CHAPTER 62

UNDERWATER MOUND FOR THE PROTECTION OF DURBAN'S BEACHES

by

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ABSTRACT

The construction of an underwater mound of sand for the protection and improvement of Durban's beaches has been recommended on the basis of intensive investigations These investigations included prototype measurements of beach changes as related to recorded sea conditions, basic scaling tests in which these beach changes were reproduced to scale in movable bed models and tests of the proposed underwater mound in models, using different scales in order to eliminate possible scale effects

The test results showed that, provided the shear-settling velocity similarity criterion is satisfied, beach changes can be reproduced in a movable bed model to a reasonable degree of accuracy Optimum dimensions for the cross section of the mound were determined on the basis of the criterion for erosive and non-erosive wave conditions which was derived from the prototype beach profile changes and confirmed by model tests The resulting dimensions are a mound of sand about 4 5 km long, about 1 200 m offshore, reaching to 7 3 m below LWOST, with side slopes of 1 in 25 and a crest width of 61 m

Of the total quantity required (8 000 000 m^3) some 2 500 000 m^3 of sand, available from harbour dredging works in Durban Bay, had been dumped by May, 1970 Model predictions on mound stability and beach improvements were confirmed to a high degree of accuracy by the full scale events

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INTRODUCTION

As part of an investigation into the siltation of the entrance to Durban harbour, South Africa's biggest port and the erosion of the adjoining ocean beaches, various possibilities for the protection and improvement of these beaches, which make Durban South Africa's premier holiday resort, were studied between 1962 and 1964[1] The causes of the deterioration of Durban's beach and conventional methods to improve the situation, e g groynes, are described by Jordaan in a separate conference paper[2] Subsequent to Jordaan's work, the senior author developed a possible solution, which emerged from the necessity of finding a suitable dumping site for material dredged from the harbour entrance and from the harbour extension works in Durban Bay[3] This scheme consisted of dumping the spoil along a line parallel to the beach line some 1 200 m offshore, in an attempt to form a continuous underwater sand ridge eventually of some 4 5 km long (see Figure 1)

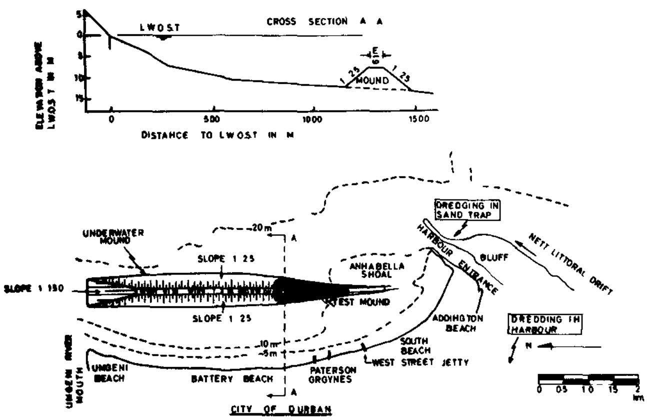

FIGURE 1 SCHEMATIC LAYOUT OF THE DURBAN UNDERWATER MOUND

If such an underwater mound could be built up to a sufficient height and provided it would remain fairly stable, it would act as a selective wave filter, e g low waves would pass unhindered, whereas large erosive waves would break on the mound and thus loose much of their energy As a result, beach building conditions were expected to improve in the lee of the mound and due to the reduction of the incident wave heights, longshore sand bar and trough dimensions were expected to be reduced, resulting in safer bathing conditions

THE UNDERWATER MOUND

Although underwater *breakwaters* have been built before for the protection of certain beach areas, particularly in Japan, the underwater mound scheme, when conceived in 1963, is believed to have been the first application of an artificially placed sand bar to protect the leeward beaches Large amounts of sand are available from harbour dredging works at Durban but since trailing-suction dredgers are used, it is impractical to discharge the sand directly onto the beaches Nearshore dumping, in an attempt to feed the beaches, was tried at Long Beach, New Jersey and Santa Barbara, California[4,5], both attempts were, however, unsuccessful because the sand remained where it was dumped instead of moving onto the beach

