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MERLIN OFFSHORE WIND TURBINE INSTALLATION SYSTEM

Final Report

CONTRACT NUMBER: W/61/00641/00/REP

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MERLIN OFFSHORE WIND TURBINE INSTALLATION SYSTEM

W/61/00641/00/REP

URN 04/1723

Contractor: The Engineering Business Ltd

Prepared by: Tim Bland

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EXECUTIVE SUMMARY

The Merlin Wind Turbine Installation System has been designed and patented by The Engineering Business Ltd (EB). This project, phase 1 of the development, comprises a feasibility study carried out by EB, and part funded by the DTI with the key objective of:

- **Investigating the technical and economical viability of the Merlin system as an alternative technique for installing offshore wind turbines.**

This is the final report of the project, encompassing all project activities completed by EB to determine the fundamental engineering principles and the economics to support the system design.

The feasibility study concludes overall that:

i) The Merlin system is a technically viable, cost effective and therefore credible installation technique. It will operate in higher Sea States and install larger turbines than most current installation vessels, yet can be produced more easily and is cheaper to build, operate and maintain than new build conventional Turbine Installation Vessels (TIVs).

ii) This installation technology contributes to the future proofing of the offshore wind industry by enabling whole turbines to be removed from site and returned to shore for future upgrades and de-commissioning.

iii) The case for further development and offshore demonstration of the Merlin installation system is overwhelming.

Merlin Intellectual Property Rights (IPR)

EB have applied for patent protection for the elements of the Merlin system with GB and International coverage. The International application is made under the Patent Convention Treaty rules and EB are confident that protection will be available following the due process.

A review of other IPR in the wind turbine installation market has described a series of developments currently being proposed by various companies in Europe and the USA. The equipment described appears significantly more expensive than the proposed Merlin installation system and is not considered to present an additional threat to the take up of the idea over and above the existing TIVs in the market.

A summary of the most significant conclusions from the various sections of this study is given below and the comprehensive list of all conclusions is given in Section 13 of this report.

Key Technical Conclusions.

- The Merlin installation system could operate in Sea State 4 without risk to the turbines or personnel, which is a higher limit state than most conventional Turbine Installation Vessels

- The Merlin system design permits safe handling of turbines up to 3.5MW in its current form and could accommodate 5MW units with minor modifications. These limits exceed the capacity of most current Turbine Installation Vessels. The system is thus "future proof" for approximately six to ten years.

- Fully assembled turbines can safely be transported vertically up to Sea State 4.

- The results achieved in this study clearly demonstrate that by using an appropriate heave compensation /damping system, dynamic landing accelerations can be reduced to levels which are comparable to those experienced during conventional installation of components and are acceptable to turbine manufacturers.

Key Economic Conclusions

i) The Merlin system can be designed and built for approximately £6.7 million, including a 3% contingency and an acceptable profit for the developer. This is estimated to be 45-50% lower than the cost for a new build, conventional Jack up TIV and over 500% cheaper than a purpose built TIV.

ii) A production Merlin system could be constructed in 30 – 36 weeks with repeat units taking only 24 –28 weeks. The construction duration is estimated to be 50% shorter than the programme for a new build conventional Jack up TIV, and over 300% shorter than the construction of a purpose built TIV.

iii) Annual operating costs and overheads for the Merlin system are estimated to be an average 25% lower than other TIVs

iv) The Merlin installation system can be sold profitably at a day rate estimated to be 40% lower than new build conventional TIVs

v) Turbines could be installed using the Merlin system for a cost of approximately 50% lower than the accepted industry standard.[ref1] Development of this technology therefore contributes to industry progress towards the DTI targets set out in the Sustainable Energy Technology Route Map of 29 October 2002.[Ref6]

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1 INTRODUCTION

1.1 PROJECT OUTLINE

The planned growth in the offshore wind industry has been well documented recently, particularly for developments in UK and European coastal waters. It is, however, already the case that high development costs are casting doubt over the economic viability of offshore wind. To progress towards the targets set out in DTI Route map [Ref6] significant effort is required from all industry participants to reduce costs in order to sustain the planned growth in the industry.

- Generating capacity per turbine must be maximised - minimum capacity is expected to be of the order of 3.5 to 5 MW per turbine beyond 2005.

- Offshore construction costs and exposure to weather risk must be reduced through the development of cost effective installation resources and technology.

- Wind farms need to be developed in deeper water, avoiding shipping lanes, navigational areas and environmentally sensitive inshore sites but without incurring disproportionate increases in installation costs.

- Turbine and foundation designs need to incorporate considerations for cost effective through life maintenance, possible mid life upgrades and end of life de-commissioning into the initial design.

Conventional construction practice involves multiple heavy lifts (foundation, tower, nacelle and rotors) from jack up crane vessels which are expensive and susceptible to weather constraints. As turbine capacity increases there is a proportionate increase in the weight, hub height and rotor diameter all of which will stretch, then quickly exceed, the capabilities of current installation vessels active in the market.

According to the Riso National Laboratory[Ref1] offshore construction activities currently account for up to 40% of total field development costs. This figure will also likely increase in proportion to the turbine size as larger vessels and handling systems will be required for installation if conventional practices are followed.

This project comprises a feasibility study to investigate the technical and economic viability of an alternative technique for installing offshore wind turbines that addresses the points above.

The Merlin system has been developed and patented by The Engineering Business to provide the basis for a new method of installing, maintaining and de-commissioning offshore wind turbines. The concept minimises seabed disruption due to turbine installation, reduces vessel costs, weather dependency and the duration of marine operations per turbine installed, and at increased safety, so contributing to the profitability of future offshore wind farm developments.

1.2 AIMS AND OBJECTIVES

The overall aims of this study were:

To investigate the likely development of offshore wind turbines over the coming decade and determine the handling requirements for installation.

To establish a conceptual engineering solution including basic engineering calculations to determine the outline feasibility of the Merlin system, its application and operation.

To assess the implications of transporting and installing fully assembled wind turbines at sea, using mathematical modelling to extend the concept from statics to include a basic appreciation of the dynamics of operation.

To determine the operational requirements of the Merlin System as an alternative installation process that reduces the number of offshore operations and exposure to weather risk.

To initiate and maintain a dialogue with turbine manufacturers and marine contractors to engage their support for the concept and the project as a whole.

To determine the approximate costs to design and build a Merlin system.

To develop an economic model for the Merlin system for its use in turbine installation, including comparison with other techniques.

1.3 SCOPE OF THIS REPORT

This report encompasses all aspects of this feasibility study, describing the process of investigation and, more importantly the results obtained and everything that has been learnt during this study.

Section 1 gives the introduction, aims and objectives and the sets out the scope of this report.

Sections 2 & 3 of this report describe the requirements of the offshore wind industry together with a description of the limitations of current installation techniques.

Sections 4 to 11 describe the technical investigations completed and the engineering principles applied to demonstrate the validity of the Merlin installation system.

Section 12 examines the economic benefits that the Merlin installation system could bring to the offshore wind industry and Section 13 summaries all conclusions derived from this study.

2 TURBINE INSTALLATION VESSEL (TIV) REQUIREMENTS

The Table below indicates the number of turbines that could be constructed in European waters to meet the planned expansion over the coming decade. It should be noted that a definitive statement of planned growth does not exist therefore the information contained in Table 1 has been derived from a number of commonly used industry sources.

Country	Total Capacity (MW)	Equivalent no of 2MW Turbines	Equivalent no of 3.5MW turbines	Equivalent no of 5 MW Turbines
Belgium	208	104	59	42
Denmark	856	428	245	171
France	157	79	45	31
Germany	26706	13353	7630	5341
Ireland	700	350	200	140
Netherlands	338	169	97	68
Spain	400	200	114	80
Sweden	452	226	129	90
UK	8842	4421	2526	1768
Totals	**38659**	**19330**	**11045**	**7732**

Table 1 - European Offshore Turbine Installation Requirements to 2015

Although the growth is not planned to be linear, this averages at 3.87GW per annum for 10 years which equates to 1933 x 2 MW, 1105 x 3.5 MW or 773 x 5 MW turbines per year for the duration.

This would require anywhere between 5 Turbine Installation Vessels (TIVs) capable of installing 5 MW turbines to 12 TIVs for installing the 2 MW units, each operating at full capacity for ten years. In reality the installed capacity is very unlikely to exceed 70% of the planned capacity hence the minimum vessel requirement would be proportionately lower.

Again, in reality, the construction programmes will not be linear but in fact a significant proportion of the planned developments are intended to commence construction within the next two to four years. This means that many of the developments could occur simultaneously generating a peak demand for even more installation vessels to be made available over a short duration.

Table 2 illustrates the perceived turbine design criteria to 2010 which indicates that 3.0 MW output will be the minimum generating capacity of turbines installed offshore during that period.

Developments	Power Rating (MW)	Tower Weight (Te)	Nacelle Weight (Te)	Rotor Weight (Te)	Hub Height (m)	Blade Diameter (m)
2002 – 2005	3 MW	120 – 250 Te	75 – 150 Te	60 – 75 Te	70m	100m
2005 – 2010	5 MW	250 – 400 Te	130 – 300Te	75 – 100Te	85m	130m

Table 2 - Offshore Turbine Design Criteria

Table 3 summarises the number and types of vessels currently available in the European theatre capable of installing offshore turbines, however this also shows that the 3 MW turbine is considered to be beyond the installation capacity of the majority of existing TIVs.

Type of Vessel	Approximate number available	Turbine Installation Capacity	Comments
Self propelled or towed Jack up crane barge	4 -5	Some up to 2MW others Up to 2.5 MW	Vessels are already in heavy demand for use on marine based, civil construction projects, i.e. coastal defences, waste outfalls etc. Crane capacity and leg length are limiting factors
Converted Turbine installation vessel (TIV)	2	Up to 2.5 MW	Jack up leg length and crane lift capacity are limiting factors with little scope for increasing the capacity within current configuration.
Purpose built TIV	1	Up to 5 MW	Very expensive to construct with planned construction period of 18 months. Note the only specialist vessel built to date took 24 –26 months to complete and deliver

Table 3 - Current Vessel Availability

Several of the vessels identified in Table 3, particularly the jack up barges, are predominantly utilised for the installation of turbine foundations which further reduces their availability for installation of turbines. It can therefore be surmised that there would be a serious shortfall in the number of available installation vessels capable of meeting industry demand if planned developments proceed to the construction phase as scheduled.

The Merlin installation system, as a low cost vessel that can install the larger turbines and can be produced far quicker than current alternatives, is therefore a credible and viable option to meet the demand for the number of TIVs.

2.1 Industry Requirement Conclusions

i) Turbines of greater generating capacity i.e. up to 5MW are needed to sustain the economic growth of the offshore wind industry.
ii) Turbines of 3MW or greater are beyond the installation capacity for most of the current TIVs
iii) Many new TIVs of greater capacity will need to be constructed to meet the planned installation targets in Europe alone over the next 5 to 10 years.

3 CONVENTIONAL INSTALLATION PRINCIPLES

Currently all offshore wind farms are constructed in a similar manner, using similar vessels and marine resources. The process starts with shipment of the major components to a marshalling area at the operational port close to the project installation site. A small degree of pre-assembly work is carried out there prior to load out, e.g. the installation of the hub and two of the three blades to form what is commonly referred to as the “bunny ears” configuration. This is usually the practical limit of pre-assembly that can be achieved without exceeding the maximum lifting capability of the installation vessel crane.

Jack up crane barges are commonly used as the TIV because of the stable working platform they provide for offshore crane operations. The TIV will load out the components for one or more complete turbines dependent upon its carrying capacity and working deck space, which can vary significantly from vessel to vessel depending upon its configuration. Some Jack up barges cannot actually carry any components in which case an additional feeder vessel is required. Components for two full turbine units at a time is the most common TIV load, however, there is one purpose built TIV that can carry the components for up to ten turbines.

Once on site, the turbines are erected piece by piece, typically taking between 10 -15 hours for completion of the main erection activities. This is then followed by a period of post erection mechanical and electrical completion prior to the start of the commissioning period.

Figure 1 illustrates all of the key facets of conventional installation. The vessel in the foreground is a feeder Jack up transporting a “bunny ear” nacelle and tower sections for a single turbine to the installation crane barge, shown in the background at the pre-installed foundation.

Figure 1 - Jack Up Installation Barge and Feeder Barge Constructing North Hoyle Windfarm

Photo by permission of Mayflower Energy Ltd

3.1 Limitations of Operation

In addition to the problems of availability described in Section 2, current TIVs are all subject to the following operational limitations to some degree.

3.1.1 Crane Limitations.

One of the primary operational limitations of current TIVs is the maximum hook height and lift capacity of their main cranes. The component height and weight parameters of the 2.0 MW turbines recently installed at the North Hoyle and Scroby Sands sites were reported to be at the upper limit of crane operations for the respective TIVs used in each case.

To install the planned next generation of 3 to 5MW turbines, installation vessels will require the capacity to lift a load of anywhere between 75 to 300Te up to a hook height of 100m or more [ref2]. Currently there is only one specialist turbine installation vessel with this capability.

Several operators are known to be considering building a new generation of offshore cranes to handle larger turbines safely but there is a practical and cost effective upper limit to which existing vessels can be modified to accommodate these larger cranes. Beyond this point larger vessels are the realistic, but far more expensive, option to cater for increased crane sizes.

3.1.2 Water Depth

The length of the jack up support legs on each vessel sets a physical limitation on the maximum operating water depth. All but two current vessels have a typical operating range of between 10m to 18m water depth with the average being 15m. Several of the planned UK Crown Estate Round Two sites are at depths >20m, therefore vessels will either require large scale modification to increase their leg length and operating depth or an alternative installation method will be required for these sites that is independent of water depth.

3.1.3 Seabed Disturbance

The support legs of the jack up vessels have to penetrate the seabed to varying degrees in order to provide the vessel with the necessary uplift. Penetration can exceed 5m and this gives rise to several concerns:

- The long term disruption to the seabed is not environmentally acceptable in some sensitive locations.
- Seabed disturbances can make cable laying and burial difficult.
- There is significant risk of the legs causing damage to pre-installed infield or export cables.
- Subsequent visits to the same site by jack up vessels may experience difficulty in leg placement as a result of the penetrations made during previous visits.
- Problems have been experienced withdrawing legs in some sea bed and weather conditions.

3.1.4 Weather Limitations

- With the exception of the only purpose built TIV, the jacking up and down operation for each vessel is subject to a maximum significant wave height of approximately 1.3 -1.8m Hs.
- Jacking up and down operations are also subject to tidal current limitations, typically of the order or 3-4 knots on the beam,
- Crane operations are always limited to a maximum wind speed of between 10 – 15m/s with a realistic practical limitation for alignment of components of approximately 12m/s.

3.2 Current Installation Technique Conclusions

i) Most current TIVs can only install turbines up to 2.5MW due to crane capacity limitations.
ii) The maximum operating water depth of most current TIV is between 15-18m.
iii) Sea bed disruption and leg placement can be an operational issue for Jack up TIVs.
iv) Weather risk during jacking and crane operations is high.

4 THE MERLIN INSTALLATION SYSTEM CONCEPT

4.1 Principle of Operation

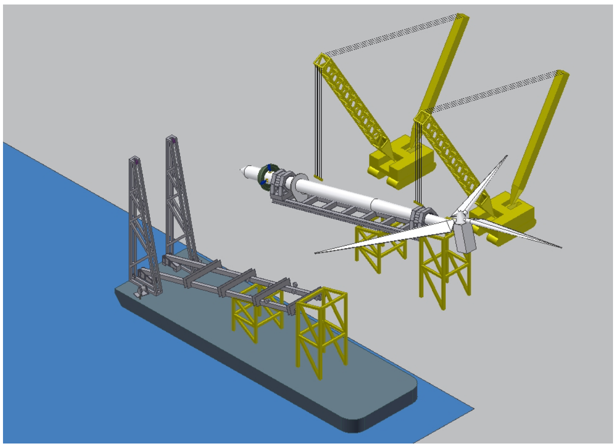
The Merlin installation concept represents a significant and innovative departure from common installation practices, with fundamental changes to:

- The sequence of assembly activities
- The type of vessels used for offshore installation
- The methodology of connection to the turbine foundation
- The capacity for future maintenance and decommissioning regimes

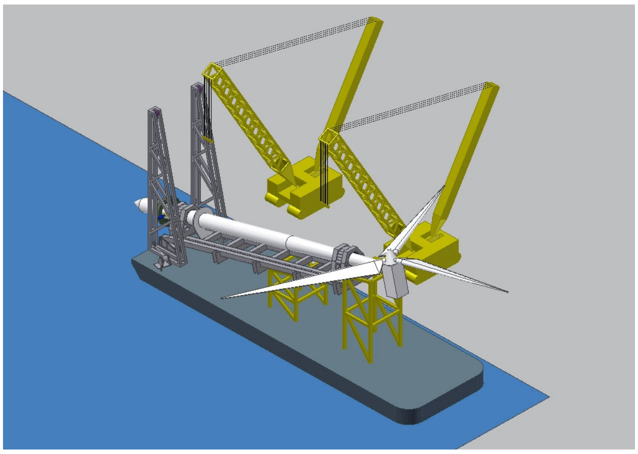
The overall concept is to fully assemble the turbines at the shore base into a purpose built cradle, either at the horizontal or 15° attitude. This permits easy and safe access to complete the electrical and mechanical assembly activities to the turbine. The complete turbine is then lifted out to a bespoke installation barge for transportation to the offshore site where it is rotated to the vertical and connected to the pre-installed foundation in a single operation.

The installation process can be just as easily reversed ie an entire turbine can be disconnected from the foundation interface and returned to the shore by the Merlin system, enabling major refurbishment, upgrades and ultimately decommissioning at the end of service. The cost benefits of carrying out these activities onshore, with minimum offshore duration, are very similar to those gained through Merlin installation in the first instance, as detailed within Section 12 of this report.

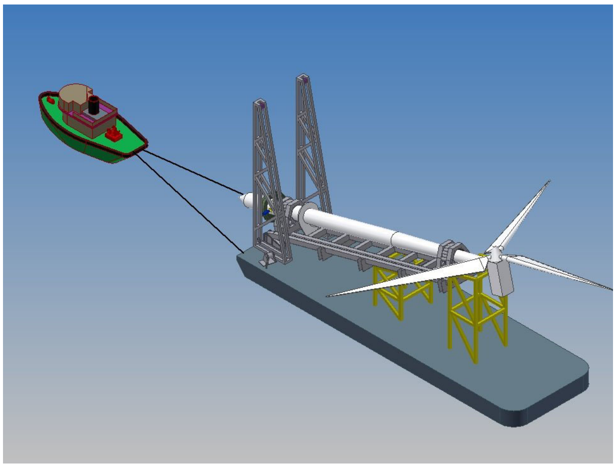
The series of drawings below and overleaf illustrate the principle of the Merlin operating concept. Note the barge, turbine and foundation attachment are represented in a simplistic format for the purpose of demonstrating the concept clearly.



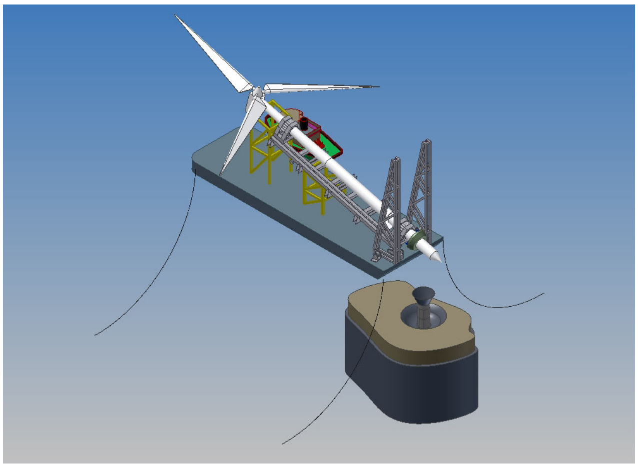
Stage1.
Fully assembled turbine in the support cradle at the shore base ready for lifting to barge.



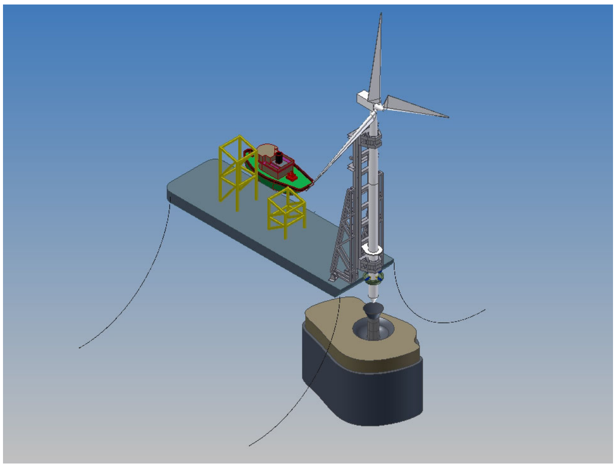
Stage 2.
Fully assembled turbine and support cradle loaded to the installation barge and locked into the A-Frame.



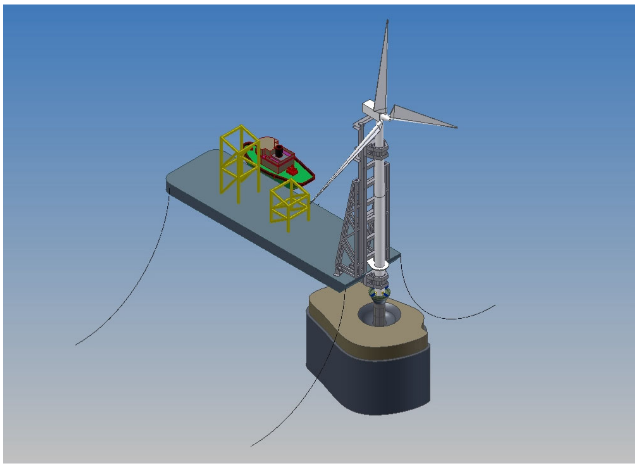
Stage 3.
Installation barge being towed to site



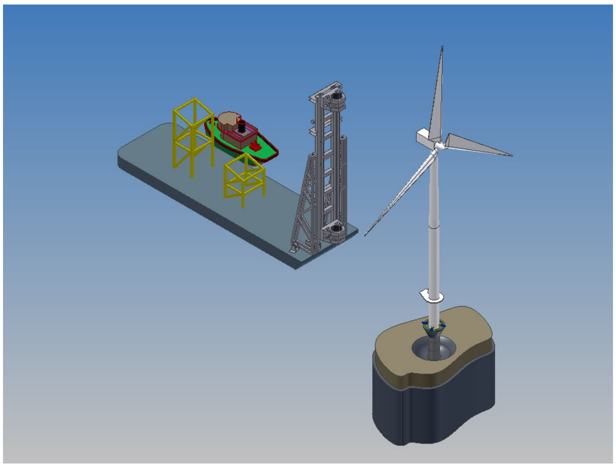
Stage 4.
Installation barge anchored on site at the foundation



Stage 5.
Turbine rotated to the vertical and aligned above the foundation



Stage 6.
Turbine lowered and aligned within the foundation, clamping / grouting taking place



Stage 7
Turbine fully installed and installation barge returning to port

Figure 2 – Installation Sequence

EB have adopted a two tiered approach to the development of Merlin with the intention of creating an installation system that offers a credible alternative to existing technology and thus generating a competitive market advantage through:

- The use of a simple, reliable technology vessels and equipment resulting in lower development costs and a reduced operating cost base.
- Reductions in the frequency and duration of offshore operations thus reducing direct offshore costs (crew costs and vessel time) and also minimising exposure to weather risk.

According to industry reports of the traditional installation method, offshore electrical / mechanical completion activities requires 75-80 man-hours, over a 3-4 day period and occurs after the main installation vessel has moved away from the turbine following erection of the major components. Specialist technical personnel and equipment have to be transferred to and from the turbines by small work boats that are highly susceptible to weather and sea limitations.

The actual limitations recorded at both the North Hoyle and Scroby Sands projects for safe transfer of personnel by this means were of the order of between 0.75 – 1.0m wave / swell height. This is well below industry expectations hence exposure to weather was high with significant periods of downtime accrued.

In the case of the Merlin system, the assembly of the complete turbine at the shore base still requires the same technical effort, however this can be carried out at onshore labour rates which are commonly a factor of 1.5 - 2 times lower than equivalent offshore rates. These operations also take less time to complete onshore, are safer, less susceptible to weather and can be removed from the critical path to a large extent.

A further offshore construction stage of the traditional method is the installation of external access platforms, boat landing arrangement and sea cable J-tubes. Typically this operation would take 4 - 6 hours of vessel time and would be carried out either as a stand alone operation or as part of the foundation installation programme. In both cases this must be carried out prior to the start of the main turbine installation activities.

Merlin potentially offers a commercial advantage in that J-tubes and platforms can be attached to the lower tower section of the turbine at the shore assembly facility, dependant upon the chosen method of connection to the foundations. This could generate possible savings in the region of £6000 - £8000 per turbine, contributing to the overall economic viability of the offshore wind farm. Discussions are continuing between EB and turbine manufacturer's to further develop this aspect of the Merlin concept and to investigate the advantages it offers.

The flowchart at Figure 3 compares the Merlin installation sequence with the traditional installation practice, which clearly illustrates the potential for significant reductions in the number of offshore operations hence exposure to weather risk.

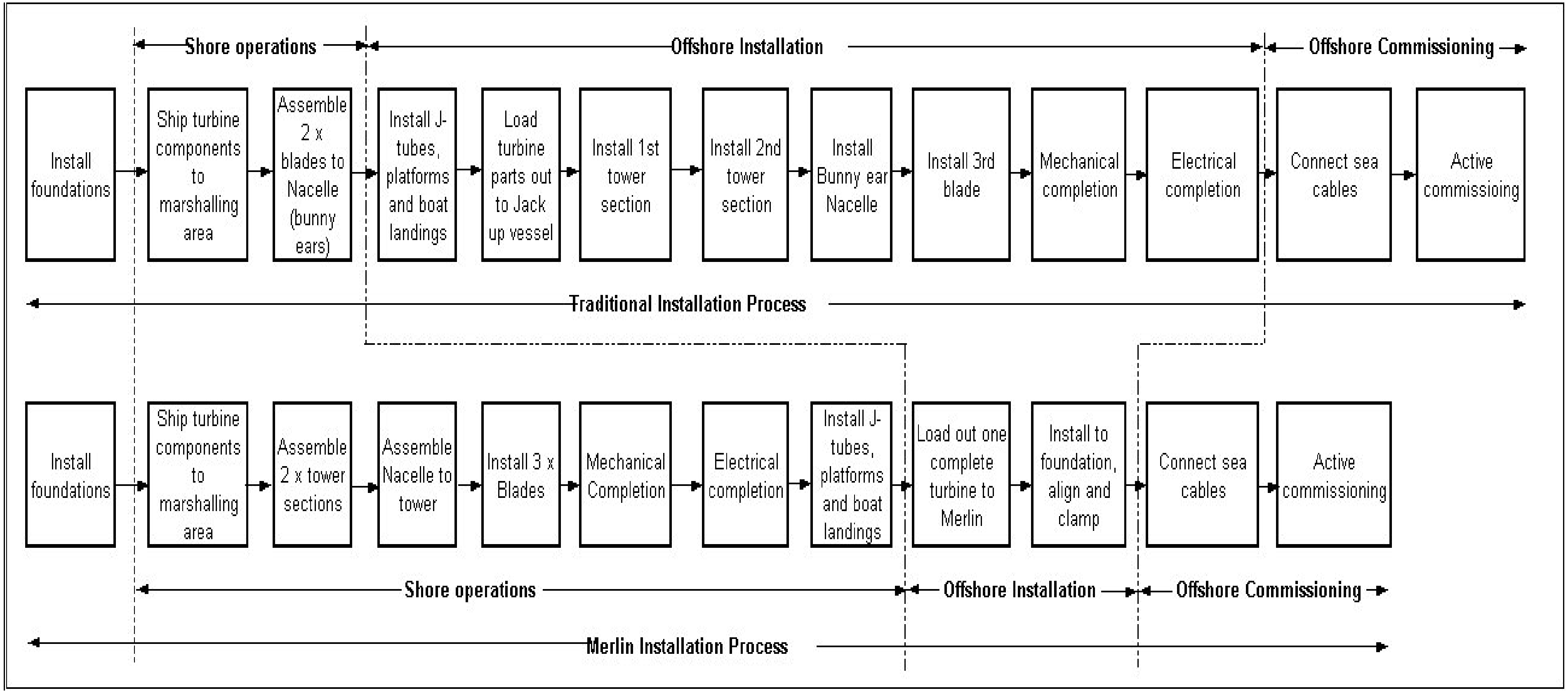


Figure 3 - Comparison of Offshore Installation Sequences

Note: This is an illustration of the required operations only and does not reflect the schedule of events. In reality some of these activities e.g. installation of foundations, J-tubes and platforms will be carried out in parallel to other activities.

4.2 Areas Common to all Installation Techniques

Despite the differences between the Merlin installation process and traditional installation techniques there are several areas where operations are common, requiring very similar resources for both the onshore and offshore phases of construction.

4.2.1 Offshore Foundations

Although the installation of the offshore turbine foundations may be part of an Engineering Procurement and Construction (EPC) contract it is common for this element to be sub-contracted and carried out as an independent scope of work. The main installation contract for all techniques usually commences on the basis that the turbine foundations have been pre-installed by others and are ready to receive the turbines. This is also the case for the Merlin concept although EB acknowledges that the foundations may require adaptation to create the appropriate interface for the turbine connection. EB have considered several alternative interface connections which are the subject of ongoing discussions with turbine manufacturers and the various options are investigated in greater detail later in Section 10 of this report.

4.2.2 Shore Based Marshalling and Assembly Area

The requirements for site acreage, ground preparations and support resources to facilitate storage and pre-assembly of the turbine components differs very little between the various installation techniques. Within the context of a typical EPC contract the responsibility for these facilities generally falls to the turbine manufacturers account, who would lease the land, organise and manage the shore base then co-ordinate all activities with the installation contractor.

EB have considered two concepts for loading the complete turbines to the installation barge:

i) Lift of the complete turbine to the barge using a tandem lift by two heavy lift crawler cranes.
ii) A self loading system utilising a barge mounted shear leg arrangement.

In the case of the first option the Merlin concept would require the support of specialist cranes due to the requirement to lift the fully assembled turbines. These cranes exceed the capacity of the cranes currently used by other load out operations.

4.2.3 Offshore Commissioning

The post installation commissioning requirements are common in all cases to all methods of turbine installation and are entirely to the turbine manufacturer's account.

4.2.4 Specialist Technical Services

The turbine manufacturer also normally provides all technical specialists and engineering support for the turbine assembly works, which are common to all projects. The Merlin system however, offers potential savings in the costs incurred to deploy and utilise these resources through reduced offshore working requirements and less risk from weather downtime.

4.3 Merlin Conceptual Conclusions

i) Merlin presents fundamental changes from the conventional method of assembling and installing offshore wind turbines.
ii) The Merlin system uses low cost, readily available vessels.
iii) The Merlin system reduces the risk of weather and operational downtime.
iv) The Merlin system offers significant potential savings through reduced offshore costs and durations.

5 DEVELOPMENT CHALLENGES

The Merlin concept, as with any innovative process introduced to improve or replace a mature technology, has encountered many challenges throughout the development phase, which fall into three distinct areas.

i) Conceptual
ii) Technical
iii) Economic

5.1 Conceptual Acceptance

Often one of the most underestimated barriers to innovation is that of basic industry acceptance of a new concept and it's operating principles. It would be natural to anticipate opposition from operators of competing technology however acceptance by the industry as a whole has been fundamental to the development of the Merlin installation concept from inception, as detailed in Section 5.4.

5.2 Technical Issues

One of the most fundamental changes Merlin adopts over traditional practice is the principle of installing from a floating barge as opposed to the stable working platform of a Jack up barge. Key technical challenges that the design of Merlin has addressed to overcome issues arising from floating installation are:

i) Limitation of the effects of wave induced dynamic forces upon turbine components.
ii) Development of a foundation interface connection / alignment system that can tolerate potentially higher movement and landing forces than previously encountered.
iii) Safe handling, rotating, lifting and lowering of a 600Te (plus) turbine without risk of damage to the components.

5.3 Economic Challenges

To be of any interest to the industry, the Merlin concept has to offer genuine reductions in offshore installation costs that can be passed up to the windfarm developers to reduce the overall costs per MW installed. The Merlin concept design premise therefore addresses specific economic targets aimed at:

i) Reducing design and construction capital expenditure.
ii) Shorter production duration and repeatability of design.
iii) Reducing operating costs.
iv) Reducing exposure to offshore weather and operational risk.

5.4 Consultation with Industry Participants

Consultation with leading developers, manufacturer's and other key participants has been an integral part of the development process throughout this study to help identify and overcome the various challenges facing the Merlin development.

5.4.1 Turbine Manufacturer's

Ongoing discussions with a leading manufacturer (Vestas) regarding the overall concept of installing turbines in the proposed manner and specifically:

- Free and reciprocal exchange of technical and operational information.
- Guidance and advice on the special handling requirements for turbine components.
- The construction and design of turbine components, with particular reference to the nacelle, yaw bearings and tower sections.
- Installation requirements, assembly sequencing, shore base and offshore construction activities.
- Modification required to the turbine components to permit assembly at attitudes other than vertical.

5.4.2 Windfarm developers

- Guidance on key operational aspects and common problems encountered during traditional installation projects to date.
- Advice on specific installation cost areas that developers are keen to see contractors reducing.
- Discussions regarding avoidance / reduction of weather and technical related risks.
- Through life maintenance requirements, mid life upgrades and de-commissioning considerations.

5.4.3 Marine and Offshore Contractors

- Discussion concerning availability, suitability and likely costs of appropriate vessels.

- Consultation relating to the dynamic effects of transferring large loads from a moving vessel to a structure fixed to the seabed.

- Vessel handling and operation, positional control and station keeping, towing and anchor handling operations.

5.5 Development Conclusions

i) Industry acceptance of this installation technique presents a significant challenge to the development of the Merlin system.
ii) To date support for the development of the Merlin system has been positive and encouraging.

6 MERLIN INSTALLATION SYSTEM SPECIFICATIONS

The minimum outline design specification for the Merlin installation system is detailed below:

6.1 Environmental conditions

6.1.1 Transit

- Normal conditions Sea State 3 to Sea State 5,any sea heading
- Exceptional conditions Sea State 6/7
- Maximum normal operating wind speed 12.5 - 15m/s depending on wind direction

6.1.2 Uprighting and Installation of Turbine

- Normal conditions Sea State 3, any sea heading
- Maximum installation conditions Sea State 4, head or stern sea
- Maximum wind speed 12.5 - 15m/s depending on wind direction

6.2 Turbine Handling Capacity

Turbine type	Typically Vestas V90 – 3MW
Rotor diameter	90 m
Hub height	80 m
Mass of fully assembled turbine & tower	510 t

Table 4 Principle Turbine Details used for Calculations

Note the barge and turbine handling equipment have the capacity to install turbines up to 5 MW with some modification to the clamps and repositioning of the deck support frames.

6.3 Barge

The initial design was based on any standard offshore barge of approximately 100m x 30m x 7m. For the purpose of engineering calculations and mathematical modelling a specific offshore barge, the AMT EXPLORER, was selected.

This vessel meets with the criteria used for the first stage investigations and the full specifications for the barge were provided by the owners.

The outline specification of the AMT EXPLORER is:

Barge Type	Swim-Ended Offshore Transportation Barge
Length overall (approx)	91.44m
Breadth moulded	30.48m
Depth (main deck)	7.62m
Gross tonnage	5689Te
Deadweight to L.W.L.	13980Te
Displacement to L.W.L.	16242Te

Table 5 Principal Barge details used for calculations

6.4 Allowable loads and stresses

There is currently no specific guidance for maximum allowable loads or stresses that are to be used for calculations for this type of installation of wind turbines. Initial calculations for the design of the Merlin system have hence been based upon guidance given in Lloyd's Register of Shipping "Code for Lifting Appliances in a Marine Environment" 1987 [ref3].

The following criteria have been used throughout this study:

Turbine tower material	S355J2G3 Carbon steel with a Yield stress of 355Mpa
Dynamic acceleration applied	1.3g
Normal maximum allowable stress	67% of yield stress
Exceptional allowable stress	85% of yield stress

Table 6 Allowable stresses and loading factors

Notes:

i) DnV "Rules for Certification of Lifting Appliances", 1994 specifies similar figures to those given in the Lloyds code.

ii) DnV Draft Offshore Standard DNV-OS-J101, Design of Offshore Wind Turbine Structures contains a section to address this point specifically however, the actual values / limit states have not been entered by DNV at the time of writing this report.

6.5 Specification Conclusions

i) Sea State limitations for the Merlin system exceed those of most conventional TIVs.
ii) The Merlin system design permits safe handling of turbines up to 3.5MW in its current form and could accommodate 5MW units with minor modifications.

7 OFFSHORE OPERATIONS

The whole purpose of this study was to confirm the viability of the Merlin installation system as a credible installation technique. A major obstacle to this is industry acceptance that turbines can be safely installed form a moving barge.

The most important technical elements of the entire investigation process were therefore:

- **To derive the limiting operational sea states relative to subjective motion criteria both under transit and stationary conditions i.e. on site at the turbine location.**

- **To demonstrate that fully assembled turbines could be transported safely at sea in a vertical orientation.**

- **To show that dynamic forces experienced when landing a turbine onto a foundation fixed to the seabed from a moving vessel could be maintained within limits that are acceptable to turbine manufacturers.**

The results of this particular investigation would determine the maximum environmental conditions in which the Merlin system could safely install turbines. Ultimately this would determine the marketability of the system and identify any commercial advantage over other installation techniques.

The fundamental design premise for operations from a floating vessel was to evaluate the implications of wave induced motions upon the various installation activities and to investigate the resultant accelerations experienced by the turbine components.

The evaluation comprised

- Analysis of the barge stability and motions

- Mathematical modelling to determine the dynamics of the concept.(Section 8)

- Finite element analysis (FEA) of the tower structure under dynamic conditions (Section 9)

7.1 Barge Motion Analysis

In order to investigate the accelerations experienced by the turbine it was necessary to analyse the behaviour of the barge for a range of Sea States and headings. The first part of the barge motion analysis took the form of a transfer function or Remote Amplitude Operator (RAO) assessment. RAO's indicate the vessel's responses to regular waves of unit wave amplitude at various frequencies and at the specified heading relative to the wave direction.

EB commissioned Melbourne Marine Ltd, consultant Naval Architects, to carry out the RAO study for the barge (AMT Explorer) using version 3.0 of the *ShiopMoPC Seakeeping* analysis system.

The study considered five loading conditions considered representative of the sequence of events involved in the deployment of a wind turbine from the barge. RAO's were derived for vessel motions in the six degrees freedom, namely: pitch, roll, heave, surge, sway and yaw, each in Sea State 3 and in sea heading from 0° (stern sea) to 180° (head sea) in 30° intervals.

The relevant data was extracted from the report of RAO results and input to the mathematical model of the system.

7.1.1 Barge Stability and Operational Assessment

EB also commissioned Melbourne Marine to carry a full stability and operability assessment of the installation barge with the Merlin system and a turbine onboard, the scope of work for this being:

- To derive an indication of the expected sea-keeping performance of the barge.
- To analyse the intact stability conditions for the barge.
- To derive an indication of irregular responses for given sea states.
- To determine the motions and accelerations experienced at the turbine hub and deck level for specified sea states.
- To investigate the implications of transiting the barge with a turbine at a vertical attitude.

7.1.2 Seakeeping Study Conditions

The sea-keeping assessment was also carried out using version 3.0 of the *ShipmoPC* seakeeping analysis system to determine the irregular responses of the barge for the following conditions: (Note stationary denotes barge on site at the turbine but not anchored).

Condition	Speed (knots)	Turbine Position	Sea state
1. Stationary	0	15° from horizontal	3-6
2. Transit	5	15° from horizontal	3-6
3. Stationary	0	vertical	3-6
4. Transit	5	vertical	3-6

Table 7 - Sea-keeping conditions

7.1.3 Irregular Responses

Irregular responses are presented in terms of motion at the vessel's centre of gravity, along with accelerations at two locations on the vessel. These values are presented in *ShipMo* in terms of Root Mean Squared Values (RMS). These values can be expressed in terms of significant and maximum expected values by means of the following relationships:

Significant response ≅ 2.0 x RMS and Maximum response ≅ 2.0 x Significant response

Where: Significant response is the average of the 1/3 highest observed values

7.1.4 Subjective Motion Criteria

The Subjective motion criteria below are considered representative of the motions that can be withstood by shipboard personnel for prolonged periods at 70% effectiveness.

Parameter	Limiting Significant Value
Single amplitude roll	10 degrees
Vertical acceleration	0.25g (2.52m/s^2)
Lateral acceleration	0.12g (1.18m/s^2)

Table 8 - Subjective motion criteria [ref4]

7.1.5 Stability Assessment Results

The full stability report is presented at Appendix A of this report. The following tables are extracts from the report to compare the peak accelerations at the turbine hub for each of the four conditions given at Section 7.1.2. Note the conditions are tabled in the order 2,4,1,3 to compare the transit conditions against each other and the vertical conditions against each other.

Condition 2: Barge transiting at 5 knots with turbine at 15°

	Sea State 3		Sea State 4		
Direction of Acceleration	Sea Heading	Acceleration Value (m/s²)	Sea Heading	Acceleration Value (m/s²)	Increase SS3 to SS4 (factor)
Vertical	Head sea	0.118	Head / Bow Quartering sea	0.177	1.5
Lateral	Beam sea	0.432	Beam sea	0.726	1.7
Longitudinal	Head / Bow Quartering sea	0.059	Head / Bow Quartering sea	0.098	1.7

Condition 4: Barge transiting at 5 knots with turbine at 90°

	Sea State 3		Sea State 4		
Direction of Acceleration	Sea Heading	Acceleration Value (m/s²)	Sea Heading	Acceleration Value (m/s²)	Increase SS3 to SS4 (factor)
Vertical	Head sea	0.137	Head / Bow Quartering	0.235	1.7
Lateral	Beam sea	1.099	Beam sea	1.884	1.7
Longitudinal	Head sea	0.235	Head / Bow Quartering	0.392	1.7

Transit conditions conclusions:

i) Transiting in Sea State 4 increases accelerations in all directions by an average factor of 1.7.
ii) Transiting with the turbine at 90° increases accelerations by approximate factors of 1.24 vertical, 2.54 lateral and 4 longitudinal respectively. These factors are common to both Sea State 3 and 4.
iii) The accelerations with the turbine vertical are still very low and considered acceptable.

Condition 1: Barge stationary at the foundation with turbine at 15°

	Sea State 3		Sea State 4		
Direction of Acceleration	Sea Heading	Acceleration Value (m/s^2)	Sea Heading	Acceleration Value (m/s^2)	Increase SS3 to SS4 (factor)
Vertical	Beam sea	0.059	Beam sea	0.118	2
Lateral	Beam sea	0.392	Beam sea	0.647	1.65
Longitudinal	All headings	0.039	All headings	0.059	1.51

Condition 3: Barge stationary at the foundation with turbine at 90°

	Sea State 3		Sea State 4		
Direction of Acceleration	Sea Heading	Acceleration Value (m/s^2)	Sea Heading	Acceleration Value (m/s^2)	Increase SS3 to SS4 (factor)
Vertical	All headings	0.078	Beam sea	0.157	2
Lateral	Beam sea	0.903	Beam sea	1.668	1.85
Longitudinal	All headings	0.098	Beam sea	0.216	2.2

Stationary Condition Conclusions

i) Predominant worse case accelerations occur with a beam sea.
ii) Increasing from Sea State 3 to 4 increases accelerations by a factor of approximately 1.72 with the turbine at 15° and a factor of 2 with the turbine at 90°.
iii) The accelerations with the turbine vertical are still very low and considered acceptable.

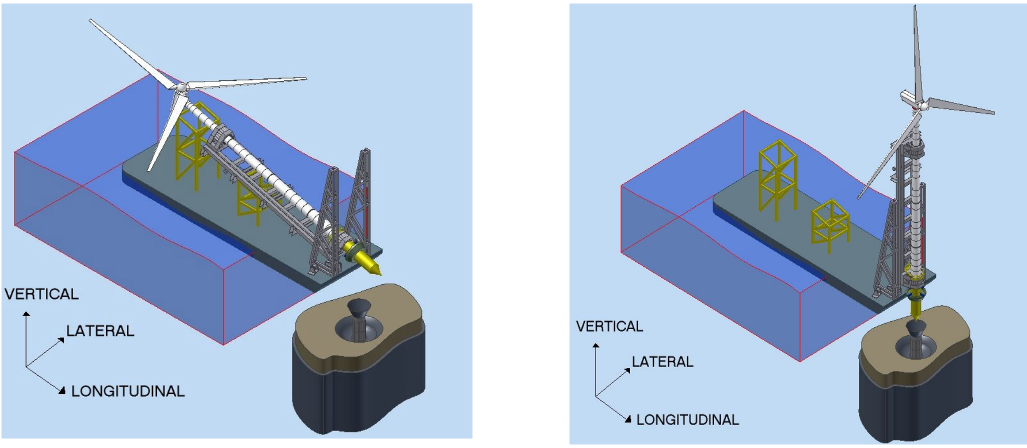


Figure 4 - Geometry of Accelerations

7.2 Barge Motion Conclusions

The table below shows the maximum peak acceleration experienced at the hub

Direction of Acceleration	Sea State	Heading	Net Acceleration (m/s^2)	Net Acceleration Value g
Vertical	6	Beam Sea	1.51	0.15

This investigation has satisfied the first two of the three primary objects set out at the beginning of this section (the third objective is discussed in Section 8.3) and concludes:

i) Sea State 6 is considered to be an exceptional condition however these results show that the maximum accelerations experienced should not cause any damage the turbine.
ii) That turbine installation and transit operations could be completed safely up to Sea State 4, without risk to the turbines or personnel.
iii) That turbines can safely be transported vertically up to Sea State 4.
iv) The type of barge investigated has very significant reserves of stability with the Merlin installation system and a fully assembled turbine onboard in an operational condition.
v) The vertical, lateral and horizontal acceleration at both the hub and the deck of the barge are acceptable to the limit of effectiveness of personnel and equipment operation on board.

The results of the motion analysis study have been sent to the turbine manufacturer for their assessment. To date comments and feedback received have been positive and encouraging, particularly with reference to accelerations in the turbine components and towards the concept of transiting with the turbine vertical at all times.

8 INVESTIGATION OF DYNAMIC FORCES

EB completed an investigation of the dynamic effects and forces involved in the various stages of the installation process to determine the loads experienced by the turbine during transportation and installation. This required the generation of a mathematical model to simulate vessel and turbine motions and an assessment of dynamic forces using first principles.

The study focused on the critical areas of the operation with the specific objectives to:

- Determine turbine loading and support requirements during transport to site.
- Determine loading and stresses in the turbine tower during rotating to vertical.
- Investigate the motions of the turbine relative to the vessel during lowering and hence determine requirements for motion compensation systems.
- Investigate turbine loads and decelerations during engagement with the foundation interface.

8.1 Modelling Process

The modelling study has been carried out in a phased approach as the design progressed.

Phase 1 was carried out in house using the *Matlab Simulink* software using a simplified model of this system to develop an understanding of the dynamics of the concept.

For Phase 2, EB commissioned dynamic modelling specialists Orcina Ltd to build a more complex and complete model using their *Orcaflex* software.

Phase 3 was again completed in house using *Matlab Simulink* with a more advanced model and carried out in conjunction with a finite element analysis (FEA) study, (Section 9).

8.1.1 Phase 1 Studies

The initial model was purposely maintained in a simplified format with the intention of developing first pass modelling of outline criteria. In this format the model did not consider:

- The effects of any bending in the turbine tower structure.
- Any sea direction other than head seas.

- Any sea state other than Sea State 3.
- The effects of roll, sway or yaw.

The initial model did, however, consider the effects of system rigidity upon the resultant moments and the model was created with the capacity for expansion to encapsulate the subsequent development of the Merlin system components. The top-level block diagram of the initial model is shown below.

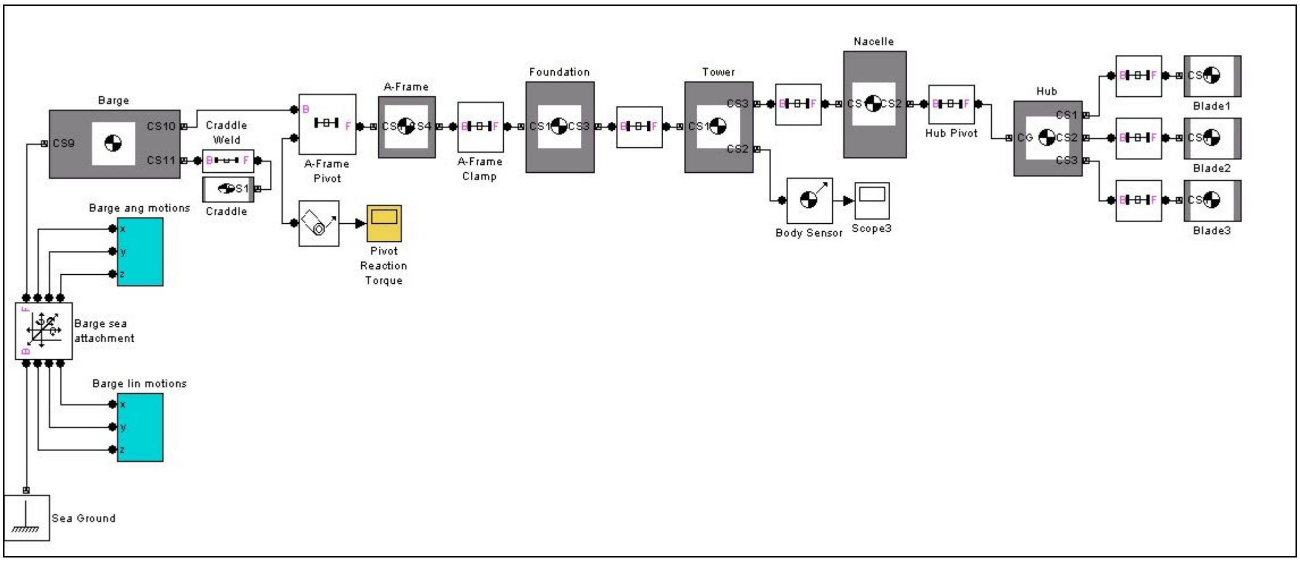


Figure 5 - Block Diagram of Initial *Matlab Simulink* Model

The conclusions drawn from the first Simulink study were:

- The pitch, heave and surge motions of the barge arising from a head sea should not be significant at Sea State 3.
- Pitch motions generate the greatest variation in moments about the A-frame for the given head sea state.
- The stiffness and natural period of the system needs to be borne in mind during the development of the structural components to avoid resonant effects.
- A dynamic factor of 1.3 was an appropriate design factor.

