RESULTS OF FIELD MONITORING OF THE NEW CORE-LOC BREAKWATER at PORT ST FRANCES - SOUTH AFRICA

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Abstract

The newly completed fishing and recreational harbour at Port St Francis, on the south-east coast of South Africa, has a 220m outer rubble mound breakwater and an inner revetment, both protected by Core-loc® armour units. This paper briefly discusses the breakwater layout and armouring design, the effect of severe storm conditions during construction, and the performance of the Core-loc armouring, as based on the results of photographic monitoring, crane-and-ball profile surveys, visual observations and diver surveys below water.

Introduction

The first prototype application of a Core-loc armoured breakwater was constructed for the small craft harbour of Port St Francis, South Africa in 1996/97. Port St Francis is a small coastal town situated on the south-east coast of South Africa, on the northern side of the Cape St Francis peninsula, adjacent to the Krom River estuary (Figure 1). In the past the squid fishing industry has used the estuary for anchorage and access to the sea. Using the unprotected river mouth for access to and from the sea is dangerous and conditions are often unsafe resulting in accidents and loss of life and fishing vessels. The dangerous conditions, together with the growth squid fishing

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industry and urban recreational developments highlighted the need to establish a small craft harbour on the east coast to support the squid fishing industry as well as recreational sport fishing and yachting. It was decided to construct a small craft harbour at the Port St Francis condominium resort to serve these needs. Construction of the harbour breakwater, marina and luxury resort facilities started in February 1996 and was completed in November 1997. The port is the first privately developed small craft harbour in South Africa.

The Core-loc armour unit was developed by the Waterways Experimental Station, Coastal Engineering Research Center (CERC) in the United States of America (Melby and Turk, 1994,1995). CERC participated in the design, testing and monitoring of the breakwater together with the South African consulting engineers AR Wijnberg Inc. Design and testing included full 3D model tests at a scale of 1:60 undertaken at the laboratories of the CSIR in Stellenbosch, South Africa. Initial baseline and subsequent breakwater surveys have been undertaken by the CSIR to monitor the performance of concrete Core-loc armour units. The use of the South African developed dolos units was also investigated, with the Core-loc units proving to be a more economic solution.

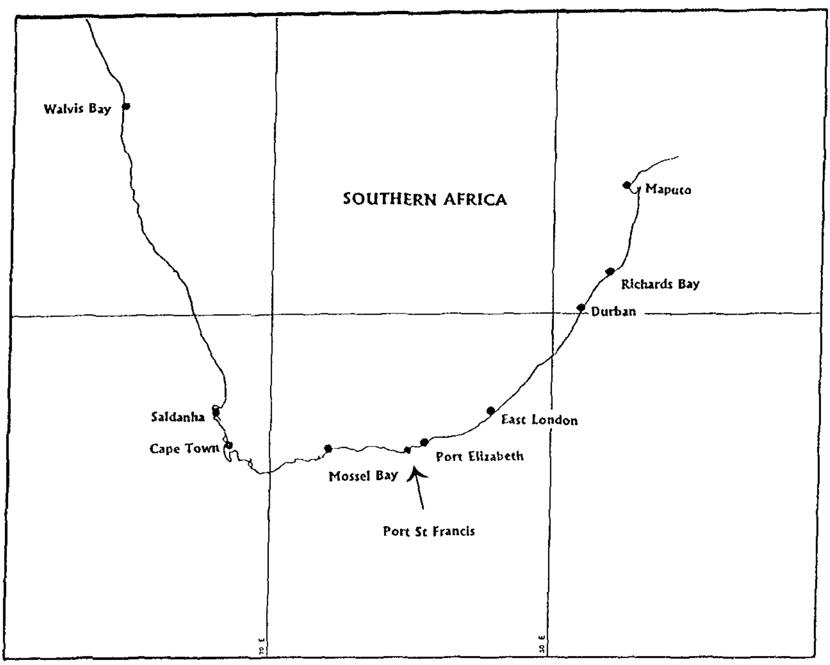

Figure 1: Location of Port St Francis

Location and Design Details of Main Breakwater and Peninsula Protection

The harbour is located on the east coast of South Africa, south of Port Elizabeth. The shoreline in the vicinity of the harbour consist of a rocky beach with a sandy beach and Krom River mouth to the south and Cape St Francis peninsula to the north (see Figure 2).