This evidence strengthened the idea that dredging spoil could be used to build an offshore underwater sand ridge or mound which would be sufficiently stable to form an effective beach protection scheme In this way a solution would be obtained for both the beach problem and the problem of finding a satisfactory dumping site Preliminary tests and calculations based on breaker depth functions[3] showed that the mound should reach a height of at least 7 3 m below LWOST* to be effective. Since this is also the minimum depth in which most of the available hopper dredgers could safely operate, this height was accepted for the further investigations In the field it was established that side slope with underwater dumping would not be steeper than about 1 in 25 and this slope was therefore used in the model tests

The final scheme which eventually evolved is shown in Figure 1 The proposed underwater mound runs parallel to the Durban beaches in a water depth varying from 7 to 16 m Its crest level is 7 3 m below LWOST, the crest width 61 m, the length about 4 5 km and the total quantity of sand required is about 8 000 000 m^3 A gradual slope of 1 in 150 is included at the northern end of the mound to minimise side effects

* Low Water Ordinary Spring Tide

Before the above scheme could, however, be recommended to the Durban Corporation, it was necessary to establish whether the underwater mound would remain sufficiently stable and what its effect would be on the beaches. Because of the uniqueness of the problem, it was decided, firstly, to carry out extensive research into *basic scaling problems* for movable bed models, whereafter optimum dimensions of the mound and the stability of the mound and its effect on the beaches were determined in movable bed models. It was also decided to supplement the model tests with the construction of a 1 200 m long test section off the Durban beach, to establish mound stability and possible sand migration from the mound under prototype conditions

BASIC SCALING TESTS

Detailed measurements of beach changes, wave conditions and sand sizes were made for a beach section along West Street Jetty, Durban, during 1965[6] Using these data, tests were carried out in a 0 23 m wide wave flume, applying the following scale ratio's

horizontal scale ratio	$L_r = 200$
vertical scale ratio	$h_r = 72$
geometric distortion	$S_r = h_r/L_r = 1/2\ 78$
hydraulic time ratio (tides)	$t_r = 23\ 6$ (based on Froude's law)
wave period scale	$T_r = h_r^{\frac{1}{2}} = 8\ 47$

The average value of the mean grain sizes, d_m, along West Street Jetty was found to be 350 micron Three separate series of tests were carried out using sand (d_m =250 micron) and anthracite (d_m = 190 and 270 micron) with a specific gravity of 1 35 Wave conditions, as measured in nature including tides, were reproduced to scale in these tests All the wave conditions were tested until equilibrium profiles had been reached

The results of these tests[7] showed that with the 270 micron anthracite, the average prototype beach slope of 5 per cent was correctly reproduced. Moreover, the general beach shapes as well as the quantitative changes compared remarkably well On the other hand, the results from the tests with 250 micron sand and 190 micron anthracite, did not compare with nature at all, average beach slopes found in the model being 8 and 3 per cent respectively

It has been shown[8,9] that in the case of river models with a movable bed, good similarity between model and prototype is achieved when, apart from the Froude and friction criteria, the shear-settling velocity criterion is also satisfied, viz $(V_*/W)_r = (hS)_r^{\frac{1}{2}} / W_r = 1$, in which V_* is the shear velocity, W is the settling velocity of the mean grain size and subscript r denotes prototype to model ratio To reproduce the 350 micron prototype sand in accordance with the shear-settling velocity criterion either sand with d_m = 120 micron, or anthracite with d_m = 260 micron should have been used in the tests The 270 micron model anthracite thus almost satisfied the above criterion and since this material resulted in nearly correct reproduction of prototype events, it is concluded that, for the model scales used for the tests, the *shear-settling velocity criterion must* be satisfied to correctly reproduce coastal changes[9]

CRITERION FOR EROSIVE AND NON-EROSIVE CONDITIONS

It has been shown[7,10] that beach deformations relative to an equilibrium beach slope, i, are a function of the deep water wave steepness, $Ho/\lambda o$ and the parameter $(gHo)^{\frac{1}{2}}/W$ (g is acceleration due to gravity, Ho wave height and λo wave length) The beach profiles measured along West Street Jetty, as related to particular wave conditions, were divided into erosive, non-erosive and equilibrium profiles and from the results the criterion shown in Figure 2 was obtained (put S_r = 1), which defines the conditions for accretion, erosion or a neutral profile in case of the Durban beach with its 5 per cent equilibrium beach slope