8.1.2 <u>Phase 2 Study</u>

The Orcina *Orcaflex* model was created in the time domain, using dimensions, masses and spatial locations of components within the system as set by EB.

The key design objectives of the Orcina model were to:

- Verify the EB results from Phase 1 studies.

- Investigate the effects of the probable maximum three hour period wave.

- Qualify the dynamic loading factor of 1.3 derived during the early stages of conceptual design.

- Investigate the loads imposed on the turbine tower support clamp(s) during the elevation process.

- Investigate internal loads within the tower structure.

- Review the sensitivity of the system to resonant behaviour.

Note the Orcina model was developed using default Remote Amplitude Operators (RAO's) and this limited the preliminary investigation to a head sea condition only.

Figure 6 shows the moment on the barge of the Merlin A-frame against time, holding the turbine at 15^0 elevation in a head sea at Sea State 3 for a 200 second period containing the 3-hour probable extreme wave.

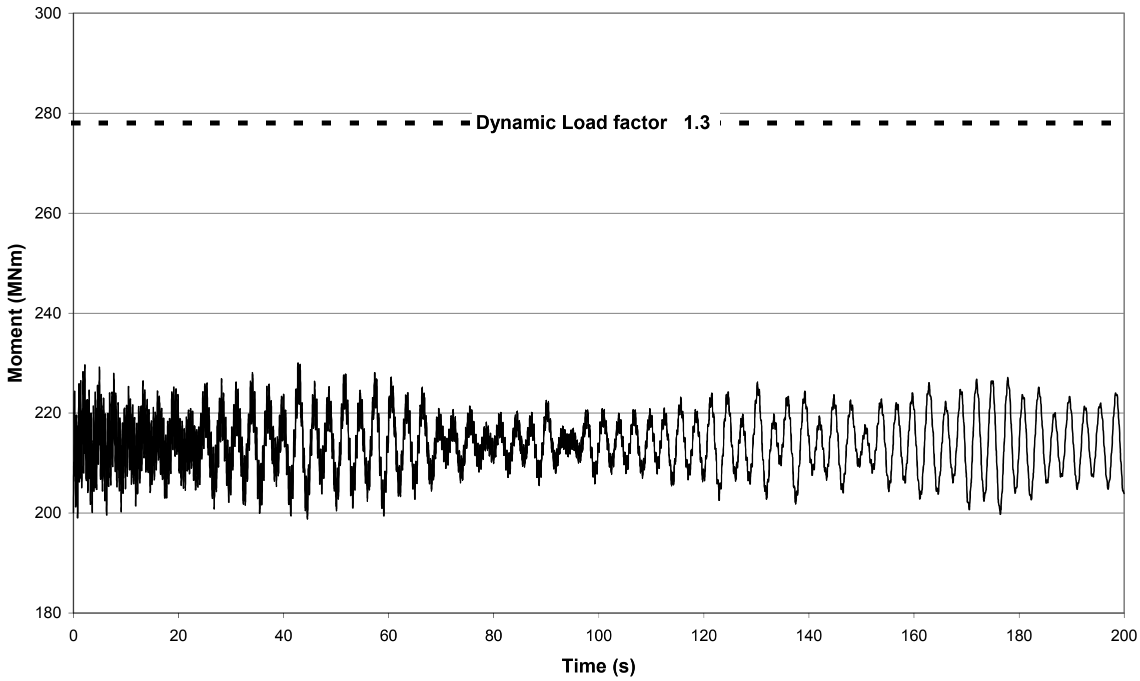


Figure 6 - Moment of A-frame and Turbine on Barge Structure

8.1.3 Phase 3 Study

The final phase of the study concentrated on the critical areas of lowering the turbine into the foundation and actually landing the turbine onto the foundation connection. The RAO's developed by Melbourne Marine were input to this second stage *Simulink* model to ensure realistic vessel motions were being considered.

The following assumptions were applied to the assessment of turbine motions during installation:

- Only vertical motion is considered.
- Seabed socket interaction is simplified.

8.2 Heave compensation

A specific modelling activity was to investigate the requirements to minimise movement of the turbine in order to prevent excessive accelerations/ loads on the sensitive components whilst it is lowered into the seabed socket. Initial results indicated that a motion compensation system would be required to dampen turbine movement in conditions of Sea State 2 and above.

In the *Simulink* model this was represented by a simple spring damper system as illustrated in Figure 12.

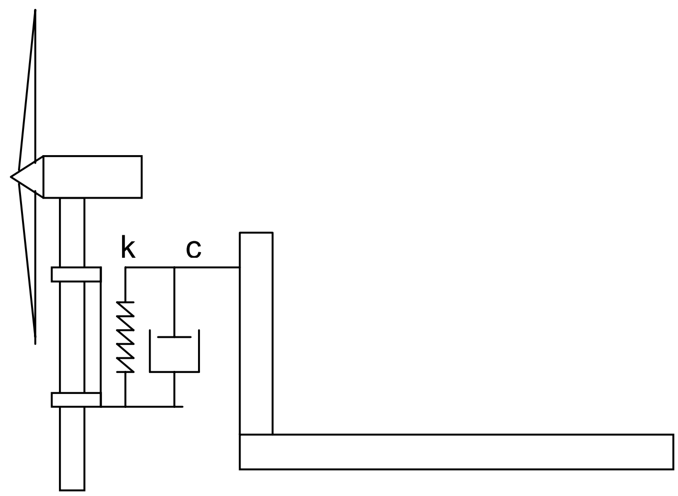


Figure 7 - Representation of motion compensation system

For this study four initial combination cases of motion compensation system characteristics were compared against a system without a motion compensation system. Each system assumed critical damping occurred.

		Barge	System 1	System 2	System 3	System 4
Stiffness Coefficient, K	N/m	No heave compensation	5533000	1000000	510000	250000
Damping Coefficient, C	Ns/m		10608000	4488000	3162000	2244000
Amplitude Ratio		1	1.065	0.69	0.47	0.34
Vertical Displacement						
max	m	0.120	0.113	0.101	0.092	0.082
min	m	-0.124	-0.117	-0.106	-0.099	-0.089
Velocity						
max	m/s	0.146	0.136	0.121	0.111	0.100
min	m/s	-0.162	-0.155	-0.141	-0.131	-0.117
Acceleration						
max	m/s^2	0.200	0.188	0.171	0.161	0.151
min	m/s^2	-0.201	-0.193	-0.178	-0.168	-0.155

Table 9 - Heave compensation Criteria for sea state 3

The graphs in Figures 8 to12 show the effectiveness of the various motion compensation configurations modelled by comparing the movement of the turbine against the movement of the barge.

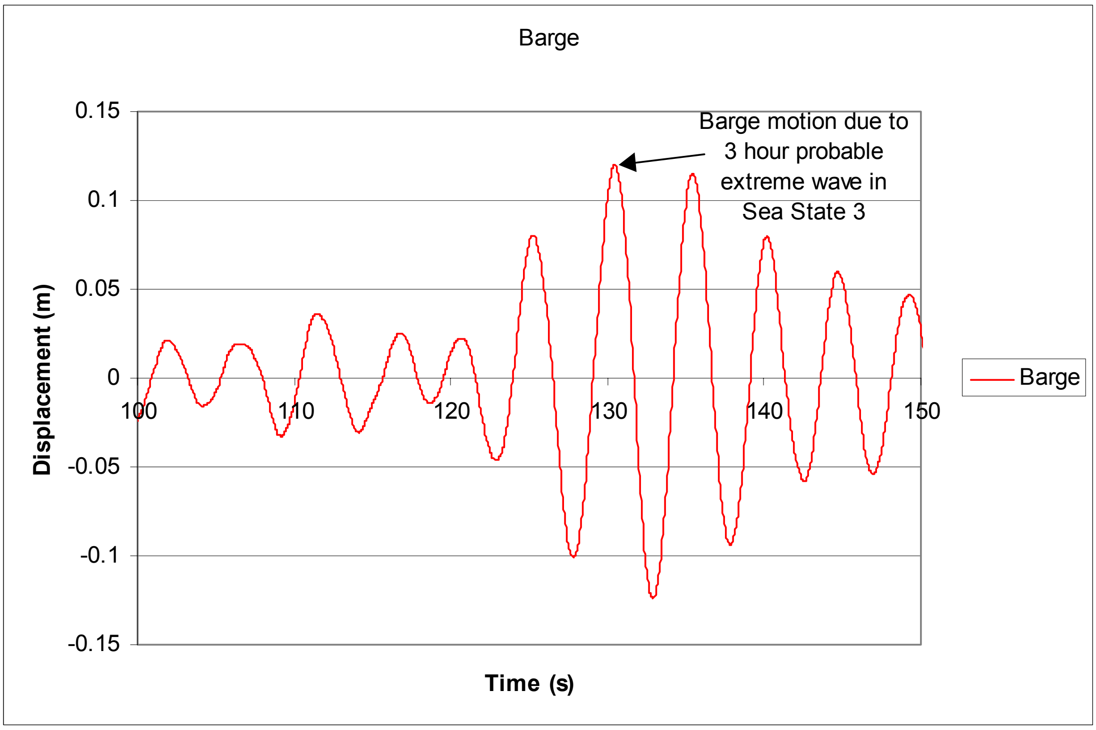


Figure 8 - Motion of barge (only) in a head sea at sea state 3

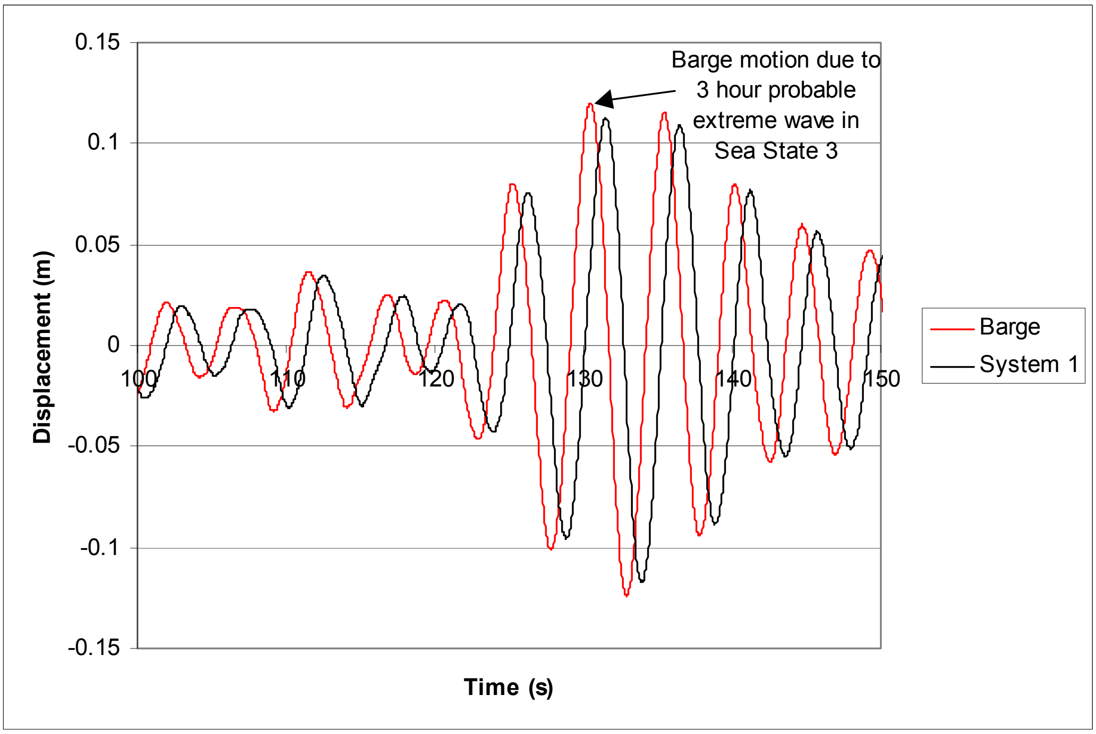


Figure 9 - Effects of a motion compensation system with an amplitude ratio of 1.06 on turbine motions

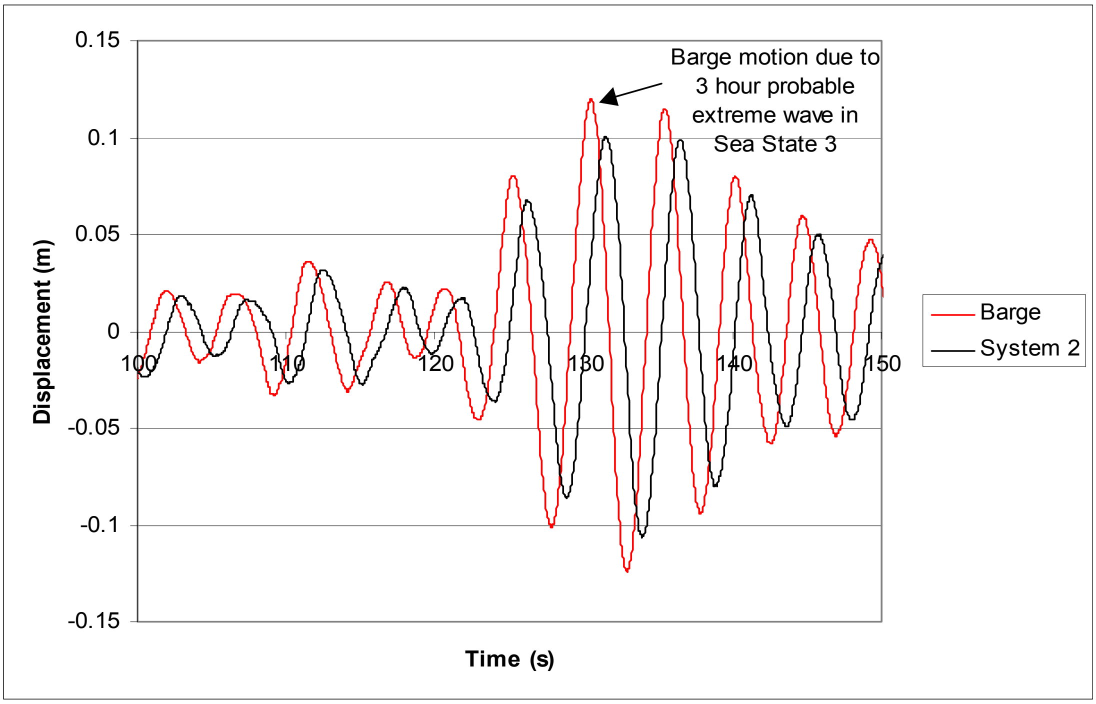


Figure 10. - Effects of a motion compensation system with an amplitude ratio of 0.69 on turbine motions

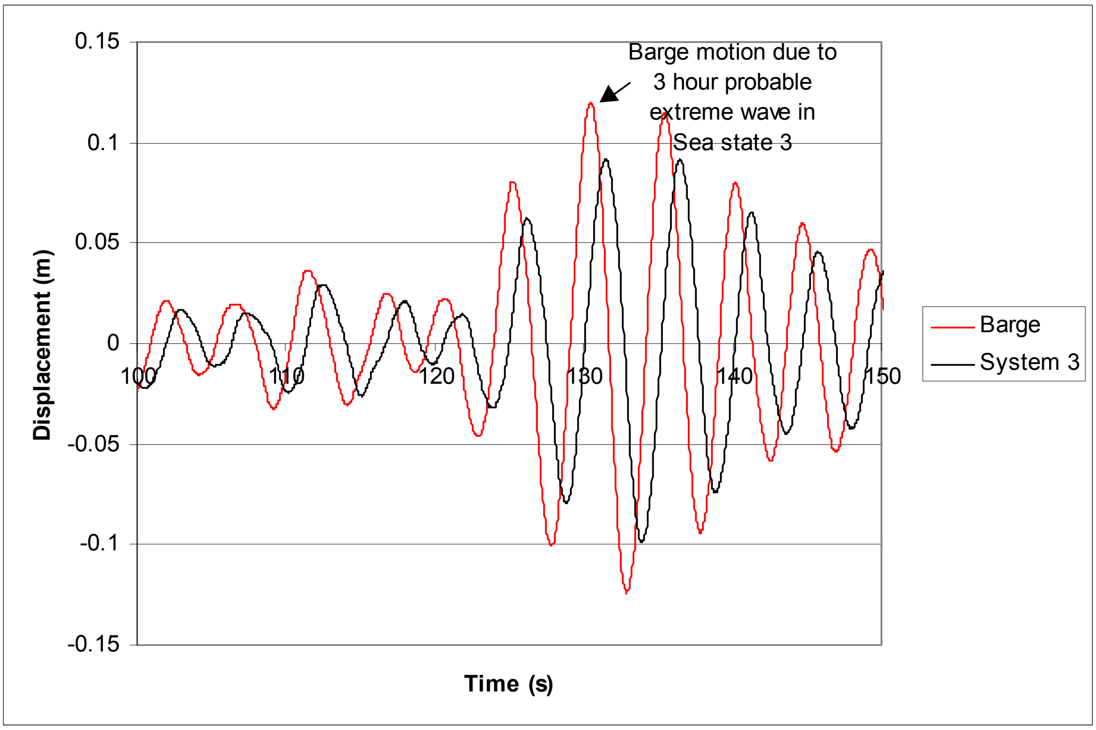


Figure 11 - Effects of a motion compensation system with an amplitude ratio of 0.47 on turbine motions

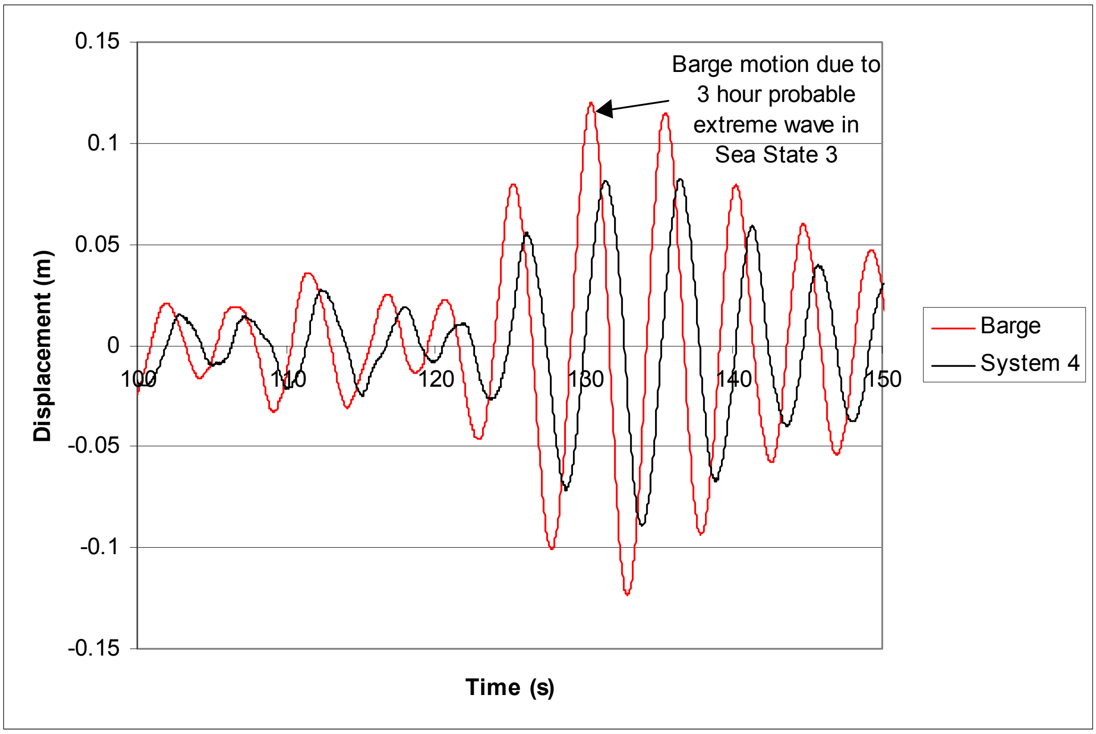


Figure 12 - Effects of a motion compensation system with an amplitude ratio of 0.34 on turbine motions

It can be seen from Figures 8 - 12 above that by the appropriate selection of component characteristics (spring rate and damping characteristics) within the motion compensation system the motions of the turbine relative to the barge during lowering can be reduced.

8.3 <u>Landing the Turbine</u>

This section is aimed at investigating and resolving the third of the major objectives set out in Section 7, ie

- **To show that dynamic forces experienced when landing a turbine onto a foundation fixed to the seabed from a moving vessel could be maintained within limits that are acceptable to turbine manufacturers.**

Whether installing a turbine from the crane of a Jack up barge or from the Merlin installation barge, landing the turbine on to the fixed foundation will always subject turbine components to a rapid deceleration. From a static platform the magnitude of the deceleration is a function of the rate of lowering of the crane which is largely reliant upon the skill of the operator.

The Merlin system however is subject to additional vessel motion and therefore has to be able to minimise landing decelerations to ensure landing forces remain within limits acceptable to the turbine manufacturers.

8.3.1 Conventional Installation

Actual dynamic loads experienced by the turbine components when being installed by a crane from a typical Jack up barge are not commonly documented. In order to determine a likely value for comparison, an approximation was made using the first equation of motion $v = u + at$

Where:

- v - final velocity
- u - initial velocity
- t - time
- a - acceleration

Values obtained from this equation were then used to determine the likely accelerations experienced by the turbine components on contact with the foundation.

As an indicative starting point, it is assumed that on contact with the seabed socket the wind turbine comes to an immediate stop in 0.1seconds. In conventional assembly, components are installed one by one and therefore the mass of each lift is significantly lower than the lifted mass that the Merlin system installs. The most sensitive component of the turbine assembly is the nacelle, complete with rotor, hence accelerations must be limited to the values that this component can tolerate.

	Units	Crane Lowering Parameters		
Maximum Velocity	m/s	0.05	0.03	0.017
Assumed time to stop	s	0.10	0.10	0.10
Acceleration required	m/s^2	-0.5	-0.3	-0.17
Proportion of g		0.05g	0.03g	0.02g

Table 10 - Expected Deceleration forces by conventional installation.

Table 10 indicates the landing accelerations for a nacelle and rotor of mass 125,892 Kg (ref : Section 9 - FEA) using lowering velocities equivalent to 3m / minute, 2m/ minute and 1m / minute.

8.3.2 Non-Compensated system

Table 11 shows the significant vertical accelerations for condition 3 (Merlin installation barge on station with the turbine vertical), derived from the vessel stability assessment of Section 7.

Heading	Sea State 3	Sea State 4	Sea State 5	Sea State 6
	Sig Vertical Accel (m/s^2)	Sig Vertical Accel (m/s^2)	Sig Vertical Accel (m/s^2)	Sig Vertical Accel (m/s^2)
Following Seas	0.078	0.137	0.510	1.177
Beam Seas	0.078	0.157	0.667	1.511
Bow Quartering Seas	0.078	0.137	0.569	1.334
Head Seas	0.078	0.137	0.530	1.236

Table 11 - Significant Vertical Accelerations for Condition 3, i.e. Merlin Barge on Station at the Foundation with Turbine Vertical.

Table 12 shows the significant turbine heave for condition 3 – Merlin installation barge on station with the turbine vertical, derived from the vessel stability assessment of Section 7.

Heading	Sea State 3	Sea State 4	Sea State 5	Sea State 6
	Sig Heave (m)	Sig Heave (m)	Sig Heave (m)	Sig Heave (m)
Following Seas	0.016	0.036	0.202	0.404
Beam Seas	0.040	0.090	0.482	0.964
Bow Quartering Seas	0.024	0.054	0.296	0.592
Head Seas	0.016	0.036	0.198	0.396

Table 12 - Significant Heave for Condition 3, ie Merlin Barge on Station at the Foundation with Turbine Vertical

Using the peak accelerations from Table 11, maximum displacements from Table 12 and a turbine mass of 510Te, the potential landing accelerations that could be experienced by the turbine are shown for various sea headings at Sea State 3 and 4 in Table 13.

Sea State 3				
Sea Direction	Maximum Velocity (m/s)	Assumed time to stop (s)	Required Acceleration (m/s2)	Proportion of g
Following Seas	0.067	0.1	-0.67	0.07
Beam Seas	0.096	0.1	-0.96	0.10
Bow Quartering Seas	0.078	0.1	-0.78	0.08
Head Seas	0.067	0.1	-0.67	0.07
Sea State4				
Sea Direction	Maximum Velocity (m/s)	Assumed time to stop (s)	Required Acceleration (m/s2)	Proportion of g
Following Seas	0.116	0.1	-1.16	0.12
Beam Seas	0.185	0.1	-1.85	0.19
Bow Quartering Seas	0.138	0.1	-1.38	0.14
Head Seas	0.116	0.1	-1.16	0.12

Table 13 – Potential Turbine Landing Accelerations without Heave Compensation

The worst case acceleration occurs with a beam sea for both Sea States. The maximum acceleration experienced of 0.19g at Sea State 4 represents a 190% increase over the maximum acceleration experienced at Sea State 3.

From an operational perspective, a head or stern sea would usually be the chosen heading for installation hence the maximum landing acceleration would be of the order of 0.12g at Sea State 4 or 0.07g at Sea State 3 for a non-compensated system.

8.3.3 <u>Compensated Systems</u>

The multi-fall winch system on the barge A-Frame will provide a degree of inherent motion compensation, or damping effect, and the winch control system will permit finite control of the lowering rate. It is not physically possible to completely isolate all vessel induced motions, however, use of appropriate heave compensation techniques as described in Section 8.2, will further reduce the vertical displacement of the turbine.

The four heave compensation systems considered in Section 8.2 - Table 9, show potential reductions of the likely turbine accelerations by factors of:

System 1 - 4%   System 2 – 13%   System 3 – 16%   System 4 – 25%

Table 14 shows the effect of heave compensated systems using these factors upon the potential landing accelerations experienced by the turbines for a normal operating case of a head sea and a worst case beam sea.

Head Sea	**Sea State 3**					**Sea State 4**				
Normal conditions	Heave Compensation System Reduction					Heave Compensation System Reduction				
	Zero	4%	13%	16%	25%	Zero	4%	13%	16%	25%
Acceleration (m/s^2)	-0.67	-0.64	-0.58	-0.56	-0.50	-1.16	-1.11	-1.01	-0.97	-0.87
Proportion of g	0.07g	0.065g	0.061g	0.059g	0.053g	0.12g	0.12g	0.104g	0.101g	0.09g
Beam Sea	**Sea State 3**					**Sea State 4**				
(worst case)	Heave Compensation System Reduction					Heave Compensation System Reduction				
	Zero	4%	13%	16%	25%	Zero	4%	13%	16%	25%
Acceleration (m/s^2)	-0.67	-0.64	-0.58	-0.56	-0.50	-1.16	-1.11	-1.01	-0.97	-0.87
Proportion of g	0.1g	0.096g	0.087g	0.084g	0.075g	0.19g	0.18g	0.17g	0.16g	0.14g

Table 14 - Potential Landing Forces with Heave Compensated System

8.4 Investigation of Dynamic Forces Study Conclusions

8.4.1 Mathematical Modelling

i) Consideration should be given to the stiffness and natural frequency of the system to avoid the effects of system resonance.
ii) 1.3 is an appropriate design factor.
iii) Principle motions of the barge are not significant at Sea State 4.
iv) The relationship between turbine and barge motions can be modified to acceptable levels by the use of an appropriate heave compensation system.

8.4.2 Landing Effect Conclusions

i) The maximum expected landing acceleration using a non-compensated Merlin system at Sea State 4 is 0.19g.
ii) The maximum expected landing acceleration using a compensated Merlin system at Sea State 4 is 0.14g.
iii) The results achieved in this study clearly demonstrate that by using an appropriate heave compensation system, expected landing accelerations can be reduced to levels which are understood to be acceptable to turbine manufacturers.
iv) The accelerations shown are higher than those estimated for conventional landing but not significantly. If necessary these can be further reduced by the use of a spring landing system.
v) The Merlin system is therefore considered to satisfy the third major objective (Section 7) and hence constitutes an acceptable and safe installation technique.

9 FINITE ELEMENT ANALYSIS (FEA)

Assembling and handling a complete turbine at any attitude other than vertical induces stresses into the tower structure and yaw bearings that they may not necessarily be subjected to when assembled in the traditional manner. Fundamental to the success of the Merlin installation system is the requirement to demonstrate to turbine manufacturers that the system handles turbines safely under all conditions and that any induced stress will remain within acceptable limits.

Following discussion with turbine manufacturers, it was recognised that the yaw bearing can be supported using temporary installation braces thus eliminating any undue stress from that critical component during installation. The tower structure would, however, be subject to increased stresses if not correctly supported by the handling system.

EB therefore carried out a finite element analysis of the tower structure with the following objectives;

- To determine the stress and resultant deflections occurring in the thin walled tower sections at various attitudes.
- To optimise the design, location and number of supports required to ensure that the stress in the tower structure is maintained within levels acceptable to the turbine manufacturer.

For the purposes of FEA, the turbine assembly can be considered to be a series of masses simply supported by the Merlin system support cradles as represented in the free body diagram shown in Figure 13 below.

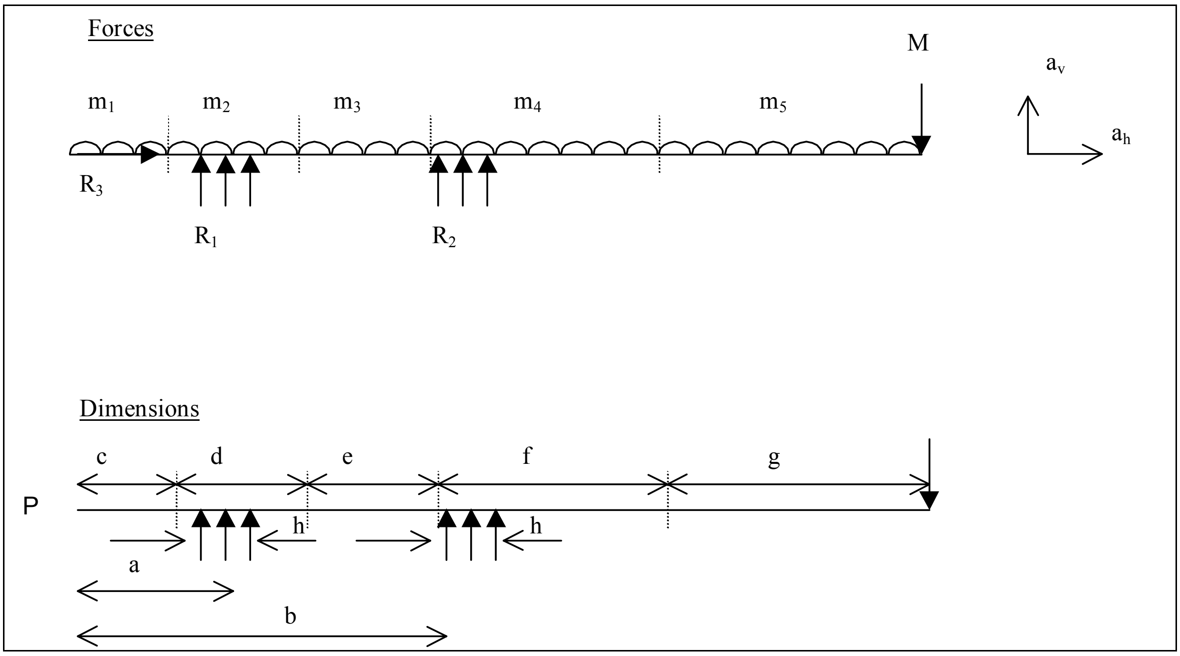


Figure 13 - Free body diagram

Tables 15 and 16 detail the turbine masses and dimension represented in the free body diagram and used to create the FEA model.

Free Body Masses		
Name	Representing	Mass (Kg)
M	Nacelle and Rotor	125,892
M1	Bottom tower section 10,700 kg/m (including additional parts)	235,400
M2	2nd tower section 3,870 kg/m	51,664
M3	3rd tower section 2,349 kg/m	47,619
M4	4th tower section 1,630 kg/m	33,350
M5	5th tower section 1,325 kg/m	30,873
Total mass		**524,800**

Table 15 - Turbine Data

Free Body Dimensions		
Dimension	Representing	Length
a	Tower bottom to centre of lower support	19.5m
b	Tower bottom to centre of upper support (varies)	65m to 85m
c	Bottom tower section length	22m
d	2^{nd} tower section length	13.35m
e	3^{rd} tower section length	20.35m
f	4^{th} tower section length	20.46m
g	5^{th} tower section length	23.30m
h	Length of support (varies)	3m to 7m

Table 16 - Turbine data

9.1 Method and Geometry Creation

An assembly model was created in *Autodesk Inventor 6* to simulate each condition of the tower and supports. The tower was created in two sections:

i) The lower section is a parallel sided, constant thickness cylinder of length 22m, outside diameter 4.19m and wall thickness 38mm.
ii) The upper section is a hollow frustum of length 77.46m, major outside diameter 4.19m, minor outside diameter 2.316m and thickness reducing from 38mm at the major diameter to 16mm at the minor diameter.

The two sections of the tower are assembled together. The flanged and bolted connections used to connect the sections of the tower together have been ignored in the analysis.

In order to arrive at a comparative solution for the different modelling cases a low-resolution hexahedral mesh has been used on the tower and supports. The axes have been designated as:

- x = tower transverse normal to plane of inclination
- z = tower longitudinal

125,892 kg has been applied at the top face to simulate the nacelle and rotor assembly load. 134,659 kg has been distributed over the base section to simulate the transition section, socket, and walkways. These forces were also vectored using y and z components.

Materials used are structural steel for the tower and a dummy material with zero density for the supports to prevent the tower being loaded by the self-weight of the supports during simulation.

Analysis has been carried out in every case in both a static condition and with a dynamic factor of 1.3g to take account of wave induced loading. This represents an 11% increase over the 1.15g factor that is the maximum turbine hub acceleration derived in the barge motion analysis described in Section 7.2 above.

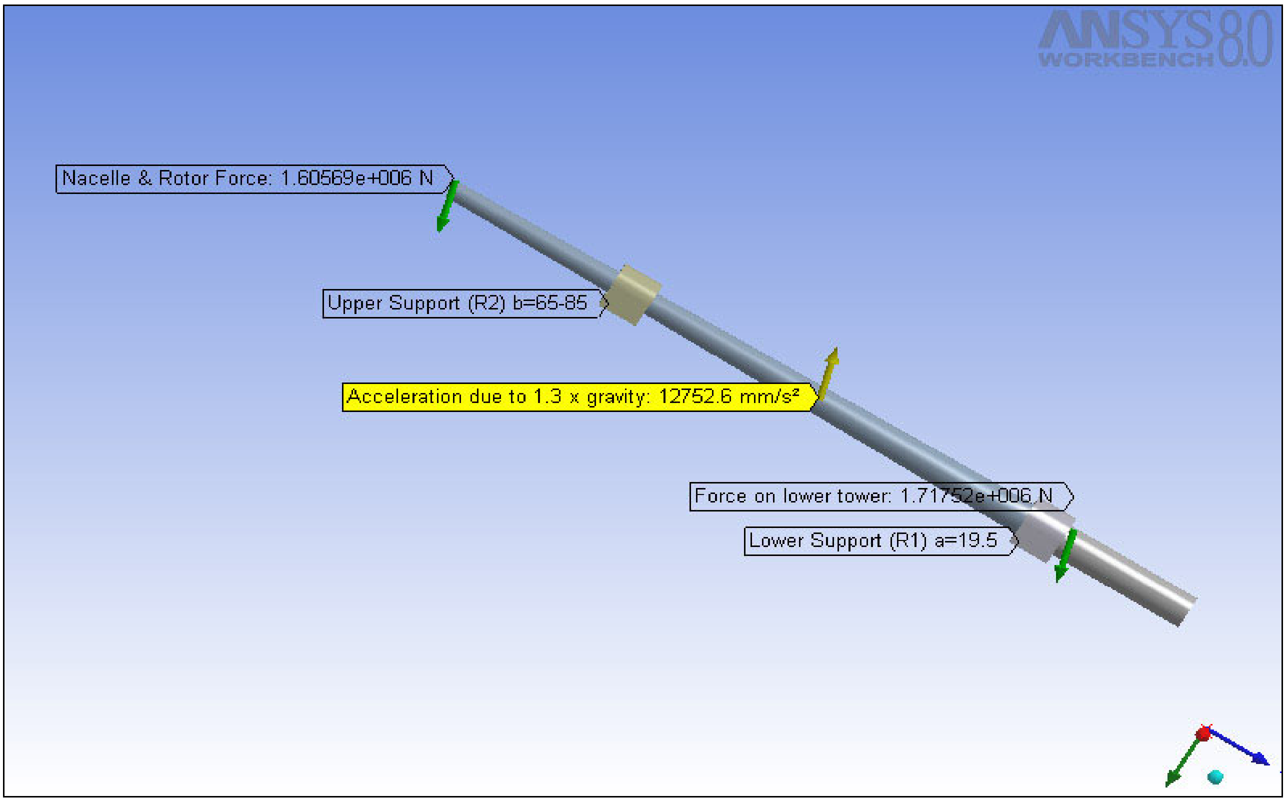


Figure 14 - Tower FEA Diagram

9.2 Tower Support Configurations

The tower is a relatively thin walled structure optimised dynamically for supporting the turbine and maximising fatigue life. It is not acceptable to modify it in any way that might change the characteristics in these respects.

The support configurations therefore have to provide either external bracing only or be backed up by removable internal bracing. It is assumed that bracing may be glued / grouted in position internal to the tower but cannot be welded due to the tower fatigue consideration.

The FEA considered three clamp configurations as shown in Figure 15, with each clamp at three different lengths and at three different locations, with respect to the bottom of the tower.

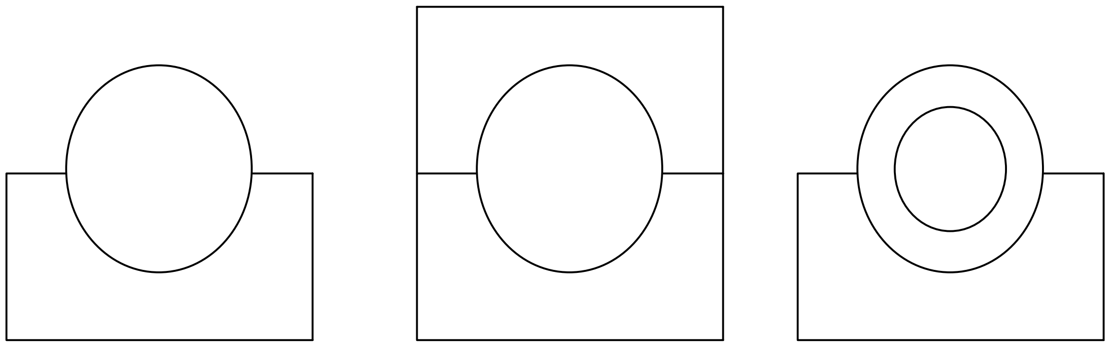


Figure 15 - Types of Support Cradle Considered in the FEA

9.3 Analysis cases

The analysis considered the following cases:

Tower orientation
- i. Horizontal – (worst case)
- ii. 15° degrees from the horizontal

Support Configuration
- i. Simple cradle support
- ii. Simple cradle support with internal tower bracing
- iii. Clamped cradle support

Support length
- i. 3m
- ii. 5m
- iii. 7m

A total of 72 modelling case runs, in 4 batches, were carried out to optimise the clamp positions, as illustrated in Table 17.

Batch no	Modelling Case no	Upper Clamp Position (from bottom of tower)	Load factor	Tower Orientation
1	1 – 9	65m	1	Horizontal
	10 -18	65m	1	15° elevation
2	19 - 27	65m	1.3	Horizontal
	28 - 36	65m	1.3	15° elevation
3	37 – 45	75m	1.3	Horizontal
	46 - 54	75m	1.3	15° elevation
4	55 - 63	85m	1.3	Horizontal
	64 - 72	85m	1.3	15° elevation

Table 17 - FEA Cases

9.4 FEA Results and Conclusions

The complete FEA results and respective diagrams are presented at Appendix B of this report. The following points summarise the key aspects of the FEA study results:

i. The S355J2G3 material used for the tower has a specified Yield Stress of 355 MPa. As indicated in Section 6 of this report, there is no guidance to the maximum allowable stress for the tower during installation hence the value of 85% has been used for the purpose of this study. Based on experience of other offshore installation works confidence is high that this level is appropriate.

ii. Assuming a dynamic load factor of 1.3 and allowable Von Mises bending stress of 85% of yield (or an equivalent combination) the 75m position of the upper clamp provides the required support maintain stress within acceptable limits.

iii. Stress levels are lowest using the clamped support configuration.

iv. Case 50 i.e. 75m position, 5m long clamped cradle at 15 degrees elevation is the optimum condition.

v. The maximum stress is always a compressive stress that occurs at the underside of the tower structure at the upper limit of the upper clamp.

vi. The maximum deflection always occurs at the upper end of the tower structure.

vii. The load is shared almost equally between the upper and lower clamps.

viii. The initial results indicate no significant difference in stress when comparing the three lengths of support used, however no detailed analysis of the interface stresses has been carried out.

ix. Further analysis would be carried out as part of the detail engineering of the support clamps.

x. Stress in the tower could actually be reduced to a very low level by the use of an additional support placed just below the nacelle. This has been factored into the design for future consideration.

10 TURBINE TO FOUNDATION INTERFACES

There are a number of foundation options including mono-pile, gravity bases or tripods. Each of these has attributes that are beneficial in a range of water depths and seabed conditions though evaluation of these is outside the scope of this report.

In the majority of situations the preferred foundation type has proved to be a mono-pile driven or bored into the seabed. Whichever foundation type is used, design of the interface between the turbine and its foundation is the responsibility of the turbine manufacturer. Traditionally this is either a grouted connection or a face to face bolted flange connection however, the Merlin installation system may necessitate changes to the interface configuration.

The fundamental requirements for the interface are:

- To provide a means of ensuring vertical alignment.
- To provide a positive connection that safely transfers all turbine loads into the foundation.
- To facilitate de-commissioning at the end of design life.

The Engineering Business (EB) has carried out a preliminary study to investigate potential interface configurations that may be more appropriate for turbines installed using the Merlin system. The interface for installation by the Merlin system is considered to be at the top of the foundation with a conical steel section acting as a guide for positioning the tower to the foundation. The conical guide area will also be used as a location and support area for the tower alignment assembly, which will allow the tower to be aligned vertically.

10.1 Comparison of Grouted & Clamped Systems

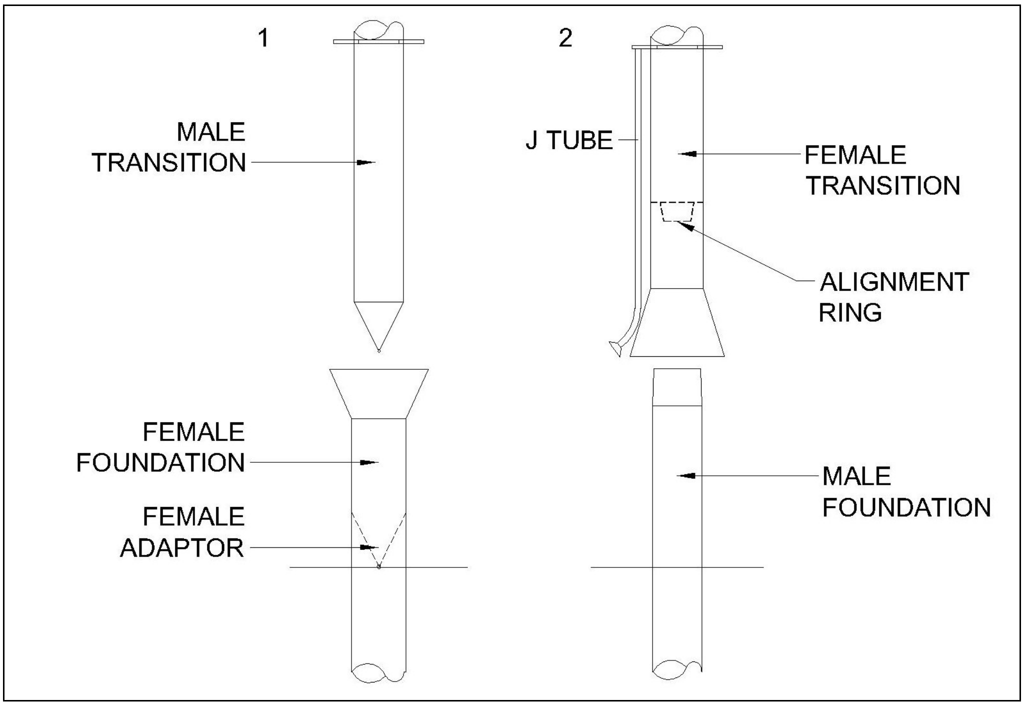
Each of the EB concepts could be utilised with either a grouted or clamped connection. Table 18 considers the advantages and disadvantages of each.

System	Advantages	Disadvantages
Grouting	▪ Allows for large pile installation tolerances. ▪ Vertical alignment easily achieved. ▪ Installation time 3-4 hours. ▪ Proven technology. ▪ Joint can be made subsea.	▪ Long-term properties uncertain ▪ Possible cracking and joint deterioration. ▪ Full strength only achieved in 28 days. ▪ Joint cannot be broken for de-commissioning. ▪ Environmentally unacceptable in some cases.
Clamping	▪ Allows for large pile installation tolerances. ▪ Vertical alignment easily achieved. ▪ Installation time 3-4 hours. ▪ Immediate full strength ▪ Joint can be dismantled for de-commissioning. ▪ Permits removal for maintenance. ▪ Joint can be made subsea.	▪ Additional complexity. ▪ Additional equipment required.

Table 18 - Grouting & Clamping Compared

10.2 Outline Interface Concepts

This study has considered two outline concepts illustrated in Figure 16.



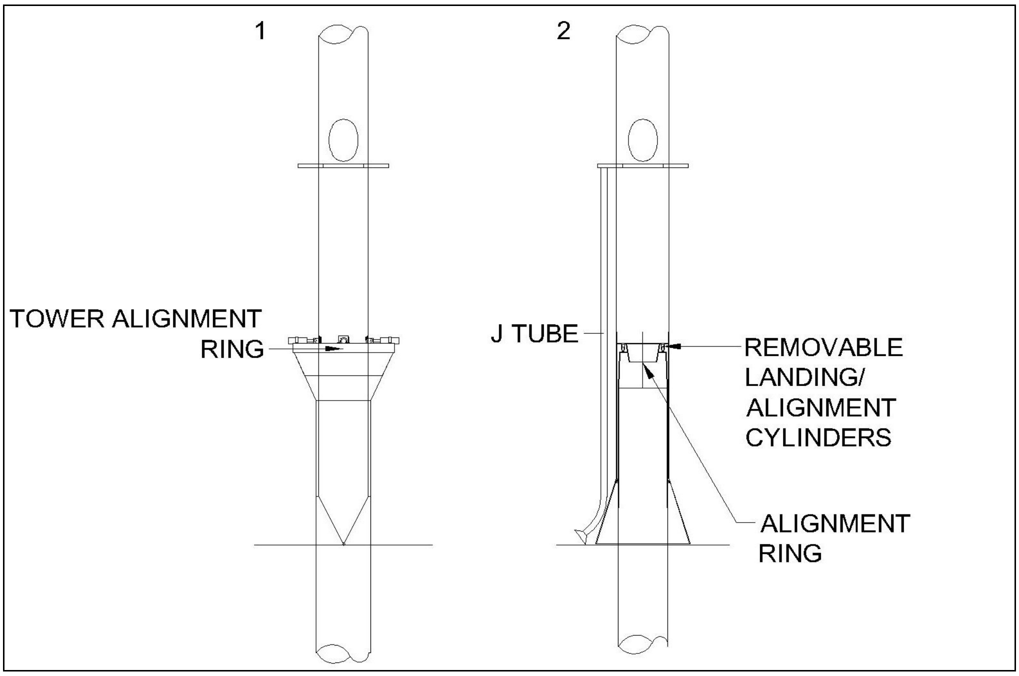
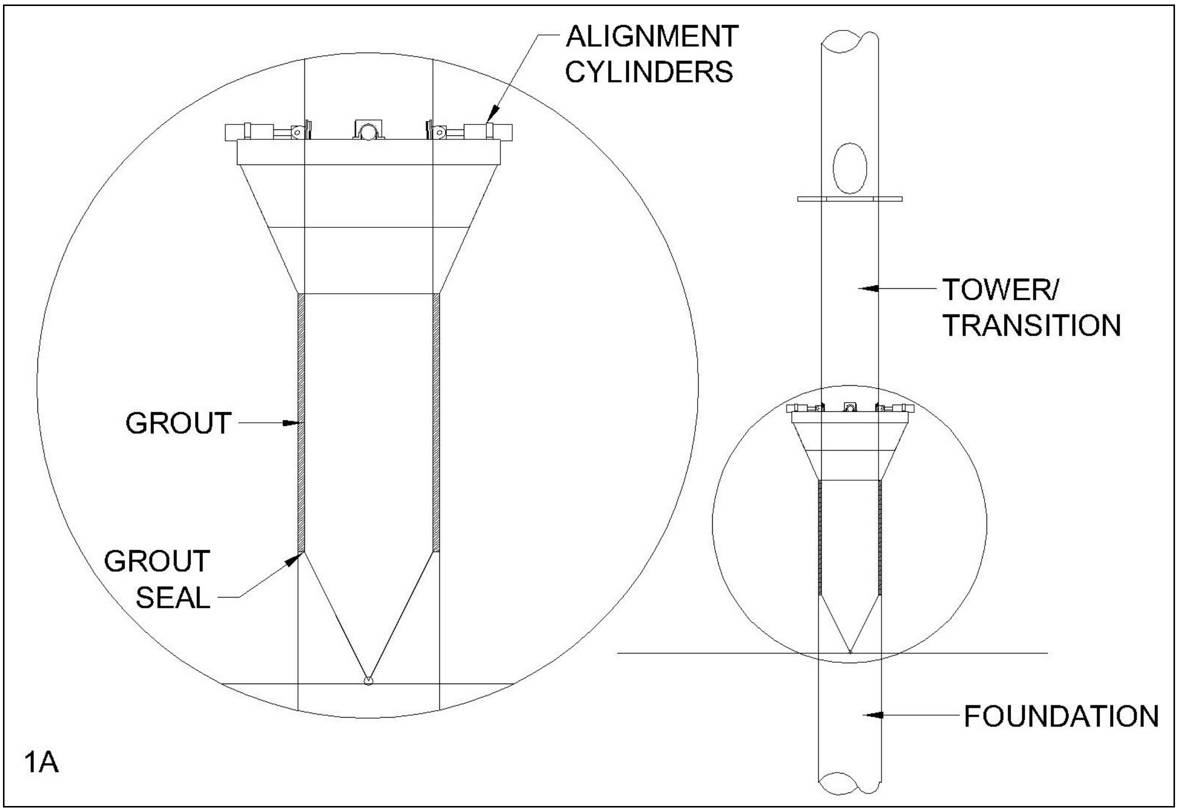


Figure 16 - Connection Configurations

Each of these options could be utilised to form either a grouted or a clamped / friction connection and both are suitable for connection above or below sea level. Option 2, the external tower transition, has the added advantages of:

i) Permitting the installation of the J-tubes and boat landing arrangement at the shore base before transit to the field.
ii) The tower bottom flared section can be sized to cover scour pits.

