Consulting Port and Coastal Engineers

BOEGOEBAAI PORT FEL 2 PHASE 2

Quay Structure Trade-off Study

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TM Consulting and Nelutha Consulting
Boegoebaai, South Africa

PRDW
Consulting Port and Coastal Engineers

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Quay Structure Trade-off Study

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TM Consulting and Nelutha Consulting
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TM CONSULTING
Transaction Advisory
Project Structuring and Funding

NELUTHA Consulting

PRDW
5th Floor, Nedbank Building, Clock Tower Precinct, Victoria & Alfred Waterfront
Cape Town, South Africa | PO Box 50023, Waterfront 8002
T: +27 21 418 3830
www.prdw.com

Cape Town, South Africa
Santiago, Chile
Perth, Australia
Seattle, USA
Vitoria, Brazil

PRDW
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1. INTRODUCTION

1.1 Background

PRDW has been appointed by TM Consulting and Nelutha Consulting to perform Phase 2 of the pre-feasibility study for the development of a new port in Boegoebaai on the west coast of South Africa. The Boegoebaai study site, illustrated in Figure 1-1, is located 20 km south of Alexander Bay and 60 km north of Port Nolloth.

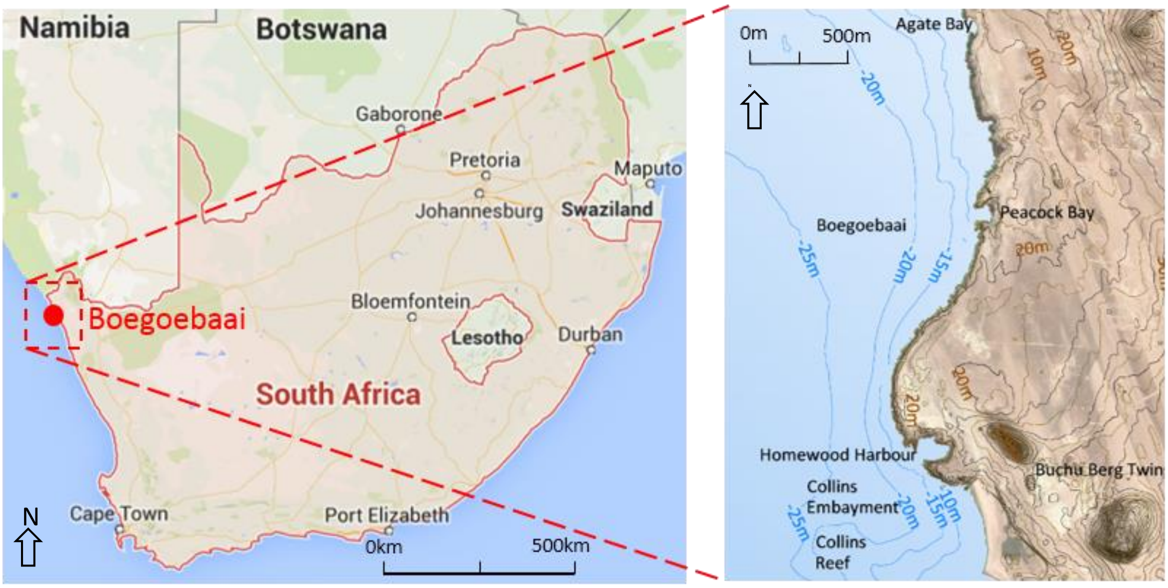


Figure 1-1: Boegoebaai site location

Previous stages of the project performed by PRDW include a concept study (PRDW, 2013), comprising a port development framework and marine works concept study, and Phase 1 of the pre-feasibility study (PRDW, 2015). Phase 2 of the pre-feasibility study aims to build on the results from Phase 1 to bring the study to a full pre-feasibility level (FEL 2) of costing accuracy (-20% to +30%).

1.2 Purpose of document

This document presents the trade-off study of the access and the berth structures for the Phase 1 development of the proposed port of Boegoebaai. The main objective of the study is to logically determine and document the selection of the most appropriate structural solution.

1.3 Methodology

Preliminary functional requirements and available site information was considered to inform numerous concept designs of the quay structure. These options were assessed qualitatively against one another to identify a few preferred options for a more detailed assessment. These preferred options were assessed in a multi criteria analysis which included the outcomes of a high-level capital cost estimate and implementation schedule

2. KEY FUNCTIONAL REQUIREMENTS

2.1 General

The Phase 1 development will consist of 2 berths, one dry bulk berth and one multipurpose berth. The development of the Phase 1 berths shall consider the geometrical requirements for access to future berths along the breakwater (access either via the Phase 1 structures or separately via an independent access structure).

Two-way vehicle access shall be provided along the length of the access and the berth structure.

2.2 Design life

The design life of the primary marine structures is 50 years. Structures shall be capable of performing their intended function over the working life with provision for planned maintenance, but without major repairs being required.

2.3 Design vessels

The design dry bulk vessel for the Phase 1 port development is a 200 000 DWT Capesize vessel based on an assessment of the most likely vessel distribution for the forecast throughput volumes and commodities. A 30 000 DWT multipurpose vessel has been included as a design vessel for the multipurpose terminal.

The design vessel parameters for the Phase 1 are presented in Table 2-1.

Table 2-1: Phase 1 design vessel parameters

Parameters	Capesize	Panamax	Multipurpose Vessel
Terminal	Dry Bulk	Dry Bulk	Multipurpose
Deadweight	200 000 t	76 500 t	30 000 t
Displacement	m^3	*88 098 m^3	41 000 m^3
Length overall (LOA)	315 m	225	188 m
Length Between Perpendiculars (L_{pp})	300 m	218	179 m
Beam	48.5 m	32.2	27.7 m
Laden Draft	19 m	14.2	11.3 m

*Inferred Parameters

2.4 Materials handling

The ship loader for the dry bulk berth will be a linear, luffing, slewing type ship loader. A crane rail gauge of 16 m has been assumed to accommodate the ship loader. A single conveyor will be required from the dry bulk stockpiles to the berth in Phase 1.

Operations on the multi-purpose quay will be undertaken using mobile harbour cranes or the vessels own gear. The multi-purpose quay must also be designed to accommodate similar ship loaders as the dry bulk berth for future handling of dry bulk products.

3. SITE INFORMATION

3.1 Introduction

This section of the report summarises the site information considered critical for the design of the marine structures. Detailed site conditions are presented in the Site Information report (PRDW, 2018).

3.2 Water levels

The published tidal levels for Port Nolloth (60 km south of Boegoebaai) are shown in Table 3-1. The levels are referenced to Chart Datum (CD), defined as 0.925 m below land levelling datum (LLD).

Table 3-1: Tidal characteristics for Port Nolloth (SANHO, 2018)

Description	Level (m CD)
Highest Astronomical Tide (HAT)	2.25
Mean High Water Springs (MHWS)	1.91
Mean High Water Neaps (MHWN)	1.40
Mean Level (ML)	1.09
Mean Low Water Neaps (MLWN)	0.78
Mean Low Water Springs (MLWS)	0.28
Lowest Astronomical Tide (LAT)	0.00

3.3 Waves

In Phase 1 of the pre-feasibility study the wave climate was based on wave refraction of the NOAA/NCEP WAVEWATCH III CFSR Reanalysis Hindcast Dataset point, located approximately 220 km offshore. The wave rose plot for Point 2, located at the head of the proposed breakwater, is presented in Figure 3-1. The rose is constructed from 31 years of modelled data.

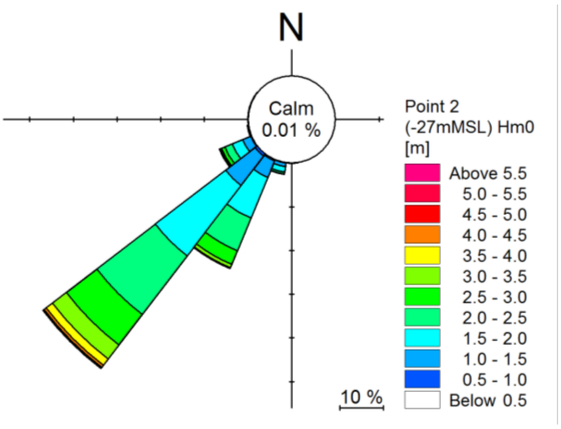


Figure 3-1: Wave rose plots for Point 2 (located at the head of the proposed breakwater)

3.4 Bathymetry

A bathymetric survey was undertaken by Tritan Survey (Pty) Ltd as part of this study phase. The area surveyed was approximately 9.5 km x 8.5 km, with a minimum surveyed depth of -1.03 m CD and a maximum of -48.98 m CD (Tritan, 2018).

Across the area of the proposed Phase 1 port development, the bathymetry dips steeply from the shoreline to a depth of approximately -25 m CD at the deepest end of the second berth.

3.5 Geotechnical conditions

Landside geotechnical site investigations were performed by SRK Consulting during April 2018 and May 2018. The investigations and interpretation are detailed in SRK's Geotechnical Investigation report (SRK Consulting, 2018)

The report notes that "the onshore site is characterised by a succession of hard rock quartzite and interbedded soft rock quartz schist / schist – there is no logical reason to assume that this succession (which is linked to the original depositional environment of the sedimentary rocks prior to being metamorphosed) does not repeat offshore" The UCS measured in quartzite samples varies considerably (from 9.2 MPa to 297.8 MPa) which may present challenges for any structural solutions which require drilling into the quartzite.

SRK (2018) present the following recommendations with regards to structure design:

- Because of the likely variability on the founding materials (alternating very competent quartzites and weak schists), piled foundations will be more challenging to design and implement (construct) – this may require an approach of having two pile designs (one for quartzite and one for schists) and implementing the appropriate design once the geotechnical profile is known at individual piling positions.
- Gravity foundations will carry a lower risk considering the probable variability in the geotechnical profile – the main idea being that loads are more effectively spread with gravity foundations. Risks that remain are linked to possible differential settlement should the caissons need to be founded on two different material types (i.e. schist and quarzite), or if adjacent caissons are founded on different material types.

In summary, the offshore geotechnical profile remains an area of uncertainty. Both offshore piled and gravity foundations carry risks with associated costs and design/construction complexities.

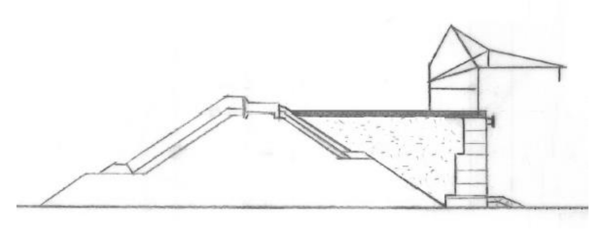
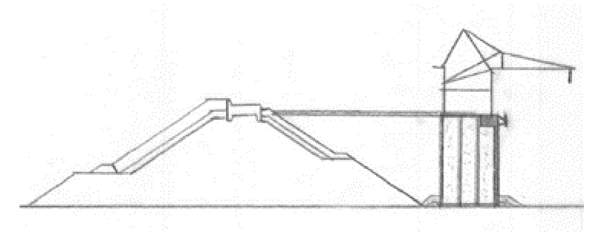
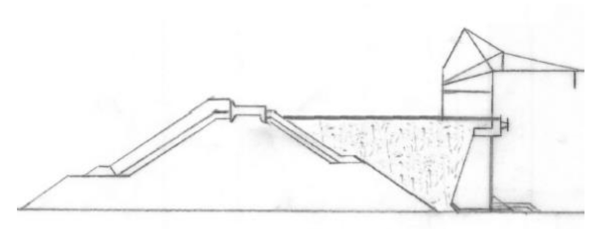
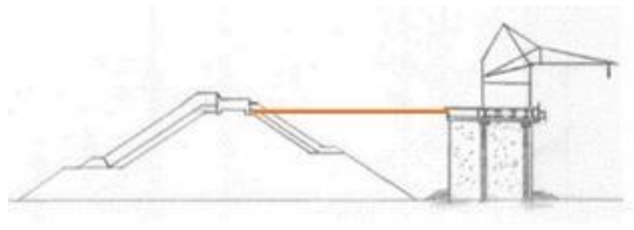
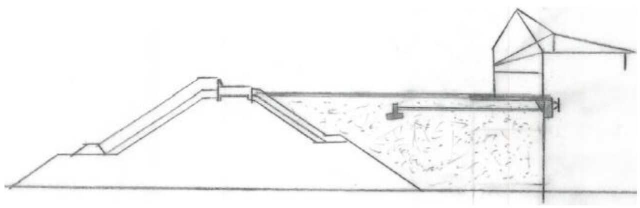
4. OPTIONS IDENTIFICATION

The options identified for the access and the berth structures can be categorised as either continuous quay wall structures, which will be integrated with the breakwater, or as jetty-type structures which are detached from the breakwater. These options are presented in the following section.

4.1 Continuous quay wall structures

The continuous quall wall structure options are summarised in Table 4-1.

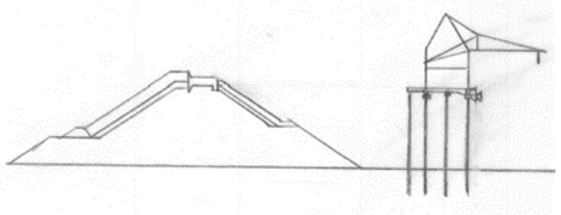
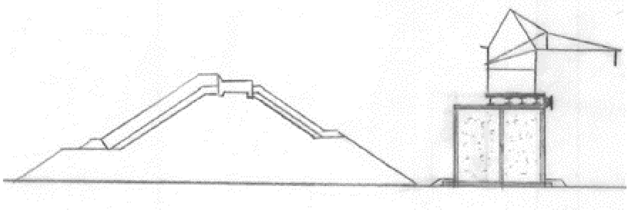
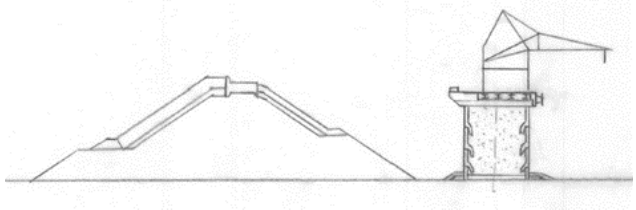
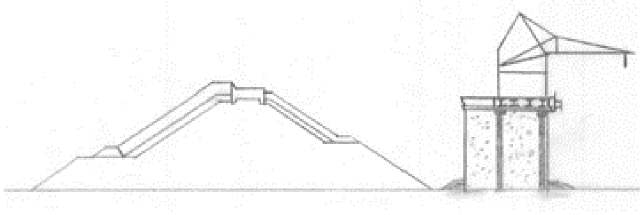
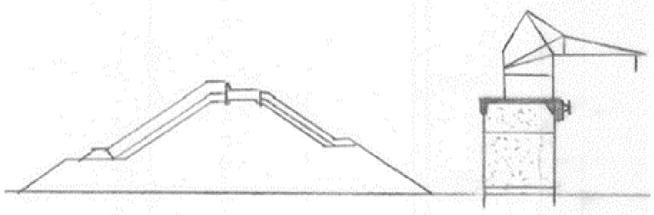
Table 4-1: Structural options – continuous quay wall structures

Type		Cross-Section	Description
(A1)	Blockwork quay wall		Continuous quay wall constructed from plain concrete or reinforced concrete blockwork
(A2)	Caisson quay wall		Continuous quay wall constructed from precast caisson units.
(A3)	Counterfort quay wall		Continuous quay wall constructed from precast counterfort units.
(A4)	Steel sheet pile cellular quay wall		Continuous quay wall constructed from steel cellular cells with bearing piles provided for the crane rail beams. Cells bear on top of the rock and are not embedded.
(A5)	Embedded quay wall		Continuous quay wall constructed from an embedded steel combi wall with bearing piles provided for the crane rail beams.