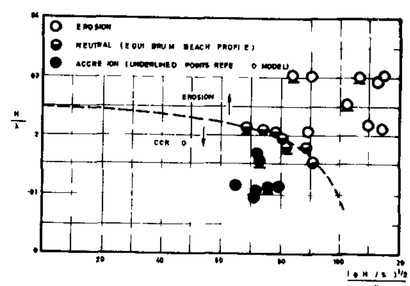

FIGURE 2 CRITERION FOR EROSIVE AND NON-EROSIVE CONDITIONS

So far only prototype conditions have been considered Assuming now that model tests are made of beach deformations and that the criterion $(hS)_r^{\frac{1}{2}} = W_r$ is satisfied, the beach deformation will become a function of[7]

$$\text{deformation} = f\left(Ho/\lambda o,\ \frac{(gHo/S_r)^{\frac{1}{2}}}{W}\right)$$

This expression is applicable to both model and prototype ($S_r = 1$ for prototype) In Figure 2 are also shown the test results with the 270 micron anthracite which closely agree with the prototype data This yields further proof of the importance of the shear-settling velocity criterion

Although it is realised that these findings are based on a limited amount of data, it may nevertheless be concluded that a reasonably accurate criterion has been established to differentiate between erosive and non-erosive wave conditions This criterion has proved invaluable for the interpretation of the results of additional scaling tests and for the determination of the optimum dimensions of the mound (see following sections) Moreover, since for points on the dividing line neither erosion nor build up occurs, it is suggested that this line be used to define the conditions which yield the *equilibrium beach profile* which is of particular value for model tests

The criterion shown in Figure 2 only applies to the Durban conditions, viz a slightly protected beach with 350 micron sand and 5 per cent beach slope However, using the relationship between beach slope and average grain size given by Wiegel[11], the Durban results can be extended to cover a range of beach slopes and grain sizes In Figure 3 a generalised criterion is given for *slightly protected* beaches, which clearly shows the influence of beach slope, i Using Wiegel's data, similar criteria can be derived for protected and unprotected beaches Extensive tests are at present being undertaken at the University of Stellenbosch to check on the validity of the generalised criterion

ADDITIONAL TESTS ON SCALE EFFECTS

In the above it was shown that the shear-settling velocity ratio must be satisfied in the case of a model, with $L_r = 200$ and $h_r = 72$, to ensure proper reproduction of prototype events It remained to establish whether this criterion also applied to other scale ratio's to be used for the model tests on the underwater mound Tests on scale effects, as listed in Table I, were therefore carried out using a typical section of the Durban beaches with 350 micron sand as a basis for the tests

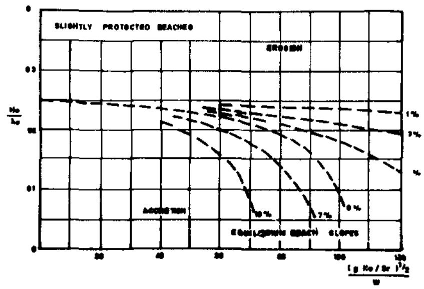

FIGURE 3 GENERALISED CRITERION FOR EROSIVE AND NON-EROSIVE CONDITIONS

TABLE I TESTS ON SCALE EFFECTS

Test Series	L_r	h_r	$\frac{1}{S_r}$	Sediment	Mean grain size, d_m (micron)		Width of flume (m)
					Req for $(V_x/W)_r = 1$	Available	
1	200	200	1	Anthracite	135	150	0 23
2	200	100	2	"	205	190	0 23
3	72	72	1	"	180	190	1 22
4	72	18	4	Mine sand	200	225	1 22

For all the above tests model sediment was used which nearly satisfied the shear-settling velocity ratio and test conditions included both erosive and build up type waves Resulting model beach profiles were compared with those predicted on the basis of Figure 2 and it was found that definite scale effects were present for the smallest model (1 in 200 undistorted) but for all scales equal to or larger than $L_r = 200$ and $h_r = 100$ the model results closely agreed with the predictions[7]

Thus it may be concluded that models in the range of scales listed in Table I (excluding the smallest scale) and for which the shear-settling velocity ratio is satisfied, may be relied upon to reproduce prototype conditions to a reasonable degree of accuracy

OPTIMUM DIMENSIONS OF THE MOUND

Initially (1964) the dimensions of the mound were rather arbitrarily chosen, i e a crest width of 92 m, side slopes of 1 in 9 and reaching to 7 3 m below LWOST From early echo sounders made in 1966 over a test section of the mound, it was found that the dumped sand reached an equilibrium underwater slope of 1 in 25 This slope was therefore accepted for all subsequent model tests