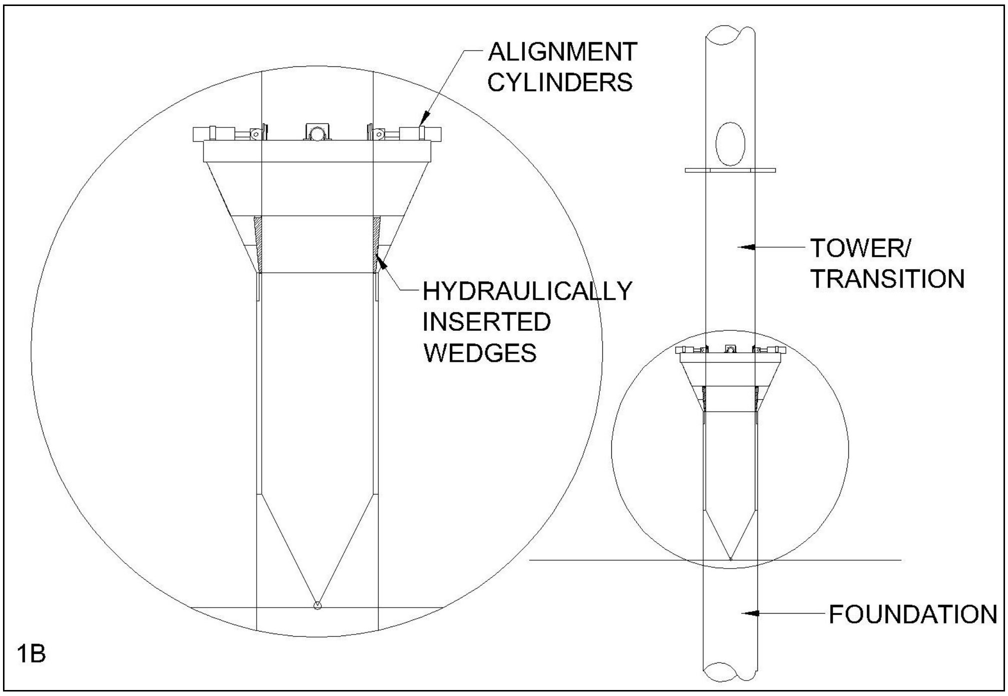
10.2.1 Grouted Male / Female Connection



Installation sequence

i) This method requires a foundation adapter to be positioned into the top of the foundation prior to installing the turbine.
ii) The turbine is lowered into the foundation until the lower end ball joint engages with the foundation adapter.
iii) The alignment ring with the alignment cylinders is lowered down the tower to engage with the foundation adapter.
iv) Turbine is vertically aligned using the cylinders and the cylinders are locked off to provide a temporary connection.
v) Grout is injected into the annulus between the turbine and the foundation.
vi) After the appropriate grout-curing period the alignment cylinders are removed to the next turbine.

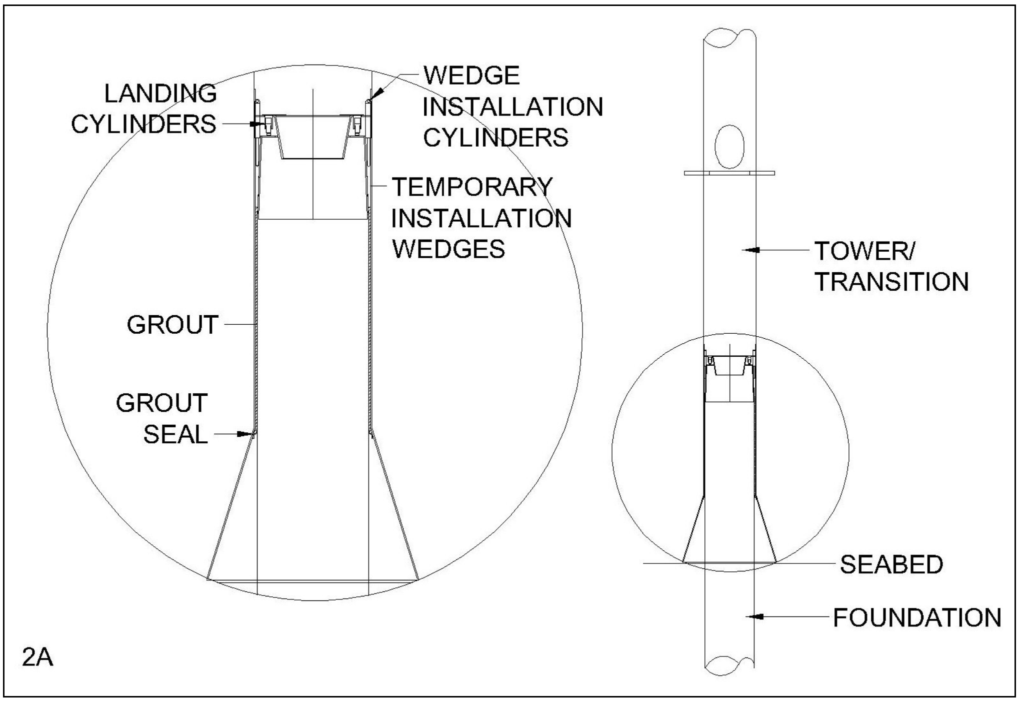
Clamped Male / Female Connection



Installation sequence

i) This method requires a foundation adapter to be positioned into the top of the foundation prior to installing the turbine.
ii) The turbine is lowered into the foundation until the lower end ball joint engages with the foundation adapter.
iii) The alignment ring with the alignment cylinders is lowered down the tower to engage with the foundation adapter.
iv) Turbine is vertically aligned using the cylinders and the cylinders are locked off to provide a temporary connection.
v) Hydraulically driven wedges are driven into the area between the conical guide and the top of the foundation and the wedges mechanically locked into engagement.
vi) Alignment cylinders and wedge cylinders can be removed to the next turbine.

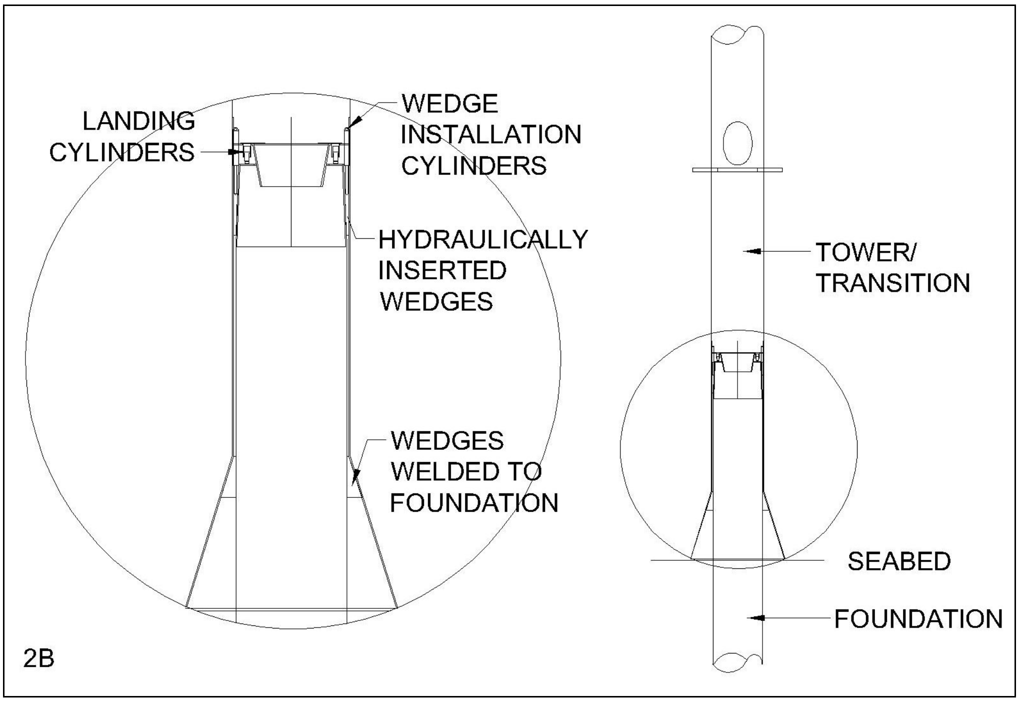
10.2.2 Grouted Female / Male Connection



Installation sequence

i) This method (and all female / male connections) requires the top section of the foundation to be tapered and have a horizontal upper landing face with a central orifice sized to accept the alignment ring.
ii) The turbine is lowered over the foundation until the alignment ring and landing cylinders come into contact with the top of foundation.
iii) Turbine is vertically aligned using the landing cylinders and the cylinders are then locked off.
iv) Hydraulically driven wedges are inserted into the area between the tower transition and the top of the foundation.
v) Grout is injected into the annulus between the turbine and the foundation.
vi) After the appropriate grout-curing period the alignment cylinders can be withdrawn.
vii) Alignment cylinders and wedge cylinders can be removed to the next turbine.

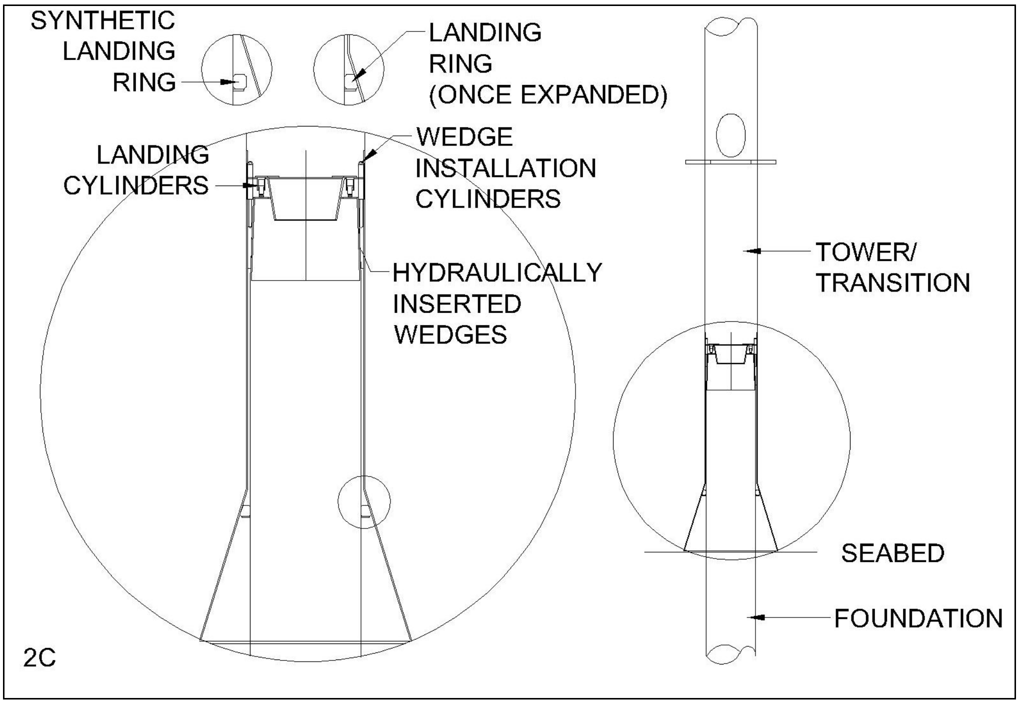
10.2.3 Wedged Female/Male Connection



Installation sequence

i) This method requires wedges to be welded around the periphery of the foundation prior to installation.
ii) The turbine is lowered over the foundation until the alignment ring and landing cylinders come into contact with the top of foundation and the transition engages with the lower foundation wedges.
iii) Turbine is vertically aligned using the landing cylinders.
iv) Hydraulically driven wedges are inserted into the area between the tower transition and the top of the foundation.
v) Landing cylinders are then retracted to ensure maximum engagement of upper and lower wedges.
vi) Upper wedges are mechanically locked into position
vii) Alignment cylinders and wedge cylinders can be removed to the next turbine.

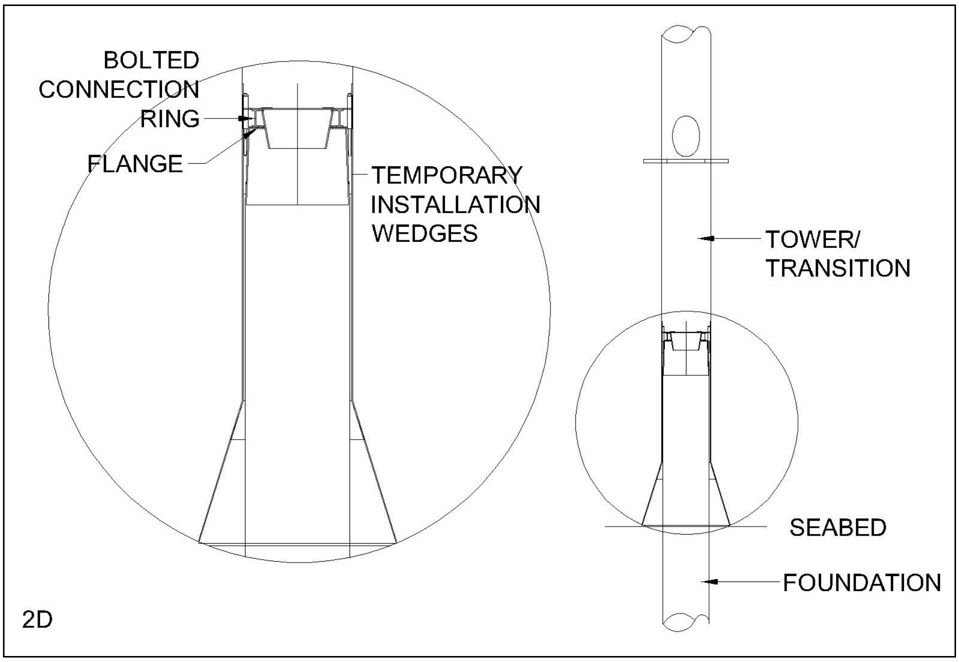
10.2.4 Wedged Female/Male Connection with Synthetic Reaction Ring



Installation sequence

i) This method requires a landing ring support plate to be welded to the foundation prior to installation.
ii) The synthetic ring is lowered over the turbine foundation, using the crane on the Merlin barge, until it rests on the landing ring support plate.
iii) The turbine is lowered over the foundation until the alignment ring and landing cylinders come into contact with the top of foundation and the guide cone comes into contact with the synthetic landing ring resting on the foundation. This compresses and extrudes the synthetic ring until it is fully in contact with the foundation and the tower transition.
iv) Turbine is vertically aligned using the landing cylinders.
v) Hydraulically driven wedges are inserted into the area between the tower transition and the top of the foundation.
vi) Landing cylinders are then retracted to ensure maximum engagement of upper wedges and maximum expansion of the synthetic ring.
vii) Upper wedges are mechanically locked into position.
viii) Alignment cylinders and wedge cylinders can be removed to the next turbine.

10.2.5 Internal Bolted Female/Male Connection



Installation sequence

i) This method requires a machined flange, pre-drilled to the appropriate pitch circle diameter to be welded to the top of the foundation prior to installation.
ii) The turbine is lowered over the foundation until the alignment ring and landing cylinders come into contact with the flange at the top of the foundation.
iii) Turbine is vertically aligned using the landing cylinders.
iv) Hydraulically driven wedges are temporarily inserted into the area between the tower transition and the top of the foundation.
v) The bolted interface ring is supplied as a two part loose item, pre-installed to the tower prior to load out, comprising a lower mating flange that aligns with the pre-drilled flange of the foundation and an upper bolted flange pre-bolted to a plain steel diaphragm. The interface ring is lowered and aligned to the foundation flange and loose bolted.
vi) The plain steel diaphragm will now be in contact with a mating support ring pre-welded into the tower transition. Final alignment of the plain steel diaphragm and mating support ring can be made using the alignment cylinders.
vii) The plain steel diaphragm is now fully welded around its periphery to the support ring, creating a permanent bolted interface without the problems of multiple flange alignment.
viii) Alignment cylinders and wedge cylinders can now be removed to the next turbine.

10.3 Foundation Interface Conclusions

EB concluded the following from this particular study:

i) The design of the turbine/foundation interface is the responsibility of the turbine designer though it is accepted that some modification may be needed in the case of Merlin installed turbines.

ii) The options presented in this section represent alternative interfaces that may be more appropriate for use with turbine installed by the Merlin system.

iii) The male/female and female/male options are both suitable for either grouted or clamped connections and both could be used above or below sea level.

iv) The female/male connection option provides the added advantage of:

- Ease of connection of the J-tubes, boat landings and platforms.
- Connection of J-tubes, boat landings and platforms at the shore base and not as a separate offshore activity.
- The opportunity to size the entry cone to cover, or part cover, the scour pit, making cable installation and burial easier.

v) EB recommend option 2B – Wedged Connection, as the option to be taken forward for further discussions with the turbine manufacturers as this has the benefits of:

- Low cost, reliable option.
- The lower wedges are fully installed to the foundation in the shore base.
- Ease of connection offshore.
- Positive and safe connection.

11 ECONOMICS OF MERLIN

As described in Section 1, any new installation technology must represent a cost effective alternative that offers reductions in offshore installation costs, thus contributing to the overall commercial viability of offshore wind development. This section describes the economic study carried out to investigate the costs associated with the Merlin installation system and determine the benefits it could offer developers of offshore windfarms.

To provide an accurate analysis this study has been carried out as a "like for like" comparison, in so far as is reasonable, with existing methods of installing wind turbines in an offshore environment. Actual values for costs associated with traditional techniques have been used where these are in the public domain. Alternatively estimates have been made based upon experience of similar offshore operations.

A full cost report including detailed breakdown spreadsheets for all cost elements has been submitted previously to the DTI, as an interim deliverable of this project. Figures and information given in this report for the various elements of the Merlin system are extracted from the respective spreadsheets of the cost report.

Wherever possible quotations have been obtained from likely suppliers to maintain the accuracy of the overall estimate as high. The quotation source for cost elements of significant value are detailed in Section 11.8.

The principle objectives of this study were

- To determine the cost to design and build a fully operational Merlin system, plus the cost for subsequent repeat builds.
- To determine realistic annual operation and maintenance costs for the Merlin system.
- To establish a potential project sales value for the Merlin system and thus determine any economic advantage over competing technology.

11.1 Cost Base Comparison

Figure 17 illustrates the process undertaken during this cost study to determine the potential value of the Merlin system against existing techniques, based on the following design premise for the Merlin system:

11.1.1 Onshore Equipment

A support and lifting cradle sized to permit the 100m long turbine, weighing 510te to be fully assembled at an attitude of 15°.

11.1.2 Offshore Equipment

- A 100m x 30m barge modified to provide a “key hole” installation aperture and the structural support for all equipment, together with installation of a 4 point mooring system.

- An A-frame to locate, support and rotate the 600te load of the cradle support frame and turbine assembly to the vertical orientation, whilst maintaining longitudinal freedom of movement of the support cradle.

- A lifting gantry / winch system with the capacity to raise and lower the 600te load over a vertical distance of +/- 8m, whilst providing motion compensation to overcome wave induced motions at the turbine.

- A turbine alignment and clamping system capable of supporting the turbine and transferring all static and dynamic loads into the foundation yet maintaining the capacity for de-mounting to permit for replacement or decommissioning at the end of turbine design life – nominally 20 years.

- Hydraulic, electrical services, cranes, winches, accommodation and domestic facilities to support continuous offshore operations.

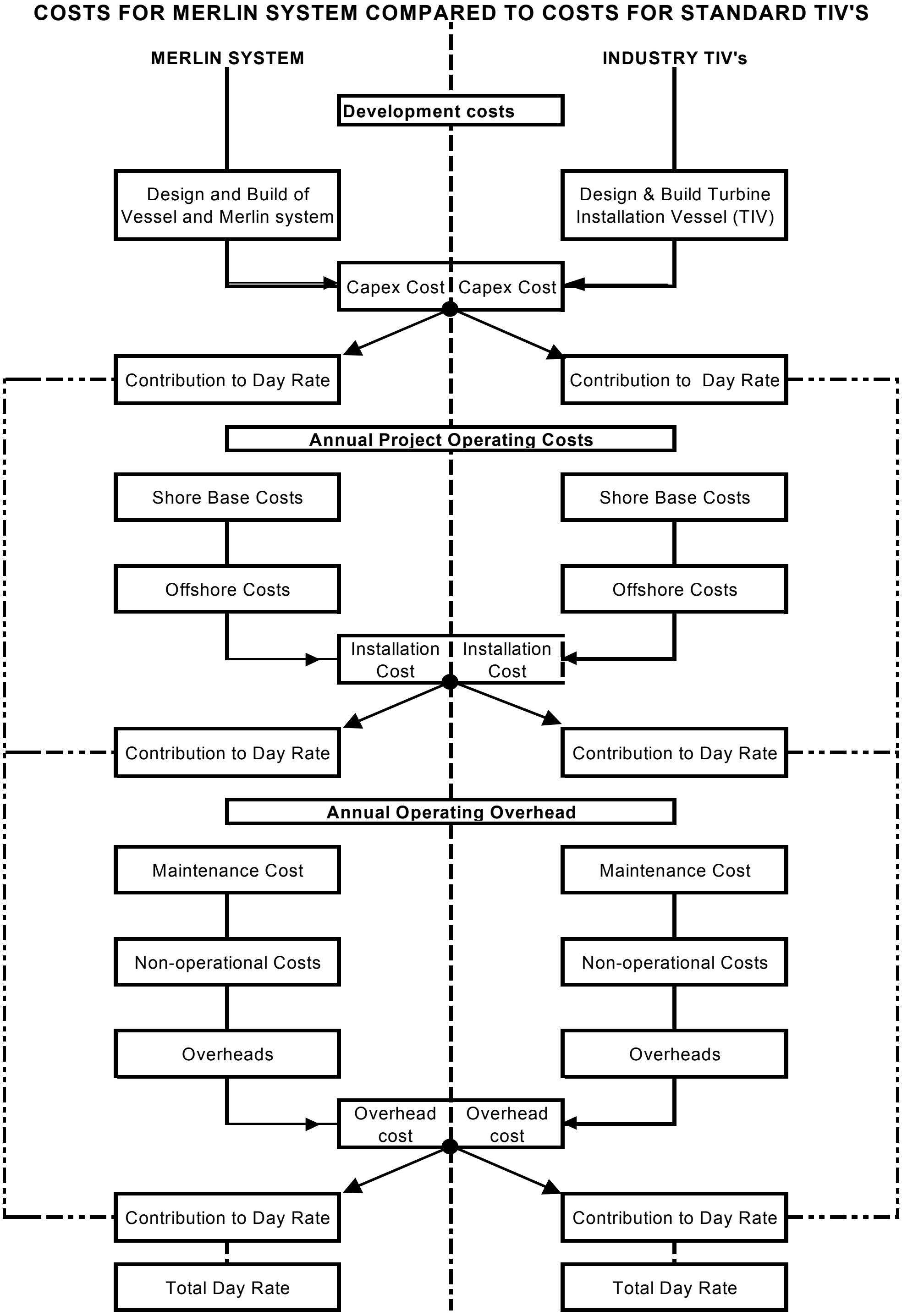


Figure 17 - Development of Cost Comparison

Note: Each cost element is based upon installation of 170 turbines per year for a period of six years.

11.2 Development Costs

The first part of this analysis focused on the cost to design and construct a production Merlin system which will operate as a self contained offshore operations vessel complete with mandatory life support systems. Following standard engineering practices, the design of the Merlin system has evolved from a simplistic concept to a practical and realistic solution, as illustrated at Figures 18 and 19.

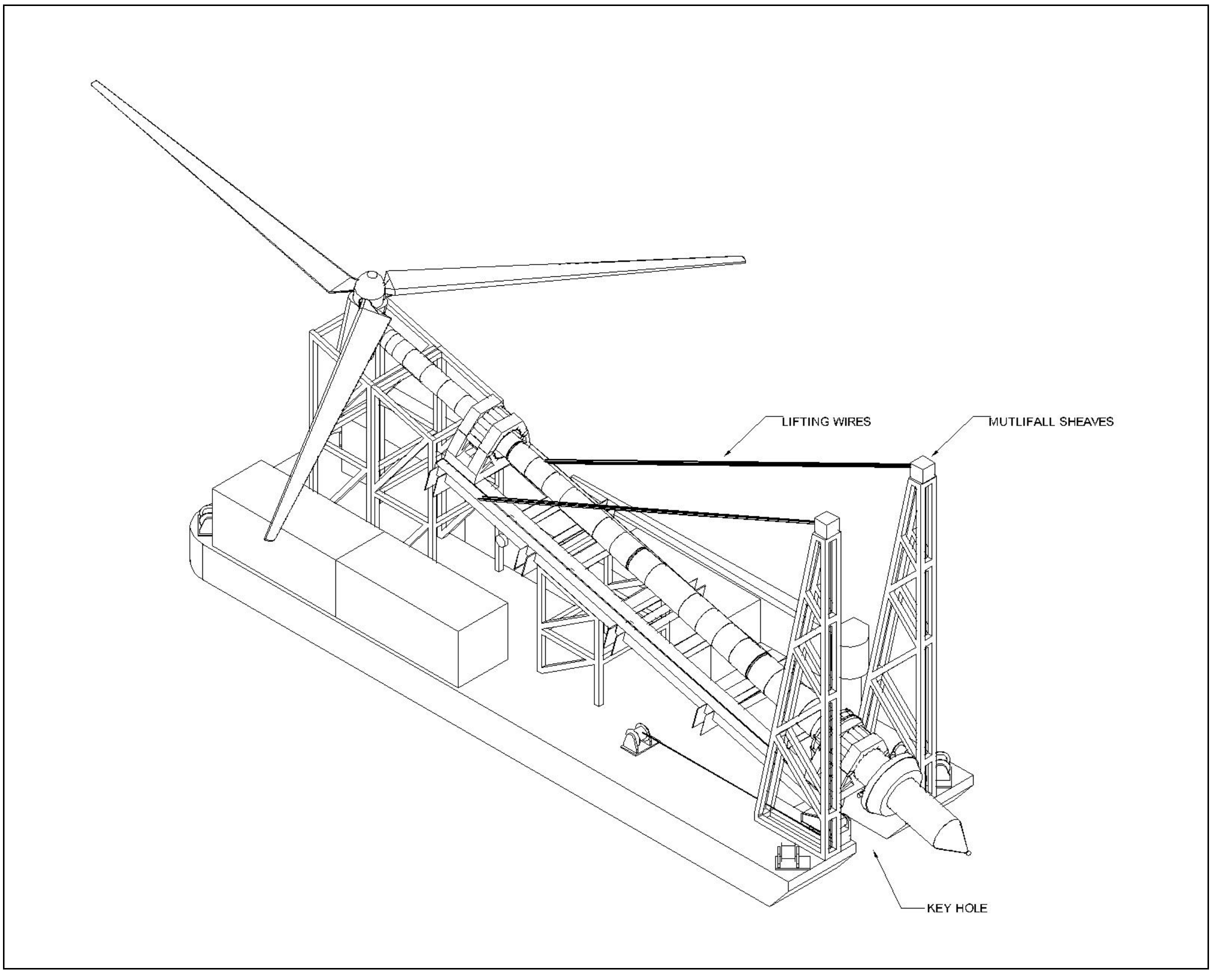


Figure 18 - Layout of Merlin Equipment on the Installation Barge

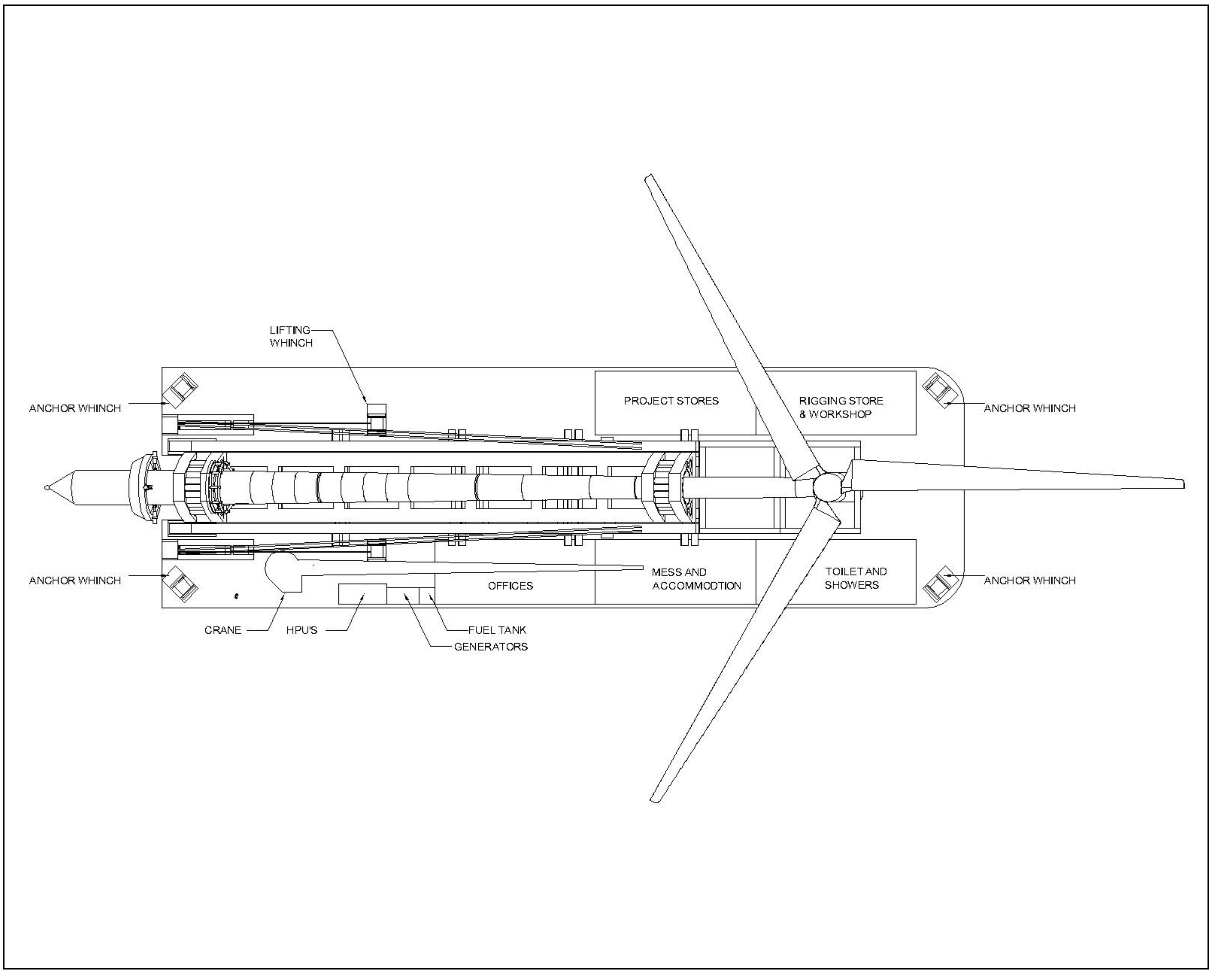


Figure 19 - Merlin Installation Barge

11.2.1 <u>Development cost build up</u>

Costs are based upon a 30-36 week design and build programme for the production system with the following constraints:

- Project management, contract administration, HSEQ functions, procurement, detail and structural engineering completed by EB.

- Purchase of the barge from current owners.

- Contracted Naval architectural design works and modification to the barge carried out by a UK ship repair facility under the supervision of EB.

- Contracted construction of the system components and subsequent installation to the barge being shared between the shipyard and local engineering companies under supervision of Engineering Business Ltd.

Using the analogy given in the illustration at Figure 17, the following comparison has been made with regard to development costs.

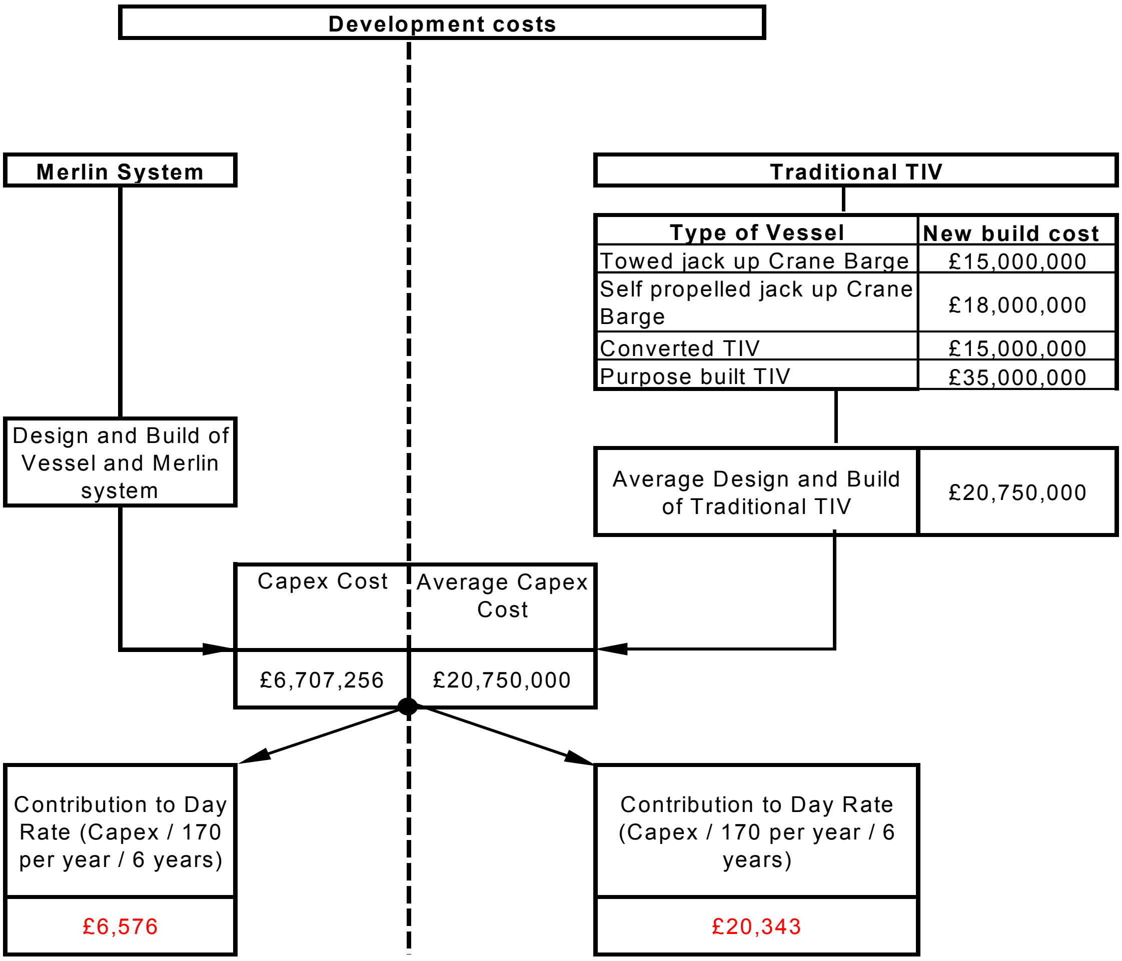


Figure 20 - Capital Development Flowchart

Notes:

i) The cost quoted in this model for the purpose built TIV is a conservative estimate for a repeat build as the cost for the first such vessel is quoted at $95 million USD by MIZUHO in their press release of 22 April 2004 [ref5].

ii) Values for other new build vessels are an average of costs given by various ship brokers.

iii) Capital expenditure quoted for Merlin includes £427K for the design and build of the shore side assembly and support cradle that is not part of the offshore equipment but is an integral part of the operation.

iv) This estimate has been made using current market rates for raw materials. Steel and oil price rises similar to those witnessed in early 2004 would most likely result in higher overall costs though this would apply to all construction programmes equally.

The development costs described indicate that the Merlin installation system is a very competitive and cost effective option for a TIV that can be produced for approximately 45% of the cost of a jack up crane barge of the equivalent capabilities.

The programme for the design and build of first production unit is estimated to be 30-36 weeks with subsequent units being constructed in approximately 24-28 weeks. This is considerably faster than any of the other types of vessel could be constructed. Repeated vessel construction would be approximately 5% cheaper than the first unit due to lower design costs and economies of scale.

The costs for the production installation barge and all necessary shore side support and lifting equipment is estimated to be £6.7 million which includes a considerable change in emphasis from leased to purchased options. This study has shown that over the design life of 10-15 years purchasing is a more cost-effective approach than long term leasing.

Confidence in the accuracy of the development costs estimate is deemed to be high and includes a 3% contingency on every item.

11.3 <u>Operating Costs</u>

The second stage of this study concentrated on the costs likely to be incurred during the performance of turbine installation contracts.

This study considers the costs in two main areas:

A. Project Operating Costs

- Assembly yard / shore base costs
- Crew costs
- Vessel costs

B. Annual Operating costs (Overheads)

- Annual maintenance
- Project and marine management
- HSEQ
- Sales and marketing
- Accounting
- Management

To permit fair comparison of operating costs and overheads it has been assumed that the first production Merlin installation barge would in effect be owned and operated by an established offshore contractor. It is also assumed that the Merlin installation barge would become the fifth vessel joining their fleet of four multi-purpose offshore construction vessels.

11.3.1 Project Operating Costs

Whilst it is recognised that each type of vessel will have it's unique operating limitations, it is felt that benefits or penalties arising from these will even themselves out between the competing techniques over any given period of similar operations.

This study considered the operating costs for each type of vessel using a set of common operating parameters over a fixed period to give the fairest comparison as follows:

- A seasonal operating period extending from 1st March to 30th September giving a maximum of 214 potential operating days.

- Of this, 20% downtime has been factored in to account for days lost through any combination of adverse weather, technical problems, relocation of resources between projects and standby for any other reason.

- Completion of 4 projects at different locations within UK coastal waters over the period, resulting in the installation of 170, 2MW turbines at the rate of one complete turbine per operational day.

11.3.2 Assembly yard / shore base costs

For competing technologies, the majority of costs associated with the storage and pre-assembly of the turbine components fall to the Manufacturer's account. Use of the Merlin system, however, will encounter costs of the order of 5 times higher than other operators although it also offers considerable benefit to offset this (see Section 12.3.1.2).

As the Merlin system installs a complete turbine in a single operation it requires facilities to assemble and transfer an average load of 600Te to the barge. The greatest variation between the Merlin system shore base requirements and that of other techniques is the cost of the specialised cranes needed to move such a large load to the vessel. These account for more than £1.3 million / year (over the stated period), equating to over 78% of the total costs envisaged for the Merlin shore operations.

As the capacity of these cranes is similar to that required for handling the monopile foundations, it is reasonable to assume that the opportunity could arise to cost share with the foundation contractor but for the purpose of this study all costs are to the Merlin system operator's account.

The cost of heavy lift craneage can be offset by the benefits that could be gained in the form of reduced offshore installation costs and less exposure to offshore weather risk (Section 4). Whilst it is difficult to quantify these savings exactly the estimate given in Section 12.3.1.2 is considered realistic.

11.4 Potential benefits from Reduced Offshore Operations

- Post installation / pre-commissioning operations for conventional installation require an average of 75-80 man-hours over a 3 – 4 day period, at an average rate of £80 (offshore rate including overheads etc) per hour plus transfer in the work boat at £650 / day.

- Installation of the boat landings, j-tubes and platforms is either carried out by the foundation contractor or requires an independent vessel with appropriate craneage and costs between £6000 - £8000 per unit.

Table 19 below shows the magnitude of potential savings that Merlin could offer by completing assembly of the turbine components onshore. Again these savings would be towards the turbine manufacturers account in an EPC contract defraying the Merlin assembly yard operating costs. This would effectively place Merlin on even terms with their competitors with regard to shore base requirements and amount to a net increase in Merlin's profitability.

Description	Unit Cost (typical)	Quantity (typical)	Cost per Turbine (typical)	Cost of weather downtime @ 10% offshore and 1% onshore (typical)	Total cost per turbine (typical)	Annual Cost per 170 Turbines (typical)
Traditional Installation Methods						
Post installation / pre-commissioning Offshore labour	£80.0	75	£6,000.0	£600.0	£6,600.0	£1,122,000.0
Work boat for personnel transfers	£650.0	3	£1,950.0	£195.0	£2,145.0	£364,650.0
Installation of boat landings, j-tubes and platforms offshore	£6,500.0	1	£6,500.0	£650.0	£7,150.0	£1,215,500.0
				Sub total offshore costs	**£15,895.0**	**£2,702,150.0**
Merlin Installation System						
Assembly / pre-commissioning labour onshore (see note 1)	£60.0	65	£3,900.0	£39.0	£3,939.0	£669,630.0
Installation of boat landings, j-tubes and platforms onshore (see note 2)	£3,000.0	1	£3,000.0	£30.0	£3,030.0	£515,100.0
				Sub total onshore costs	**£6,969.0**	**£1,184,730.0**
Potential saving on offshore costs using the Merlin system					**£8,926.0**	**£1,517,420.0**
notes 1: Labour without offshore uplift and over shorter period due to easier access 2: Includes estimated alowance for modifications to steelworks and installation methods						

Table 19 - Potential Savings in Offshore Costs

11.4.1 Crew costs

In all cases, crew costs for these operations are split between the marine crew who operate and maintain the vessel and the Construction crew, under the management of a Construction Superintendent, who operate and maintain the vessel mounted installation system. As Merlin is mounted onboard a "dumb" barge, the marine crew element is minimal with manning levels set by international law to meet statutory marine safety requirements. In order to keep overall numbers to a minimum, several of the Merlin marine crew are employed in a dual role acting as construction crew once their marine duties are complete.

It is envisaged that Merlin will operate on a 24-hour, 2 shift, 7 day basis, in a similar manner to conventional installation practice. A total crew of 8 per shift will be required per shift therefore 16 personnel will be onboard during operations. Additionally crews will be rotated on a two on / one off basis hence the total crew comprises 24 personnel. All crew are a paid a retainer during their off periods and travel to / from the vessel are company costs.

With regard to competitors, every vessel used to date for the turbine installation is a "jack up" vessel and more than 50% of these investigated are self propelled vessels. This means crew levels for competing contractors, from both a marine and construction perspective, are significantly higher than for Merlin. Estimated manning is given in Table 20.

Type of vessel	No of Marine Crew	No of Construction Crew	Total Crew (Onboard)
Merlin tug propelled barge	10	6	16
Self propelled jack up barge or ship	17	16	33
Tug propelled jack up barge	10	16	26

Table 20 - Comparison of Manning Requirements

Assuming that crew salary levels are comparable between contractors then the table above shows that the average crew costs for competitors will be of the order of 1.8 greater than Merlin's

Notes:

i) Three Merlin marine crew members per shift fulfil a dual marine / construction role.
ii) Support vessel crews are included within the vessel cost section below.

11.4.2 Vessel costs

The operating philosophy for Merlin is to use low cost vessels comprising a readily available, standard offshore barge, a tug of approximately 80Te bollard pull and two Multicat work boats / anchor handling vessels. These support vessel requirements are common to other types of TIV in many cases.

Port entry and harbour costs vary between ports and also between different types of vessel however the variance is not significant. For the purpose of this study the value of these costs are deemed constant though Merlin requires more frequent port visits, i.e. at the rate of one per day, than some, but not all of the alternative contractors. Merlin will thus likely incur overall port / harbour dues estimated to be 20-25% greater than other contractors.

As the Merlin equipment is mounted on the deck of the barge and only requires powering up during actual times of loading and installation, the requirements for fuel are considerably lower than other vessels which require constantly running generators to support the vessel systems. Merlin should therefore see significant savings on fuel costs with an estimated consumption 2.5 - 3 times lower than other vessels.

The development of Annual Operating Costs is illustrated in Figure 21 using the following summary of input comparison factors for existing installation techniques.

Cost Element	Multiplication Factor
Shore base costs	Merlin cost / 5 [Note 1]
Crew costs	Merlin costs x 1.8
Vessel costs	
1.Tugs	Merlin cost x 1
2.Port	Merlin cost x 0.8
3.Fuel	Merlin cost x 2.75
4.Misc	Merlin cost x 1.5

Table 21 – Annual operating costs, multiplication factors

Fuel and other consumable costs for the tugs and Multicats is included in the quoted price for each vessel respectively, this applies to the Merlin system and other TIVs equally.

Note 1 Merlin shore base costs still include crane costs at this stage

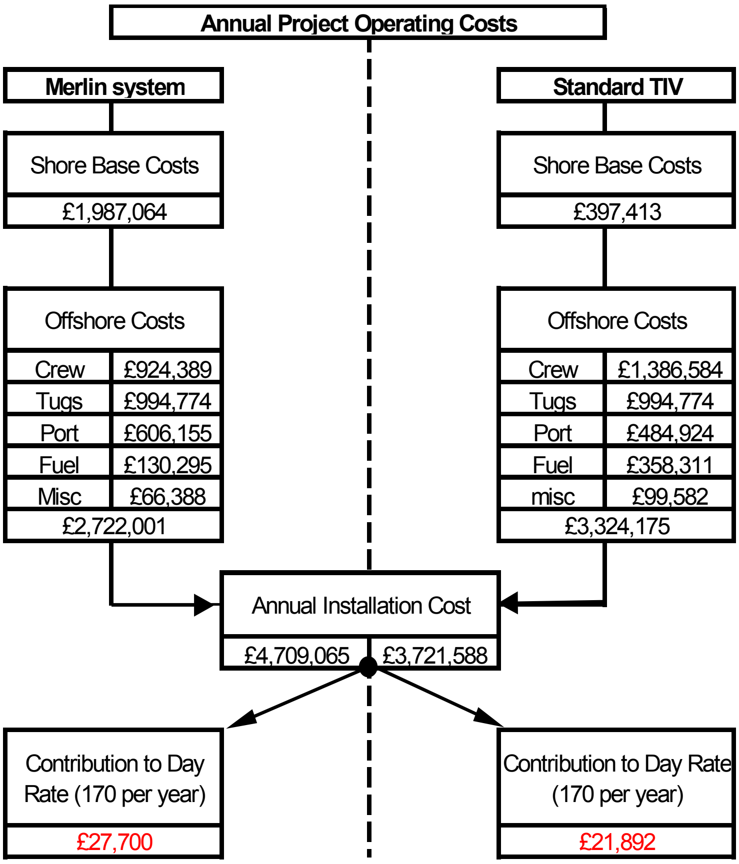


Figure 21 - Comparison of Annual Project Operating Costs

Confidence in all estimated project operating and annual operating costs is rated as medium to high and every element contains a 3% contingency.

Note this comparison still includes the cost for specialist cranes at the shore base. Without this element the anticipated annual operating cost for Merlin installations is approximately 20% lower than other vessels compared.

11.5 Annual Operating Overhead Costs

As stated in Section 12.3, the Merlin system installation barge is assumed to be the fifth vessel of a multi-purpose fleet of an established offshore operator. The annual operating costs and overheads described herein are thus calculated on the following basis.

- Total annual company overhead is estimated to be £1.4 million for a fleet of five vessels.

- Merlin overhead contribution equates to 20% of total overhead. Note the values entered for several of the company overhead functions are based upon EB values factored to incorporate Marine operations and experience of the type of vessels considered.

- Project / Marine Management costs and annual maintenance costs are not part of the overhead but are included as Merlin specific annual costs. The values entered have been calculated on the basis of consultation with other Marine operators using similar vessels together with experience of these functions for the types of vessels considered.

- Calculation is for year one only and no allowance has been included for inflation or industry price uplift.

With respect to annual maintenance requirements, all vessels considered are significantly more complex than Merlin and will therefore require considerably more maintenance and servicing both to the installation / construction equipment and to the vessel hull and marine equipment. Again this information is commercially confidential and not available for direct comparison, though from experience of these types of vessels it is a reasonable assumption that the costs associated with annual servicing, repairs and maintenance will be at least twice that anticipated for Merlin.

Information regarding the overheads of other TIV operators is not available for direct comparison. The offshore operators considered in this report are all established contractors each with several vessels and other divisions within their organisation. It has therefore been assumed that the Project / Marine management costs together with the contribution to each company's overhead from their turbine installation operations is in proportion to the value of their respective offshore assets and the annual project costs they each incur.

For the purpose of this assessment, the rate of comparative management costs and overhead are calculated using the same factors as the annual project operating cost comparison above, i.e. a factor of 1.2 higher than that likely for the Merlin installation system.

Figure 22 illustrates the comparison of annual overhead cost for the Merlin system using the summary of input comparison factors indicated in Table 22.