4.2 Jetty-type structures

The jetty-type structure options are summarised in Table 4-2.

Table 4-2: Structural options – jetty-type structures

Type		Cross-Section	Description
(B1)	Piled substructure		Steel tubular casings anchored into bedrock and filled with reinforced concrete. Superstructure could be constructed from structural steel and/or reinforced concrete.
(B2)	Caisson pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning between piers. Each pier constructed from a single caisson founded on a stone bed.
(B3)	Precast ring pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning between piers. Each pier constructed from a stack of reinforced concrete rings founded on a stone bed.
(B4)	Steel sheet pile cellular pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning in-between the piers. Each pier constructed from a steel cellular cells founded on top of the seabed rock.
(B5)	Embedded wall pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning between piers. Each pier is constructed using steel combi wall elements.

4.3 Initial options assessment

4.3.1 Introduction

An initial qualitative options assessment was carried out on all the identified possible structures with the aim of eliminating options which are practically or fatally flawed, and to identifying preferred options which should be investigated in more detail as part of this trade-off study.

4.3.2 Assessment criteria

The options were assessed qualitatively against the following criteria:

- Temporary works and construction equipment

  The extent of temporary works required to facilitate the structural solution such as precast yards, storage areas, temporary load-out quays and launching areas or syncrolifts. The significant items of construction plant and equipment, such as jack-up barges, floating dry-docks, floating cranes, construction cranes and travelling bogeys for hand-over-hand construction.

- Implementation schedule

  The relative construction duration for each option, considering the rate of construction and the reliance on the construction of the breakwater to provide protected water for construction.

- Maintenance requirements

  Relative extent of the preventative maintenance requirements for each option.

- Geotechnical conditions/risk

  Design or construction risks associated with variable geotechnical conditions i.e. how adaptable is the structure should geotechnical conditions differ from those assumed during the design phase.

- Constructability

  Considerations around the practical aspects of construction and the extent to which the construction relies on commonly available infrastructure, plant and equipment, conventional and well-developed construction methodologies, local skills etc.

For all criteria the options were assessed qualitatively, relative to the other options being considered, according to the scoring guideline outlined in Table 4-3.

Table 4-3: Initial option assessment – scoring guideline

Rating
Favourable
Neutral
Unfavourable
Fatal/Practical Flaw

4.3.3 Results

The summary results of the initial options assessment for the continuous quay wall and the jetty-type structures are presented in Table 4-4. The detailed assessment comments are provided in Annexure A.

Table 4-4: Initial options assessment summary of results (preferred options are bordered in green)

Type		Initial Options Assessment				
		Temporary Works & Construction Equipment	Implementation Schedule	Maintenance Requirements	Geotechnical Conditions/Risk	Constructability
A: Continuous Quay Wall						
(A1)	Blockwork quay	Favourable	Unfavourable	Favourable	Neutral	Unfavourable
(A2)	Caisson quay	Unfavourable	Unfavourable	Favourable	Neutral	Favourable
(A3)	Counterfort quay	Unfavourable	Unfavourable	Favourable	Neutral	Unfavourable
(A4)	Steel sheet pile cellular quay wall	Unfavourable	Unfavourable	Unfavourable	Neutral	Unfavourable
(A5)	Embedded quay	Neutral	Unfavourable	Unfavourable	Unfavourable	Fatal Flaw
B: Jetty-type Structure						
(B1)	Piled structure	Neutral	Neutral	Favourable	Unfavourable	Neutral
(B2)	Caisson pier	Unfavourable	Unfavourable	Favourable	Neutral	Favourable
(B3)	Precast ring pier	Unfavourable	Unfavourable	Favourable	Neutral	Neutral
(B4)	Steel sheet pile cellular pier	Unfavourable	Unfavourable	Unfavourable	Neutral	Unfavourable
(B5)	Embedded wall pier	Neutral	Unfavourable	Unfavourable	Unfavourable	Fatal Flaw

4.4 Preferred Options

Based on the initial options assessment, the caisson quay was considered to be the preferred continuous quay wall structure as it scores favourably on 2 of the 5 criteria. While both the blockwork quay and counterfort quay have similar maintenance, requirements compared to the caisson quay, their constructability is an issue. The construction of the caisson is deemed to be conventional once protected water is provided by the breakwater. However, the blockwork quay and counterfort quay are eliminated primarily because conventional construction techniques require prohibitively large cranes for placement of units and significant founding stone bed on the seabed. Furthermore, even though the blockwork quay scores favourably for Temporary Works & Construction Equipment criterion, it scores unfavourably on the Constructability criterion which is more critical. All other continuous quay wall options score unfavourable on 3 criteria and were therefore not selected. The embedded quay structure is fatally flawed due to the quay wall height being beyond practical limit for this type of solution. While, the steel sheet pile cellular solution is difficult to construct and has high maintenance requirements.

Regarding the jetty-type structure options, the piled structure and caisson structure were identified as the prefered optons because they are robust, durable and fairly common. The caisson pier structure was selected because it scores favourable on 2 criteria. The piled structure was selected because it scores favourable on 1 criterion and neutral on 3 criteria. The piled structure is typically a cost effective solution that many local contractors can build. However, the expected geotechnical conditions increase the risks associated with this option. Hence, the caisson pier was also selected as an alterntive because its structural form lends itself to lower bearing pressures which helps mitigate the risks associated with the expected variable geotechnical conditions.

All other Jetty-type structure options score less favourably and were therefore not selected. The embedded wall pier is fatally flawed due to the required wall height being beyond the practical limit for this type of solution. While, the steel sheet pile cellular solution is difficult to construct and has high maintenance requirements. The precast ring pier provides a more durable alternative to the steel sheet pile cellular pier however it is a novel untested design.

5. CONCEPT DEVELOPMENT

5.1 Caisson quay wall

The concept for the caisson quay wall is illustrated in Figure 5-1.

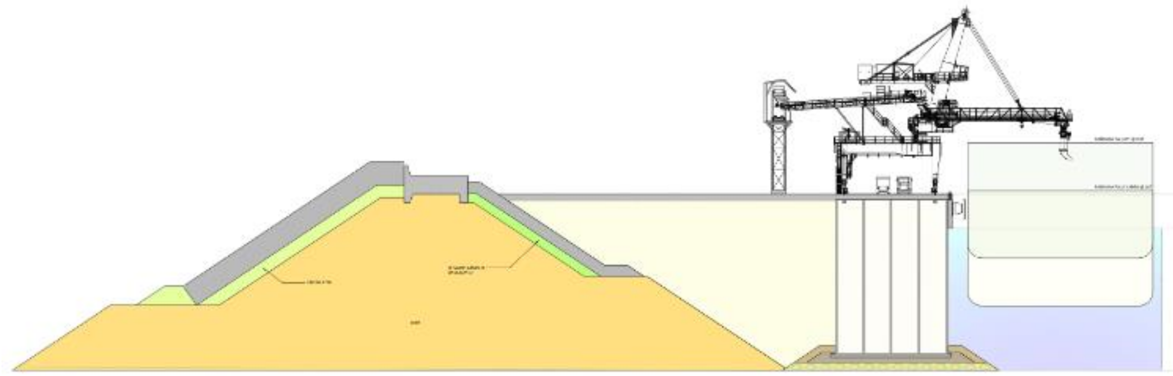


Figure 5-1: Cross-section of the caisson quay wall at the berth

The continuous quay wall would be constructed from precast concrete caisson units. Reclamation is required between the caisson wall and the breakwater to create the required working space.

5.2 Caisson pier structure

The concept for the caisson pier structure is illustrated in Figure 5-2 below.

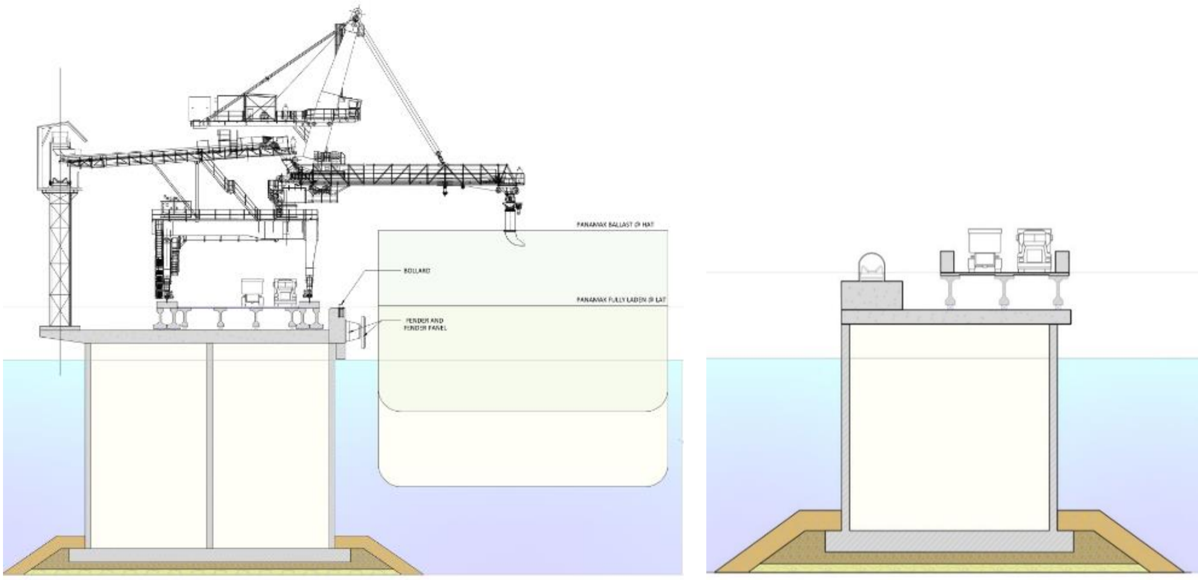


Figure 5-2: Cross-sections of the caisson pier jetty at the berth and at the access way

The caisson pier jetty consists of discrete piers at 30 or 40 metre centres with a prestressed and reinforced concrete deck spanning between piers. Each pier is constructed from a single caisson founded on a stone bed. The access way will consist of smaller caisson units with a concrete deck spanning between piers to accommodate two-way traffic to the berths.

5.3 Piled jetty structure

The concept for the piled jetty structure is illustrated in Figure 5-3 below.

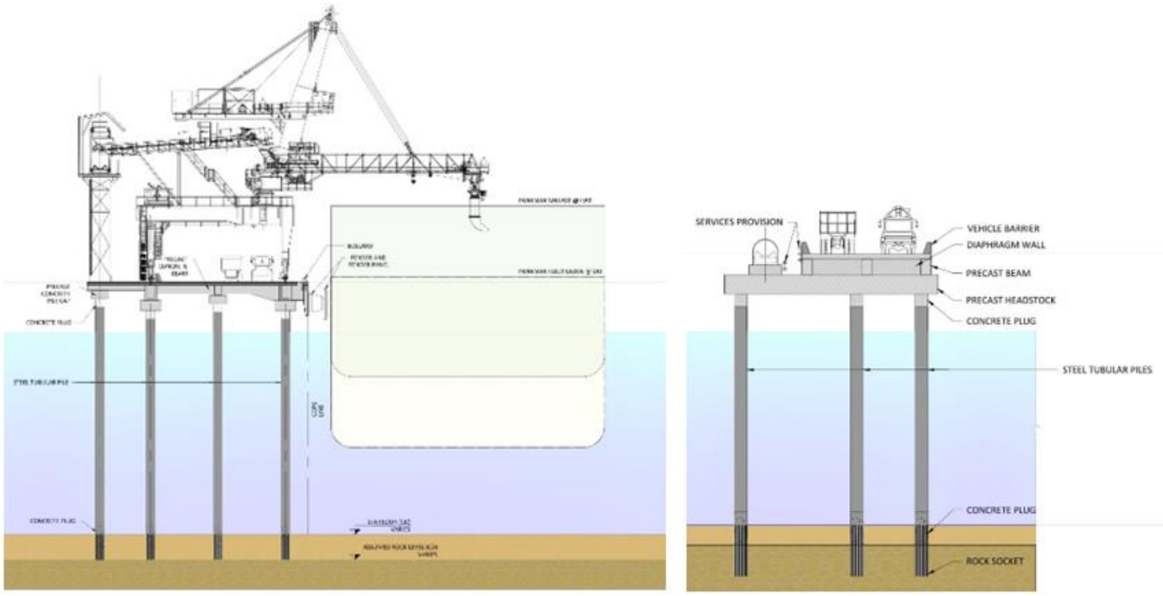


Figure 5-3: Cross-sections of the piled jetty at the berth and access way

The deck on pile structure consists of steel tubular casings anchored into bedrock, with either rock sockets or steel dowels, and filled with reinforced concrete. The piles are tied together by a reinforced concrete superstructure. As for the caisson pier structure, the access way will accommodate two-way traffic to the berths.

6. MULTI-CRITERIA ASSESSMENT

A Multi-criteria Assessment (MCA) was completed to select a single preferred option for the required access way and berth structure for the port of Boegoebaai. The criteria, the associated criteria weightings and the scoring approach for the MCA are presented in the following sections.

The MCA scoring was debated and analysed in several workshops. A presentation summarising the content of these discussions is included in Annexure B.

6.1 Assessment criteria

The criteria considered in the MCA are described briefly in Table 6-1 below.

Table 6-1: Multi-criteria assessment criteria

Main Criteria	Sub-criteria
Inherent Safety	Safety of personnel during construction *(extent of dive work, working over water, etc.)*
	Structural Redundancy *(localisation and repair-ability of damage i.e. is damage localised or does it place the complete facility at risk)*
Geotechnical Conditions/Risk	Risk associated with ground conditions *(design or construction risks associated with variable geotechnical conditions i.e. how adaptable is the structure should geotechnical conditions differ from those assumed during the design phase)*
Implementation Schedule	Concept-level schedule estimate for the berth structures *(including time to establish all temporary facilities required to facilitate construction of the structure)*
Value and Cost	Concept-level capital cost estimate

6.2 Criteria weighting

Table 6-2: Multi-criteria assessment – base case weightings

Criteria	Weighting
Inherent Safety	5%
Geotechnical Conditions/Risk	20%
Implementation Schedule	20%
Value and Cost	55%
Total	100%

A sensitivity analysis was also completed to assess the sensitivity of the MCA to the criteria weightings. The criteria weightings for the various scenarios considered in the sensitivity analysis are presented in Table 6-3 below.

Table 6-3: Multi-criteria assessment – sensitivity analysis weightings

Main Criteria	Weighting Bias				
	Equal	Inherent Safety	Geotechnical Conditions/Risk	Implementation Schedule	Value and Cost
Inherent Safety	25%	40%	20%	20%	20%
Geotechnical Conditions/Risk	25%	20%	40%	20%	20%
Implementation Schedule	25%	20%	20%	40%	20%
Value and Cost	25%	20%	20%	20%	40%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**

6.3 Scoring

For all criteria, other than implementation schedule and value and cost, the options were assigned qualitative scores, relevant to the other options being considered, according to the scoring guideline outlined in Table 6-4.

Table 6-4: Multi-criteria assessment – scoring guideline

Score	Comment
10	Good
5	Average
1	Bad

6.4 Results

6.4.1 Base case weighting

The assigned scores for each criterion and the MCA outcome for the base weighting are presented in Table 6-5 below.