Figure 2: Rocky beach to the north of Port St Francis and

The total protective structures include a main outer breakwater and an inner peninsula revetment, both protected by 15 ton Core-locs. The breakwater consists of a rubble mound at a slope of 1:1,5 with 1,5 ton median under-layer rock and a concrete mass capping. A total number of 800 Core-loc units were used plus 20 spare units cast (approximately 560 for the breakwater and 260 for the revetment). The finish level of the mass capping is +4,4 m MSL and splash wall at +6,5 m MSL. The inner slope of the main breakwater is rock protected towards the head (Figures 3 and 4) and abuts directly onto the main harbour quay wall.

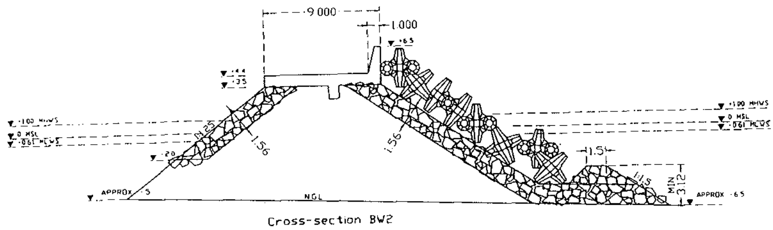

Figure 3: Cross section of the breakwater

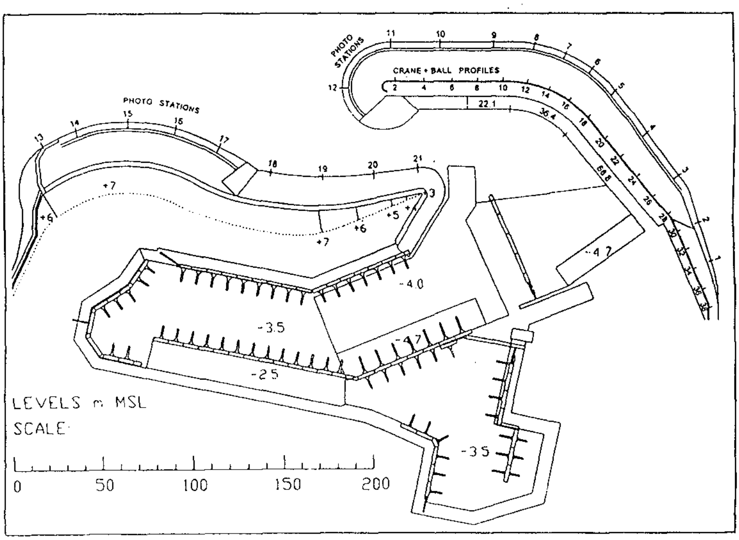

Figure 4: Layout of small craft harbour of Port St Francis -showing the positions of the photo stations and crane and ball profile positions

Sea Conditions

Although the bathymetry off the harbour causes depth limited wave conditions, four near design storms were experienced during construction (i.e. when the breakwater was uncapped and at +3,5m MSL working level). This resulted in overtopping and breaching of the uncompleted breakwater. As a result several Core-loc units required replacement and re-packing. One design storm has also been experienced after completion of the construction of the breakwater and the first baseline survey in October 1997. This caused little further damage to the well compacted (shaken down) slope.

The initial Core-loc design was base on Mclby and Turk (1995). Maximum design depths of 8 m can be expected for the main breakwater, which means that the design is depth limited. With a foreshore slope of 1:50 and peak wave periods of up to 16 s, the maximum wave height at the structure is estimated to be approximately 7,2 m. using Hudson K_d factor of 16, a unit mass of 15 t was selected as a preliminary design. Further details of the design and construction of the breakwater see the ICCE '98 paper "The First Core-loc Breakwater" by Holtzhausen.

