



BREAKWATER REHABILITATION PROJECT AT THE PORT OF POTI, GEORGIA

ABSTRACT

The breakwater at the Port of Poti, Georgia, located on the Black Sea, was started in the 19th century and has been repaired often in the course of almost two centuries. The breakwater is meant to provide protection for the port. Still, as a result of significant settlement of the structure over time, the crest level has been reduced considerably, overtopping of waves frequently occurs and this has a negative impact

on the port. A rehabilitation programme using Xbloc® and Xbase® armour units and rock from local quarries resulted in an economical solution, which both reduced down-time at the port and reduced the need for maintenance.

Above: At the Port of Poti, Georgia, located on the eastern coast of the Black Sea, the old breakwater was in disrepair. An economical and sustainable solution was found to be the use of the Xbloc® and Xbase® armour units seen here for the rehabilitation.

INTRODUCTION

At the mouth of Georgia's largest river, the Rioni, which flows into the Black Sea, lies the city of Poti, which has been an important trade centre for centuries. Plans to develop a major seaport at Poti have been around since the early 1800s and in the 1850s the construction of a breakwater was begun. That breakwater still protects the port today.

Built in multiple phases with various cross sections between 1856 and 1929 (Figure 1), this main breakwater has endured because of a history of continual maintenance. 20 to 60 tonnes of concrete cubes have frequently been added to the armour layer of the structure. Still, as a result of significant settlement of the structure over time, the crest level has been reduced considerably. This has resulted in large overtopping volumes which then cause an inordinate amount of down-time for port operations. Consequently, the port authority decided to undertake a rehabilitation project. This project, executed between 2006 and 2008 by Royal Boskalis Westminster nv, aims

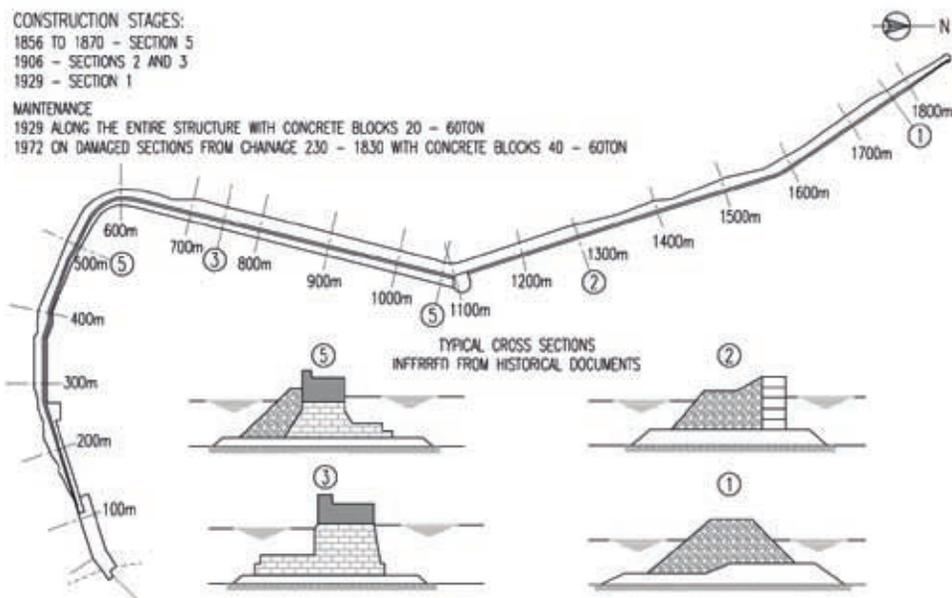


Figure 1. Historical overview of construction stages of the existing old cube breakwater.



