CONSTRUCTION SEQUENCE MODELLING FOR HARBOUR BREAKWATER

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Abstract

Gansbaai fishing and pleasure craft harbour is situated approximately 160km east of Cape Town. Modifications and extensions were required to the existing breakwater as well as construction of an internal access mound. An investigation was commissioned into alternative construction methods and construction sequences for the modifications and extensions.

The aim of the study forming the subject of the paper was to establish as accurately as possible the optimum sequence of construction for the various phases of the work and to establish the optimum construction methods to be adopted so that any damage to the work was minimised as construction proceeded. By means of a three dimensional hydraulic model, alternative construction methods and sequences were investigated under varying wave heights and sea conditions. Minimum wave heights and the sea direction causing damage or localised displacement of the elements of construction were studied.

1.0 INTRODUCTION

1.1 General

Gansbaai fishing and pleasure craft harbour is situated approximately 160km east of Cape Town. Modifications and extensions were required to the existing breakwater as well as construction of an internal access mound. The contractor awarded with the contract for the work to be carried out commissioned an investigation into alternative construction methods and construction sequences for the modifications and extensions. The investigation was to be undertaken by means of a three dimensional hydraulic model. Various construction methods and construction sequences were to be studied under certain wave heights and sea conditions for the modifications and extensions to the new harbour.

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Certain construction phases were to be modelled, varying the sequence of operations, during which time the minimum wave height parameters were to be established which would result in damage or localised displacement of the elements used in the construction. Simultaneously the extent of the damages would be assessed and possible protective measures to be taken would be studied.

1.2 Model Availability

The National Rsearch Institute for Oceanology (NRIO) at Stellenbosch was commissioned by the Fisheries Development Corporation to make available to Oames & Moore the model of the New Harbour at Gansbaai which had been used during the design stage model analysis (Ref 1). Personnel for the operation of the model and for building the additional model facets required for the tests were supplied by NRIO.

2.0 CONSTRUCTION SEQUENCE

Various methods of construction and possible construction phase sequences which were envisaged as being viable during prototype construction were considered during the planning of the construction sequence modelling. The various construction sequence alternatives would require to be analysed on the model under varying sea conditions. A diagrammatic representation of the harbour is shown in Figure 1.

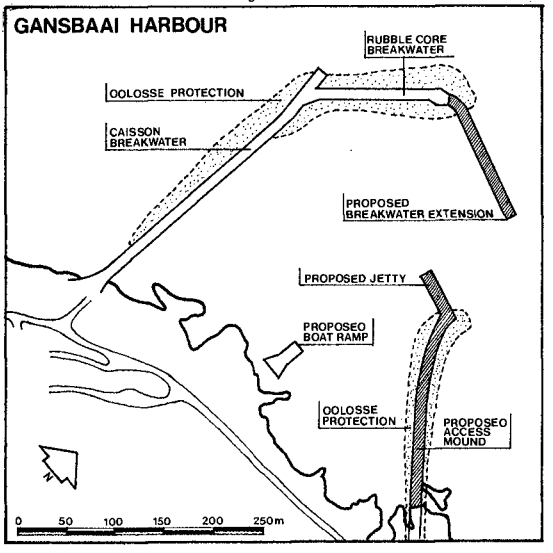

Fig. 1 Gansbaai Harbour

The information required from the model analysis may be summarised as follows:

2.1 Rubble Access Mound

It was required to establish sea and wave height parameters under which the construction of the rubble access mound could proceed.

The rubble access mound was to be modelled to two different lengths representing two stages of construction. At each of the two construction stages the access mound would be subjected to a range of wave height conditions from the direction 11° north of west.

During the test series the proposed caisson breakwater extension would be varied in length from its fully completed length to approximately 1/3 of its length.

2.2 Caisson Extension to Rubble Core Breakwater

It was required to examine the effect of various sea and wave height parameters on the construction of the caisson extension to the rubble core breakwater.