Table 6-5: MCA base-case scenario

Ref.	Criteria	Weighting	Option 1: Continuous Caisson Quay Wall	Option 2: Caisson Jetty-type Structure	Option 3: Piled Jetty-type Structure
	NC (S2023) Boegoebaai FEL 2 Phase 2 - Berth Structure Assessment				
	Multi Criteria Analysis for Selection of Preferred Option				
	TOTAL				
1	**Inherent Safety**	5%	5%	5%	4%
2	**Geotechnical Conditions/Risk**	20%	20%	20%	10%
3	**Implementation Schedule**	20%	13%	15%	20%
4	**Value and Cost**	55%	20%	39%	55%
	Total	**100%**	**58%**	**79%**	**89%**
1	**Inherent Safety**	100%	**10**	**10**	**7.5**
1.1	Safety of personnel during construction *(extent of dive work, working over water, etc.)*	50%	10	10	10
			Caissons are constructed in the dry and therefore less risk in working over water, however, significant dive work will be required to prepare stone bed. Both piled structure and caisson jetty-type structure require over-water work (pile driving, placing of bridge beams), with the piled option potentially being constructed in more exposed conditions. Therefore all options score the same as there is no significant safety differentiator.		
1.2	Structural Redundancy *(localisation and repairability of damage i.e. is damage localised or does it place the complete facility at risk)*	50%	10	10	5
			Caissons are more redundant and can remain functional should damage occur to one of the cells. Piled structures are more difficult to repair and may require that operations at the facility be halted until such time that the pile is repaired, particularly if a pile supporting the crane rail beam is damaged). Options 1 and 2 therefore score higher than Option 3.		
2	**Geotechnical Conditions/Risk**	100%	**10**	**10**	**5**
2.1	Risk associated with ground conditions *(design or construction risks associated with variable geotechnical conditions i.e. how adaptable is the structure should geotechnical conditions differ from those assumed during the design phase)*	100%	10	10	5
			Drilling rocket sockets for the piled jetty-type structure may be challenging given the very hard quartzite. The Schist layers also pose a risk as they much weaker and variable in quality. Variation in offshore geotechnical conditions may therefore require drilling ahead of construction to mitigate some risks with a variation in design of the pile socket to suite position-specific conditions. The risk for caissons is if the material is found to be unsuitable for bearing load, for example if a weak clay layer is found. In this case a late change to the design would be difficult and expensive. However, based on the results of landside investigations, clay layers are considered unlikely and the caisson options therefore score higher.		
3	**Implementation Schedule**	100%	**6.4**	**7.5**	**10**
3.1	Construction duration	100%	6.4	7.5	10
	Concept-level schedule estimate (months):		33	28	21
4	**Value and Cost**	100%	**3.7**	**7.1**	**10**
4.1	Capital cost	100%	3.7	7.1	10.0
	Concept-level capital cost estimate:		*R 2 700 000 000*	*R 1 400 000 000*	*R 1 000 000 000*

The base-case scenario indicates that Options 1 and 2 score higher for inherent safety and geotechnical risk while Option 3 scores higher for implementation schedule and value and capital cost. The importance of the implementation schedule and the value and cost criteria, and their selected weightings lead to the piled jetty structure gaining the highest score in the MCA due to its clear lead in those two areas.

6.4.2 Sensitivity analysis on the weightings

The sensitivity analysis on the criteria weightings is provided in Table 6-6.

Table 6-6:MCA Sensitivity Analysis

Weighting Bias	Option 1: Continuous Caisson Quay Wall	Option 2: Caisson Jetty-type Structure	Option 3: Piled Jetty-type Structure
Base Case	58%	79%	89%
Equal	75%	87%	81%
Inherent Safety	80%	89%	80%
Geotechnical Conditions/Risk	80%	89%	75%
Implementation Schedule	73%	84%	85%
Value and Cost	68%	83%	85%

The sensitivity analysis indicates that Option 1 scores consistently poorly across all weighting biases and is therefore not preferred.

Option 2 scores favourably for the equal, inherent safety and geotechnical risk biases while Option 3 scores favourably for the base case, implementation schedule and value and cost biases.

7. Preferred option

Based on the results on the MCA and the sensitivity analysis, Option 3 has been selected as the preferred option for the following reasons:

- The magnitude of the difference in the capital cost between Option 2 and 3 is significant and Option 3 is therefore preferable to minimise the Phase 1 port development capital cost; and
- The criteria for which Option 3 scores poorly, namely inherent safety and geotechnical risk, do not justify the capex premium associated with Option 2 and can be mitigated with good engineering design of Option 3.

8. REFERENCES

PRDW, 2013. *Boegoebaai Harbour Concept Design: Marine Works Concept Study Report.* Cape Town: PRDW.

PRDW, 2015. *Boegoebaai Port, Pre-feasibility Study: Phase 1, Study Report. Report No. S2011-RP-GA-001,* Cape Town: PRDW.

PRDW, 2018. *Boegoebaai Port FEL2 Phase 2: Summary of Available Site Information. PRDW Report No. S2023-RP-SI-001,* Cape Town: PRDW.

SANHO, 2018. *South African Tide Tables,* Tokai, Cape Town: The Hydrographer, South African Navy.

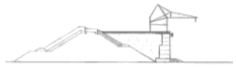
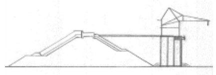
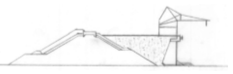
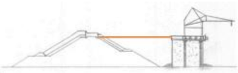
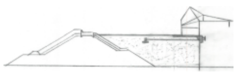
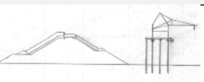
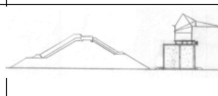
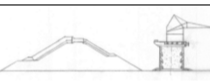
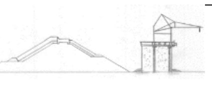
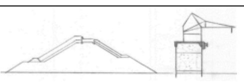
SRK Consulting, 2018. *Boegoebaai Port: Preliminary Geotechnical Investigation (Quarry and Near Port Area) – Final Report Rev1. Report Number 526679 / 529671. August 2018.,* Cape Town: s.n.

Tritan, 2018. *Boegoebaai Hydrographic Survey. REPORT NO. 9051.1bathy. 23 May 2018,* Cape Town: Tritan Survey (Pty) Ltd..

ANNEXURE A | INITIAL OPTIONS ASSESSMENT

Client			Rating			
			Favourable	Unfavourable	Neutral	Fatal/Practical Flaw

	Document Title	Responsibilities	Intials
	Initial Options Assessment	Compiled	DJC
	Document Number	Checked	YH
	S2023-TN-ST-001	Approved	PES

OPTION		CROSS-SECTION	DESCRIPTION	PRELIMINARY OPTIONS ASSESSMENT				
				Temporary Works & Construction Equipment	Implementation Schedule	Maintenance Requirements	Geotechnical Conditions/Risk	Constructability
A: Continuous Quay Wall								
(A1)	Blockwork quay wall		Continuous quay wall constructed from plain concrete or reinforced concrete blockwork.	Marine spread with good craneage required for the transportation, and placing of the concrete blocks.	The construction of the breakwater would need to be significantly in advance of the quay construction to create a calm environment for placing units. This would have a significant impact on the overall project construction duration.	Limited maintenance is required during the life time of the unreinforced concrete structure	Geotechnical conditions are suitable for founding gravity structures with some foundation preparation. There is a risk of differential settlement should the structure span two different founding conditions.	Conventional construction techniques for gravity quay walls although the size of the units will require large equipment. The crane reach required if placing from the breakwater would practically limit the size of the unit, require a larger number of units to be manufactured and placed. May require significant stone bed to build up to a practical founding level.
(A2)	Caisson quay wall		Continuous quay wall constructed from precast caisson units.	Significant temporary works and equipment required for the casting and launching of the caissons. A dedicated floating dry dock, slipway way or synchrolift would be required for launching the caissons. A finishing quay may be required if a two stage construction methodology is adopted.	The construction of the breakwater would need to be significantly in advance of the quay construction to create a calm environment for placing units. This would have a significant impact on the overall project construction duration.	Limited maintenance is required during the life time of the concrete structure	Geotechnical conditions are suitable for founding gravity structures with some foundation preparation. There is a risk of differential settlement should the structure span two different founding conditions.	Conventional construction techniques for caisssons once protected water is provided by breakwater and temporary works are in place. Protected conditions required during construction.
(A3)	Counterfort quay wall		Continuous quay wall constructed from precast counterfort units.	Significant temporary works and equipment required for the casting, transportation, and placing of the counterforts. A dedicated load-out facility would be required to transfer the precast units from the casting yard to the water side. Significant floating craneage required to transport and place the precast counterfort units.	The construction of the breakwater would need to be significantly in advance of the quay construction to create a calm environment for placing units. This would have a significant impact on the overall project construction duration.	Limited maintenance is required during the life time of the concrete structure	Geotechnical conditions are suitable for founding gravity structures with some foundation preparation. There is a risk of differential settlement should the structure span two different founding conditions.	Conventional construction techniques for gravity quay walls although the size of the units will require large equipment. Protected conditions required during construction.
(A4)	Steel sheet pile cellular quay wall		Continuous quay wall constructed from steel sheet pile cells with bearing piles provided for the crane rail beams. Cells bear on top of the rock and not embedded.	A substantial multi-layer pile guide frame would be required to form the template for the cells. A jack-up barge would be required for the piling crane, and transport barges to convey materials.	The construction of the breakwater would need to be significantly in advance of the quay construction to create a calm environment for driving of the sheet piles. This would have a significant impact on the overall project construction duration.	Regular monitoring and maintenance is required for the steel sheets (replacement of cathodic protection anodes).	Geotechnical conditions are suitable for driving sheet piles which bear on top of the bedrock. Some risk of differential settlement should the structure span two different founding conditions.	Requires a jack-up barge and protected conditions during construction. Required wall height is on the practical limit for this type of wall. Additional piles would be needed to carry the crane rail beams.
(A5)	Embedded quay wall		Continuous quay wall constructed from an embedded steel sheet pie wall with bearing piles provided for the crane rail beams.	Construction equipment would include one or more jack-up barges, rock drilling equipment, a piling crane and hammers, pile guide frames and transport barges.	The construction of the breakwater would need to be significantly in advance of the quay construction to create a calm environment for driving of the sheet piles. This would have a significant impact on the overall project construction duration.	Regular monitoring and maintenance is required for the sheet pile wall (replacement of cathodic protection anodes).	Piles will need to toe into bedrock. This will require pre-drilling into very hard rock which would require specialised drilling equipment. Potentially some challenges with the softer more variable schists, which may require additional work at specific pile locations	Piling from breakwater will be challenging due to reach. Construction is likely to require a piling barge with sufficient temporary support for drilling into rock. Protected conditions required during construction. **Required wall height is beyond the practical limit for this type of wall.**
B: Jetty-type Structure								
(B1)	Piled substructure		Steel tubular casings placed on the seabed and anchored into the rock. Reinforced concrete pile cast into casing for the full height. Superstructure could be constructed from structural steel and/or reinforced concrete.	The piled structure could be advanced using a hand-over-hand construction method advancing seawards from the coastline. This will require special construction plant in the form of a dedicated travelling bogey to carry the construction crane. If the jetty were to be constructed from marine plant at least two jack-up barges would be required, one for the piling crane and one for superstructure assembly.	Suited to being constructed in an exposed environment and deep water, eliminating the reliance on the breakwater to provide sheltered calm waters. Overall construction duration is therefore significantly reduced by constructing in parallel with the breakwater. However risks associated with unknown geotechnical conditions, and drilling sockets in unprotected waters, may negate some of the schedule benefits.	Limited maintenance is required during the life time of the structure (assuming concrete-filled piles)	Drilling rocket sockets may be challenging given the very hard quartzite. Tension piles may be problematic if founded in schists. Variation in offshore geotechnical conditions may require a drilling investigation ahead of construction to mitigate some risks.	Can be advanced using either hand-over-hand construction or from a jack-up barge. Drilling rock sockets in exposed conditions may be problematic and additional temporary works may therefore be required to stabilise piles.
(B2)	Caisson pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning in-between the piers. Each pier constructed from a single caisson founded on a stone bed.	Significant temporary works and equipment required for the casting and launching of the caissons. A dedicated floating dry dock, slipway way or synchrolift would be required for launching the caissons. A finishing quay may be required if a two stage construction methodology is adopted.	The construction of the breakwater would needs to be significantly in advance of the pier construction to create a calm environment for placing units. This would have a significant impact on the overall project construction duration. There would, however, be significantly less caissons required for this structure than the continuous quay option.	Limited maintenance is required during the life time of the concrete structure	Geotechnical conditions are suitable for founding gravity structures with some foundation preparation. There is a risk of differential settlement should the structure span two different founding conditions.	Conventional construction techniques for caisssons once protected water is provided by breakwater and temporary works are in place. Protected conditions required during construction.
(B3)	Precast ring pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning in-between the piers. Each pier constructed from a stack of reinforced concrete rings founded on a stone bed.	Significant temporary works and construction equipment required for the casting, transportation, and placing of the rings. A dedicated load-out facility will be required for loading rings onto barges for placing.	The construction of the breakwater would need to be significantly in advance of the pier construction to create a calm environment for placing units. This would have a significant impact on the overall project construction duration.	Limited maintenance is required during the life time of the concrete structure	Geotechnical conditions are suitable for founding gravity structures with some foundation preparation. There is a risk of differential settlement should the structure span two different founding conditions.	Construction can be advanced from a jack-up barge although the size of the concrete rings will require special lifting equipment. Protected conditions required during construction. No precedence for this type of structure which introduces the additional risk of 'unknowns'.
(B4)	Steel sheet pile cellular pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning in-between the piers. Each pier constructed from a steel sheet pile circular cell founded on top of the seabed rock.	A substantial multi-layer pile guide frame would be required to form the template for the cells. At least two jack-up barge would be required for the piling crane, and deck construction, plus transport barges to convey materials.	The construction of the breakwater would need to be significantly in advance of the quay construction to create a calm environment for driving of the sheet piles. This would have a significant impact on the overall project construction duration.	Regular monitoring and maintenance is required for the steel sheets (replacement of cathodic protection anodes).	Geotechnical conditions are suitable for driving sheet piles which bear on top of the bedrock. Some risk of differential settlement should the structure span two different founding conditions.	Requires a jack-up barge and protected conditions during construction. Required wall height is on the practical limit for this type of wall. Support piles will be required to carry the vertical loads of crane rail beams. Bridge beams will need to span between the piles which esentially makes this a combi tubular pile and circular cell structure.
(B5)	Embedded wall pier substructure		Discrete piers at 30 or 40 metre centres with a reinforced concrete deck spanning in-between the piers. Each rectangular pier constructed from a cell formed by an embedded sheet pile wall.	Construction equipment would include at least two jack-up barges, rock drilling equipment, a piling crane and hammers, pile guide frames and transport barges.	The construction of the breakwater would need to be significantly in advance of the quay construction to create a calm environment for driving of the sheet piles. This would have a significant impact on the overall project construction duration.	Regular monitoring and maintenance is required for the sheet pile wall (replacement of cathodic protection anodes).	Piles will need to toe into bedrock. This will require pre-drilling into very hard rock which would require specialised drilling equipment. Potentially some challenges with the softer more variable schists, which may require additional work at specific pile locations	Construction will require a piling barge with sufficient temporary support for drilling into rock. Protected conditions required during construction. **Required wall height is beyond the practical limit for this type of wall.**

