CHAPTER 365

RICHARDS BAY NORTH BREAKWATER - REPAIR OF A ROUNDHEAD: MONITORING, MODEL TESTING, DESIGN AND CONSTRUCTION

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ABSTRACT

The head section of the north breakwater, at the entrance to the Port of Richards Bay, has suffered some damage since its construction in 1973. This paper briefly discusses the changes in the design conditions, the first unsuccessful repair in 1986/87, using 15t dolosse, the annual photographic monitoring results showing the rates of damage to the roundhead since then, and the model testing of various repair options, using available spare 20t and 30t dolosse. Finally the construction of the optimal repair, carried out in 1996, using a heavy duty mobile crane (with 48m boom reach) and DGPS positioning, is described. Construction was still in progress at the time of publishing this paper.

INTRODUCTION

The Port of Richards Bay, on the east coast of South Africa, has two dolos breakwaters, a shorter straight breakwater on the northern side of the harbour entrance channel and a longer curved breakwater on the southern side. The north breakwater consists of a straight rubble mound structure, constructed in 1973, which stretches for approximately 600m perpendicular to the coastline. The original armouring on this breakwater consists mainly of 5t dolosse on both sides of the trunk, but includes 15t dolosse on the roundhead (Figure 1). Like many similar breakwaters, the neck of the roundhead was found to have experienced the worst damage to the armour layer.

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Annual photographic monitoring of the north breakwater showed an increase in damage in localised areas on the head, particularly on the southern side (Figures 1 and 2), despite temporary repairs using 15t dolosse, carried out by Portnet in 1986/87. A previous model study (CSIR, 1992a) indicated that the spare 20t and 30t dolosse, available from a stockpile of spare dolosse at the root of the south breakwater, would be suitable for the repairs. It was therefor decided to test various repair options using 20t and 30t dolosse.

In June 1994 the CSIR was commissioned by Portnet to carry out a physical model study to determine the most cost effective design for the repair work. These included repair solutions in which a toe of anchored 30t dolosse was constructed around the head and 20t dolosse were placed in the cusps and over the anchor chains. After an initial calibration run, a total of four different repair options were tested. Due to delays in the commissioning of a suitable crane, the construction of the final repair was delayed to the end of 1996. This paper does however include construction details of a temporary repair using 5t dolosse (placed using an available smaller crane) and the start of the final repair, using the 20t and 30t dolosse.

FIGURE 1: View of North Breakwater and Cross-Section through head.

MONITORING RESULTS

The crane/helicopter photographic survey method (Phelp *et al*, 1994) was used to annually monitor the breakwater. The photographic survey stations are spaced at 25m intervals, and both sides of the breakwater are monitored; the breakwater was however already 13 years old before annual photographic monitoring was commenced. The areas with the highest damage (over 25% breakage) continued to deteriorate the fastest. At stations P2 and P3 on the round-head, the damage was mostly localized in cusps, which are visible in Figure 1. A sharp increase in the rate of damage in the worst areas, since 1992 (72 months), can be seen in Figure 2. This damage has mainly been attributed to bottom scour resulting in increased wave heights reaching the breakwater, ie. increased depth limited wave heights. Station P1 also lies at the transition between the 5t and 15t dolosse, which is at an inherent weak point in the armouring.

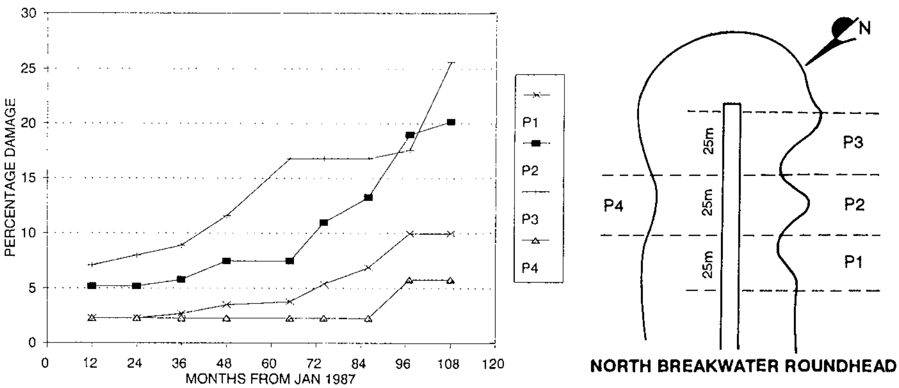

FIGURE 2: Rates of Damage to the Dolos Armouring Since 1987.