The hollow caissons to be used during construction were to be modelled to the appropriate mass and dimensions. Various placing sequences and stacking permutations were to be modelled with both hollow and concrete filled caissons. As the caissons were to be placed in various sequences, they were to be subjected to a wide range of sea and wave conditions.

2.3 Modifications to Existing Caisson Breakwater

It was required to examine the effect of varying wave heights, particularly storm conditions, on an advancing construction stage of the modifications to the existing caisson breakwater. It was assumed that 8t fluted concrete blocks would be used in the core underneath the dolosse armouring. The blocks were to be modelled and installed at a particular chainage. The advancing face of the blocks would be left exposed and the dolosse armouring would be completed to a distance of some 10 metres (in the prototype) behind the advancing face.

This construction stage was to be subjected to a range of wave height conditions.

3.0 MODEL FACILITIES

The scale of the model was 1:80. Wave height and period input to the model were based on records obtained from a prototype wave rider situated approximately 1,4km west of the harbour.

The two wave directions used during the model analysis were 11° north of west and due west. The period of the waves from both directions was 13 secs and the sea was considered to be at Mean Sea Level (MSL).

Apart from the basic model layout at NR10 the construction sequence modelling required certain additional features for incorporation in the model during testing. The main items which were to be used in the model testing programme and which were constructed for the model are as follows:

Dolosse	20t and 25t
Caissons	20t (approximately)
Rubble	50-500kg
	1, 2 and 3t
Concrete blocks (fluted)	8t
Concrete blocks (plain)	25t
	40t (for experimental purposes only)
Chain mesh	10t

4.0 MODEL TESTING

4.1 Test programme

For various reasons, some concerning the time required for the manufacture of certain items of construction to be incorporated in the model, it was decided that the order in which the major aspects of the contract would be studied, would be as indicated below.

1 Rubble Access Mound to the jetty
2 Caisson Extension to Rubble Core Breakwater
3 Modifications to Existing Caisson Breakwater

4.2 Model Testing Sequence

The following table, Table 1, contains the sequence of testing carried out during the study of the three aspects of the test programme.

TABLE 1 4.2.1 Rubble Access Mound

Rubble Access Mound	Caisson Extension	Sea Conditions
Full construction length (Ch190)	Full construction length (Ch125)	Wave spectrum 1-6,7m Wave direction 11° North of West
" " "	2/3 construction length (Ch93)	Wave spectrum 1-7,1m Wave direction 11° North of West
" " "	1/3 construction length (Ch40)	Wave spectrum 1-7,1m Wave direction 11° North of West

4.2.2 Caisson Extension to Rubble Core Breakwater

Caisson Placing System	Sea Conditions
Horizontal : 1 to 7 layers Caissons not concrete filled	Wave spectrum 1-4m Wave direction west
Stepped : 1 to 7 layers Caissons not concrete filled	Wave spectrum 1-3m Wave direction west
Vertical (single column) : 1 to 7 layers Caissons not concrete filled	Wave spectrum 1-2m Wave direction west
Vertical (single to multiple columns): 1 to 7 layers Caissons concrete filled	Wave spectrum 1-5m Wave direction west
Vertical and Stepped multiple columns Caissons concrete filled	Wave spectrum 1-6m Wave direction west

4.2.3 Modifications to Existing Caisson Breakwater

Exposed advancing face of 8t block core beneath dolosse	Sea Conditions
No protection	Wave spectrum 1-3m Wave direction 11° north of west
Protection : 4 strings of 3 blocks each fixed to breakwater	Wave spectrum 1-3m Wave direction 11° north of west

Exposed advancing face of 8t block core beneath dolosse	Sea Conditions
Protection : 40t blocks along toe of advancing face	Wave height 3m Wave direction 11° north of west
Protection : 25t blocks along toe of advancing face and chained to breakwater	Wave spectrum 3-7m Wave direction 11° north of west
Protection : Chain mesh approximately 10t	Wave height 4m Wave direction 11° north of west

5.0 RESULTS AND OBSERVATIONS OF MODEL TESTING

The model testing was carried out in the sequence shown in Section 4.2. Photographs were taken prior to the commencement of any test sequence and following each test performed.