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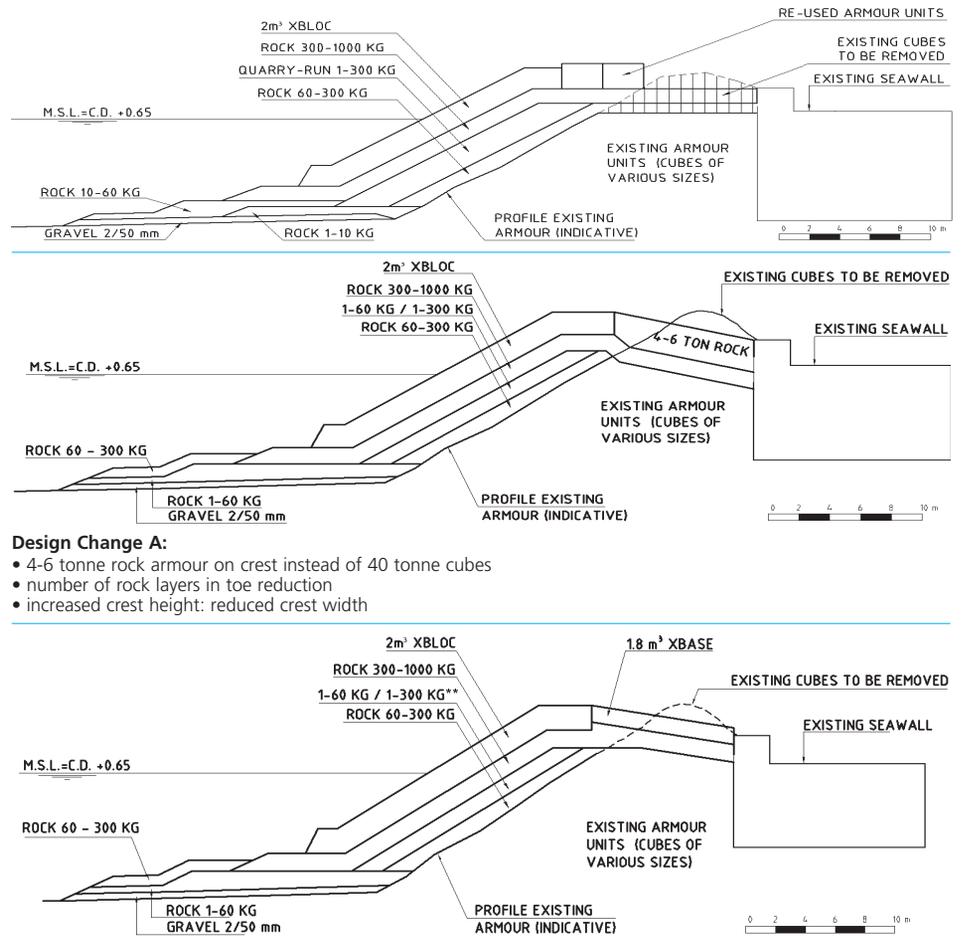


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holds a BSc in Engineering which he obtained in The Hague, the Netherlands. From 2002 to date he has been working at Royal Boskalis Westminster, starting as a trainee and now working as a superintendent with various dredging equipment since 2003. For two years starting at the end of 2006 he worked as a superintendent on the breakwater rehabilitation project at Poti, Georgia.

to reduce the need for constant maintenance and to limit the port's down-time caused by overtopping waves. The project financing was organised by Boskalis Westminster and as a result the project was partly financed by the Dutch export stimulating subsidy for developing countries (ORET) and partly by a commercial loan via the ING bank.

This article presents the various design options that were considered. It also explains how the construction equipment and method dictated the design choices and includes a description of the experiences encountered during construction. The part of the breakwater which needed to be repaired is comprised of an impermeable wall structure with a homogeneous body of large cubes in front of it (see Figure 1, cross-sections 2 and 5). As specified in the general design for the rehabilitation, the "breakwater toe," located



Design Change A:

- 4-6 tonne rock armour on crest instead of 40 tonne cubes
- number of rock layers in toe reduction
- increased crest height: reduced crest width

Design Change B:

- Xbase Units instead of 4-6 tonne rock armour on crest

Figure 2. Development of the cross section: Top, original plan and below, design change A and design change B.

in front of the existing body of cube, consists of multiple rock layers. This design was chosen because the individual concrete cubes in front of the breakwater are partially protruding from the seabed making the use of geotextiles impossible. The old existing cubes on the breakwater slope had been covered by a number of rock layers and finally covered by a single layer of 2 m³ Xbloc® armour units. In total 50,000 tonnes of Filter Material, 100,000 tonnes of Rock and 6000 nos (number of units) of Xbloc® units were placed.