FACTORS CONTRIBUTING TO THE HIGH DAMAGE

The occurrence of low pressure cyclonic storms (cyclones Demoina and Emboa in 1984) subjected the breakwater to wave heights exceeding the 7,9m 1:50 year design H_{mo}. Storm wave and low atmospheric pressure set-up associated with these storms also had the effect of raising the water level, thereby raising the depth limited wave heights reaching the breakwater. A previous model study on wave penetration in the entrance channel (CSIR 1974) also showed, based on wave refraction that wave conditions between SE and S (deep sea) result in the worst conditions opposite the north breakwater head.

Bathometric surveys carried out regularly by Portnet revealed a general erosion of sand, of up to 2m, around the head and seawards of the breakwater, especially between 1989 and 1994. This would have resulted in further increasing the depth limited heights of the waves reaching the breakwater. Besides the scour at the toe (seismic surveys carried out by CSIR in August 1993 confirmed the toe erosion) the breakwater was also subjected to severe storms in October 1990 (max H_{mo} of 6.1m) and moderate storms since then, resulting in accelerated damage to the dolos armouring behind the weakened toe.

Like many similar breakwaters, both sides of the neck of the roundhead were found to have experienced the worst damage to the armour layer. Jensen (Jensen, 1984) found that for tetrapods, relative to the stability coefficients for the breakwater trunk, the roundhead area at 135° from the wave direction showed the lowest stability. This indicates that some of the damage found on the southern side of the north breakwater could also have been caused by more northerly waves. Model tests also showed evidence of eddies on the lee-side of the roundhead where toe dolosse were pulled off the slope.

Repairs which were carried out in 1986/87 using 200 additional 15t dolosse have proved unsuccessful, mainly due to the toe damage and sea-bed erosion mentioned above. No model tests were done for these initial repairs. The area where the 15t dolosse on the roundhead meet the 5t dolos trunk (Figure 1) has also been a focus of damage, likely as a result of poor interlocking between the different sized units.

RESULTS OF MODEL TESTS

Constraints to the Repair Design

Model tests were carried out in an existing 3D model of Richards Bay (CSIR, 1995), to save both time and costs. This available model was built at a scale of 1:110 and covered the harbour entrance and part of the inner channel. The model test options were restricted to using available 200 20t and 100 30t dolosse, which have been brought across the harbour from a stockpile near the southern breakwater. The proposed repair consists of a double row of 30t dolosse at the toe, with a double layer of 20t dolosse behind. 5t dolosse were also available to wedge into the gaps behind the 20t repair and between the existing 5t slope where the repair overlapped the breakwater trunk section.

The removal of rubble and pre-repair slope preparation was limited to the removal of only large broken dolos pieces (assisted by divers), and the filling of holes at the toe of the armour slope. The crane reach was limited to 45m for a 30t dolos, which was achieved by using a specially designed crane which could fit onto the 6m wide mass-concrete capping of the north breakwater.

Choice of Model Scale

The scale of 1:110 used for the tests gives a Reynolds number of approximately 1×10^4, which is just within the minimum range recommended by Van der Meer (Van der Meer, 1988) but less than the value recommended by CERC. Some scale effects should therefore be expected, especially on the 5t dolosse, but these scale effects have been found (Oumeraci, 1984) to make the model results conservative. The scale effects, being similar for all the test runs, still allowed the comparisons made between the options tested. The results were however interpreted as giving an indication rather than an exact prediction of the possible damage. The calibration test showed that the hindcast of the damage which occurred in the 1990 storm is in qualitative agreement with the observed prototype damage confirming the validity of the physical model. A plan of the model is shown in Figure 3 and the "as-built" cross-section through the head in Figure 1.