Cost Element	Multiplication Factor
Maintenance costs	Merlin cost x 2
Project & Marine Management costs	Merlin costs x 1.2
Overhead costs	Merlin costs x 1.2

Table 22 Annual overhead costs, multiplication factors

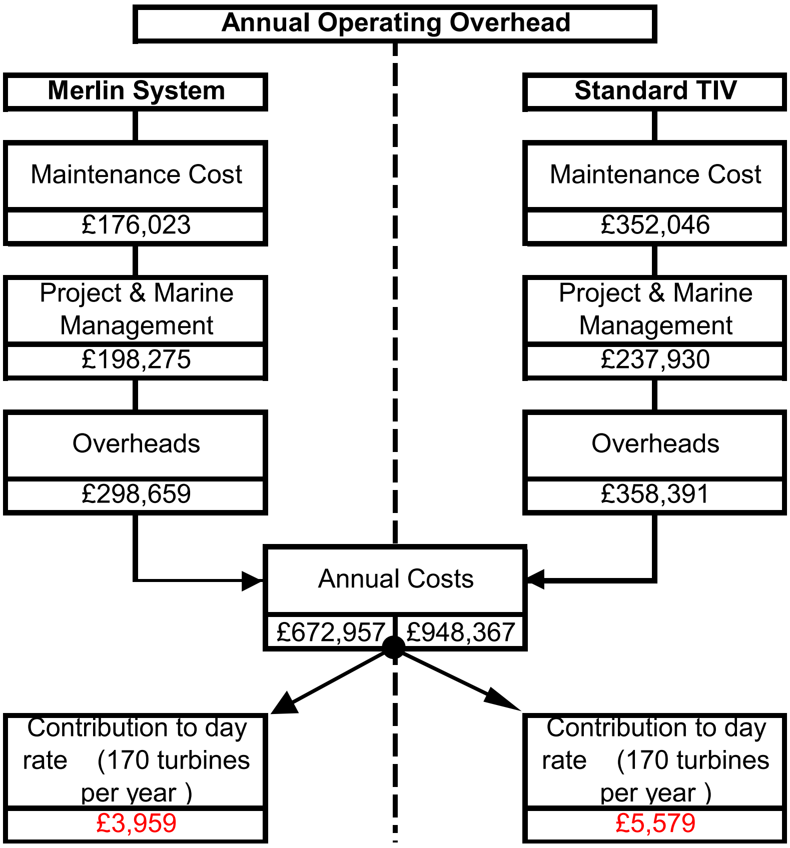


Figure 22 - Comparison of Annual Overhead

Figure 22 indicates the annual overhead for the Merlin installation system to be of the order of 30% lower than other Turbine Installation Vessels compared in this study

11.6 Overall Cost Comparison Between Turbine Installation Vessels

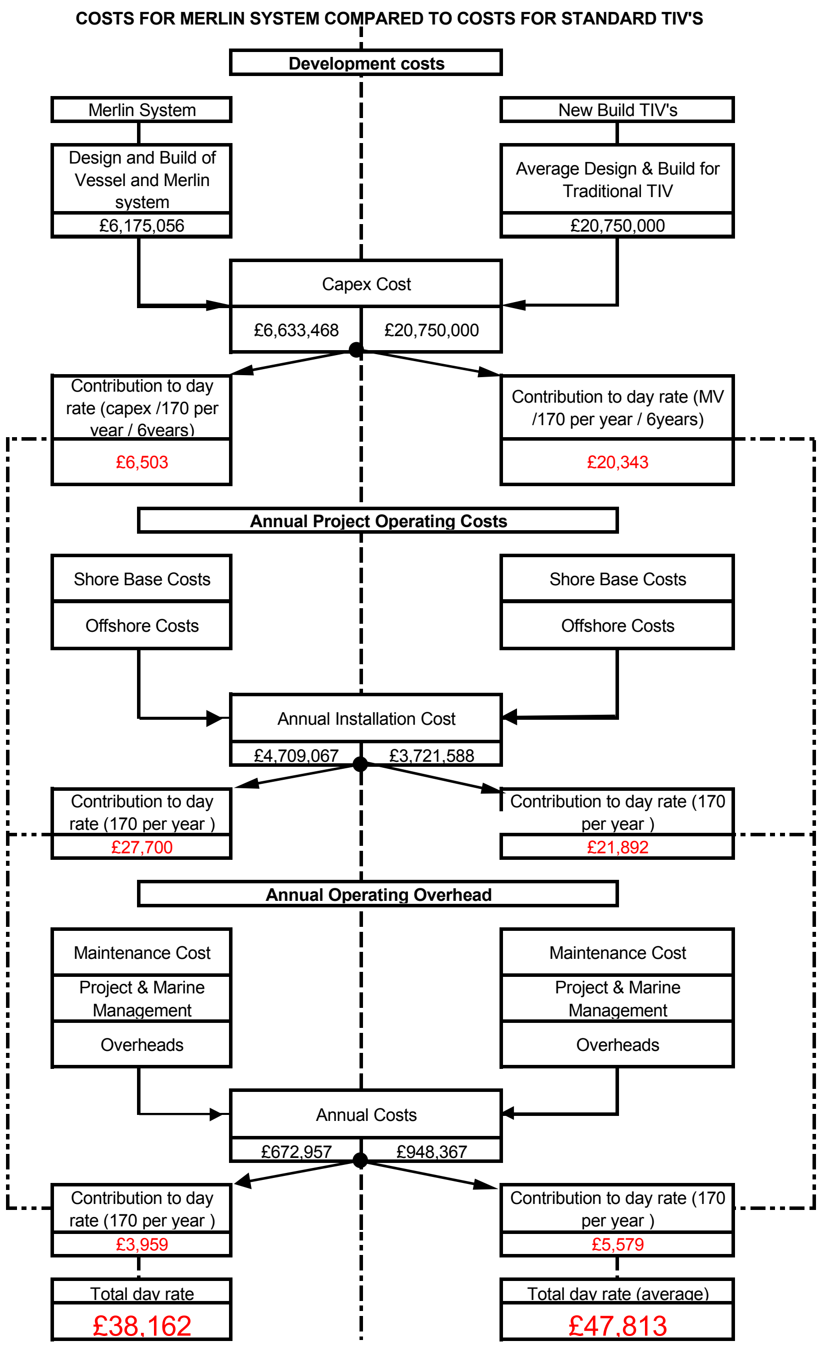


Figure 23 - Overall Cost Comparison

Figure 23 indicates a predicted sales rate in the region of £38,000 per day for the Merlin system, which is very competitive at approximately 20% lower than a new build, conventional TIV. The day rates indicated include a net operating profit margin of approximately 8-9% for both the Merlin System and other TIV operators. This level of operating profit is in agreement with levels declared by Marine operators consulted during this study.

It must be remembered that this calculation still includes a contribution for the shore base costs which alone amounts to £10,294 per day.

11.6.1 Final Comparison

- Section 12.3.1.2 indicated a potential saving of £1.5 million per annum through reduced offshore working and lower exposure weather / offshore risk.

- Section 12.3.1 indicates anticipated crane costs of £1.3 million per annum, equivalent to approximately £10,000 per operational day thus giving rise to a net potential saving of £200,000 per annum.

- Removing the crane costs from the Merlin system calculation reduces the minimum potential rate for the Merlin installation system to £28,000 per day, representing a potential saving of over 40% over new build conventional installation vessels.

Note: This study has been conducted to define a floor level value for likely day rates. The actual day rates for current TIVs is market driven and in some cases has been recorded to be of the order of between £60,000 - £70,000 per day, with one reported, but uncorroborated, value of £110,000 per day.

11.6.2 Installation Contracts

In reality operators of the Merlin installation system would tender for projects on an equal footing with other contractors, usually for the contract for offshore installation of turbines only, as a sub-contract element of the Main EPC contract. ITT's for these contracts typically call for submission of tenders comprising:

- A lump sum price
- A schedule including weather downtime allowance – normally in the region of 10%, plus planned maintenance requirements (contractors risk).
- Day rates for additional scope of work (clients risk).
- Day rates for additional weather downtime (clients risk)
- Day rates for standby a) at sea operational, b) in harbour operational / non-operational (all at clients risk)

Breakdowns of existing projects have not been available for comparison however the Riso National Laboratory in Denmark quote an average assembly cost of £68,000 per turbine in their "Cost Optimisation of Wind Turbines for Large Scale Offshore Windfarms" Report of 1998 [Ref1.]

For a typical 30 x 2 MW turbine installation contract, using the figures above it is estimated that the Merlin Installation system could be tendered on the basis of:

- A conservative schedule comprising 30 turbines @ 1.0 day / unit plus a) 10% weather downtime, b) 2 days maintenance, c) 10% contingency.
- Installation cost of between £30,000 - £44,586 per turbine, (dependant upon chosen day rate equivalent).

This value represents a very competitive tender and also generates an acceptable profit margin, confirming the overall economic viability of the Merlin installation system.

11.7 Limiting sea state and wind speeds

The number of operational days per period used in the above calculations was based upon an operational limit sea state of Sea State 3. The mathematical modelling and stability assessment described earlier in this report concluded that the Merlin system is capable of completing safe turbine installation operations in conditions up to Sea State 4.

Sea State 4 is characterised by significant waves of the approximate order 2.0m to 3.9m[Ref 3] which are greater than the operational limit for most Jack up vessels to carry out jacking up or down operations. Further the average wind speeds associated with Sea State 4 are in the range of 8.2m /s to 11.3m/s [Ref3] which are very close, to and in some cases, exceed the stated limitations for offshore crane operations. Therefore if the Merlin installation system can be operated safely at Sea State 4 there is clearly a potential market advantage, offering increased working time and reduced weather risk.

It is estimated that an operational limit of Sea State 4 would afford between 2-3% additional working time per summer operating season, equivalent to between 4 and 7 additional working days per 214 day period.

11.5 Costs for modifying the Turbines

Discussions with the turbine manufacturer have shown that modifications will be required to certain components of turbines if they are to be assembled at any attitude other than vertically. These include such items as gearbox oil seals and bearings, access platforms and equipment mountings however, the manufacturer has indicated that these are all relatively minor modifications and the costs associated with this are far outweighed by the potential benefits that could be gained.

11.8 Quotations from Suppliers

Cost Element	Item	Likely Supplier
Development Costs	HPU	Dowty
	Barge Purchase	Anchor Marine Transport Ltd (AMT)
	Lift winches	Leibus
	Project Management	Offshore, Power & Energy Ltd
	Anchor winches, anchor and wires	Balmoral Marine
	Service Crane	National Oilwell (formerly Hydalift)
	Deck offices, domestic facilities and accommodation	Ravenstock
	Generators, Fuel tanks, cables and switch gear	Power Rent
	Steel fabrication / construction Approximately 550te @ £ 2500 – 3000 per te	NE UK Shipyard / Fabricators standard rates
	Fabrication / Installation services	River Tees Engineering & Welding Ltd
	Survival & safety equipment	Cosalt
Annual Operating Costs		
Shore base costs	Shore base heavy lift cranes, mobilisation and operations	Weldex (LR1750 & CC2800)
Vessel	Tugs & Multicats	DSB offshore
Vessel	Harbour costs, port dues, pilotage and conservancy fees	Tees and Hartlepool Port Authority

11.9 Merlin Intellectual Property Rights.(IPR)

EB have applied for patent protection for the elements of the Merlin system with GB and international coverage. The international application is made under the Patent Convention Treaty rules and EB are confident that protection will be available following the due process.

A review of other IPR in the wind turbine installation market has described a series of developments currently being proposed by various companies in Europe and the USA. The equipment described appears significantly more expensive than the proposed Merlin installation system and is not considered to present an additional threat to the take up of the idea over and above the existing TIVs in the market.

11.10 Upside Potential Benefits

This economic study has so far demonstrated the likely costs, sales value and profitability of the Merlin Installation system however the potential benefits of a successful development of this technology extend beyond this.

11.10.1 Benefits to the Engineering Business.

In addition to the direct economic benefits of increased turnover / profit, and sales / IPR licensing revenue, EB would also benefit from:

- Increased workforce and skills base, particularly in Project management, design / drafting, and sales / marketing disciplines.
- Growth of technical expertise and experience of equipment construction, vessel conversions and marine operations.
- Extension of corporate product and capability portfolio.
- Greater understanding of offshore wind industry construction practices together with closer co-operation / partnership with industry participants.
- Increased recognition and credibility within the Offshore wind industry.

11.10.2 Benefits to the Offshore Wind Industry.

The offshore wind industry at large is under considerable pressure on economic and environmental fronts, amongst others. The Merlin installation system will offer many direct and indirect benefits to developers, manufacturers and other participants in the industry, including:

- Genuine reductions in offshore installation costs contributing to the economic viability of developments, particularly marginal projects.
- Production schedules / durations for new installation vessels that meets the planned windfarm construction programmes.

- The capability to install the larger turbines that are a key economic driver to sustain the industry, and thus stimulate the development of the next generation of turbines.

- Development of projects in deeper water.

- Increasing numbers of jobs in both the construction and manufacturing sectors from within the UK supply chain.

- Increased political benefit of secured jobs and revenue may help to offset other political barriers.

- Reduced weather risk and offshore operational downtime with increased safety profile.

- Increased scope for mid life upgrades, major overhauls and ultimate de-commissioning requirements.

11.10.3 Benefits to UK PLC

Stimulation of the UK offshore wind industry will also benefit the UK economy on the whole specifically by:

- Assisting the UK Government to achieve their renewable energy obligations with respect to both the "green energy" and reduced CO^2 emission policies.

- Securing funding and grant benefits from the European community.

- Encouraging turbine, cable, tower and foundations manufacturers to set up production facilities within the UK.

- Increasing the UK standing and recognition in the world renewable energy markets.

- Creation of new jobs or safe guarding existing positions within the UK supply chain, during the development and construction phase of the Merlin system these would include:

i) Fabrication, engineering, ship design / building, electrical, hydraulic and mechanical installation services, which would necessitate a total requirement of the order of 140,000 to 150,000 man-hours or approximately 70 - 75 man years per Merlin system produced (see note 1 below).
ii) Steel, electrical and hydraulic materials and equipment stockists
iii) Transport hauliers

- During operational phases the list would be expanded to include:

i) UK port authorities
ii) Marine support vessel operators
iii) Cable installation and trenching services
iv) Specialist crane contractors / services
v) Local labour to support shore assembly operations

Note1. The man-hours entered have been calculated using industry norms on the basis of:

An average of 145 hours per tonne for fabricated steel construction, including material handling, consumables, QA and painting x 550 tonne ≅ 80,000.

10,000 Naval architectural, construction, electrical and mechanical design hours

5,000 Project, HSEQ and general management hours

45,000 – 50,000 installation and commissioning hours during barge modification / mobilisation

5,000 supply, procurement and misc' hours.

11.11 <u>Economic Conclusions</u>

The objectives of this study have been fully realised, verifying EB's initial premise that the Merlin installation system is a very cost-effective approach to installing offshore wind turbines and demonstrates the following specific conclusions:

i) The Merlin system can be designed and built for £6.7 million, including a 3% contingency and an acceptable profit for the developer. This is estimated to be 50-55% lower than the cost for a new build, conventional Jack up TIV.
ii) A production Merlin system could be constructed in 30-36 weeks with repeat units taking only 24-28 weeks. The construction duration is estimated to be 50% shorter than the programme for a new build conventional Jack up TIV.
iii) Annual operating costs for the Merlin system are estimated to be 20% lower than other TIVs.
iv) Annual overheads for the Merlin system are estimated to be 30% lower than other TIVs.
v) The Merlin installation system can be sold profitably at a rate estimated to be 40% lower than new build conventional TIVs.
vi) Turbines could be installed using the Merlin system for a cost of £30,000 - £38, 000 per turbine, up to 50% lower than the accepted industry standard [ref1].
vii) The Merlin installation system could operate in Sea State 4, which is a higher limit state than most conventional TIVs. Over an operational year it is estimate

that this gives a 2-3% increased window of opportunity for operations, equating to between 4 and 7 additional working days per 214 day period.

viii) The ability to operate in deeper water than most conventional TIVs could generate a specific single market for the Merlin installation system.

ix) The Merlin system design already caters for the next generation of turbines and can accommodate even larger units with some modification. These turbines are beyond the capacity of most current TIVs and give the system a distinct advantage over most conventional installation techniques. The system is thus "future proof" for approximately six to ten years.

x) Contrary to previous studies carried out by other parties, this study has demonstrated that the turbines can be safely transported in a vertical orientation. If this practice is accepted by turbine manufacturers, then the Merlin system can be greatly simplified by the removal of the equipment required to support the turbine at 15° and rotate it to the vertical. This would result in significant development and maintenance costs savings, further contributing to the profitability of the Merlin system.

12 MERLIN INSTALLATION SYSTEM SWOT ANALYSIS.

1. System Development			
Strengths	Weaknesses	Opportunities	Threats
Merlin uses simple, reliable technology, Including standard offshore barges that are widely available, as are the next standard size up if required.	This is a novel and untried installation technique that will require rigorous demonstration to convince turbine manufacturers that turbines can be installed safely in this manner	To offer a credible and cost effective, alternative installation system to a market in which appropriate offshore resources are at a premium and in heavy demand.	Turbine manufacturers may not be willing to co-operate or participate in trials leaving *Merlin Offshore Ltd* exposed to full financial risk
Cost for design and built of the Merlin installation system would be approximately 45 – 45% lower than new build Jack up TIV and up to 80% lower than specialist TIVs	Significant investment is required just to take the project to full-scale offshore demonstration stage together with the will of turbine manufacturers to supply appropriate components.	To encourage developers to proceed with sites that are marginal and thus increase potential available market.	Turbine manufacturers and Windfarm Developers may simply accept that current installation methods are adequate and there is no need for new techniques
Design & construction of the first Merlin installation barge should take 30-36 weeks which is estimated to be a minimum of 50% shorter duration than Jack up TIVs of similar specifications and up to 70% shorter than for specialist TIVs. Repeat build of Merlin barges are expected to take between 16- 20 weeks		The form of connection proposed is de-mountable creating the opportunity to remove whole turbine to the shore for maintenance / replacement. This also meets the growing market demand for ease of de-commissioning at the end of design life.	Current prices and availability of steel and oil on world markets could result in very significant increases in development costs and delays to programme.

System capacity and outline design already cater for the next generation of turbines in terms of weight, size and water depths which "future Proofs" the system for approximately ten years.		Development of a self-loading version of the Merlin system would make the operation even more cost effective, negating the requirement for large shore based cranes.	More effective / cheaper alternative techniques may be developed

2. Operational Aspects			
Strengths	Weaknesses	Opportunities	Threats
Modelling analysis and stability analysis have shown the Merlin system capable of operating at higher Sea States than some existing TIVs. A Sea State 4 limitation could create a 2-3% increase in operating window.	Vessel is subject to wave motion during installation thus it requires a motion compensation systems to dampen wave induced motion from the turbine during engagement with the foundation	To stimulate the offshore wind industry by offering reduced installation costs, operating at increased sea states, giving greater windows of opportunity for offshore operations and by reducing exposure to weather risk.	Turbine manufacturers may not accept that the loading and accelerations experienced by the turbine components during installation at sea state 4 are acceptable.
Turbine is fully assembled onshore reducing offshore working requirements and exposure to weather and therefore offering significant cost savings	Requires significantly greater resources for assembly at the shore base, particularly with respect to very large cranes. (not applicable in the case of the self-loading Merlin option)	To install turbines that are outside of the size and weight limitations of current TIVs. This could also stimulate the market for manufacturers to develop turbines of greater output generating capacity.	There are only a few Cranes in the UK with the capacity required for the shore base operations. They are in heavy demand from civil construction projects and are very expensive.
There is sufficient reserve capacity in the barge to accommodate still larger turbines, i.e.>5MW, but this would require modification of the installation equipment	Some modification and therefore additional cost will be required to the foundation interface to enable alignment and engagement of the turbine installed by Merlin	To expand the local supply chains through use of local labour and engineering support in the assembly yard operations	Design of turbine towers may change significantly requiring completely different installation techniques.

Vessel does not use jack up legs and therefore does not have the same water depth restrictions as competitors and can bid for projects in deeper water.		To capitalise on the market for planned developments in deeper water. Also to extend the current depth driven limitation on site selection increasing the market potential.	Current foundation design rapidly become very uneconomical beyond a certain depth of water and that would most likely curtail any development
Crew and vessel requirements are lower than other systems hence annual offshore operating costs are estimated to be of the order of 20% lower than traditional TIVs		To expand the design of the Merlin installation barge to incorporate a self-loading system, negating the reliance on large shore side cranes	Growth in Offshore Windfarms may simply not reach predicted levels for any number of reasons and therefore the residual demand may not generate demand for more TIVs.
Annual overheads are estimated to of the order of 30% lower than other techniques compared.		To encourage development of Bespoke mechanical lifting aides to support the turbine industry at large.	

13 SUMMARY OF CONCLUSIONS

For ease of reference, the conclusions from each section of this report are reiterated below, under the three main report headings.

13.1 Requirements of Industry.

Section 2 Requirement Conclusions

i) Turbines of greater generating capacity i.e. up to 5MW are needed to sustain the economic growth of the offshore wind industry.
ii) Turbines of 3MW or greater are beyond the installation capacity for most of the current TIVs.
iii) Many new TIVs of greater capacity will need to be constructed to meet the planned installation targets in Europe alone over the next 5 to 10 years.

Section 3 Current Installation Technique Conclusions

i) The maximum operating water depth of most current TIV is between 15-18m.
ii) Sea bed disruption and leg placement can be a problem for Jack up TIVs.
iii) Weather risk during jacking operations is high.

13.2 Technical Issues

Section 4 Merlin Conceptual Conclusions

i) Merlin presents fundamental changes from the conventional method of assembling and installing offshore wind turbines.
ii) The Merlin system uses low cost, readily available vessels.
iii) The Merlin system reduces the risk of weather and operational downtime.
iv) The Merlin system offers significant potential savings through reduced offshore costs and durations.

Section 5 Development Conclusions

i) Industry acceptance of this installation technique presents a significant challenge to the development of the Merlin system.
ii) To date support for the development of the Merlin system has been positive and encouraging.

Section 6 Specification Conclusions

i) Sea State limitations for the Merlin system exceed those of most conventional TIVs.

ii) The Merlin system design permits safe handling of turbines up to 3.5MW in its current form and could accommodate 5MW units with minor modifications.

Section 7 Barge Motion Conclusions

i) Sea State 6 is considered to be an exceptional condition however these results show that the maximum accelerations experienced should not cause any damage the turbine.
ii) Turbine installation and transit operations could be completed safely up to Sea State 4, without risk to the turbines or personnel.
iii) Turbines can safely be transported vertically up to Sea State 4.
iv) The type of barge investigated has very significant reserves of stability with the Merlin installation system and a fully assembled turbine onboard in an operational condition.
v) The vertical, lateral and horizontal acceleration at both the hub and the deck of the barge are acceptable to the limit of effectiveness of personnel and equipment operation on board.

Section 8 Investigation of Dynamic Forces Study Conclusions

Mathematical Modelling

i) Consideration should be given to the stiffness and natural frequency of the system to avoid the effects of system resonance.
ii) 1.3 is an appropriate design factor.
iii) Principle motions of the barge are not significant at Sea State 4.
iv) The relationship between turbine and barge motions can be modified to acceptable levels by the use of an appropriate heave compensation system.

Landing Effects Conclusions

i) The maximum expected landing acceleration using a non-compensated Merlin system at Sea State 4 is 0.19g.
ii) The maximum expected landing acceleration using a compensated Merlin system at Sea State 4 is 0.14g.
iii) The results achieved in this study clearly demonstrate that by using an appropriate heave compensation system, expected landing forces can be reduced to levels which are understood to be acceptable to turbine manufacturers.
iv) The accelerations shown are higher than those estimated for conventional landing but not significantly. If necessary these can be further reduced by the use of a sprung landing damping system.

v) The Merlin system is therefore considered to satisfy the third major objective (Section 7) and hence constitutes an acceptable and safe installation technique.

Section 9 FEA Results and conclusions

i) Assuming a dynamic load factor of 1.3 and allowable Von Mises bending stress of 85% of yield (or an equivalent combination) the 75m position of the upper clamp provides the required support maintain stress within acceptable limits.
ii) Stress levels are lowest using the clamped support configuration.
iii) Case 50 i.e. 75m position, 5m long clamped cradle at 15 degrees elevation is the optimum condition.
iv) The maximum stress is always a compressive stress that occurs at the underside of the tower structure at the upper limit of the upper clamp.
v) The maximum deflection always occurs at the upper end of the tower structure.
vi) The load is shared almost equally between the upper and lower clamps.
vii) The initial results indicate no significant difference in stress when comparing the three lengths of support used, however no detailed analysis of the interface stresses has been carried out.
viii) Further analysis would be carried out as part of the detail engineering of the support clamps.
ix) Stress in the tower could actually be reduced to a very low level by the use of an additional support placed just below the nacelle. This has been factored into the design for future consideration.

Section 10 Foundation Interface Conclusions

i) The design of the turbine / foundation interface is the responsibility of the turbine designer though it is accepted that some modification may be needed in the case of Merlin installed turbines.
ii) The options presented in this section represent potential alternative interfaces that may be more appropriate for use with turbine installed by the Merlin system.
iii) The male / female and female / male options are both suitable for either grouted or clamped connections and both could be used above or below sea level.
iv) The female / male connection option provides the added advantages of:

- Ease of connection of the J-tubes, boat landings and platforms.
- Connection of J-tubes, boat landings and platforms at the shore base and not as a separate offshore activity.
- The opportunity to size the entry cone to cover, or part cover, the scour pit, making cable installation and burial easier.

EB recommend option 2B – Wedged Connection, as the option to be taken forward for further discussions with the turbine manufacturers as this has the benefits of:

♦ Low cost, reliable option.

♦ The lower wedges are fully installed to the foundation in the shore base.

- Ease of connection offshore.

- Positive and safe connection.

13.3 Economic Considerations

Section 11 Economics of Merlin

The objectives of this study have been fully realised, verifying EB's initial premise that the Merlin installation system is a very cost-effective approach to installing offshore wind turbines and demonstrates the following specific conclusions:

i) The Merlin system can be designed and built for £6.7 million, including a 3% contingency and an acceptable profit for the developer. This is estimated to be 45-50% lower than the cost for a new build, conventional Jack up TIV.

ii) A production Merlin system could be constructed in 30 - 36 weeks with repeat units taking only 24 - 28 weeks. The construction duration is estimated to be 50% shorter than the programme for a new build conventional Jack up TIV.

iii) Annual operating costs for the Merlin system are estimated to be 20% lower than other TIVs.

iv) Annual overheads for the Merlin system are estimated to be 30% lower than other TIVs.

v) The Merlin installation system can be sold profitably at a rate estimated to be 40% lower than new build conventional TIVs.

vi) Turbines could be installed using the Merlin system for a cost of approximately 50% lower than the accepted industry standard [ref1].

vii) The Merlin installation system could operate in Sea State 4, which is a higher limit state than most conventional TIVs. Over an operational year it is estimate that this gives a 2-3% increased window of opportunity for operations, equating to between 4 and 7 additional working days per 214 day period.

viii) The ability to operate in deeper water than most conventional TIVs could generate a specific single market for the Merlin installation system.

ix) The Merlin system design already caters for the next generation of turbines and can accommodate even larger units with some modification. These turbines are beyond the capacity of most current TIVs and gives the system a distinct advantage over most conventional installation techniques. The system is thus "future proof" for approximately six to ten years.

x) Contrary to previous studies carried out by other parties, this study has demonstrated that the turbines can be safely transported in a vertical orientation. If this practice is accepted by turbine manufacturers, then the Merlin system can be greatly simplified by the removal of the equipment required to support the turbine at 15° and rotate it to the vertical. This would result in significant development and maintenance costs savings, further contributing to the profitability of the Merlin system.

References:

i) Cost Optimisation of Wind Turbines for Large Scale Offshore Wind Farms, Riso National Laboratory 1998

ii) Concerted Action on Offshore Wind Energy in Europe (2001) (CA-OWEE)

iii) Lloyd's Register of Shipping "Code for Lifting Appliances in a Marine Environment" 1987

iv) Melbourne Marine – Assessment of Operability and Stability, Document C04016-R02

v) MIZUHO International PLC, Press release 22nd April 2004 concerning acquisition of business and assets of Mayflower Energy Ltd

vi) DTI Sustainable Energy Technology Route Map of 29th October 2002.

Appendix A - Extracts from Melbourne Marine Services Assessment of Operability and Stability

APPENDIX 1 - OPERATING SCENARIOS AND LOADING CONDITIONS

INTRODUCTION

This report has been prepared by Melbourne Marine Services Limited on behalf of The Engineering Business Limited and is concerned with the findings of an assessment of the stability, loading and operability characteristics of the barge *AMT EXPLORER* whilst being used to deploy wind turbines as part of the *Merlin* project. The results of the assessment will be used in future investigations of the barge's dynamic behaviour in the context of wind turbine installation projects.

The operability assessment was carried out using Version 3.0 of the ShipmoPC seakeeping analysis system (ref. 1) from Sable Maritime of Ontario, Canada. This industry-standard analysis package, which utilises 2-dimensional strip theory for the assessment of vessel motion responses in the frequency domain for six degrees of freedom, was originally developed by the research and development organisation of the Canadian Department of National Defense. It is widely considered as one of the most reliable and accurate ship motion prediction systems currently available.

The stability and loading assessment carried out by Melbourne Marine considered five individual loading scenarios as being representative of the sequence of events involved in the deployment of a wind turbine from the barge. The hydrostatic particulars of the barge in relation to each of these scenarios were derived from an AutoHydro model (ref. 2) of the barge. The basic barge geometry and internal arrangement details were obtained from information supplied by EBL.

Utilising information relating to barge geometry and loading, motion responses in regular waves for six degrees of freedom (roll, heave, pitch, surge, sway and yaw) were determined at wave frequencies ranging from 0.30 to 1.30 radians/second and at vessel headings relative to the wave direction ranging from 0° (following seas) to 180° (head seas) at 30° intervals. The barge motion responses derived from this analysis are presented in terms of transfer functions, also known as Response Amplitude Operators (RAOs), for each of the six degrees of freedom. These Response Amplitude Operators indicate the barge's responses in regular waves of unit wave amplitude at various wave frequencies and at the specified headings relative to the wave direction. This basic response information was subsequently used to derive an indication of the likely effect on the operability of the barge and of its motion responses in irregular seas.

This report contains details of the scope of work undertaken by Melbourne Marine Services, the assumptions made regarding the geometry and loading of the barge and the derivation and presentation of the stability, loading and operability information.

SCOPE OF WORK

Summary of workscope

The basic aim of the assessment undertaken by Melbourne Marine and reported here was to derive an indication of the expected seakeeping performance of the *AMT EXPLORER* for a number of predefined loading conditions corresponding to various stages in the deployment of wind turbines from the barge.

An analysis of the vessel's ability to satisfy intact stability requirements for each condition was also required.

The RAOs for six degrees of freedom are presented in non-dimensional tabular format for a range of wave frequencies for two defined operating scenarios. These are in addition to those given in Report C04016-R01-0 and contain Conditions 1 and 5 at a forward speed of 5.0 knots.

An indication of irregular responses assessment for agreed sea states and vessel headings.

Determination of motions and accelerations at the turbine hub and deck level for specified sea states and vessel headings is presented in both graphical and tabular format.

The derivation of values of limiting operational sea state relative to Subjective Motion Criteria are also given.

In consultation with EBL it was decided that the seakeeping assessment would be carried out on the vessel for the following conditions:

Condition	Speed (knots)	Turbine Position (deg)	Sea State
1	0.0	15	3 – 6
1a	5.0	15	3 – 6
5	0.0	90 Upper	3 – 6
5a	5.0	90 Upper	3 – 6

Table 23 – Vessel and environmental parameters

The location of the turbine hub was given by EBL as being:

Condition	Height Above Deck (m)	Distance Fwd of AP (m)
1 and 1a	27.665	74.259
5 and 5a	90.430	-4.380

Table 24 Turbine Hub Locations

A point at a height of 1.5 m above deck, 4.0 m forward of the AP and 7.62 m off the centreline was chosen as being representative of a typical working position.

METHODOLOGY

Vessel details

The following information relating to the *AMT EXPLORER* was provided by EBL and used in the course of the assessment:

Document/Drawing	Reference	Rev.
Profile and Decks	-	1
Combined GA and Capacity Plan	-	-
Midship Section	-	2
AMT EXPLORER Trim and Stability Book	-	0
Merlin Centre of Mass 15 Degrees	C130-20-0024	0
Merlin Centre of Mass 30 Degrees	C130-20-0025	0
Merlin Centre of Mass 60 Degrees	C130-20-0026	0
Merlin Centre of Mass 90 Degrees Middle	C130-20-0027	0
Merlin Centre of Mass 90 Degrees Upper	C130-20-0028	0

Table 25 – Reference Documentation

The *AMT EXPLORER* is a rectangular, swim-ended offshore transportation barge which has the following main particulars:

Length overall (approx.)	91.44 m
Breadth moulded	30.48 m
Depth (main deck)	7.62 m
Scantling draft	6.17 m

Table 26 – Barge Main Particulars

Information relating to the barge's hull geometry was supplied by EBL in the form of a general arrangement and associated structural drawings. This information was initially used to create a numerical model of the external hull of the vessel. The accuracy of this model was confirmed by comparison of the hydrostatic particulars derived from the model with those contained in the vessel's current trim and stability booklet. The ShipmoPC model also included details of hull appendages (such as the skegs) which act to provide roll motion damping.

Loading conditions

A loading model of the barge was developed for use in the AutoHydro naval architectural analysis system. This model comprised a complete representation of the barge's internal and external geometry. The validity of this model was checked against data contained in the vessel's stability information booklet as provided by EBL. A basic loading condition was derived using this AutoHydro model with the amount and disposition of ballast water being determined so as to provide an acceptable basis for the assessment. In all cases the amount of ballast water in each tank was maintained at a level greater than 70% of the maximum level in accordance with the requirements of Lloyd's Register for deep sea operations.

For each of the five operating scenarios the mass and location of each item comprising the *Merlin* system were added to the basic barge configuration in order to arrive at the loading conditions to be used in the assessment. The intact stability characteristics of each loading condition were derived in order to demonstrate to the acceptability of the proposed loading configurations. Details of the five operating scenarios and the associated barge loading conditions are contained in Appendix 3 of this report.

Table 27 provides details of the five loading conditions considered during the course of the assessment. For the purposes of this seakeeping assessment only Conditions 1 and 5 have been considered at both 0.0 knots and 5.0 knots for each case.

	Loading Condition				
Parameter	No. 1/1a	No. 2	No. 3	No. 4	No. 5/5a
Draft aft (T_A)	4.766	4.824	4.916	4.899	4.899
Draft forward (T_F)	4.872	4.815	4.923	4.888	4.888
Mean draft (T_M)	4.819	4.820	4.919	4.894	4.893
Trim by stern	-0.107	0.009	-0.007	0.011	0.011
Longl. centre of gravity (LCG)	45.844	45.649	45.682	45.651	45.651
Vertical centre of gravity (KG)	5.465	5.787	6.223	6.305	6.719
Metacentric height (GM)	14.725	14.422	13.673	13.671	13.259

Table 27 – Loading Conditions

Notes to Table 27 :

LCG in metres fwd. A.P.

KG in metres above baseline

Trim is positive by the stern

GM is transverse metacentric height with free surface correction.

Analysis

Using the information defined above, together with the model of the vessel's hull geometry, vessel responses in regular waves for six degrees of freedom (roll, heave, pitch, surge, sway and yaw) were determined at wave frequencies ranging from 0.30 to 1.30 radians/second and at vessel headings relative to the wave direction ranging from 0° (following seas) to 180° (head seas) at 30° intervals. The vessel motion responses derived from this analysis are presented in terms of transfer functions, also known as Response Amplitude Operators (RAOs), for each of the six degrees of freedom. These Response Amplitude Operators indicate the vessel's responses to regular waves of unit wave amplitude at various wave frequencies and at the specified headings relative to the wave direction. The RAOs relating to each of the specified loading conditions are contained in Report C04016-R01-0. The RAOs for Conditions 1 and 5 at 5.0 knots are given in Appendix 1 and 2 of this report.

Further to the determination of regular responses, the behaviour of the vessel in irregular seas was also assessed based upon a JONSWAP (Joint North Sea Wave Project) spectrum with a $\cos^2$ spreading function. The JONSWAP spectrum was utilised with the following wave period and wave height parameters:

Sea State	Modal Wave Period (Tp) (seconds)	Significant Wave Height (Hs) (metres)
3	5.20	0.80
4	5.50	1.30
5	6.50	2.90
6	7.00	5.30

Table 28 – JONSWAP Parameters

For each of the wave period/wave height combinations listed above, irregular responses were determined, with these being presented in terms of motions at the vessel's centre of gravity, and accelerations at the two locations on the vessel.

PRESENTATION OF RESULTS

Intact Stability

The *AMT EXPLORER* is defined as an unmanned dumb pontoon barge and as such must satisfy the following stability criteria:
the area under the righting lever curve (GZ) should not be less than:-
0.08 metre radians up the angle at which the maximum righting lever occurs, and
0.03 metre radians between the angle of 30 degrees and 40 degrees, or the angle of downflooding.

The actual areas under the GZ curve for each condition are given below:

Condition	Area 0 – MaxGZ (metre radians)	Required (metre radians)	Excess (metre radians)	Area 30 – 40 (metre radians)	Required (metre radians)	Excess (metre radians)
1 and 1a	1.085	0.080	1.005	0.628	0.030	0.598
2	1.016	0.080	0.936	0.596	0.030	0.566
3	0.903	0.080	0.823	0.524	0.030	0.494
4	0.898	0.080	0.818	0.522	0.030	0.492
5 and 5a	0.833	0.080	0.753	0.482	0.030	0.452

Table 29 – Areas under GZ curve

From these results it is apparent that the *AMT EXPLORER* has ample stability in all of the conditions which have been assessed in this study.

Presentation of regular responses

The results of the regular motions analysis are given in terms of Response Amplitude Operators for each of the six degrees of freedom and seven headings in tabular format in Appendix 1 and 2 of this report. These RAOs are in addition to those given in Report C04016-R01-0 and contain the results for Conditions 1 and 5 with a forward speed of 5.0 knots.

Presentation of irregular responses

The irregular responses are presented in terms of motions at the vessel's centre of gravity along with accelerations at two locations on the vessel.
These values are presented by ShipMo in terms of Root Mean Squared values (RMS). These values can be expressed in terms of significant and maximum expected values by means of the following relationships:

Significant response { 2.0*RMS

Maximum response { 2.0*Significant response

Where:

Significant response is the average of the 1/3 highest observed values.

The results of the irregular responses analysis are given in the following pages in both graphical and tabular format. These show the relationship between significant motion response and significant wave height for roll, heave and pitch motions for selected headings relative to the principal wave direction.

In addition, the vertical, lateral and longitudinal significant accelerations at the hub of the turbine and a location on the deck are also shown. It is these particular parameters which are generally accepted to limit the effectiveness of personnel and equipment operation onboard a vessel.

Condition 1

Heading	Sea State 3 Significant Roll (degrees)	Sea State 4 Significant Roll (degrees)	Sea State 5 Significant Roll (degrees)	Sea State 6 Significant Roll (degrees)
Following Seas	0.286	0.498	0.752	1.158
Beam Seas	0.676	1.154	2.050	3.240
Bow Quartering Seas	0.400	0.688	1.182	1.872
Head Seas	0.256	0.446	0.690	1.088

Heading	Sea State 3 Significant Heave (metres)	Sea State 4 Significant Heave (metres)	Sea State 5 Significant Heave (metres)	Sea State 6 Significant Heave (metres)
Following Seas	0.016	0.036	0.202	0.526
Beam Seas	0.040	0.092	0.486	1.220
Bow Quartering Seas	0.024	0.056	0.298	0.758
Head Seas	0.016	0.036	0.200	0.520

Heading	Sea State 3 Significant Pitch (degrees)	Sea State 4 Significant Pitch (degrees)	Sea State 5 Significant Pitch (degrees)	Sea State 6 Significant Pitch (degrees)
Following Seas	0.076	0.162	0.784	1.976
Beam Seas	0.082	0.180	0.846	2.008
Bow Quartering Seas	0.076	0.166	0.804	1.996
Head Seas	0.074	0.162	0.790	1.990

Table 30 – Condition 1 Significant Motion Responses

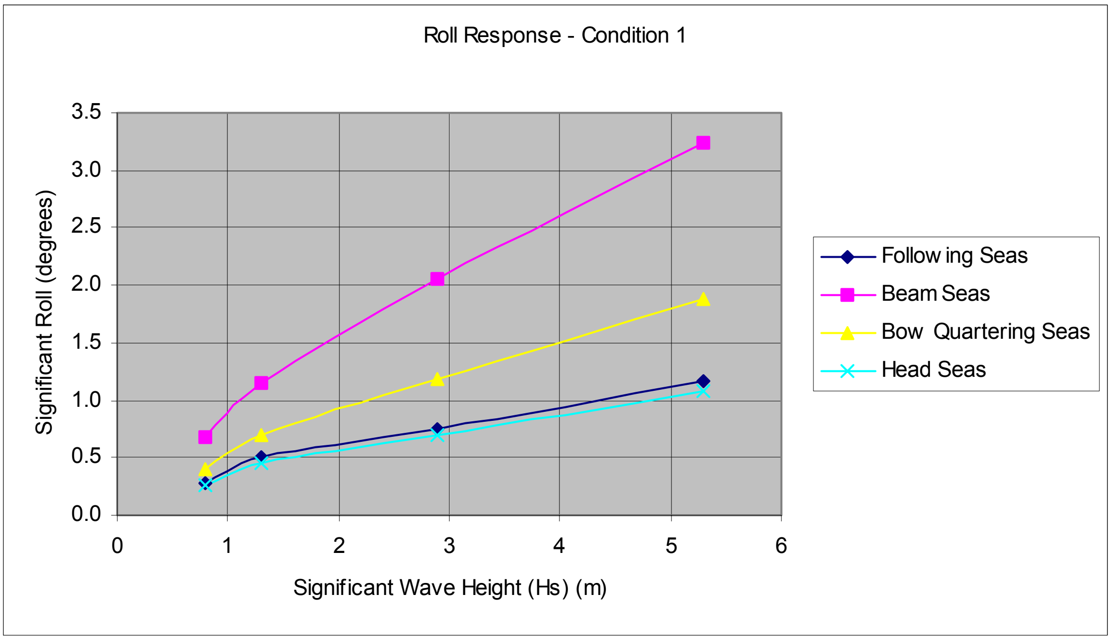


Figure 24 – Significant roll vs. significant wave height

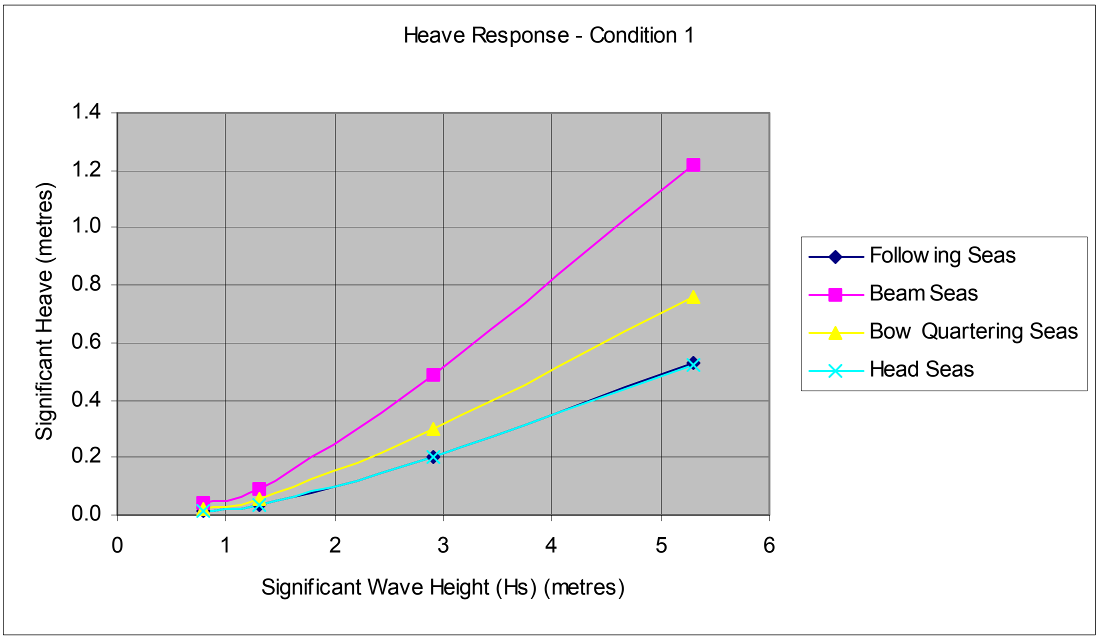


Figure 25 – Significant heave vs. significant wave height

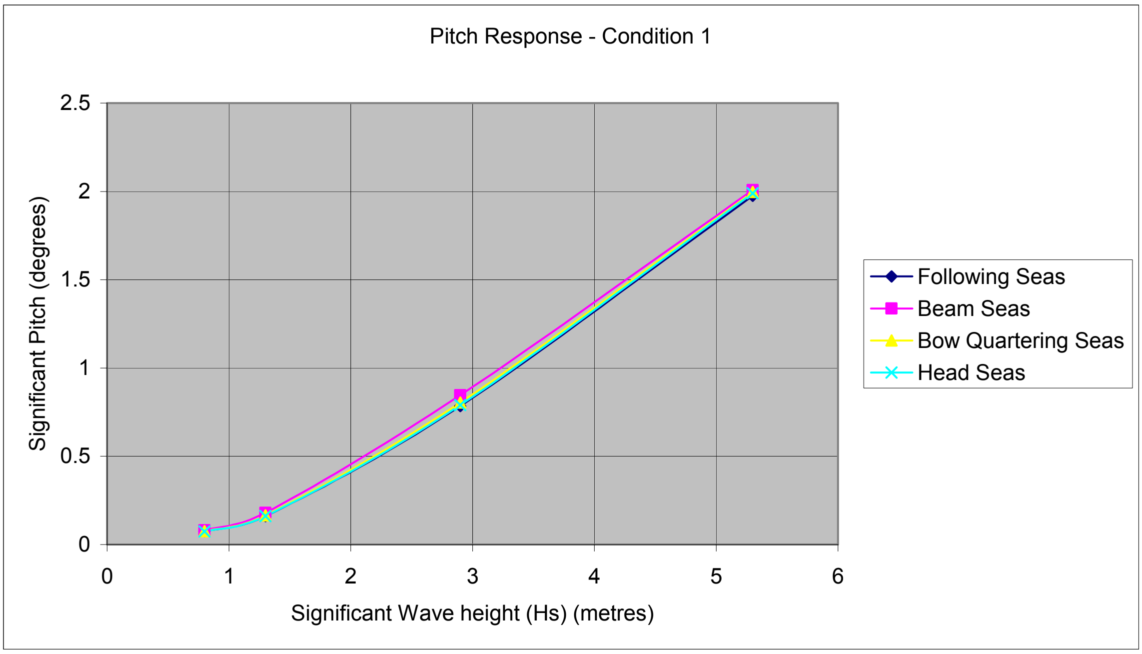


Figure 26 - Significant pitch vs. significant wave height

Condition 1

Heading	Sea State 3 Sig Vertical Accel (m/s^2)	Sea State 4 Sig Vertical Accel (m/s^2)	Sea State 5 Sig Vertical Accel (m/s^2)	Sea State 6 Sig Vertical Accel (m/s^2)
Following Seas	0.039	0.078	0.314	0.765
Beam Seas	0.059	0.118	0.491	1.099
Bow Quartering Seas	0.039	0.098	0.353	0.824
Head Seas	0.039	0.078	0.314	0.726

Heading	Sea State 3 Sig Lateral Accel (m/s^2)	Sea State 4 Sig Lateral Accel (m/s^2)	Sea State 5 Sig Lateral Accel (m/s^2)	Sea State 6 Sig Lateral Accel (m/s^2)
Following Seas	0.177	0.314	0.471	0.746
Beam Seas	0.392	0.647	0.903	1.236
Bow Quartering Seas	0.235	0.373	0.549	0.804
Head Seas	0.137	0.235	0.353	0.589

Heading	Sea State 3 Sig Longitudinal Accel (m/s^2)	Sea State 4 Sig Longitudinal Accel (m/s^2)	Sea State 5 Sig Longitudinal Accel (m/s^2)	Sea State 6 Sig Longitudinal Accel (m/s^2)
Following Seas	0.039	0.059	0.118	0.451
Beam Seas	0.039	0.059	0.118	0.471
Bow Quartering Seas	0.039	0.059	0.118	0.491
Head Seas	0.039	0.059	0.118	0.491

Table 31 – Condition 1 Significant Accelerations at Turbine Hub

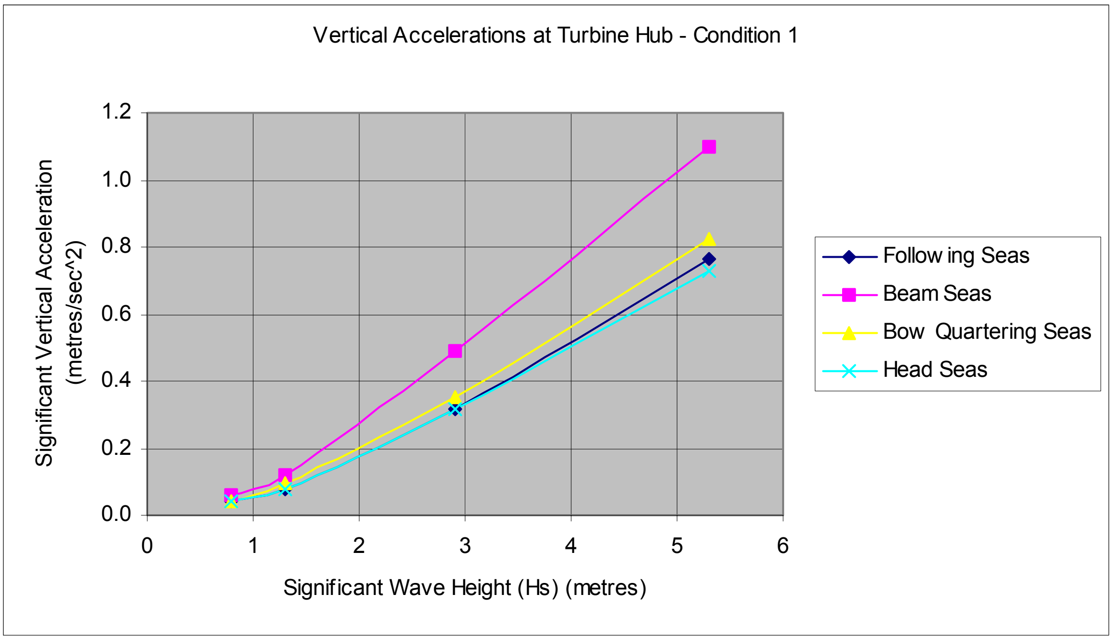


Figure 27 – Significant vertical acceleration vs. significant wave height at Turbine Hub