ANNEXURE B | PRESENTATION: STRUCTURE TECHNICAL REVIEW

PRDW

Consulting Port and Coastal Engineers

LEADERS IN PORT ENGINEERING PROJECTS

Funding and oversight

TRANSNET

Transaction advisors

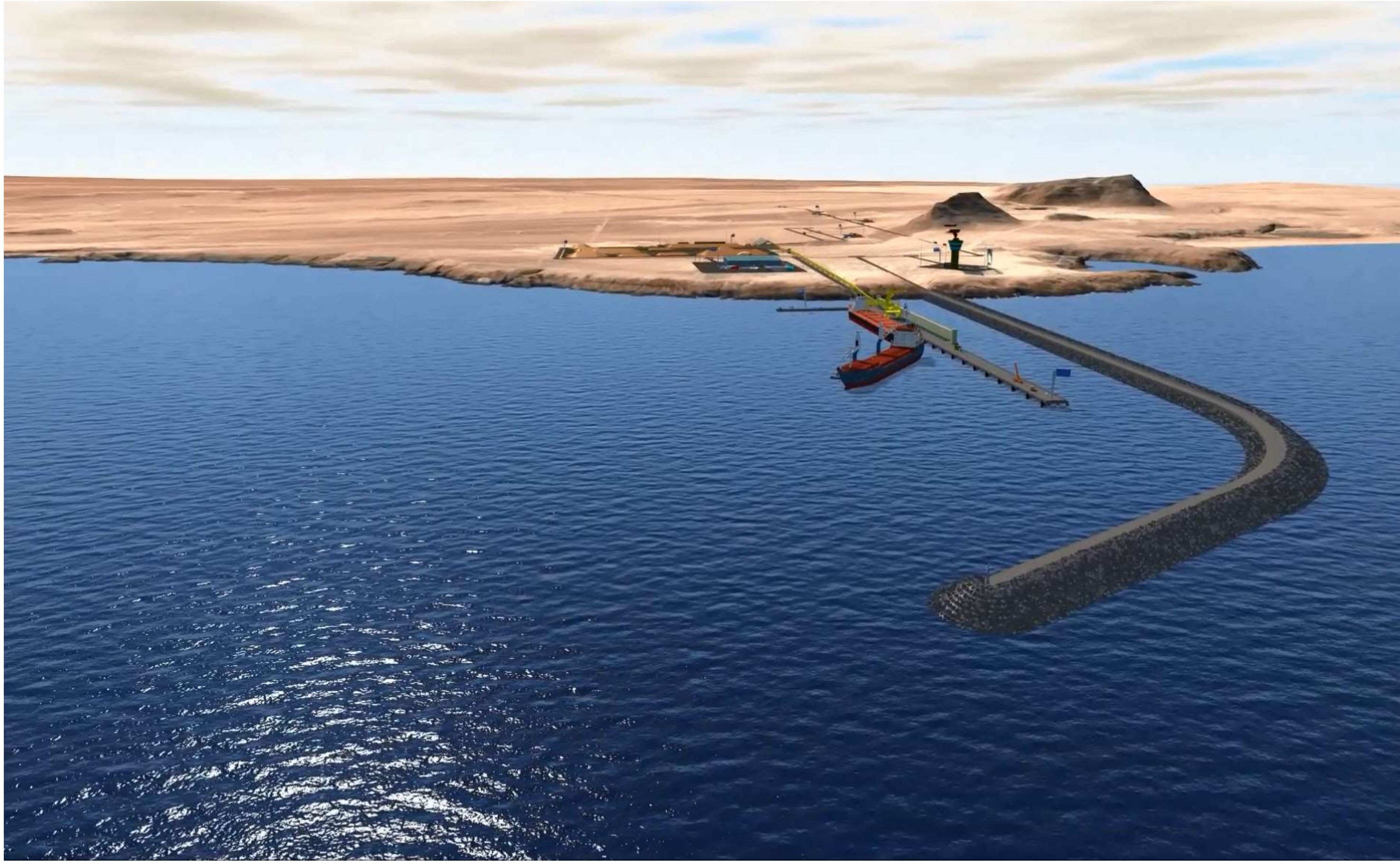
TM CONSULTING
Transaction Advisory
Project Structuring and Funding

NELUTHA Consulting

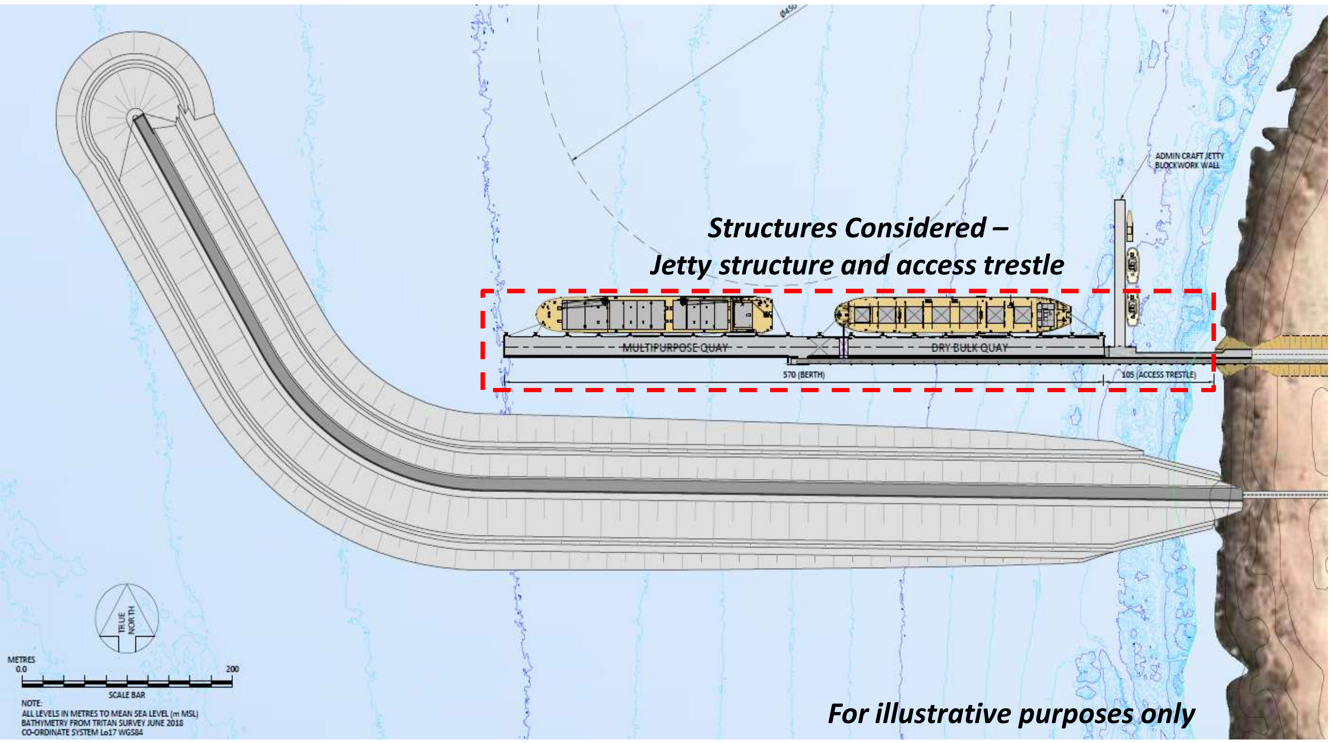
Landside engineering

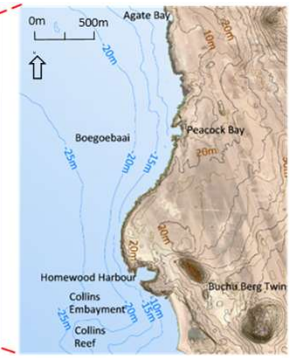
NAKO ILISO

- General arrangement
- Site conditions
- Functional requirements
- Trade-off study
- Structural analysis



Jetty Structure Technical Review
Site Overview

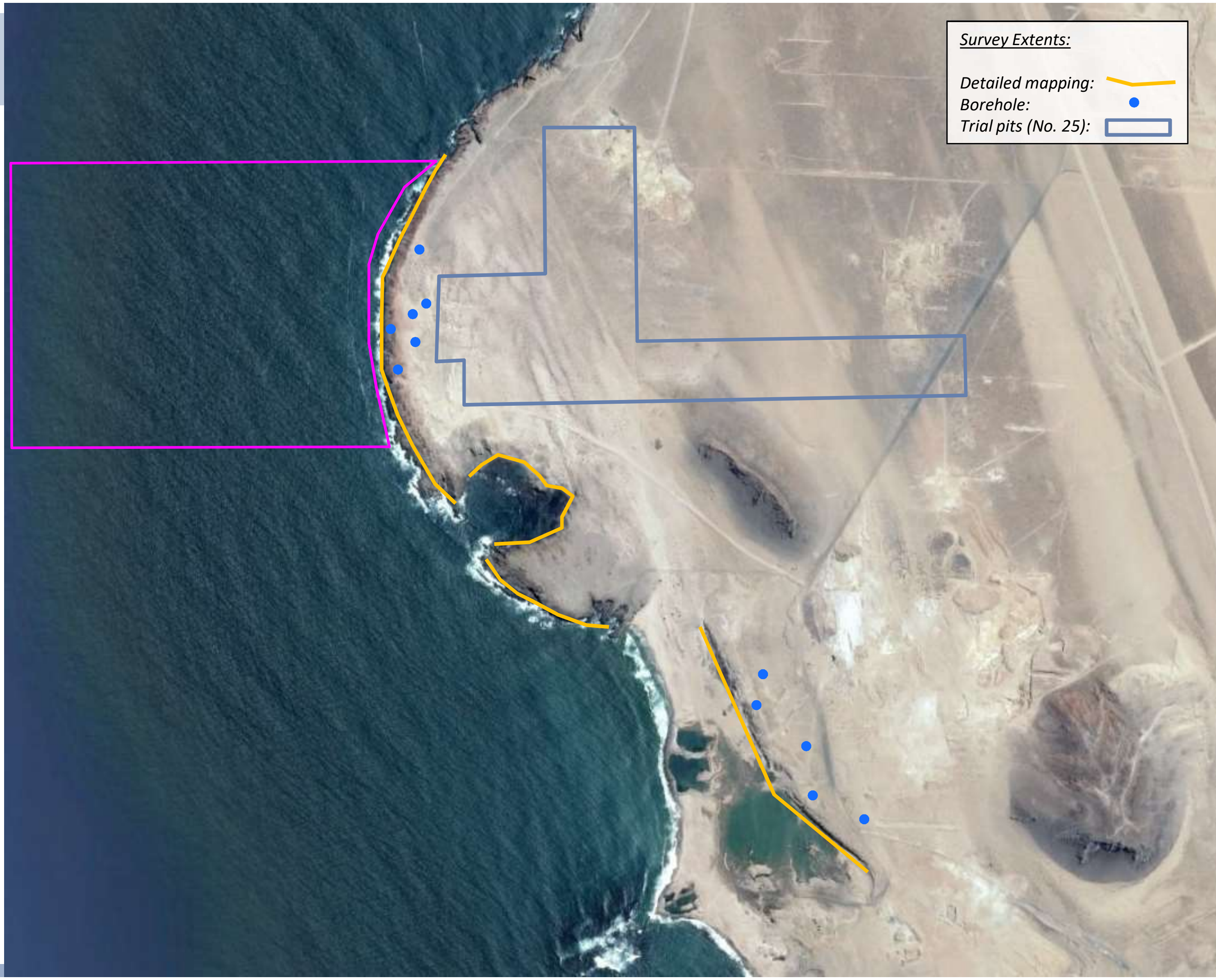




Jetty Structure Technical Review
Site Conditions

- **Site Investigations - Completed**
  - Marine – Hydrological Survey
    - Bathymetry
    - Geophysical
    - Sediment samples
  - Land – Geotechnical Investigations
    - Quarry investigation
    - Rock face mapping
    - Boreholes
    - Geotechnical model
  - Site visit

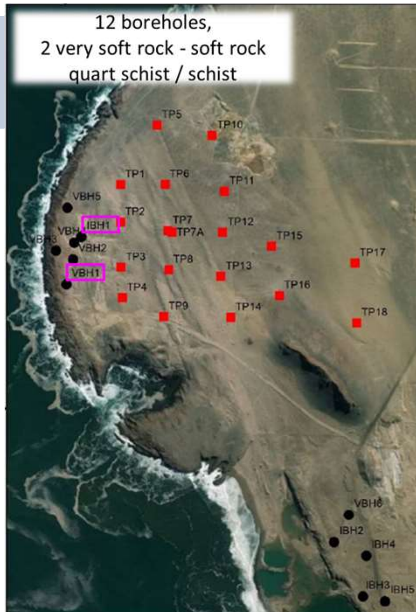
- **Site Investigations – Planned**
  - Vibrocores
  - Jet probes
  - Dive inspections

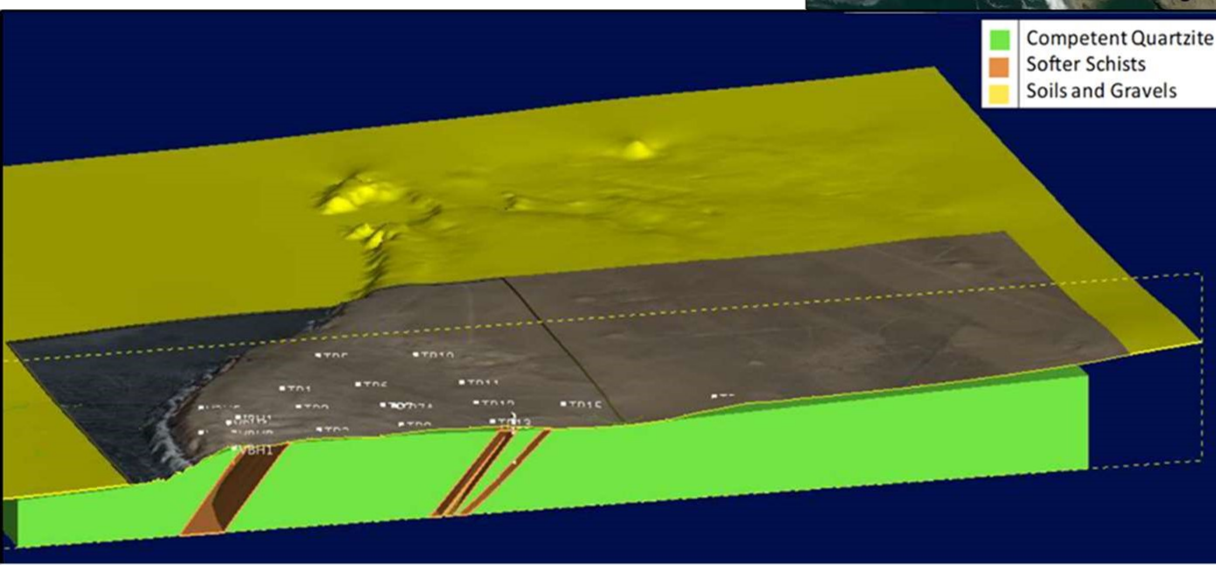


Jetty Structure Technical Review
Site Conditions

Geotechnical Conditions

- Overlain by thin layer of sand and gravel (1m-2m)
- Alternating bands of:
  - Quartzite (200 Mpa) – Competent
  - Slate/schist (13 Mpa) - Incompetent





Jetty Structure Technical Review
Site Conditions

SRK Geotechnical Investigation Report:

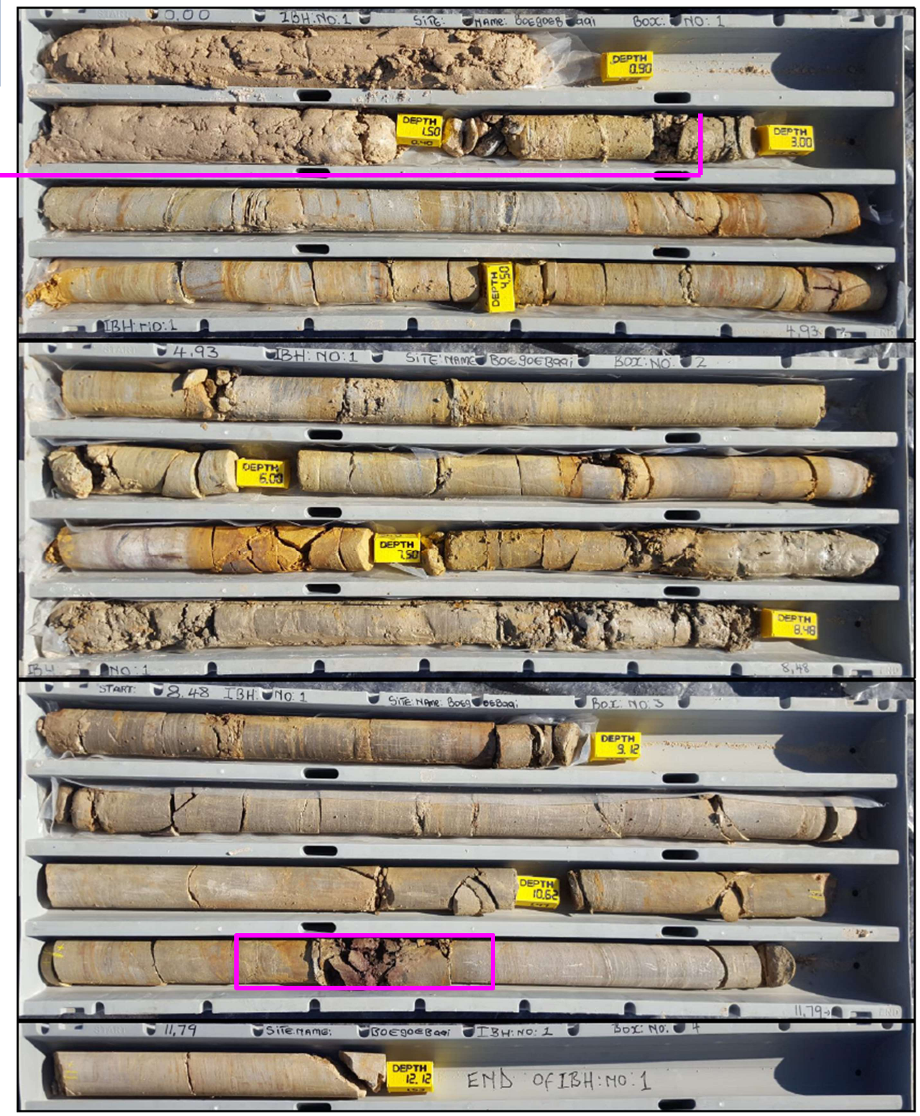
- Piled foundations:
  - Likely variability in founding materials
  - May require two pile designs
  - It will reduce risk to not rely on tension piles – Schist material more reliable in compression as they are generally confined – however should extensive/thick distributions of schist occur as were mapped onshore, reliance on compression piles will again become a risk as the confining effects will abate
  - Plan for extensive investigational drilling ahead of quay construction

- Gravity foundations
  - SRK's professional opinion that gravity foundations will carry a lower risk – loads spread
  - Differential settlement remains a risk
  - Additional risk = late design change if extensive distributions of clay (weathered schist) are found. Although it is probable that clay would have been eroded out by the sea.

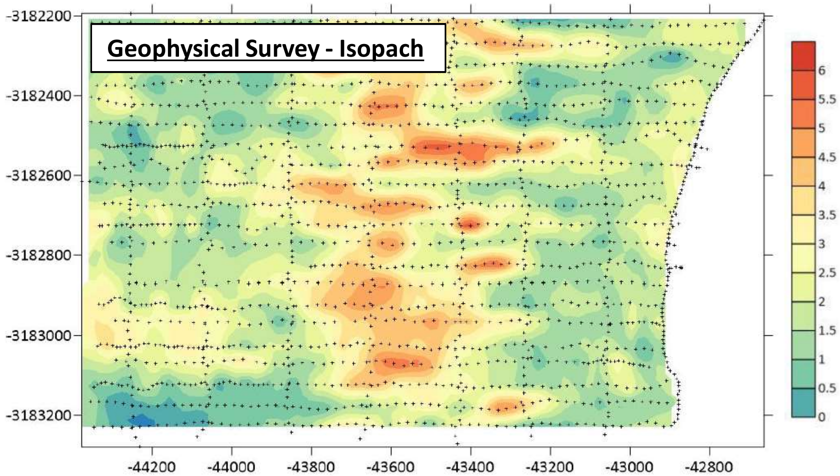
- Conclusion
  - Both offshore piled and gravity foundations carry risks with associated costs and design/construction complexities. The choice of founding solution needs to be evaluated holistically within the project context before a specific founding type is selected.

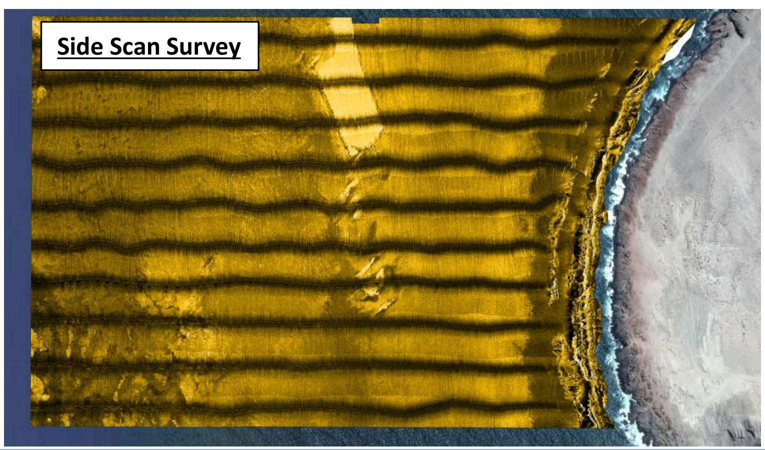
quartz schist / schist

INCLINE BOREHOLE IBH1

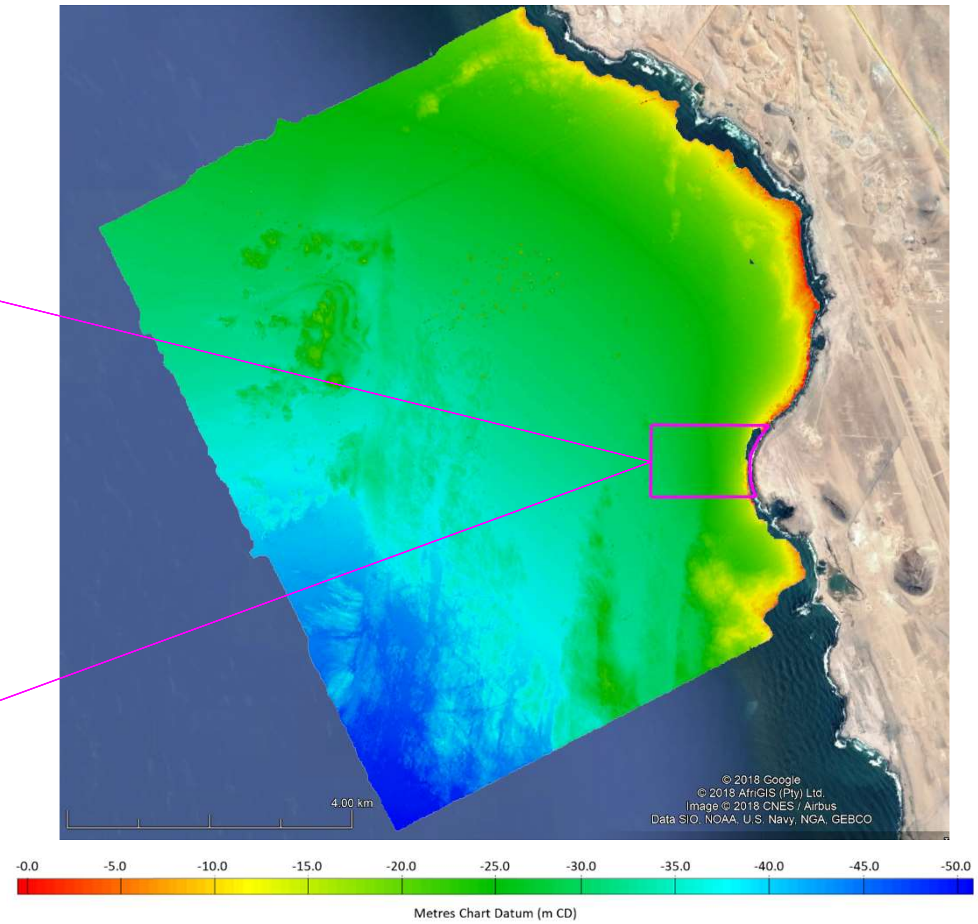


Hydrographic survey





Multibeam Bathymetry

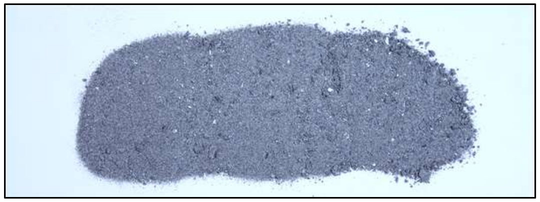


Sediment samples

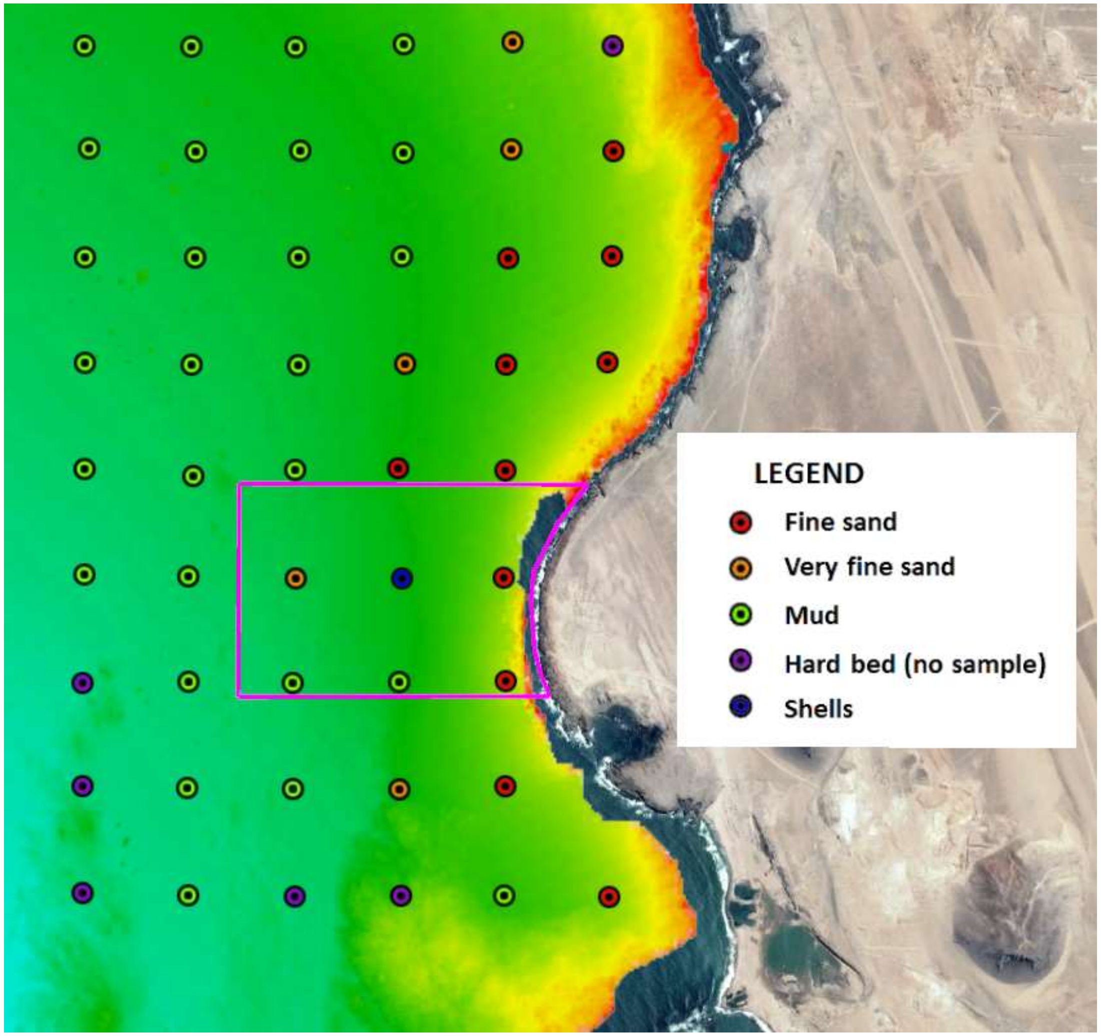
Fine sand

Very fine sand

Mud



Shells



Bathymetry and Water level

Deep water berth: Depth reaches -25m CD

LAT = 0m CH, MLWS = 0.3m CD

MHWS = 1.9m CD, HAT = 2.25mCD

Waves

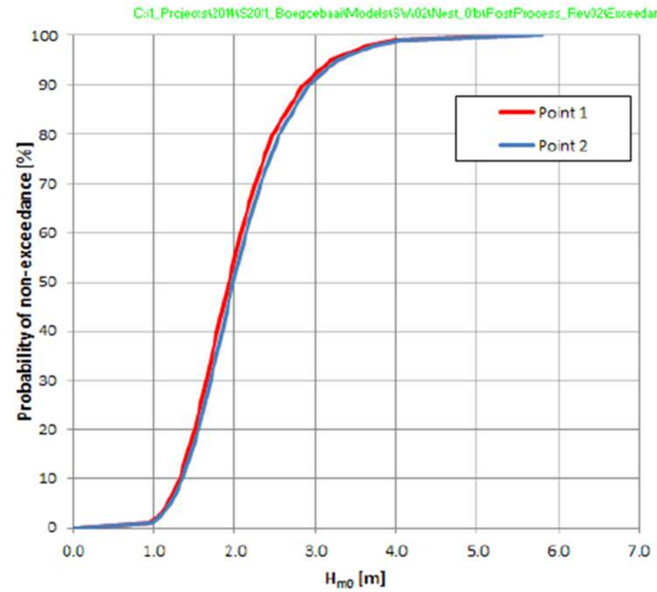
Site wave climate is severe with waves originating from South West.

