

Hans Bijen

Ennore Breakwater Construction

Abstract

The eastern coast of India is subject to storms and cyclones during the monsoon, and the littoral drift creates a sand transport along the coast. Construction of a new harbour on this coast, known as the Ennore Coal Port, required the construction of two new breakwaters to protect the future coal harbour and incoming ships from waves and sedimentation problems. Because the soil there was determined to be insufficient to support such breakwaters, additional dredging and backfilling were needed and a new method of compaction was developed.

Introduction

As one of the world's fast emerging new economies, India plans to develop new infrastructure to open up its vast hinterland, so goods, commodities and produce can be transported from the coast to India's interior and vice versa. This implies that harbourage and harbour facilities have to be ameliorated, and the same applies to India's road system and railway infrastructure. India's rapid population growth (approximately 980 million inhabitants in 1998, expected to increase to over a thousand million before the end of the millennium) and expanding economy (approximately 6% in 1998) call for immediate action to ensure continuity and improvement of present and future living conditions for the Indian people.

Chennai – formerly known as Madras – is one of India's major harbours on the eastern coast of India, situated directly on the Gulf of Bengal, in the state of Tamil Nadu. Bulk vessels, loaded with coal, call at Chennai's harbour to deliver their tonnes of cargo. Coal is used as fuel for Chennai's electricity plants, that supply the city and its northern industrial hinterland with electric power. To protect the city from further contamination caused by the transshipment of coal and unburden the workload of the harbour facilities, the Chennai authorities decided to construct a satellite harbour at Ennore, a small village, situated 20 kilometres north of Chennai. This project is called the Ennore Coal Port Project (see article on page 3).

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ECPP/C4 BREAKWATER CONSTRUCTION

As this part of the coast is subject to storms and cyclones during the monsoon and the littoral drift creates a sand transport along the coast, two breakwaters had to be constructed to protect the future coal harbour and incoming ships from waves and sedimentation problems.

The main features of the port consist of a Northern Breakwater with a length of approx. 3200 m and a Southern Breakwater with a length of approx. 1300 m, distanced approx. 2500 m, thus creating a harbour basin of approx. 2500 x 1500 m² to be dredged at a depth of -15.50 m, with an access channel to be dredged at -18.00 m (Figures 1 and 2).

Inside the harbour a Coal Wharf is under construction.

The Employer of the project is Chennai Port Trust. The Engineer for the project is a Joint Venture consisting of Haskoning of The Netherlands with Rites of India, responsible for the design and supervision of the works. Approximately 60% of the project is financed by the Asian Development Bank and the remaining part by the Chennai Port Trust.

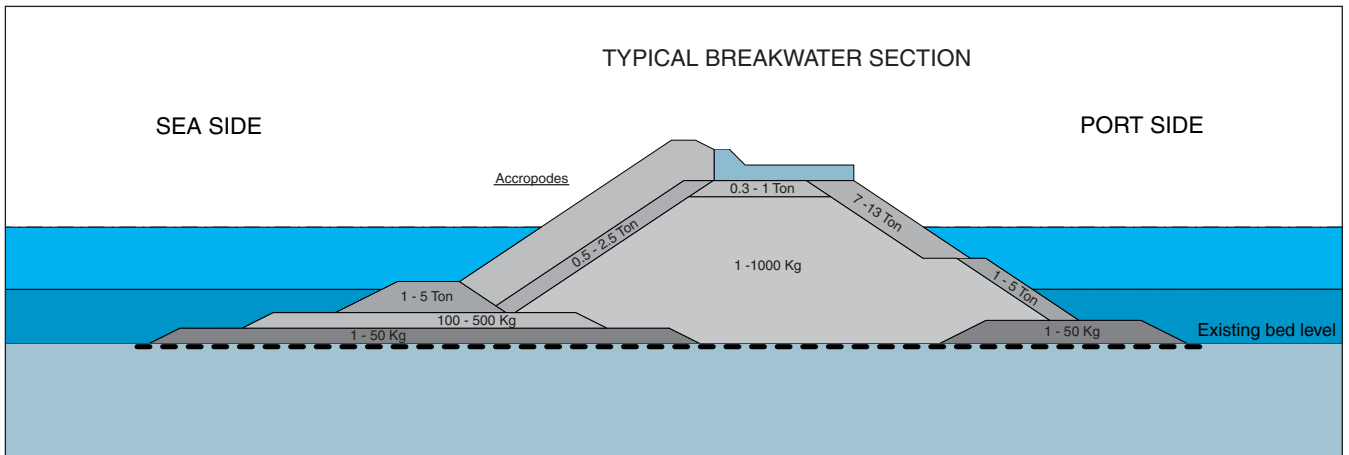


Figure 1. A cross-section of a typical breakwater.