Although the underwater mound is a long way from the beach, since its function is to cause the larger waves to break over it, its behaviour could well be similar to that of a bar in the main breaker zone Keulegan has found that for a nearshore bar to be stable for different wave steepnesses, the depth of crest immersion must be about half the water depth[12,13] As can be seen from Figure 1 the main body of the mound will be in about 15 m water depth and thus the crest should reach to about 7 5 m below LWOST Based on this and considering the required depth for safe manoeuvring of the hopper dredgers, the original crest level of 7 3 m below LWOST was maintained for the further tests on the mound To determine an effective crest width for the mound, both fixed bed and movable bed model tests were carried out in the 0 23 m and 1 22 m wide wave channels

The *fixed bed* model tests were performed for a beach and mound cross section just north of the Patterson Groynes (Section A-A, Figure 1) The water depth near the mound in this area is 13 m, side slopes of 1 in 25 and a crest level of 7 3 m below LWOST were used The tests were carried out in the 0 23 m wide flume at an undistorted scale of 1 in 100, using crest widths of 0, 30, 61 and 92 m respectively Tides were not reproduced, the tests were performed at MSL*

The results of the tests are shown in Figure 4 where the incident wave heights are plotted against the wave heights in the lee of the mound It should be noted that with no breaking of waves over the mound, the reduction in wave height due to the mound is about 30 per cent but as soon as the waves start to break the reduction increases rapidly From Figure 4 it is clear that the mound is significantly

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* Mean Sea Level, i e 0 9 m above LWOST for Durban

effective only when the crest width is at least 61 m In this case wave heights behind the mound are limited, due to breaking, to 2 5 m irrespective of the incident wave height A further rather insignificant reduction to 2 25 m is effected by an increase in crest width to 92 m On the basis of these tests it was therefore concluded that the crest width of the mound should be at least 61 m

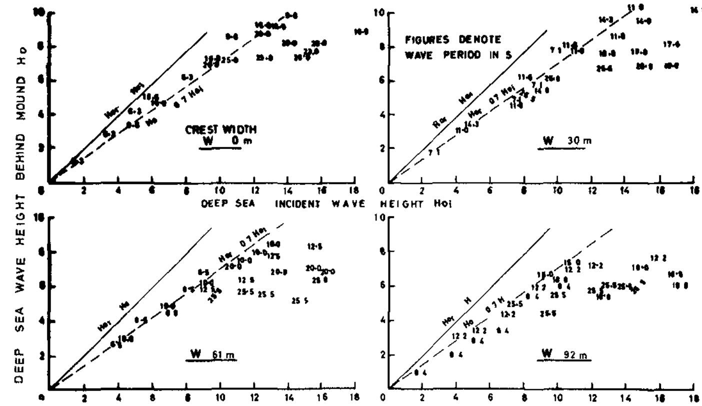

FIGURE 4 RELATIONSHIPS BETWEEN MODEL WAVE HEIGHTS SEAWARDS AND BEHIND THE MOUND

In Figure 5 are shown density patterns of waves recorded in Durban with a wave clinometer over the period 22/7/65 to 27/10/66, superimposed on the criterion for erosive and non-erosive waves (see Figure 2) The full lines in Figure 5 represent incident wave conditions as recorded in Durban, whereas the dotted lines enclose the reduced wave conditions behind a 61 m wide underwater mound It is clear from a comparison of these density patterns that the balance between erosion and build up will be disturbed by the mound and accretion can be expected to take place until a new equilibrium beach profile is established For the incident waves 30 per cent of the waves lie in the erosion zone and 70 per cent in the build up zone (of course the smaller waves in the build up zone are too small to cause any sand movement so that the large difference in the percentages is misleading) When a similar percentage division between erosive and non-erosive waves is assumed, the expected new equilibrium beach slope in the lee of the mound would be steeper if the generalised criterion given in Figure 3 would still apply to the conditions behind the mound Although the latter is probably not the case, there is a strong indication that the equilibrium beach slope behind the mound will be somewhat steeper than the beach profile without the mound