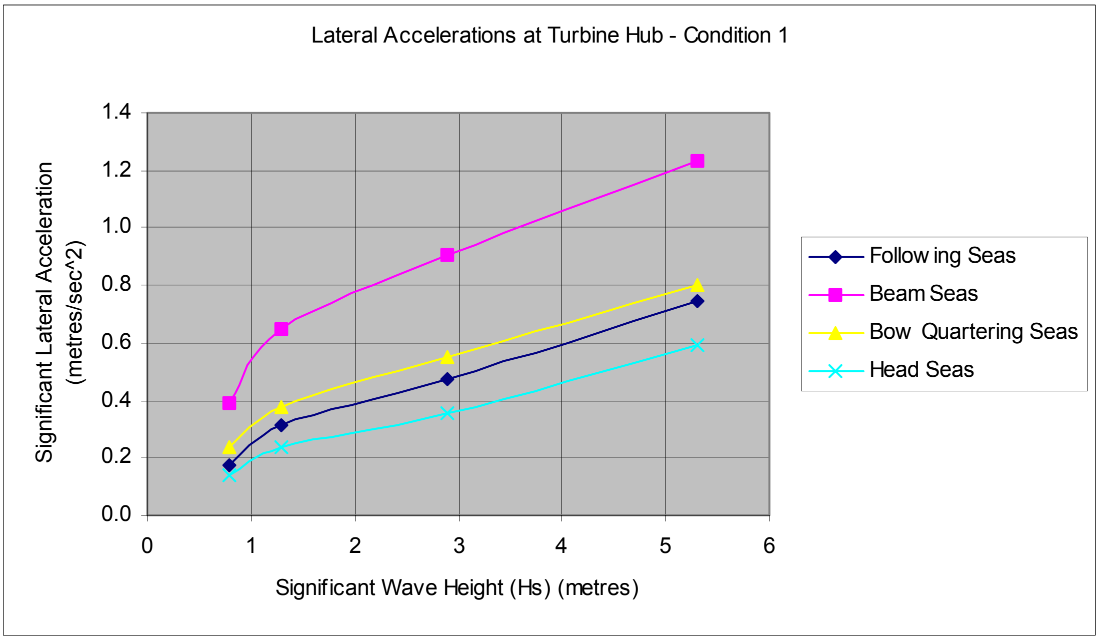


Figure 28 – Significant lateral acceleration vs. significant wave height at Turbine Hub

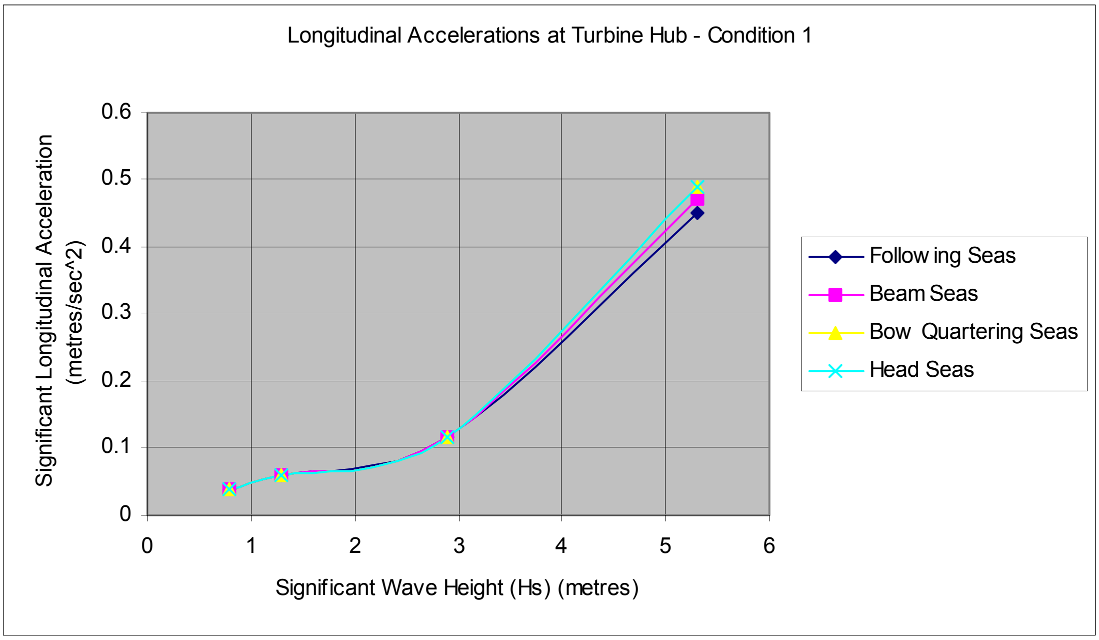


Figure 29 – Significant longitudinal acceleration vs. significant wave height at Turbine Hub

Condition 1

Heading	Sea State 3 Sig Vertical Accel (m/s^2)	Sea State 4 Sig Vertical Accel (m/s^2)	Sea State 5 Sig Vertical Accel (m/s^2)	Sea State 6 Sig Vertical Accel (m/s^2)
Following Seas	0.078	0.157	0.451	1.020
Beam Seas	0.137	0.255	0.746	1.550
Bow Quartering Seas	0.098	0.177	0.569	1.256
Head Seas	0.078	0.137	0.451	1.079

Heading	Sea State 3 Sig Lateral Accel (m/s^2)	Sea State 4 Sig Lateral Accel (m/s^2)	Sea State 5 Sig Lateral Accel (m/s^2)	Sea State 6 Sig Lateral Accel (m/s^2)
Following Seas	0.059	0.118	0.373	0.706
Beam Seas	0.118	0.216	0.608	1.138
Bow Quartering Seas	0.078	0.157	0.451	0.863
Head Seas	0.078	0.137	0.373	0.726

Heading	Sea State 3 Sig Longitudinal Accel (m/s^2)	Sea State 4 Sig Longitudinal Accel (m/s^2)	Sea State 5 Sig Longitudinal Accel (m/s^2)	Sea State 6 Sig Longitudinal Accel (m/s^2)
Following Seas	0.039	0.078	0.196	0.373
Beam Seas	0.020	0.059	0.157	0.334
Bow Quartering Seas	0.039	0.078	0.177	0.353
Head Seas	0.039	0.078	0.196	0.373

Table 32 – Condition 1 Significant Accelerations at Working Deck

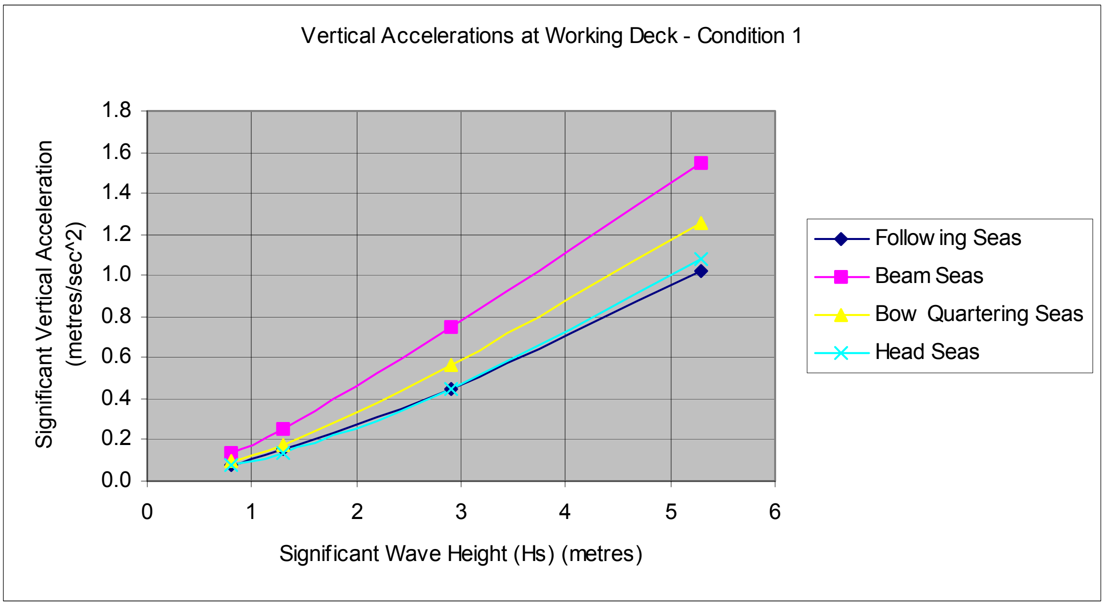


Figure 30 – Significant vertical acceleration vs. significant wave height at Working Deck

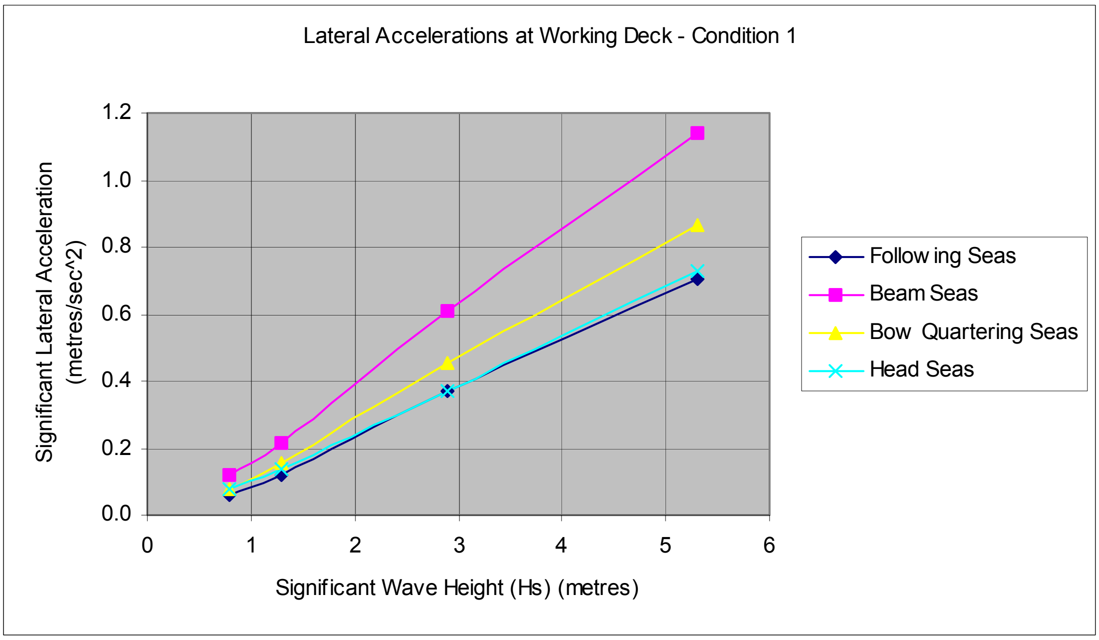


Figure 31 – Significant lateral acceleration vs. significant wave height at Working Deck

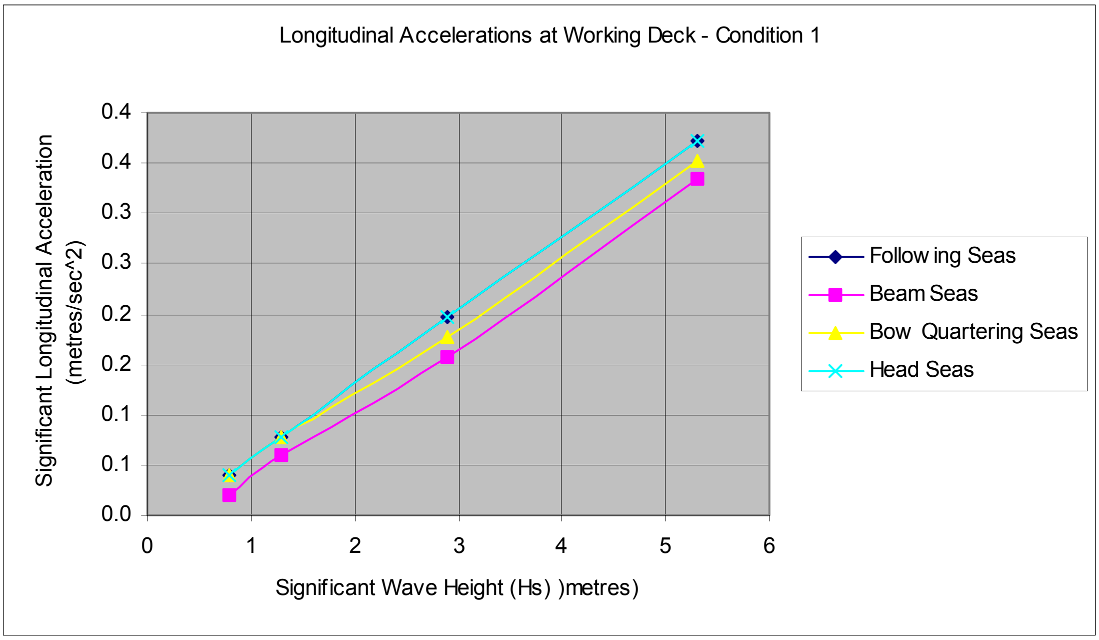


Figure 32 – Significant longitudinal acceleration vs. significant wave height at Working Deck

Condition 1a

Heading	Sea State 3 Significant Roll (degrees)	Sea State 4 Significant Roll (degrees)	Sea State 5 Significant Roll (degrees)	Sea State 6 Significant Roll (degrees)
Following Seas	0.178	0.292	0.522	0.878
Beam Seas	0.740	1.270	2.214	3.476
Bow Quartering Seas	0.400	0.698	1.392	2.252
Head Seas	0.180	0.328	0.930	1.574

Heading	Sea State 3 Significant Heave (metres)	Sea State 4 Significant Heave (metres)	Sea State 5 Significant Heave (metres)	Sea State 6 Significant Heave (metres)
Following Seas	0.042	0.082	0.318	0.704
Beam Seas	0.044	0.100	0.508	1.262
Bow Quartering Seas	0.026	0.054	0.280	0.720
Head Seas	0.018	0.036	0.180	0.486

Heading	Sea State 3 Significant Pitch (degrees)	Sea State 4 Significant Pitch (degrees)	Sea State 5 Significant Pitch (degrees)	Sea State 6 Significant Pitch (degrees)
Following Seas	0.160	0.310	1.070	2.400
Beam Seas	0.116	0.242	0.958	2.068
Bow Quartering Seas	0.080	0.152	0.574	1.442
Head Seas	0.082	0.152	0.546	1.394

Table 33 – Condition 1a Significant Motion Responses

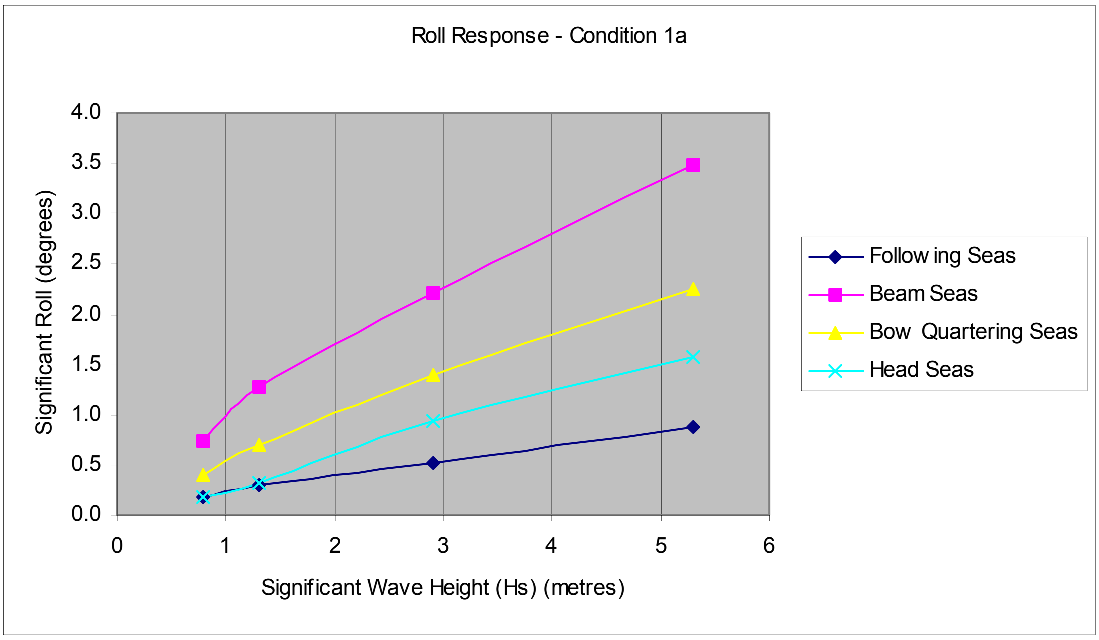


Figure 33 – Significant roll vs. significant wave height

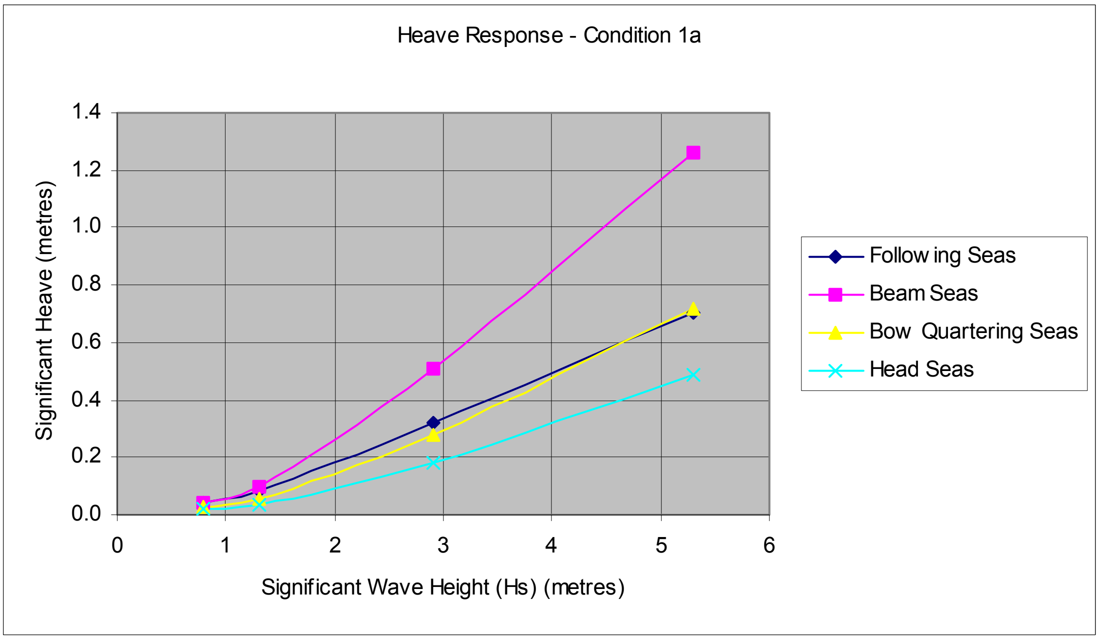


Figure 34 – Significant heave vs. significant wave height

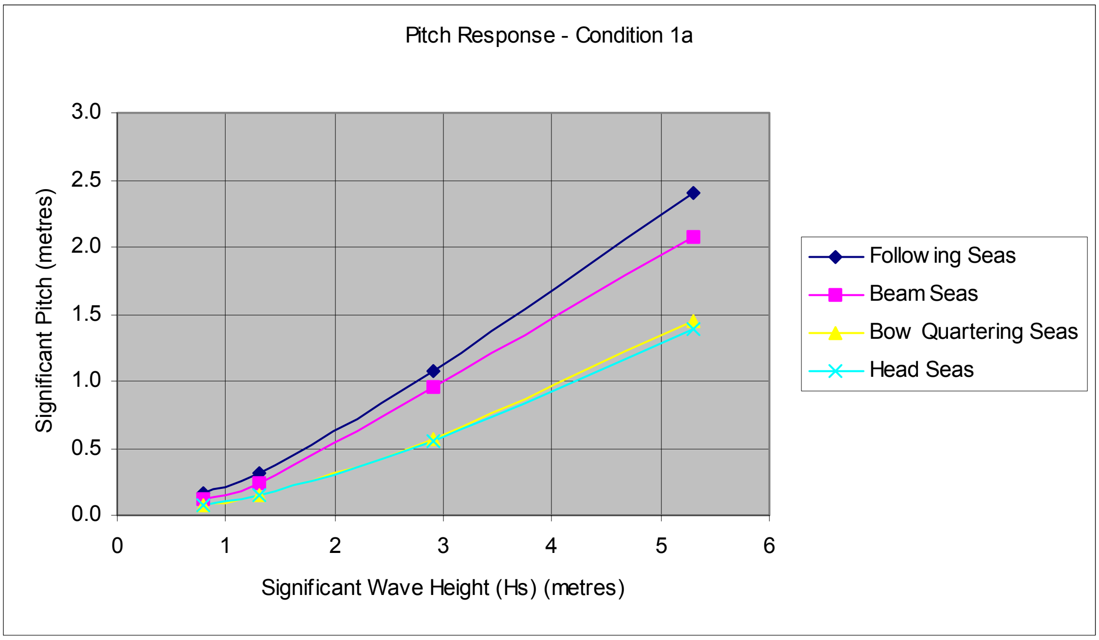


Figure 35 – Significant pitch vs. significant wave height

Condition 1a

Heading	Sea State 3 Sig Vertical Accel (m/s^2)	Sea State 4 Sig Vertical Accel (m/s^2)	Sea State 5 Sig Vertical Accel (m/s^2)	Sea State 6 Sig Vertical Accel (m/s^2)
Following Seas	0.078	0.137	0.412	0.824
Beam Seas	0.078	0.157	0.569	1.138
Bow Quartering Seas	0.098	0.177	0.392	0.785
Head Seas	0.118	0.177	0.373	0.746

Heading	Sea State 3 Sig Lateral Accel (m/s^2)	Sea State 4 Sig Lateral Accel (m/s^2)	Sea State 5 Sig Lateral Accel (m/s^2)	Sea State 6 Sig Lateral Accel (m/s^2)
Following Seas	0.098	0.157	0.294	0.510
Beam Seas	0.432	0.726	1.001	1.393
Bow Quartering Seas	0.255	0.432	0.687	1.040
Head Seas	0.118	0.216	0.510	0.804

Heading	Sea State 3 Sig Longitudinal Accel (m/s^2)	Sea State 4 Sig Longitudinal Accel (m/s^2)	Sea State 5 Sig Longitudinal Accel (m/s^2)	Sea State 6 Sig Longitudinal Accel (m/s^2)
Following Seas	0.020	0.059	0.196	0.373
Beam Seas	0.039	0.078	0.216	0.432
Bow Quartering Seas	0.059	0.098	0.255	0.510
Head Seas	0.059	0.098	0.255	0.510

Table 34 – Condition 1a Significant Accelerations at Turbine Hub

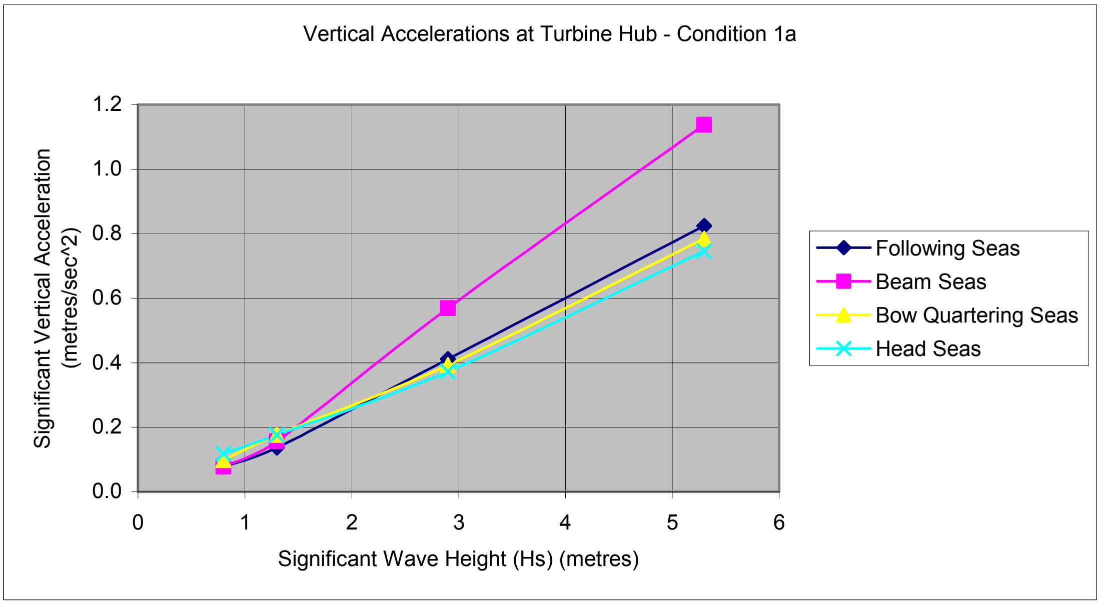


Figure 36 – Significant vertical acceleration vs. significant wave height at Turbine Hub

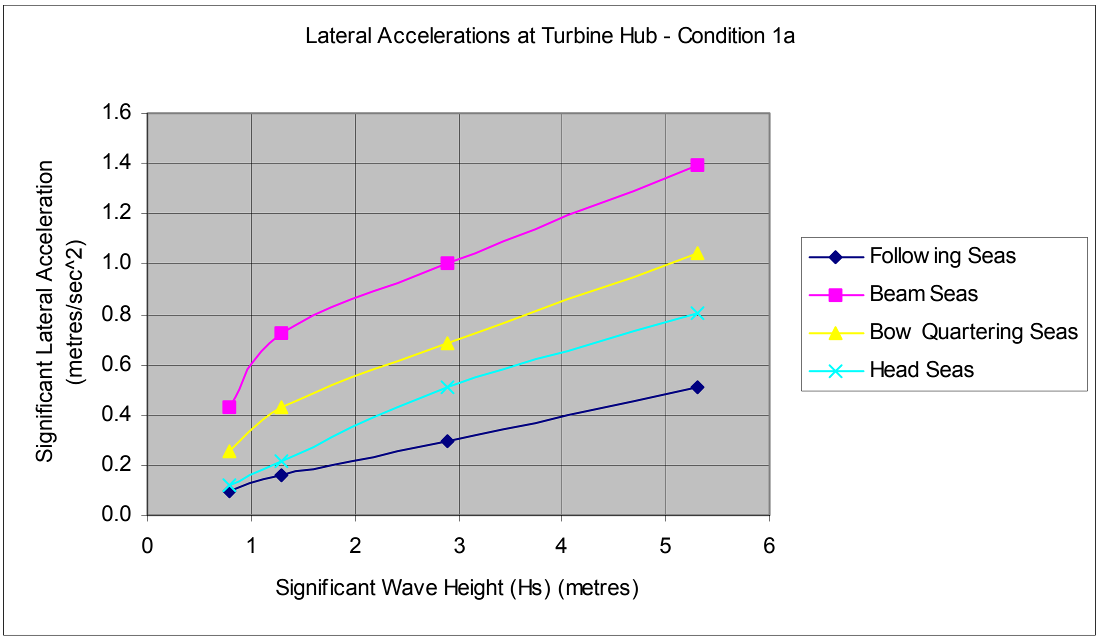


Figure 37 – Significant lateral acceleration vs. significant wave height at Turbine Hub

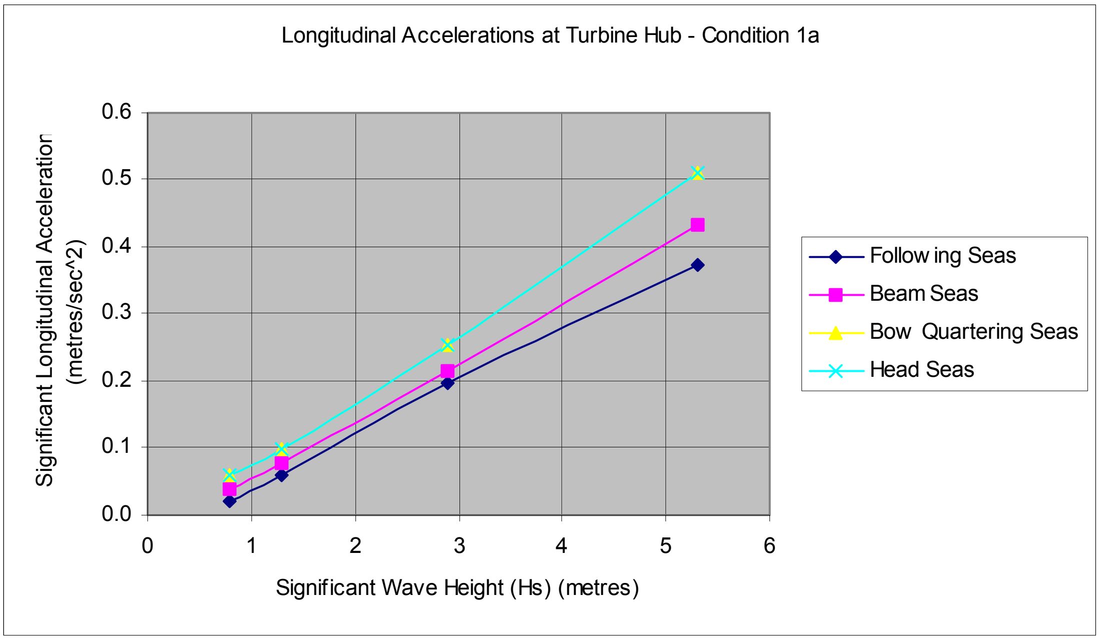


Figure 38 – Significant longitudinal acceleration vs. significant wave height at Turbine Hub

Condition 1a

Heading	Sea State 3 Sig Vertical Accel (m/s²)	Sea State 4 Sig Vertical Accel (m/s²)	Sea State 5 Sig Vertical Accel (m/s²)	Sea State 6 Sig Vertical Accel (m/s²)
Following Seas	0.078	0.137	0.412	0.824
Beam Seas	0.157	0.275	0.726	1.432
Bow Quartering Seas	0.137	0.235	0.569	1.177
Head Seas	0.118	0.216	0.471	0.981

Heading	Sea State 3 Sig Lateral Accel (m/s²)	Sea State 4 Sig Lateral Accel (m/s²)	Sea State 5 Sig Lateral Accel (m/s²)	Sea State 6 Sig Lateral Accel (m/s²)
Following Seas	0.059	0.098	0.314	0.628
Beam Seas	0.118	0.216	0.608	1.138
Bow Quartering Seas	0.098	0.177	0.491	0.942
Head Seas	0.078	0.157	0.432	0.824

Heading	Sea State 3 Sig Longitudinal Accel (m/s²)	Sea State 4 Sig Longitudinal Accel (m/s²)	Sea State 5 Sig Longitudinal Accel (m/s²)	Sea State 6 Sig Longitudinal Accel (m/s²)
Following Seas	0.039	0.078	0.196	0.373
Beam Seas	0.039	0.059	0.177	0.353
Bow Quartering Seas	0.039	0.078	0.177	0.353
Head Seas	0.039	0.078	0.196	0.373

Table 35 – Condition 1a Significant Accelerations at Working Deck

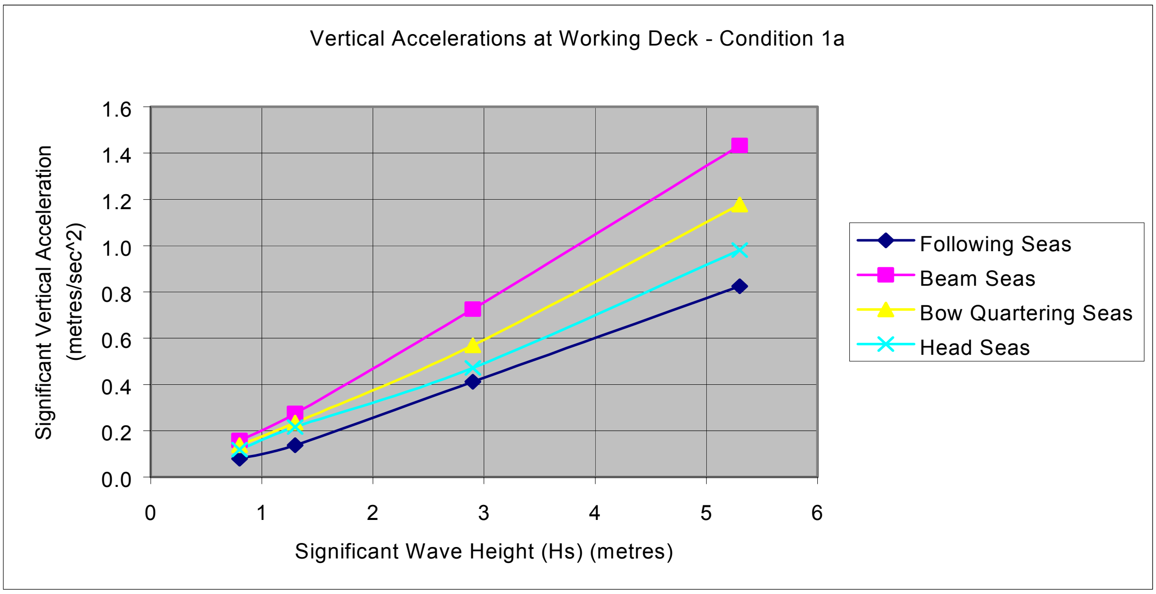


Figure 39 – Significant vertical acceleration vs. significant wave height at Working Deck

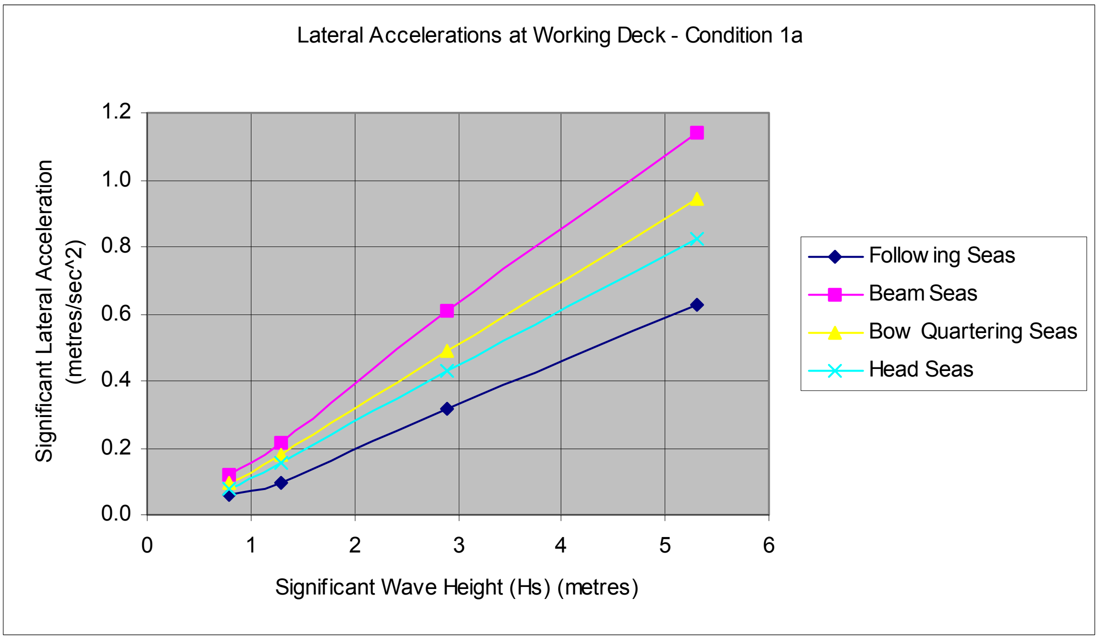


Figure 40 – Significant lateral acceleration vs. significant wave height at Working Deck

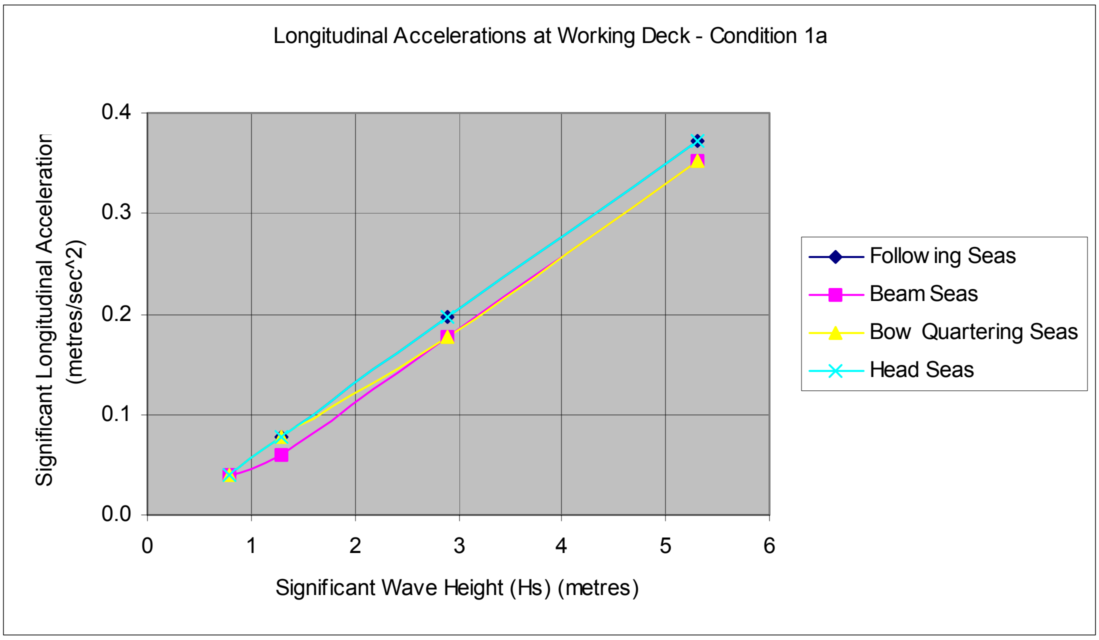


Figure 41 – Significant longitudinal acceleration vs. significant wave height at Working Deck

Condition 5

Heading	Sea State 3 Significant Roll (degrees)	Sea State 4 Significant Roll (degrees)	Sea State 5 Significant Roll (degrees)	Sea State 6 Significant Roll (degrees)
Following Seas	0.252	0.482	0.890	1.262
Beam Seas	0.514	0.960	1.990	3.020
Bow Quartering Seas	0.322	0.610	1.216	1.820
Head Seas	0.232	0.446	0.826	1.186

Heading	Sea State 3 Significant Heave (metres)	Sea State 4 Significant Heave (metres)	Sea State 5 Significant Heave (metres)	Sea State 6 Significant Heave (metres)
Following Seas	0.016	0.036	0.202	0.404
Beam Seas	0.040	0.090	0.482	0.964
Bow Quartering Seas	0.024	0.054	0.296	0.592
Head Seas	0.016	0.036	0.198	0.396

Heading	Sea State 3 Significant Pitch (degrees)	Sea State 4 Significant Pitch (degrees)	Sea State 5 Significant Pitch (degrees)	Sea State 6 Significant Pitch (degrees)
Following Seas	0.076	0.160	0.776	1.960
Beam Seas	0.080	0.178	0.838	1.996
Bow Quartering Seas	0.076	0.164	0.800	1.990
Head Seas	0.074	0.160	0.786	1.982

Table 36 – Condition 5 Significant Motion Responses

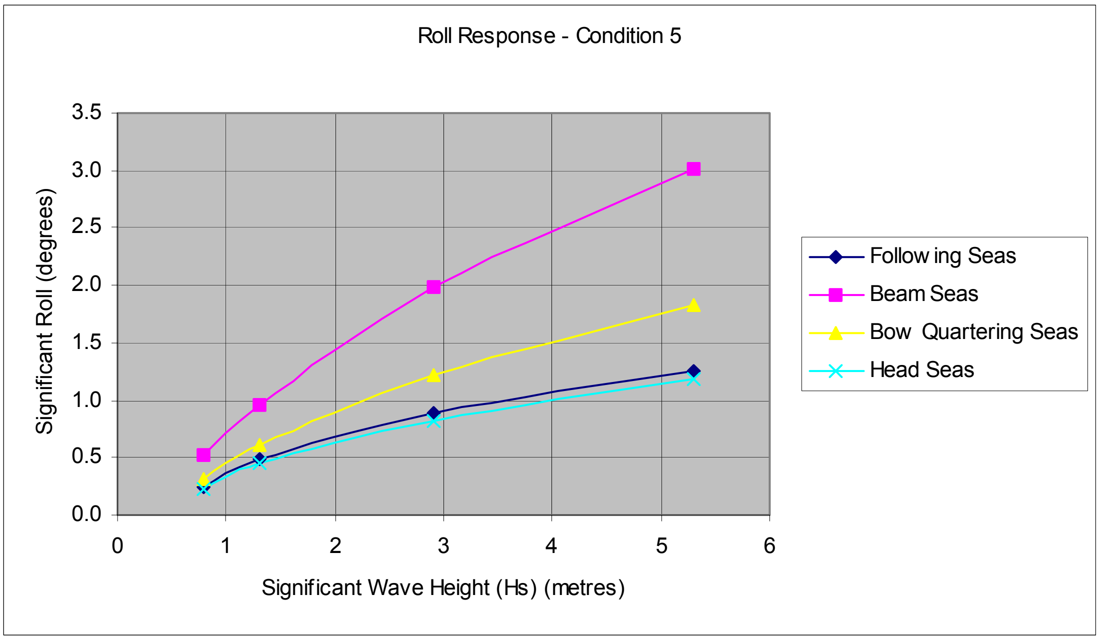


Figure 42 – Significant roll vs. significant wave height

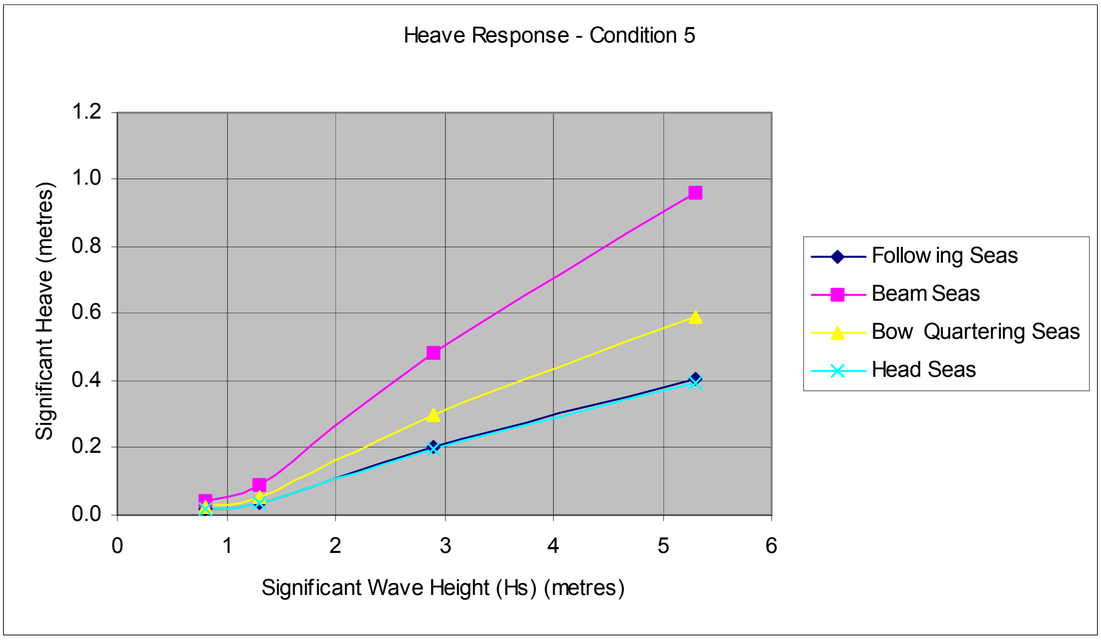


Figure 43 – Significant heave vs. significant wave height

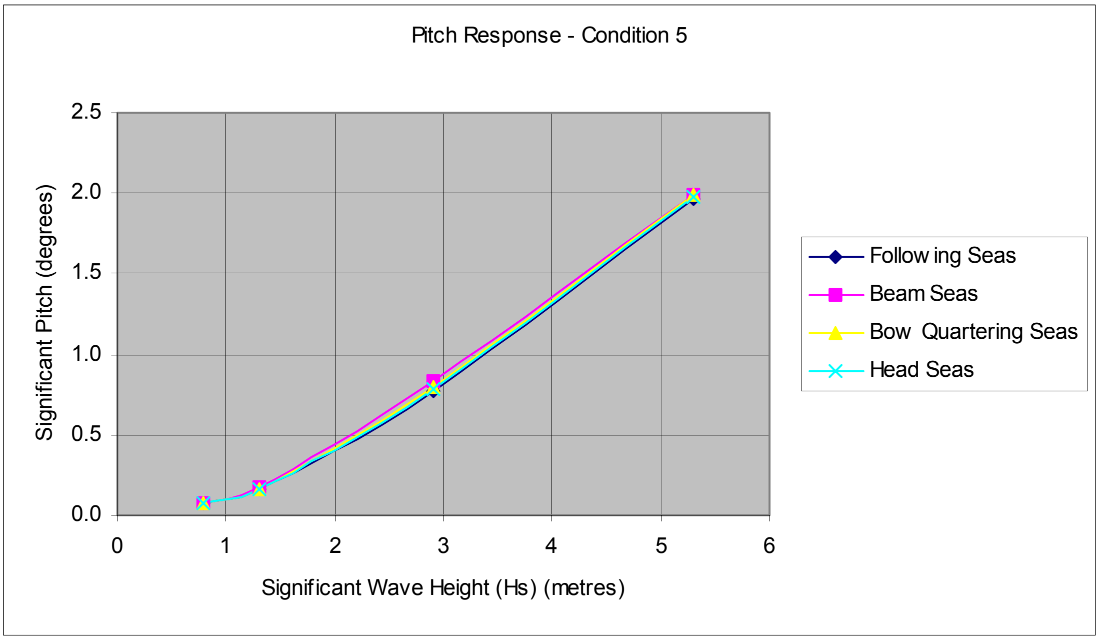


Figure 44 – Significant pitch vs. significant wave height

Condition 5

Heading	Sea State 3 Sig Vertical Accel (m/s^2)	Sea State 4 Sig Vertical Accel (m/s^2)	Sea State 5 Sig Vertical Accel (m/s^2)	Sea State 6 Sig Vertical Accel (m/s^2)
Following Seas	0.078	0.137	0.510	1.177
Beam Seas	0.078	0.157	0.667	1.511
Bow Quartering Seas	0.078	0.137	0.569	1.334
Head Seas	0.078	0.137	0.530	1.236

Heading	Sea State 3 Sig Lateral Accel (m/s^2)	Sea State 4 Sig Lateral Accel (m/s^2)	Sea State 5 Sig Lateral Accel (m/s^2)	Sea State 6 Sig Lateral Accel (m/s^2)
Following Seas	0.451	0.844	1.393	1.903
Beam Seas	0.903	1.668	3.002	4.042
Bow Quartering Seas	0.589	1.099	1.982	2.747
Head Seas	0.432	0.824	1.511	2.119

Heading	Sea State 3 Sig Longitudinal Accel (m/s^2)	Sea State 4 Sig Longitudinal Accel (m/s^2)	Sea State 5 Sig Longitudinal Accel (m/s^2)	Sea State 6 Sig Longitudinal Accel (m/s^2)
Following Seas	0.098	0.196	0.765	1.785
Beam Seas	0.098	0.216	0.883	1.942
Bow Quartering Seas	0.098	0.196	0.804	1.864
Head Seas	0.098	0.196	0.785	1.825

Table 37 – Condition 5 Significant Accelerations at Turbine Hub

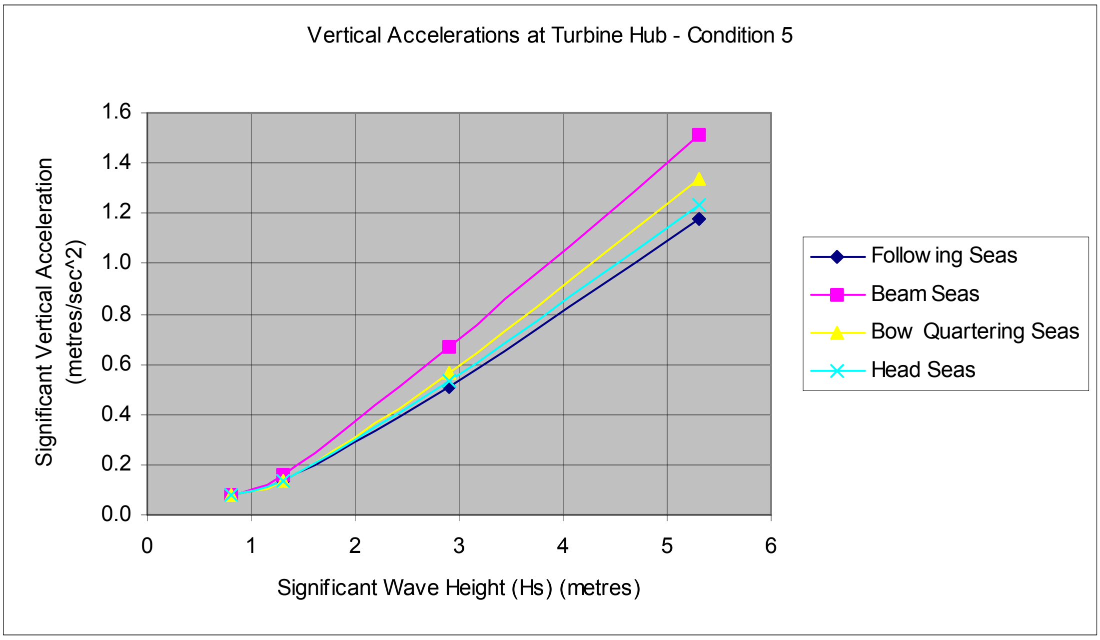


Figure 45 – Significant vertical acceleration vs. significant wave height at Turbine Hub

