Rehabilitation of the old Cube Breakwater of Port of Poti – Georgia with Xbloc® Armour Units

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Introduction

The city of Poti – Georgia lies at the mouth of Georgia's largest river, the Rioni, and has been an important centre of trade since ancient history. Since the early 19th century many plans were developed to create a major sea port and in the 1850's construction began of the main breakwater that is still protecting the port today.

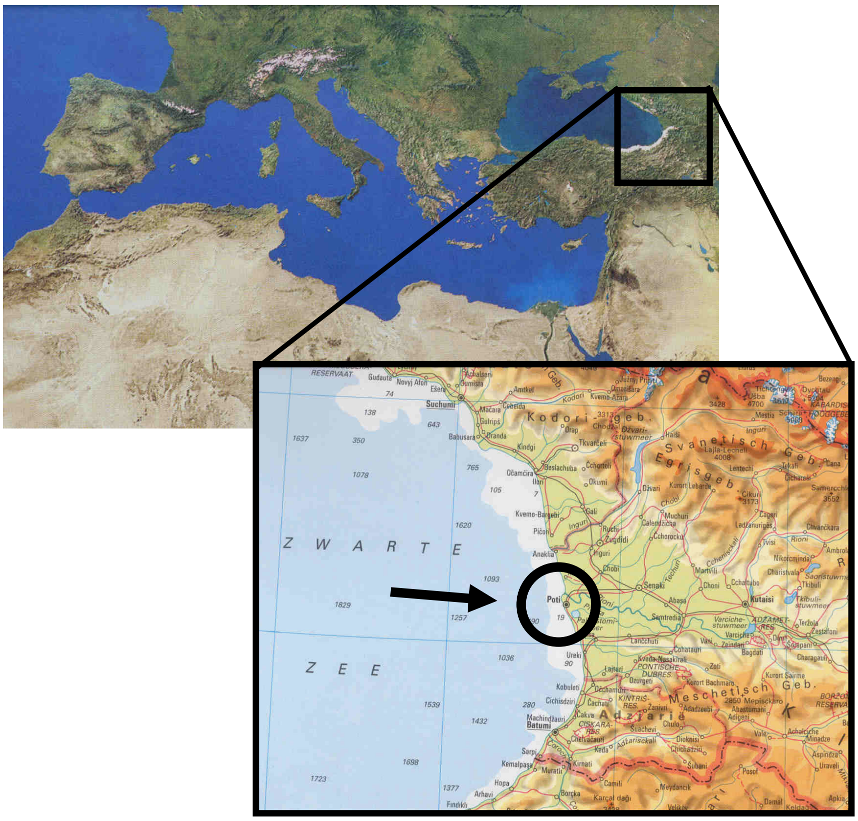


Figure 1: Project Location

This main breakwater was built in multiple phases with various cross sections between 1856 and 1929 (Figure 2). During its long lifetime maintenance has been carried out to the structure by frequently adding 20-60 tons concrete cubes to the armour layer. Due to significant settlements of the structure over time, the crest level was reduced considerably which resulted in large overtopping volumes and as a consequence in downtime of port operations. Therefore a rehabilitation project has been carried out between 2006 and 2008 by Royal Boskalis Westminster nv in order to reduce the need of maintenance and to reduce the downtime due to overtopping waves. This paper describes the different design options that have been considered for the rehabilitation works and how the construction equipment and method dictated the design choices. Furthermore the construction experiences are described.