The project was tendered in several separate contracts, which included the Contract ECPP/C4 Breakwater Construction. This contract was awarded to the Joint Venture, consisting of Hindustan Construction Company (HCC) of Mumbai/India and Van Oord ACZ (VOACZ) of The Netherlands, partaking for respectively 70%-30% in the construction works. HCC, the leading partner in the Joint Venture, and responsible for constructing the work harbour and the upper sections of the Northern and Southern Breakwaters on the foundations, constructed by their joint venture partner VOACZ, specialised in dredging and marine construction works.

The overall construction period was planned initially from 22nd August 1997 to 15th August 2000. In the course of the project an extension of time was granted, owing to extra works involving the realignment and extension of the Northern Breakwater. This resulted in the extension of the construction period to 1st September 2001.

SETTING UP CAMP

After a long period of contract negotiations, the contract for the ECPP/C4 Breakwater Construction was awarded in July 1997. Establishing offices and housing facilities for the staff were the first challenges.

Work had to start immediately, so the majority of the VOACZ staff were based in Chennai where temporary offices were set up in a hotel, because camp site facilities were still under construction by HCC. However, excessive traffic and traffic jams on the roads between the site at Ennore and the Chennai hotel cost too much valuable time, better spent on preparing the actual dredging and rock dumping activities.

The decision was made to move the team to the site for housing and offices at Ennore while the surrounding

infrastructure works and final completion of the camp site facilities were still in progress.

By the beginning of 1998, Van Oord ACZ staff had moved to these facilities. The camp was fully equipped for food and lodging of the, in the majority, European staff and a well had to be bored to provide fresh water. The necessary precautions were taken to provide medical care in this rather remote area, including contracting a helicopter service to evacuate employees to the leading Chennai hospital in case of an emergency.

CONE PENETRATION TESTS AND SOIL BORING

Additional engineering studies, based on the future use of the Ennore Coal Port, had shown that the Northern Breakwater had to be realigned and extended with 400 m. To determine the extent of the additional dredging and backfill works, a soil investigation campaign had to be conducted. These works were subcontracted to Fugro, a Dutch company specialised in soil research.

The Indian branch of Fugro mobilised a self-elevating platform to the site and started taking boreholes in the specified zone. The researchers soon found out that the bearing capacity of the sea bottom was so low that the poles of the platform got stuck in the mud and clay.

Owing to this constraint and the bad sea conditions, only a limited number of borings could be taken. During this process it was decided to execute further cone penetration tests (CPT) that could then be compared to the limited number of boreholes, which were possible to execute. The results of these tests were then compared with previous test results and extrapolated over the whole area. The conclusion was reached that substantial additional dredging and backfilling were necessary. All these extra works had to be executed in the same non-monsoon period.

DREDGING AND BACKFILL

Previous surveys and soil investigations, particularly within the breakwater alignment, had shown that the bearing capacity of the soil was insufficient to support the weight and to ensure the stability of the breakwaters. Therefore, in future breakwater locations large quantities of soil had to be removed to a level of -15.00 m. and backfilled with suitable sand. This had to be accomplished in the short time frame during the non-monsoon period. Additional soil investigation, which was executed as a result of the realignment of the Northern Breakwater, resulted in a further increase in depth and length of the trench to be backfilled by suitable sand from the offshore borrow area.

The unsuitable materials were dredged with hopper dredgers and dumped at sea in a designated area at water depths of at least 20 m. Suitable sand was dredged in an offshore borrow area, located approximately 6 km from the tip of the Northern Breakwater. In May the first two trailing suction hopper dredgers *Orwell* and *Volvox Hansa* arrived at Ennore to start the dredging activities. Bringing in two trailing suction hopper dredgers was necessary, because of the available time frame and the limited water depths of the working locations where dredging and infill were required.

The *Volvox Hansa* with an unloaded draught of approximately 6 m started dredging in the deeper trenches of the Southern and Northern Breakwater in water depths varying from 11.5 to 8 m. and also worked with reduced loads in shallower areas. The *Orwell*, on the other hand, concentrated on the Coal Wharf Trench as her loaded draught was more suitable to manoeuvre in

shallower water depths. This trench had to be dredged on the future location of the coal unloading jetty, to be constructed as part of the overall construction scheme.

