DETACHED BREAKWATERS PROTECT LARGE MARINE INFRASTRUCTURE FROM SEVERE STORMS

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INTRODUCTION

The port of Richards Bay in south Africa is constantly being subjected to extreme storm events where recorded wave heights exceed 5 m. Over the last decade, these storms have caused significant damage to the port's breakwater structures, especially to the main southern breakwater. The frequency and intensity of large storms are increasing, and therefore much needed repairs to the aging infrastructure are becoming more frequent. This scenario is not unique to the port of Richards Bay since, together with climate change and sea level rise, aging marine infrastructure all over the world are becoming more vulnerable to severe storm events.

BACKGROUND

As part of a campaign to enhance the structural integrity of the breakwaters at Richards Bay, the CSIR was contracted to undertake a 3D physical model study, which was completed in 2019. Different repair options were tested, all of which proposed constructing a new, more robust armour layer over the existing armour layer. The new armour layer designs included bulky concrete armour units weighing in excess of 60 ton. Given the sheer size of these units, it was anticipated that the implementation of the proposed remedial works will be very complex and expensive.

Subsequent to the 2019 study, the CSIR initiated a study to investigate alternative solutions that could potentially be implemented to safeguard marine infrastructure similar to the main breakwater at Richards Bay. This study focused on a submerged detached breakwater constructed in front of the existing main breakwater to shelter it from extreme storm events.

GENERAL APPROACH

This study was undertaken entirely in a 3D physical model setup at a scale of 1:65. The test structure comprised the main breakwater of the port of Richards Bay and the areas for stability comparison were limited to the roundhead and adjacent trunk sections. Figure 1 shows the layout of the 3D model setup. The areas of interest for the main breakwater are indicated, as well as the location of the detached breakwater. This is the same model setup as that of the 2019 study, however the smaller northern breakwater was omitted for this study.

The detached breakwater was constructed as a rubble mound structure conforming to a basic breakwater design (CIRIA, 2007). A more robust armour layer design was selected comprising of 65 ton Antifer Cubes. A double pyramid packing arrangement, with a higher K_D value (Frens et al., 2008) was adopted, helping to ensure that the detached structure would remain in place during all test conditions.

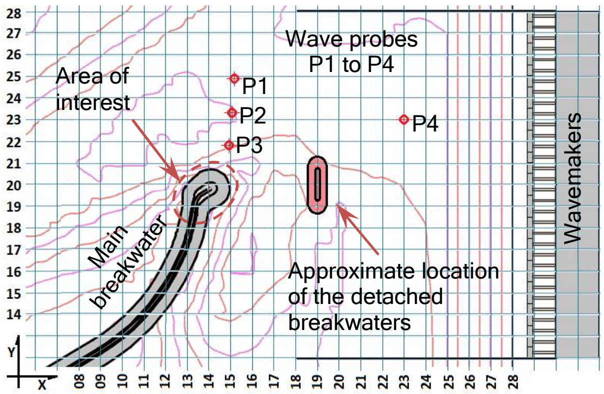

Figure 1 - Layout of the 3D model setup

Since the model setup was the same as that of the 2019 study, the same wave conditions were used to verify the effectiveness of the submerged detached breakwater. Table 1 lists the test conditions for this study. These conditions were repeated for each series.

Table 1 - Input parameters for wave conditions (prototype)

Wave Condition	Water Elevation	T_p	H_{m0}	Test Duration
1	2.8 m CD	18 s	7.34 m	6 Hrs
2	2.8 m CD	18 s	8.27 m	6 Hrs
3	2.8 m CD	18 s	9.11 m	6 Hrs
4	2.8 m CD	18 s	9.77 m	6 Hrs
5	2.8 m CD	18 s	10.2 m	6 Hrs

Changes to the detached breakwater included varying the structure length, crest elevation and its location. The detached breakwater for each series were constructed about 250 m (prototype) away from the main breakwater as shown in Figure 1.