Construction Problems

To ensure sound breakwater concrete armour protection, it is imperative that good interlocking is achieved, especially when placing a single layer armouring system such as with Core-loc. This is done by accurately placing the individual units on a prescribed grid. This grid must be correct, right from the toe units which then form the foundation for the upper rows to lock onto. On the main breakwater it was apparent from diving surveys that some Core-loc were incorrectly placed seawards of the design toe.

Unfortunately at Port St Francis, the extreme storms experienced during early stages of construction also contributed to the displacement of many Core-loc units out of their allocated positions. This gave rise to poor interlocking in some areas and resulted in a non-uniform slope, especially on the bend of the breakwater. Additional Core-loc units were needed to fill gaps in the armouring, sometimes resulting in a semi-double layer. Up to 20 loose or damaged units were also removed from the toe and re-used on the breakwater.

These problems experienced during the construction phase of the breakwater, contributed to the majority of damage (displaced and broken Core-loc units) found on the breakwater. During this phase the low crest (+3,5 m MSL) working level was unprotected against wave overtopping, resulting in the displacement of a number of units during the near design storms that were experienced before construction of the mass-capping. During one of the storms, overtopping caused a breach of the core material and the displacement of Core-loc units into the harbour. Most of these units were recovered and re-packed on the front slope. Some grading problems with the under-layer rock also caused an irregular profile. Figure 5 shows the breakwater, revetment and marina still under construction.

Figure 5: Breakwater, revetment and marina under construction

Initial placement problems were largely overcome during the construction of the revetment as this was constructed after the breakwater. This lead to a better constructed armour protection in this area, with good interlocking and a uniform slope (Figure 9). The revetment was also partially protected by the main breakwater and the working level during construction was higher, so that there were no serious overtopping problems.

Breakwater Monitoring Methods

The baseline survey of the breakwater and revetment included an aerial photographic survey, a "crane and ball" survey (Phelp, 1994), a visual inspection and a diving inspection. These were used to provide as-built data (against which future monitoring could be compared) and document the breakage type, providing a count and location of damaged Core-loc armour units. The baseline surveys were carried out in October 1997 to capture the damage which occurred during construction, while follow-up surveys were done in May 1998.

Visual Inspection

A visual inspection was carried out to record the location and type of Core-loc breakage. This was done by climbing over the Core-loc slope during low spring tide and relating the positions to the ball survey lines. The recorded damage was later correlated with that seen in the aerial photographs taken by the CSIR.

Photographic Survey

A "Robinson 44" 4-seater helicopter, was used for the photographic survey. It allowed the camera to be elevated to a position perpendicular to the slope of the Core-loc armouring. Pre-determined coordinates were chosen to give good coverage, with photo stations spaced at 26m centres on the straight sections of breakwater and 13m over the curved sections. Figure 4 shows the layout of the survey stations on both the outer breakwater and inner revetment.

Navigation of the helicopter was carried out with the aid of a "Landstar" Differential Global Positioning System (DGPS) which was fitted to the helicopter (Figure 6). DGPS is a satellite-based positioning system which achieves high accuracies by utilizing real time radio transmitted corrections from a reference station, placed at a known location. This then provides dynamic positioning of the survey camera, to an accuracy of plus/minus 0,5 m. The altitude of the helicopter was kept at 65 m above the breakwater slope.

Figure 6: DGPS system fitted to helicopter for position fixing.

The photographs were taken with a Nikon FM 35 mm camera with a 50 mm lens and using 200 ISO colour film. The photo stations were marked on the breakwater and the revetment and numbered 1 to 12 and 13 to 21 respectively (Figure 4) and were positioned at the centre of each photograph. This allowed for each station to include approximately 50 Core-loc units per photograph. By careful observation of the approaching waves, the photographs were taken at maximum wave draw-down to ensure the maximum area of Core-locs (approximately 90%) exposed, including those toe units located below the still-water line.

Crane and Ball Survey

A mobile crane with an 18 m reach was used for the "crane and ball survey". The radius of the ball used for the survey was 1 metre. The survey was carried out by positioning that crane at each station (Figure 7) with the boom perpendicular to the breakwater. The profile of the Core-loc armour units was then measured by suspending the ball from the boom by a calibrated staff. Starting from the splash wall the levels were measured at 3 m intervals, horizontally along the boom.

