Planning and Design for the Oakajee Port Development project in Western Australia

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Abstract
The Oakajee Port project has been described by the Premier of Western Australia as "*..the single most important project for WA's economic development over the next 50 years*". The estimated value of the port and rail project being around $4M, the critical importance of the port to the project cannot be underestimated. In additional to opening up the mid-west region of Western Australia to iron ore export opportunities, future port development plans incorporate additional berths for other industrial users.

This paper concentrates on the planning and design aspects relating to the port layout, breakwaters, dredging and navigation channels for the future port facility. Following on from a number of previous investigations and studies, further work has been undertaken over the past 12-18 months to deal with the numerous design challenges at the site. Ongoing, further detailed work will follow this planning phase of the project to understand and resolve in the design and construction of the port at Oakajee.

1 Background

A number of companies are developing iron ore deposits in Western Australia's Mid West region. Geraldton is the closest port for these developments (Figure 1), but Geraldton Port is limited in depth and the largest vessel it can handle is about a 60,000 DWT Panamax, at high tide.

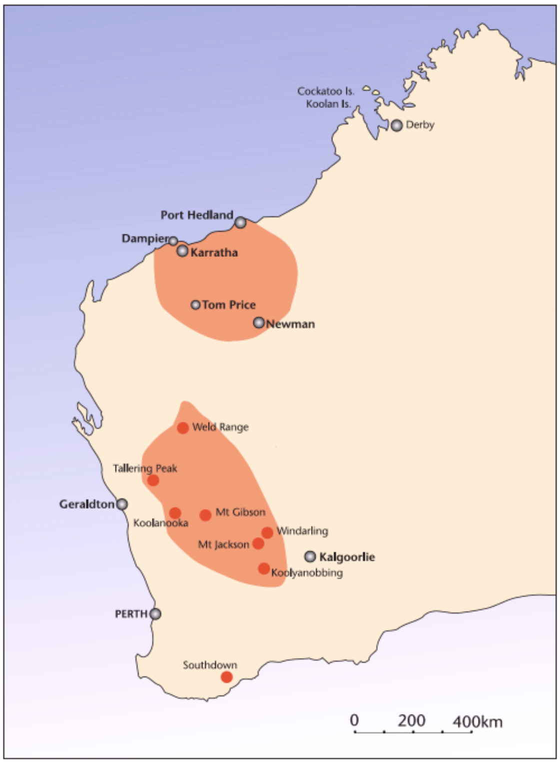


Figure 1: Iron Ore Deposits, Western Australia (source: Macquarie presentation to OPR, 2008)

To enable economic export of ore, a new deep water port is required to enable Cape Class vessels (to 180,000 DWT) to operate. Hence, it is proposed to build Oakajee Port, 23 km north of Geraldton, in a region where there is deep water close to the coast (Figure 2).

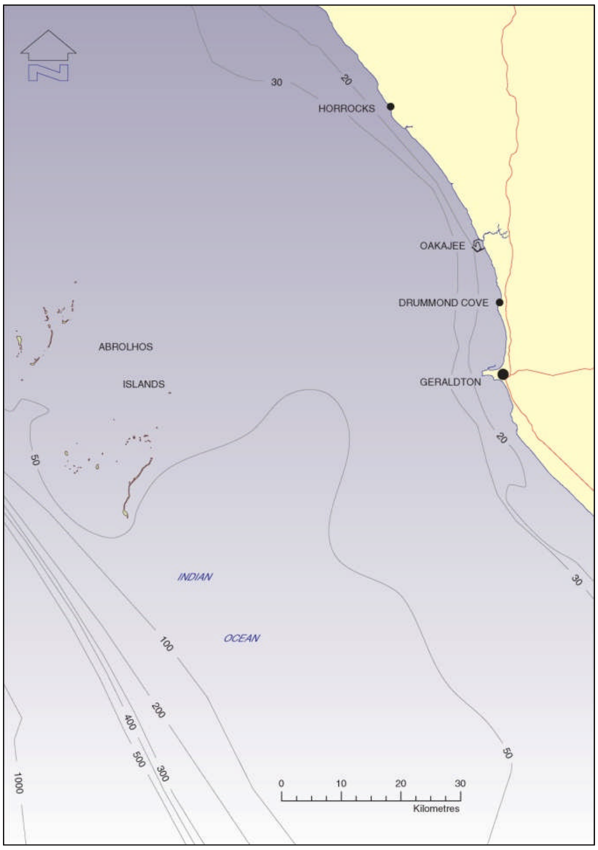


Figure 2: Seabed Bathymetric Contours

After an exhaustive tender process, the State Government of Western Australia nominated

