

CHAPTER 128

PROBLEMS OF DESIGN AND CONSTRUCTION OF AN OFFSHORE SEAWATER INTAKE

by

D.W. STANDISH-WHITE^{*}

and

J.A. ZWAMBORN^{**}

ABSTRACT

A seawater intake had to be constructed for a diamond mine on the coast of Namibia just north of Oranjemund. The solution adopted consisted of a piled jetty with a dolos island on its seaward end protecting the pump chamber which was built of closely spaced concrete piles.

The paper briefly describes the various problems encountered during the construction of the intake, including :

- limited penetration of the piles leading to the failure of the first jetty,
- serious slump of the initial dolos island,
- breakages of dolosse due to excessive movements during storms,
- considerable wear of the vertical spindle pumps due to sand and surging.

Also described are the engineering solutions which had to be found at very short notice for immediate application.

INTRODUCTION

An assured supply of 2 200 m³ per hour (37 m³/min = 10⁴ U.S. gall/min) of sea water was required for a diamond recovery plant to be commissioned early in 1977 on the southern coast of Namibia (South-West Africa). This coastline consists of a particularly featureless beach of deep sand underlain by variable coarse boulder gravel beds covering saw-tooth profile schistose bed rock. Often pounded by high surf caused by heavy swells, a strong littoral drift transports large amounts of sea-bed material

^{*} Consulting Civil Engineer, Anglo American Corporation of South Africa Limited, Johannesburg, South Africa.

^{**} National Research Institute for Oceanology, CSIR, Stellenbosch, South Africa

northwards along the coast, depending on the prevailing weather conditions.

Various alternative solutions were considered for this sea water intake, including a submarine tunnel, an on-shore stilling basin, in-shore beach filtration ponds, radial interception caisson wells and finally a piled jetty with a vertical pump well formed of closely spaced piles at its seaward end situated in the centre of an artificial dolos island. All but the last alternative had already been tried before with varying degrees of success along the 200 km of arid coastline reserved exclusively for diamond mining.

Having no time to conduct extensive model studies but armed with offshore seabed profiles and various other regional marine data and experience, it was decided, because of the evident impracticability of the other solutions in this locality, and on the advice of the Specialist Marine Contractors, to opt for the offshore island approach.

ORIGINAL JETTY DESIGN

The design adopted was for a light precast concrete jetty carried on slim precast concrete piles, each with a stub rail toe to penetrate the heavy seabed gravels (see Fig. 1.a). This type of construction had been used successfully by the contractors in other situations along the same coast. Construction commenced late in 1974, but it soon became apparent that adequate penetration of the piles to the bedrock through the overlying layer of boulders and gravels was not being achieved and various means of grout stabilization of the toes were attempted in 1975. After 180m had been completed this jetty failed in a storm, partly through excessive pile settlements from the scouring action around some of the pile toes and partly because the whole structure was set too low, and this jetty was abandoned.

FINAL JETTY DESIGN

After full scale tests on shore, a redesigned special pile which would penetrate down to the bedrock and then allowed for subsequent axial drilling, rock anchoring and grouting was developed. The modified pile toe adopted consisted of a long, thick-walled steel tube with a specially hardened cutting edge (see Fig. 1.b). A new similar jetty 321 metres long (but 1.5m higher) was successfully constructed on this basis adjacent to the old one between September 1975 and February 1976 (see Figs. 2 and 3).

The old jetty was partially demolished to avoid any possible future interference with the stability of the new one due to its further collapse. Both the embedded and attached steelwork of the new structure were cathodically protected against corrosion using a constant impressed current and sacrificial anodes.

