 1995 installation work programme would be lengthy, so predictions of operational and installation wind, wave and current magnitudes were required almost immediately. For these, reasonable summer data existed (from recent drilling programmes), but there was a lack of long term winter data.

#### Early Decisions

The Field operator (Britoil / BP Exploration) and Partner (Shell U.K. Limited) have been closely involved in the industry effort to obtain a better understanding of the WoS metocean environment. This background enabled work to commence immediately in several areas:

- Winter current data would be of prime importance. An immediate decision was made, therefore, to deploy a range of current meters and associated oceanographic sensors (tide gauge and thermistor

strings). The temporary loss of some of the current meters over the 1993 Christmas period emphasised the difficulty of obtaining data at such a remote, unattended, open-ocean site. This experience has, unfortunately, been repeated in the 94/95 winter. The logistical effort required to keep such instrumentation at the location often exceeds the initial cost of the equipment. Fig. 3 gives a schematic cross section of the metocean data gathering effort since the end of 1993.

- Early design values were required which included adequate and substantiated margins to reflect the state of knowledge at that time. It was also realised that a conventional approach, requiring an extended period of data gathering, was not applicable. Therefore, it was decided that a “parallel” approach would be necessary whereby data gathering, analysis of existing data, design requirements, review for certification and ongoing development would all need to be progressed with a wide variety of involved parties.
- Development of design criteria for the selection of drilling rigs, to facilitate the extensive WoS exploration and appraisal drilling programme. These criteria were also used to select drilling equipment and riser components, as well as assist the design of suitable moorings.
- Generation of operability statistics (downtime analyses) for several different FPSO and shuttle tanker configurations, as well as field economic and commercial appraisals.

The initial “dissemination” group, identified in early 1994, involved more than 25 specialist engineers from Contractors (6+), Specialist Consultants (3), Certification Agencies (3), and Governmental Agencies (2), as well as the core Metocean Group (6). By the time the first installation takes place, over 50 design engineers across the industry will be fully aware of all necessary data and how the conditions need to be interpreted for their own specialist requirements.

### KEY ISSUES FOR DESIGN BASIS

In order to initiate the process of designing a field specific installation, it has been necessary to identify the scale of problems to be addressed. These can be grouped into three initial categories:

- Specification for the analysis of existing measured data, with projection requirements for maximum

design values (taking account of joint probability or, in this case, the lack of it).

- Assessment of possibilities for modelling the conditions in a model test basin and the likely accuracy of any test results.
- Identification of key data still not achieving the standard of accuracy or confidence sufficient for detailed design

### Analysis of Existing Data in a Compressed Schedule

A team of consultants was employed over the period December 1993 to July 1994 to analyse the available data and develop design and operational metocean criteria. The scope of this work was initially agreed by the BP/Shell AFP team. It was subsequently amended and extended during that period as part of the interactive consultation process with the design contractor and the regulatory and certification agencies.

### Selection of a Maximum Storm for Operational Safety Evaluation

It was considered essential to try and model a real occurrence as closely as possible. This was based on the need to gain confidence in the ability to produce oil safely over a reasonable period of the year (more than 90%) in a more exposed location for an FPSO than present operational experience. This initial work anticipated that, at later stages in the design, a more analytical approach would be required to investigate the sensitivity of vessel designs to various parameters.

The DB3 spectral wave archive was searched for an appropriate condition, which contained both wind sea and swell components from widely differing directions. Fig 4 shows the parameters of the selected event schematically. The storm occurred on 1st October 1985, when the wind sea component (Hs 6.7m) was from the North West, with a swell component (Hs 4.2m) almost orthogonal to it from the South West. The wind at the time was 21 m/s from the North West. Although no simultaneous current data were available, a typical surface current speed associated with such a storm was deemed to be 1.2 m/s, also from the South West. Two tests were run; the first as outlined above, the second under the assumption that a weather front had recently crossed the location and the wind had veered from North West to a direction just East of North (60 degree shift). All other parameters remained unchanged.

### Independent Verification

The development of the metocean Design Basis proceeded in parallel with engineering design and equipment procurement. This resulted in minimal time

for checking and auditing. It was, therefore, necessary to understand the risks inherent in the procedure at an early stage. The main issues identified were classified as follows:

- Confidence in the initial data on which the preliminary Design Basis was issued.
- Validity and accuracy of the interpretation theories to be used in the prediction process for the new design values.
- Acceptability of the statistical processes used in the data analysis and interpretation.
- Applicability of the results to the needs of the specific FPSO design requirements.
- Assurance that the "end users" would be able to fully understand the presented results.