Oakajee Port and Rail (OPR) as the successful proponent for the development of the new deep water port for the export of bulk iron ore at Oakajee in July 2008. This has been followed up with the signing of a State Development Agreement in March 2009, which includes the rights to develop the required rail links, from the mines to the Oakajee Port.

Oakajee Port and Rail (OPR) is a Western Australian based company comprised of Murchison Metals Ltd and Mitsubishi Corporation, (see Figure 3). Crosslands is a 50:50 Murchison:Mitsubishi company, and OPR is owned 50% by Crosslands, 25% by Murchison and 25% by Mitsubishi.

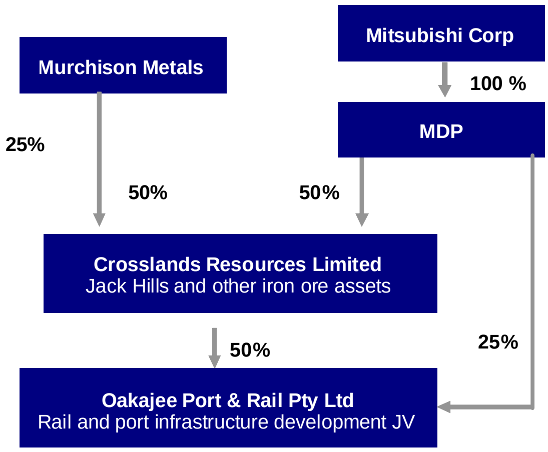


Figure 3: OPR Ownership Structure

In late 2007 and early 2008, JFA Consultants (JFA), a Western Australian based specialist coastal, port and harbour engineering consultancy, working with international consultants HR Wallingford (HRW) and Icelandic Maritime Administration (IMA) developed a pre-feasibility level design for the breakwaters, dredging and quarry sources for the port development, which OPR subsequently used for the basis of their successful submission.

Further, more detailed planning studies have now also been undertaken covering many aspect of the proposed development, including; onshore quarry resource investigations; offshore geotechnical investigations; cyclonic and non-cyclonic wave modelling studies; ship and tug simulation studies; assessment of dredging requirements; and detailed port layout and breakwater designs.

This paper gives a brief coverage of the proposed port development by considering the following issues:

- Design challenges;
- Overall port layout;
- Design aspects of port layout;
- Breakwater design;
- Dredging design; and
- Conclusions.

2 Design Challenges

The Oakajee port development is particularly interesting as it presents a number of significant challenges, including the following:

- It is an area of high energy sea state (50% of total waves exceed H_s=1.5m), with persistent swells and a very large breakwater (2.4 km long, including causeway) in water depth of up to 23m is required;
- A quarry, or quarries, must be developed with rock of sufficient size and in sufficient quantity to provide material for breakwater construction;
- The persistent swells will make breakwater construction difficult (must be recognised in the design and construction methodology);
- The seas, and a seabed comprised of high strength calcarenite material (up to 30 Mpa), will make dredging difficult. The conditions are similar to Geraldton, where dredging was undertaken in 2003, and where there was major damage to the dredger and a large claim; and
- The Port of Geraldton is known to have significant harbour tranquillity issues, particularly associated with long period waves (with typical wave lengths of 30-200sec) which present particular issues with at the ship berths.

3 Overall Port Layout

For many years, the State Government has planned for a large industrial area and port to be built at Oakajee, and the failed Kingstream development in the late 1990's was located in the same area. The Government has purchased about 5,000 hectares of land in the area, with the industrial area comprising 1,000 hectares, surrounded by a further 3,000 - 4,000 hectares of land acting as a buffer zone (see Figure 4). The ultimate development envisages the port servicing industries built in the industrial area.