DAMAGE TO ORIGINAL DOLOS MOUND

The Contractor designed and constructed the first terminal island mainly of 6 ton dolosse below MSL, capped with 10 ton units above MSL, on a

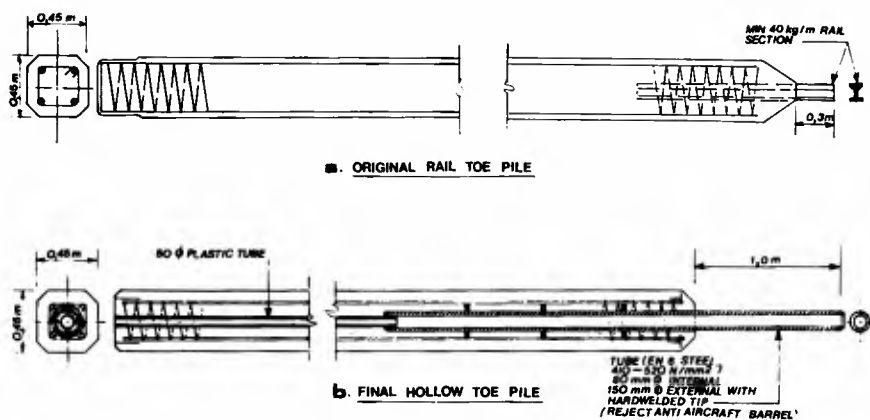


FIG. 1 SPECIAL PILE TOES

FIG. 2 NEW AND OLD JETTIES WITH DIAMOND RECOVERY PLANT
IN THE BACKGROUND

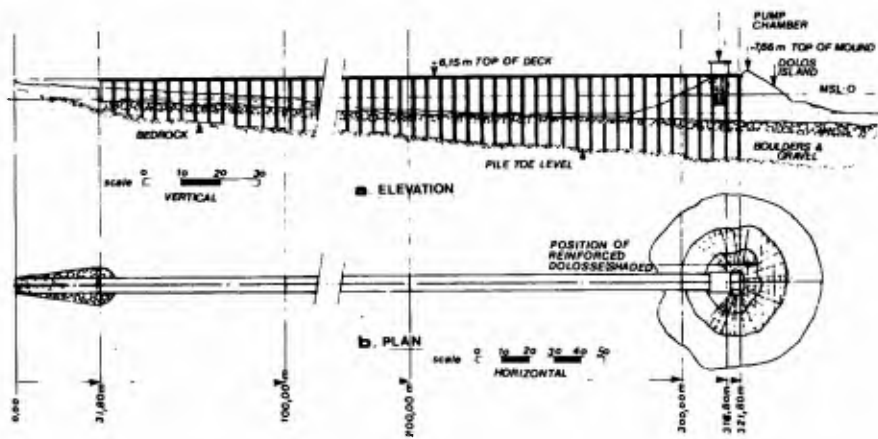


FIG. 3 FINAL JETTY LAY-OUT



FIG. 4 CLOSE-UP OF DAMAGED DOLOS MOUND

foundation of a carefully placed gravel mat. A total of 1100 6 ton and 120 10 ton dolosse were placed between April and June of 1976 but the mound settled considerably more than expected. At this stage, the National Research Institute for Oceanology was called in for advice and during an inspection in September 1976 it was noted that several 6 and 10 ton Dolosse had broken and the mound had slumped by about 3 to 4 m, exposing the pump chamber (see Fig. 4).

The apparent reasons for the damage to the dolos mound were :-

1. The dolos mass was too small, resulting in their removal from the mound.
2. Sea-bed changes of up to 4 to 5m have been recorded in the jetty area, and underscour of the mound itself could well have occurred, also resulting in larger waves.
3. Dolos breakage of up to 5 per cent occurred during placing and further breakages may have occurred due to excessive movements during heavy seas.
4. Possibly insufficient tensile strength of the original dolos concrete for the wave loads imposed.

REQUIRED DOLOS MASS

The structure was originally designed for a wave height of 6m, but a further study using more extensive wave data revealed that a 7,1m deep-sea wave could occur once in 25 years, which would increase (due to shoaling) to 7,7m at the seaward toe of the structure. The original foundation of the dolos mound was set at about -5m to mean sea level, but the water depth immediately seaward of the structure could well increase up to about 10m due to scour, and thus a 7,7m wave could reach the structure. A 7,7m wave height was therefore adopted for the re-design of the dolos mound.