5.1 Construction of Rubble Access Mound

The construction of the rubble access mound was modelled at two construction stages:

(i) Full construction length
(ii) Approximately 2/3 construction length

During the testing of the rubble access mound at both of these stages in construction, the caisson extension to the existing rubble mound breakwater was varied from a fully constructed length to 1/3 of the proposed construction length.

The layout of the breakwater model showing the rubble access mound and the caisson extension to full construction lengths is shown in Figure 2.

Each test was run for 10 minutes in the model representing a time of approximately 1½ hours in the prototype. The wave direction was set at 11° North of West at a period of 13 sec. The level of the sea was set at mean sea level (MSL) and the heights of the waves were varied, all waves being as measured at the prototype wave rider buoy west of the harbour.

The results of the testing at the various stages of construction of both rubble access mound and the caisson extension to the breakwater are summarised in Table 2.

Fig. 2 Model layout of Gansbaai Harbour

TABLE 2

Deep Sea Direction	Wave Height	Duration (prototype)	Observation
RUBBLE ACCESS MOUND FULL CONSTRUCTION LENGTH CAISSON BREAKWATER FULL CONSTRUCTION LENGTH			
11° N of W at 13 sec	1,0m - 2,0m	1½ hrs	No damage
"	3,2	1½ "	Slight movement of 2t rock on seaward slope
"	4,2	1½ "	Increased movement of 2t rock
"	5,4 - 6,0	1½ "	Appears calmer at entrance. No further damage
"	6,7	1½ "	No further damage

TABLE 2 (contd)

Deep Sea Direction	Wave Height	Duration (prototype)	Observation
RUBBLE ACCESS MOUND FULL CONSTRUCTION LENGTH CAISSON BREAKWATER 2/3 CONSTRUCTION LENGTH			
11° N of W at 13 sec	1,0m - 3,8m	1½ hrs	No damage
"	5,0	1½ "	50-500kg rubble movement. 1,2&3t rock movement. Damage becoming severe
"	5,9	1½ "	Severe damage
"	7,1	1½ "	" "
RUBBLE ACCESS MOUND FULL CONSTRUCTION LENGTH CAISSON BREAKWATER 1/3 CONSTRUCTION LENGTH			
11° N of W at 13 sec	1,0m - 1,5m	1½ "	No damage
"	1,8	1½ "	Slight rock movement
"	2,8	1½ "	Rock movement increasing
"	4,0	1½ "	Damage becoming severe
"	4,8 - 7,1	1½ "	Severe damage
RUBBLE ACCESS MOUND 2/3 COMPLETE CAISSON BREAKWATER 1/3 CONSTRUCTION LENGTH			
11° N of W at 13 sec	1,0	1½ "	Slight rock movement
"	2,0	1½ "	Severe damage. Advancing face destroyed
CONSTRUCTION OF ACCESS MOUND 2/3 COMPLETE CAISSON BREAKWATER AT 2/3 CONSTRUCTION LENGTH			
11° N of W at 13 sec	1,1m	1½ "	No damage
"	2,0	1½ "	Severe damage to advancing face

TABLE 2 (contd)

Deep Sea Direction	Wave Height	Duration (prototype)	Observation
CONSTRUCTION OF ACCESS MOUND 2/3 COMPLETE CAISSON BREAKWATER AT FULL CONSTRUCTION LENGTH			
110° N of W at 13 sec	1,0m	1½ "	No damage
"	2,0	1½ "	Fairly severe damage
"	3,0	1½ "	Severe damage advancing face demolished

The effect of a wave causing severe damage to the advancing face of the rubble access mound is illustrated in Figure 3. This shows a typical erosion and mixing of rubble to the leeward and seaward sides of the mound. Rubble is also tossed up onto the capping as the whole of the mound ahead of capping becomes eroded.