With respect to export of iron ore, it is a typical Pilbara-type development. Rail brings ore to port where it is offloaded through a car dumper (nominal 50 Mtpa capacity). From the car dumper, the ore is transported via conveyors to stackers (10,000 tph), which place the ore into stockpiles. The outloading starts with a reclaimer (12,000 tph) loading on to a conveyor, which transports the lump to be rescreened, from where it is placed onto another conveyor for delivery to the shiploader located on the wharf. The shiploader loads the ship.

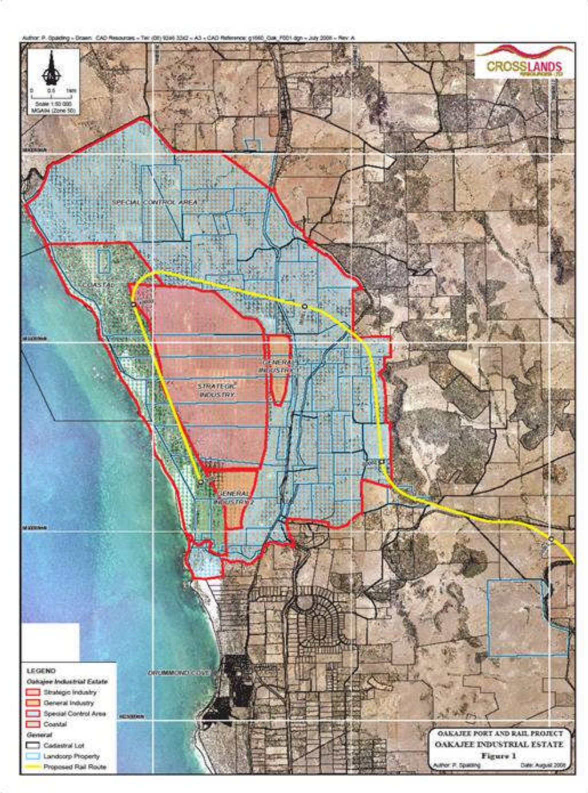


Figure 4: Oakajee Industrial Area and Buffer Zones

The plan as shown caters only for DSO. There is also a requirement to be able to handle concentrate, and this will be incorporated over the next few months.

A desalination plant is required to provide water for the development. A small package unit will be installed to provide water during the construction phase.

The initial port development will provide one Cape Class berth, protected by a breakwater and with dredging to provide berthing and channel – as per Figure 5. This arrangement should allow export of up to 35 Mtpa DSO. The throughput will decrease slightly with introduction of concentrate.

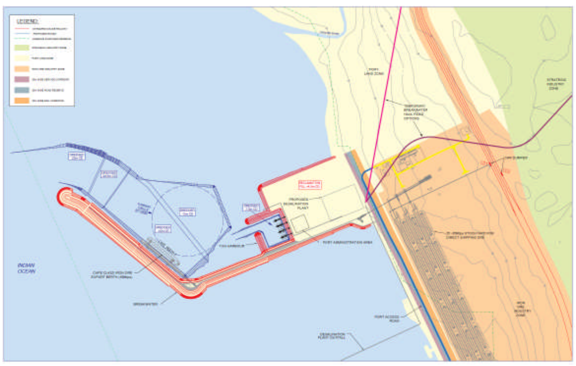


Figure 5: Stage 1 Oakajee Port Development

The breakwater has been made of sufficient length to be able to construct a second berth in the same line as the first berth, enabling the shiploader from Berth 1 to operate over Berth 2, and thereby increasing exports by another 5 Mtpa DSO. With a second shiploader at Berth 2, exports could be increased to give a total throughput of up to 70 Mtpa DSO.

The ultimate port development envisages three Cape Class berths and seven Panamax berths, as shown on Figure 6.