Using a simple formula for a breakwater trunk¹, the following desirable dolos unit mass was deduced :-

$$W = (0,3H)^3 = (0,3 \times 7,7)^3 = 12,3t$$

Considering that the mound is effectively a 'double breakwater head', this mass should be further increased by 50 per cent to 18,5t as compared with the original 6 to 10t dolos design.²

Because no tower crane was readily available to handle such heavy units it was decided to try to increase the concrete density to 2,7t/m³ in an attempt to increase dolos stability. From all known stability formulae, the required block mass is inversely proportional to the relative density

to the third power² and an 11,3t dolos should theoretically be as stable as an 18,5t dolos, if cast in the same moulds as the earlier 10t units, but with a nett density of $2,7\text{t/m}^3$. Moreover, the available tower crane could still handle these units. A re-design, using 11,3t dolosse of higher density to protect the pump well and an 8m wide toe protection of 6t normal density dolosse was therefore adopted as the best expedient in all the circumstances of the problem (see Fig. 5).

HYDRAULIC MODEL TESTS

Due to the exposed position of the structure - right in the breaker zone during heavy seas (see Fig. 6) - and because of its dissimilarity to usual breakwater structures, it was considered necessary to carry out confirmatory hydraulic model tests. Due to severe lack of time, only two simple tests using a 'half model' in a wave flume could be done, one test using normal density dolosse ($2,3\text{t/m}^3$ in the model representing $2,37\text{t/m}^3$ prototype), and a second test with higher density dolosse ($2,57\text{t/m}^3$ representing $2,63\text{t/m}^3$ prototype). The tests were done in a 1,5m wide and 0,7m deep regular wave flume with the model built on the available 1:20 slope (prototype slope was about 1:30). A water depth of -7,5m below mean sea level at the centre of the mound was used. The entire mound (half model) was built of 530 82 and 92 gr dolosse, representing 10,3 and 11,5t full scale units. Model wave heights were increased in small intervals up to the equivalent of 7 m high waves with a period of 11,5s. A model view is shown in Fig. 7.

With the *normal density* dolosse, the model showed the first damage for 5m high waves. The damage, particularly on the side of the mound, increased rapidly with the 7m waves causing a 2m slump thus exposing the pump sump to the direct wave forces. A marked improvement was obtained using the *high density* dolosse. With the 5m waves, very few dolosse were displaced (< 1%) while a total of only 17 model dolosse were displaced with the 7 m waves (about 4%).

HIGH DENSITY DOLOSSE

The tests thus confirmed the significantly greater stability for the higher density dolosse and a high density concrete mix was designed to produce the required 11,3t dolosse using the original 10t dolos moulds. Cost and time considerations ruled out importing a very suitable magnetite ore from inland with a relative density of $4,8\text{t/m}^3$ and any other densifying possibilities such as the use of cast steel Scrubber-Mill Balls. Some higher density aggregate was eventually obtained from the mine itself, being the lighter fraction (S.G. $2,89\text{t/m}^3$) from the heavy media separators of the diamond recovery process. A $2,7\text{t/m}^3$ concrete mix was achieved in the laboratory using this heavier aggregate, with a compressive strength of 40 MPa.