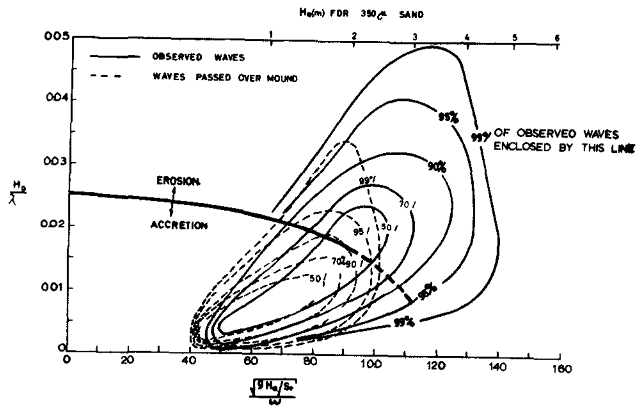

FIGURE 5 DENSITY PATTERN OF OBSERVED WAVES AND WAVES AFTER PASSING OVER MOUND

The percentages erosive waves behind mounds with different crest widths were calculated in the same way as for the 61 m wide mound The results, shown in Table II, emphasise the validity of the conclusion reached earlier that the crest width should be 61 m

TABLE II PERCENTAGES EROSIVE WAVES

Without mound	With mound with crest width (m)			
	0	30	61	92
30	10	5½	3	2½

This conclusion was further confirmed by *movable bed* model studies which showed a significant improvement on the beaches only for a crest width of 61 m and over[7] The dimensions of the underwater mound as shown in Figure 1 viz mound crest level at 7 3 m below LWOST, side slopes 1 in 25, crest width 61 m and total volume about 8 000 000 m^3 were therefore accepted

WIND-WAVE FLUME TESTS

In order to study the long term stability of the proposed mound and its effect on the beaches tests were performed in the CSIR's 120 m long, 3 m wide wind-wave flume[14,15] For these tests a beach section at Battery Beach was used (see Figure 1) with a 1 in 25 beach slope above and 1 in 40 below low water The beach sand had an average diameter of 350 micron whereas the sand in the mound was assumed on average 250 micron The choice of the model sediment was based on the shear-settling velocity criterion The scale factors used are given in Table III

TABLE III SCALES FOR WIND-WAVE FLUME TESTS

Scale ratio		Mound	Beach
vertical scale	h_r	50	50
horizontal scale	L_r	50	150
wave period scale	$T_r = h_r^{\frac{1}{2}}$	7 06	7 06
hydraulic time scale (tides)	$t_r = L_r/h_r^{\frac{1}{2}}$	7 06	21 25
sedimentological time scale	$(Ts)_r \approx 10t_r$	70	212
model sediment (anthracite) mean grain size (micron)		190	360

As can be seen from Table III different scales were used to model the mound and the beach although they were tested at the same time This was essential because no distortion could be allowed for the mound, since the wave attenuation for a distorted mound, i e with a too small crest width relative to the wave length, would be too small (see Figure 4) Since the whole object of the underwater mound is beach improvement, the time scales pertaining to the beaches were adopted for the entire system

Wave conditions as recorded in Durban from June, 1965 to June, 1967 (2 years) were schematised and scaled down in accordance with the above scale ratio's Recorded wave height spectra were found to agree closely with the Rayleigh distribution of wave heights which could very nearly be reproduced in the flume by a combination of machine and wind generated waves (see Figure 6)

A continuous test, representing the two years prototype conditions, was carried out whereby two models, one with and the other without the mound were tested simultaneously side by side in the flume Profiles were measured after each wave condition and a typical result is shown in Figure 7, which shows the beach and mound sections after an extremely severe storm condition Even with these large waves the mound remained virtually stable, whereas a considerable improvement, due to the mound, is noted on the beach (2 5 m vertical or 90 m horizontal)

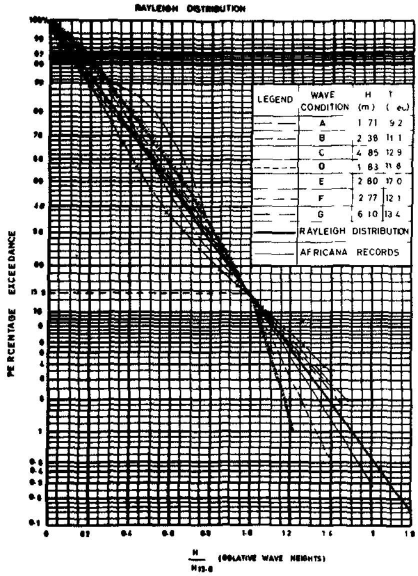

FIGURE 6 WAVE HEIGHT SPECTRA

The maximum change of the crest level of the mound was found to be 1 m and the maximum horizontal movement about 40 m for the entire period of the test As was expected, a slightly steeper beach slope established under most conditions as a result of the presence of the mound