Taking into account the fairly small manoeuvring space for this type of ship in combination with the shallow water depths and a tight schedule of working in the non-monsoon season, the planning and coordination of the dredging activities was a complicated process.

After an initial in-survey, the dredging operations could start. During the dredging operations interim surveys were carried out to monitor the progress of the works. When sections of the dredged trench were completed and the final survey was approved, backfill could start with the dumping of suitable sand. Backfill materials have to be placed in successive layers.

Because of the shallow water depths in and surrounding the trenches, especially close to the shore, the *Volvox Hansa* could work in these areas only with reduced loads. Dredging and dumping had to be carried out with utmost care according to a strict dumping sequence. To ensure safe operations, the overflow system of the *Hansa* was modified to allow maximum access in shallow waters. The final result of the backfilling/dumping process was that final levels were achieved within the contractual tolerances.

AN INNOVATIVE METHOD OF COMPACTION

The contract specified the following criteria for the specific density, q_c , to be obtained for the underwater fill underneath the breakwaters:

Figure 2. A three-dimensional model of the North Breakwater at Ennore.

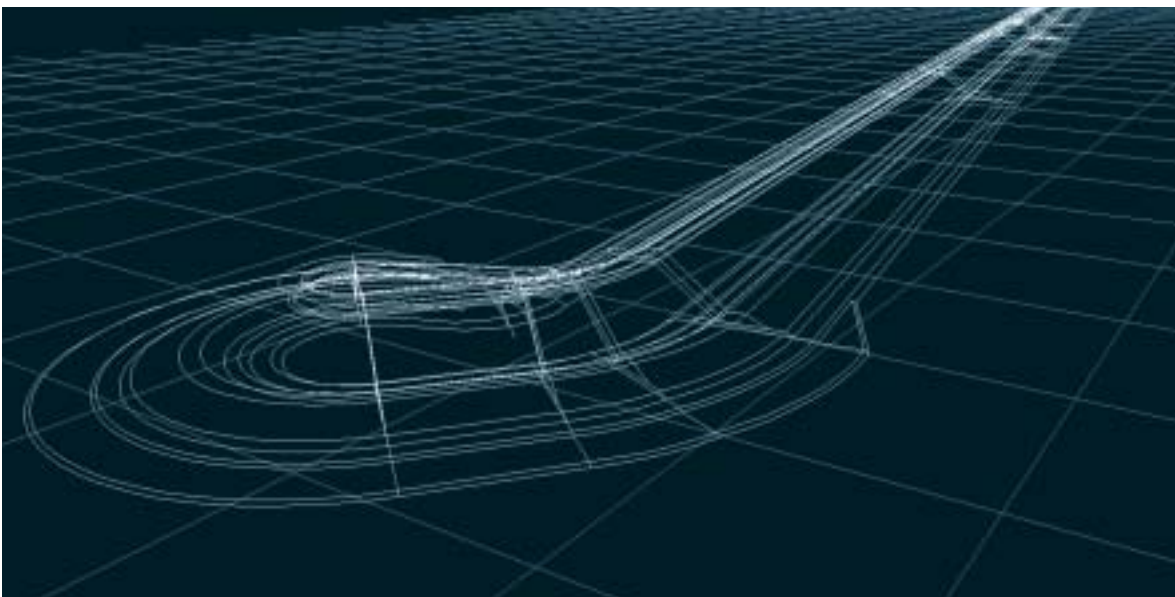




Figure 3. The side stone dumping vessel Frans being loaded at the temporary work harbour.

1 m below top of the fill	: qc ≥ 6 mpa
2 m " " " " "	: qc ≥ 10 mpa
3 m " " " " "	: qc ≥ 12 mpa

To meet with these criteria, the contract also specified that underwater compaction of the fill had to be undertaken, according to a method to be proposed by the contractor. Cone penetration tests (CPTs) had to be executed to verify the correct density in the upper 3 m of the fill.

To make sure that the compaction of the sand met with these requirements, a special dumping method was adopted for the backfill operations. Based on laboratory tests and tests undertaken in the borrow area, the contractors came to the conclusion that the borrow area contained sufficient quantities of good quality coarse sand with phi-values of 34° and 35°. These phi-values were such that, in combination with the adopted dumping method, good stability and compaction of the fill could be expected in accordance with the contractual requirements. VOACZ carried out a number of additional laboratory tests and studies of the sand to verify the relation of the CPT and the phi-value for this type and gradation of sand.