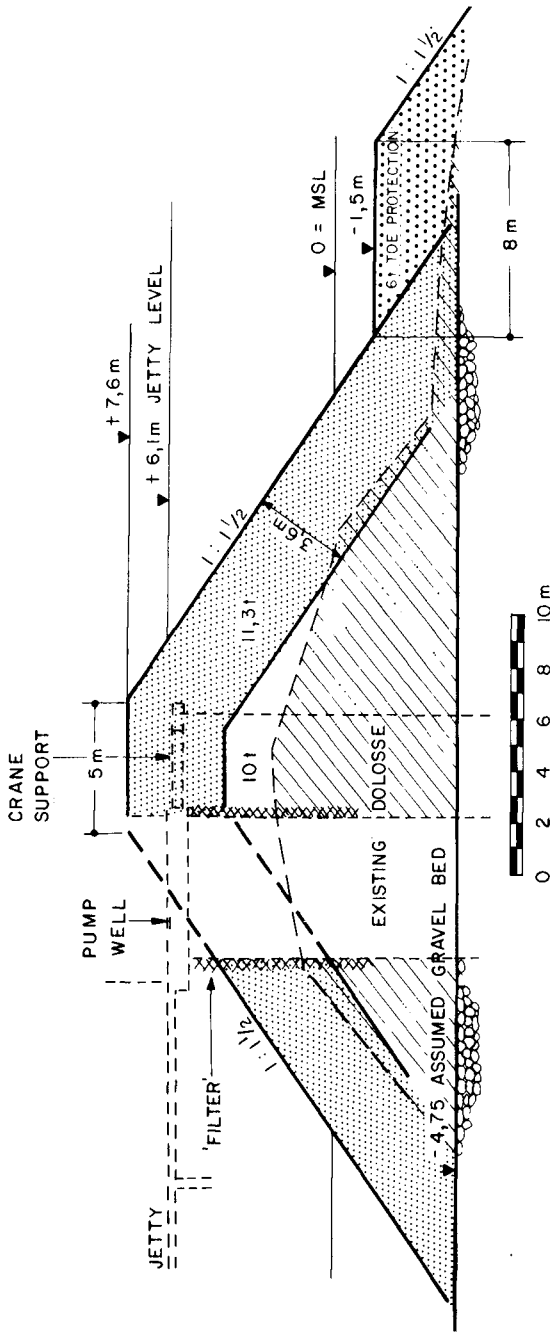


FIG. 5 RE-DESIGN OF DOLOS MOUND



FIG. 6 HEAVY SURF POUNDING THE STRUCTURE



FIG. 7 FLUME TEST ON 'HALF MODEL'
7 M BREAKING WAVES

Unfortunately it was later established that, because of high density aggregate supply problems from the mine, the concrete density actually obtained was only $2,55 \text{ t/m}^3$ and not the $2,7 \text{ t/m}^3$ required, thus making the dolosse still too light (maximum mass $10,7 \text{ t}$) for the accepted design wave height.

The physical dimensions of the dolosse were as follows : dolos height 3,00 m, waist to height ratio 0,313, circular fillets 0,033 of the dolos height and a volume of $4,2 \text{ m}^3$.

STORM DAMAGE DURING CONSTRUCTION OF THE REDESIGNED DOLOS MOUND

Placing the new heavier dolosse to the revised profiles began in the late summer (February 1977) and during the subsequent two months, half of the required additional 518 "ten ton" and 1 150 "six ton" dolosse had been placed. At this juncture the Contractor was on schedule to complete the mound before the winter storms, but the availability of the placing crane became less and less as the plant engineers used it while battling to keep the pumps operating at a rate sufficient to supply adequate water to the plant.

Early in May 1977 and before the island was complete, a heavy swell arose, coinciding with a near equinoxial high tide (2m variation). By then, 350 ten-ton capping units and 617 six-ton toe protection units had been placed.

Breakers of between 5 to 6m, corresponding to 4 to 5 m incident waves with a projected occurrence of 7 and 1 day per year respectively, occurred continuously for three days. Over 100 dolosse were lost from the mound which represented about 10 per cent damage. The damage was especially heavy on the seaward side, where the mound slumped some 3m. The dolos breakages varied from a single fluke broken off to breaks through the shank. It was also obvious from the wear on the dolosse that the units had been thrown around during the storm.

The main reasons for the damage to the structure are as follows :

1. For an incident wave height of 5 m , the model tests showed considerable damage for the $2,37 \text{ t/m}^3$ but only 1% damage for the $2,63 \text{ t/m}^3$ dolosse. For the $2,55 \text{ t/m}^3$ dolosse, which were used on the island, several per cent damage, were therefore, to be expected.
2. It had been reported by the supervising staff that 5 per cent of the dolosse broke during placing which was probably caused by generally heavy surf conditions (see Fig. 6). This represents about 17 of the ten ton and 30 of the six ton units placed since February 1977. The broken dolosse were thrown around during the storm causing other units to break.
3. Because the crest of the mound was still several metres below its

final design height, the top layer of dolosse was relatively loose and exposed to the full overtopping breaker force, causing excessive dolos movement resulting in breakages.

4. The timing of the storm was also particularly destructive, because a freshly-built dolos structure usually requires an initial shakedown period for minor settlement caused by average waves.