Fig. 3 Damage caused to advancing construction by 3m wave

5.2 Construction of the Caisson Extension to the Rubble Core Breakwater

The caissons to be used in the prototype construction are shown in Figure 4.

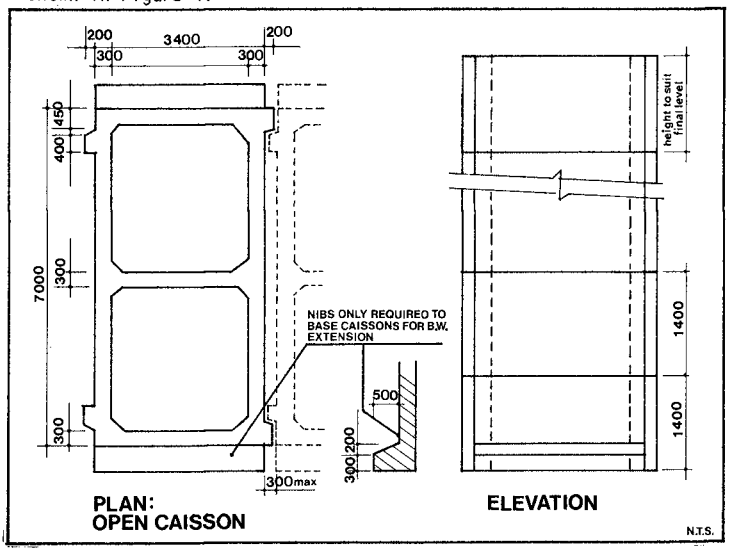

Fig. 4 Caisson design for extension to breakwater

These were modelled using polyester resin and barium sulphate.

In the prototype the caissons were to be placed in position singly and empty. Once in position, they were to be concrete-filled. During this phase of the model testing, an attempt was made to establish the optimum placing and concrete filling sequence, so that in the prototype under all likely sea conditions, the caissons would remain stable immediately after placing prior to and after concrete filling.

Filling the empty caissons in position in the model was simulated by pouring sand and a fine gravelly material into the caissons. This was found to be relatively successful although when the caissons reached the level of the surface of the water, the gravel tended to be washed out of the upper caissons by the wave action, and had to be continually topped up.

The proposed plant to be used during construction was also taken into account during the modelling. It was envisaged that a block/dolosse placing rig would be used on the breakwater with

a maximum load carrying capacity of 25t at a radius of 35m. Taking the parameters of this equipment into account and the dimensions of the caissons, it was assumed that the maximum number of caissons which could be placed on one level in line would be 7. On this basis the model analysis went ahead and within this range various placing sequences were modelled. The wave direction was adjusted from that used in the access mound testing described in Section 5.1, to try and simulate the most arduous conditions which might be experienced on the caisson extension. To give the worst conditions which might be expected at the harbour entrance the wave was therefore set at a direction west at a period of 13 sec. The duration of each test was approximately 10 minutes on the model simulating an hour and a half in the prototype. Occasionally the test run was shortened to approximately 1 hour in the prototype.

Figure 5 shows a typical layout of caissons in five horizontal layers and seven per layer.

Fig. 5 Typical layout 5 caissons high in 7 columns

Figure 6 illustrates the type of damage which could be expected after a particular wave had acted on the structure for a specific length of time.

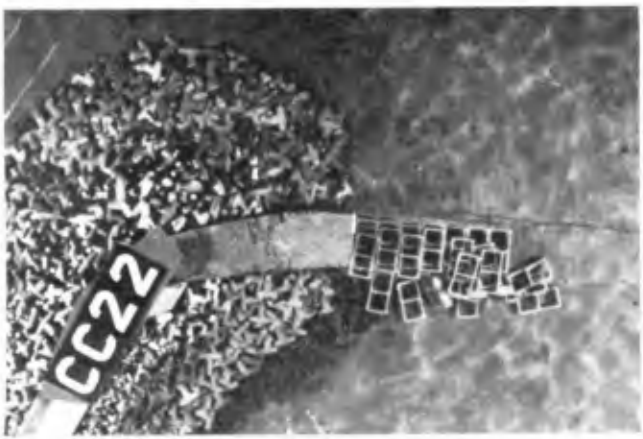

Fig. 6 Displacement by 2,0m wave of 6 layers, 7 columns placed empty

The results of the testing with various block placing combinations and sequences are summarised in Table 3.