Parallel verification at all stages by an independent and impartial expert was started at an early stage. His primary scope was to address the overall methodology (as opposed to formal checking). This has achieved an auditable confirmation that all the identified concerns were addressed to an adequate level for a design to be used to meet a Safety Case approach for the system as a whole.

In the early stages this procedure also brought a secondary benefit to the analytical development process. The interactive nature of the Independent Expert's questioning (developed by virtue of the time constraints) helped the engineers involved to develop a clear strategy for their own work. The result has been a rational and well-documented history behind the development of the Design Basis.

## METOCEAN SUMMARY

### Introduction

BP's standard philosophy in setting metocean design criteria for UK applications is to adopt 100 year return period criteria. This return period is chosen in order to be consistent with the remainder of the design process, and the setting of risk and reliability levels for the overall design. The same return period is used in the Norwegian codes and also in API RP2A. It was agreed at an early stage that this approach would be maintained for Foinaven, despite the fact that UK regulations specify a minimum return period of only 50 years.

BP has traditionally adopted relationships between the key metocean parameters and the related design rules from North Sea data and experience. Extensive efforts were made to examine how realistic these were in the WoS context. One significant difference from general BP metocean design practice is the fact that Foinaven is

a floating production system. Many of the standard metocean analyses routinely performed are, in general, geared towards the design of fixed structures. Therefore, during the development phase of the criteria, several meetings with the contractors and Certification Agency were held to ensure that appropriate analyses were carried out and presented. Items that received particular attention included:

- wave period relationships ( $T_z$  and  $T_p$ )
- wave steepness
- wave spreading and directionality
- wave spectral formulations
- extended scatter diagrams
- assessments of the joint occurrence of winds, waves and currents

Work on wave crest elevation statistics was also performed. This is less important for the floating system, but will have a significant impact in the review of alternative concepts for later developments in the area.

A large number of statistical analyses of the various data sets were commissioned as an intrinsic part of the studies used to generate the design criteria. Both cumulative frequency and peaks-over-threshold (POT) techniques were used, as well as several distribution functions (e.g. Weibull, FT-1 or "Gumbel", FT-2, and FT-3), along with different curve-fitting methodologies. This comprehensive approach was deemed necessary in this new "basin" to ensure that as wide a view of the data as possible was established.

### Wind

The measured data sets available WoS (DB3, Fitzroy and Foula) are of relatively short duration. By contrast, the NESS database provides 25 years of modelled wind data across the area. On the basis of BP's (and Shell's) experiences of applying NESS data in the North Sea, the following studies were performed to confirm the validity of the NESS results for the West of Shetland area:

- calibration against the short measured data set at DB3
- adjustment of the seasonal bias in using winter only NESS data
- adjustment of the results to account for the lack of WoS data post March 1989

The finally selected 100 year return period hourly mean wind speed at 10 metres above sea level is 40.0 m/s. This value shows good agreement with UK Guidance (ref. 2) and the long-term measured datasets at Magnus and Shell's NNS fields. Estimates for other return

periods, for eight directions and for calendar months, were assessed using Weibull analyses.

For wind spectral information, and speeds for durations less than 1 hour, procedures given in the NPD guidelines (ref. 5) were recommended. These resulted from a comprehensive experiment on wind speed profiles over the marine environment, performed in the Haltenbank area off Norway, and were deemed to be relevant to the West of Shetland area (ref. 7).

### Waves

As with the winds, the measured data sets available WoS are of relatively short duration. In common with the NESS winds, the wave data had to be suitably calibrated and adjusted before establishing design criteria. Similar procedures as for the winds were adopted. As an indication of the extensive nature of the statistical effort, some 320 separate extreme value analyses were performed to establish the design wave height. The finally selected 100 year return period significant wave height (Hs) is 18.0 m. This value suggests that the extreme wave climate at Foinaven is approximately 5% to 10% more severe than the northern North Sea.

Estimates of Hs for other return periods, for eight directions and for calendar months were assessed using Weibull analyses. Unfortunately, concerns over the accuracy of the directional DB3 data precluded use of this measured data set, and reliance was placed on the calibrated NESS data, and 5 grid points were used.