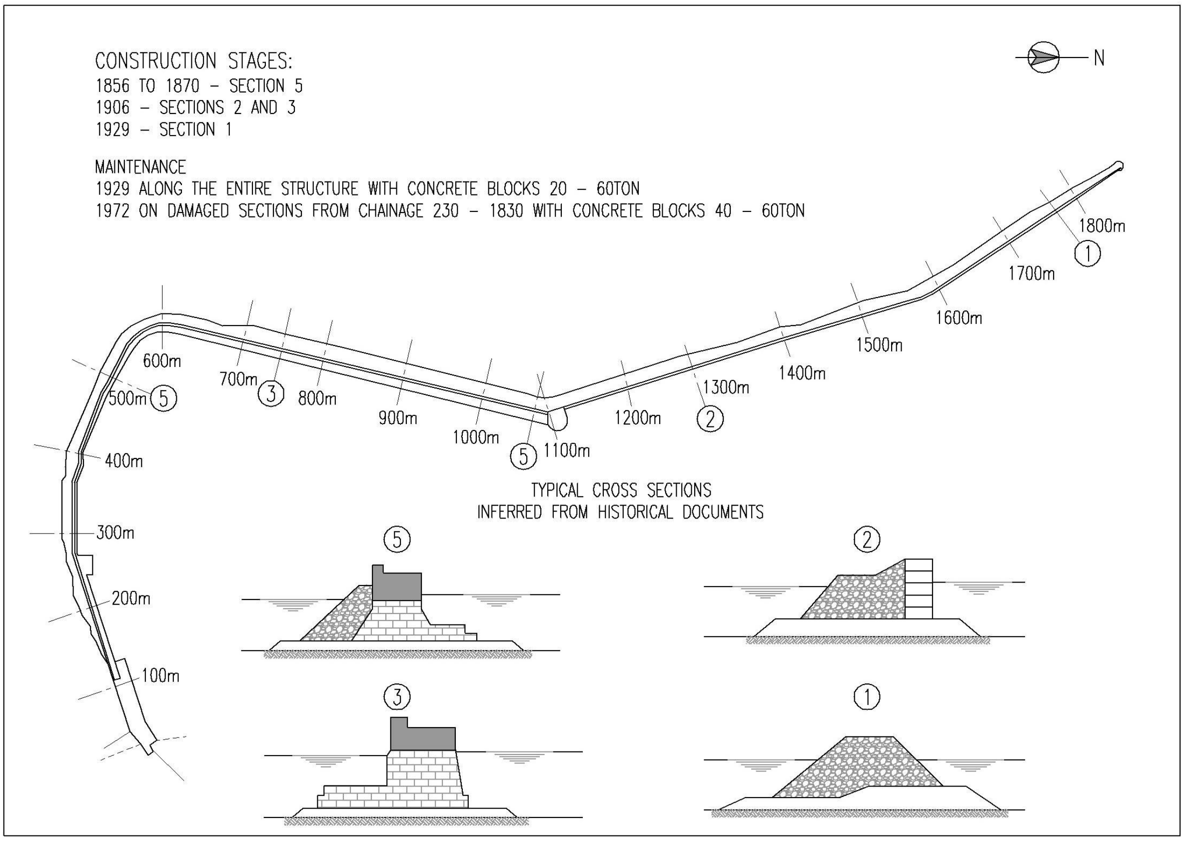


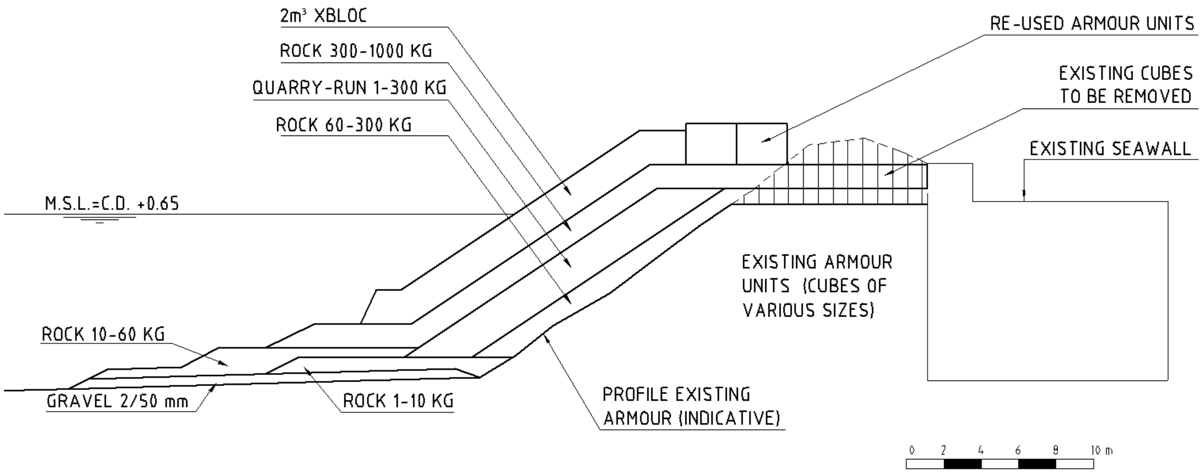
Figure 2: Overview of Construction stages of Existing Breakwater