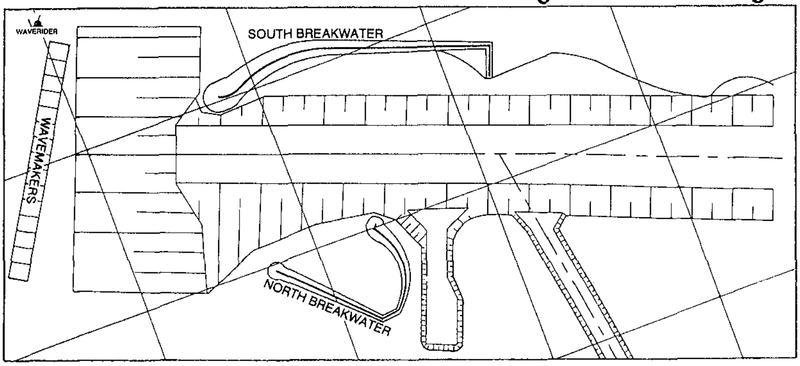

FIGURE 3: Plan showing Model Layout

Wave Generation and Measurement

Eight standard wire resistance wave probes were used which were coupled so that measurements could be carried out over prescribed areas. The wave generator bank was 9,75 m long situated at the 1 km mark (Figure 3). The direction of the generators was 30° N, ie: waves coming perpendicularly out of the wave boxes have a direction of 120°. Based on a review of existing data, the following main test conditions:

- Wave direction, entrance area (12s) 145°
- Storm input, **Richards Bay Spectrum**, γ = 2,74 with the following approximate steps H_{mo} = **4, 5, 6, 8 m** with following wave per respectively: T_p = **10, 12, 13, 15,5** s
- Water level for main test MHWS = **2,0 m CD**

DESCRIPTION OF THE TESTS

Test procedure

In order to calibrate the physical model, a calibration test was carried out in which the prototype damage resulting form the 1990 storm was reproduced in the model. A number of repair options were then investigated, starting with the simplest option and then extending the repair until a stable solution was found. Before each repair option was constructed, the original damage (after the 1990 storm) was replicated in the model. The repaired breakwater was than exposed to the five different wave conditions described above. After each test, the repair dolosse were removed and the 1990 damage reconstructed, after which the next repair option was implemented.

Measurement of Damage

Movements of Dolosse

The number of dolos movements was determined by comparing the photographs taken before and after each run. A number of swing tests were carried out on full-scale 9t dolosse to determine the degree of movement these dolosse could sustain without breakage (Zwamborn and Phelp, 1989). Based on the results of these tests it was recommended that all movements greater than half the height of a dolos be included as damage. The number of dolosse which moved was determined separately for a number zones located at the head of the breakwater. The damage was then expressed as a percentage of the number of dolosse placed in each zone.

Rocking Dolosse

In addition to determining the movements, the number of dolosse which were rocking was estimated visually during each test. However due to the difficulty in observing these movements over the whole test area, it was decided to use the small movements (less than h/2), which were measured from the photographs, as an estimation of rocking dolosse. In (CSIR, 1992b) this alternative approach was also adopted, where it was found that dividing the movements less than h/2 by nine, would give a reliable estimation of the number of rocking dolosse.

DETAILS OF THE REPAIR OPTIONS TESTED

Discussion on the Repair Strategy Followed

The strategy of placing 20t or 30t dolosse on top of the damaged 5t and 15t dolosse was originally tested and found to be feasible in previous model tests (CSIR, 1992a and 1992b). Static tests on dolosse have shown that a dolos can carry 4 to 6 times its own weight without breaking; this implies that a number of layers can be constructed without breakage under static load. Thus it was considered feasible to place a 1 to 2 layer thick 20t dolos strengthening layer, safely on top of the existing damaged 15t dolosse. Although the quality of the underlying 15t dolosse is questionable, the dynamic loading over the past 8 years has caused the weaker dolosse to break, and careful placing of new dolosse should not result in significant further breakages. However, since most parts of the repair sections will consist of already broken units, the repair itself was designed as well interlocked armour, finished to a uniform slope, which should be able to stand on its own.