A DGPS satellite system was mounted on the top of the boom to fix the positions at which the levels were taken. The level of the ball were recorded by dumpy level from the capping and related back to the top of the splash wall at a level of +6,5 m. At each position the ball was lowered until it touched the Core-locs. The levels were then plotted with Figure 8 showing the plot for stations 1 to 5.

The ball survey gave a profile generally 1 metre higher than the design profile. The latter was closer to the levelling survey taken by holding a staff on the centroid of each Core-loc, as carried out by A.R. Wijnberg Inc. (Figure 8).

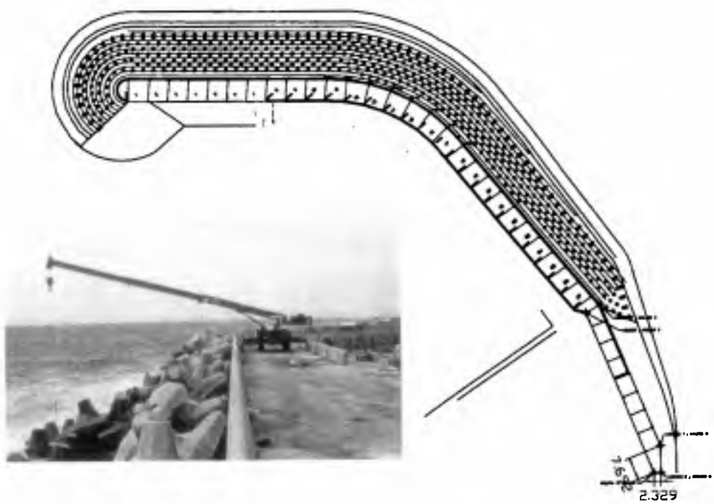

Figure 7: Crane and ball survey stations

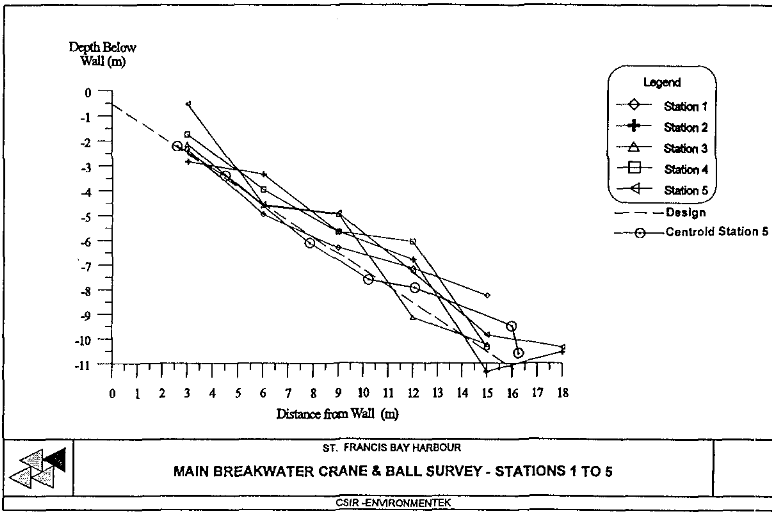

Figure 8: Main Breakwater crane and ball survey - stations 1 to 5

Diving Inspection

A diving inspection was undertaken by a diver in the water and one assistant on the breakwater to record the position and state of the underwater part of the breakwater. The diver swam along the toe of the main breakwater from the inner roundhead, along the outer slope to the root. The inner revetment was not included in the diving survey, as the toe was mostly exposed during low spring tide, and could be monitored by the aerial photographic survey.

Poor visibility reduced the effectiveness of the main breakwater diving survey to counting broken units and recording those units which had moved away from the breakwater toe. The latter were no longer interlocked with the rest of the armour slope, and therefor not contributing to the stability of the structure. Some of these units, displaced by the storm, were recovered and re-used higher up the slope. The diving inspection also confirmed the buildup of sand along the toe which had completely covered the rock berm and the first row of Core-loc. This buildup occurred within the fist year after completion of the breakwater.