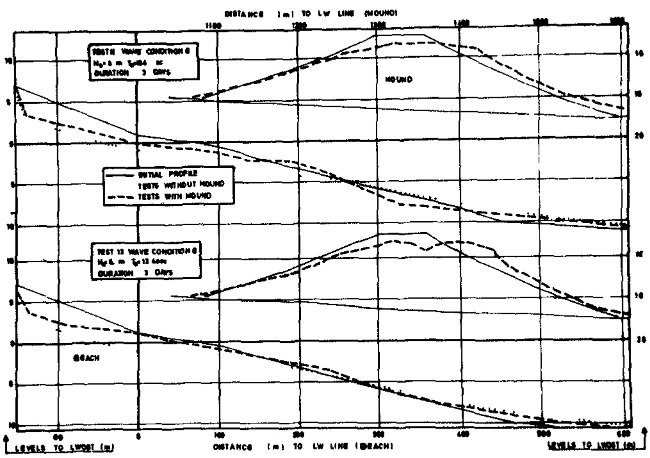

FIGURE 7 LONG TERM MOUND STABILITY AND BEACH CHANGES

On the basis of this extensive test programme, it was concluded that the underwater mound (as shown in Figure 1) *would remain virtually stable, with maximum crest level fluctuations of about 1 m and that the beaches in the lee of the mound would significantly improve*

CONSTRUCTION OF TEST SECTION

In order to investigate dumping techniques, stability of the dumped sand, side slopes and possible sand migration from the dumping area towards the nearby harbour entrance or the roadstead, it was decided to supplement the model tests with the construction of a test section of the underwater mound (see Figure 1) Sand dumping started in June, 1966 at the most southern end of the mound and the test mound was virtually completed in November, 1966 when some 700 000 m^3 of sand, coming from dredging works in Durban Bay, had been dumped (see Figures 8 and 9) By this time the test mound had reached a height of 8 to 8 5 m below LWOST over a length of about 1 200 m with side slopes of 1 in 25

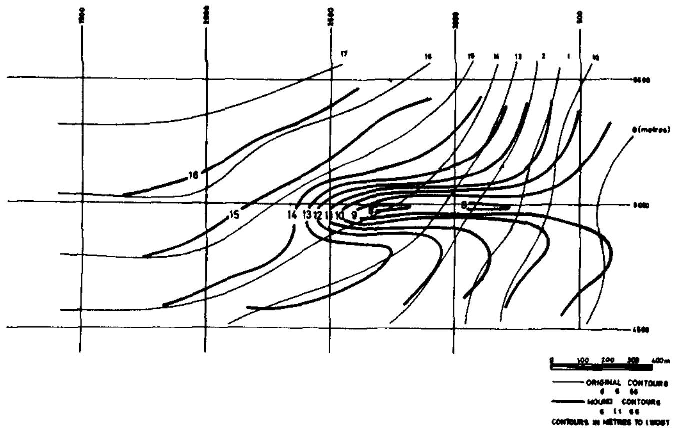

FIGURE 8 BUILD UP OF TEST MOUND AFTER FIVE MONTHS

The test mound provided answers to most of the above questions No difficulties were encountered with dumping with a 1 000 m^3 capacity hopper dredger in 8 m water depth, in fact the contractor found it advantageous to dump in this area because of the shorter haulage Weekly echo sounding surveys were made of the area to check on the dumpings and sand quantities calculated from these surveys are compared in

Figure 9 with the dumping records This comparison shows close agreement and it was thus concluded that there was no loss of sand and that the dumped sand remained in place