Once the wave heights were determined, several period parameters were required, as well as an estimate of the maximum wave height in a 3 hour period (Hmax). The mean zero crossing period for any wave height (Tz) was calculated assuming a steepness relationship of 1:18. The spectral peak wave period (Tp) has been calculated, based on analyses of DB3 spectral data relating to Hs, Tp and Tz. A regression based approach has been adopted, similar to that employed by Torsethaugen et al (Ref 6) in the North Sea. The period associated with the maximum wave (Tmax) was calculated based on a relationship between Hs and Tp developed by Torsethaugen, and the likely range of Tmax values was based on relationships provided in the UK Guidance Notes (Ref 1). The maximum wave height (Hmax) was calculated from Hs and Tz under the assumption of a Rayleigh distribution of individual wave heights. This assumption is currently under review with further detailed analyses of DB3 individual wave data.

Following discussions with the Certification Agency (DnV), further calculations of Tz were performed under an assumed wave steepness of 1/15. A review of

available wave records in the northern North Sea indicated that such steepness values were commonly encountered during severe storms. A similar check with the DB3 database did not reveal such steep conditions, but the highest Hs wave height in the 4 year database was limited to around 12.3m. In addition to the main design case, several additional cases were derived with an assumed steepness of 1/15 to check various parts of the Foinaven design.

Considerable effort was expended in examining the measured wave spectra from DB3, and checking how close these "real" spectra are to the traditionally accepted wave spectral formulations such as Pierson-Moskowitz and JONSWAP. Over 8,200 spectra were analysed, and fitted by a method specifically developed for the analysis. This allowed meaningful statistical results to be extracted from the mass of data with direct application to the design work. The main conclusions can be summarised as:

- over half the spectra were bi-modal (i.e. 2 or more peaks)
- there is a tendency for increasing uni-modality with increasing wave height
- spectral peak ("gamma") values lie in the range 1 to 3, with an average around 1.9. This is between the usual range of gamma values associated with PM (1.0) and mean JONSWAP (3.3) spectra.

Several standard scatter diagrams of wave height (Hs) versus wave period (Tz or Tp) were derived from both the measured and modelled data. There was an additional requirement, for several design aspects of the floating system, to produce a 100 year Hs/Tp diagram. In summary, this diagram was generated from the measured DB3 data under the following assumptions and suitably scaled to give the correct number of sea states in 100 years:

- measured Hs distribution for Hs < 3.5 m
- modified Weibull distribution (which fits the design Hs of 18m) for Hs ≥ 3.5 m
- measured Tp distribution with extended tails for Hs < 8.5 m
- modelled Tp distribution based on FT-1 for Hs ≥ 8.5m

### Currents

Two main data sources were the CONSLEX and Strategic measurement campaigns, performed by the industry and UK Government in the early 1980's. The Strategic data set was particularly valuable. It covered a period of 1 year, with 5 moorings across the continental slope in Block 205. Additional data was provided by

instruments deployed during drilling operations from the rigs. These ADCP (Acoustic Doppler Current Profiler) instruments provide real time and recorded current data through the water column. The available data sets are, however, limited to the drilling season - approximately April to November at present.

The measured data has been combined to form composite data sets for a series of levels in the water column where data are available. These data sets have, in turn, been analysed by fitting the Weibull distribution to the cumulative frequency distributions of the total currents. As no surface current data was available, extreme surface currents were generated by extrapolating the values from the upper two meters (at 350 and 446 metres above the bed). This increases the value for the surface, and implicitly includes a probable increase to account for the wind-induced surface shear. Owing to the uncertainties in the data, the 100 year surface current speed has initially been determined as 2.0 m/s, until the 1994/95 winter data is fully analysed.

The near seabed extreme current profile was based on extrapolation of the available measurements (at 4 metres and 12 metres above the bed). 100 year criteria for 1 metre were assumed to be the same as at 4 metres, a value of 1.15 m/s. The profile below 1 metre is thought to be logarithmic for most of the time, but further work is in progress to confirm this hypothesis.

Directional and seasonal values have been generated by scaling the omnidirectional values using directional 10% exceedence speeds from the most appropriate data set.

At this stage in the analysis and understanding of the current data gathered at Foinaven, no attempt has been made to impose a theoretical current profile for the whole depth as is normally done in the North Sea. It is anticipated that, as more data becomes available and our understanding of the processes improves, it will be possible to move away from criteria fixed at the levels of the current meters and generate a smooth profile matching the data and the background physics to the processes occurring. This is an area of ongoing research.