DESIGN OPTIONS CONSIDERED

During the detailed design and preparation for the construction rehabilitation, three different design solutions were developed to protect the low and wide crest of the breakwater as shown in Figure 2.

The original design was based on the availability of a heavy crane capable of lifting the old cubes. By selecting the best cubes and

re-using them as a crown wall, the breakwater crest would be protected and the armour layer would be keyed in horizontally. During the preparation of the construction phase, however, lifting the existing cubes was considered to be an unsafe and unattractive solution for several reasons. These included both the high costs of using such a large crane as well as the high risk of poor quality cubes dropping from the crane.

Consequently, a new design was model tested with large 4 to 6 tonne rocks on the breakwater crest (Design Change A, Figure 2). Although this solution was stable under the design and overload cases that were tested, during the production of the different rock gradings at the quarry it became apparent that the required quantity of 4 to 6 tonne rock was insufficient and a third design was made.

This third design consisted of a crest protection made of 1.8 m³ Xbase® units instead of Xbloc® units (Design Change B, Figure 2).



Figure 3. Xbase® layer on the crest of the breakwater.

XBASE® UNITS ON BREAKWATER CREST

The steepness of the slope is an important parameter in this breakwater construction, because the interlocking between armour units such as Xblocs® derive an important part of their stability from the interlocking itself. However, on a horizontal berm or on a very mild slope such as the breakwater crest in Poti, Xblocs® would derive their stability primarily from their own weight and interlocking would not contribute significantly to the stability. In addition, Xblocs® have a large surface area exposed to the overtopping waves compared to, for instance, rock armour. The use of highly interlocking armour units on a low crest or berm therefore can lead to rocking of armour units under wave attack and hence to breakage of armour units.

Several years ago the idea developed to remove one of the noses of the Xbloc®. These modified Xblocs®, known as Xbase® units are less sensitive to overturning and are kept in position by friction between the unit and the rocky seabed. Therefore, applying Xbase® units at the crest instead of normal Xblocs® was a better choice

because it takes into account that the wave loads on the breakwater crest are significant owing to the low crest height (freeboard / design wave height = 0.76). The advantages of Xbase® units in this respect are that less surface area is exposed to the waves and they have a lower centre of gravity. Both these aspects reduce the chances of rocking and unit breakage.

The 1.8 m³ Xbases® were cast in the same formwork as those used for production of the 2 m³ Xblocs®. One of the “noses” in the Xbloc® moulds was simply closed off. The design with Xbase® units on the crest was model tested in March 2007 and was found to be stable under all design and overload tests (wave height varying between H_s = 2.6 m and H_s = 5.3 m; 14 test series with durations of 3 hours in prototype scale). No notable rocking movements or settlements of the Xbase® layer were found (Figure 3).

TRANSITION FROM CUBES TO XBLOCS®

For budgetary reasons, only part of the breakwater works could be rehabilitated. Although the rest of the breakwater is

expected to be rehabilitated in the near future, transitions between the old cube structure and the new Xbloc® section will necessarily occur. To ensure the stability of the Xbloc® section, the blocks have been horizontally keyed so that they cannot be unravelled during storm conditions.

Initially the construction strategy called for the availability of cranes with sufficient capacity to lift and place the existing 40-tonne cubes. In this design two rows of 40-tonne cubes would be placed against and on top of the Xblocs® in the transition section. However, when the use of the heavy crane was rejected, this design to stabilise the Xblocs® with heavy cubes was also no longer possible.