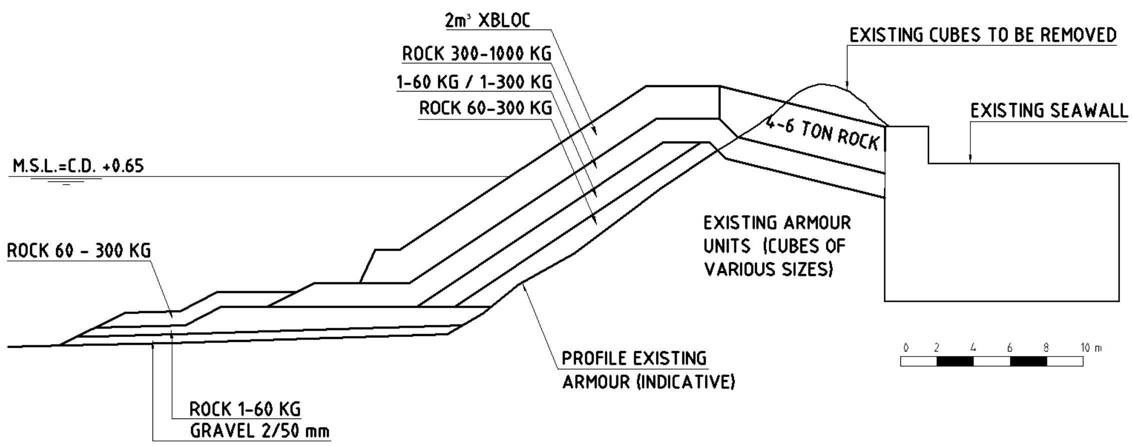
Design Aspects

Design Options Considered

The part of the breakwater that has been repaired consists of an impermeable wall structure with a homogeneous body of large cubes in front (cross sections (2) and (5) in Figure 2). In the general design of the rehabilitation works the breakwater toe, which is placed in front of the existing body of cubes, is made of multiple rock layers. This was designed as the use of geotextile was not possible due to the presence of individual concrete cubes in front of the breakwater partially emerging from the sea bottom. The existing cubes on the breakwater slope are covered by a number of rock layers and finally covered by a single layer of 2m3 Xbloc armour units. During the detailed design and the preparation of the construction phase, three different design solutions have been developed to protect the low and wide crest of the breakwater as shown in Figure 3.

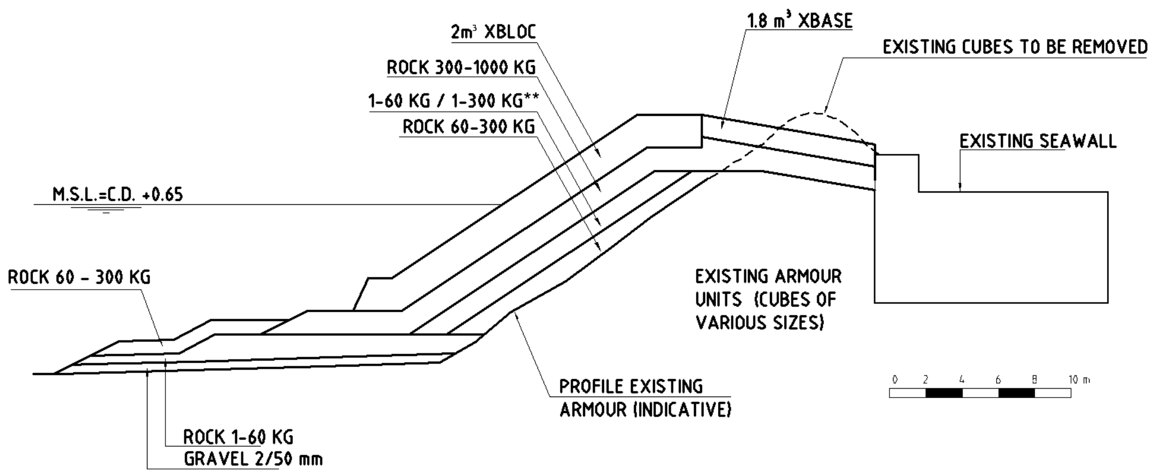
The initial design of the breakwater rehabilitation works was based on the availability of a heavy crane that would be capable of lifting the existing cubes. By selecting the best cubes and re-using them as crown wall, the breakwater crest would be protected and the armour layer would be keyed in horizontally. During the preparation of the construction phase however, the contractor decided that lifting the existing cubes was not a safe and attractive solution due to the high costs of the large crane required and the risk of poor quality cubes dropping from the crane. Therefore a design was model tested with large 4-6ton rocks on the breakwater crest (Design Change A in Figure 3). This solution was stable under the design and overload cases that were tested, however it became apparent during the production of the different rock gradings in the quarry that the required quantity of 4-6 ton rock was not sufficient and a design was made with a crest protection made of 1.8m3 Xbase units.