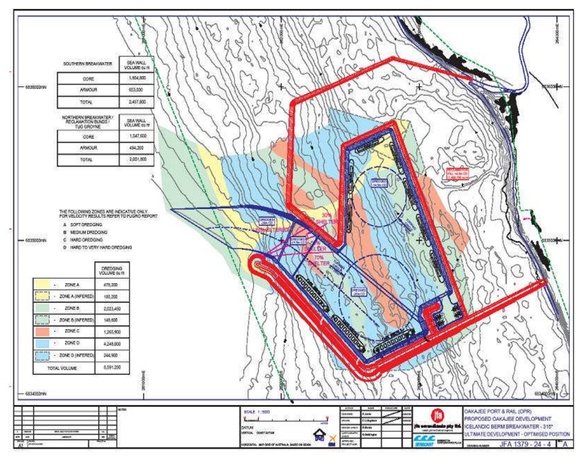


Figure 6: Ultimate Oakajee Port Development (under development)

4 Design – Port Layout

Oakajee is a region a of high energy seas with a consistent swell approaching from the SW. Figure 6 shows the consistence of the swell – 95% of the time swell is in excess of 0.75m (Hs), 50% of the time swell is in excess of 1.5m (Hs). Figure 7 shows direction of the main swell. With these conditions, the berth must be protected by a breakwater for effective operation. The breakwater orientation has been determined according to:

- the main requirement to provide protection to berthed vessels from the predominant SW swell and weather which can affect the site from the SW through to the NW; and
- to exclude as much as possible the influence of cyclones (from W-NW), with the potential to pluck armour from the inside of the breakwater.

The breakwater layout has been determined by consideration of the following:

- requirement to provide at least one Cape Class berth (preferably two) for initial development;
- taking cognisance of the ultimate development dictated by government;
- existence of paleochannel providing better material for excavation and generally keeping dredging away from inshore reef area; and

- optimising costs of dredging and breakwater construction.

The causeway connects the breakwater to shore.

The breakwater orientation and location has and will be further tested and amended as appropriate following a number of simulation and model tests, including:
- further analysis of design and operating wave conditions at the vessel berths;
- vessel simulation - some has been undertaken, more is to follow
- consideration of very long period waves;
- ship mooring and UKC studies; and
- geotechnical investigations.

The causeway and breakwater contain about 2.5 Mm^3 rock, with another 600,000 m^3 in the reclamation seawalls. Dredging is about 2.7 Mm^3, mainly calcarenite material.