Other options were considered including using heavy in-situ filled grout bags. Ultimately the decision was taken to create a ¼ circle roundhead against the existing wall structure and lock in the Xblocs® firmly against this wall (Figure 4). Following placement of the Xbloc® roundhead, the remaining wedge is filled completely with Xblocs® thus reducing the impulsive wave forces on the wall.

Wedge of cubes removed by hammering; filled after construction with Xblocs® to reduce wave forces on wall.

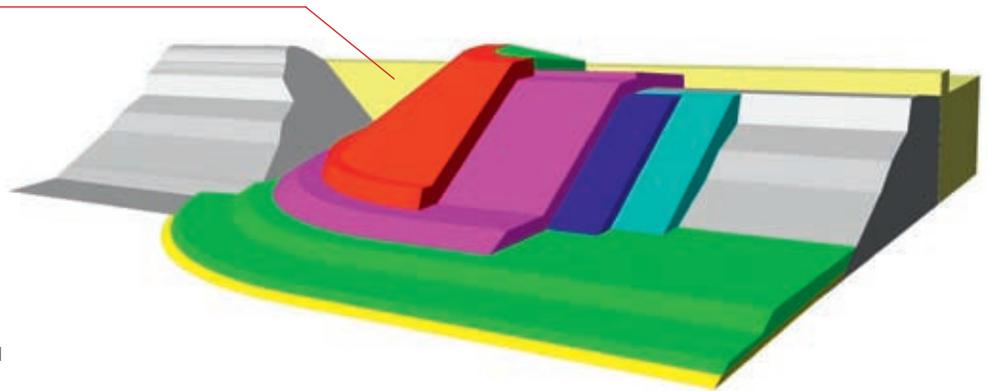


Figure 4. One quarter (¼) circle roundhead at transition with existing cubes.

THE QUARRY AND ROCK TRANSPORT

Rock was brought in by rail from a quarry in the Kursebi area of Georgia, 120 km from the breakwater project at Poti. Prior to this project, the quarry produced small dimension stones and large size rock for cutting tiles. The original face of the quarry was some 125 m long with a maximum height of about 20 m. At the top of the quarry was a pasture with cows, some small trees and bushes and soft overburden. The rock was of a low quality.

New surveys established the features (levels and distances) of the terrain and the borders of the concession. A survey was also used to design the haul roads and the development of the working faces in the mine. Trial holes were drilled with the drill crawler to check the thickness and the extent of overburden and bad rock layer at various places in the deposit.

The breakwater required rock materials for use as filter, core and underlayer. The following rock gradings were used:

- 2-50 mm filter stone
- 1-60 kg filter and work layer material
- 60-300 kg filter stone
- 300-1000 kg under layer

To keep the face height limited at the height of 20 m, a bench floor was created halfway and to maintain a proper working sequence, three working faces were created: for drilling and blasting; for selecting and loading the stones; and for cleaning and remedial work.

DRILLING AND BLASTING

To meet the requirements for 60-300 and 300-1000 kg stones, the blasting techniques previously used in the quarry were adjusted (i.e. increased burden, reduced spacing,

reduced column diameter so that the explosive ratio was reduced). The drill hole diameter was 89 mm. The results of the drilling and blasting parameters were monitored in order to adjust the blast geometry and to obtain the optimum yield throughout the quarry operations (Figure 5). Applying loosely poured ANFO (ammonium nitrate/fuel oil) commonly used for blasting was not an option as the drill holes contained water. Although the water could be blown out of the hole with air, the water returned before the round of explosives could be fired. Instead Gelignite (primed with a millisecond delay non-electric detonator) was placed in the drill hole.

Fine aggregates were used to stem the top of the hole. Continuous checking with special rods during the loading of the explosives was conducted to ensure that the explosives were loaded at the correct level inside the drill hole. Initiations of the explosives were carried out with millisecond delay detonators on the vibration measurements that had been made during the test programme. Blasting occurred on average once or twice per week with an average production of 1200 tonne per day.