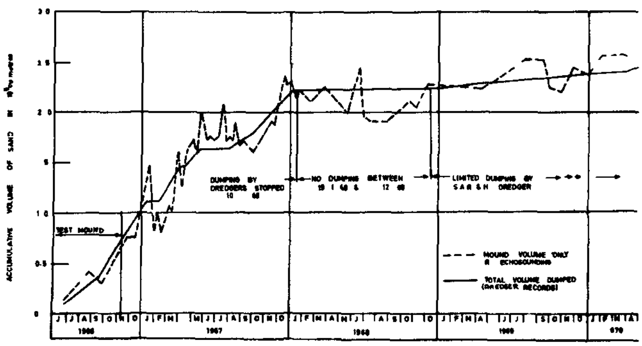

FIGURE 9 ACCUMULATIVE QUANTITIES OF SAND IN THE MOUND FROM JUNE 1966 TO APRIL 1970

This was further confirmed by detailed sediment movement studies Sieve analyses of the sand in the mound area were carried out before dumping commenced The mean grain sizes of the sand on the sea-bottom were found to vary between 212 and 340 micron Samples from the sand in the hopper collected daily by the dredger crew showed fluctuations in mean grain size from 130 to 495 micron Subsequent sampling operations of the sea-bottom at strictly controlled positions provided some evidence of the stability of the dumped sand but this evidence was not conclusive because of these large variations A better check was obtained from the separation of heavy and light minerals by using heavy liquid (bromoform, s g = 2 88) The heavy mineral content of the samples was found to be throughout much higher in the original sea bed than in the dumped sand from the dredging site The high content of heavy minerals in the sand on the sea-bottom is due to an abundance of ilmenite, magnetite and garnets, while the dumped sand is rich in light feldspars, calcites and clay minerals (phyllosilicates) Six weeks after dumping started, when 130 000 m^3 had been dumped, a considerable reduction in the heavy mineral content of the sand collected from the dump area could be discerned, while samples collected from the surrounding areas showed no change at all

Finally, tests were performed using fluorescent tracers dumped at the site of the test mound Earlier model results were confirmed by these tests in that sand movements, if any, were found to be inshore Recorded sand grain velocities varied between 5 to 30 mm/s for significant wave heights from 1 to 2 m

Based on these results it was concluded that the underwater mound could be expected to remain stable and that no sand from the mound would move towards either the harbour entrance or the roadstead seaward of the mound

FURTHER CONSTRUCTION OF THE MOUND

Some 1 500 000 m^3 of sand were dumped between November, 1966 and January, 1967 (see Figure 9) The main 1 000 m^3 hopper capacity dredger ceased operating in August, 1967 and was replaced by three hopper barges with a capacity of 120 m^3 each No dumping took place during 1968, which provided an ideal opportunity to study the stability of the completed part of the mound From the end of 1968 onwards limited amounts of sand were dumped by the South African Railway dredgers, carrying out maintenance dredging of the harbour entrance To date (May, 1970) a total of some 2 500 000 m^3 has been dumped

In Figure 9 are shown the cumulative quantities dumped as recorded by the dredger masters, in comparison with quantities calculated from echo sounding surveys These surveys were made weekly or fortnightly during intensive dumping periods to control the dumping and at monthly intervals after January, 1968 It is clear from Figure 9 that no sand is permanently lost from the mound, although fluctuations in quantities do occur as a result of adverse wave conditions For instance, a 20 per cent reduction occurred after a storm in August, 1966 (significant wave height Hs = 2 4 m, wave period Ts = 14 s, direction ESE) and a 23 per cent loss occurred, mainly from the incomplete sections of the mound, after a storm in June, 1968 (Hs = 3 5 m, direction S) However, in both cases these losses were regained by natural forces and it thus appears that the mound, once it has been built up to the required level of 7 3 m below LWOST, is reinstated naturally even after considerable temporary losses of sand

THE STABILITY OF THE MOUND

In the above it has been shown that the sand quantities in the completed section of the mound do not change materially as a result of the actions of the sea Figure 10 gives an example of contours of the mound for December, 1969 and comparisons with similar surveys before and after this date showed that no significant displacement of the mound takes place[16]

This is further borne out by a study of some of the cross sections of the mound shown in Figure 11 (for positions of cross sections refer to Figure 12) These cross sections are based on echo sounding surveys made during 1969 when no dumping took place, except at the northern extremity of the mound (sections 1000 to 1500, see Figure 12) The profiles show random variations with a maximum fluctuation in crest levels of 1 m and maximum lateral movements of the crest of the mound of about 75 m

