Consulting Port and Coastal Engineers

BOEGOEBAAI PORT FEL 2 PHASE 2

Breakwater 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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FEL 2

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TM Consulting and Nelutha Consulting
Boegoebaai, South Africa

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

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1. INTRODUCTION

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 is located 20 km south of Alexander Bay and 60 km north of Port Nolloth. A preliminary layout of the port is shown in Figure 1-1.

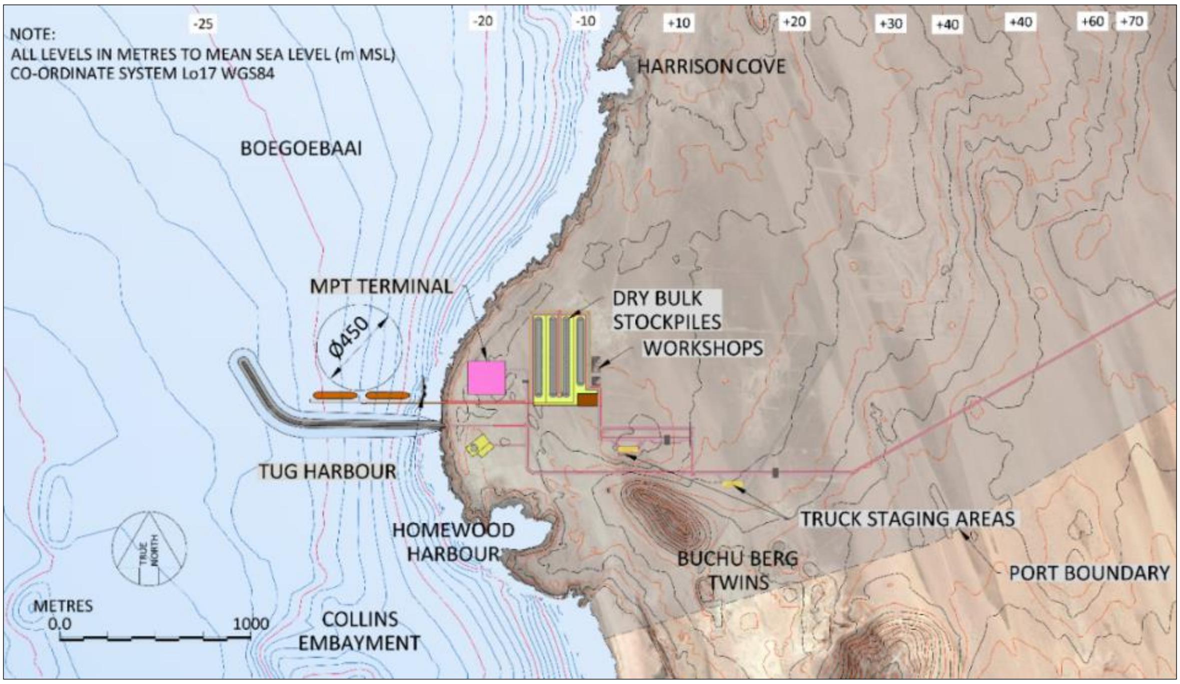

Figure 1-1: Boegoebaai port layout (Phase 1).

This document addresses the trade-off study carried out for the proposed breakwater. The following aspects of the breakwater were considered:

- Type of breakwater structure
- Type of primary armour protection

2. SITE CONDITIONS

A brief summary of the wave climate at Boegoebaai is provided in the following sections. For the detailed assessment of dominant coastal processes at the site, refer to the PRDW Coastal Processes Technical Note (PRDW, 2018).

2.1 Operational wave climate

In order to characterise the wave climate at Boegoebaai, a wave refraction modelling study was carried out using the '*MIKE by DHI' Spectral Waves Flexible Mesh* model (DHI, 2018), making use of 39 years of spectral hindcast wave data. The operational wave climate was characterised using 39 years of modelled data extracted from -29 m CD.

An exceedance and scatter plot of the wave parameters is presented in Figure 2-1 and Figure 2-2.

The exceedance plot indicates the wave climate to be moderate to rough, with a probability of exceedance of 80 percent for a wave height of 1.5 m. A wave height of 1 m has a 99 percent probability of exceedance.

The maximum wave height experienced over the 39-year period was 7.8 m with a peak period T_p of 16.8 s.