SELECTING LARGE STONES

The required armour stones were selected from the blasted pile at the face and loaded onto a truck by an excavator fitted with a grab. The truck hauled the stones from the

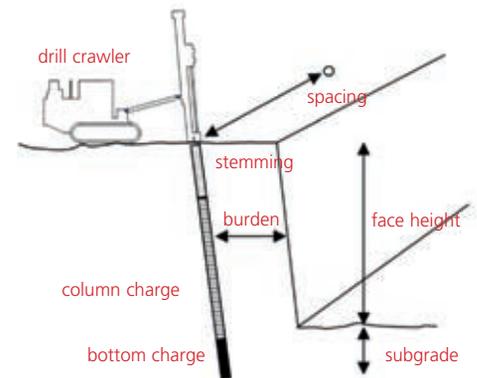


Figure 5. Sketch of the blasting set-up.

mine and tipped them into the stockpile area where they were then placed by a wheel loader in the various graded stockpiles.

Stones from the blast pile that were bigger than required (and consequently too big to handle) were left at the face. When the major of rock was removed and the cleaning of the face was begun, small holes were drilled into these large stones and measured amounts of explosives were inserted to break the stones into 2 or 3 pieces. Inspection of the quality of these armour stones occurred at the face. Flat or elongated stones (with a ratio of $L/d > 3.0$) were placed aside and using a hydraulic excavator with a break hammer the stones were broken into pieces to improve their shape. These stones were then placed in the appropriate stockpile (Figure 6).

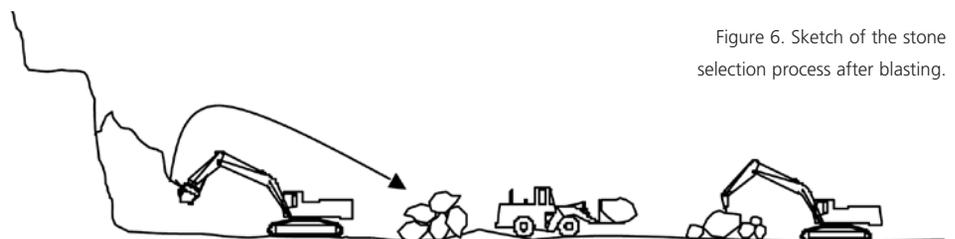


Figure 6. Sketch of the stone selection process after blasting.

The integrity of the armour stone was also inspected: Stones with fractures or weak spots were put aside and here too, a hydraulic excavator fitted with a break hammer was used to break the stone at the fracture of the weak spot. These stones were then placed in the appropriate stockpile.

SELECTING CORE AND SMALL ARMOUR ROCKS

After removing the larger stones, the remaining stones were loaded into dump trucks and hauled to the selection plants. A drum screen was used for the major quantity of the rock selection, i.e. producing 0-1 kg, 1-60 kg, 60-300 kg and 300-1,000 kg. The separated material fell into separated sections and a wheel loader then loaded the materials onto the road trucks travelling to the various graded stockpiles on the stockpile area (Figures 7 and 8).



Figure 7. The Drum Screen, the crane and the dump truck.

ROCK TRANSPORT BY RAIL

The main transportation of the rock material was by rail. Once the stockpile of rock was sufficient at the quarries, the railway transport between the quarries and Poti was initiated. This process took place in three phases:

- from Kursabi to Gelati to Kutaisi, about 15 km on a single track
- from Kutaisi to the Poti siding, about 100 km
- from the Poti siding to the Offloading Yard, about 5 km

The railway had a small siding at Kursabi, suitable for about four wagons. At Kutaisi about twenty wagons were assembled for the daily transport to Poti. At the Poti siding the wagons