The present design profile of current speed from the surface to the seabed typically shows a gradual decrease with depth, like an inclined "slab". It does not have the strongly sheared profile typical of many other areas. This has implications for the design and operation of risers and moorings. Strong currents are also liable to occur at the seabed, caused by mixing of different water masses. In the North Sea, near seabed currents are usually much lower, caused by frictional retardation of the flow in the single water mass. This has implications for subsea equipment design and operation.

During the work on the derivation of the current criteria, it was clear that the currents at the deep water of Foinaven are far more complex than those traditionally encountered by the oil industry in the shallower North Sea. Several oceanographic processes absent in the North Sea are active in the area. A summary of the processes believed to be present is provided in Table 1. This indicates that many processes contribute to the overall flow. Some of these are not directly coupled to storm conditions, and therefore strong currents can occur at different times. Although there does appear to be a seasonal variation, with generally stronger currents in the winter time, there are still relatively strong currents in the summer. The processes are briefly described below:

- The 'slope current' is the main current component in the area. This is a thermohaline flow moving towards the North Pole as a meandering stream, generally parallel to the slope. It is composed of relatively warm Atlantic water, a part of the North Atlantic Drift. Below this water mass, at depths around 500 metres, lies much colder water which is flowing to the South West from the Norwegian Sea (Fig. 5). Temperatures in this water mass are typically below 0°C, and can reach -1.5 °C. Often a third water mass (Icelandic Intermediate Water) sits between the two, to complicate the flow patterns.
- Eddies and meanders form on the outer boundary of the slope current where it passes the cooler waters on the Faeroes slope.
- Internal waves form on the summer thermocline and also on the deeper thermocline (water mass boundary at depth). Where the latter is close to the seabed, internal waves are liable to intensify (and possibly break) as seabed surges.
- Burst events are imperfectly understood. They are seen in ADCP records as transient increases in current speed over sections of the water column.
- Tides are semi-diurnal, and flow parallel to the slope. They are generally weaker than those in the North Sea.
- Storm surges and wind drift are little documented in the area.
- Inertia currents occur when strong winds cease or change direction abruptly; the surface currents they have generated then describe circular patterns, caused by the earth's rotation (Coriolis effect).

One development required by the project during recent months has concerned the real-time transmission of near seabed current data to a nearby drilling rig. A hard wire connection was not possible, so an acoustic transmission system was successfully developed and proved very effective (see ref. 4).

The ADCP instruments proved invaluable not only in providing data for subsequent processing, but also during drilling operations, particularly in the winter. In this area, decisions on riser operation and control are critically dependent on the current regime, and the real-time displays are used continuously to monitor the conditions.

#### Other Parameters

##### *Water Levels*

Design water level information was largely based on data from the UK Admiralty and the Proudman Oceanographic Laboratory (POL). POL's models provide both tidal and surge information for the UK area. Although more usually used for the North Sea, they were believed generally applicable for the WoS area, at least in terms of water levels. Tidal measurements are currently in progress at the location, and the data obtained will subsequently be analysed to provide site specific criteria in due course.

##### *Air Temperature*

In 1988, NWAG prepared design metocean summaries for this area which included air temperature criteria based on the analysis of ships' observations. As there was insufficient new data to alter these conclusions significantly, it was deemed appropriate to accept the NWAG values. Design maximum is 21.8° C and design minimum is -5.5° C.

##### *Sea Temperature*

Design and operational sea temperature profiles were based on relatively large data sets provided by the UK's MOD Hydrographic Office and the US NODC. As sea water temperatures are relatively conservative, there is some confidence in the values derived. Of particular importance is the fact that, in the bottom part of the water column, the sea temperature will often be below 0° C. The lowest value for design has been set at -1.5° C.

##### *Ice and Snow*

There is a lack of information on the occurrence of ice and snow on offshore structures in the UK generally. Initial criteria were, therefore, based on the relevant guidelines from the UK and Norway.

##### *Marine Growth*

Marine growth criteria were based on studies performed by Aberdeen University. Design thicknesses (on a radius) were 40mm throughout the water column, with a reduction to 20mm between 25m and 200m below the surface.

## **OUTSTANDING ISSUES**

#### Limitations of Existing Data and Approach

The lack of long-term simultaneous wind, wave and current data limits the use of joint probability statistics and hinders the study of operations planning and performance. The current data sets are also relatively short in length, despite the merging of several individual records to produce a composite set for initial design values.