Design Change A:

- 4-6 ton rock armour on crest instead of 40ton cubes;
- number of rock layers in toe reduced
- increased crest height; reduced crest width



Design Change B:
Xbase Units instead of 4-6 ton rock armour on crest

Figure 3: Development of Cross Section

Xbase Units on Breakwater Crest

The reason to apply Xbase units on the crest instead of normal Xblocs is that the wave loads on the breakwater crest are significant due to the low crest height (freeboard / design wave height = 0.76). For interlocking between armour units such as Xblocs, which derive an important part of their stability from interlocking, the slope steepness is an important parameter. On a horizontal berm or on a very mild slope such as the breakwater crest in Poti, Xblocs would derive their stability mostly from their own weight and interlocking would not form a significant contribution to the stability. Furthermore the Xblocs have a large surface area exposed to the overtopping waves compared to e.g. 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.

The advantages of Xbase units in this respect are their reduced surface area that is exposed to the waves and their low centre of gravity. This reduces the chances of rocking and unit breakage. The 1.8m3 Xbases were cast in the same formwork as was used for the production of the 2m3 Xblocs by closing off one of the "noses" in the Xbloc moulds. This 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 Hs=2.6m and Hs=5.3m; 14 test series with durations of 3 hours in prototype scale) without notable rocking movements or settlements of the Xbase layer.

Figure 4: Xbase layer on breakwater crest

Transition from Cubes to Xblocs

As the available budget for the rehabilitation works was (as all budgets) finite, the works have been carried out only for a part of the breakwater. Although the rehabilitation of the remainder of the breakwater is expected to take place in the near future, this introduces transitions between the old cube structure and the new Xbloc section. For the stability of the Xbloc section it is important that the blocks are horizontally keyed in and that they can not be unravelled during storm conditions.

In the initial construction strategy, cranes would be available with sufficient capacity to lift and place the existing 40 ton cubes. A transition was designed by placing 2 rows of 40ton cubes against and on top of the Xblocs in the transition section. When the use of the heavy crane was found not feasible, it was no longer possible to stabilise the Xblocs with heavy cubes. After considering options with heavy in-situ filled grout bags, it was decided to create a ¼ circle roundhead against the existing wall structure and lock in the Xblocs firmly against this wall (Figure 5). After placement of the Xbloc roundhead, the remaining wedge is filled completely with Xblocs in order to reduce the impulsive wave forces on the wall. As these armour units are not placed systematically, the transition is expected to deform during storm conditions, but given the fact that the transitions only have a temporary function, this option was considered the most attractive solution with the equipment available.