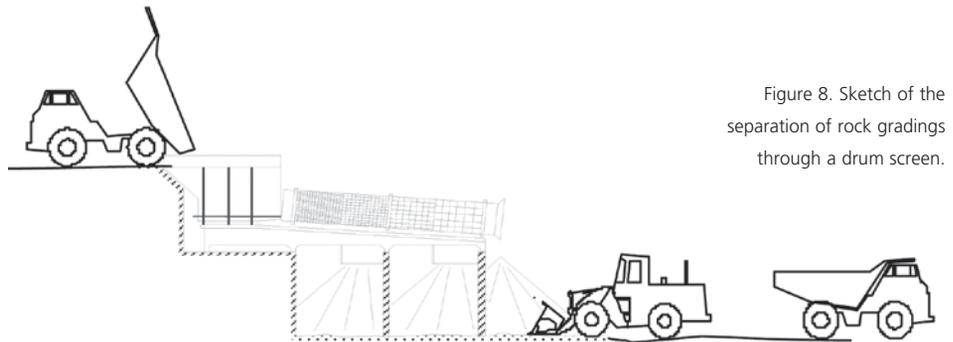


Figure 8. Sketch of the separation of rock gradings through a drum screen.

were divided in two for the last part of the transport to the off-loading area. Upon arrival at the city of Poti, the rock was unloaded by tipping the so-called "duncan" wagons. Once

dumped, the rock was loaded onto trucks of 6 to 10 m³, which hauled the rock on the purpose-built construction road towards the stockpile area in the vicinity of the port (Figure 9).



Figure 9. Loading (left) and unloading (right) of rock from the railway transport wagons.



Figure 10. Xblocs® being poured from concrete mixing truck.

During the breakwater construction, the rock was transported to the breakwater by four 16-m³ trucks. These trucks passed a weighbridge before dumping their load directly onto one of two 1500-tonne barges. A Multi Purpose Vessel then moved these barges to the required location at the breakwater. The loaded barges were moored off on bollards on the inside of the breakwater where an excavator CAT375 emptied the barges. The excavator deposited the material on the breakwater before it was placed in its designated layer.

The rock destined for the Side Stone Dumping Vessel ARCA was transported from the stockpile, over the weighbridge by the same four 16 m³ trucks. This rock was hauled to a loading wall near the mooring quay of the SSDV ARCA.

XBLOC® PRODUCTION

Moulds and Concrete Pouring

Using 30 steel Xbloc® moulds that were produced in the Netherlands and transported to Georgia by road, the Xblocs® were cast on site. The moulds were filled directly from concrete mixing trucks, which reached the moulds by means of an elevated roadway. The trucks were filled under a batching plant at close distance from the production site. The moulds consist of two identical mould halves, so that each mould half could be connected to the other mould half. This optimised the production cycle because two adjacent mould halves could be

turned around, connected and filled again immediately after striking the mould from a completed block. This casting method allowed a production speed of one Xbloc® per mould per day. The units were then left in place for two days before being transported to the storage area.

Concrete Mix and Investigations

The concrete mix for the production of the Xblocs® was based on locally available sulphate resistant Portland cement. On paper this mix design seemed suitable for achieving

the concrete grade required for the Xbloc® production (C25/30). In fact, cube and cylinder compression tests indicated that the concrete strength development was very slow and that after 28 days strengths were lower than expected. The cement was therefore investigated in more detail in a specialised laboratory in The Netherlands. These analyses showed that the cement contained a relatively low quantity of Alite (C3S; responsible for early concrete strength development) and a high quantity of Belite (C2S; generating concrete strength later in the hardening process). Compared to common Dutch cement which contains about 60% Alite and 10% Belite, the cement used in Poti contains 40% Alite and 30% Belite.

In addition, the compressive strength development of the cement was tested over a 90-day period at temperatures of 20°C and 8°C (Figure 11). These results were compared to the strength development of more standard type Dutch cement at the same temperatures. The test results indicated that the strength development of the Georgian cement, especially at low temperatures, was indeed slow, but that the strength increased significantly between 28 days and 90 days.