During the course of the mobilisation period of the secondary compaction equipment, it was decided that 100% compaction of the backfill area would be carried out, based on the results of a pilot test. This pilot test was executed over an area of 100 x 100 m², within the alignment of the Southern Breakwater. After compaction tests had been carried out, the engineer would then decide whether additional compaction was still necessary over the remaining area.

A vibro-compaction method, especially developed by VOACZ for this project was chosen for the compaction.

After being refitted with special equipment for this operation, the multipurpose, stone-dumping vessel *Jan Steen* was mobilised from Singapore and brought to the site. The *Jan Steen* disposes of a dynamic position system and has a I 3/3 Special Service Deep Sea classification. Given the rough sea conditions on the site, it was necessary to develop a technique whereby the ship and vibration unit could operate independently.

Therefore on the rear side of the ship a 200-tonne crane was mounted to lift a special frame (rig) with a weight of 20 tonnes from the ship to and from the sea bottom. This frame was specially developed for this project, designed in The Netherlands and built in Batam, Indonesia. Its purpose was to manoeuvre the vibration needle, mounted in the frame, underwater into the fill. The frame was designed in such a way that it could absorb the underwater sea movements and the forces resulting from the vibrator block and needle. The vibration unit consisted of a vibrator block and specially designed needles, 1.2 m wide at the needle's point. This equipment was shipped in from The Netherlands. With this equipment it was possible to achieve the compaction criteria for the upper 3 m of the fill.

After the *Jan Steen* had been mobilised and the frame erected, the multipurpose vessel was brought into position above the test location (100 x 100 m²) and the frame with vibration blocks and needle was lowered down by crane and winches. Steered by remote control, the needle penetrated into the soil until the lowest point was reached. Then, in one unanimous movement, the needle was pulled up, vibrating at the same time, to compact the sand.

These penetrations were executed according to a predetermined depth/time sequence and according to a grid agreed with the Engineer.



Figure 4. The fully loaded SSDV Frans leaving the workharbour.

After completion of the vibro-compaction in this area, several cone penetration tests were executed and soil samples were taken by borings and tested in the laboratory. Based on the test results it was decided that the required angle of internal friction and thus the required density of the fill had been achieved. So further improvement by means of compaction resulting from the vibro-vibration was not required and the *Jan Steen* and compaction equipment were demobilised from the site.

ROCK DUMPING OPERATION

After the trenches of the Northern and Southern Breakwaters had been filled in and compacted, the rock-dumping operation was carried out by VOACZ up to 4 m below sealevel with the side stone dumping vessel *Frans* (Figures 3, 4 and 5). Approximately 1,250,000 tons of rock had to be placed by this method. Above the – 4.00 m CD level, HCC then took over the rock dumping with land-based equipment by back tipping method, for which they used 40 tonne dumpers (Figure 6). By this method, HCC completed the breakwaters by dumping the remaining core and placing the armour layers, accropodes and concrete capping. In total over 2,500,000 tons of rock had to be placed.

While the *Jan Steen* was still working on the compaction trial of the backfill of the Southern Breakwater, the dynamic positioned side stone dumping vessel *Frans* was already dumping rock on the areas where no soil improvement was required for both the Southern and the Northern Breakwaters. With the *Frans*, first rock grade G- (1-50 kg) and F-filters (50-500 kg) on both seaside and portside had to be dumped, prior to dumping the quarry run (1 to 1000 kg) for the core of the

breakwaters. Then different grades of rock, varying between 300 kg and 2.5 tonne were used for the underwater slopes of the Southern and Northern Breakwaters, according to the design of the construction.

The northeast monsoon

The northeast monsoon started while the *Frans* was still working on the rock-dumping operations. If weather conditions became unsafe because of a cyclone, the vessels would not be able to seek shelter in the harbour of Chennai as all ships are evacuated from this harbour when a cyclone is expected. The vessels would therefore have to sail to Colombo, in Sri Lanka, four days sailing from Ennore.

Luckily the weather stayed good enough to continue working off the coast of Ennore. Only once did the ships have to seek refuge in the harbour of Chennai because of high waves, and only once did she have to anchor offshore. In general, weather conditions were

Figure 5. Close up of the *Frans* sailing to the South Breakwater.





Figure 6. Stone dumpers discharging rock class G at the work harbour.

better than expected and weekly productions of sometimes above 50,000 tonnes a week were able to be achieved.