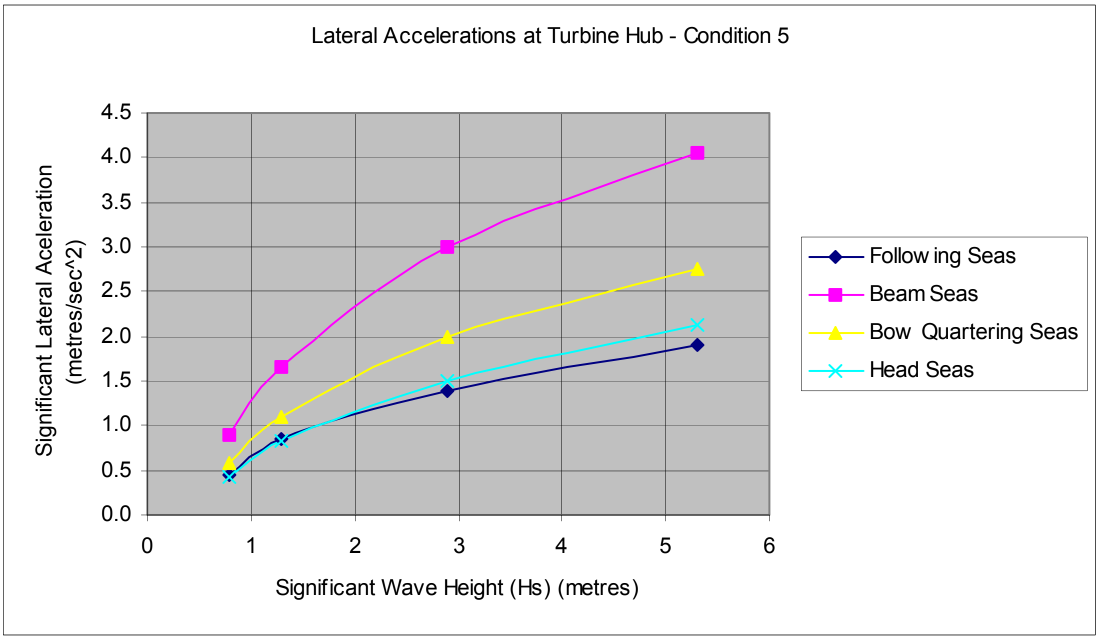


Figure 46 – Significant lateral acceleration vs. significant wave height at Turbine Hub

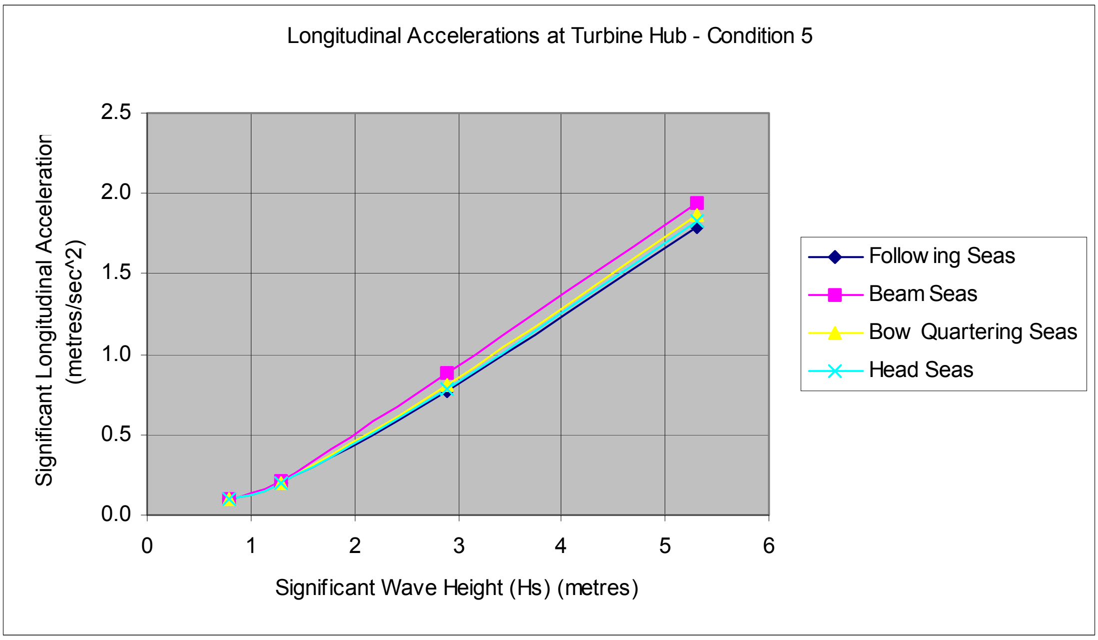


Figure 47 – Significant longitudinal acceleration vs. significant wave height at Turbine Hub

Condition 5

Heading	Sea State 3 Sig Vertical Accel (m/s^2)	Sea State 4 Sig Vertical Accel (m/s^2)	Sea State 5 Sig Vertical Accel (m/s^2)	Sea State 6 Sig Vertical Accel (m/s^2)
Following Seas	0.078	0.137	0.451	1.020
Beam Seas	0.118	0.216	0.726	1.511
Bow Quartering Seas	0.078	0.157	0.530	1.216
Head Seas	0.078	0.137	0.451	1.059

Heading	Sea State 3 Sig Lateral Accel (m/s^2)	Sea State 4 Sig Lateral Accel (m/s^2)	Sea State 5 Sig Lateral Accel (m/s^2)	Sea State 6 Sig Lateral Accel (m/s^2)
Following Seas	0.078	0.137	0.392	0.726
Beam Seas	0.118	0.235	0.647	1.177
Bow Quartering Seas	0.078	0.157	0.451	0.863
Head Seas	0.078	0.137	0.373	0.726

Heading	Sea State 3 Sig Longitudinal Accel (m/s^2)	Sea State 4 Sig Longitudinal Accel (m/s^2)	Sea State 5 Sig Longitudinal Accel (m/s^2)	Sea State 6 Sig Longitudinal Accel (m/s^2)
Following Seas	0.039	0.078	0.216	0.412
Beam Seas	0.020	0.059	0.177	0.373
Bow Quartering Seas	0.039	0.078	0.196	0.373
Head Seas	0.039	0.078	0.216	0.392

Table 38 – Condition 5 Significant Accelerations at Working Deck

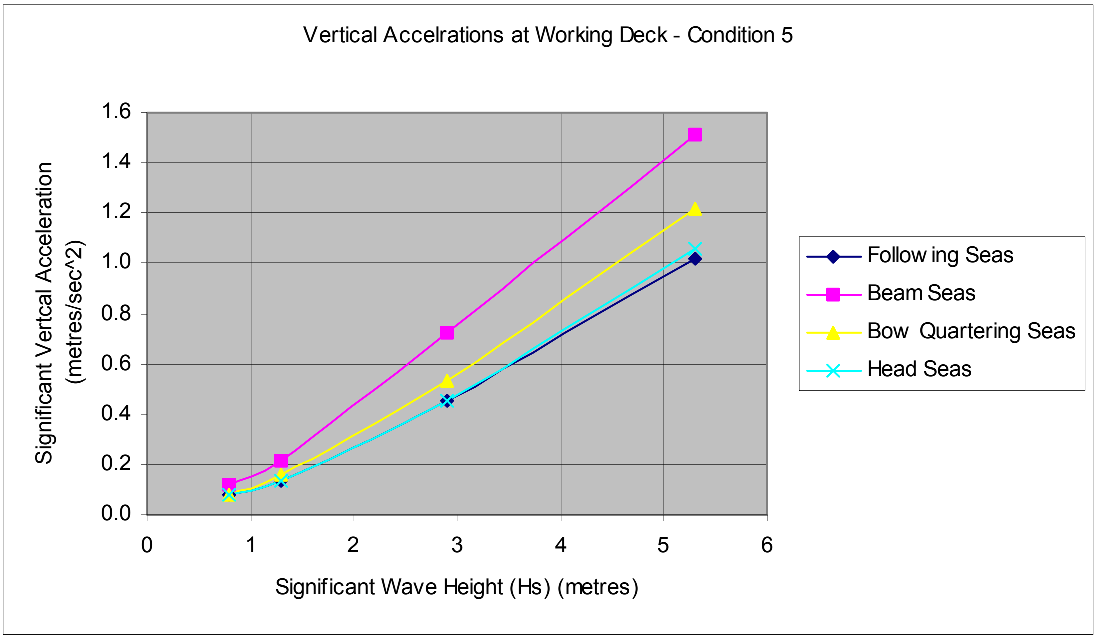


Figure 48 – Significant vertical acceleration vs. significant wave height at Working Deck

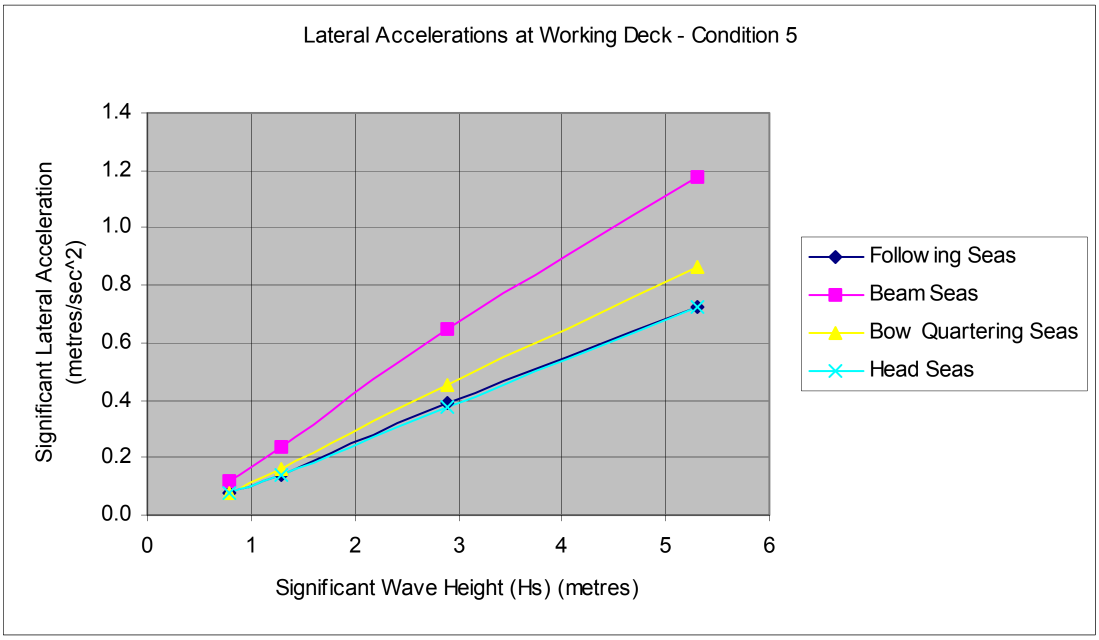


Figure 49 – Significant lateral acceleration vs. significant wave height at Working Deck

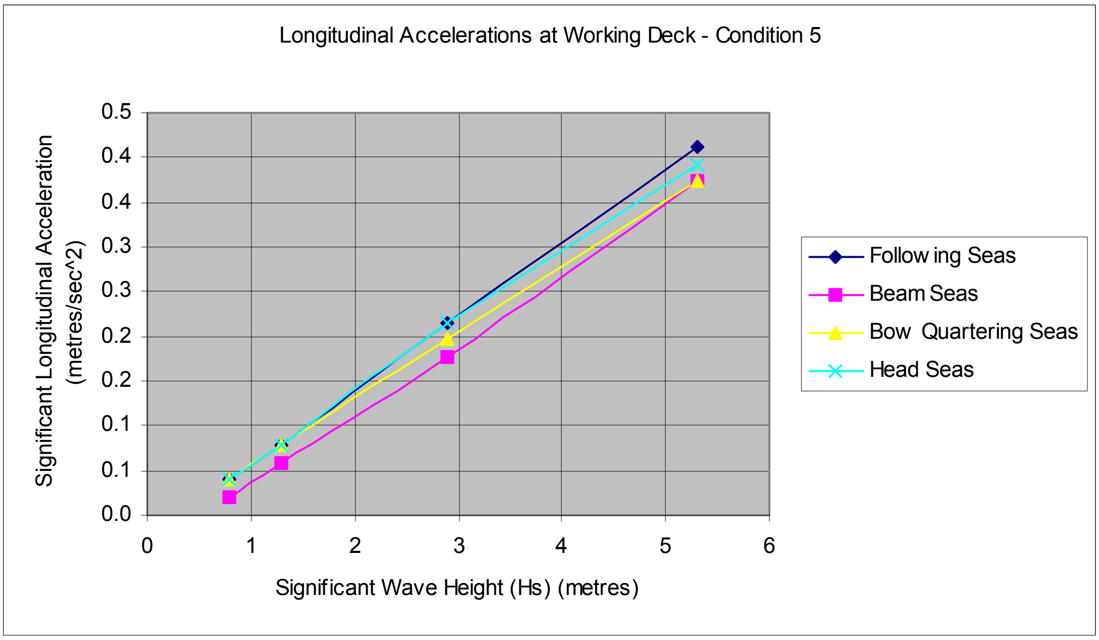


Figure 50 – Significant longitudinal acceleration vs. significant wave height at Working Deck

Condition 5a

Heading	Sea State 3 Significant Roll (degrees)	Sea State 4 Significant Roll (degrees)	Sea State 5 Significant Roll (degrees)	Sea State 6 Significant Roll (degrees)
Following Seas	0.310	0.416	0.670	1.024
Beam Seas	0.630	1.088	2.246	3.362
Bow Quartering Seas	0.310	0.586	1.462	2.386
Head Seas	0.162	0.324	1.046	1.906

Heading	Sea State 3 Significant Heave (metres)	Sea State 4 Significant Heave (metres)	Sea State 5 Significant Heave (metres)	Sea State 6 Significant Heave (metres)
Following Seas	0.042	0.082	0.316	0.702
Beam Seas	0.044	0.098	0.506	1.256
Bow Quartering Seas	0.024	0.054	0.276	0.714
Head Seas	0.018	0.036	0.178	0.480

Heading	Sea State 3 Significant Pitch (degrees)	Sea State 4 Significant Pitch (degrees)	Sea State 5 Significant Pitch (degrees)	Sea State 6 Significant Pitch (degrees)
Following Seas	0.158	0.308	1.066	2.394
Beam Seas	0.114	0.238	0.952	2.062
Bow Quartering Seas	0.078	0.148	0.572	1.438
Head Seas	0.080	0.146	0.540	1.388

Table 39 – Condition 5a Significant Motion Responses

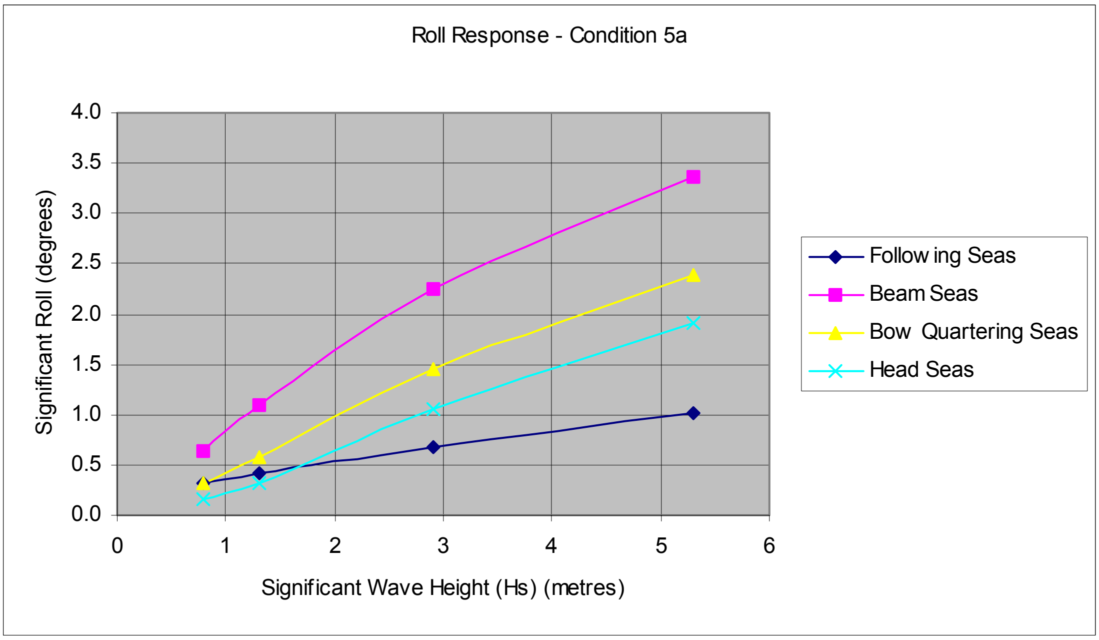


Figure 51 – Significant roll vs. significant wave height

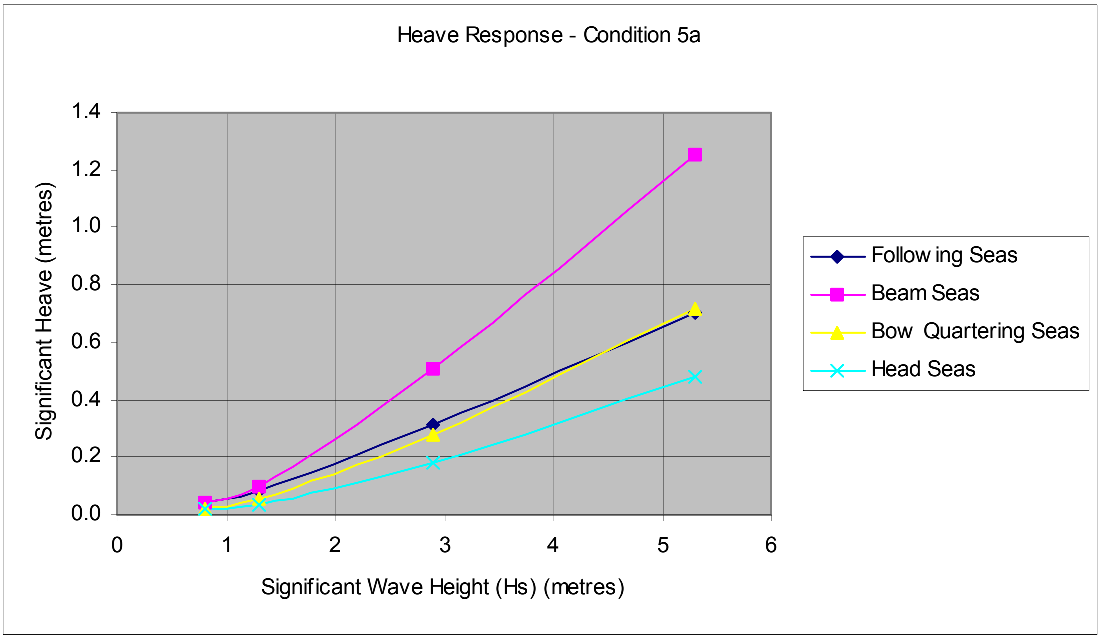


Figure 52 – Significant heave vs. significant wave height

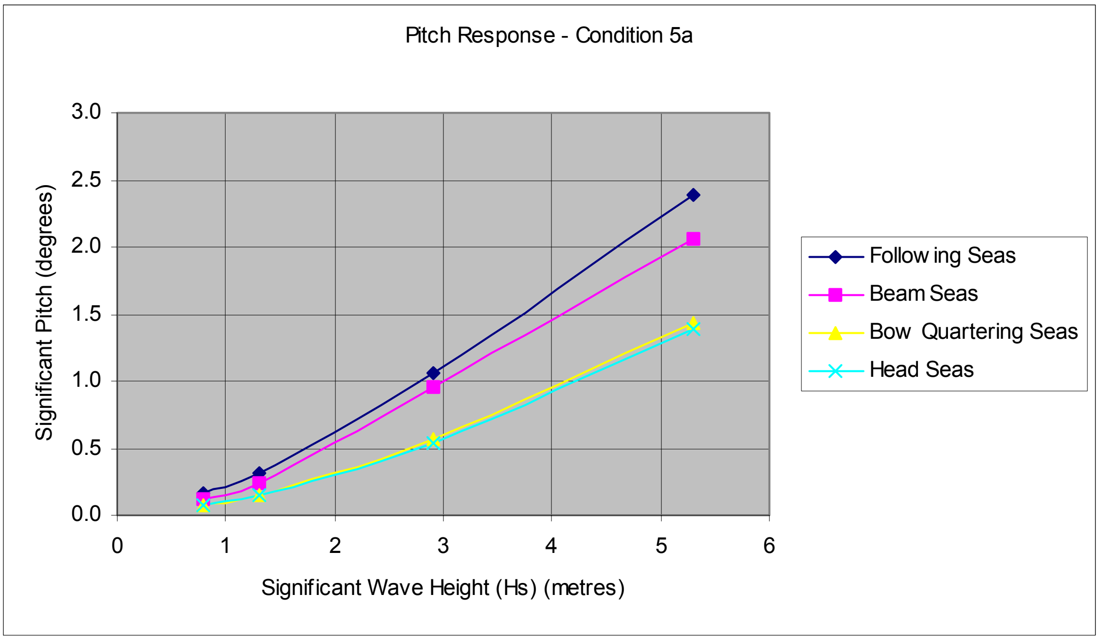


Figure 53 – Significant pitch vs. significant wave height

Condition 5a

Heading	Sea State 3 Sig Vertical Accel (m/s^2)	Sea State 4 Sig Vertical Accel (m/s^2)	Sea State 5 Sig Vertical Accel (m/s^2)	Sea State 6 Sig Vertical Accel (m/s^2)
Following Seas	0.098	0.157	0.471	0.981
Beam Seas	0.098	0.196	0.628	1.354
Bow Quartering Seas	0.118	0.216	0.530	1.177
Head Seas	0.137	0.235	0.510	1.099

Heading	Sea State 3 Sig Lateral Accel (m/s^2)	Sea State 4 Sig Lateral Accel (m/s^2)	Sea State 5 Sig Lateral Accel (m/s^2)	Sea State 6 Sig Lateral Accel (m/s^2)
Following Seas	0.471	0.608	0.942	1.373
Beam Seas	1.099	1.884	3.512	4.807
Bow Quartering Seas	0.589	1.099	2.570	4.159
Head Seas	0.353	0.687	2.060	3.747

Heading	Sea State 3 Sig Longitudinal Accel (m/s^2)	Sea State 4 Sig Longitudinal Accel (m/s^2)	Sea State 5 Sig Longitudinal Accel (m/s^2)	Sea State 6 Sig Longitudinal Accel (m/s^2)
Following Seas	0.137	0.255	0.804	1.628
Beam Seas	0.157	0.294	0.942	1.884
Bow Quartering Seas	0.216	0.373	0.824	1.766
Head Seas	0.235	0.392	0.824	1.746

Table 40 – Condition 5a Significant Accelerations at Turbine Hub

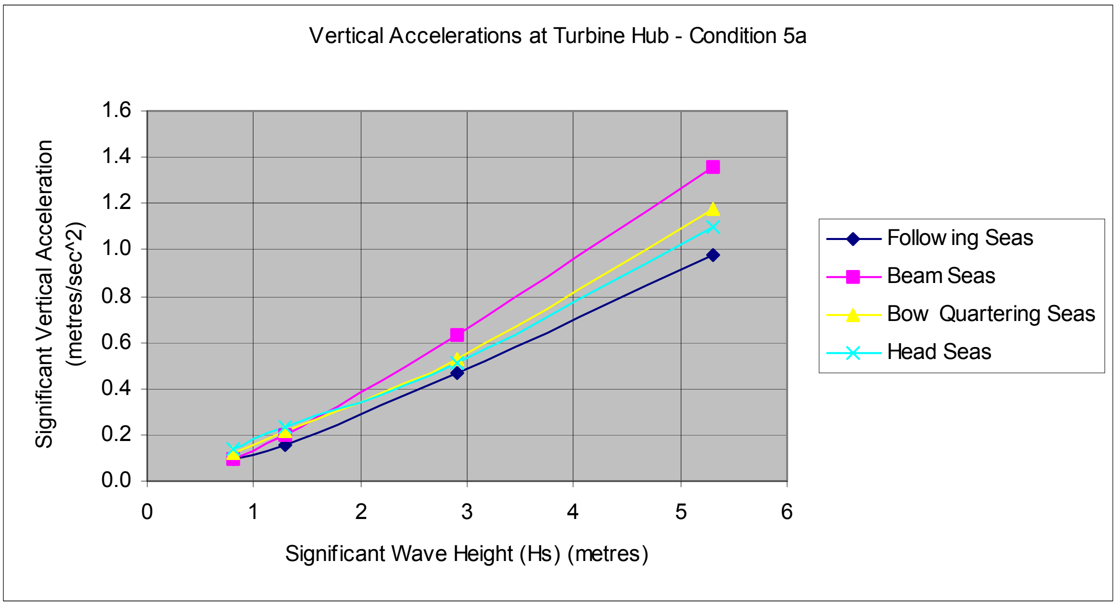


Figure 54 – Significant vertical acceleration vs. significant wave height at Turbine Hub

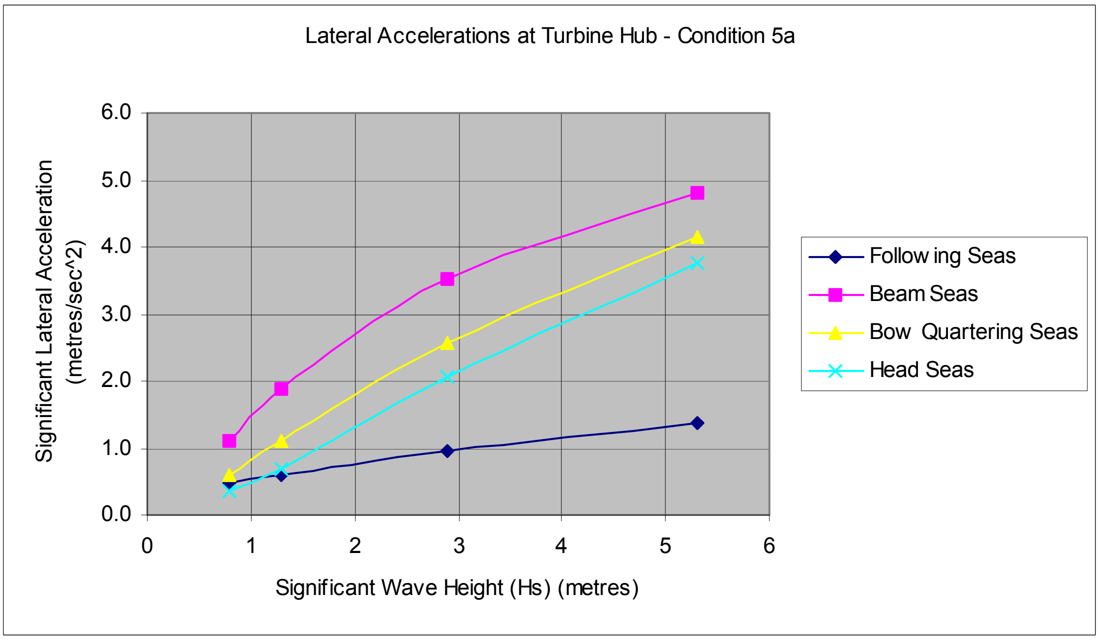


Figure 55 – Significant lateral acceleration vs. significant wave height at Turbine Hub

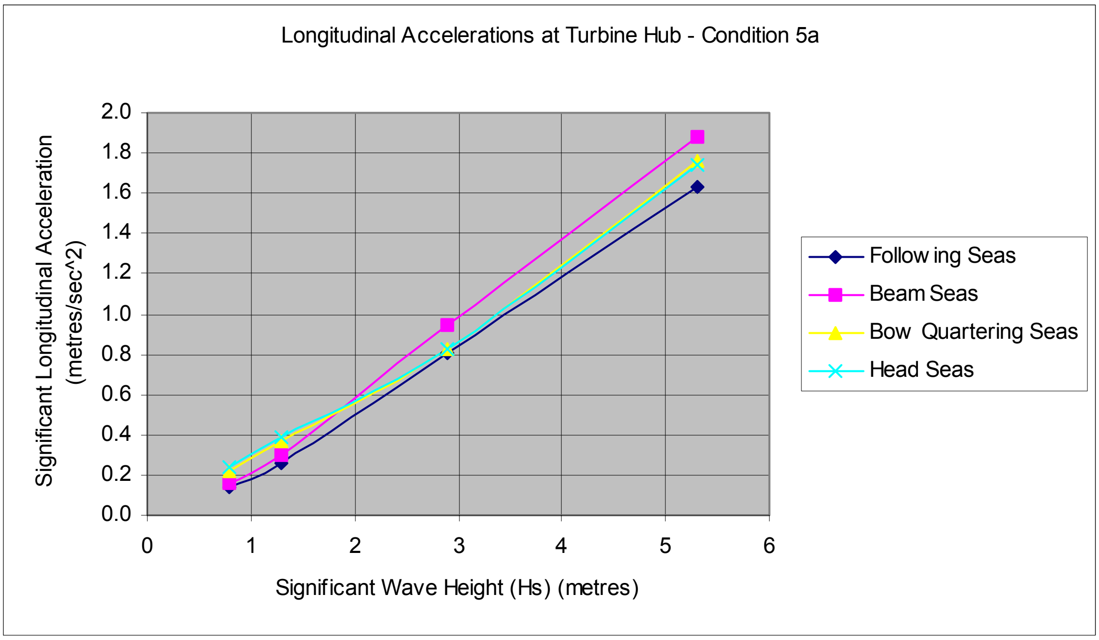


Figure 56 – Significant longitudinal acceleration vs. significant wave height at Turbine Hub

Condition 5a

Heading	Sea State 3 Sig Vertical Accel (m/s^2)	Sea State 4 Sig Vertical Accel (m/s^2)	Sea State 5 Sig Vertical Accel (m/s^2)	Sea State 6 Sig Vertical Accel (m/s^2)
Following Seas	0.078	0.157	0.412	0.824
Beam Seas	0.137	0.235	0.706	1.393
Bow Quartering Seas	0.118	0.216	0.549	1.138
Head Seas	0.118	0.196	0.451	0.961

Heading	Sea State 3 Sig Lateral Accel (m/s^2)	Sea State 4 Sig Lateral Accel (m/s^2)	Sea State 5 Sig Lateral Accel (m/s^2)	Sea State 6 Sig Lateral Accel (m/s^2)
Following Seas	0.059	0.118	0.334	0.628
Beam Seas	0.118	0.235	0.628	1.177
Bow Quartering Seas	0.098	0.177	0.491	0.942
Head Seas	0.078	0.157	0.412	0.785

Heading	Sea State 3 Sig Longitudinal Accel (m/s^2)	Sea State 4 Sig Longitudinal Accel (m/s^2)	Sea State 5 Sig Longitudinal Accel (m/s^2)	Sea State 6 Sig Longitudinal Accel (m/s^2)
Following Seas	0.039	0.098	0.216	0.412
Beam Seas	0.039	0.059	0.177	0.373
Bow Quartering Seas	0.039	0.078	0.196	0.373
Head Seas	0.039	0.098	0.216	0.392

Table 41 – Condition 5a Significant Accelerations at Working Deck

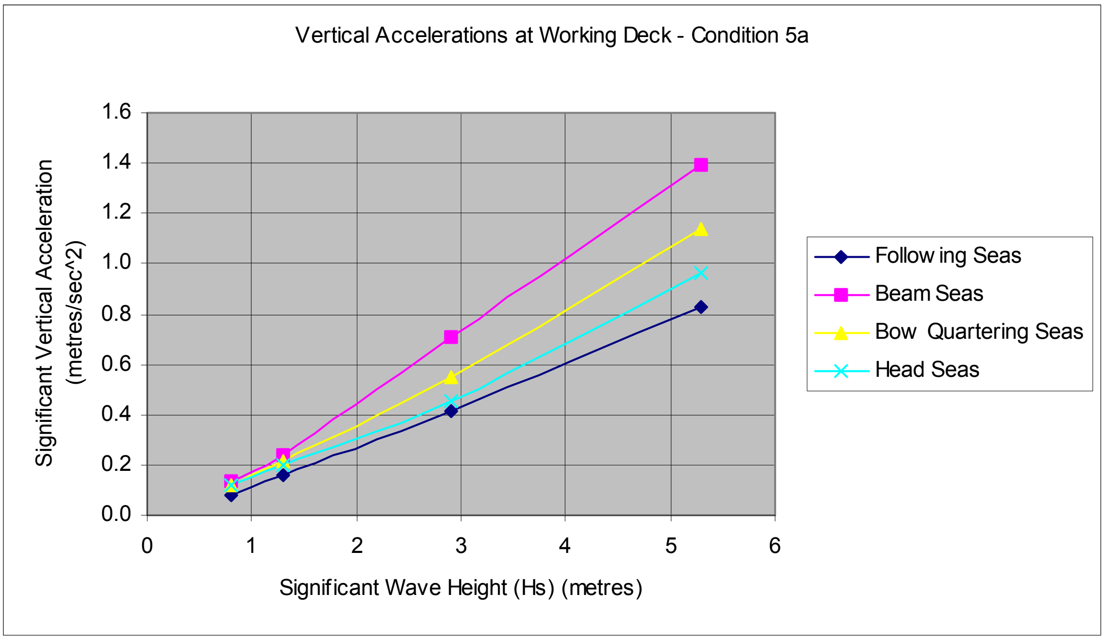


Figure 57 – Significant vertical acceleration vs. significant wave height at Working Deck

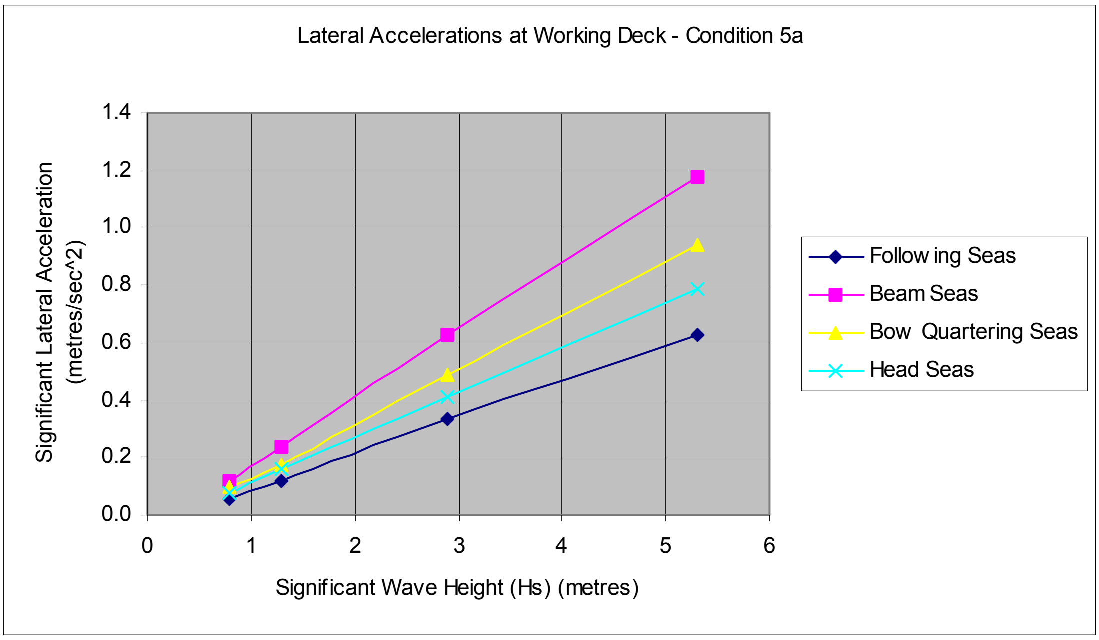


Figure 58 – Significant lateral acceleration vs. significant wave height at Working Deck

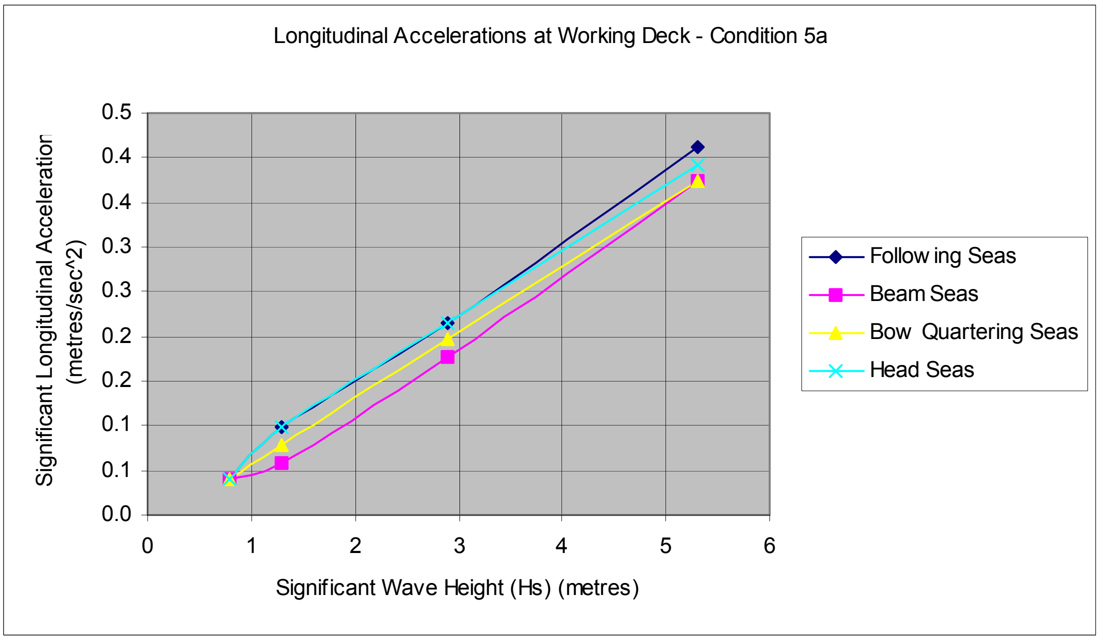


Figure 59 – Significant longitudinal acceleration vs. significant wave height at Working Deck

DISCUSSION OF RESULTS

Subjective Motion Criteria

The previous section of this report has presented the results of the seakeeping assessment carried out on the *AMT EXPLORER* whilst involved in the carriage and deployment of a wind turbine. These results have been presented in terms of motion responses in various sea states and at various vessel headings relative to the principal wave direction.

In deriving an indication of the vessel's likely level of operability in such sea states, use is made of subjective criteria which have been obtained from both experimentation and observation of actual operations made at sea. The criteria used in such assessments, and adopted for use in the present study, are given below:

Parameter	Limiting Significant Value
Single Amplitude Roll	10 degrees
Vertical Acceleration	0.25g (2.52 m/s^2)
Lateral Acceleration	0.12g (1.18 m/s^2)

Table 42 – Subjective Motion Criteria

The above criteria are considered to be representative of the motions which can be withstood by shipboard personnel for prolonged periods whilst operating at around 70% of maximum effectiveness.

Operability limitations

Referring to the graphs of significant response versus significant wave height (Figures 24 to 26, 33 to 35, 42 to 44 and 51 to 53), it can be seen that the single amplitude roll criterion is not reached in any case and the maximum value attained is 3.48° (Condition 1a). Therefore the limits on effective operation would be in excess of sea state 6 (5.30 m significant wave height) for all vessel headings and conditions.

Referring to the location on the working deck included in the assessment and in particular to the graphs of significant accelerations versus significant wave height, similar limits on effective operation can be derived of sea state 6 and 5.30m significant wave height.

It is not anticipated that any personnel would be working at the location on the turbine hub, therefore the accelerations derived for this point should not have any effect on operability. However, the accelerations at this point are higher and should any personnel be working in this area the subjective motion criteria would induce the following limits:

Vessel Heading and Condition	Significant Wave Height (m)	Sea State
Condition 1 Head Seas	>5.30	6
Condition 1 Beam Seas	2.90	5
Condition 1a Head Seas	>5.30	6
Condition 1a Beam Seas	2.90	5
Condition 5 Head Seas	1.30	4
Condition 5 Beam Seas	1.30	4
Condition 5a Head Seas	1.30	4
Condition 5a Beam Seas	0.80	3

Table 43 – Acceleration-induced operability limits at turbine hub

As can be seen from the above, assuming no personnel at the turbine hub location, the vessel could be operated effectively at sea states in excess of sea state 6 at any vessel heading relative to the principal wave direction.

SUMMARY AND CONCLUSIONS

This report presents the findings of an assessment of the stability, loading and operability of the dumb barge *AMT EXPLORER* whilst carrying and deploying wind turbines as part of the *Merlin* Project.

The assessment was carried out for five representative loading conditions using the ShipmoPC strip-theory based programme. The results are presented in terms of Response Amplitude Operators in each of six degrees of freedom for the two additional scenarios of Conditions 1 and 5 with a forward speed of 5.0 knots. The motion responses of the vessel along with the accelerations at given points on the vessel is shown in graphical and tabular format and used to assess the operability limits of the vessel.

The loading conditions and stability were determined using AutoHydro (ref. 2) and are detailed in Appendix 3. The results show that in the five predetermined loading conditions the vessel does satisfy all stability criteria.

Application of the Subjective Motion Criteria to the vessel responses in irregular seas indicate that operation in seas up to and including sea state 6 should be possible without any adverse effect on shipboard personnel assuming no personnel are located at the turbine hub. In this case, vessel operations would be limited to the sea states denoted in Table 43.

REFERENCES

1. Sable Maritime Limited
ShipmoPC for Windows – Version 3.0
User Manual, 2003.

2. AutoShip Systems Corporation
AutoHydro for Windows – Release 5.0
User Manual, 1997.

APPENDIX 1 – RAOS FOR LOADING CONDITION 1A AT 5.0 KNOTS

APPENDIX 2 – RAOS FOR LOADING CONDITION 5A AT 5.0 KNOTS

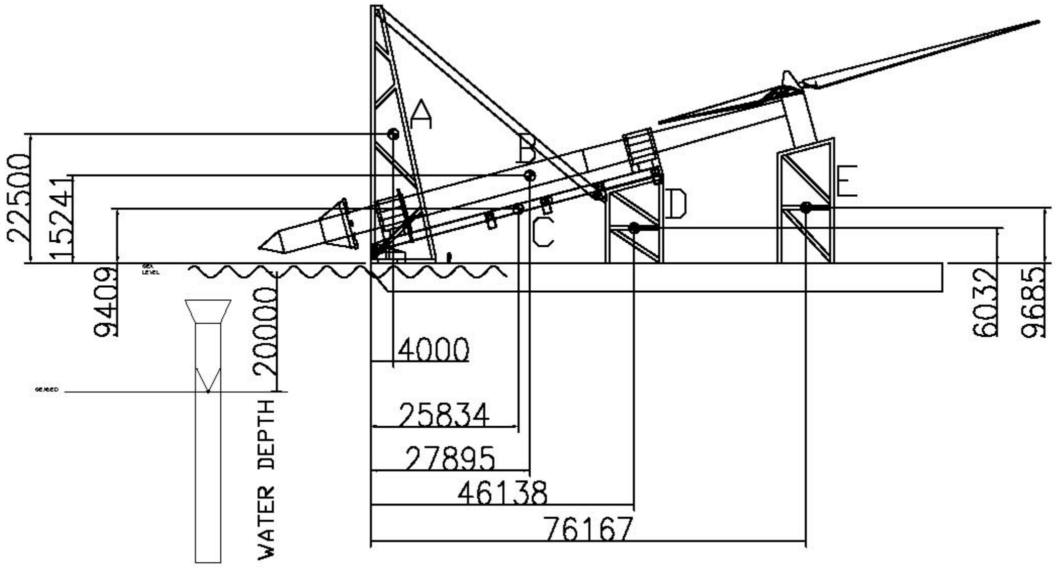
These appendices are tables of RAOs developed for the Merlin System in the specified operating conditions. These appendices are not reproduced here but the values generated from them are inputs to Appendix 3.