FINAL COMPLETION OF THE DOLOS MOUND

Although attempts to produce high density dolosse have not been abandoned, the need to complete the dolos island, which forms the protection of the pump chamber, dictated an urgent 'engineering' solution. Accepting that the 10,7 ton dolosse were too light for the 7,1 m incident design wave height, it was decided to 'reinforce' them using sections of old 20 kg/m railway lines readily available on the mine. This rail reinforcement was tack-welded in a dolos shape to provide core reinforcement. Experience has since shown that this reinforcement holds the dolosse together well, even if the concrete cracks. Thus, although the steel may eventually corrode, it meanwhile contributes to the mound's stability by keeping the dolosse intact for a much longer period. A small beneficial increase in total mass also results from the steel inclusion but these 'reinforced' dolosse were made of normal density concrete (S.G. 2,4) and the mass of these units was therefore only about 10,0t.

It finally took a total of 2 414 six ton and 853 ten ton dolosse to complete the dolos mound in accordance with the profile shown in Fig. 8 (August 1977).

Settlement of approximately 1 metre has since occurred during its first winter season, but no heavy storms have been experienced so far. Considerable stability does now seem to have been achieved, together with calm pumping conditions. A close watch will be kept of the island's future performance and its behaviour will be correlated with wave heights recorded seaward of the jetty with a waverider buoy.

PUMP PROBLEMS

During the early commissioning of the large (175 kw) vertical spindle centrifugal pumps (Early 1977), it became apparent that surging and turbulence in the pump chamber was far greater than had been expected. A concrete baffle platform was then cast and lowered down the chamber and set at mean sea level, and the pumps were encased in stainless steel sleeves (see Figs. 9 and 10). These measures were highly successful in both supporting the pumps and in damping out the surges in the chamber. Completion of the final mound has also had a beneficial effect on surging and sand build-up in the sump.

The pump installation has necessarily been fully operational since July 1977, but was plagued with high wear rates due to the high