TABLE 3

Deep Sea Direction	Observation
CAISSONS PLACED IN HORIZONTAL LAYERS	
1 LAYER (empty)	
West at 13 sec	Caissons displaced at 2,9m
2 LAYERS (empty)	
West at 13 sec	Caissons displaced at 4,0m
4 LAYERS (empty)	
West at 13 sec	Caissons displaced at 1,9m
6 LAYERS (empty)	
West at 13 sec	Caissons displaced at 2,0m
CAISSONS PLACED IN STEPPED CONSTRUCTION	
3 LAYERS STEPPED (empty)	
West at 13 sec	Caissons displaced at 2,0m

TABLE 3 (contd)

Oeep Sea Oirection	Observation
5 LAYERS STEPPEO (empty)	
West at 13 sec	Caissons displaced at 1,0m
7 LAYERS STEPPED (empty)	
West at 13 sec	Caissons displaced at 1,4m
CAISSONS PLACEO IN VERTICAL COLUMNS	
1 VERTICAL (empty)	
West at 13 sec	Caissons slightly displaced at 2,0m
4 VERTICAL (empty)	
West at 13 sec	Caissons displaced at 1,0m
CAISSONS PLACEO IN VERTICAL/STEPPEO CONSTRUCTION AND CONCRETE FILLEO	
5 VERTICAL CONCRETE FILLEO	
West at 13 sec	No damage up to 6m wave
7 VERTICAL CONCRETE FILLED	
West at 13 se	Caissons destroyed at 4,6m
7 VERTICAL - 3 COLUMNS - CONCRETE FILLEO	
West at 13 sec	Caissons displaced at 4,9m
CAISSONS PLACEO VERTICALLY ANO STRAPPEO TOGETHER	
7 VERTICAL - 3 COLUMNS & 3 COLUMNS STEPPED - CONCRETE FILLED	
West at 13 sec	Caissons tend to become displaced at 5,0m wave but straps prevent further movement

Figure 7 shows a typical 3 column construction without strapping.

Fig. 7 Typical 7 layers placed in 3 columns unstrapped filled with gravel (simulating concrete)

In Figure 7 all caissons have been concreted to a level approximately 1,5m above MSL. The caissons are not strapped together. Figure 8 shows the same group of caissons after a 4,9m wave has impacted it for 45 minutes. After 35 minutes the outside column began to sway and move away from the second column. After 45 minutes the upper three caissons on the outside column toppled forwards.

Fig. 8 Model damage to structure in Figure 7 after prototype 4,9m wave impact

Figure 9 shows a typical layout of caissons in 7-stepped arrangement. All caissons are filled with concrete except for top caisson in each column. The arrangement represents 7 caissons recently placed in stepped construction on top of previously placed and concreted caissons.

Fig. 9 Stepped arrangement in 7 columns

5.3 Modifications to Existing Caisson Breakwater

The first phase of construction during the modifications and extensions to the Gansbaai Harbour will be the modifications to the existing Caisson Breakwater.

It was decided therefore, based on the previous model analysis by NRIO, that the area subjected to the worst sea conditions was in the vicinity of chainage 280 to 300 on the existing caisson breakwater. The modification to the existing caisson breakwater required a core consisting of 8t fluted concrete blocks placed along the outside of the breakwater to be protected by 20t dolosse which included toe dolosse held in position by means of connecting chains. The chains fixed to the toe dolosse were held in position by the core blocks. A typical section through the caisson breakwater is shown in Figure 10.