The near sea bed data sets for currents are limited. At Foinaven it is thought that, due to possible presence of mixing processes between different water masses, strong currents may occur in an unpredictable manner.

There is a lack of surface current data, a problem related to the immense physical difficulty of actually measuring the current flow at the sea surface. Estimates for the surface are extrapolated from lower levels.

The statistical analyses to date have tended to follow traditional metocean practice, which is geared towards fixed structures. Several additional presentations need to be addressed to meet the requirements for an FPSO, especially the operating case with shuttle tankers.

#### Strategy for the Future

A joint BP/Shell strategy developed to address the limitations outlined above was agreed late in 1994. This is intended to increase confidence levels in predictions for other specific locations and the WoS area generally. The strategy will include several studies and measurement campaigns including:

- Routine monitoring of winds and directional wave spectra, first from a drilling rig, later from the production vessel. This will be combined with vessel mounted current monitoring equipment, which will include the capability of monitoring surface currents (using radar technology). Real time ADCP monitoring will continue as this has been shown to be a necessary operating tool. The data set derived will be invaluable in providing a long term database of simultaneous winds, waves and currents in order to check system performance against the design premise and will facilitate joint probability based studies.

- Further research using simultaneously measured and modelled wind and wave data will assist operational planning assessments.
- The NWAG group are developing a comprehensive 3-D current model for the area. This work is being performed by a consultant in the USA. The first phase of the work will be completed at the end of 1995. The current measurements taken in the area are being used to calibrate and validate the model, which will give the spatial and temporal coverage lacking in the present measured database. The model results should enable better estimates of design and operational currents to be made for the WoS area as a whole, as well as provide data to assist in joint probability studies.

A considerable volume of data is now being generated WoS, and planning of a suitable database management system is being addressed to maximise the long term value of the scarce analytical resources available.

Efforts will continue to work closely with the industry and regulatory authorities to ensure that the relevant rules and regulations are amended or updated (where necessary) to account for the unique circumstances WoS.

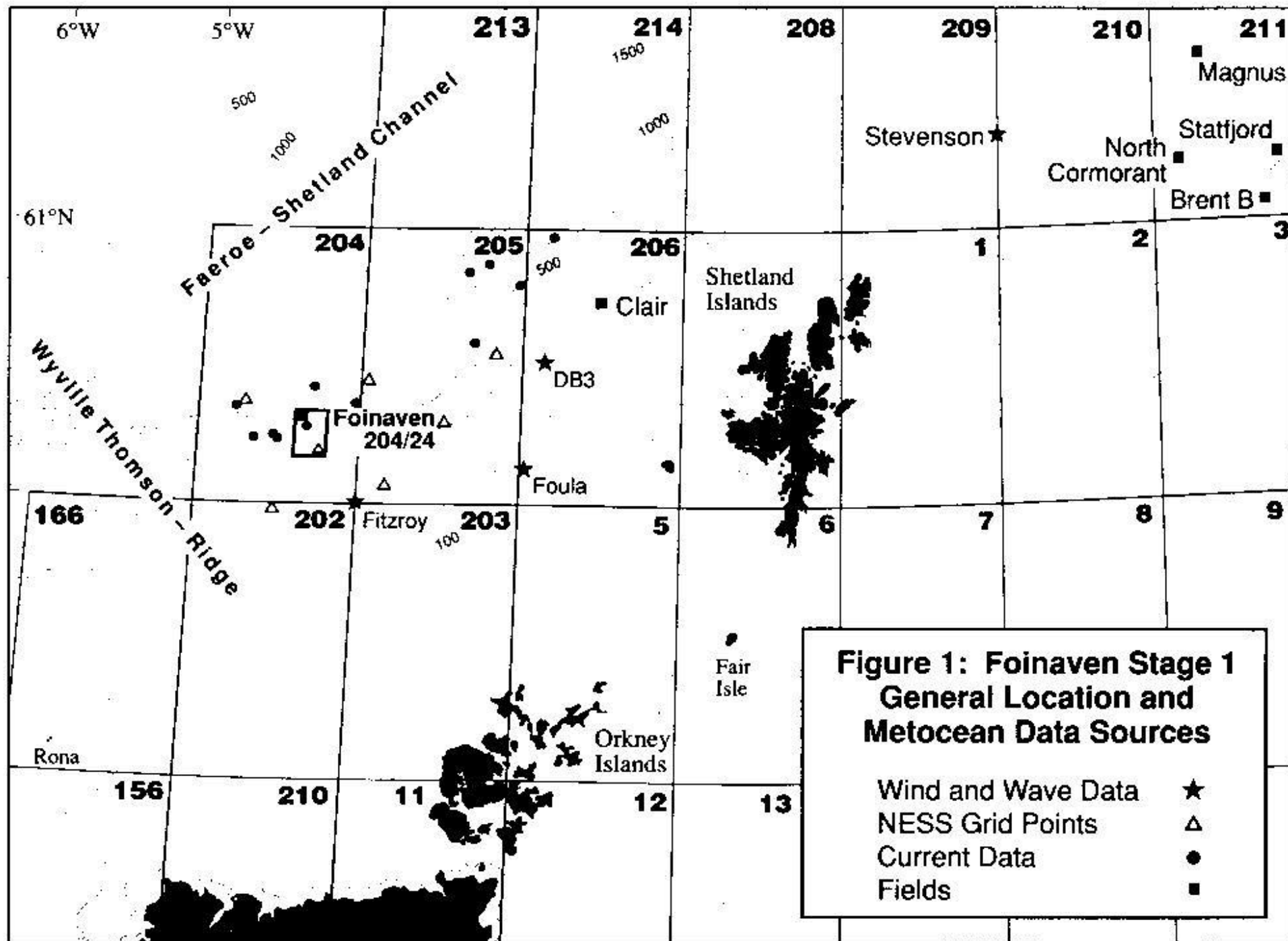
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**Figure 1: Foinaven Stage 1  
General Location and  
Metocean Data Sources**