APPENDIX 3 OPERATING SCENARIOS AND LOADING CONDITIONS

MASSES

A) WINCH FRAMES : 100,000KG
B) WIND TURBINE : 510,000KG
C) A FRAME/ SUPPORT CRADLE : 100,000KG
D) FWD SUPPORT FRAME : 25,000KG
E) AFT SUPPORT FRAME : 25,000KG

NOTE: MASSES CAN BE ASSUMED TO BE ON CENTRE LINE OF BARGE



CONTRACT REF		ORIGINAL SHEET SIZE A4	CUSTOMER REF	
MATERIAL		3RD ANGLE PROJECTION	TITLE MERLIN CENTRE OF MASS 15 DEGREES	
DESIGNED BY	DO NOT SCALE			
DRAWN BY DB	DRAWN DATE 07/04/04	REMOVE ALL BURRS AND SHARP EDGES		
CHECKED BY	CHECK DATE	DIMENSIONS mm	ORIGINAL SCALE	DRAWING No C130-20-0024 / SHEET 1 OF 1 / REVISION 0

THE ENGINEERING BUSINESS Ltd

LOADING CONDITION 1 – MERLIN CENTRE OF MASS 15 DEGREES

Fuel Oil — Specific Gravity 0.897 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
FUEL OIL	21	5.0	6.840	34	3.765	19	17
TOTAL		5.0	6.840	34	3.765	19	17

Ballast Water — Specific Gravity 1.025 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
No 1 INNER PS	90	374.7	85.618	32081	4.436	1662	378
No 1 INNER SB	90	374.7	85.618	32081	4.436	1662	378
No 1 OUTER PS	90	374.7	85.618	32081	4.436	1662	378
No 1 OUTER SB	90	374.7	85.618	32081	4.436	1662	378
No 2 INNER PS	-	0.0					
No 2 INNER SB	-	0.0					
No 2 OUTER PS	70	658.7	73.395	48344	2.667	1757	609
No 2 OUTER SB	70	658.7	73.395	48344	2.667	1757	609
No 3 INNER PS	90	846.9	57.294	48520	3.429	2904	609
No 3 INNER SB	90	846.9	57.294	48520	3.429	2904	609
No 3 OUTER PS	-	0.0					
No 3 OUTER SB	-	0.0					
No 4 INNER PS	-	0.0					
No 4 INNER SB	-	0.0					
No 4 OUTER PS	90	846.9	41.194	34886	3.429	2904	609
No 4 OUTER SB	90	846.9	41.194	34886	3.429	2904	609
No 5 INNER PS	90	846.9	25.094	21252	3.429	2904	609
No 5 INNER SB	90	846.9	25.094	21252	3.429	2904	609
No 5 OUTER PS	-	0.0					
No 5 OUTER SB	-	0.0					
No 6 OUTER PS	90	747.7	9.788	7319	3.892	2910	644
No 6 OUTER SB	90	747.7	9.788	7319	3.892	2910	644
TOTAL		9392.9	47.799	448965	3.557	33406	7672

Cargo

Compartment		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
WINCH FRAMES	-	100.0	4.000	400	30.120	3012	0
WIND TURBINE	-	510.0	27.895	14226	22.861	11659	0
A FRAME/SUPPORT CRADLE	-	100.0	25.834	2583	17.029	1703	0
FWD SUPPORT FRAME	-	25.0	46.138	1153	13.652	341	0
AFT SUPPORT FRAME	-	25.0	76.167	1904	17.305	433	0
TOTAL		760.0	26.668	20267	22.563	17148	0

Total Deadweight

Item	Specific Gravity (t/m³)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
Fuel Oil	0.897	5.0	6.8	34.2	3.8	18.8	17
Ballast Water	1.025	9392.9	47.8	448965.4	3.6	33406.0	7672
Cargo	-	760.0	26.7	20267.5	22.6	17147.9	0
TOTAL		10157.9	46.197	469267	4.979	50573	7689

Loading Summary

Item		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)
Light Ship		2262.0	44.258	100112	4.250	9614
Deadweight		10157.86	46.20	469267	4.98	50572.74
Displacement		12419.86	45.84	569379	4.85	60186

Floating Summary

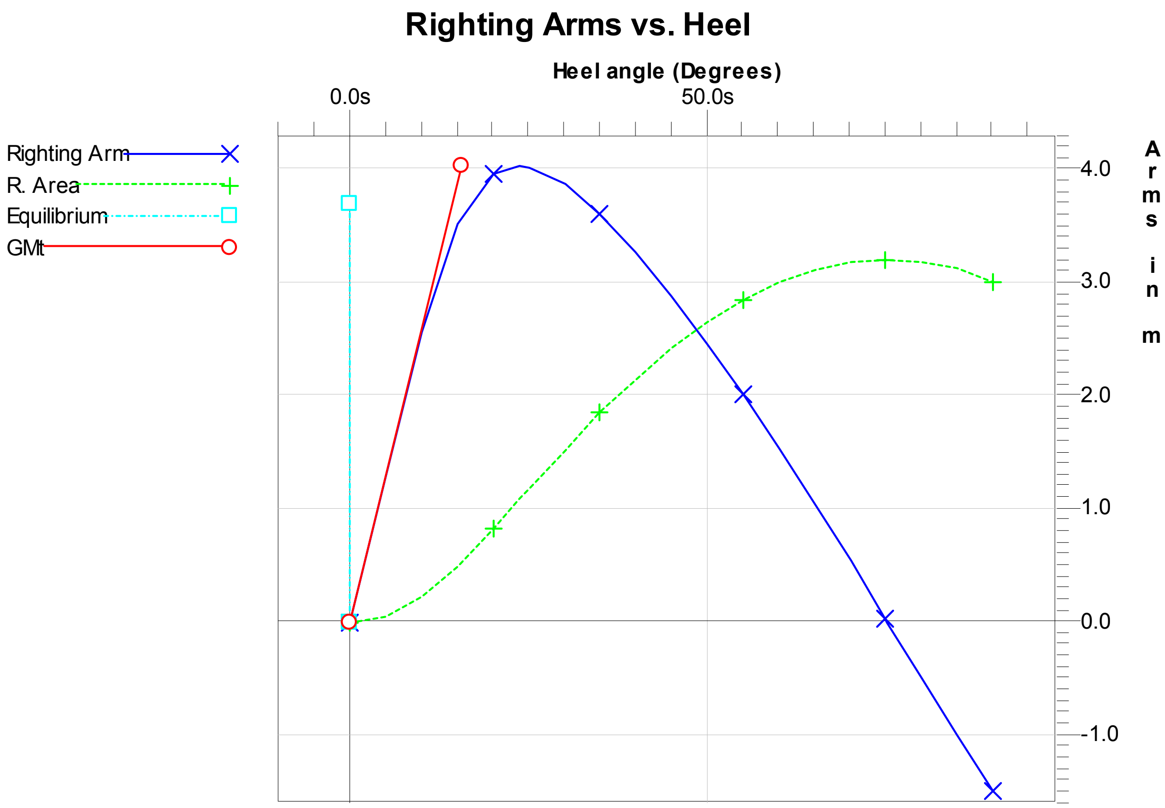
Draft FWD	4.872	m	LCG	45.844	m	GM(Solid)	15.344	m
Draft MS	4.819	m	KG(Solid)	4.846	m	F/S Corr.	0.619	m
Draft AFT	4.766	m	KG(Fluid)	5.465	m	GM(Fluid)	14.725	m
Trim (+ve by stern)	-0.107	m	Heel	0.000	degrees	KMT	20.190	m

Intact Stability

Angle, s	0	10	20	30	40	50	60	70	80	90
sins	0.000	0.174	0.342	0.500	0.643	0.766	0.866	0.940	0.985	1.000
KN	0.000	3.515	5.855	6.685	6.926	6.846	6.511	5.948	5.174	4.219
KGsins	0.000	0.949	1.869	2.733	3.513	4.186	4.733	5.135	5.382	5.465
GZ	0.000	2.567	3.958	3.870	3.275	2.466	1.537	0.539	-0.485	-1.499

Stability Criteria

Max GZ	4.029	m	Occurs at	24.14	degrees
Area 0 - Max GZ	1.085	m-rads	Required	0.080	m-rads
Area 0 - 30	1.519	m-rads	Area 0 - 40	2.147	m-rads
Area 30 - 40	0.628	m-rads	Required	0.030	m-rads



Righting Arms vs. Heel
Heel angle (Degrees)
0.0s
50.0s
Righting Arm
R. Area
Equilibrium
GMt
4.0
3.0
2.0
1.0
0.0
-1.0
Arms in m

MASSES

A) WINCH FRAMES : 100,000KG

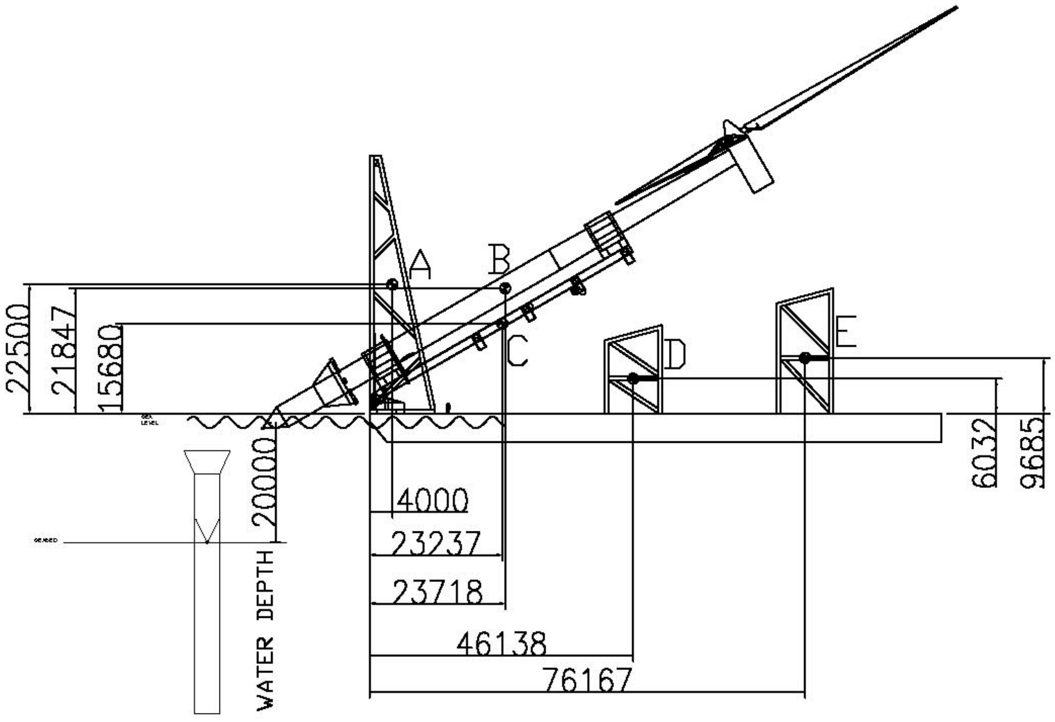
B) WIND TURBINE : 510,000KG

C) A FRAME/ SUPPORT CRADLE : 100,000KG

D) FWD SUPPORT FRAME : 25,000KG

E) AFT SUPPORT FRAME : 25,000KG

NOTE: MASSES CAN BE ASSUMED TO BE ON CENTRE LINE OF BARGE



CONTRACT REF		ORIGINAL SHEET SIZE A4	CUSTOMER REF
MATERIAL		3RD ANGLE PROJECTION	TITLE MERLIN CENTRE OF MASS 30 DEGREES
DESIGNED BY	DO NOT SCALE		
DRAWN BY DB	DRAWN DATE 07/04/04	REMOVE ALL BURRS AND SHARP EDGES	
CHECKED BY	CHECK DATE	DIMENSIONS mm	ORIGINAL SCALE

THE ENGINEERING BUSINESS Ltd

DRAWING No C130-20-0025 | SHEET 1 OF 1 | REVISION 0

LOADING CONDITION 2 – MERLIN CENTRE OF MASS 30 DEGREES

Fuel Oil — Specific Gravity 0.897 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
FUEL OIL	21	5.0	6.840	34	3.765	19	17
TOTAL		5.0	6.840	34	3.765	19	17

Ballast Water — Specific Gravity 1.025 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
No 1 INNER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 INNER SB	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER SB	90	374.7	85.616	32080	4.436	1662	378
No 2 INNER PS	-	0.0					
No 2 INNER SB	-	0.0					
No 2 OUTER PS	70	658.7	73.390	48341	2.667	1757	609
No 2 OUTER SB	70	658.7	73.390	48341	2.667	1757	609
No 3 INNER PS	90	846.9	57.290	48517	3.429	2904	609
No 3 INNER SB	90	846.9	57.290	48517	3.429	2904	609
No 3 OUTER PS	-	0.0					
No 3 OUTER SB	-	0.0					
No 4 INNER PS	-	0.0					
No 4 INNER SB	-	0.0					
No 4 OUTER PS	90	846.9	41.190	34883	3.429	2904	609
No 4 OUTER SB	90	846.9	41.190	34883	3.429	2904	609
No 5 INNER PS	90	846.9	25.090	21248	3.429	2904	609
No 5 INNER SB	90	846.9	25.090	21248	3.429	2904	609
No 5 OUTER PS	-	0.0					
No 5 OUTER SB	-	0.0					
No 6 OUTER PS	90	747.7	9.783	7315	3.892	2910	644
No 6 OUTER SB	90	747.7	9.783	7315	3.892	2910	644
TOTAL		9392.9	47.795	448928	3.557	33406	7672

Cargo

Compartment		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
WINCH FRAMES	-	100.0	4.000	400	30.120	3012	0
WIND TURBINE	-	510.0	23.718	12096	29.467	15028	0
A FRAME/SUPPORT CRADLE	-	100.0	23.237	2324	23.300	2330	0
FWD SUPPORT FRAME	-	25.0	46.138	1153	13.652	341	0
AFT SUPPORT FRAME	-	25.0	76.167	1904	17.305	433	0
TOTAL		760.0	23.523	17878	27.821	21144	0

Total Deadweight

Item	Specific Gravity (t/m^3)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
Fuel Oil	0.897	5.0	6.840	34	3.765	19	17

Ballast Water	1.025	9392.9	47.795	448928	3.557	33406	7672
Cargo	-	760.0	23.523	17878	27.821	21144	0
TOTAL		10157.9	45.958	466840	5.372	54569	7689

Loading Summary

Item		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)
Light Ship		2262.0	44.258	100112	4.250	9614
Deadweight		10157.9	45.958	466840	5.372	54568.90
Displacement		12419.9	45.649	566951	5.168	64182

Floating Summary

Draft FWD	4.815	m	LCG	45.649	m	GM(Solid)	15.041	m
Draft MS	4.820	m	KG(Solid)	5.168	m	F/S Corr.	0.619	m
Draft AFT	4.824	m	KG(Fluid)	5.787	m	GM(Fluid)	14.422	m
Trim (+ve by stern)	0.009	m	Heel	0.000	degrees	KMT	20.208	m

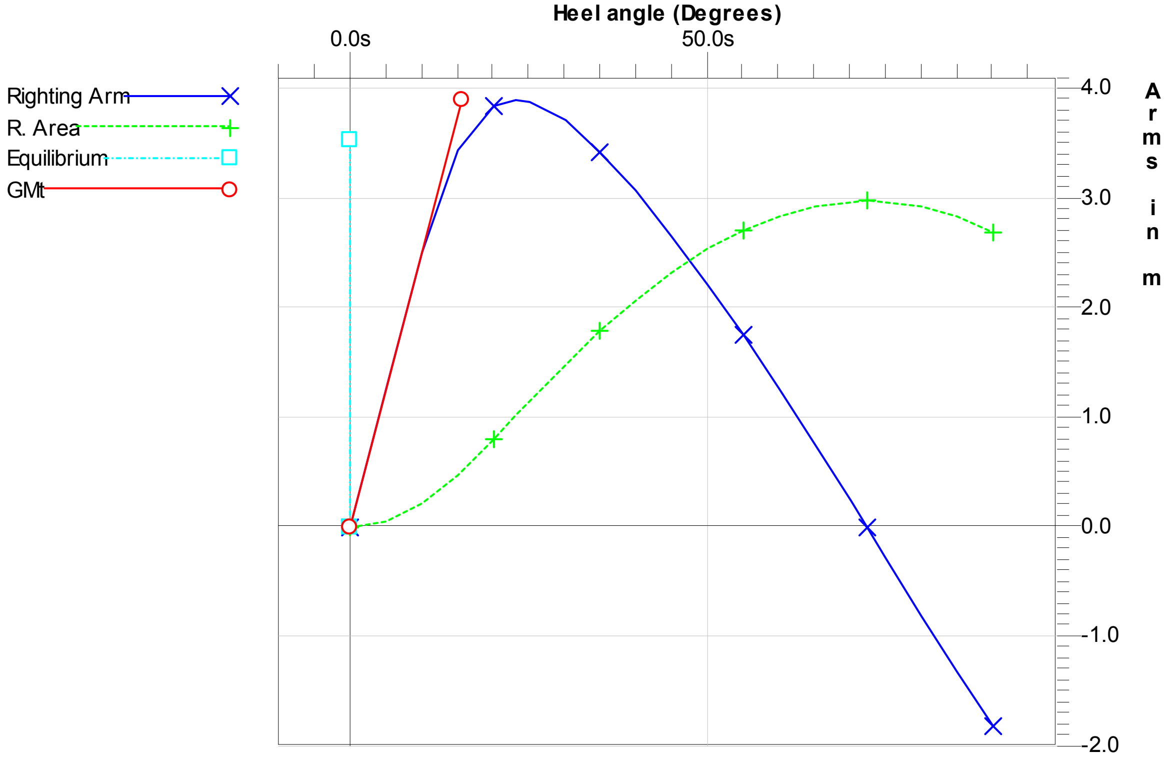
Intact Stability

Angle, s	0	10	20	30	40	50	60	70	80	90
sins	0.000	0.174	0.342	0.500	0.643	0.766	0.866	0.940	0.985	1.000
KN	0.000	3.516	5.827	6.602	6.789	6.652	6.270	5.675	4.897	3.966
KGsins	0.000	1.005	1.979	2.893	3.720	4.433	5.012	5.438	5.699	5.787
GZ	0.000	2.511	3.848	3.709	3.069	2.219	1.258	0.237	-0.802	-1.821

Stability Criteria

Max GZ	3.900	m	Occurs at	23.14	degrees
Area 0 - Max GZ	1.016	m-rads	Required	0.080	m-rads
Area 0 -30	1.476	m-rads	Area 0 -40	2.072	m-rads
Area 30 - 40	0.596	m-rads	Required	0.030	m-rads

Righting Arms vs. Heel



MASSES

A) WINCH FRAMES : 100,000KG

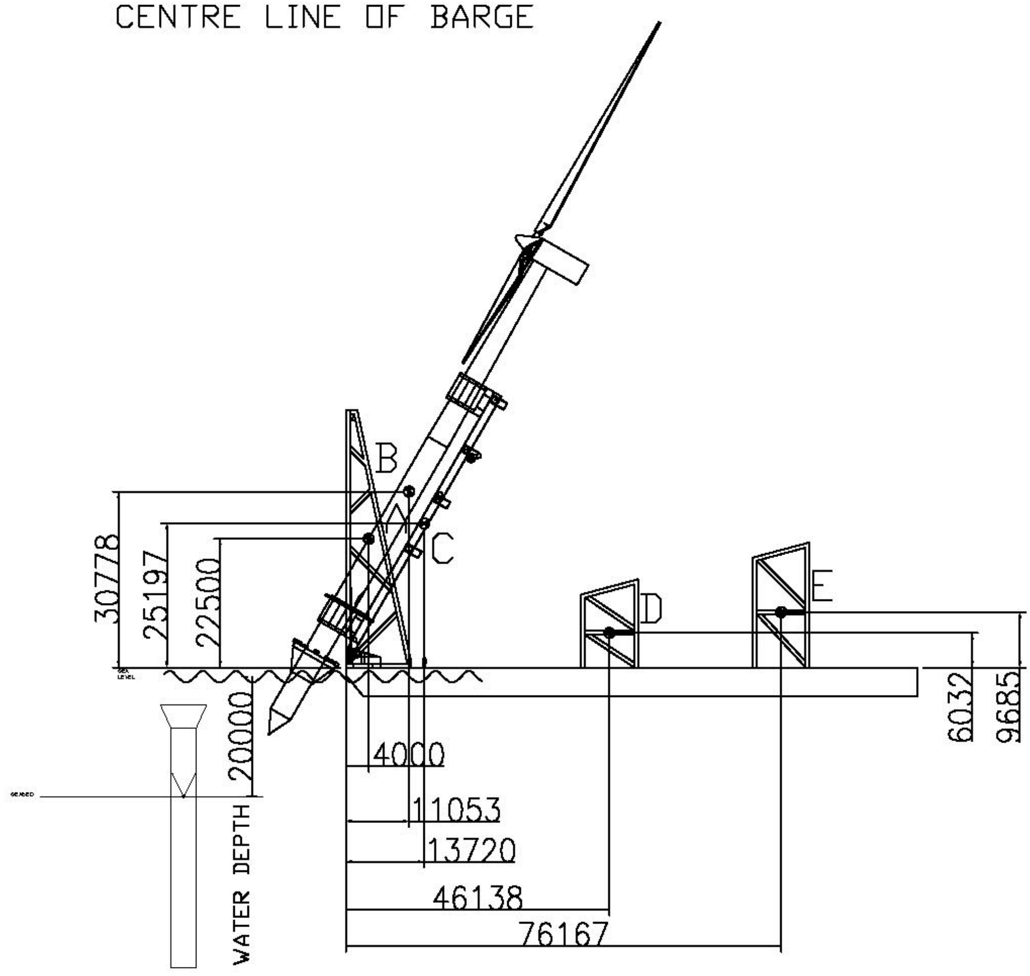
B) WIND TURBINE : 510,000KG

C) A FRAME/ SUPPORT CRADLE : 100,000KG

D) FWD SUPPORT FRAME : 25,000KG

E) AFT SUPPORT FRAME : 25,000KG

NOTE: MASSES CAN BE ASSUMED TO BE ON CENTRE LINE OF BARGE



CONTRACT REF		ORIGINAL SHEET SIZE A4	CUSTOMER REF
MATERIAL		3RD ANGLE PROJECTION	TITLE MERLIN CENTRE OF MASS 60 DEGREES
DESIGNED BY	DO NOT SCALE		
DRAWN BY DB	DRAWN DATE 07/04/04	REMOVE ALL BURRS AND SHARP EDGES	
CHECKED BY	CHECK DATE	DIMENSIONS mm	ORIGINAL SCALE

THE ENGINEERING BUSINESS Ltd

DRAWING No	SHEET	REVISION
C130-20-0026	1 OF 1	0

LOADING CONDITION 3 – MERLIN CENTRE OF MASS 60 DEGREES

Fuel Oil Specific Gravity 0.897 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
FUEL OIL	21	5.0	6.840	34	3.765	19	17
TOTAL		5.0	6.840	34	3.765	19	17

Ballast Water Specific Gravity 1.025 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
No 1 INNER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 INNER SB	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER SB	90	374.7	85.616	32080	4.436	1662	378
No 2 INNER PS	-	0.0					
No 2 INNER SB	-	0.0					
No 2 OUTER PS	85	799.8	73.390	58700	3.239	2591	609
No 2 OUTER SB	85	799.8	73.390	58700	3.239	2591	609
No 3 INNER PS	90	846.9	57.290	48517	3.429	2904	609
No 3 INNER SB	90	846.9	57.290	48517	3.429	2904	609
No 3 OUTER PS	-	0.0					
No 3 OUTER SB	-	0.0					
No 4 INNER PS	-	0.0					
No 4 INNER SB	-	0.0					
No 4 OUTER PS	90	846.9	41.190	34883	3.429	2904	609
No 4 OUTER SB	90	846.9	41.190	34883	3.429	2904	609
No 5 INNER PS	90	846.9	25.090	21248	3.429	2904	609
No 5 INNER SB	90	846.9	25.090	21248	3.429	2904	609
No 5 OUTER PS	-	0.0					
No 5 OUTER SB	-	0.0					
No 6 OUTER PS	90	747.7	9.783	7315	3.892	2910	644
No 6 OUTER SB	90	747.7	9.783	7315	3.892	2910	644
TOTAL		9675.2	48.541	469646	3.625	35074	7672

Cargo

Compartment		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
WINCH FRAMES	-	100.0	4.000	400	30.120	3012	0
WIND TURBINE	-	510.0	11.053	5637	38.398	19583	0
A FRAME/SUPPORT CRADLE	-	100.0	13.720	1372	32.817	3282	0
FWD SUPPORT FRAME	-	25.0	46.138	1153	13.652	341	0
AFT SUPPORT FRAME	-	25.0	76.167	1904	17.305	433	0
TOTAL		760.0	13.772	10467	35.067	26651	0

Total Deadweight

Item	Specific Gravity (t/m^3)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
Fuel Oil	0.897	5.0	6.840	34	3.765	19	17

Ballast Water	1.025	9675.2	48.541	469646	3.625	35074	7672
Cargo	-	760.0	13.772	10467	35.067	26651	0
TOTAL		10440.2	45.990	480147	5.914	61743	7689

Loading Summary

Item		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)
Light Ship		2262.0	44.258	100112	4.250	9614
Deadweight		10440.2	45.990	480147	5.914	61743
Displacement		12702.2	45.682	580258	5.618	71357

Floating Summary

Draft FWD	4.923	m	LCG	45.682	m	GM(Solid)	14.278	m
Draft MS	4.919	m	KG(Solid)	5.618	m	F/S Corr.	0.605	m
Draft AFT	4.916	m	KG(Fluid)	6.223	m	GM(Fluid)	13.673	m
Trim (+ve by stern)	-0.007	m	Heel	0.000	degrees	KMT	19.895	m

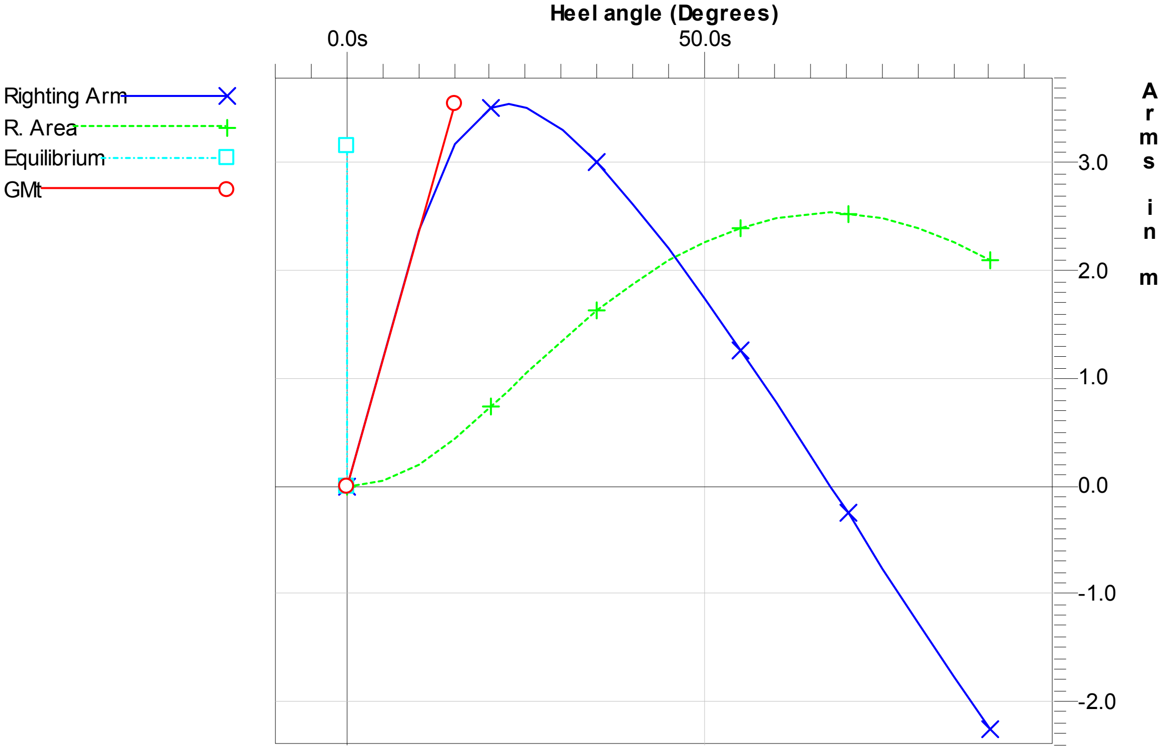
Intact Stability

Angle, s	0	10	20	30	40	50	60	70	80	90
sins	0.000	0.174	0.342	0.500	0.643	0.766	0.866	0.940	0.985	1.000
KN	0.000	3.463	5.654	6.432	6.634	6.521	6.167	5.605	4.860	3.966
KGsins	0.000	1.081	2.128	3.112	4.000	4.767	5.389	5.848	6.128	6.223
GZ	0.000	2.382	3.526	3.320	2.634	1.754	0.778	-0.243	-1.268	-2.257

Stability Criteria

Max GZ	3.559	m	Occurs at	22.45	degrees
Area 0 - Max GZ	0.903	m-rads	Required	0.080	m-rads
Area 0 -30	1.361	m-rads	Area 0 to 40	1.885	m-rads
Area 30 - 40	0.524	m-rads	Required	0.030	m-rads

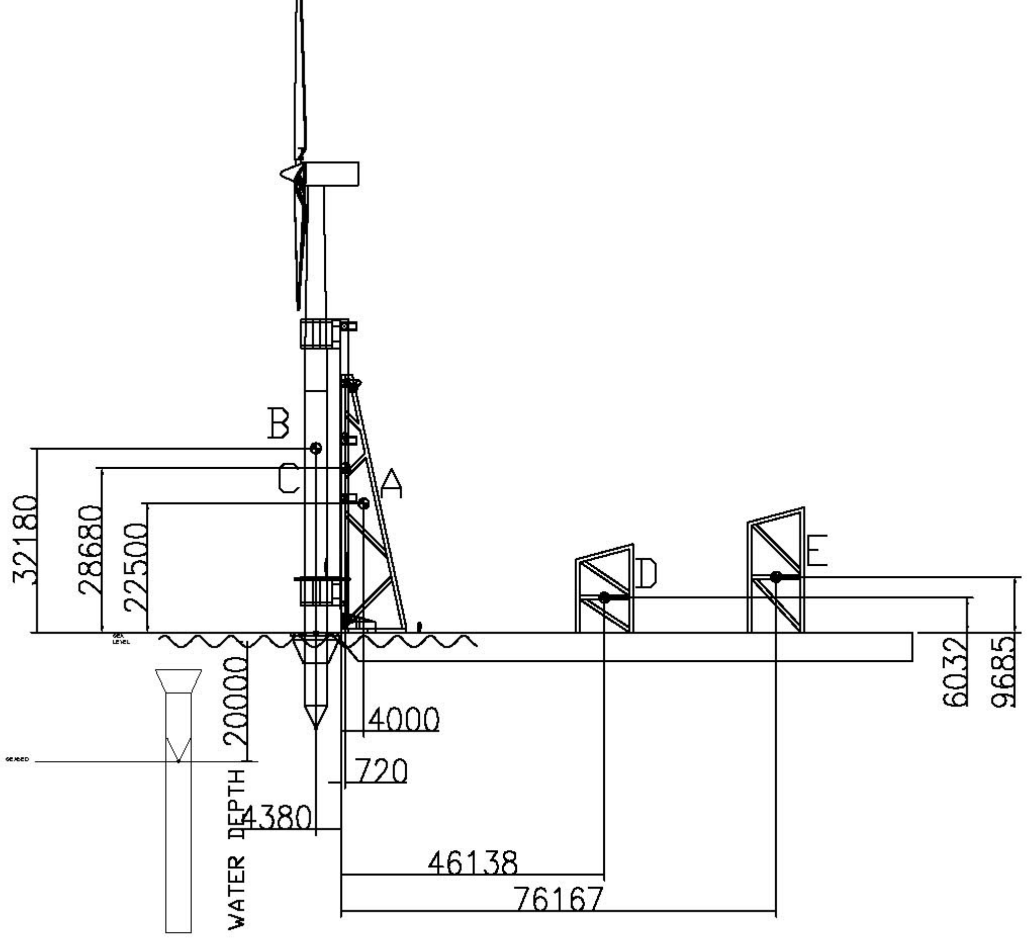
Righting Arms vs. Heel



MASSES

A) WINCH FRAMES : 100,000KG
B) WIND TURBINE : 510,000KG
C) A FRAME/ SUPPORT CRADLE : 100,000KG
D) FWD SUPPORT FRAME : 25,000KG
E) AFT SUPPORT FRAME : 25,000KG

NOTE: MASSES CAN BE ASSUMED TO BE ON CENTRE LINE OF BARGE



CONTRACT REF	ORIGINAL SHEET SIZE A4	CUSTOMER REF	
MATERIAL	3RD ANGLE PROJECTION	TITLE MERLIN CENTRE OF MASS 90 DEGREES MIDDLE	
DESIGNED BY / DO NOT SCALE			
DRAWN BY DB / DRAWN DATE 07/04/04	REMOVE ALL BURRS AND SHARP EDGES		
CHECKED BY / CHECK DATE	DIMENSIONS mm	ORIGINAL SCALE	DRAWING No C130-20-0027 / SHEET 1 OF 1 / REVISION 0

THE ENGINEERING BUSINESS Ltd

LOADING CONDITION 4 – MERLIN CENTRE OF MASS 90 DEGREES MIDDLE

Fuel Oil Specific Gravity 0.897 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
FUEL OIL	21	5.0	6.840	34	3.765	19	17
TOTAL		5.0	6.840	34	3.765	19	17

Ballast Water Specific Gravity 1.025 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
No 1 INNER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 INNER SB	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER SB	90	374.7	85.616	32080	4.436	1662	378
No 2 INNER PS	-	0.0					
No 2 INNER SB	-	0.0					
No 2 OUTER PS	90	846.9	73.390	62153	3.429	2904	609
No 2 OUTER SB	90	846.9	73.390	62153	3.429	2904	609
No 3 INNER PS	90	846.9	57.290	48517	3.429	2904	609
No 3 INNER SB	90	846.9	57.290	48517	3.429	2904	609
No 3 OUTER PS	-	0.0					
No 3 OUTER SB	-	0.0					
No 4 INNER PS	-	0.0					
No 4 INNER SB	-	0.0					
No 4 OUTER PS	90	846.9	41.190	34883	3.429	2904	609
No 4 OUTER SB	90	846.9	41.190	34883	3.429	2904	609
No 5 INNER PS	90	846.9	25.090	21248	3.429	2904	609
No 5 INNER SB	90	846.9	25.090	21248	3.429	2904	609
No 5 OUTER PS	-	0.0					
No 5 OUTER SB	-	0.0					
No 6 OUTER PS	80	664.7	9.940	6607	3.546	2357	644
No 6 OUTER SB	80	664.7	9.940	6607	3.546	2357	644
TOTAL		9603.2	49.477	475136	3.602	34594	7672

Cargo

Compartment		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
WINCH FRAMES	-	100.0	4.000	400	30.120	3012	0
WIND TURBINE	-	510.0	-4.380	-2234	39.800	20298	0
A FRAME/SUPPORT CRADLE	-	100.0	0.720	72	36.300	3630	0
FWD SUPPORT FRAME	-	25.0	46.138	1153	13.652	341	0
AFT SUPPORT FRAME	-	25.0	76.167	1904	17.305	433	0
TOTAL		760.0	1.705	1296	36.466	27714	0

Total Deadweight

Item	Specific Gravity (t/m³)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
Fuel Oil	0.897	5.0	6.840	34	3.765	19	17
Ballast Water	1.025	9603.2	49.477	475136	3.602	34594	7672
Cargo	-	760.0	1.705	1296	36.466	27714	0
TOTAL		10368.2	45.955	476466	6.011	62327	7689

Loading Summary

Item		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)
Light Ship		2262.0	44.258	100112	4.250	9614
Deadweight		10368.2	45.955	476466	6.011	62327
Displacement		12630.2	45.651	576578	5.696	71940

Floating Summary

Draft FWD	4.888	m	LCG	45.651	m	GM(Solid)	14.280	m
Draft MS	4.894	m	KG(Solid)	5.696	m	F/S Corr.	0.609	m
Draft AFT	4.899	m	KG(Fluid)	6.305	m	GM(Fluid)	13.671	m
Trim (+ve by stern)	0.011	m	Heel	0.000	degrees	KMT	19.976	m

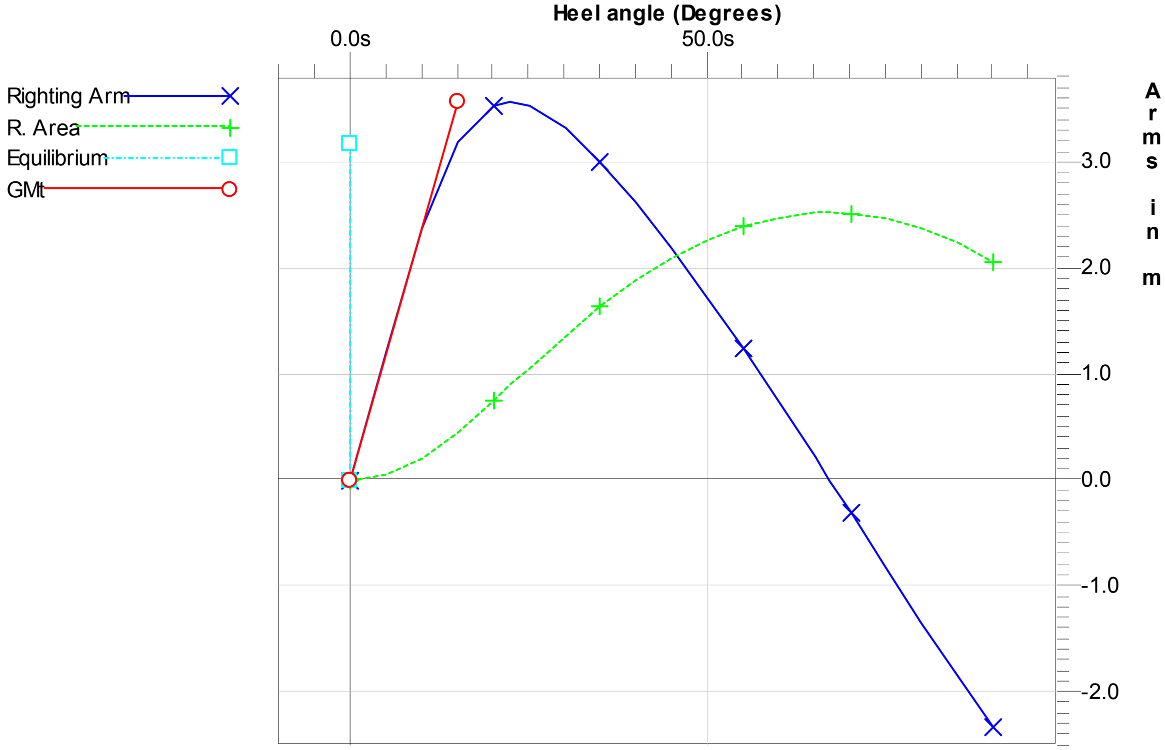
Intact Stability

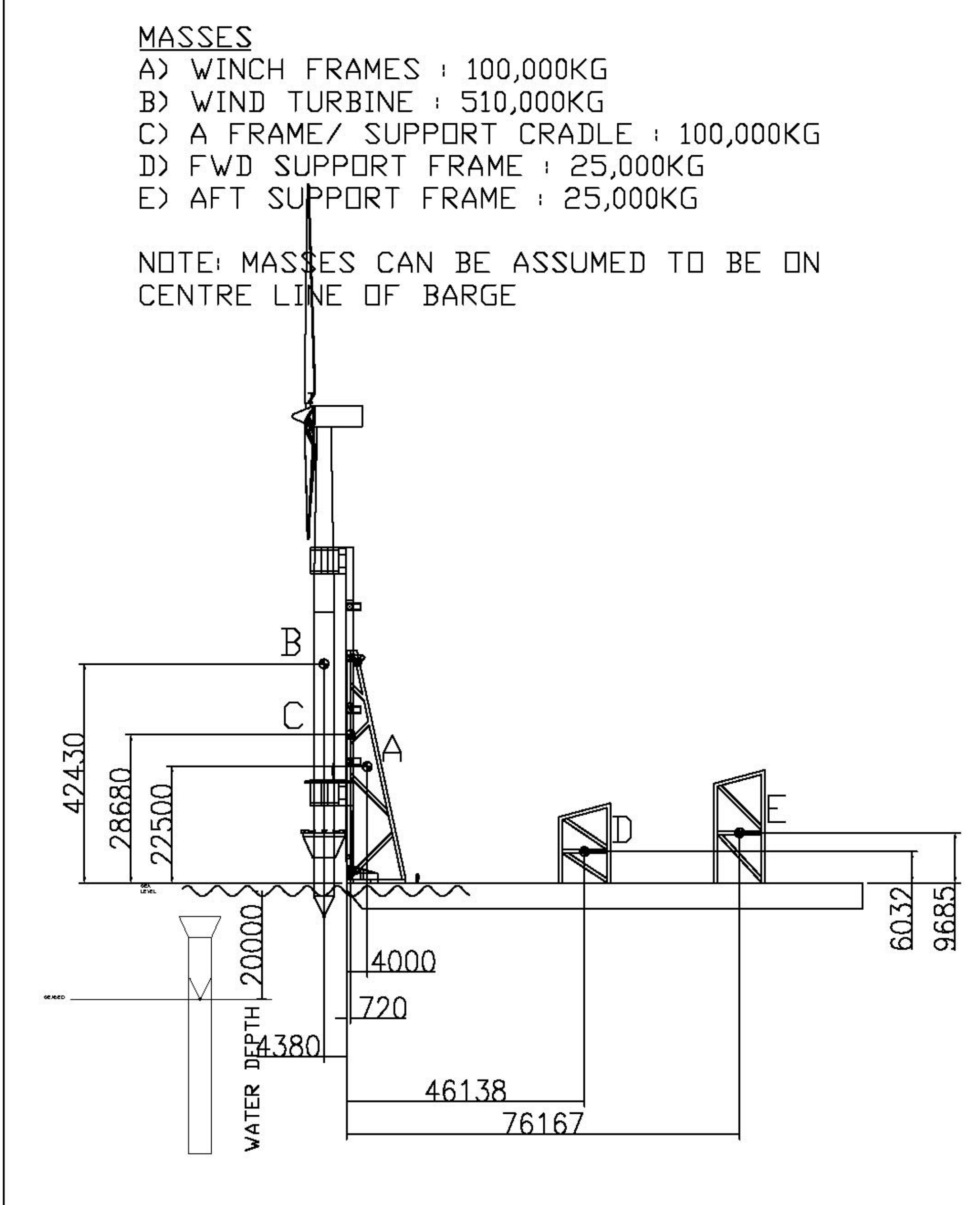
Angle, s	0	10	20	30	40	50	60	70	80	90
sins	0.000	0.174	0.342	0.500	0.643	0.766	0.866	0.940	0.985	1.000
KN	0.000	3.477	5.698	6.475	6.674	6.555	6.193	5.622	4.870	3.966
KGsins	0.000	1.095	2.156	3.152	4.053	4.830	5.460	5.924	6.209	6.305
GZ	0.000	2.382	3.542	3.323	2.621	1.725	0.733	-0.302	-1.339	-2.339

Stability Criteria

Max GZ	3.573	m	Occurs at	22.34	degrees
Area 0 - Max GZ	0.898	m-rads	Required	0.080	m-rads
Area 0 -30	1.365	m-rads	Area 0 - 40	1.887	m-rads
Area 30 - 40	0.522	m-rads	Required	0.030	m-rads

Righting Arms vs. Heel





CONTRACT REF		ORIGINAL SHEET SIZE A4	CUSTOMER REF
MATERIAL		3RD ANGLE PROJECTION	TITLE MERLIN CENTRE OF MASS 90 DEGREES UPPER
DESIGNED BY	DO NOT SCALE		
DRAWN BY DB	DRAWN DATE 07/04/04	REMOVE ALL BURRS AND SHARP EDGES	
CHECKED BY	CHECK DATE	DIMENSIONS mm	ORIGINAL SCALE

THE ENGINEERING BUSINESS Ltd

DRAWING No C130-20-0028 | SHEET 1 OF 1 | REVISION 0

LOADING CONDITION 5 – MERLIN CENTRE OF MASS 90 DEGREES UPPER

Fuel Oil — Specific Gravity 0.897 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
FUEL OIL	21	5.0	6.840	34	3.765	19	17
TOTAL		5.0	6.840	34	3.765	19	17

Ballast Water — Specific Gravity 1.025 tonnes per m3

Compartment	Fill (%)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
No 1 INNER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 INNER SB	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER PS	90	374.7	85.616	32080	4.436	1662	378
No 1 OUTER SB	90	374.7	85.616	32080	4.436	1662	378
No 2 INNER PS	-	0.0					
No 2 INNER SB	-	0.0					
No 2 OUTER PS	90	846.9	73.390	62153	3.429	2904	609
No 2 OUTER SB	90	846.9	73.390	62153	3.429	2904	609
No 3 INNER PS	90	846.9	57.290	48517	3.429	2904	609
No 3 INNER SB	90	846.9	57.290	48517	3.429	2904	609
No 3 OUTER PS	-	0.0					
No 3 OUTER SB	-	0.0					
No 4 INNER PS	-	0.0					
No 4 INNER SB	-	0.0					
No 4 OUTER PS	90	846.9	41.190	34883	3.429	2904	609
No 4 OUTER SB	90	846.9	41.190	34883	3.429	2904	609
No 5 INNER PS	90	846.9	25.090	21248	3.429	2904	609
No 5 INNER SB	90	846.9	25.090	21248	3.429	2904	609
No 5 OUTER PS	-	0.0					
No 5 OUTER SB	-	0.0					
No 6 OUTER PS	80	664.7	9.940	6607	3.546	2357	644
No 6 OUTER SB	80	664.7	9.940	6607	3.546	2357	644
TOTAL		9603.2	49.477	475136	3.602	34594	7672

Cargo

Compartment		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
WINCH FRAMES	-	100.0	4.000	400	30.120	3012	0
WIND TURBINE	-	510.0	-4.380	-2234	50.050	25526	0
A FRAME/SUPPORT CRADLE	-	100.0	0.720	72	36.300	3630	0
FWD SUPPORT FRAME	-	25.0	46.138	1153	13.652	341	0
AFT SUPPORT FRAME	-	25.0	76.167	1904	17.305	433	0
TOTAL		760.0	1.705	1296	43.344	32941	0

Total Deadweight

Item	Specific Gravity (t/m³)	Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)	Free Surface Moment (t-m)
Fuel Oil	0.897	5.0	6.840	34	3.765	19	17
Ballast Water	1.025	9603.2	49.477	475136	3.602	34594	7672
Cargo	-	760.0	1.705	1296	43.344	32941	0
TOTAL		10368.2	45.955	476466	6.516	67554	7689

Loading Summary

Item		Weight (tonnes)	LCG Fwd AP (metres)	Longl Moment (t-m)	VCG Abv Base (metres)	Vertical Moment (t-m)
Light Ship		2262.0	44.258	100112	4.250	9614
Deadweight		10368.2	45.955	476466	6.516	67554
Displacement		12630.2	45.651	576578	6.110	77168

Floating Summary

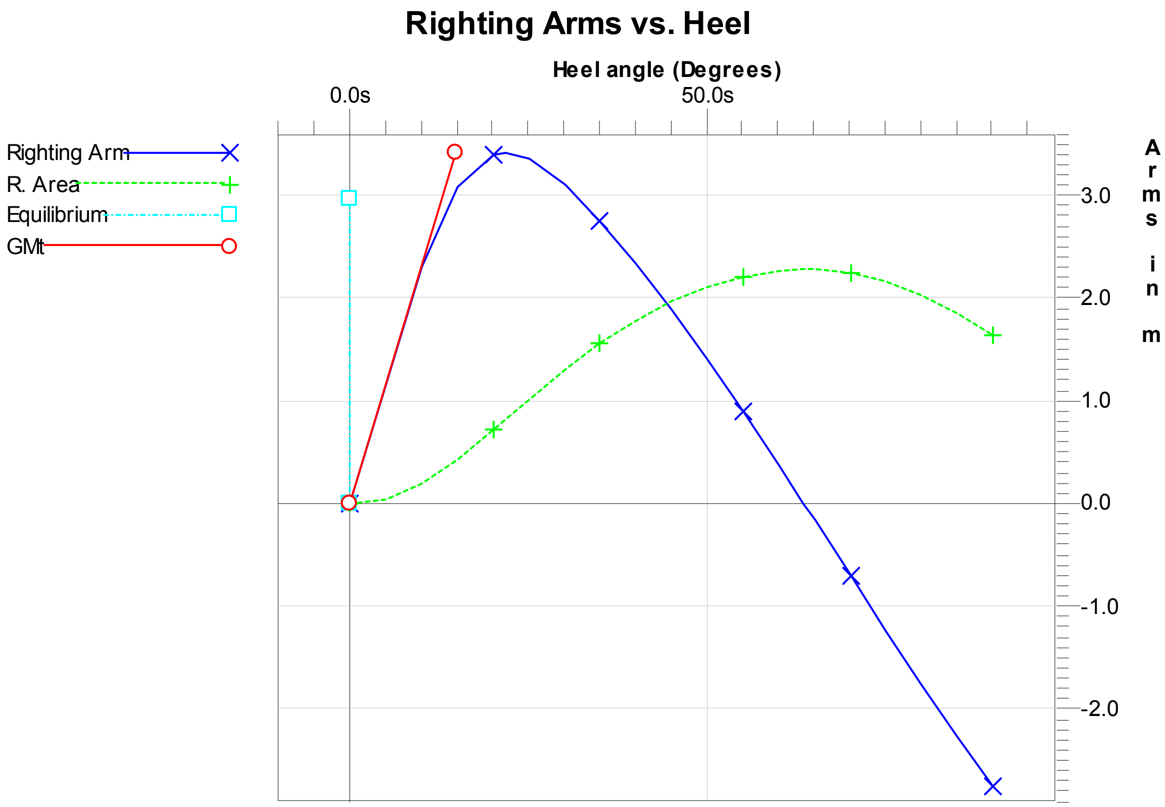
Draft FWD	4.888	m	LCG	45.651	m	GM(Solid)	13.868	m
Draft MS	4.893	m	KG(Solid)	6.110	m	F/S Corr.	0.609	m
Draft AFT	4.899	m	KG(Fluid)	6.719	m	GM(Fluid)	13.259	m
Trim (+ve by stern)	0.011	m	Heel	0.000	degrees	KMT	19.978	m

Intact Stability

Angle, s	0	10	20	30	40	50	60	70	80	90
sins	0.000	0.174	0.342	0.500	0.643	0.766	0.866	0.940	0.985	1.000
KN	0.000	3.477	5.698	6.475	6.674	6.555	6.193	5.622	4.871	3.966
KGsins	0.000	1.167	2.298	3.359	4.319	5.147	5.818	6.313	6.617	6.719
GZ	0.000	2.310	3.400	3.116	2.355	1.408	0.375	-0.691	-1.746	-2.753

Stability Criteria

Max GZ	3.419	m	Occurs at	21.77	degrees
Area 0 - Max GZ	0.833	m-rads	Required	0.080	m-rads
Area 0 -30	1.309	m-rads	Area 0 - 40	1.791	m-rads
Area 30 - 40	0.482	m-rads	Required	0.030	m-rads



Righting Arms vs. Heel
Heel angle (Degrees)
0.0s
50.0s
Righting Arm
R. Area
Equilibrium
GMt
3.0
2.0
1.0
0.0
-1.0
-2.0
Arms in m

APPENDIX B – FEA OF MERLIN WIND TURBINE TOWER

Support type			Simple Cradle			Clamped Cradle			Simple Cradle/internal support		
Support Length (m)			3	5	7	3	5	7	3	5	7
Modelling Case No.			1	2	3	4	5	6	7	8	9
Horizontal	Max Stress MPa		324.55	312.77	288.03	255.09	279.68	259.97	287.2	252.01	280.5
	% of Yield Stress		91.42%	88.10%	81.14%	71.86%	78.78%	73.23%	80.90%	70.99%	79.01%
	Max Deflection mm		463.58	427.67	399.23	406.17	376.96	352.75	399.9	371.45	347.55
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-248.88	-238.69	-232.25	-225.76	-224.12	-223.67	-224.06	-223.1	-223.11
		Z	-273.35	-155.55	-91.38	-44.12	-15.07	-7.7	-21.09	-5.25	-1.66
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-260.28	-270.47	-276.91	-283.4	-285.04	-285.49	-285.1	-286.06	-286.05
		Z	273.35	155.55	91.38	44.12	15.07	7.7	21.09	5.25	1.66
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-509.16	-509.16	-509.16	-509.16	-509.16	-509.16	-509.16	-509.16	-509.16
		Z	0	0	0	0	0	0	0	0	0
Modelling Case No.			10	11	12	13	14	15	16	17	18
15 degrees elevation	Max Stress MPa		309.43	303.74	279.81	248.22	272.16	253.07	279.45	245.26	273.02
	% of Yield Stress		87.16%	85.56%	78.82%	69.92%	76.66%	71.29%	78.72%	69.09%	76.91%
	Max Deflection mm		447.1	412.54	385.12	392.26	364.11	340.75	386.24	358.8	335.73
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-239.14	-229.62	-223.59	-217.82	-216.4	-216	-216.31	-215.45	-215.48
		Z	-322.97	-209.11	-146.95	-100.63	-72.36	-65.19	-78.02	-62.68	-59.28
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-252.66	-262.18	-268.21	-273.98	-275.4	-275.8	-275.49	-276.35	-276.33
		Z	191.19	77.33	15.17	-31.15	-59.42	-66.59	-53.76	-69.1	-72.5
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-491.8	-491.8	-491.8	-491.8	-491.8	-491.8	-491.8	-491.8	-491.81
		Z	-131.78	-131.78	-131.78	-131.78	-131.78	-131.78	-131.78	-131.78	-131.78

Table 1 Comparative Stresses, Deflections and Support loadings, with dynamic factor of 1, Dimension b=65m

Support type			Simple Cradle			Clamped Cradle			Simple Cradle/internal support		
Support Length (m)			3	5	7	3	5	7	3	5	7
Modelling Case No.			19	20	21	22	23	24	25	26	27
Horizontal	Max Stress MPa		422.03	406.6	374.44	331.62	363.58	337.96	373.36	327.61	364.65
	% of Yield Stress		118.88%	114.54%	105.48%	93.41%	102.42%	95.20%	105.17%	92.28%	102.72%
	Max Deflection mm		602.83	555.97	518.99	528.02	360.05	458.58	519.87	482.89	451.82
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-323.61	-310.3	-301.93	-293.49	-291.36	-290.77	-291.28	-290.03	-290.04
		Z	-355.42	-202.22	-118.79	-57.36	-19.59	-10.01	-27.42	-6.83	-2.16
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-338.3	-351.61	-359.98	-368.42	-370.55	-371.14	-370.63	-371.88	-371.87
		Z	355.42	202.22	118.79	57.36	19.59	10.01	27.42	6.83	2.16
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91
		Z	0	0	0	0	0	0	0	0	0
Modelling Case No.			28	29	30	31	32	33	34	35	36
15 degrees elevation	Max Stress MPa		402.28	394.86	363.75	322.68	353.81	328.99	363.29	318.84	354.93
	% of Yield Stress		113.32%	111.23%	102.46%	90.90%	99.66%	92.67%	102.34%	89.81%	99.98%
	Max Deflection mm		581.27	536.31	500.65	509.94	473.34	442.98	502.11	466.44	436.45
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-310.9	-298.54	-290.69	-283.17	-281.32	-280.8	-281.2	-280.13	-280.16
		Z	-419.89	-271.84	-191.04	-130.82	-94.07	-84.75	-101.43	-81.48	-77.06
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-328.49	-340.85	-348.7	-356.22	-358.07	-358.59	-358.19	-359.26	-359.23
		Z	248.57	100.52	19.72	-40.5	-77.25	-86.57	-69.89	-89.84	-94.26
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39
		Z	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32