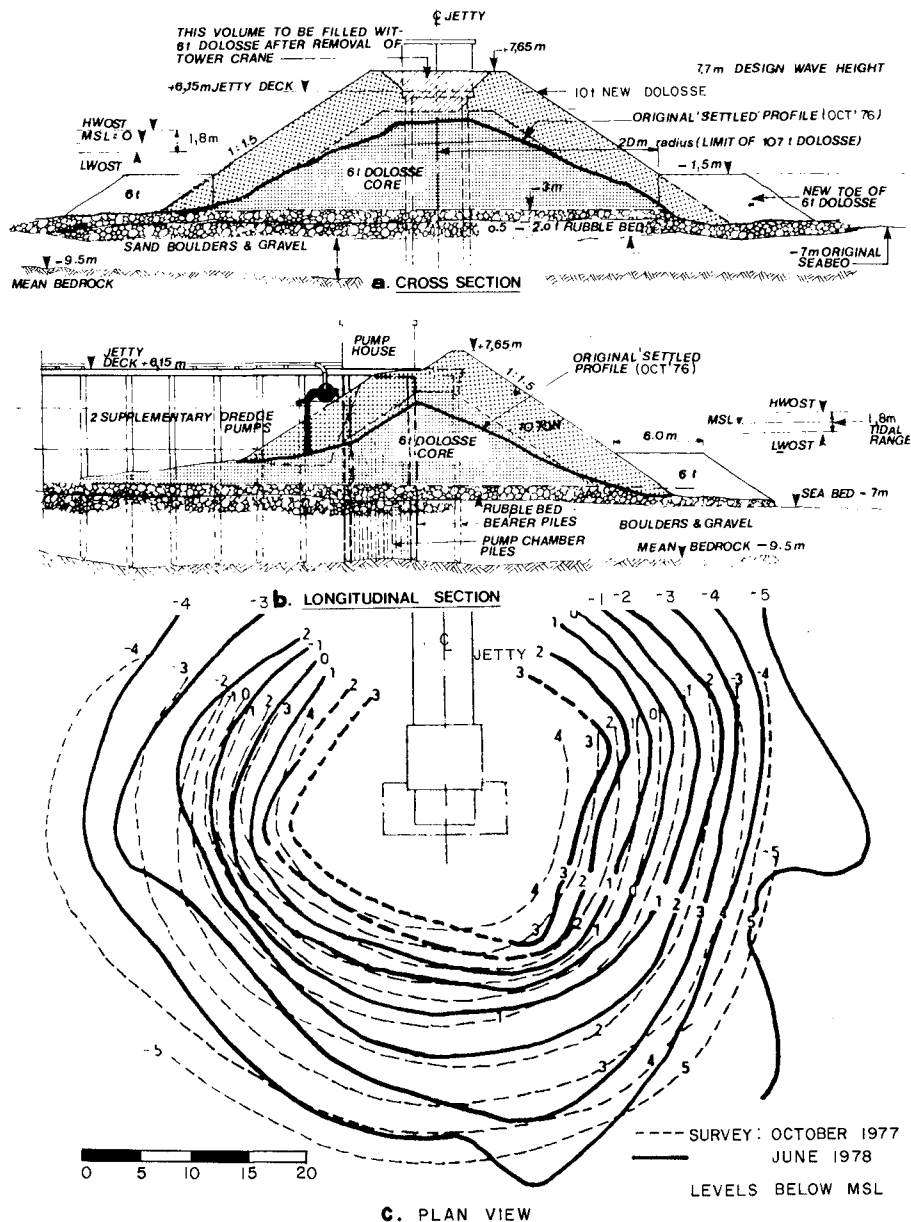


FIG. 8 DOLOS MOUND AFTER COMPLETION

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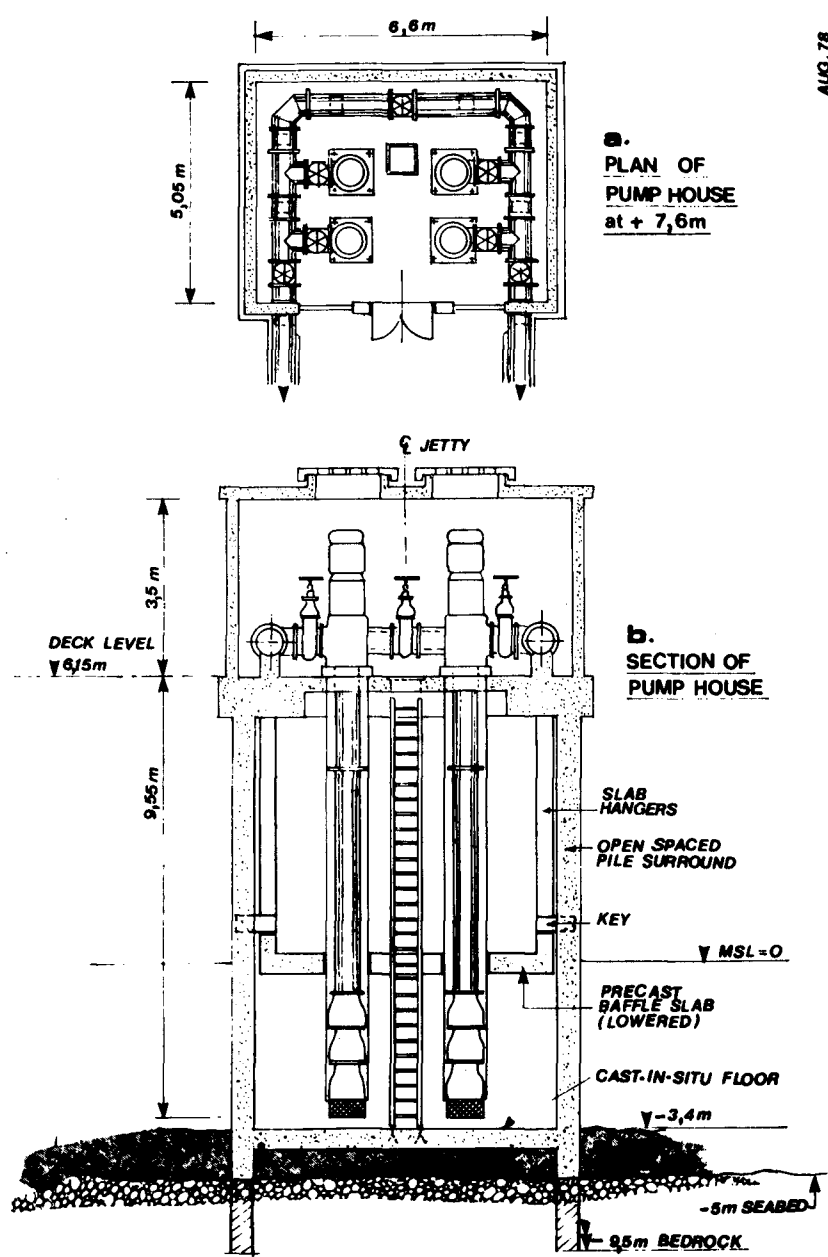
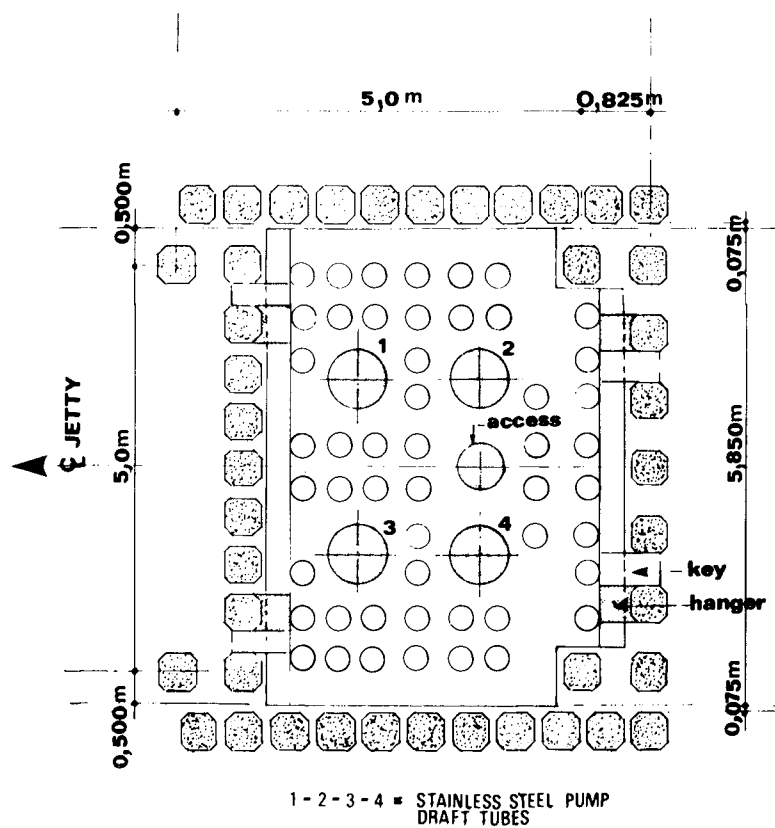