Wind and Current

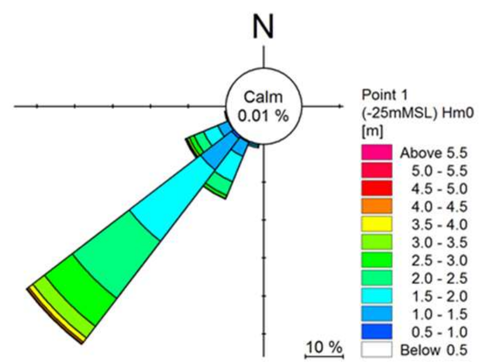
Not significant for structure design

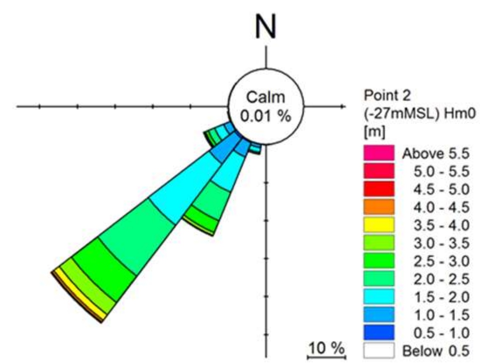
Seismic Activity

Site located in a benign area with PGA = 0.05g



Probability of non-exceedance [%]	Hm0 [m] Point 1	Hm0 [m] Point 2
0	0.00	0.00
1	0.95	0.98
2	1.04	1.07
5	1.18	1.22
10	1.33	1.36
20	1.51	1.55
30	1.65	1.70
40	1.79	1.84
50	1.92	1.98
60	2.07	2.13
70	2.25	2.31
80	2.47	2.54
90	2.83	2.91
95	3.19	3.27
98	3.63	3.71
99	3.97	4.05
100	5.67	5.80





Jetty Structure Technical Review
Functional Requirements

Design Service Life

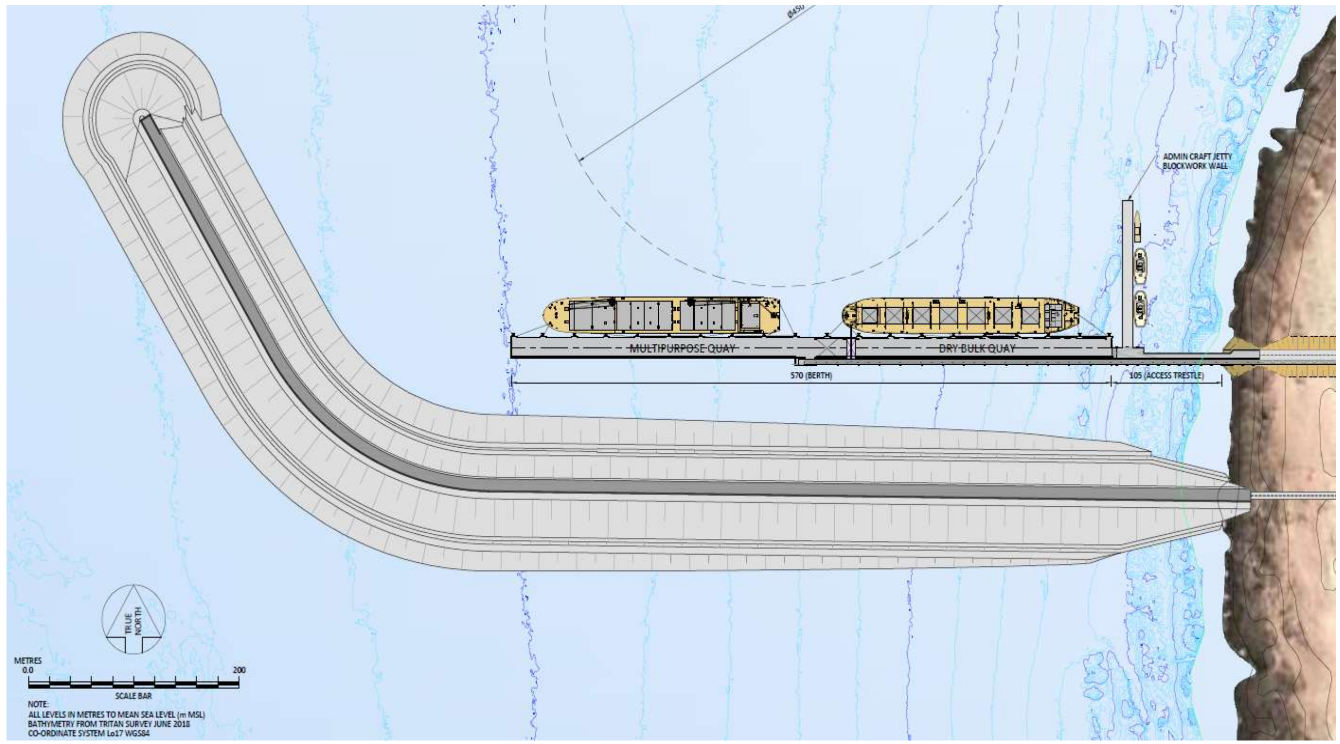
- Marine structure – 50 years

Design Vessels

- Capesize 200 000 dwt – Dry bulk Jetty
- Panamax 76 500dwt – MPT Jetty

Structure Layout

- Width - 26m
- Equipment: Shiploader, Conveyor, Cargo,
- 4 lanes of traffic
- Suitable turning circles for trucks.



CONSULTING
Transaction Advisory
Project Structuring and Funding

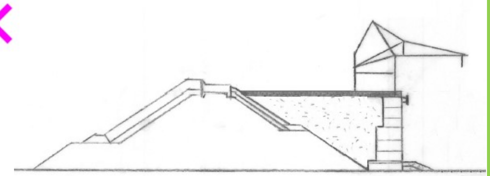
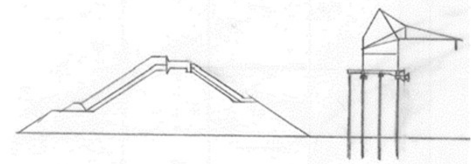
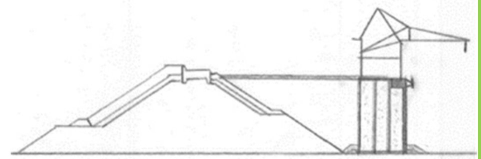
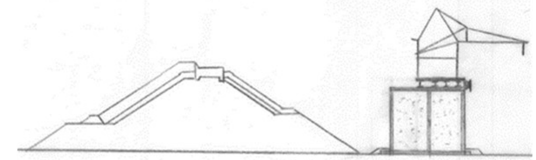
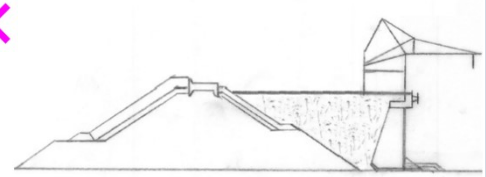
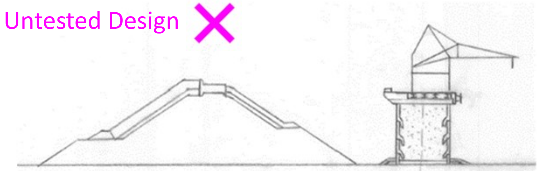
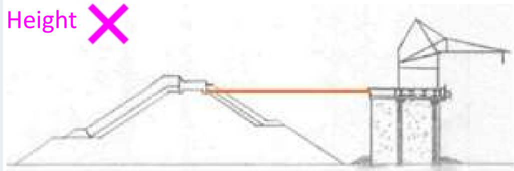
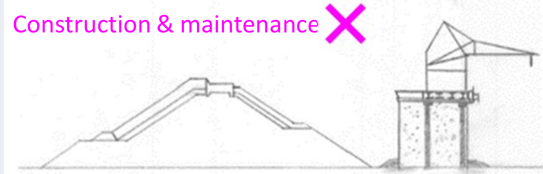
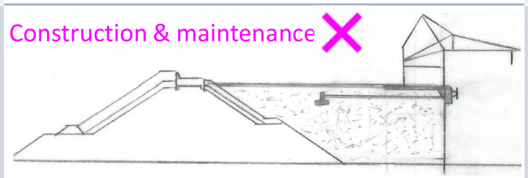
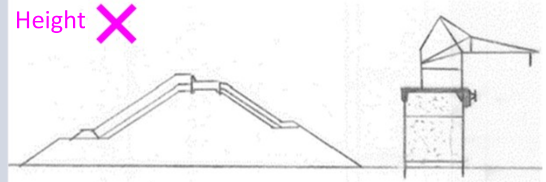
Jetty Structure Technical Review
Trade off Study

Initial Options Assessment

Continuous quay wall
- Caisson wall

Jetty type
- Caisson pier
- Piled

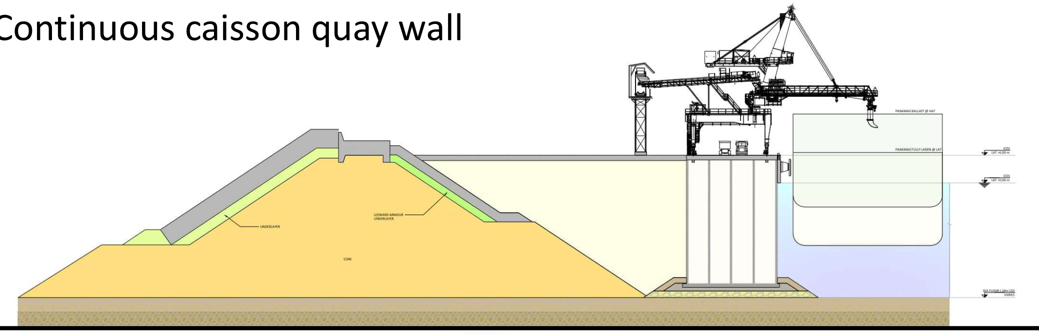
Conventional construction techniques require prohibitively large cranes for placement of units and significant founding stone bed on the seabed.

Continuous quay wall		Jetty type	
Blockwork quay wall	X 	Piled substructure	
Caisson quay wall		Caisson pier substructure	
Counterfort quay wall	X 	Precast ring pier substructure	Untested Design X 
Steel sheet pile cellular quay wall	Height X 	Steel sheet pile cellular pier substructure	Construction & maintenance X 
Embedded quay wall	Construction & maintenance X 	Embedded wall pier substructure	Height X 

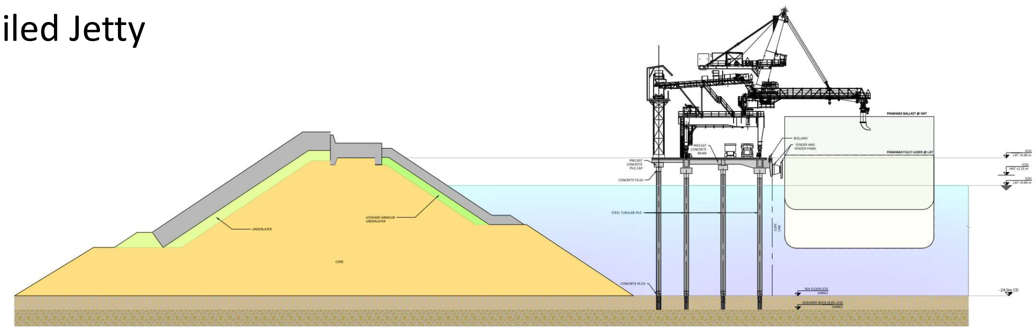
MCA

- Criteria & Weighting
  - Risk (20%)
    design or construction risks associated with variable geotechnical conditions
  - Schedule (20%)
    including time to establish all temporary facilities required to facilitate construction of the structure
  - Cost (55%)
    Concept-level capital cost estimate
  - (Safety 5%)

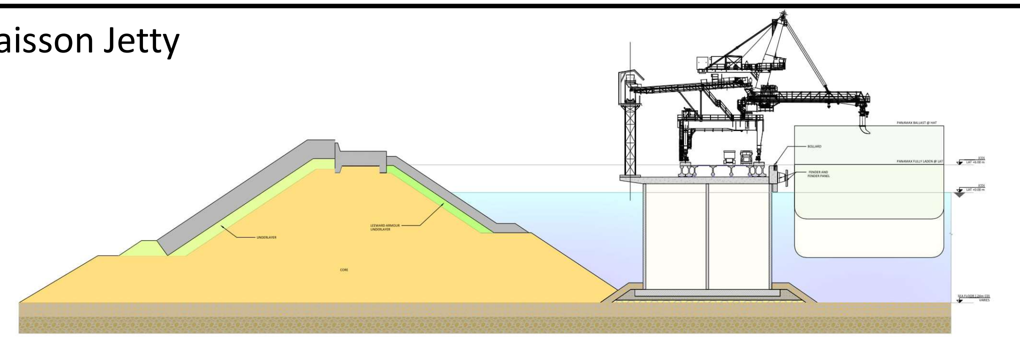
Continuous caisson quay wall



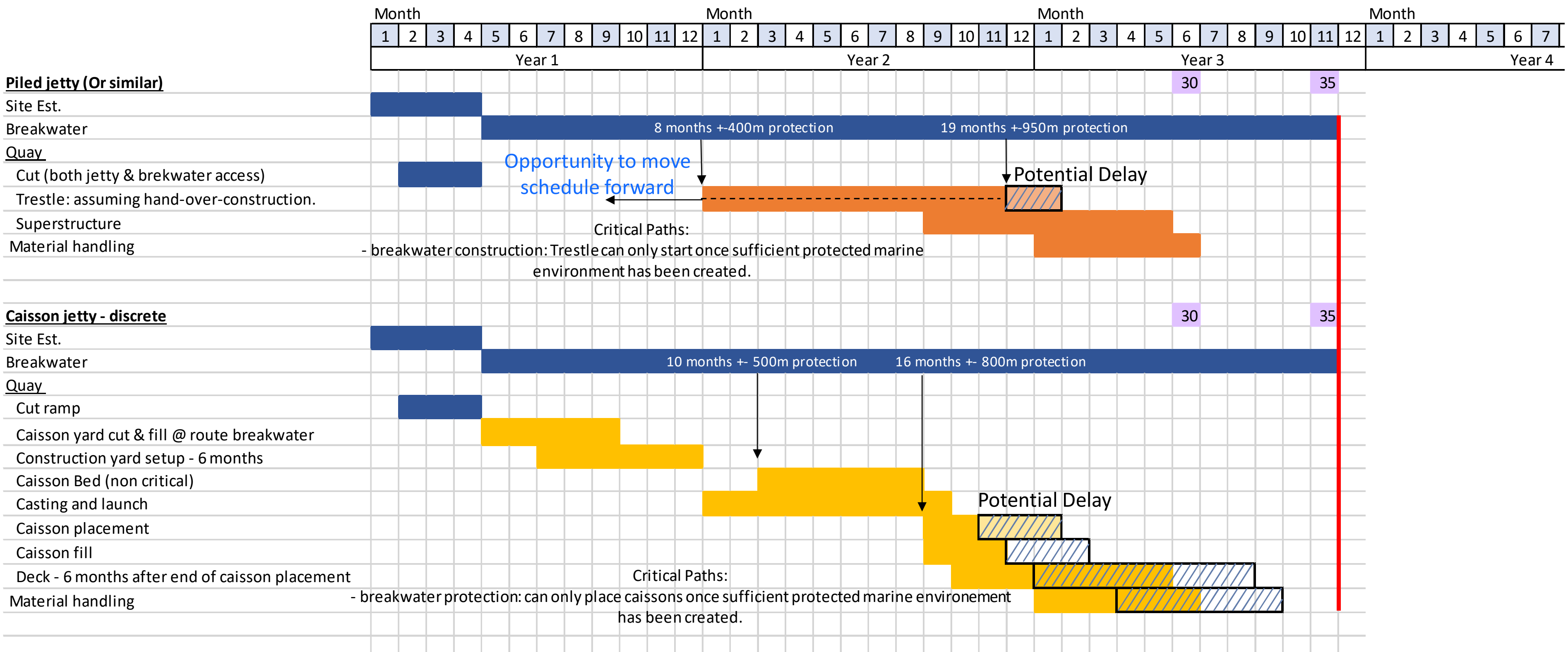
Piled Jetty



Caisson Jetty

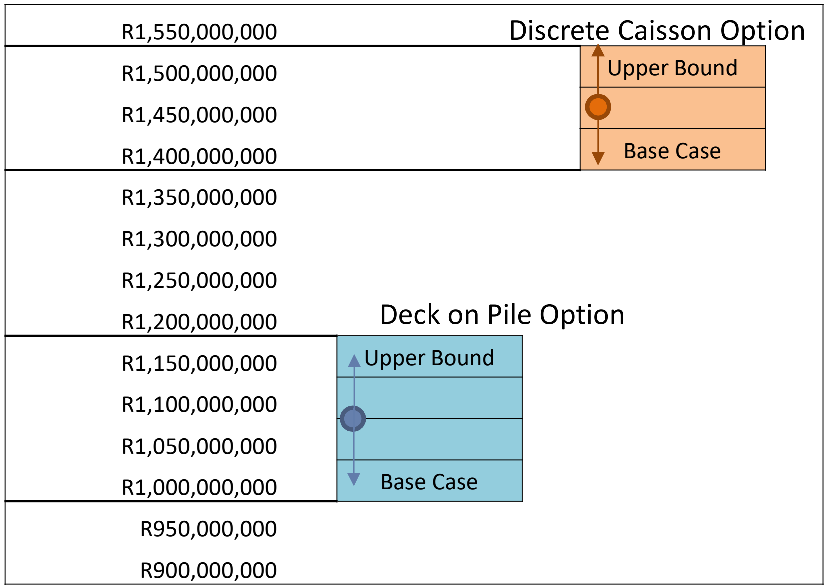


Implementation schedule



Jetty Structure Technical Review
Trade off Study

Costing - Sensitivity Assessment



Deck on Pile Option

<u>Base Case Assumptions</u>: 50% of piles in rock and 50% of piles in weathered schist