- Wind and Wave Data ★
- NESS Grid Points △
- Current Data ●
- Fields ■

Feature	Typical Current speed m/s	Current direction towards	Cycle	Duration	Length scale km	Coverage	Translation speed *
Slope current	0.2 - 0.5	NE	none	semi-permanent	1000's	Most intense on upper slope (Foinaven lies at its centre)	n/a
Eddies / Meanders	0.3 - 0.7	NE	none	1-3 days	10's	primarily centred on lower slope but extend up to shelf	0.3 m/s
Internal waves	0.1?	NE (and SW?)	minutes	various	various	summer near surface thermocline (also around 500m in deep water)	1 - 3 m/s
Burst events	0.3 - 0.5	NE	none	10-100 min	?	Throughout NW Approaches	?
Seabed surges	Up to 0.5+	NE to E	none	a few hours	?	Within 50m of seabed between 350 - 700 m	0.5 - 3.0 m/s
Tides	up to 0.3	elliptical	12.4 hrs	permanent	n/a	Global, all depths	n/a
Storm surges	0.2 - 0.4	various	none	approx. 1 day	100's	Global, top few hundred m	5+ m/s
Wind drift	up to 1.0	with the wind	none	approx. 1 day	100's	Global, near-surface but dispersed by rough seas	n/a
Inertia currents	0.2	clockwise	13.8 hrs	1-2 days	n/a	typical of summer stratification but also possible at depth	n/a