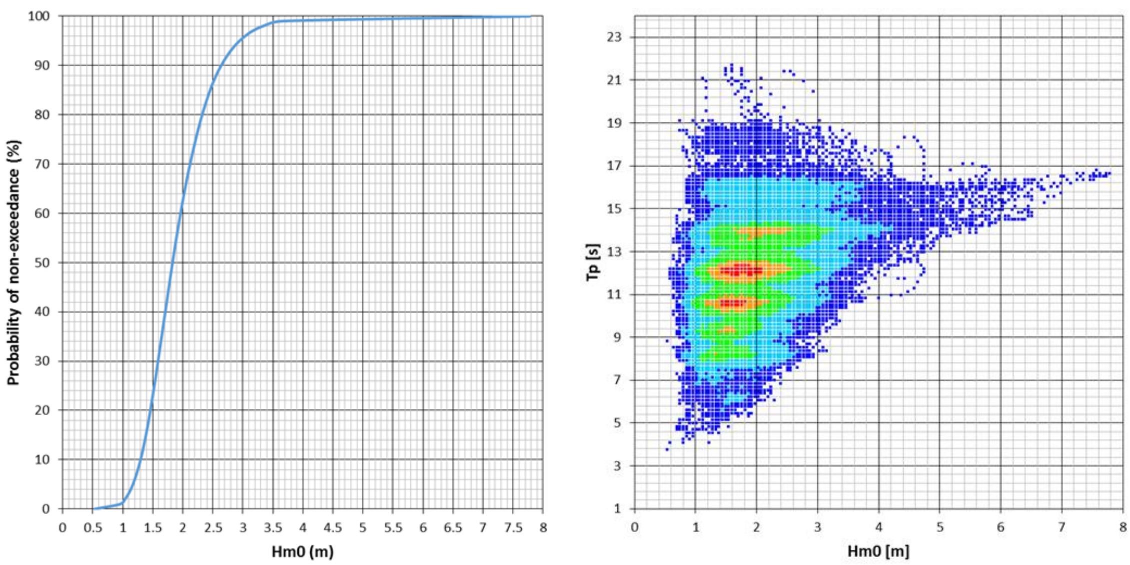

Figure 2-1: Operational exceedance plot of the significant wave height (H_{m0}) and peak period (T_p) versus H_{m0} scatter plot, extracted from 39 years of modelled data at -29 m CD.

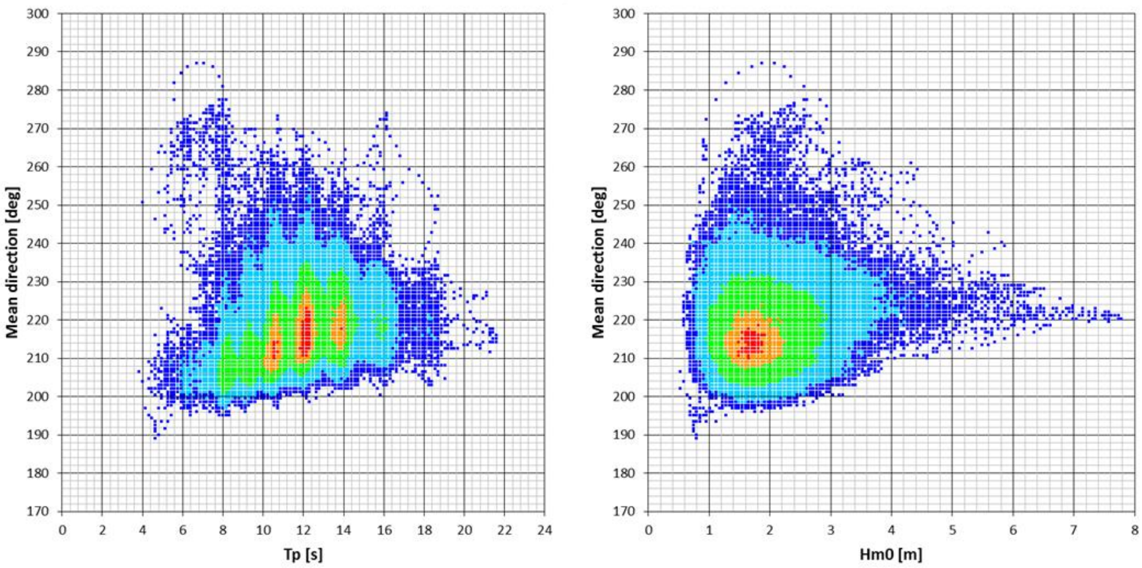

Figure 2-2: Scatter plot of the mean direction, peak period (T_p) and the significant wave height H_{m0}, extracted from 39 years of modelled data at -29 m CD.

2.2 Extreme wave climate

Extreme value analyses (EVA's) were carried on the modelled H_{m0} using the MIKE Zero EVA toolbox (DHI, 2018) to calculate the design wave height. EVA results near the breakwater head are presented in Table 2-1. Climate change was was excluded as recommended by PRDW (2018).

For design purposes the extreme wave height (H_{m0}) is 9.9 m. The wave height is obtained from the upper 95 percent estimate for a 1 in 475-year return period storm event with a design life of 50 years and probability of exceedance of 10 percent (AS4997, 2005).