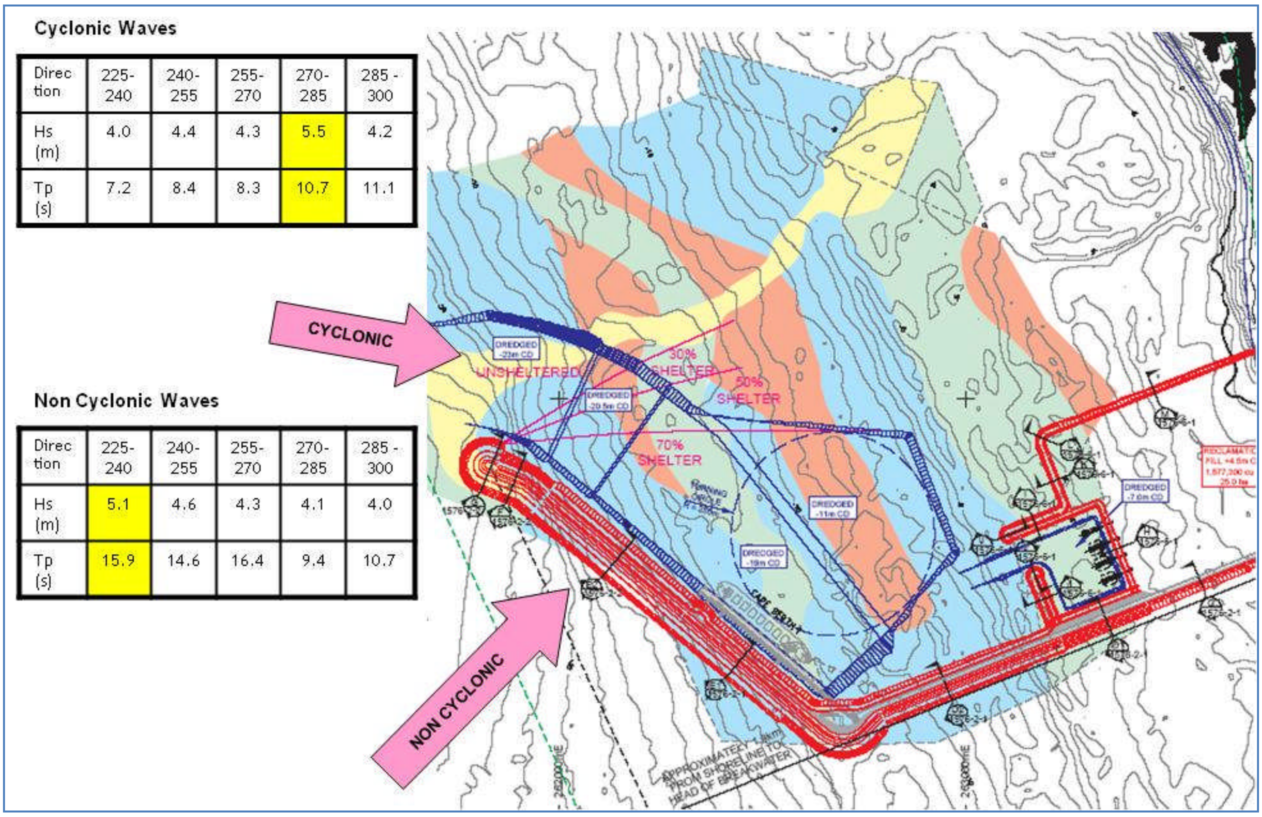
5 Design – Breakwater

5.1 Design Wave Conditions

As noted above, the predominant 1:100yr design wave approaches from SW, with the 1 in 100 year wave H_s = 5.1m, T_p= 15.9s, although severe wave conditions can approach from a number of directions (Figure 7). The cyclone design wave is Hs = 5.5m, T_p= 10.7s. The tide range is small, as are tidal currents.

Derivation of both the operational and design conditions at Oakajee has included a number of both measured and modelled datasets, including:
- various historical wave measurement campaigns between 1997 and 2008 incorporating over 4 years of measured data;
- a 20 year hindcast of ambient conditions calibrated against 1.5 years of historical data by RPS MetOcean (2004); and
- a further 7.5 year hindcast of ambient conditions calibrated against 11 months of more recent measured data by GEMS (2009).

Since December 2008, continuous wave measurements have been undertaken and the data collected is being monitored against the operational design conditions. Recently, a further measurement device has been deployed to specifically monitor long period waves at the site.



Cyclonic Waves

Direction	225-240	240-255	255-270	270-285	285 - 300
Hs (m)	4.0	4.4	4.3	5.5	4.2
Tp (s)	7.2	8.4	8.3	10.7	11.1

Non Cyclonic Waves

Direction	225-240	240-255	255-270	270-285	285 - 300
Hs (m)	5.1	4.6	4.3	4.1	4.0
Tp (s)	15.9	14.6	16.4	9.4	10.7

Figure 7: Design Wave Conditions

5.2 Breakwater Type Selection

In the early stages of the project development, different structure types for the breakwaters were investigated, including concrete caisson, sheet pile caisson, conventional rubble mound, berm breakwaters and the use of concrete armour units. The result of this work determined that, subject to availability of rock, a berm breakwater would be most suitable and most cost effective solution.

Following on from this earlier work, an independent review of the breakwater selection process was undertaken by HR Wallingford and included a review of breakwater types, safety levels, failure modes and the influence of the key design factors on breakwater selection.

A summary of the scoring factors relevant to the Oakajee location is presented in **Error! Reference source not found.**. This confirmed the use of the berm type breakwater at Oakajee with the possibility of the use of concrete armour units, subject to satisfaction of concerns regarding the placement of such units in the steady swell conditions that would be experienced at Oakajee.

Table 1. Scoring of key factors on breakwater selection at Oakajee (outer section) – HR Wallingford

		Rubble mound			Vertical / battered	
Factor	**Degree**	**Rock armoured**	**Concrete units**	**Berm breakwater**	**Caisson**	**Blockwork or sheet pile**
Water depth	Deep	-	✓	-	✓	×
Wave height	$H_s \approx$ 4-7m	-	✓✓	✓✓	✓	?
Length	Long length, shore connected	-	✓	-	✓	-
Seabed	Hard	-	✓	✓	-	✓
Overtopping	Low overtopping	✓	✓✓	✓✓	✓	✓
Reflections from rear face	Need low reflections	✓	✓	✓	×	×
Mooring use	Provides quay wall on rear side	-	-	-	✓	✓
Rock armour	Local, good quality	✓✓	✓	✓✓	-	-
Site access from land	Easy access	✓	✓	✓	-	-
Construction duration	Restricted on site	?	?	?	✓✓	✓
Frequent wave conditions	Steady swell, little calm	-	×	-	×	×
Tidal range and currents	Small tidal range and currents	✓	✓	✓	✓	✓
Expenditure preference	May require op. exp.	×	-	-	-	-