FIG. 9 PUMPHOUSE



SECTION AT MEAN SEA LEVEL

FIG. 10 PLAN OF BAFFLE SLAB IN PUMPING CHAMBER

percentage of sand suspended in the seawater inside the chamber. Each of the four pumps had an average initial life of only 30 days before lifting for replacement of the wearing components. A number of mechanical solutions were tried but no suitable vertical spindle pumps of this size and duty are on the market at present.

Very reluctantly, recourse had to be made to installing a pair of horizontal spindle, rubber-lined dredge pumps mounted on a platform underslung below the jetty in the immediate lee of the mound (see Fig. 8). This system has proved embarrassingly effective and reliable up to date. Two standby submersible pumps are installed in two of the draft tubes and an experimental vertical spindle pump with continuously grease-fed bearings is being operated in the third tube with good results over the past six months.

CONCLUSION

This paper is presented not as a technical success story but as an opportunity for fellow coastal engineers to assess and consider the many problems that presented themselves and perhaps to avoid them on a similar structure in the future.

Figs. 11 and 12 show the structure about one year after completion.

REFERENCES

1. Zwamborn, J.A. "Dolosse for Coastal Works". Proc. 5th S.A.I.C.F. Western Cape Convention, Stellenbosch, September 1976.
2. PIANC, "Final Report of the International Commission for the Study of Waves". Annex Bull. No. 25 Volume III, Brussel, 1976.

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FIG. 11 DREDGE PUMPS IN LEE OF DOLOS MOUND



FIG. 12 COMPLETED INSTALLATION, JULY 1978