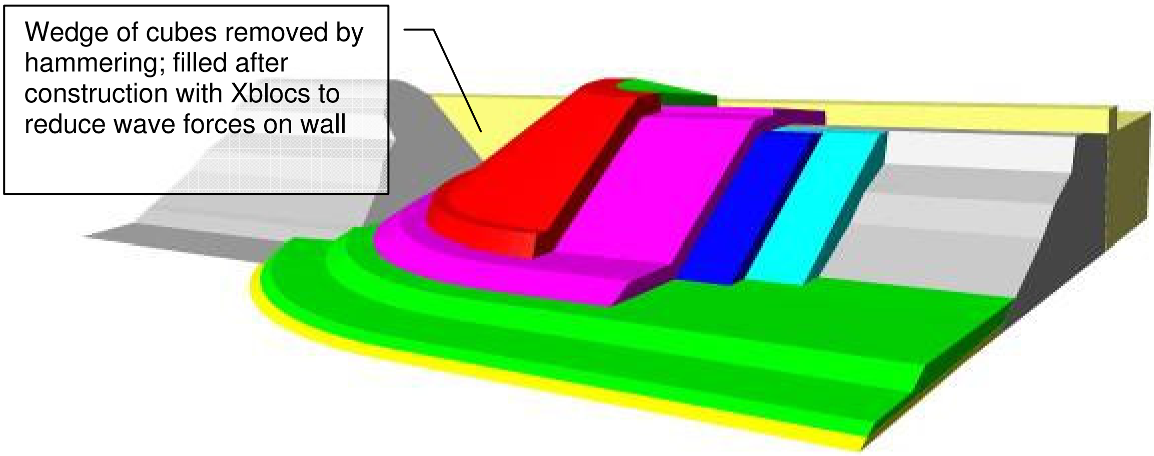


Figure 5: ¼ circle roundhead at transition with existing cubes

Quarry Operations and Rock Transport

Rock materials were required for use as filter, core and under layer for the breakwater. The rock was supplied from a quarry located in the Kursebi area at 120 km distance by rail from the Works. The following rock gradings were required:

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

The quarry had been used before the start of the project to produce small dimension stones and large size rock for cutting tiles. The existing face was approx. 125 m long and had a maximum height of around 20 m. The top of the quarry was covered with grassland used by cows, some small trees + bushes, soft overburden and was a low quality rock. Survey's established the features in the terrain (levels and distances) and the borders of the concession. The survey was also used for the design of the haul roads and the development of the working faces in the mine. At various places in the deposit trial holes were drilled with the drill crawler to check the thickness and the extend of overburden and bad rock layer.

The present face had a height of approx. 20 m. To keep the face height limited a bench floor was created halfway and for a proper working sequence 3 working faces were created a) for drilling + blasting; b) for selecting and loading the stones and c) for cleaning and remedial work.

Drilling and blasting

Because of the requirement for 60/300 and 300/1000 kg stones the blasting techniques were adjusted compared to the techniques previously used in the quarry (i.e. increased burden, reduced spacing, reduced column diameter so that the explosive ratio is reduced). The diameter of the drill holes was 89 mm. Monitoring of the selection results in relation to the drilling and blasting parameters was carried out to adjust the blast geometry and to obtain the optimum yield throughout the quarry operations.

As the drill holes contained water, it was not possible to apply loosely poured ANFO. The water could be blown out of the hole with air but the water returned before firing of the round of explosives could take place. Therefore gelignite (primed with a millisecond delay non-electric detonator) was placed in the drill hole. The top of the hole was stemmed with fine aggregates. During the loading of the explosives continuous checking with special rods was carried out to ensure that the explosives were loaded at the correct level inside the drill hole. The initiations of the explosives were carried out with millisecond delay detonators. The numbers required were depending on the vibration measurements made during the test programme. Blasting was carried out average once or twice per week and the average production was 1200 ton per day.

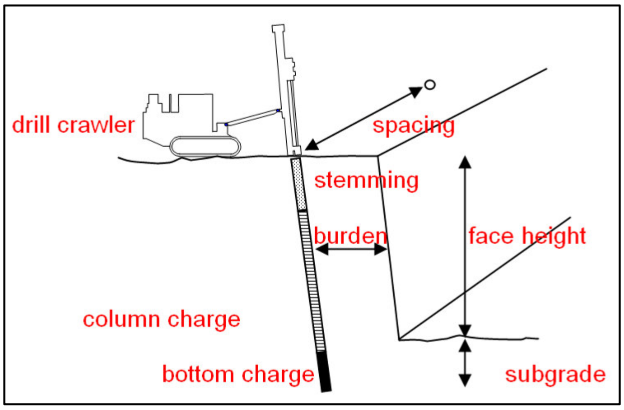


Figure 6: Sketch of blasting set-up

Selection of large stones

An excavator fitted with a grab selected the required armour stones from the blasted pile at the face and loaded these onto a truck. The truck hauled the stones out of the mine and tipped the stones in the stockpile area where a wheel loader stockpiled these stones in the various graded stockpiles.