Table 2 Comparative Stresses, Deflections and Support loadings, with dynamic factor of 1.3, Dimension b=65m

Support type			Simple Cradle			Clamped Cradle			Simple Cradle/internal support		
Support Length (m)			3	5	7	3	5	7	3	5	7
Modelling Case No.			37	38	39	40	41	42	43	44	45
Horizontal	Max Stress MPa		348.79	338.11	319.94	312.26	286.98	320.75	291.86	319.29	291.58
	% of Yield Stress		98.25%	95.24%	90.12%	87.96%	80.84%	90.35%	82.21%	89.94%	82.14%
	Max Deflection mm		277.73	248.28	224.03	232.9	208.61	350.52	229.92	207.19	186.52
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-283.88	-277.87	-273.87	-271.55	-270.98	-273.38	-270.52	-270.2	-270.57
		Z	-187.86	-96.65	-45.01	-29.4	-9.56	-7.43	-12.55	-2.03	-0.03
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-378.03	-384.04	-388.04	-390.36	-390.93	-388.53	-391.39	-391.71	-391.34
		Z	187.86	96.65	45.01	29.4	9.56	7.43	12.55	2.03	0.03
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91
		Z	0	0	0	0	0	0	0	0	0
Modelling Case No.			46	47	48	49	50	51	52	53	54
15 degrees elevation	Max Stress MPa		330.96	323.06	311.35	304.44	279.84	312.43	284.37	305.38	278.64
	% of Yield Stress		93.23%	91.00%	87.70%	85.76%	78.83%	88.01%	80.10%	86.02%	78.49%
	Max Deflection mm		267.54	239.24	215.87	224.87	201.47	338.52	222.02	200.09	180.14
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-273.08	-267.57	-263.88	-262.07	-261.64	-263.98	-261.18	-260.95	-261.3
		Z	-253.07	-164.69	-114.65	-98.62	-79.24	-76.91	-81.96	-71.76	-69.92
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-366.31	-371.82	-375.51	-377.32	-377.75	-375.41	-378.21	-378.44	-378.09
		Z	81.75	-6.63	-56.67	-72.7	-92.08	-94.41	-89.36	-99.56	-101.4
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39

Table 3 Comparative Stresses, Deflections and Support loadings, with dynamic factor of 1.3, Dimension b=75m

Support type			Simple Cradle			Clamped Cradle			Simple Cradle/internal support		
Support Length (m)			3	5	7	3	5	7	3	5	7
Modelling Case No.			55	56	57	58	59	60	61	62	63
Horizontal	Max Stress MPa		265.79	220.49	237.43	223.22	211.95	223.17	229.89	212.01	212.11
	% of Yield Stress		74.87%	62.11%	66.88%	62.88%	59.70%	62.86%	64.76%	59.72%	59.75%
	Max Deflection mm		77.86	64.34	54.24	59.92	48.84	40.07	58.72	48.61	38.14
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-255.79	-253.66	-252.38	-252.04	-252.25	-252.39	-251.59	-251.78	-252.2
		Z	-71.49	-25.19	0.39	-11.4	-3.41	-1.8	-3.85	0.03	1.08
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-406.12	-408.25	-409.53	-409.87	-409.66	-409.52	-410.32	-410.13	-409.71
		Z	71.49	25.19	-0.39	11.4	3.41	1.8	3.85	-0.03	-1.08
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91	-661.91
		Z	0	0	0	0	0	0	0	0	0
Modelling Case No.			64	65	66	67	68	69	70	71	72
15 degrees elevation	Max Stress MPa		249.75	215.41	232.24	218.6	206.43	219.07	225.11	206.34	206.24
	% of Yield Stress		70.35%	60.68%	65.42%	61.58%	58.15%	61.71%	63.41%	58.12%	58.10%
	Max Deflection mm		74.75	61.84	52.05	57.84	47.18	38.72	56.7	46.92	36.79
	Upper Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-246.31	-244.47	-243.33	-243.29	-243.59	-243.75	-242.93	-243.15	-243.56
		Z	-135.74	-90.72	-65.86	-76.33	-68.45	-66.89	-68.71	-64.93	-64.01
	Lower Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-393.08	-394.92	-396.06	-396.1	-395.8	-395.64	-396.46	-396.24	-395.83
		Z	-35.58	-80.6	-105.46	-94.99	-102.87	-104.43	-102.61	-106.39	-107.31
	Total Support Load te	X	0	0	0	0	0	0	0	0	0
		Y	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39	-639.39
		Z	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32	-171.32

Table 4 Comparative Stresses, Deflections and Support loadings, with dynamic factor of 1.3, Dimension b=85m

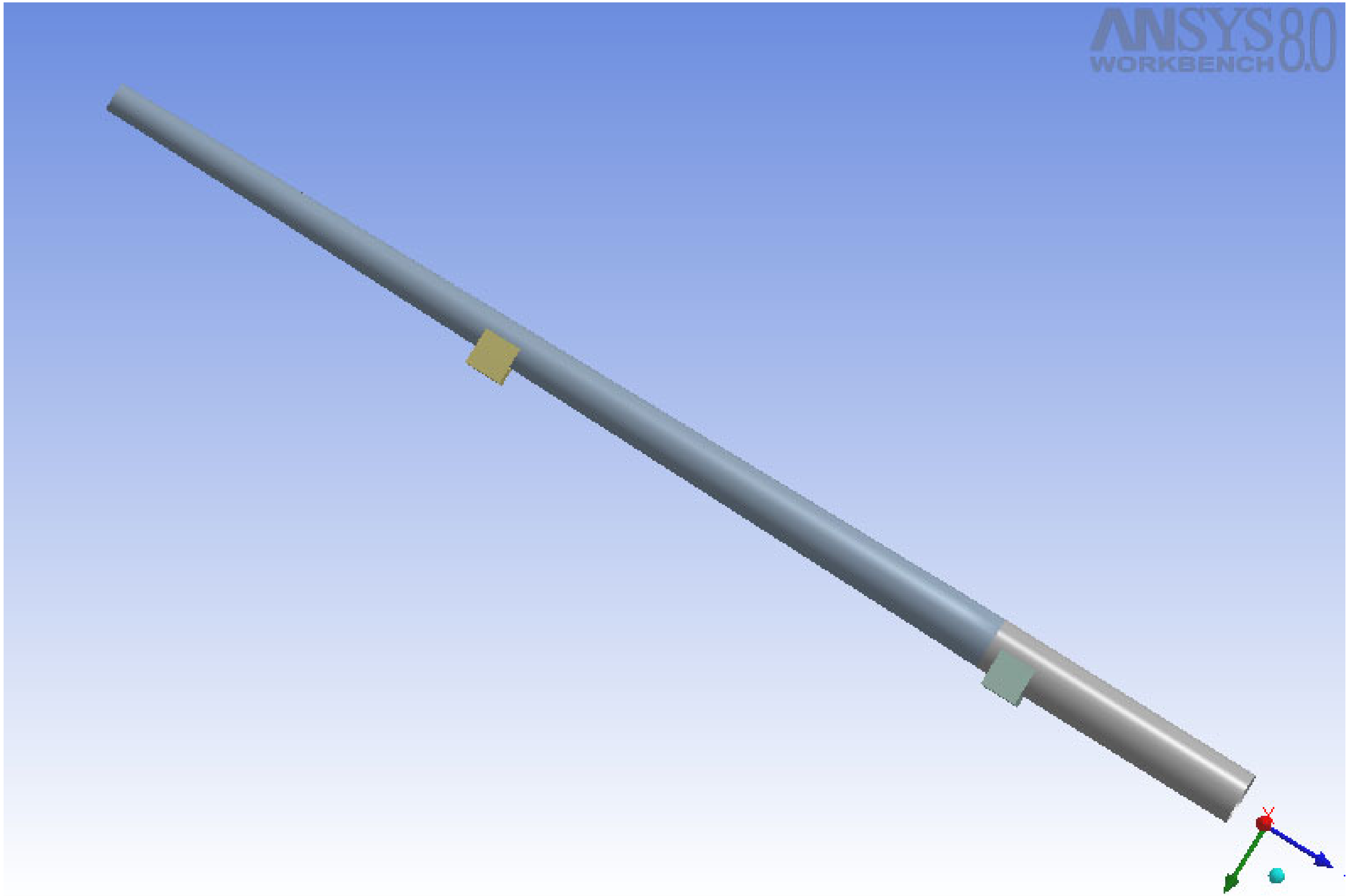


Figure 1 Case 19 Geometry

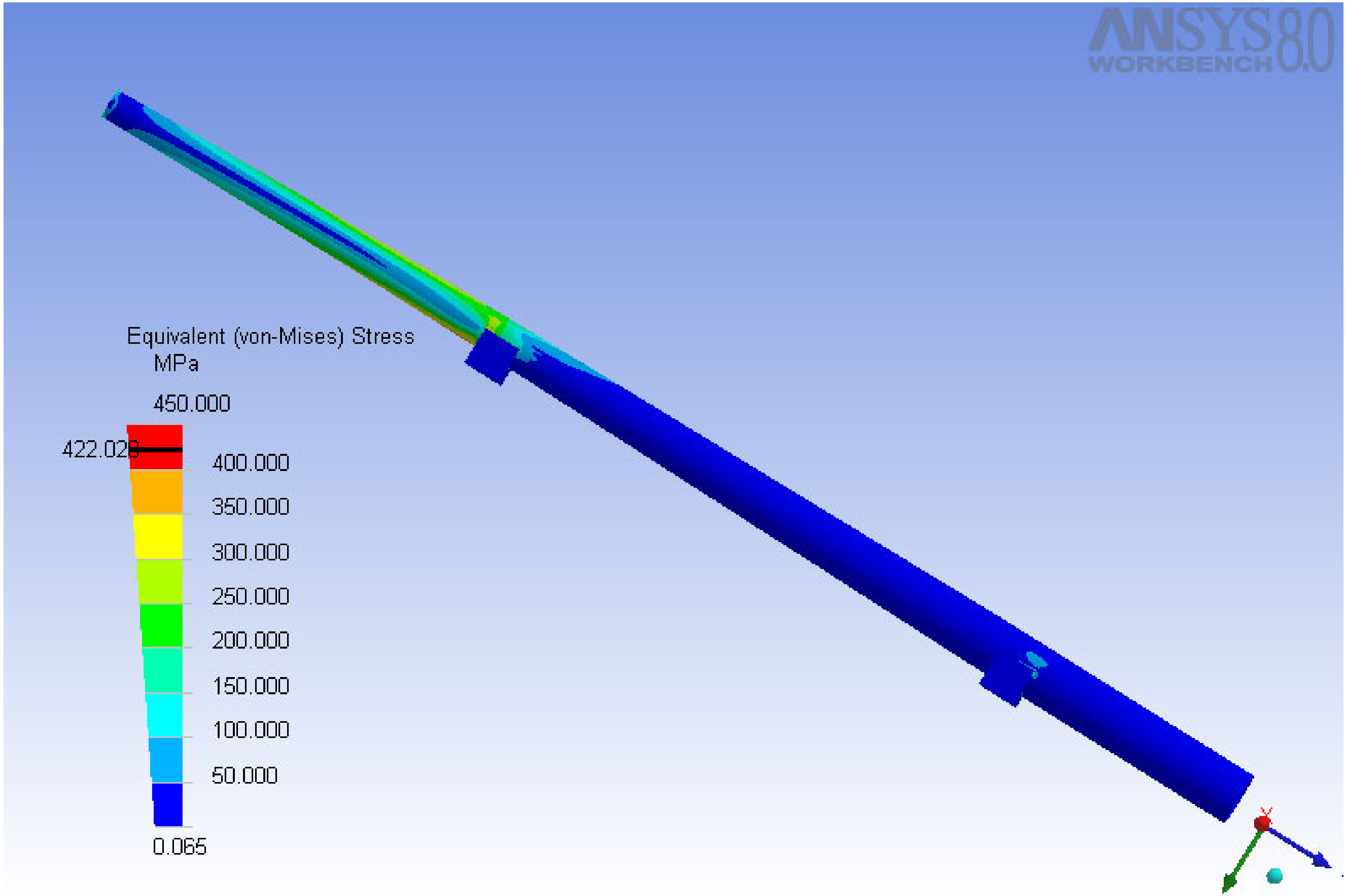


Figure 2 Case 19 - Overall view

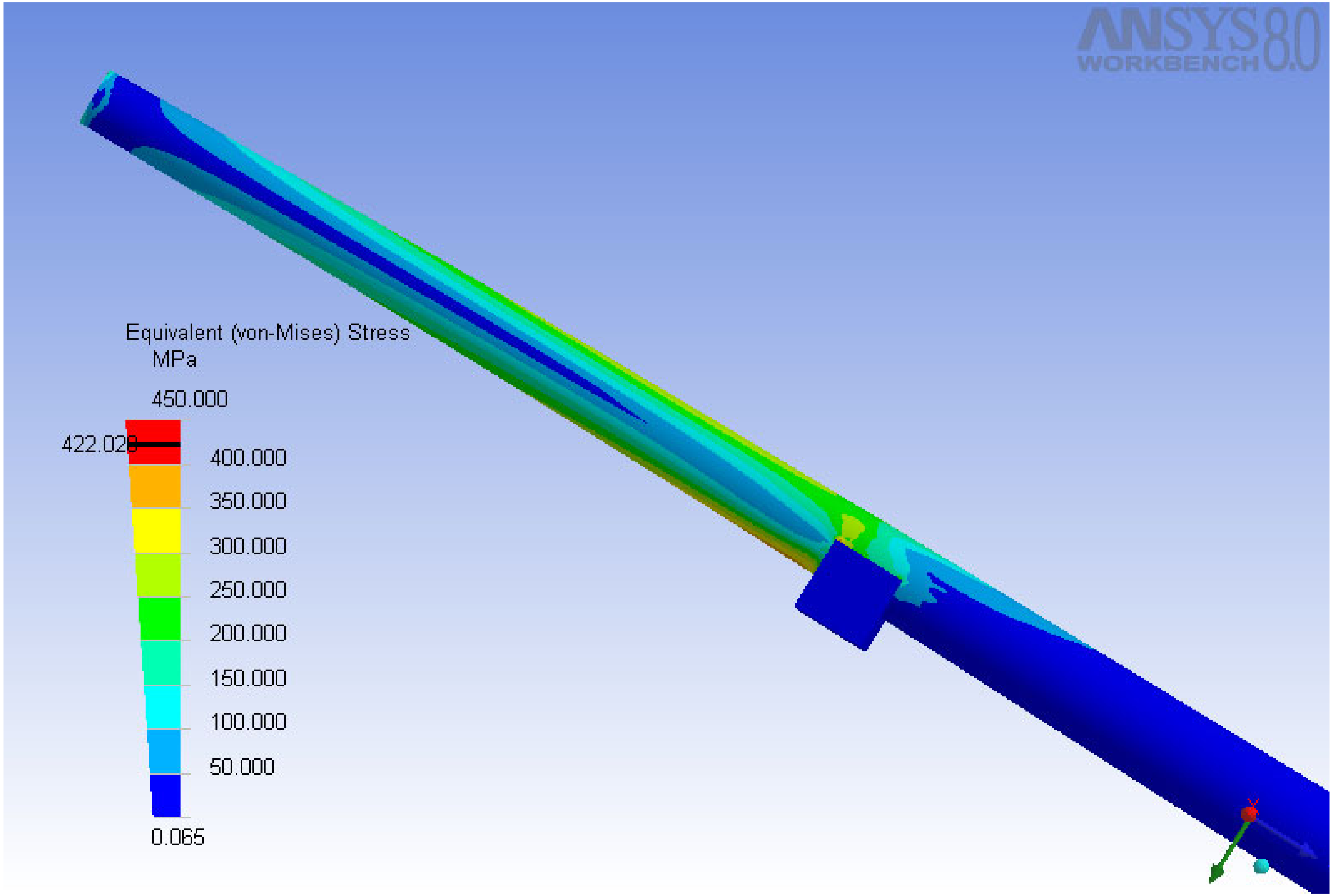


Figure 3 Case 19 - Close up view

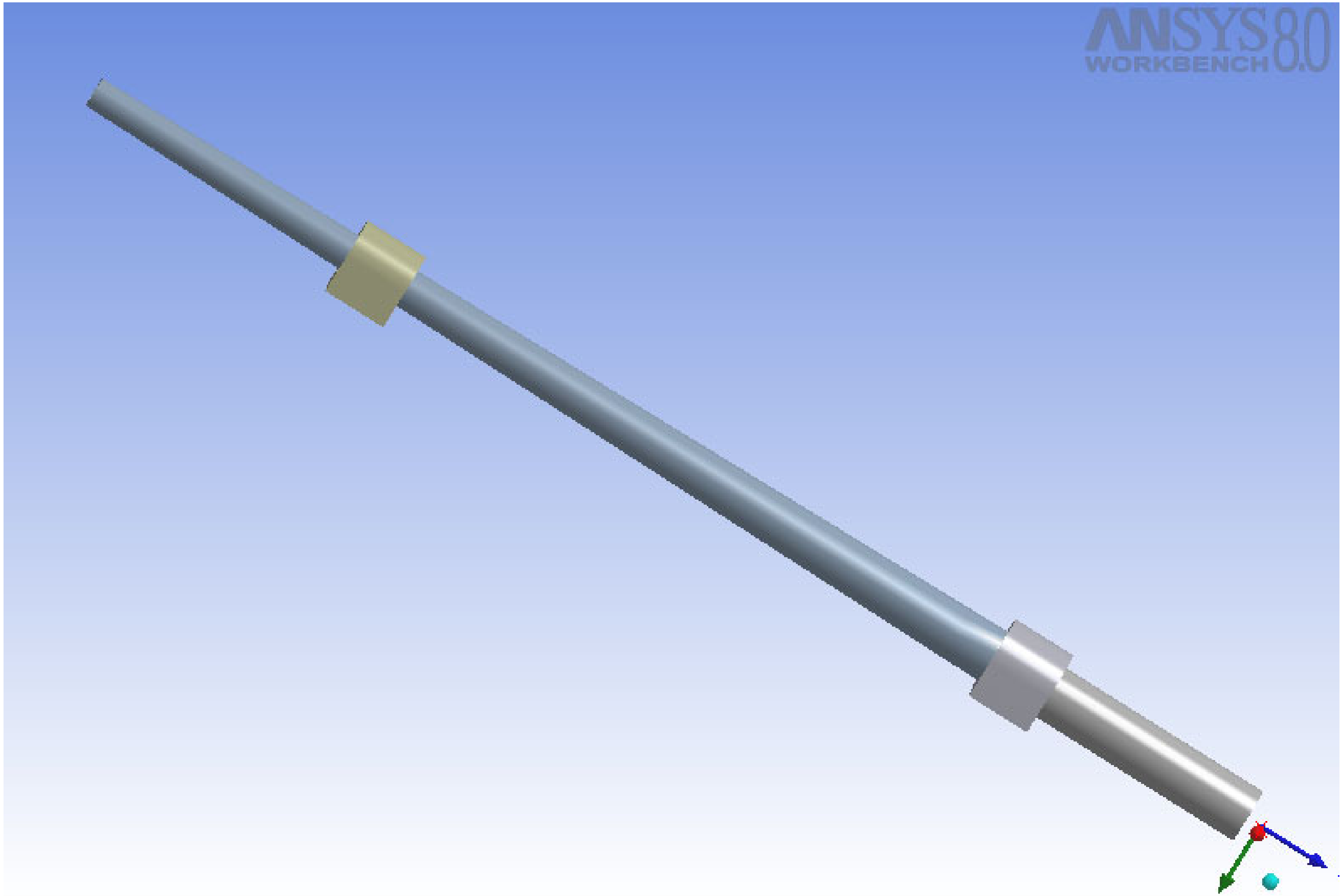


Figure 4 Case 50 Geometry

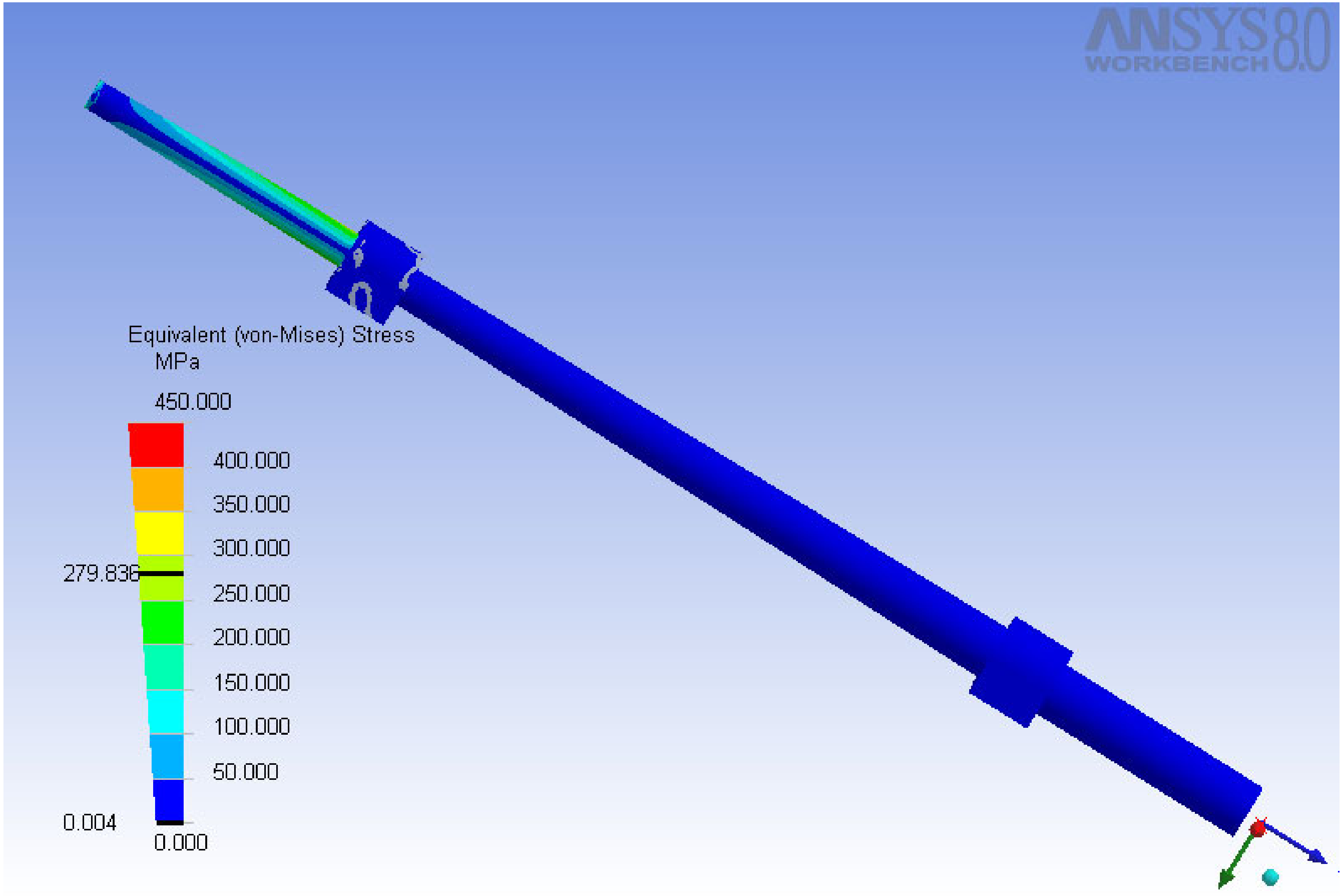


Figure 5 Case 50 - Overall view

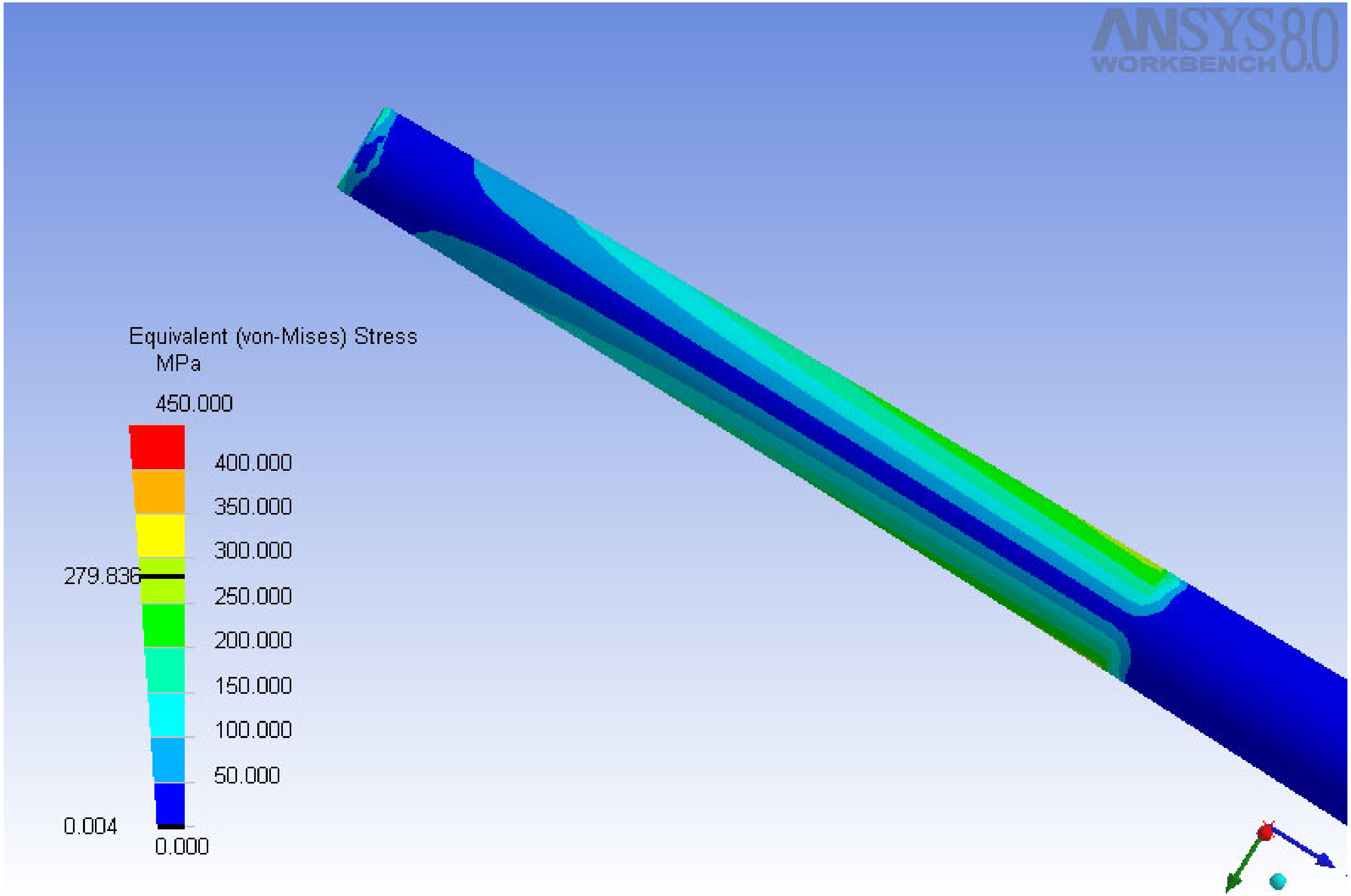


Figure 6 Case 50 - Close up view with upper support hidden

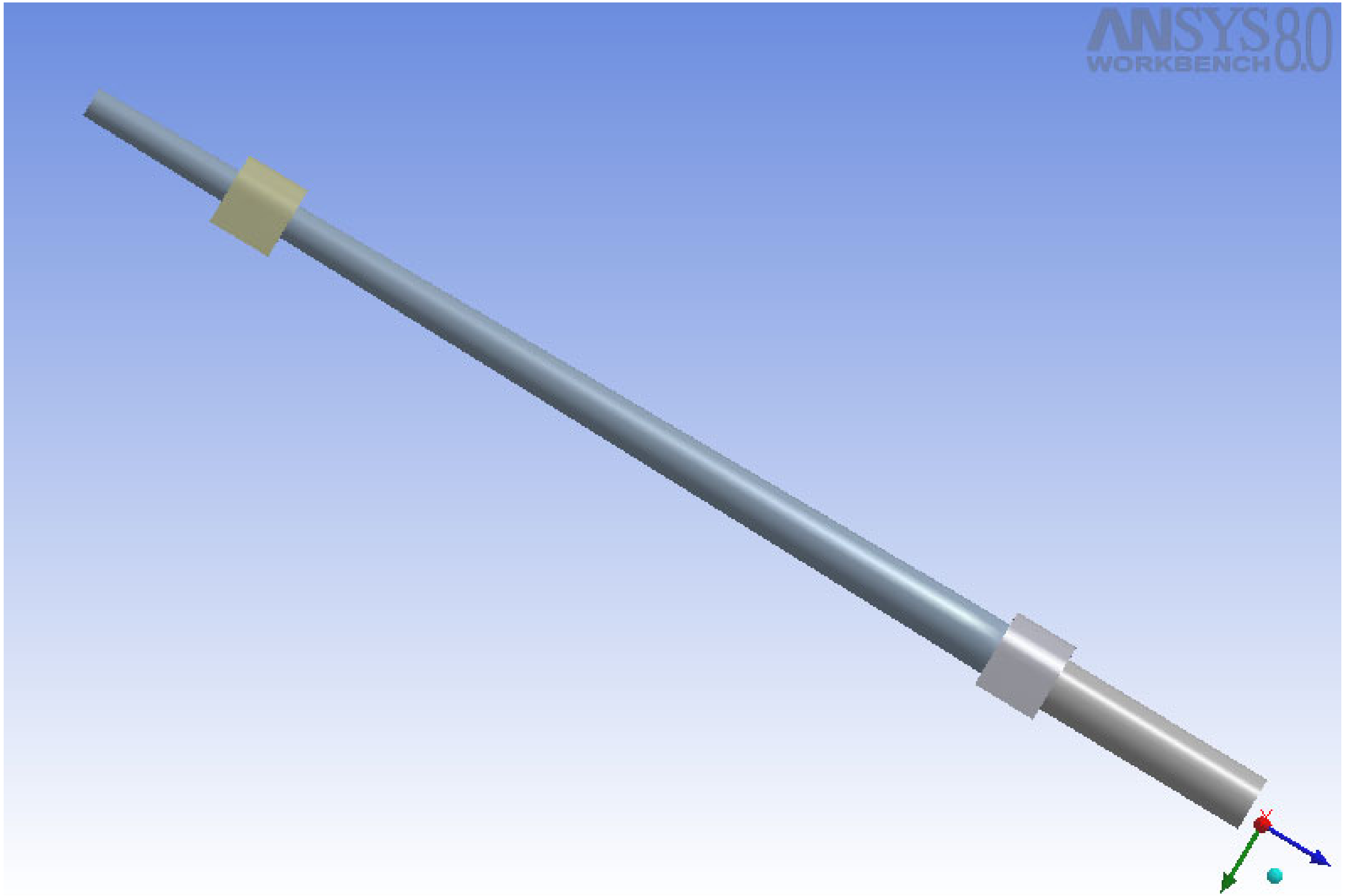


Figure 7 Case 68 Geometry

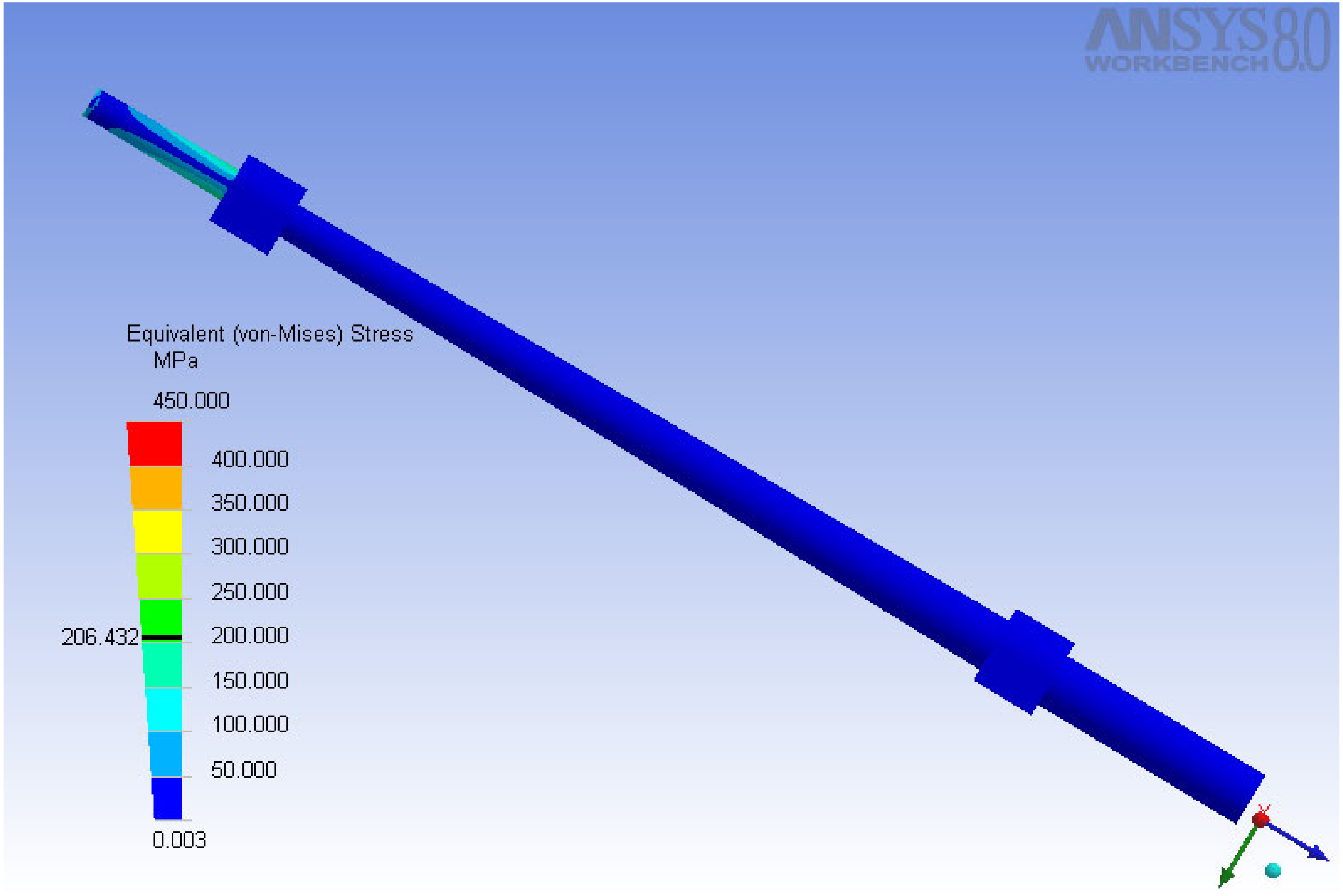


Figure 8 Case 68 – Overall view

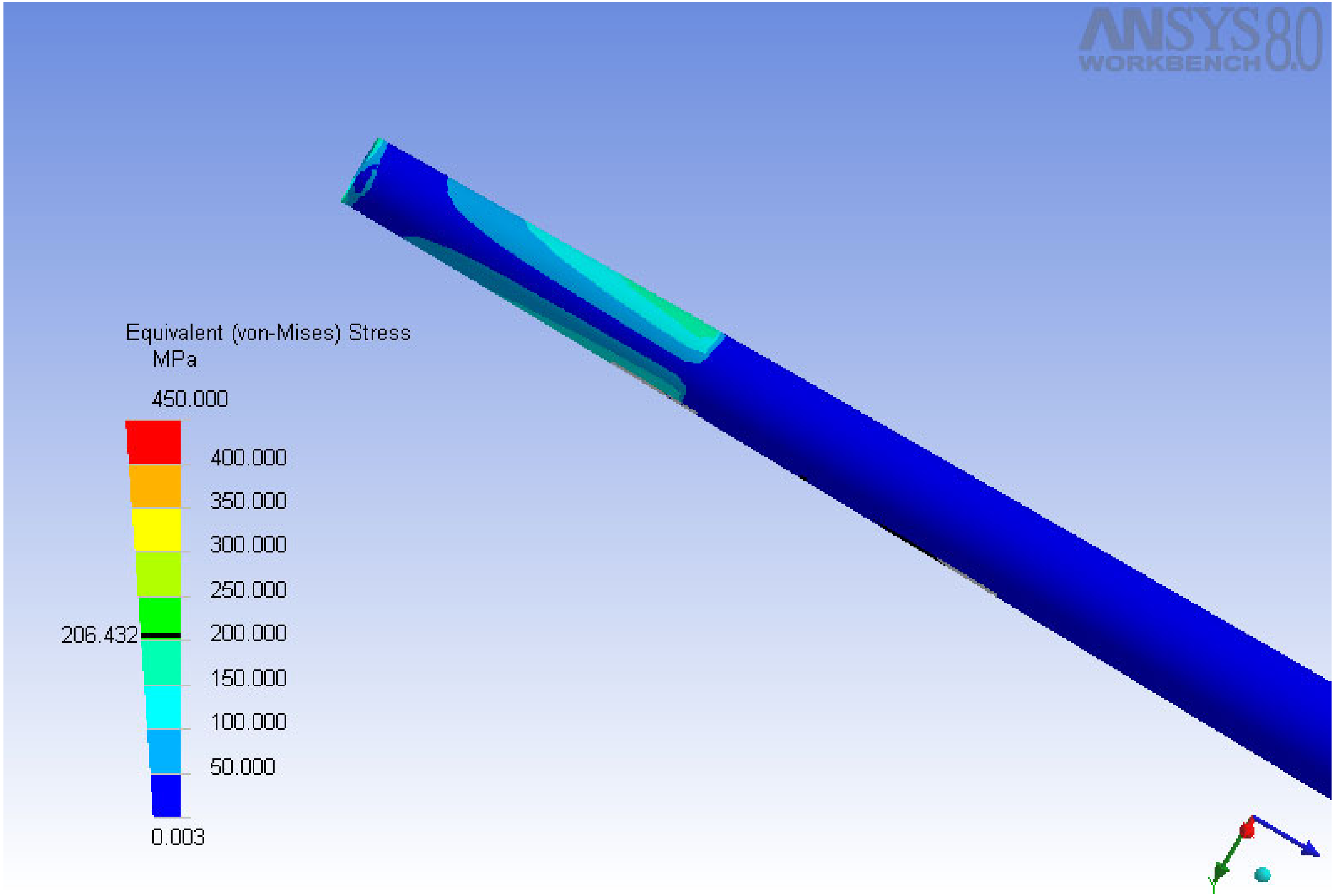


Figure 9 Case 68 – Close up view with upper support hidden

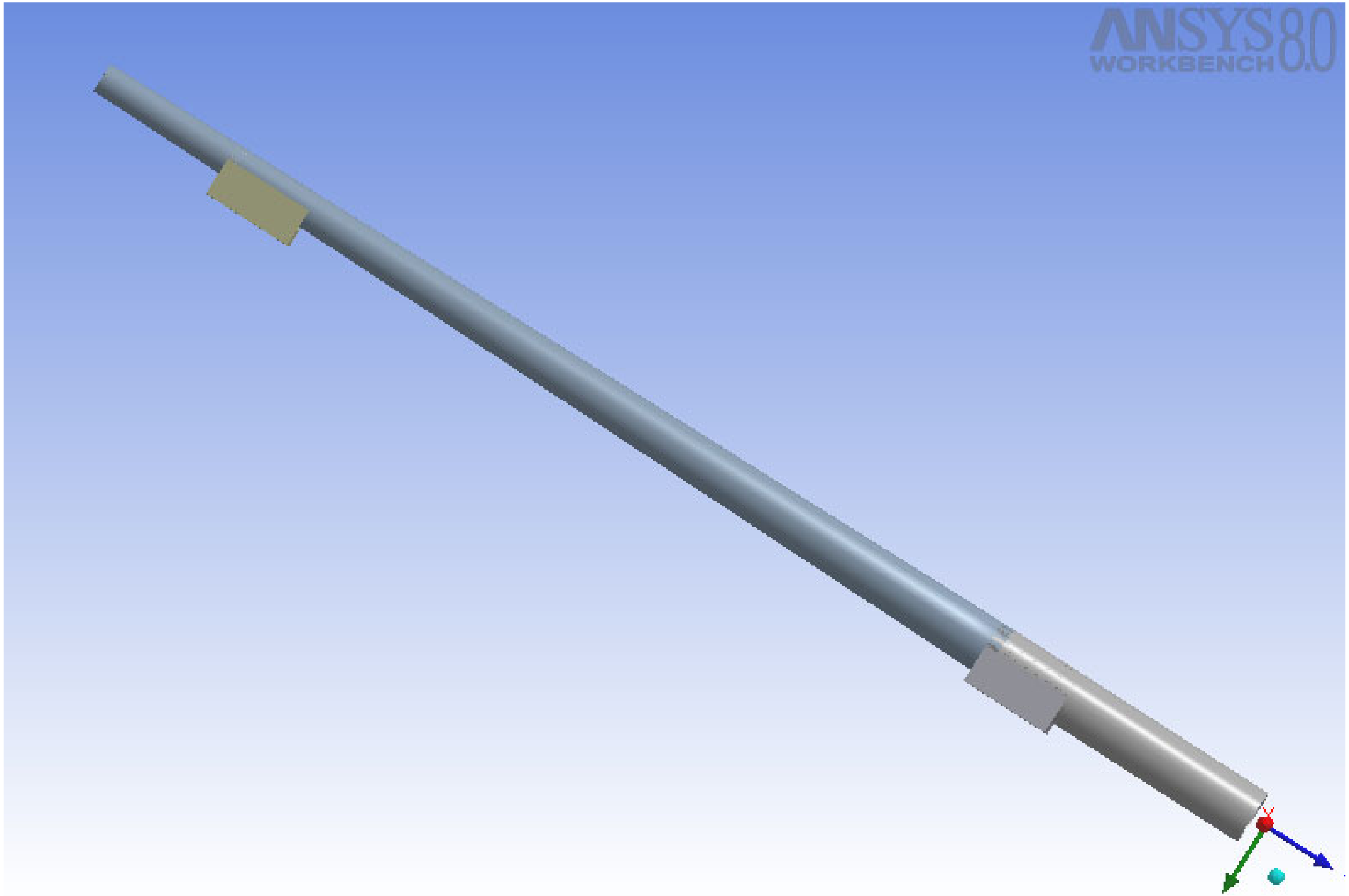


Figure 10 Case 72 Geometry

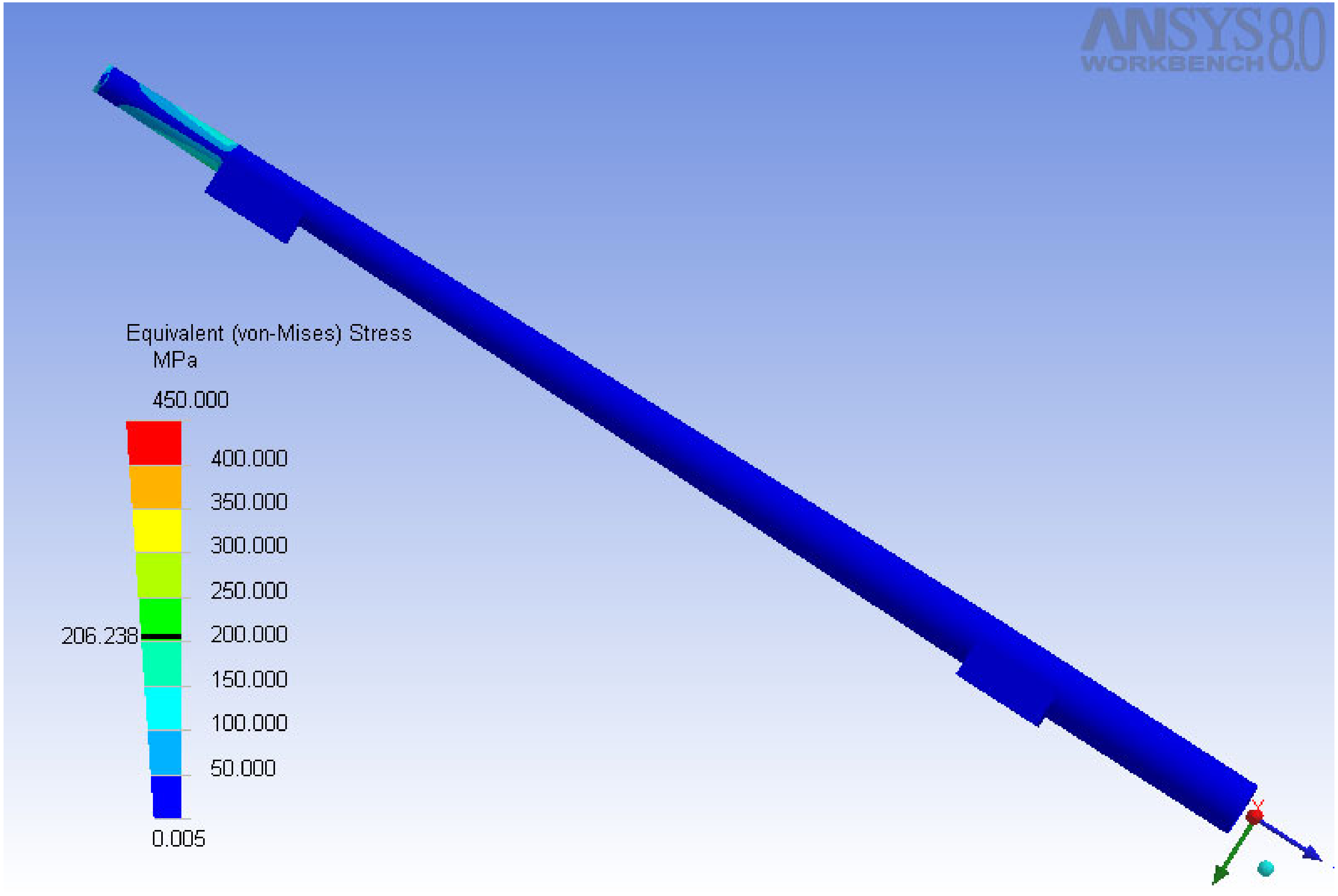


Figure 11 Case 72 – Overall view

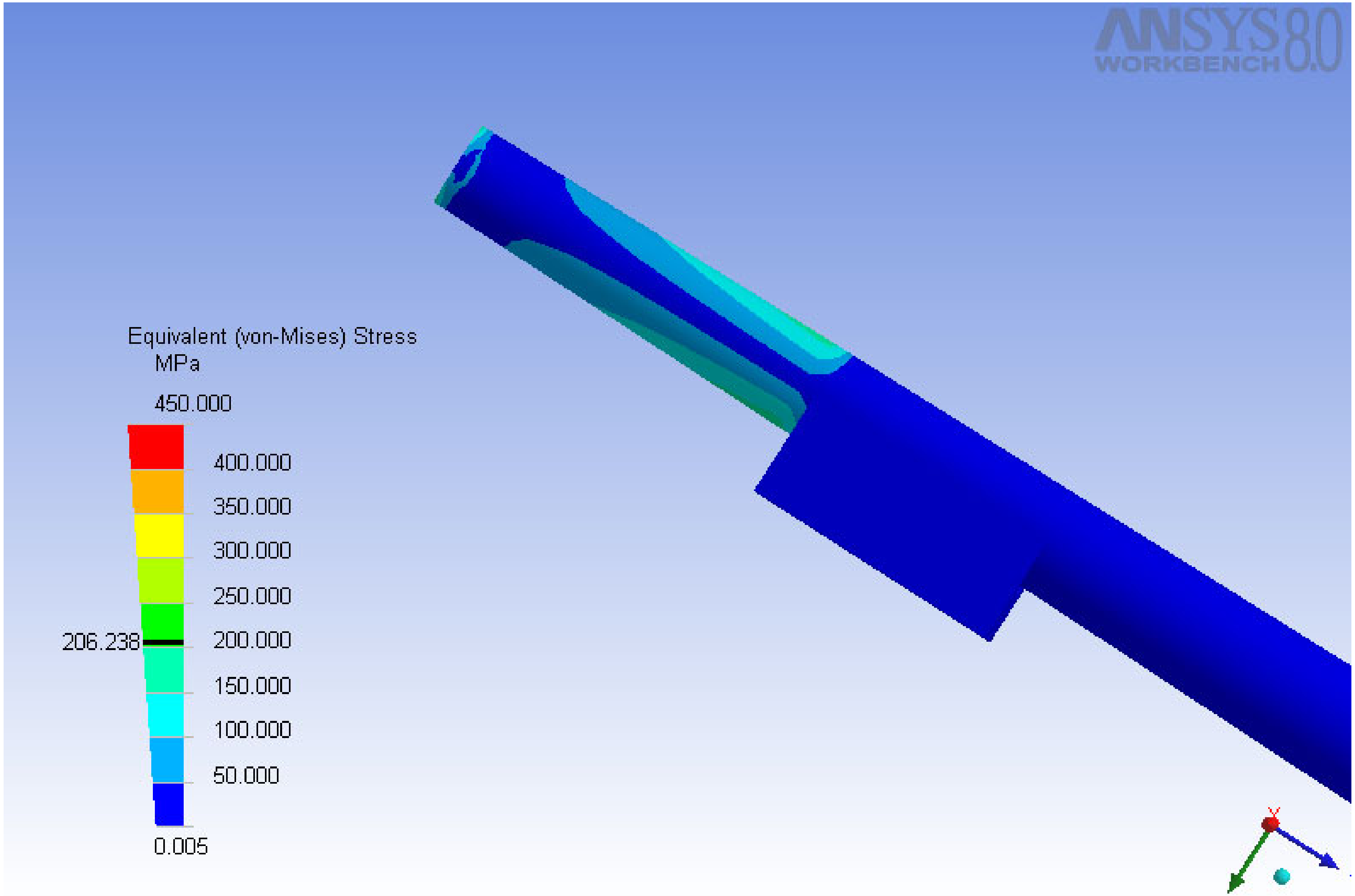


Figure 12 Case 72 – Close up view