Table 2-1: Extreme wave heights at the breakwater.

Return period [years]	Best Estimate H_{m0} [m]	Upper 95% confidence H_{m0} [m]
1	4.9	5.1
5	6.4	6.7
10	6.8	7.2
20	7.1	7.7
50	7.6	8.3
100	7.9	8.8
475	**8.5**	**9.9**

3. QUALITATIVE TRADE-OFF

A qualitative trade-off was carried out to determine appropriate options and eliminate non-starters. The following aspects of the breakwater were considered:

- Type of breakwater
- Type of primary armour

3.1 Type of breakwater

A comparison between a rubble mound and caisson breakwater is presented is Table 3-1, in which the feasibility of each structure is discussed.

Table 3-1: Comparison of breakwater types.

Type of breakwater	Feasibility	Reason
Rubble mound	Yes	Constructible in local wave climate, good quality rock is available based on the quarry assessment (SRK Consulting, 2018), founding conditions appear to be reasonable
Caisson	No	Unsuitable wave climate. Calm sea conditions (generally H_{m0} < 1.0 m) are required for towing, positioning and sinking operations of caisson units. A wave height of 1 m has a 99 percent probability of exceedance, which will result in excessive downtime for caisson placement - see Figure 2-1

3.2 Type of primary armour

Site investigations have indicated that sufficient rock should be available to serve as core and underlayer material. Due to the high energy wave climate and expected quantities, a trade-off between common primary armour units was carried out. Types of primary armour units are illustrated in Figure 3-1.

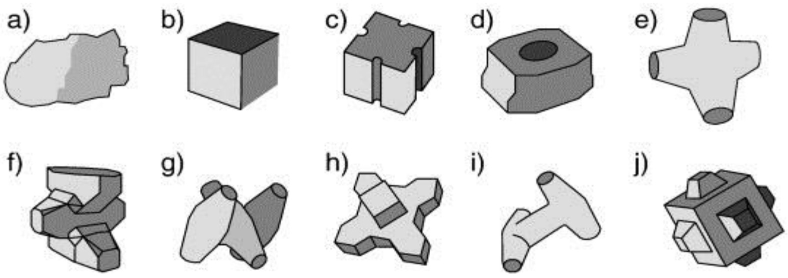

Figure 3-1: Common armour unit types.

(a) rock; (b) cube; (c) Antifer; (d) Haro; (e) Tetrapod; (f) Accropode™; (g) Core-loc™; (h) Xbloc; (i) dolos and (j) Cubipod

(J Molines, 2015)

3.2.1 Results

A comparison of the applicability of common breakwater armour units for Boegoebaai is shown in Table 3-2.

Table 3-2: Comparison of common breakwater primary armour units [1, 2, 3].

Type of primary armour layer	Advantages	Disadvantages	Applicability	Reason / comments
Cubipods	Large units (> 30 t) can be used due to good structural stability. Improved performance (less breakages than dolosse) in dynamic sea conditions	Higher concrete volumes required due to unit geometry. Royalty fee required	Yes	To be assessed further
Antifers	Simple substitute for rock. Large units can be used (> 30 t) due to good structural stability. More stable than concrete cube. Improved performance (less breakages than dolosse) in dynamic sea conditions. No royalty fee as Antifers are not patented	Higher concrete volumes required due to unit geometry. Less stable than Cubipods	Yes	To be assessed further
Dolosse	Good hydraulic stability. Cost effective. Most stable interlocking unit and preferred solution in South Africa	Maximum recommended size is 30 t, after which frequent breakages are likely to occur	No	Wave climate is unsuitable to use dolosse at breakwater head. Preliminary calculations indicate that a dolos mass >> 30 t would be required for stability
Tetrapods	Relatively good stability	Maximum recommended size is 30 t, after which frequent breakages are likely to occur	No	Less cost effective when compared to dolosse. Tetrapods are more effective than other interlocking units such as Stabits, Akmons and Tripods
Single layer armour (Accropode, Xbloc, CORE-LOC)	Lower concrete volumes	Strict tolerances apply to the placement of each unit, which is only possible in calm water conditions with good underwater visibility	No	Moderate to rough wave climate is unsuitable for placement
Hollow Units (Haro, Cob, Shed, Seabee, Diode)	Lower concrete volumes	Strict tolerances apply to the placement of each unit (generally placed in a single layer), which is only possible in calm water conditions with good underwater visibility	No	Moderate to rough wave climate is unsuitable for placement
Rock	Most simple armour solution, cost effective in calm to moderate wave climates, robust	Available rock armour size is determined by the site geology, which is seldom available in sizes above 20 t	No	A median mass (M_{50}) >> 20 t would be required for stability

1) (CIRIA; CUR; CETMEF, 2007)
2) (TNPA, 2015)
3) www.cubipod.com

4. QUANTITATIVE TRADE-OFF

A quantitative trade-off was carried out between Cubipods and Antifer Blocks to determine the relative cost and suitability of the two units at Boegoebaai. Considering that the trunk comprises most of the breakwater, the head was not included in this study. The following factors were included:

- Armour unit royalty
- High-level concrete supply cost
- High-level unit placement cost
- Armour unit size
- Design wave height

Examples of Cubipods and Antifer Blocks are shown in Figure 4-1.