Legend:
✓✓ very favourable
- neutral
× unfavourable
✓ favourable
? depends strongly on local circumstances
×× very unfavourable

5.3 Berm Breakwater Design

PIANC and CIRIA codes nominate three categories of berm breakwaters, as follows:

- Statically stable non-reshaping – a few rocks are allowed to move;
- Statically stable reshaped structures – profile is allowed to reshape into a stable profile with the individual rocks also being stable;
- Dynamically stable reshaped structures – profile is allowed to reshape into stable profile but the individual rocks still move up and down.

In broad terms, the differences between the statically stable and reshaping berm breakwaters are as shown in Table 2.

Table 2. Comparison of berm breakwater types

Statically Stable	Reshaping
Several rock classes	One or two rock classes
Larger rock sizes	Smaller rock sizes
High permeability	Low permeability
Non-reshaping structures	Reshaping structures
Less voluminous	More voluminous
Narrow rock gradation	Wide rock gradation

The initial berm design was for a reshaping type breakwater, which had the advantage of relatively easy construction and reasonable rock size (about 10 tonne maximum). However, at about the time of the RFP process, the design was changed to a statically stable non-reshaping breakwater, which is line with latest recommendations in the CIRIA and PIANC guidelines. This is also known as an "Icelandic-type" berm breakwater, as it has developed from extensive work in Iceland. In addition to issues contained in the above table, this structure utilises all material from the quarry, and is well proven with many structures worldwide, most in conditions worse than conditions at Oakajee.

However, construction is more challenging, and it incorporates larger rock sizes (currently up to 30-35 tonnes in the breakwater head).

The outcome of on-site quarry investigations, which have recently been completed (see following section), have determined the maximum rock size would be available as well as the other rock sizes that will be used in the design. The design has now been refined and will now be subjected to rigorous 2D and 3D physical model testing.

Further details on the Icelandic type design developed for Oakajee can be found in the accompanying paper at this conference, Mocke et al, 2009.

5.4 Quarry and Haul Road Planning

A number of previous site investigation in and around the proposed port location had been undertaken but none supported the presence of suitable rock for the breakwaters. Prospective off-site quarries were being considered anywhere up to 50km distant which would have required a significant volume of transport on and across public roads.

During the course of further site inspections with both a local and an international geologist (highly experienced in the locating, investigation and development of quarries specifically for the purposes of the Icelandic-type breakwater) a highly prospective quarry, which had not previously been investigated, was encountered less than 6km from the port location.

The site was particularly advantageous being within the Oakajee buffer zone and therefore being owned by the government and not requiring any transport on or across public roads.

Both seismic and two borehole drilling campaigns have now been completed (see Figure 8) with very encouraging results. As per the design, further details can be found in the accompanying paper at this conference, Mocke et al, 2009.

A number of haul road options between the quarry and the site have been considered and preferred options nominated. Further work will be undertaken to confirm the preferred haul route.

Figure 8: Offshore Quarry Drilling Investigations

6 Design – Dredging

6.1 Geotechnical Investigations

Previously, limited dredging design has been possible, as there had been very little geotechnical information available for material in the proposed dredged region. The main reason for lack of information was the high energy seas at Oakajee, and the difficulty of a drill rig operating, even from a jack up barge. Limiting wave height for large jack up barges is H_{max} = 1.5 – 2.0 m. These conditions had severely impacted on previous drilling campaigns.

Previous to 2009, the following had provided an indication of dredging conditions that would be expected at Oakajee:

- seismic survey over the area (2007) (Figure 11);
- information over the general area from the original Kingstream investigations of 10 years ago;
- knowledge of the Geraldton Port dredging (2003), in similar calcarenite material; and
- limited results from an abortive geotechnical campaign in 2008.