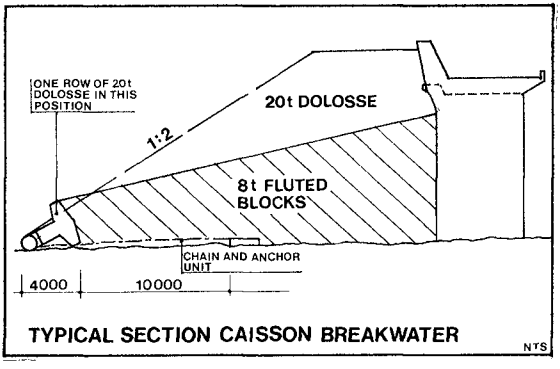

Fig. 10 Typical section of caisson breakwater as modelled

The model of the completed cross section of the modifications was constructed up to chainage 280. From Ch280 to Ch290 the density of dolosse was reduced and from Ch290 to Ch300 the 8t concrete blocks were exposed and constructed in a slope from a level of +1 GMSL to the sea bed. Toe dolosse anchored back underneath the concrete blocks over this section were also constructed. The advancing face of exposed construction is shown modelled in Figure 11.

Fig. 11 Advancing face of breakwater protection

During this series of tests the advancing face of the construction was protected in various ways and subjected to waves varying in height from 1m to 6,2m. The following methods of protection were studied:

(i) Protection by chaining exposed 8t blocks together
(ii) Protection to exposed toe of advancing construction using 25t blocks chained to breakwater
(iii) Protection to the 8t block core by means of a chain mesh

The test was also carried out with no protection at all to the advancing core and dolosse construction.

To prevent the advancing face of the core blocks from being displaced parallel to the breakwater and seaward and thus releasing the holding chains of the toe dolosse, the most effective method proved to be by means of 25t toe anchor blocks tied back across the advancing face and fixed to the breakwater. A recorded wave height of 6,2m at the wave rider failed to dislodge the 25t protective blocks. The importance of keeping the dolosse armouring as close as possible to the advancing face was clearly illustrated during the tests.

Figure 12 shows the damage resulting from a wave 11° N of W at an height of 2,8m lasting for 1½ hours. The unprotected 8t core blocks washed away from the core mass towards the sea. Others bunched up against the caisson wall. Toe dolosse broke free when the anchor chains became exposed.

Fig. 12 Damage to advancing face of breakwater protection by 2,8m wave

6.0 CONCLUSIONS

Some of the basic essentials for carrying out the contract under the sea conditions prevailing in the Gansbaai area were established. The model study indicated in specific areas the most advantageous sequences of prototype construction when adopting certain methods. Within the bounds of model error wave heights at the wave rider were established above which construction would not be possible without protective measures against damagement and displacement.

It was not possible to simulate meaningfully the actual placing of the caissons and dolosse through the waves and the tests were therefore directed at the stability of the elements once these had been lowered into position.

6.1 Rubble Access Mound

On completion of the above series of model tests, it was felt that within the bounds of experimental error and scale model limitations, a considerable amount of useful information was gathered regarding construction sequence and protection measures to be adopted.

From the tests carried out at the intermediate construction stage (approximately 2/3 of full length), it became clearly apparent that only in relatively calm seas, i.e. when the wave height as

recorded at the Waverider B registered less than 1m to 2m would construction of the rubble access mound be possible, without first considerably advancing the construction of the caisson extension to the rubble core breakwater. As continuous calm conditions do not exist, particularly in the vicinity of the proposed works, it was apparent that no construction could be commenced on the rubble access mound until construction of the caisson extension to the rubble core breakwater had been constructed at least ¾ of its length.

During prototype construction, this conclusion from the model testing was observed and only one small washaway was experienced with a wave height of 6m recorded at the wave rider buoy. Protection by means of 1, 2 and 3t rock was kept close to the advancing face.