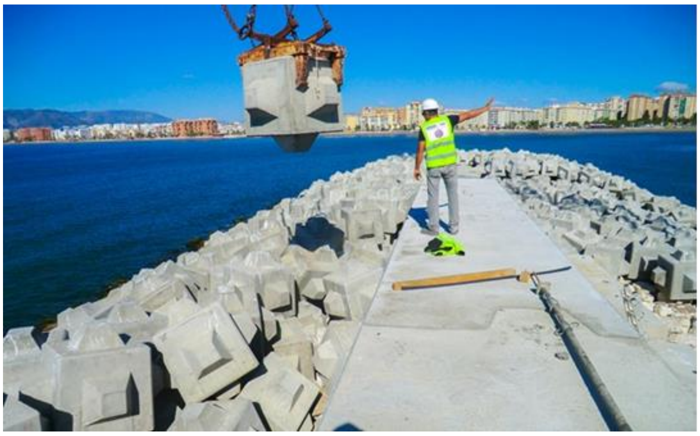

Figure 4-1: Example of Cubipod (left) and Antifer Block (right) armouring systems. (Medina & Gomez-Martin, 2016), (Frens, 2007)

4.1 Results

The preliminary mass of the armour units required for hydraulic stability was determined in accordance with the *Rock Manual* (CIRIA; CUR; CETMEF, 2007). Specifically, Hudson's equation was used to determine the size of required concrete armour units. Relevant input parameters are presented in Table 4-1.

Table 4-1: Input design parameters for trade-off between Cubipods and Antifer Blocks at Boegoebaai.

Parameter	Cubipod (trunk)	Antifer Block (trunk)
Stability coefficient (K_d) (1) [-]	12 (2)	7 (3)
Slope [1:X]	1.5	
Packing density coefficient [-]	1.16 (4)	1.17 (4)

(1) Stability based on virtually no damage (i.e. no maintenance except after unusually severe storms)
(2) (Medina & Gomez-Martin, 2016). A more conservative stability coefficient (K_d) of 12 has been considered (instead of 28) based on PRDW's own experience with the stability of this type of unit
(3) (CIRIA; CUR; CETMEF, 2007)
(4) (Medina & Molines, 2014)

The preliminary armour unit characteristics and costs required for hydraulic stability at Boegoebaai are presented in Table 4-2. Note that the weights and costs are for comparison purposes only and are subject to change during detailed design and costing.

Table 4-2: Summary of quantitative trade-off between Cubipods and Antifer Blocks at Boegoebaai.

Parameter	Cubipod (trunk)	Antifer Block (trunk)
Armour unit mass [t]	54	92
Armour unit volume [m^3]	22.3	38.3
Supply per unit (incl. concrete, casting and transport)	R 80 389	R 137 810
Placement per unit (1)	R 31 263	R 53 593
Royalty per unit	R 3 700	R 0
Estimated trunk area [m^2]	48 700	
Number of units [No.]	7 124	5 016
Armour cost	R 822 mil.	R 960 mil.
Relative cost	100 %	117 %

(1) Liebherr LR 1750 crawler crane

4.1.1 Discussion

A considerable difference in cost between Cubipods and Antifer Blocks at Boegoebaai is noted. For a design wave height of 9.9 m, Antifer Blocks have a relative cost of 117 percent when compared to Cubipods.

The British Standards (BS6349-7, 2010) recommends a maximum Antifer Block mass of 60 t to due concerns over structural stability. Considering that armour units placed at the head of the breakwater will be at least 1.5 times larger than those on the trunk, it is advisable to limit the armour unit size where possible.

Cubipods rather than Antifer Blocks are therefore recommended based on cost and structural stability.

5. CONCLUSIONS

It was determined that a rubble mound breakwater should be considered for further feasibility design. The wave climate in the region is not suitable for placement of caisson structures.

Two primary armour units were considered possible and were investigated further: Cubipods and Antifer Blocks. Dolosse were not considered due to concern over the structural stability of units weighing more than 30 t.

Cubipods were selected as the most efficient and cost effective primary armour for the breakwater.

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