The diving inspection also revealed the importance of the manner in which the first row of Core-locs are placed behind the toe berm. Where good toe placement was achieved, such as on the revetment, it provided a stable foundation on which to build the rest of the slope. Areas where the toe units were loose, the armour slope had become flattened (e.g. storm damage around the bend in the main breakwater) resulted in looser packing and poorer interlocking of the Core-loc above. The slope of the revetment was more uniform with each row of Core-loc anchored by the row above, resulting in a strong well interlocked slope (Figure 9).

Figure 9: Revetment and main breakwater

Analysis of Damage

In October 1997 the first detailed "as-built" survey was undertaken of the first Core-Loc armoured breakwater. A visual inspection of the breakwater was conducted by CERC while the CSIR carried out an aerial photographic survey to record the location and type of breakages. As discussed above, most of the damage recorded can be attributed to difficulties arising from several design storms experienced during construction of the breakwater, and to the placement of Core-loc units too far in front of the design toe. The type and position of the breakages were categorised as H-tip breaks, double H-tip breaks, nose-tip breaks, middle breaks and multiple breaks (Figure 11).

It was noted from the analysis of the photographs that almost double the damage was recorded than that recorded from the visual survey alone. This is possibly because it was difficult to reach the lower units due to wave action, whereas the helicopter could hover while waiting for wave draw-down, before taking the photograph. The broken Core-loc units were indicated by highlighting them on the photographic records.

Although there was unusual storm damage during construction, the normal "shake down" or "settling in" damage (for dolos breakwaters this was found to be more than double the average annual damage - Phelp, 1994) took place before the baseline survey. Additional Core-loc units were also placed on the upper slope of the breakwater, after completion of the mass capping, to complete the armour slope up to the top of the splash wall. Without a complete re-pack of the entire slope, it proved difficult to fit additional units in the open spaces. Minor further damage to the breakwater occurred after shake down, as shown by the follow-up survey in May 1998. The repairs to the bend in the breakwater have resulted in an "S" shaped cross-section similar to a dynamically stable rock berm.

The revetment was built to a final height of +7 m MSL, whereas the main breakwater was built to an interim height of +3,5 m before the mass-capping was cast. The revetment was also built after the main breakwater, which meant that, besides being partially in the lee of the main breakwater, the construction crew had more experience with handling the single layer Core-loc units. The underlying rock layer also appeared to be more uniform which allowed for easier placing of the Core-loc units, correctly positioned right from the toe of the slope. The free Core-loc units at the northern end of the revetment were secured by a concrete buttress / caissons anchored to the sea-bed, which proved very successful. In general, the revetment has shown minimum shake down damage.

Figure 10: View of completed small craft harbour

Of the total 800 Core-loc used for the breakwater and the revetment, a total of 35 units were damaged during the construction of the harbour, ie. before the baseline survey. The majority of the damaged units being on the main breakwater (30 on the breakwater and 5 on the revetment). The reasons for the high construction damage have been discussed above.

A follow-up aerial photographic survey done in May 1998, showed very little further damagc to the breakwater (**and no further damage to the revetment**), despite the occurrence of another near-design storm after the baseline survey. Only 3 Core-loc units were recorded as new damage resulting from extreme storm conditions between October 1997 and May 1998. Two of the previously damaged units, which were already weakened, were found to have broken further. This low damage figure represents the true performance of the new Core-loc breakwater, excluding the problems experienced during construction.

It was however felt that it would be useful to classify the different types of breaks which took place during construction (see Figure 11). These were identified for each damaged Core-loc unit and totals were calculated accordingly. The percentages of the various breakage categories is indicated in the table below:

Breakage Type (during construction)	**% Breakage**
H-tip breaks (one tip only) = 5% wt. Loss	61%
Double H-tip breaks = 10% wt. Loss	5%
Nose-tip breaks = 5% wt. Loss	13%
Middle breaks (unit broken in half)	13%
Multiple breaks (more than 2 pieces)	8%

Of the breakage that did occur, 13% were located towards the top of the breakwater slope, 47% in the middle and 40% at the bottom. Some of these broken units were however re-used during remedial work and are no longer located at the position where they were originally damaged. Large Core-loc movements (> 3H, where H is the height of a Core-loc unit) wcre recorded without breakage, especially at the section that was breached during the construction phase. Breakages that were noted at the breached section may have resulted from the tumbling that occurred as a result of the erosion of the lee side of the breakwater. Several Core-locs displayed signs of impact (spalling) without breakage.