A detailed offshore borehole investigation was subsequently undertaken in April/May 2009 with 20 boreholes completed and a total of 290m of core retrieved for further testing and analysis (see Figure 9). Ongoing testing of the core samples is now underway, which will be followed with the development of a detailed geological model for the assessment of dredging conditions at Oakajee.

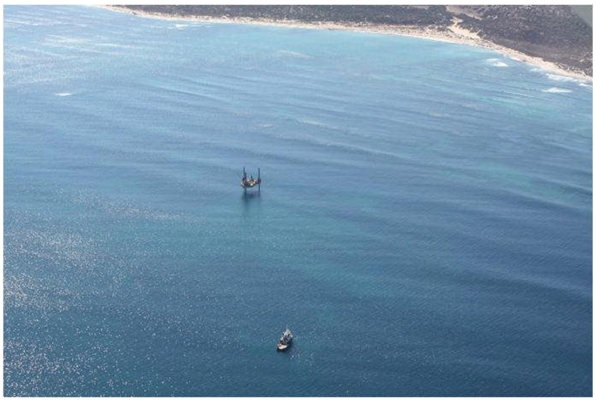


Figure 9: Offshore Seabed Drilling Investigations

6.2 Dredging and Reclamation Studies

Seismic investigations had been undertaken at the Oakajee site but were unable to be compared to the Geraldton location due to changes in analysis techniques between the two datasets. Significant experience of dredging seastate limits and dredge production rates had been gained from the 2002/03 channel deepening project at Geraldton.

To rectify this situation, the previous Geraldton seismic data was reanalysed to match the Oakajee datasets with the results showing equal or lower seismic velocities than the Geraldton seismic results. Ongoing work is continuing in this area, along with the consideration of the offshore drilling results.

The consistent swell conditions along this coastline have a huge effect on the dredger performance, and with the current dredging seastate limits, it will be necessary to build the entire length of breakwater before beginning the dredging work. The unprotected dredging would be undertaken when conditions were suitable and protected dredging when conditions deteriorated. The current layout is such that it should be possible to complete the dredging without any weather downtime.

All dredge material will be deposited in reclaimed area or on land. It is intended that a significant quantity of dredge material will be used beneficially to fill low lying area for the future stockyard areas and hence reduce the volume of cut/fill required for the onshore works.

7 Design – Channel

In order to provide some early confidence in the port layout as well as to confirm the ability of tugs to make fast to arriving ships in the swell conditions expected at Oakajee, a full bridge simulation was undertaken at HR Wallingford's state-of-the-art simulation centre in the UK (see Figure 10).

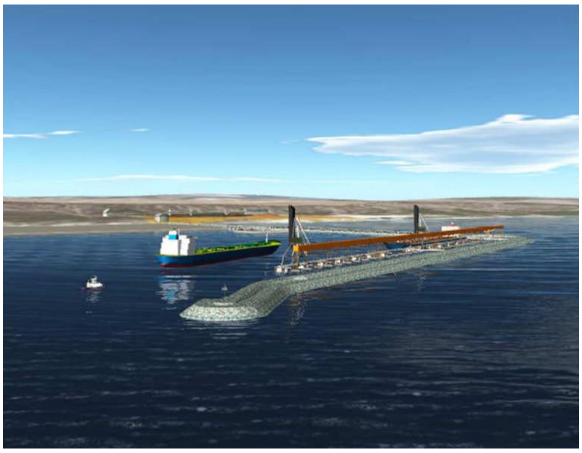


Figure 10: Ship Simulation Modelling

The outcome of these studies determined that:

- the proposed layout was found to be navigationally feasible for design vessel to wind speed = 30 knots and Hs = 2.5m;
- arrival during adverse conditions found to be preferable from the N-NW sector to minimise lateral velocities on the ship; and
- the required number and size of tugs were identified as well as the preferred configuration during shipping manoeuvres.

A final round of simulation will be undertaken once the layout is finalised, as well as underkeel clearance (UKC) studies.

8 Conclusion

There are a number of interesting and challenging issues to understand and resolve in the design and construction of the port at Oakajee. These issues are being addressed, and the port is gradually becoming a reality.

The Western Australian State Government is strongly supportive of the project and a Development Agreement has been signed with the project proponent, OPR.

Current timing is for construction to commence early 2011 for an operational port by 2014.

9 References

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