\* Translation speed is the speed at which the current feature progresses

Table 1 Approximate Scales of Current Processes occurring at Foinaven

Figure 2 - Foinaven Phase 1 Metocean Design Criteria

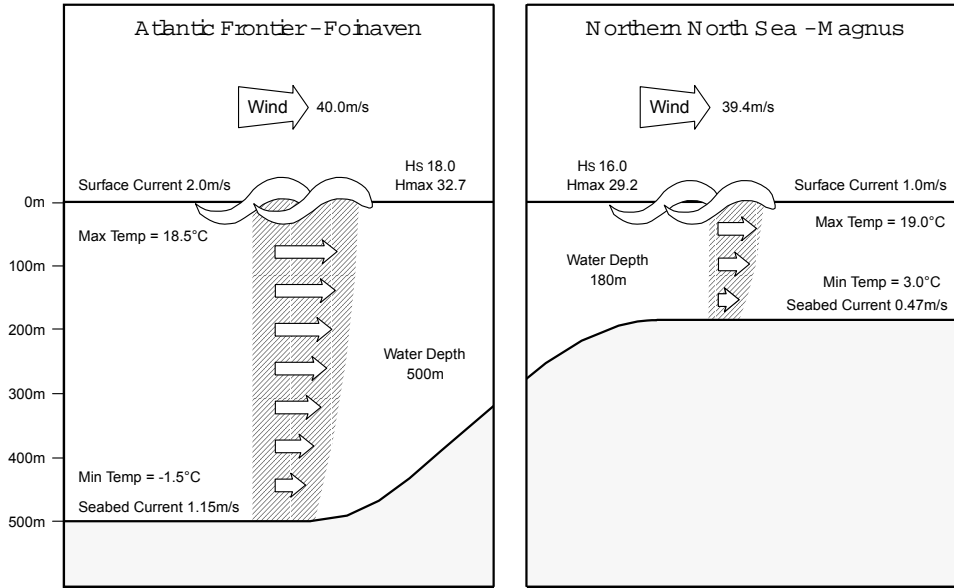


Figure 3 - Schematic Diagram of WOS Metocean Measurements 1993 - 1995

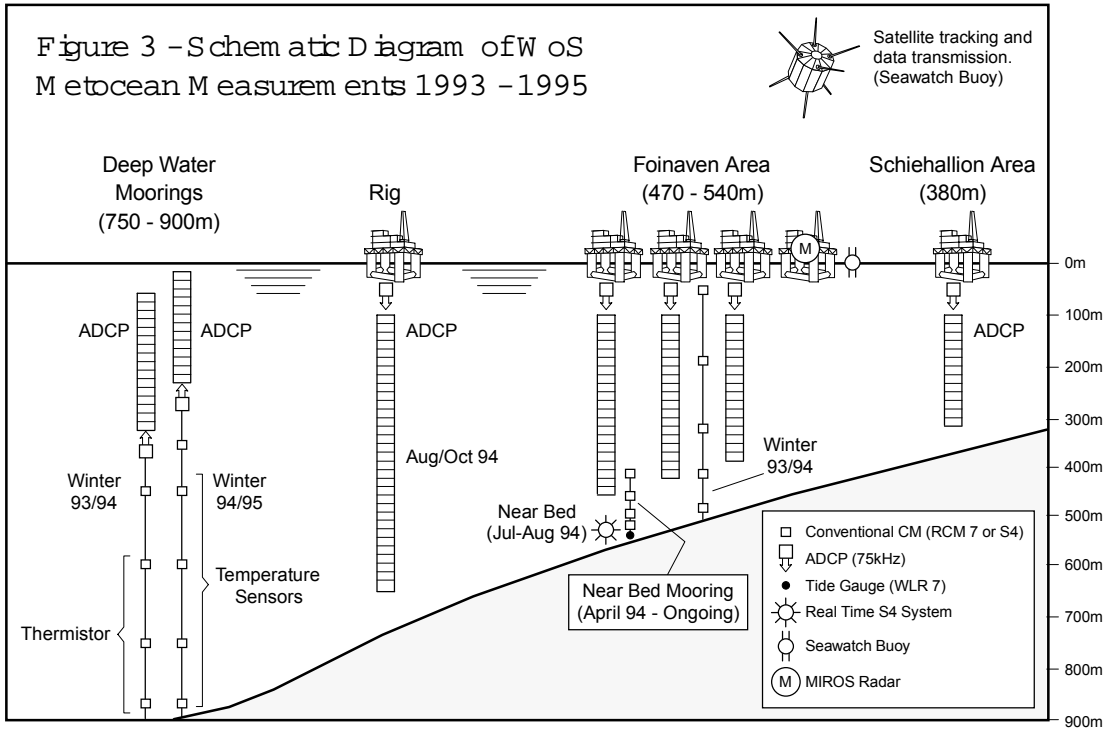


Figure 4 - Maximum Storm Criteria for Operational Safety

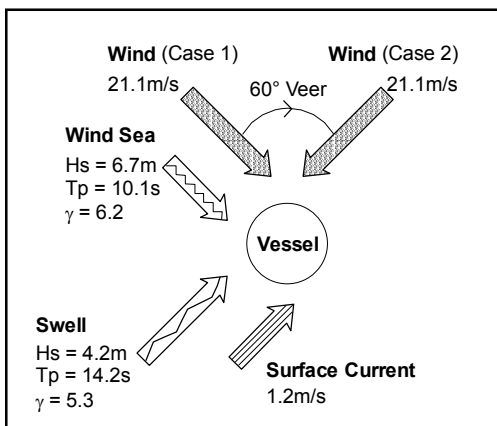


Figure 5 - Current Velocities Faeroe - Shetland Transect