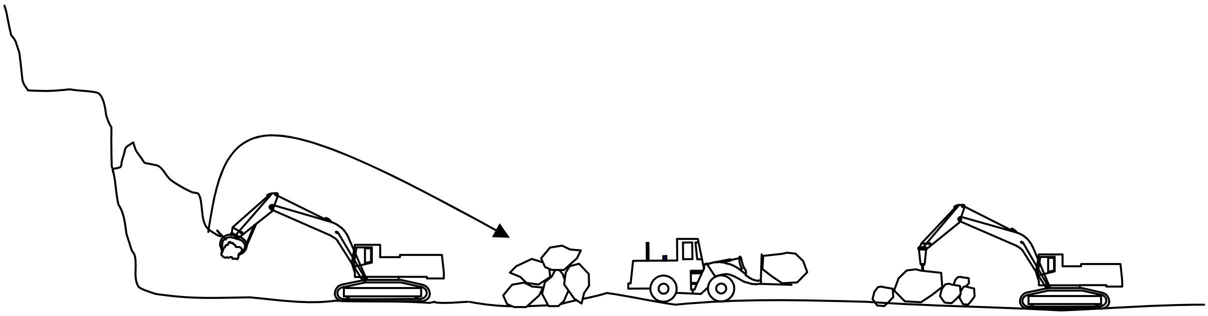


Figure 7: Sketch of stone selection after blasting

Any stones in the blast pile at the face that were bigger than the requirement (and consequently too big to handle) were left at the face. When the removal of the major quantity of rock was complete and cleaning of the face had started small holes were drilled in the stones and a small amount of explosives was inserted to break them in 2-3 pieces. The quality of the armour stones was inspected at the face. Stones which were flat or elongated (i.e. with a ratio of L/d > 3.0) were put aside and a hydraulic excavator with a break hammer broke pieces of the stone to improve the shape where after the stone was placed in the appropriate stockpile. The armour stone integrity was also inspected and stones which had fractures or weak spots were put aside. A hydraulic excavator fitted with a break hammer broke the stone at the fracture of weak spot where after the stone was placed in the appropriate stockpile.

Selection core and small armour rocks

When the big stones had been taken out, the remaining stones were loaded into dump trucks which hauled the stones 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 falls down into separated sections where a wheel loader took the materials and loaded it onto the road trucks travelling to the various graded stockpiles on the stockpile area.

Figure 8: Drum Screen

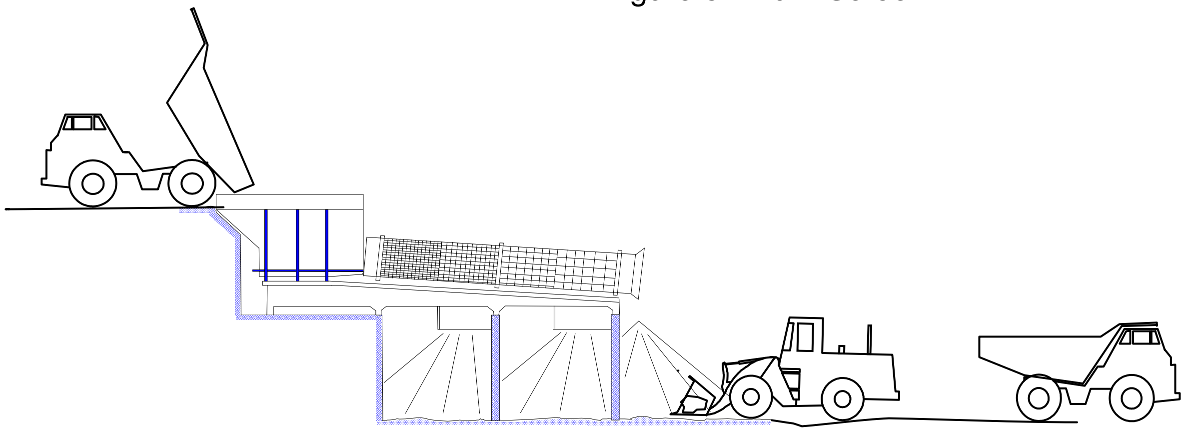


Figure 9: Sketch of separation of rock gradings through drum screen

Rock Transport

The main transport of the rock material was by rail. After sufficient stockpile of rock products were available at the quarries, the rail transport was started between the Quarries and Poti. This transport can be separated in three sections:

- Kursabi – Gelati – Kutaisi (length about 15 km single track)
- Kutaisi – Poti siding (length about 100 km)
- Poti siding – Offloading Yard (length about 5 km)

Figure 10: Loading and unloading of rock transport wagons

The railway had a small siding into Kursabi, suitable for about 4 wagons. At Kutaisi the wagons were assembled till about 20 wagons for the daily transport to Poti. At the Poti siding the wagons were split in two for the last part towards the offloading area. Once the rock material had arrived in the city of Poti it was unloaded by means of tipping the so called duncan wagons. Once dumped, the rock would be loaded onto 6 to 10 m3 trucks which hauled the rock over a purpose built construction road towards the stock pile area close to the port.

During the construction of the breakwater rock was transported towards the breakwater by four 16 m3 trucks that passed a weighbridge before dumping their load directly on one of two 1.500 ton barges. These barges where transported by a Multi Purpose Vessel to the required location on the breakwater. The loaded barges were moored off on bollards on the inside of the breakwater where the barges were emptied by an excavator CAT375. 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. The rock was hauled to a loading wall near the mooring quay of the “ARCA”.

Xbloc Production

Moulds and Concrete Pouring

The Xblocs were cast on site using 30 steel Xbloc moulds that were produced in the Netherlands and transported to Georgia by road. The moulds were filled directly from concrete mixing trucks which reached the moulds by means of an elevated road way. The trucks were filled under a batching plant at close distance from the production site. The moulds consist of two identical mould halves, i.e. each mould halve could be connected to each other mould halve. This was done to optimize the production cycle by enabling two adjacent mould halves to be turned around, connected and filled again immediately after striking the mould from a completed block. With this casting method a production speed of one Xbloc per mould per day was achieved whereas the units were left in place 2 days before transporting them to the storage area.

Figure 11: Pouring Xbloc from concrete mixing truck

Concrete Mix and Investigations

For the production of the Xblocs the concrete mix was based on locally available sulphate resistant Portland cement. On paper this mix design was suitable to obtain the concrete grade that was required for the production of Xblocs (C25/30). However from cube and cylinder compression tests it was concluded that the concrete strength development was very slow and that the strengths after 28 days were lower than expected. For this reason the cement was investigated in more detail in a specialised laboratory in The Netherlands. From this analyses it was concluded 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). Whereas common Dutch cement contains around 60% Alite and 10% Belite, the cement used in Poti contains 40% Alite and 30% Belite.