Although stresses cannot be modelled, extensive prototype observations and structural tests on full size dolosse support the above conclusions. For example the main breakwater at Gansbaai, on the South African southern coast, consists of an original layer of 4.5t dolosse covered by one layer of 12.4t units, covered by one layer of 17.1t dolosse overlapped with a double layer of 25t dolosse. This repair has thus far proved to be successful.

Repair Option 1

The first repair option tested involved the filling of the cusps with the minimum number of dolosse, ie. starting with the simplest option and then extending the repair until a stable solution was found. This was a temporary (intermediate) repair solution to protect the breakwater core from further damage, but would also eventually form part of a more permanent repair. The number of repair dolosse per hole was approximately 10 30t and 20 to 30 20t dolosse. The total number of dolosse needed to repair all the cusps (northern and southern sides) was approximately 40 30t and 150 20t. The 30t dolosse were used to construct a toe at the bottom in front of the cusps to anchor the 20t dolosse filling up the cusps behind.

Repair Option 2

After repair option 1 had shown extensive damage to the edges of the repaired areas, it was decided to extend the repaired area to provide a more uniform profile. The second repair option was similar to the first repair option but with a more continuous row of 30t dolosse at the toe around the whole breakwater head. The construction of a toe with a double layer of 30t dolosse was an attempt to increase the stability of the repaired slope. The 20t repair layer was then placed on top of the 15t dolosse. The shape of the head was modified slightly to have a slightly flatter slope. Approximately 80 30t and 200 20t dolosse were used.

Repair Option 3

In this repair option the cusps were also filled with 20t dolosse, but the 30t dolosse on the southern-side of the breakwater were fixed using anchor chains (scrap, ship's anchor chains). First, a double row of 30t dolosse were placed to construct the toe, after which the 20t dolosse were used to repair the cusps and to cover the chains. This method proved to be very successful in the construction of the Port of Cape Town breakwater where similar conditions exist at the toe (CSIR, 1985 and Zwamborn *et al*, 1990). As was done in Cape Town, the end of the chains should be connected to a piece of scrap rail to provide improved anchorage. Approximately the same number of dolosse were used as for the temporary repair option (option 1). The chains used to fix the 30t dolosse can be clearly seen. Figure 4 shows the anchor chains in the model and as used in prototype.

FIGURE 4: Anchor Chains used to Secure 30t Toe Dolosse

Repair Option 4

In this repair option, a double row of anchored 30t dolosse was used to construct the toe around a slightly wider head. The 20t dolosse were then placed in the cusps and over the chains. Also, before the 20 t dolosse were placed on top of the 15t dolosse, the damaged slope beneath the repair was reprofiled to allow for a double layer of 20t dolosse, to provide a more uniform repair slope. In this last repair option all the 30t dolosse were fixed by anchor chains.

INTERPRETATION OF RESULTS

Comparison of Damage to the Repair Options Tested

A comparison of the damage at the end of each run is shown graphically in Figure 5. The x-axis presents the section of the breakwater which starts at the northern-side of the breakwater, around the head to the southern side of the breakwater. These location numbers are given in Figure 5. Repair Option 4 is clearly the best option.