RESULTS

This study included five test series, each comprising of the test conditions listed in Table 1. Results from this study showed that the detached breakwater has the potential to reduce damage to the main breakwater caused by severe storm events. This is achieved by creating a disturbance in the water column approaching the main breakwater and thereby reducing the wave energy reaching the structure. The magnitude of this disturbance is dependent on the design and location of the detached structure.

Figure 2 shows the main breakwater after Test 3 of the first test series. During this series, the detached structure was not present, therefore the main breakwater remained unprotected. The structural integrity of the roundhead failed during Test 3 and the test series was terminated. Figure 2 also indicates the areas where the underlayer material were completely exposed.

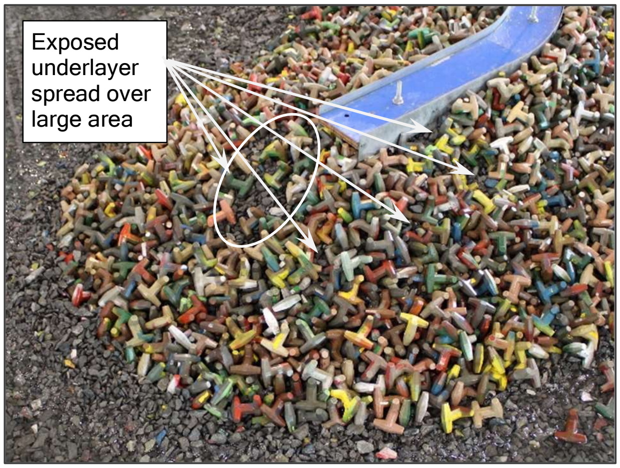

Figure 2: Test Structure after Test 3 of Series 1

In comparison, the condition of the main breakwater after Test 5 of the third test series is shown in Figure 3. One of the larger detached breakwaters were constructed for this this series, measuring nearly 100 m in length, and had a crest elevation of 0 m CD. The main breakwater remained mainly intact by the end of this series, with some minor exposure of the underlayer, which was confined to a single area.

Figure 3: Test Structure after Test 5 of Series 3

Apart from Series 1, all other test series were completed successfully. Table 2 shows the cumulative damage results for the most critical section of the main breakwater located on the roundhead. The results indicate that the effectiveness of the detached breakwater is dependent on its crest elevation (H_{Crest}), as well as its crest length (L_{Crest}). The same detached structure design was used for Series 3 and Series 5, however the location of the structure was offset by roughly 50 m measured along the longitudinal axis. With reference to the local grid included in Figure 1, the crest locations for the two structures were between points (19 ; 20) to (19 ; 21.5) for Series 3, and (19 ; 19.25) to (19 ; 20.75) for Series 5.

Table 2 - Cumulative damage results for the most critical section of the main breakwater

		Wave Condition				
	Description	1	2	3	4	5
1	No detached structure	19%	30%	Fail	Fail	Fail
2	H_{Crest} = 0.0 m CD L_{Crest} = 65 m	13%	20%	23%	28%	39%
3	H_{Crest} = 0.0 m CD L_{Crest} = 97.5 m	1%	1%	2%	6%	6%
4	H_{Crest} = -2.0 m CD L_{Crest} = 97.5 m	15%	25%	34%	Fail	Fail
5	H_{Crest} = 0.0 m CD L_{Crest} = 97.5 m	2%	2%	3%	6%	7%

The detached breakwaters remained intact throughout the duration of the different test series. Some minor damage to the structure crest were observed, however no damage was recorded to the roundheads or trunk. Optimisation of the armour layer is proposed with the aim to reduce the size of the armour units used during this study.

The use of detached submerged breakwaters at this magnitude can be a viable solution to protect similar infrastructure at other ports. In the case of Richards Bay, it will mitigate the need for complex and expensive modifications to the main breakwater since it can be constructed independently from any existing infrastructure. For the same reason, it is also well suited to safeguard historical and environmentally sensitive sites.

REFERENCES

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Frens, Van Gent and Olthof (2008): Placement methods for Antifer armour units, Proceedings of ICCE 2008, DOI:10.1142/9789814277426_0276