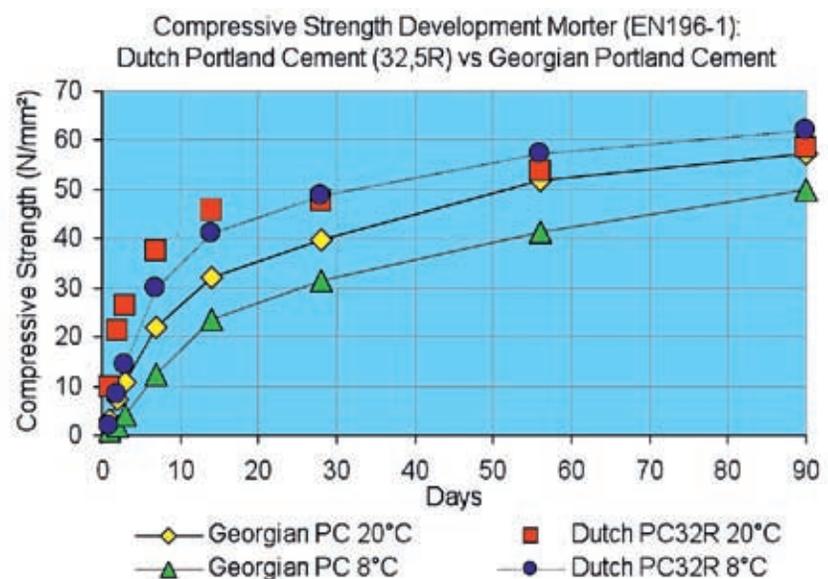


Figure 11. Compressive Strength at 8°C and 20°C.



Figure 12. Set-up for the drop tests.

As a result of this slow concrete strength development early on, some units were observed with settlement and shrinkage cracks (slow strength development leads to a longer plastic period and hence to more time for cracks to develop). These cracks were encountered either in the top surfaces of the units (shrinkage cracks) or in the “arm pits” and “thighs” of the units (settlement cracks).

To test the robustness of these units, several units were subjected to drop tests on a solid concrete floor covered by a steel plate (Figure 12). Although the drop tests were done with units that were considered to be the more severe units, no damage was caused by the drop tests in which units were dropped on a leg with fall heights increasing in increments of 5 cm, up to a fall height of 50 cm. Other units were rolled over 25 times.

PREPARATION OF BREAKWATER AND ROCK PLACEMENT

To create a platform for the new construction, first some 8,200 cubic metres of old concrete cubes had to be removed. The average weight of the cubes was approximately 60 tonne per piece and they were of varying quality. Lifting these cubes was considered a potentially unsafe operation, and a safer solution was found which consisted of destroying the blocks in a controlled manner using hydraulic hammers. Rammer 100s hammers mounted on a CAT330 and a CAT375 long reach excavators were used. The hammers with a working weight of 4 tonne were equipped with pointed chisels of 10-cm in diameter (Figure 13).

When the first machinery entered the breakwater, the first job was to create a working space by hammering a path through the cubes. The hammers of the excavators were aimed perpendicular to the cubes surfaces to constantly break the cubes into smaller pieces, e.g., concrete fragments of approximately half a metre. As the excavators moved over the hammered material they broke these into even smaller pieces. The resulting material was not removed but simply fell into the voids between the remaining cubes. The cubes above a level of one metre CD were removed in this way at an average rate of 400 m³ per 24 hours.

The hammering rate at the two ¼ roundheads was considerably slower because in these sections the cubes had to be removed down to a level of -3.50 m CD, that is below the water line. To be able to function underwater, the hammers were equipped with an air compressor (7 bar, 4 m³/min) to ensure the

recoil chamber did not fill up with water, but regardless, hammering underwater was more difficult because visibility is limited.

Placing Rock Layers

The placement of the different gradations of rock can be divided into two construction methods namely

- 1) with land-based machinery; and
- 2) with the SSDV ARCA (Figure 14).