Littoral tide effects

A setback was caused by the littoral tide and strong waves, before and during the northeast monsoon in 1997. When the *Orwell* and *Volvox Hansa* started working on the Southern Breakwater in accordance with the contractual programme, the waves and littoral tide caused great problems. Outside the northeast monsoon, the littoral drift causes erosion of the coast line in a south to north direction. During the northeast monsoon the wind direction changes and the erosion of the coast line is reversed: from north to south.

Before the monsoon, as the Southern Breakwater was being constructed, the coastal line north of Chennai to the Ennore shoals reclined for approximately 120 m inland as a result of the breakwater's obstruction. That year, the coastal recline was so grave that the coastal road, along which sand for the infill of the breakwater trenches was transported to the site, came under threat of being undermined.

At the same time the whole area south of the Southern Breakwater was transformed into an enormous shoal, while sand sedimentation also threatened to block the harbour entrance and therefore the entrance to the work harbour VOACZ needed for their operations. Meanwhile the alignment of the Northern Breakwater suffered from severe erosion on the seaside.

The location of the work harbour had to be adjusted and additional maintenance dredging had to be executed. When the northeastern monsoon started and the littoral tide reversed, the recline of the coastline and the erosion of the Northern Breakwater were back to normal within four weeks.

QUARRY, STOCKPILE, WORK HARBOUR AND CONCRETE PLANT

To construct the Ennore breakwaters, 3 million tonnes of rock were needed for the rock-dumping operations (Figure 7). The Employer and the Engineer had appointed an area at Karikal, situated approximately 80 km inland east of Chennai, for the development and exploitation of the rock quarry. Former investigation tests had established that the specific gravity of the rock (SG 2.6) in that area complied with the contract criteria.

Under a separate contract, the ECPP/C1-contract, it was the task of HCC, who were awarded this contract as well, to develop and exploit the Karikal quarry. The quarry had to produce different grades of rock: over 1.7 million tonnes of quarry run and over 1.3 million tonnes of rock grading between 50 kilograms up to a quantity of 173,000 tonnes ranging between 2.5 and 12 tonnes.

Transport of the rock was provided by trucks from the quarry to a nearby railway station over a distance of 10 km and from there by train up to the site at Ennore. The existing railway was extended to the Ennore site, where the stockpile was situated. Also special skips were constructed for the transport of the rock. The skips were loaded in the quarry on trucks and, at the railway station, lifted from the trucks and placed by portal cranes into the railroad carriages. Another set of portal cranes at the Ennore site lifted the skips off the train into awaiting trucks. The trucks then drove to the selected stock pile area on site, where the rocks would be dumped in specially assigned areas for the different grades of rock.

According to contract, rock-dumping operations could only be started after 1 million tonnes of rock had been put in the stockpile. Before starting the rock-dumping operations with the *Frans*, a work harbour had to be constructed. On this location the rocks, loaded on



Figure 7. The placing of in situ concrete slab and wave wall at the South Breakwater under construction.

trucks at the stockpile area, were unloaded with cranes on board the *Frans*. This work harbour was located at the existing seashore, halfway between the two future breakwaters, and had to be built in an area not yet protected by the breakwaters.

A causeway with a length of approximately 200 m was built from the beach into the sea, with rock taken from the stockpile to reach a water depth of -3.00 m. At this point the harbour was built, consisting of a platform made of quarry-run, a quay wall made of concrete blocks for the mooring of the *Frans* and other vessels, and a harbour basin dredged by a small dredger. A temporary breakwater protected the harbour. All these works were executed by HCC. As indicated earlier, the changing littoral drift caused problems for the maintenance of the required depth of the harbour.

For the ECPP/C-4 contract HCC built a complete concrete plant at the Ennore site for the production of the accropodes and concrete capping slabs, necessary for the top layer of both breakwaters. Over 8500 accropodes were fabricated with weights of 9.6, 12 and 15 tonnes each. Also over 65,000 m³ of concrete had to be produced for the construction of the concrete slab on the breakwaters and the blocks of the work harbour. Furthermore a well-equipped laboratory was built to test concrete, sand, soil and rock samples.

Conclusion

Although VOACZ's part of the works is completed by now, the final completion of the breakwaters by HCC and the dredging of the harbour basin, some of the construction of the coal jetty and other building and road works by other contractors is still in progress.

The execution of this project was a challenge to develop and apply new techniques and solutions for a project that was executed under sometimes difficult circumstances.

Thanks to solid foundations, the new port will provide a safe shelter for all ships when the port becomes operational in the year 2001.