It is important to note that the units that experienced the H-tip and double H-tip breakages still retain 90% of their original weight allowing them to adequately provide the necessary protection. Furthermore, the majority of these units still appear to be well interlocked with the surrounding units. Other types of breakages recorded may also have occurred as a result of poor quality control during the making and placing of the units in the construction phase.

Figure 8 gives an example of the results of the "crane and ball" survey. Included on the figure is a plot of the design slope. The "S" shape damage apparent in the cross-sections nearest the bend in the breakwater was most likely caused by breaching during storm conditions and by poor placement.

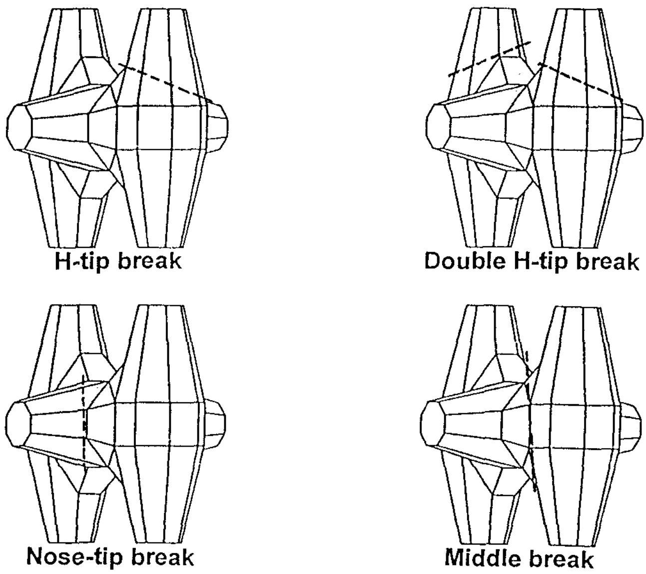

Figure 11: Types of breakages of Core-loc unit

Some loose Core-locs were found in front of the rock toe of the breakwater during the diving inspection. These units were mostly placed too far seawards of the designed position of the toe, but were also subject to displacement due to poor interlocking. The interlocking also appears to be less effective where the slope of the toe is flatter. Most loose Core-locs were recovered and re-used on the breakwater - where a toe unit could be removed without affecting the stability of the slope, it was re-used elsewhere on the slope. This accounted for up to 15 of the damaged units. Since the baseline survey it was also evident that sand has built up along the main breakwater toe, thus making it more stable and resulting in reduced wave heights

The toe of the revetment showed no displacement damage compared to the breakwater. This was due to better placing allowing for the effective interlocking achieved for most of these units.

Conclusions

- The Core-loc breakwater armour unit, as used for the first time at Port St Francis, has proved successful, despite some difficulties during construction.
- Excluding the damage recorded during the breakwater construction, the damage recorded by a follow-up survey was 3 broken units, which is less than 0,5% of the total of 800 units, despite the occurrence of further design storm sea conditions.
- Minimal as-built damage was found on the revetment, and no additional damage was recorded by the follow-up survey. This was no doubt due to the good packing and interlocking achieved on this part of the protection structure.
- CERC research showing improved structural stability (over other slender units) has proved itself in the field, with less breakage under extreme conditions. This allows recovery and re-use of displaced units (> 3H displacement recorded without breakage).
- Despite the high damage during construction, almost 80% of the total number of breaks consisted of either single "H-tip" fluke breaks, "nose-tip" breaks or double "H-tip" breaks, which still leaves 90% of the original unit weight allowing the units to remain well interlocked and functional. This will reduce the maintenance required during the lifetime of the structure.
- Good interlocking (as achieved on the revetment) is especially important for single layer armour units such as Core-loc. A well placed toe and a uniform slope are essential to achieve this, as is accurate placement of the armour units on a pre-determined grid.
- The stability of the toe units is especially important for a "shallow water" breakwater, such as is the case at Port St Francis, where the waves break directly onto the toe of the structure.

References

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