Because the ARCA can operate in shallow water (2.6 m) and because of the long-reach capability of the excavator (21 m), these two types of equipment were able to cover each others working area.

The ARCA works with a multi conveyor-belt dumping system. The loading deck consists of six pairs of conveyor-belts which are separated by five coamings. The conveyors work perpendicular to the vessels hull. Upon arrival at the dumping site, the conveyor belts are started and the loaded material is moved from the deck into the water. A DGPS system ensures the correct position for dumping and sailing speed during the dumping. The vessel can carry 550 tonnes of rock and she did a maximum of four trips in a 12-hour working day.

The excavator used for the actual construction of the breakwater was CAT375 equipped with the Boskalis Crane Monitoring System (CMS) based on GPS. This system enables the operator to view the design and the location of the bucket of the machine in real time on a screen in the cabin. With the CMS the operator knows exactly how much rock needs to be applied or removed. This type of system is considered indispensable in all underwater works and especially in bends and roundheads.

The first two rock layers have been applied on the seabed with the ARCA. These filter layers (2-50 mm and 1-60 kg) were placed against the existing breakwater. From the breakwater the long reach excavator applied the next layer (60-300 kg) on top of the filter layer against the breakwater slope. Once this layer was fully applied, the next layers (1-300 kg



Figure 13. Destruction of the old blocks in a controlled manner using hydraulic hammers.



Figure 14. The ARCA at work during rock placement.

and 300-1000 kg) were placed by the excavator. The 300-1000 kg layer was applied on top of the filter layers in the berm and against the slope, creating an under layer for the Xblocs. Finally the 60-300 kg layer in the breakwater toe was placed by the ARCA.

Leaving the finer rock layers exposed to potential storms was considered to be risky, so these layers had to be covered as quickly as possible. Planning of the various placement operations was therefore crucial. Once the joint effort to create a seamless underwater construction was finished, the excavator was able to finish placing the last rock layer (300-1000) from the slope over the top of the breakwater.

XBLOC® PLACEMENT

Prior to the Xbloc® placement a computer model was prepared to determine the locations of all the units to be placed. The units in the lowest row were placed on three points. The other blocks were placed with one leg pointing downwards so that the blocks easily find their position in between the units of the previous row.

The Xblocs® were transported by barge from the storage area to the breakwater where they were unloaded by excavator and placed with the CAT375 long boom excavator equipped with the Boskalis Crane Monitoring System (CMA). This system enables the crane operator to know the position of the boom and accurately release the units at their predefined location (Figure 15).

As the placement accuracy of the first two rows affects the ease of placement of the remaining rows, diver inspections were carried out after the first and second rows. Because of the crane monitoring system, the effective

quick release hook and the simplicity of the Xbloc® placement procedure, high placement rates were obtained of approximately 20 units per hour below the water line and up to 40 units per hour above the water line.

Although occasionally some armour units broke during the placement operation by their impact against other units, with a breakage rate of less than 0.5% the amount of broken units was very limited.

After a short interruption of the construction during the Russian-Georgian conflict in August 2008, when the contractor temporarily left the site, construction was re-started in September 2008. When the Xbloc® placement was completed, the remaining wedges between the Xblocs®, the cubes and the wall structure were filled with Xblocs®. Finally the breakwater crest was covered with the Xbase® units and in October 2008 the rehabilitation project was completed.



Figure 15. Xbloc® placement with the crane.

CONCLUSIONS

The breakwater rehabilitation at Poti, Georgia, with concrete armour units was a necessary and economical solution to the long-standing deterioration of the old cube breakwater built originally in the 19th century. The old breakwater had been repeatedly repaired but this need for maintenance was insufficient and caused frequent down-time at the port.

The use of single layer units like Xbloc® and Xbase® armour units provided an economical solution compared with the traditional solution of reinforcing and modernising the breakwater with large rocks. In the long term the solution of using single layer units will also reduce the need for constant maintenance. Consequently, this will limit the port's down-time caused by overtopping waves and thus improve the overall economic viability of the port.