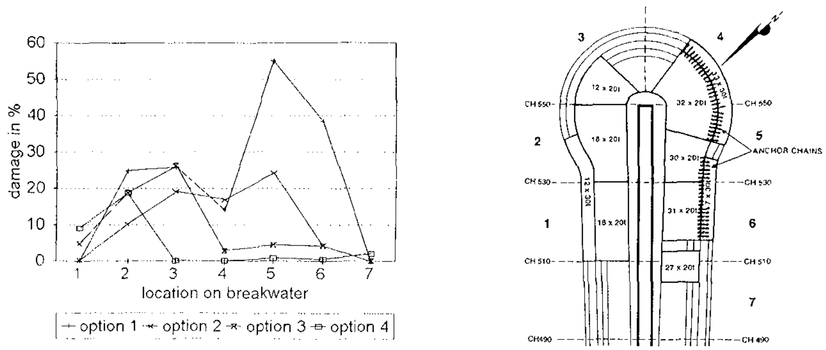

FIGURE 5: Comparison of Damage to the Repair Options Tested

For all the repair options, the existing 15t dolosse were well protected by the additional dolosse. For repair options 1 and 2 it was clear that again, similar to the prototype, the highest damage could be observed just behind the head at the southern side of the breakwater. The eddies caused by the waves passing around the head were responsible for rolling the toe dolosse along the surface of the rubble. Once a dolos had been extracted from the slope it was easily rolled along by big waves.

The 30t dolosse, which were fixed by anchor chains, reduced the damage in that specific area considerably. Repair Option 4 showed acceptable damage levels for all the repair dolosse, apart from the area on the northern side of the head where the 20t dolosse showed higher damage - poor interlocking of this section may have been the cause. The damaged 15 t dolosse on this side were not reprofiled as was done on the southern side, which meant that the 20t repair dolosse were not interlocked properly in a double layer. Although the original prototype damage (CSIR, 1994) on the northern side of the head is less than one third of that on the southern side, it is felt that the repairs would have been more effective if the whole northern side had also been properly prepared (reprofiled) before the repair.

Based on the results of the model study and from previous experience, the following recommendations for the repair works were made:

a) Before any repairs, as many as possible of the broken pieces of dolosse should be removed without disturbing adjacent dolosse.
b) Crane and ball surveys should be used to identify all underwater depressions, both before and during construction of the repair.
c) Particular care should be taken when placing the dolosse to ensure that dolosse interlock as well as possible with the

underlying dolosse. Re-slinging of a newly placed dolos is worth the effort if a better interlocking is obtained.

d) For the placing of dolosse, both above and below water, a predetermined grid pattern should be developed with angles and distances for the crane, or x,y references for DGPS positioning.

e) The 30t toe dolosse should be anchored by chains.

CONSTRUCTION OF THE OPTIMUM REPAIR

Construction Methods

Based on the results of the model tests, 20t and chained 30t dolosse were to be used for the repair. The 20t and 30t dolosse were brought across from the south side of the entrance channel to a stockpile at the root of the north breakwater, while the 5t dolosse were also already available from a part of the root of the original breakwater which was now covered with sand. Three double direction trailers were then used to transport the dolosse onto the breakwater. These trailers could only pass when unloaded, which meant that only one 20t or 30t dolos could be brought onto the breakwater at any one time (Figure 6).

Initial crane and ball surveys were done with 5m profile intervals over the damaged areas. A certain amount of reprofiling was then carried out to remove irregularities in the overall profile. Broken pieces of dolosse were removed and placed in erosion holes. Another crane and ball survey was then carried out to get the underlayer profile, from which the repair dolos placing grid could be calculated. The smoother the underlayer profile, the easier it was to set a placing grid with uniform packing density.

The repair dolosse were then placed, starting with the double row of chained 30t dolosse at the toe. The chains, which were lifted on a separate hook were laid at an angle of 45° seawards along the toe of the slope, later to be covered with 20t dolosse. The crane hook was fitted with a 15m sling (to ensure the hook and pulley remained out of the seawater), a quick release hook (Figure 6) and a double cable sling. The double slings which support the dolosse were hand spliced (instead of swage joined) to allow easy removal of the slings once the dolos was in position. The quick release hook was hung from a swivel and fitted with two torque bars, which allowed easy rotation of the dolosse to ensure good interlocking. The torque bars were attached to 10mm nylon (light and water resistant) ropes, which were pulled perpendicularly from the mass capping to orientate the dolosse.