- 15% design development allowance
- 2.5% static pile load test
- Average pile casing length 35m
- Average socket length 8m

<u>Upper Bound Assumptions</u>: 100% of piles founded in weathered schist

- 10% design development allowance
- 5% static pile load test
- Average pile casing length 45m
- Average socket length 10m

Discrete Caisson Option

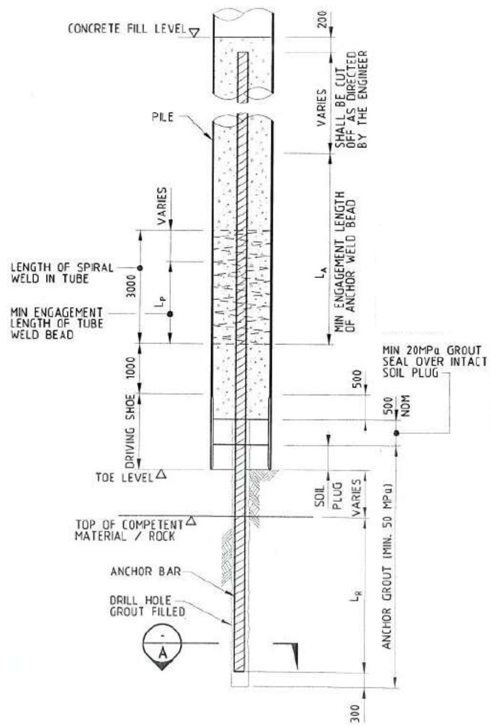
<u>Base Case Assumption</u>:

- 15% design development allowance

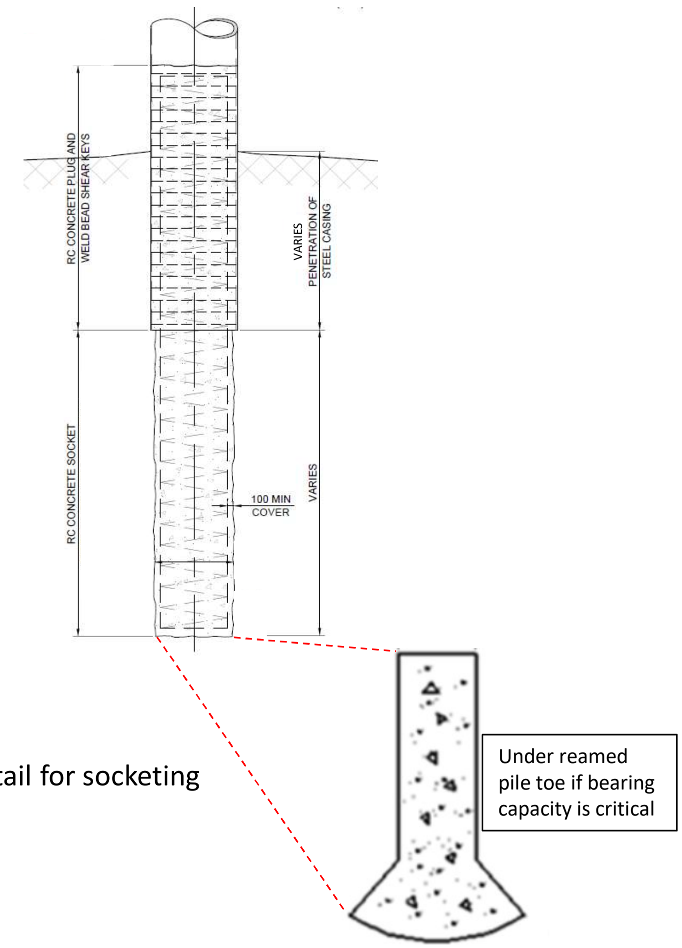
<u>Upper Bound Assumptions</u>: 2 caissons are founded on weak clay

- 10% design development allowance
- 2 caissons requiring soil improvement in the form of stone columns
- 1 month worth of standby costs

CONSULTING
Transaction Advisory
Project Structuring and Funding



Type 1 - Pile Toe detail for socketing in competent rock (Quartzite)



Type 2 - Pile Toe detail for socketing in weathered schist

Jetty Structure Technical Review
Trade off Study

The base-case scenario

Risk

Options 2

- more difficult to adapt the caisson structure and design to Geotech variances and extreme cases of large areas of clay

Option 3

- able to adapt and implement an appropriate design to conditions, engineer on site for timely decisions.

Implementation Schedule

- Caisson placement sensitive to wave climate = Large unknown factor in schedule.
- Piled jetty start as soon as contractor comfortable with conditions, less sensitive to wave climate and protected conditions.

	NC (S2023) Boegoebaai FEL 2 Phase 2 - Berth Structure Assessment				
	Multi Criteria Analysis for Selection of Preferred Option				
	TOTAL		**Option 1: Continuous Caisson Quay Wall**	**Option 2: Caisson Jetty-type Structure**	**Option 3: Piled Jetty-type Structure**
Ref.	**Criteria**	**Weighting**			
1	**Inherent Safety**	5%	5%	5%	4%
2	**Geotechnical Conditions/Risk**	20%	20%	20%	10%
3	**Implementation Schedule**	20%	13%	15%	20%
4	**Value and Cost**	55%	20%	39%	55%
	Total	**100%**	**58%**	**79%**	**89%**
1	**Inherent Safety**	100%	**10**	**10**	**7.5**
1.1	Safety of personnel during construction *(extent of dive work, working over water, etc.)*	50%	10	10	10
			Caissons are constructed in the dry and therefore less risk in working over water, however, significant dive work will be required to prepare stone bed. Both piled structure and caisson jetty-type structure require over-water work (pile driving, placing of bridge beams), with the piled option potentially being constructed in more exposed conditions. Therefore all options score the same as there is no significant safety differentiator.		
1.2	Structural Redundancy *(localisation and repairability of damage i.e. is damage localised or does it place the complete facility at risk)*	50%	10	10	5
			Caissons are more redundant and can remain functional should damage occur to one of the cells. Piled structures are more difficult to repair and may require that operations at the facility be halted until such time that the pile is repaired, particularly if a pile supporting the crane rail beam is damaged). Options 1 and 2 therefore score higher than Option 3.		
2	**Geotechnical Conditions/Risk**	100%	**10**	**10**	**5**
2.1	Risk associated with ground conditions *(design or construction risks associated with variable geotechnical conditions i.e. how adaptable is the structure should geotechnical conditions differ from those assumed during the design phase)*	100%	10	10	5
			Drilling rocket sockets for the piled jetty-type structure may be challenging given the very hard quartzite. The Schist layers also pose a risk as they much weaker and variable in quality. Variation in offshore geotechnical conditions may therefore require drilling ahead of construction to mitigate some risks with a variation in design of the pile socket to suite position-specific conditions. The risk for caissons is if the material is found to be unsuitable for bearing load, for example if a weak clay layer is found. In this case a late change to the design would be difficult and expensive. However, based on the results of landside investigations, clay layers are considered unlikely and the caisson options therefore score higher.		
3	**Implementation Schedule**	100%	**6.4**	**7.5**	**10**
3.1	Construction duration	100%	6.4	7.5	10
	Concept-level schedule estimate (months):		33	28	21
4	**Value and Cost**	100%	**3.7**	**7.1**	**10**
4.1	Capital cost	100%	3.7	7.1	10.0
	Concept-level capital cost estimate:		*R 2 700 000 000*	*R 1 400 000 000*	*R 1 000 000 000*

Sensitivity Analysis

- Option 1 scores consistently poorly across all weighting biases
- Option 2 scores favourably for the equal, inherent safety and geotechnical risk biases
- Option 3 scores favourably for the base case, implementation schedule and value and cost biases.

	Equal	Inherent Safety	Geotechnical Conditions/Risk	Implementation Schedule	Value and Cost
Inherent Safety	25%	40%	20%	20%	20%
Geotechnical Conditions/Risk	25%	20%	40%	20%	20%
Implementation Schedule	25%	20%	20%	40%	20%
Value and Cost	25%	20%	20%	20%	40%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**

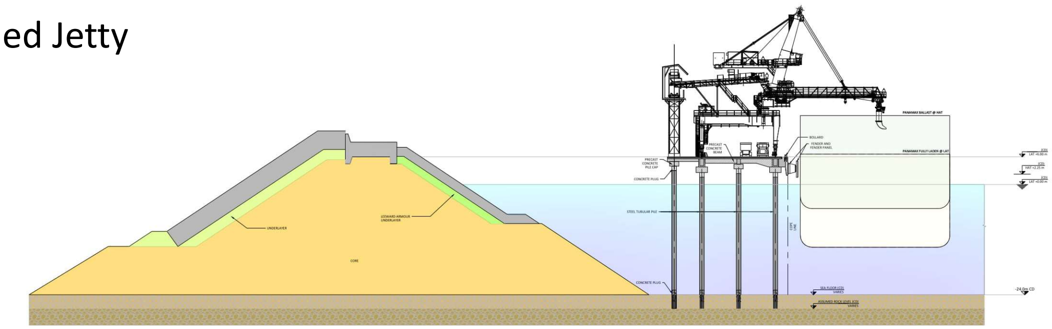
Weighting Bias	Option 1: Continuous Caisson Quay Wall	Option 2: Caisson Jetty-type Structure	Option 3: Piled Jetty-type Structure
Base Case	58%	79%	89%
Equal	75%	87%	81%
Inherent Safety	80%	89%	80%
Geotechnical Conditions/Risk	80%	89%	75%
Implementation Schedule	73%	84%	85%
Value and Cost	68%	83%	85%

Jetty Structure Technical Review
Trade off Study

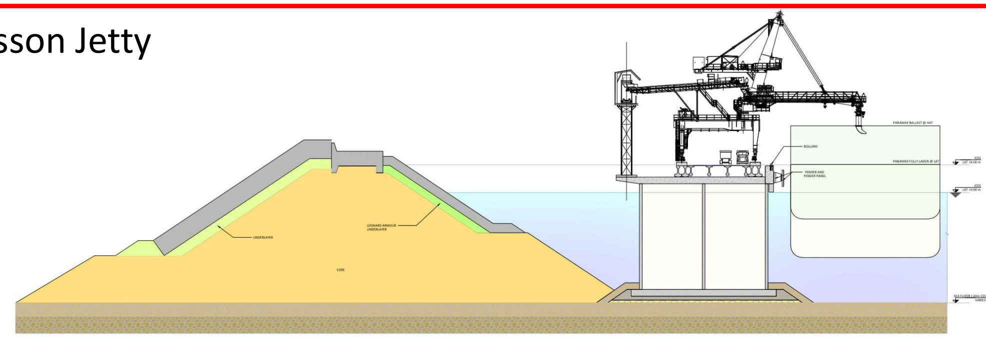
Conclusion

- Piled jetty has been selected as preferred
- The potentially lower geotechnical risk attributed to the caisson jetty does not justify the CAPEX premium
- The piled jetty risk may be mitigated with appropriate attention to design, on site supervision and geotechnical investigations
- The caisson jetty also has potential geotechnical risks and considerable schedule and placement risk.

Piled Jetty



Caisson Jetty

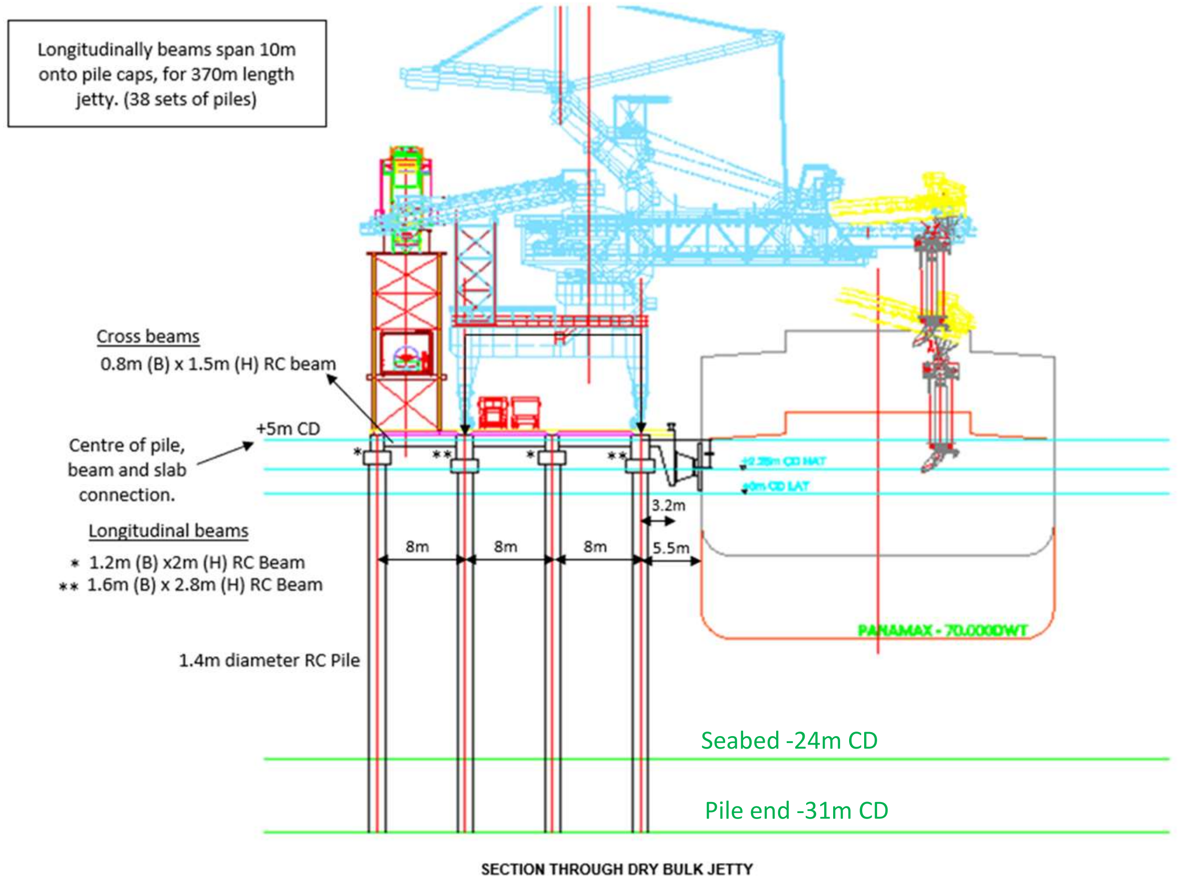


Piled Jetty Structure

- Initial design vertical piles only, prevent use of raker piles due to geotechnical variability