6.2 Caisson Extension to Breakwater

Least damage to the caissons was experienced when these were advanced in stepped fashion (Figure 9). However caissons placed in this manner which had not been concreted became unstable when placed to within 2,5m of MSL when a wave height exceeding 1,5m was recorded. Nearer the surface the caissons became unstable in waves of 1m height. A form of fixing the caissons to each other using temporary tiebacks increased their resistance against sliding and toppling forwards. The stability of caissons filled with concrete is considerably higher than empty ones in the same position in the construction. For example, a filled caisson showed no tendency to slide laterally or forwards within 2,5m of MSL when the wave height was increased to 6,0m. An empty one became displaced in a wave height of 1,0m at this position. However there was a tendency for consecutive rows or columns of concreted caissons to open up under severe wave conditions. For example, caisson construction (concreted) to the level of the underside of the capping, i.e. above water level but not fixed together in any way, remained stable in wave heights up to about 4m. An increase over this wave height however caused the outside rows or columns to start moving apart. It was therefore concluded that when the construction height of the concreted caissons reached to within a metre or so of MSL, a form of linking the rows or columns of caissons together should be introduced. This would safeguard against the outer column moving away from the remainder as construction advanced. The tendency of the completed columns of caissons to part in high wave conditions decreased as construction moved further from the end of the rubble core breakwater.

During prototype construction placing of caissons commenced in steps as suggested by the model. However as with the model, the wave pattern parallel to the breakwater tended to suck out the concrete from the recently filled caissons. The method of placing caissons was therefore changed to a rapid placement of caissons in column formation. In addition, nibs were cast into the top of

each caisson which would fit into slots cast in the bottom of each succeeding caisson. Caissons were placed empty one at a time until the column had reached a height of one caisson above water level. The whole column was then cast. Protection against the removal of concrete through a sucking action of the passing wave was afforded by the top caisson which was approximately 1,5m above MSL. The tendency for the front column to move forwards as demonstrated by the model was pre-empted by strapping the exposed column to the previously cast columns until such time as the column was filled and the concrete set. The straps used for this purpose in the prototype were highly stressed by the wave action on the foremost column of caissons proving their absolute necessity.

6.3 Modifications to Existing Caisson Breakwater

It was established during the model study that either protection would be needed if construction was discontinued for a spell or a continuous operation and good luck would be required. Tests performed on this section of the construction proved conclusively that the advancing face of the 8t block core would require protection if left unattended in a storm. However there appeared little danger of the dolosse immediately behind the 8t concrete blocks becoming seriously displaced.

The most effective method established during the model testing of preventing movement and thus protecting the core block mass, was by means of 25t toe anchor blocks tied back across the advancing mass face and fixed to the breakwater. As the mass of blocks tends to shift the anchor blocks prevent forward movement and the chains holding back the blocks become very taut. These tieback chains fixed to the breakwater in turn assist in holding the mass of core blocks preventing them from vertical and lateral displacement. The chains and toe blocks are easily removed enabling further construction to continue. However during prototype construction the practicalities of constructing placing and anchoring 25t blocks were not considered feasible. Rather a continuous operation was carried out until the construction was past the critical area on the breakwater. The dolosse protection was kept close behind the core blocks and the toe dolosse were held back by chains on top of which the concrete blocks were placed. A wave height of 8m was experienced during one stage of construction and the concrete core blocks and toe dolosse behaved precisely as predicted by the model. There was a tendency for the blocks to move away from the breakwater and the toe dolosse to move seawards. Figure 12 illustrates this in the model.

7.0 ACKNOWLEDGEMENTS

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8.0 REFERENCES

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FISHERIES DEVELOPMENT CORPORATION OF S A LTD. Limited Contract F92 K243 Modifications and Extensions to Breakwater and the Construction of a Boat Ramp and a Jetty with Rubble Approach Mound.

Supplementary Information to Contract F92 K243 Climatic and Sea Conditions.