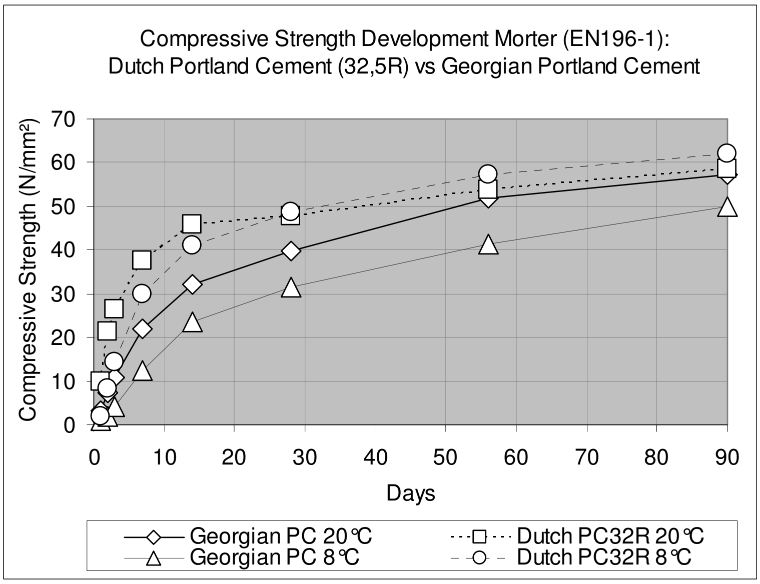


FIGURE 12: Compressive Strength at 8°C and 20°C

Furthermore the compressive strength development of the cement was tested over a duration of 90 days at a temperature of 20°C and 8°C. These results were compared to the strength development of a more standard type Dutch cement at these same temperatures. The results of these tests indicated that the strength development of the Georgian cement was indeed slow, especially at low temperatures, but that the strength increased significantly between 28 days and 90 days.

Due to the slow concrete strength development 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). In order to test the robustness of these units, a number of units were subjected to drop tests on a solid concrete floor covered by a steel plate. The objective of these drop tests was to simulate as good as possible the loads an armour unit could undergo if wave loads would cause it to rock against neighbouring units. Although the drop tests were done with units that were considered to be the more severe units, no damage was caused by the tests during which units were dropped on a leg with fall heights increasing in steps of 5cm up to a fall height of 50cm and other units were rolled over 25 times.

Figure 13: Test Setup Drop Tests

Preparation of Breakwater and Rock Placement

In order to create a platform for the new construction some 8.200 cubic meters of existing concrete cubes had to be removed. The cubes had an average weight of approximately 60 ton per piece and where of varying quality. Lifting these cubes was considered a potential unsafe operation and a safer solution was found in destroying the blocks in a controlled manner by use of hydraulic hammers. The hammers used were "Rammer 100's" mounted on a CAT330 and a CAT375 long reach excavator. The hammers with a working weight of 4 ton were equipped with pointed chisels of 10 centimetre diameter.

Figure 14: Impression of Rock Hammering

The first job that had to be done when the first machinery entered the breakwater was to create a working space by hammering a way through the cubes. The excavators aimed their hammers perpendicular to the cubes surfaces to constantly break the cubes into smaller pieces. The concrete was broken into fragments of approximately half a meter. Because the excavators moved over the hammered material it broke into smaller pieces. The obtained material was not removed but simply fell into the voids between the remaining cubes. The cubes above a level of 1 meter 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 due to the fact that in these sections the cubes had to be removed down to a level of -3,50 m CD hence also below water. For the hammers to function under water they were equipped with an air compressor (7 bar, 4 m3/min) to ensure the recoil chamber did not fill up with water, but still hammering under water was more difficult due to the lack of vision.

Placing rock layers

The placement of the different gradations of rock can be subdivided into two construction methods namely 1) with land based machinery; and 2) with the Side Stone Dump Vessel ARCA (Figure 15). Due to the ability of this vessel to operate in shallow water (2,6 m) and due to the long reach capability of the excavator (21 m) the 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 working direction of the conveyors are perpendicular to the vessels hull. Upon arrival on the dumping site the conveyor belts are started and the loaded material will be moved from the deck into the water. A DGPS system insures its correct position for dumping and sailing speed while dumping. The vessel carries 550 ton of rock and did a maximum of four trips in a twelve hour working day.

The excavator used for the actual construction of the breakwater was CAT375 equipped with the Boskalis Crane Monitoring System 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 and such a system is considered indispensable in all underwater works and especially in bends and roundheads.

The first two rock layers have been applied on the sea bed 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 (60-300kg) on top of the filter layer against the breakwater slope. Once this layer was fully applied the next layers (1-300kg and 300-1000kg) 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 60-300kg layer in the breakwater toe was placed by the ARCA.

Figure 15: Rock dumping with Arca

As it was considered to be a risk to leave the finer rock layers exposed to potential storms, these layers had to be covered as soon as possible. Planning of the different placement operations therefore was 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

The Xbocs were transported by barge form 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. This system enables the crane operator to know the position of the boom and accurately release the units at their predefined location.

Prior to the 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.

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 row. Due to the availability 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.

Figure 16: Xbloc placement

Although occasionally some armour units broke during the placement operation due to the 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 abandoned 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 17: Impression of completed rehabilitation works

Keywords
Breakwater Rehabilitation; Quarry Operations; Armour Units; Xbloc; Xbase; Cubes.