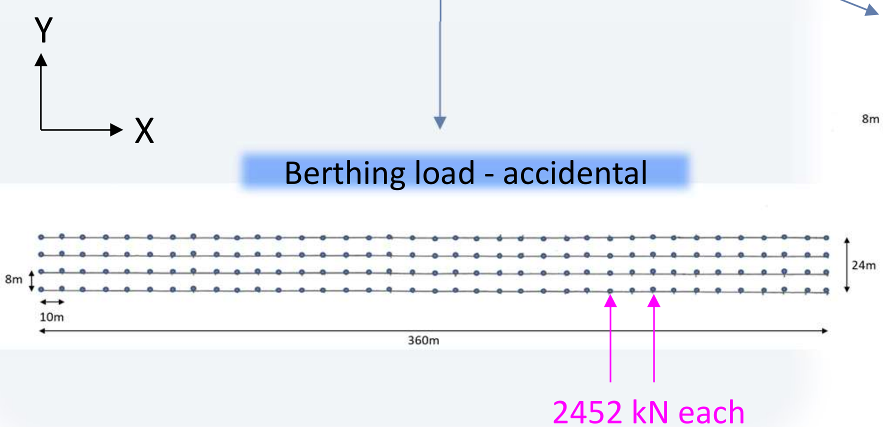
  - 360m length of Dry Bulk Jetty
  - Deck-on-Pile structure (RC piles, beams & deck)
  - Pile spacing: 10m x 8m @ 1.4m diameter piles
  - Fender and Bollard Spacing: 20m
  - Deck level +6m CD

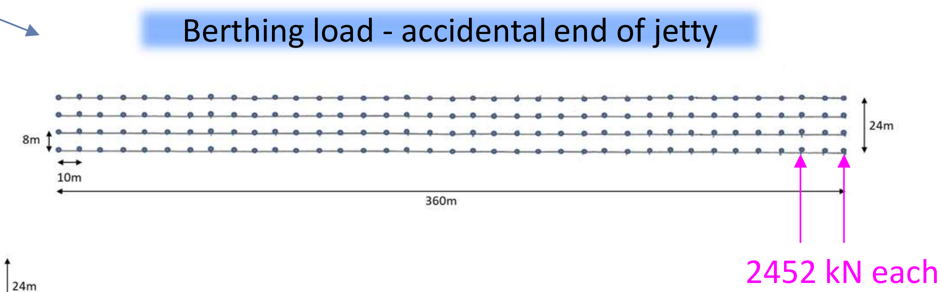
Initial Vertical Pile Layout

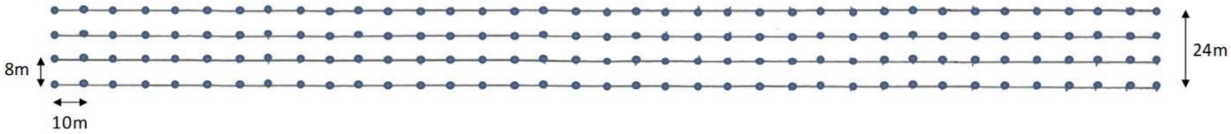


Pile Arrangement

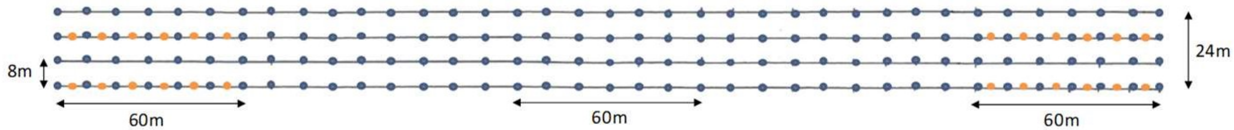
- Lateral Stability Governing Pile Design (UY)
- Focus on Berthing Load: Cases 502 and 505
- Limiting displacement 100mm



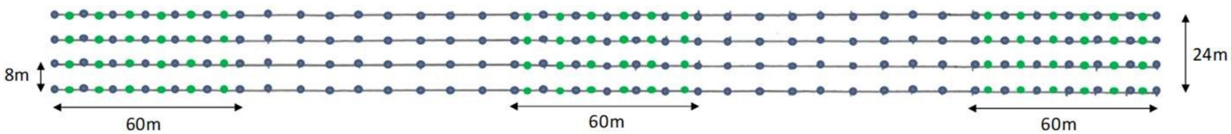




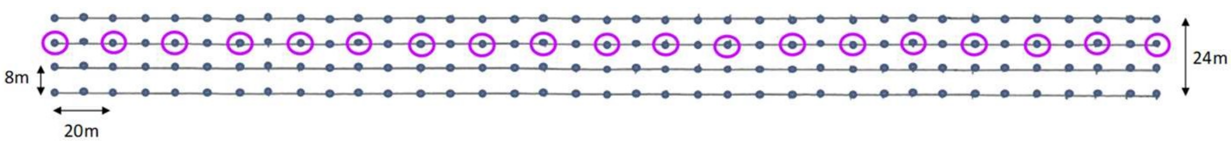
Vertical Piles @ 1.4m Ø , 2m Ø, 2.4m Ø, 2.5m Ø



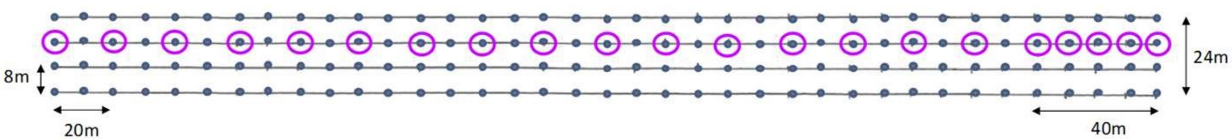
+ additional Vertical Piles, 5m spacing, 2m Ø
- Crane rail beams only



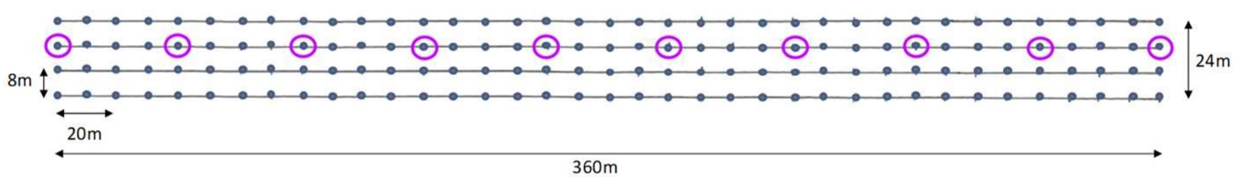
+ additional Vertical Piles, 5m spacing, 2m Ø



+ additional Raker Piles, 20m spacing, 1.4m Ø



+ additional Raker Piles, 20m spacing & 10m spacing at end, 1.4m Ø



+ additional Raker Piles, 40m spacing, 1.4m Ø

Pile Arrangement

Vertical Piles Only [10m x 8m grid]	Case 502 (SLS)	Case 505 (SLS)
	UY (mm)	UY (mm)
1.4m Ø	289	457
2m Ø	88	165
2.4m Ø	54	113
2.5m Ø	49	105

Pile Arrangement

Vertical Piles Only [10m x 8m grid]	Case 502 (SLS)	Case 505 (SLS)
	UY (mm)	UY (mm)
1.4m Ø	289	457
2m Ø	88	165
2.4m Ø	54	113
2.5m Ø	49	105

Vertical Piles Only - Increased Density	Case 502	Case 505
	UY (mm)	UY (mm)
+ 2m Ø Piles @ 5m centres, 60m either end – crane beams only	67	145
+ 2m Ø Piles @ 5m centres 60m, either end & middle – all longitudinal beams	55	124

Pile Arrangement

Vertical Piles Only [10m x 8m grid]	Case 502 (SLS)	Case 505 (SLS)
	UY (mm)	UY (mm)
1.4m Ø	289	457
2m Ø	88	165
2.4m Ø	54	113
2.5m Ø	49	105

Vertical Piles Only - Increased Density	Case 502	Case 505
	UY (mm)	UY (mm)
+ 2m Ø Piles @ 5m centres, 60m either end – crane beams only	67	145
+ 2m Ø Piles @ 5m centres 60m, either end & middle – all longitudinal beams	55	124

Pile Arrangement

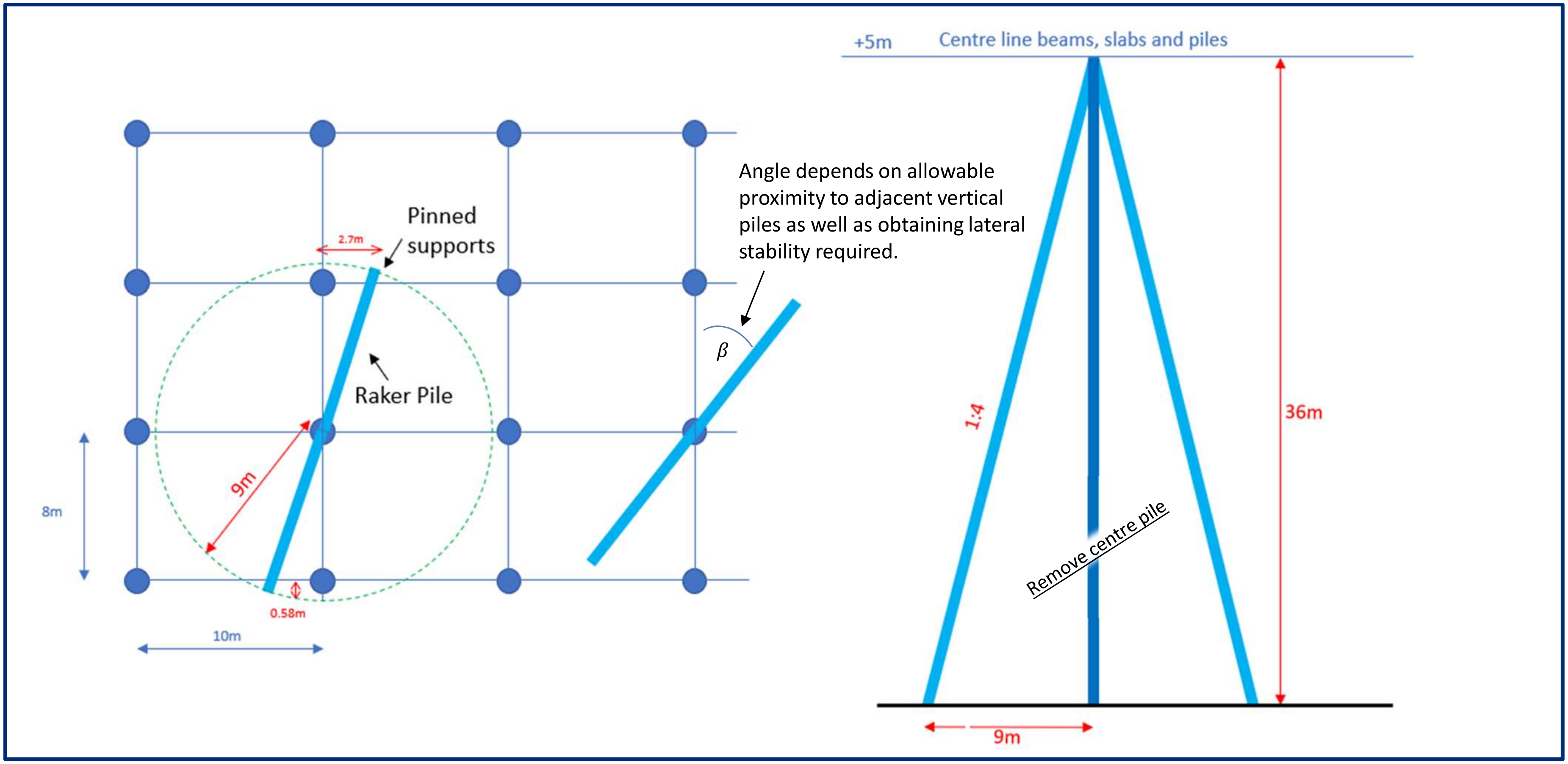
Vertical Piles Only [10m x 8m grid]	Case 502 (SLS) UY (mm)	Case 505 (SLS) UY (mm)
1.4m Ø	289	457
2m Ø	88	165
2.4m Ø	54	113
2.5m Ø	49	105

Vertical Piles Only - Increased Density	Case 502 UY (mm)	Case 505 UY (mm)
+ 2m Ø Piles @ 5m centres, 60m either end – crane beams only	67	145
+ 2m Ø Piles @ 5m centres 60m, either end & middle – all longitudinal beams	55	124

Vertical Piles + Raker Piles all 1.4m Ø	Case 502 (SLS) UY (mm)	Case 505 (SLS) UY (mm)
Raker Piles @20m spacing + 10m at end	14	19
Raker Piles @20m spacing	14	24
Raker Piles @40m spacing	18	31

Force FX Compression	Reaction RZ	Force FX Tension	Reaction RZ
6 690 kN	6 530 kN compression	2 990 kN	1 080 kN **tension**
8 180 kN	7 970 kN compression	4 670 kN	2 700 kN **tension**
10 540 kN	10 260 kN compression	7 100 kN	5 070 kN **tension**

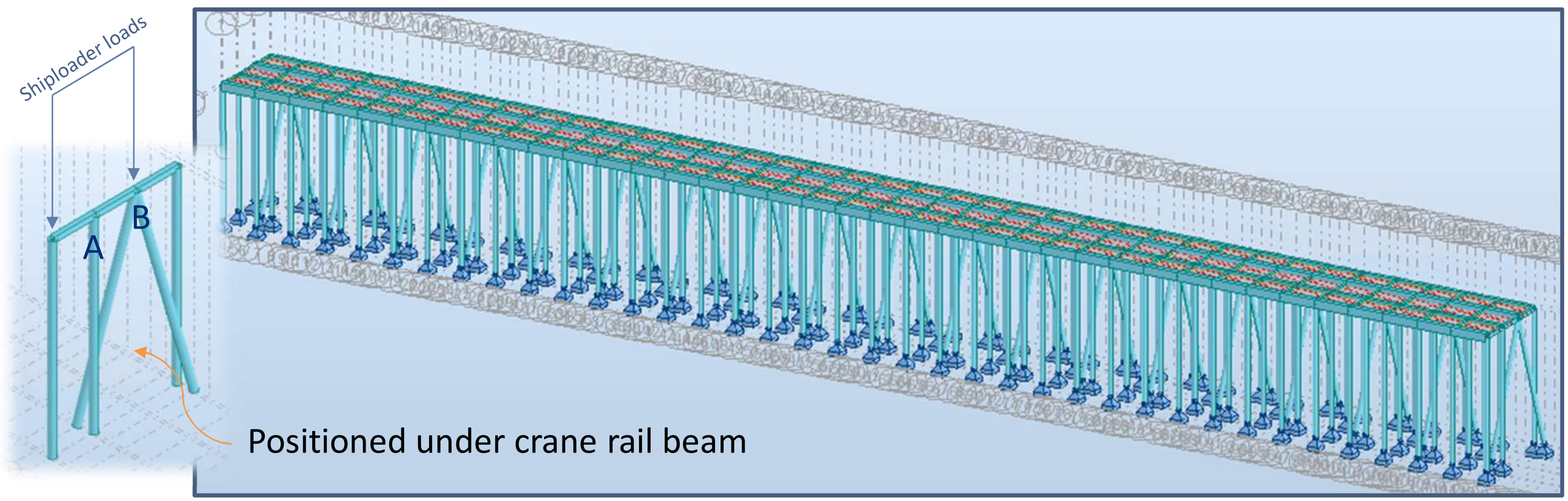
Inclusion of Raker Piles



Inclusion of Raker Piles

More efficient than increasing density of vertical pile system to achieve results.

- Implementing raker piles = 19 additional piles
- Max axial tension top of Raker Pile decreases from when shifted from Position **A** to Position **B** (under crane beam).



- END