It was found that to ensure correct packing density, the dolos placing must be kept as close as possible to the grid coordinates. The final orientation and positioning of the dolos is then done by eye to ensure good interlocking. Dolosse are placed with a minimum of three contact points to reduce the change of rocking under wave action. After all the grid positions were full, it was found that up to 10% additional dolosse had to be placed "in holes" to ensure a well interlocked uniform profile. To identify these "holes" it is advisable to get an aerial view of the slope form a helicopter, or from a basket hung from the crane.

DGPS for Crane Positioning

For both the crane and ball surveys of the slope profiles, and the correct placing of the dolosse, there was a need to accurately position the hook of the crane. The original method used was triangulation from two theodolites, but this proved labourious and time consuming. Another method was to fit the crane with a pendulum boom angle indicator and a horizontal slew protractor whereby the horizontal and vertical angles of the boom could be measured and converted from polar to x,y grid coordinates.

Recently a differential GPS system has been introduced using satellite positioning linked to a portable computer onboard the crane (Figure 7). The satellite receiver is positioned on top of the crane boom, directly above the position of the hook. The pre-determined positions are entered into AutoCAD software on the computer, and standard survey software enters the real time navigation parameters which indicate the position of the boom. By entering the standing position of the crane along the breakwater, the boom reach and safety circle can also be indicated on the screen. The crane operator can then immediately see which dolosse can be placed from the present position of the crane. The AutoCAD dolos placing grid is shown in Figure 8.

The positioning software includes the following useful features:

- Zoom in and out, and centring the cranes position on the screen.
- The entry of up to 20 predetermined crane standing positions on the breakwater, including facility to orientate and offset.
- The entry of up to 500 top and 500 bottom layer dolosse, including an indication of size and numbering (colour options)
- The facility to import and editing of an AutoCAD or other CAD drawing of the breakwater eg: the "as-built" layout.
- Indication and editing of the safe radius of the cranes reach.
- The input and storage of the placed positions of the dolosse.
- A backup system where the polar coordinates can be entered to position the crane, should the DGPS signal fail.

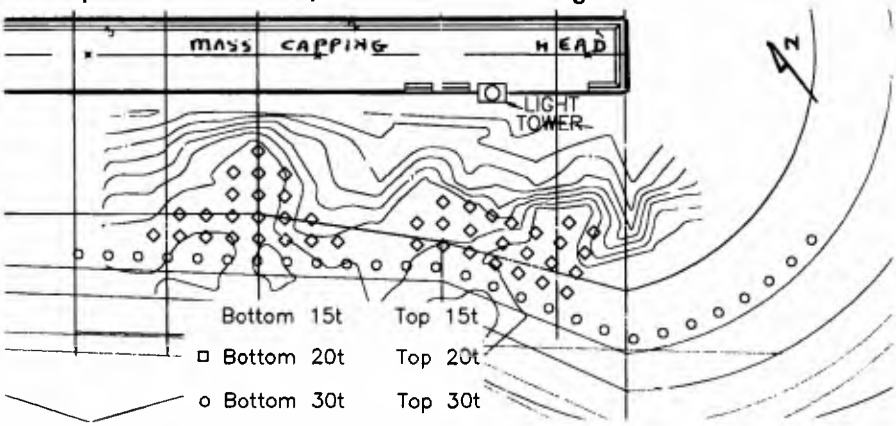

FIGURE 8: Example of DGPS AutoCAD Dolos Placing Grid

Emergency Temporary Repair and Final Repair

Planning for the repair was well underway by mid 1996, when a breakdown of the special crane (the only crane which could fit onto the breakwater and have sufficient reach for placing the 30t dolos toe) resulted in having to delay the final repair to the end of 1996. As the localised damage on the southern side of the roundhead was starting to expose the underlayer rock, it was decided to carry out emergency temporary repairs. These took the form of filling the cusps with 5t dolosse (which could be placed with a smaller mobile crane). This repair was not extended further than the original slope profile so that it would form part of the underlayer of the final repair. The same construction method was used as described above. Figure 9 shows this section before and after the emergency repair. Figure 10 shows the chained 30t dolosse at the start of the final repair in December 1996.

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