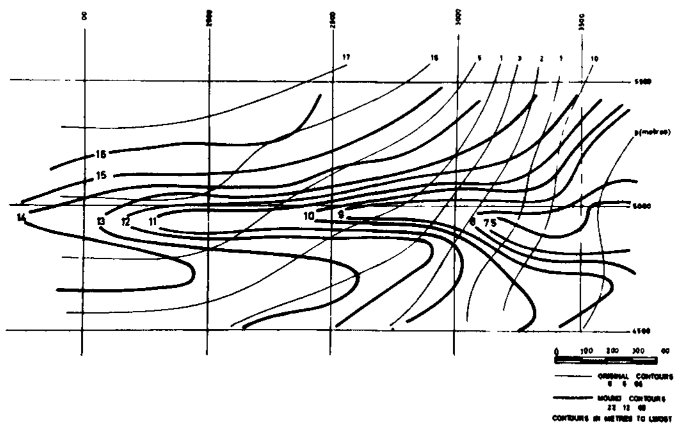

FIGURE 10 DEPTH CONTOURS OF THE UNDERWATER MOUND AS ON 22.12 69

Although it can be seen from Figure 11 that, except for section 3300, the mound did not yet have the required cross section, the agreement between these recorded movements with those obtained in the model tests, viz 1 m crest level variation and about 60 m lateral movement, are extremely good

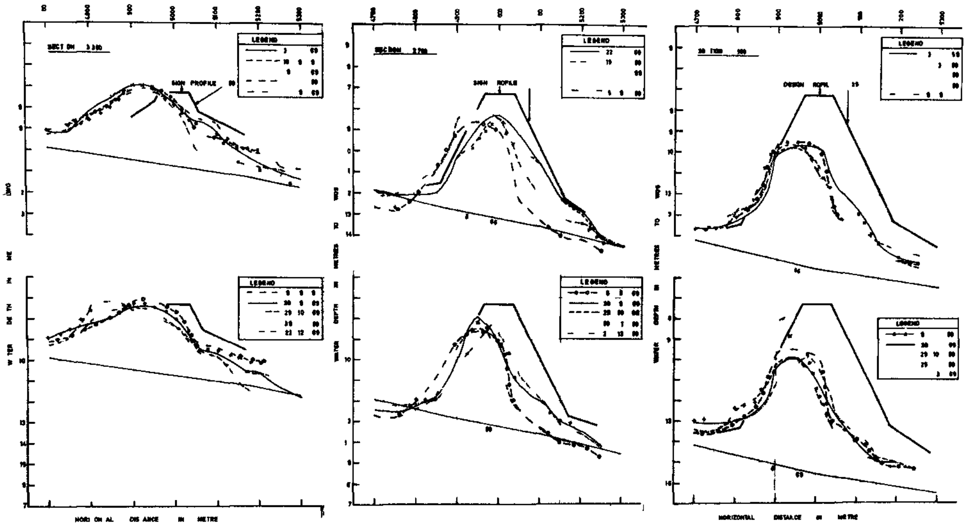

FIGURE 11 BEHAVIOUR OF UNDERWATER MOUND CROSS SECTIONS DURING 1969

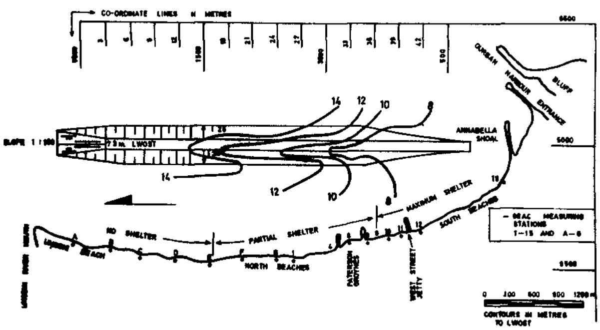

FIGURE 12 SCHEMATIC PLAN OF THE DURBAN UNDERWATER MOUND AS ON 22 12 69

EFFECT ON THE BEACHES

As can be seen from Figures 11 and 12, the underwater mound is still far from complete Only 2 500 000 m^3 had been dumped by May, 1970 against the required 8 000 000 m^3 and the crest level is only reasonably close to the required 7 3 m below LWOST over a length of some 1 500 m, which is about one third of the required length of the mound The most logical method in assessing the beaches therefore, is to compare the beaches in terms of the amount of protection they receive from the partly completed mound A sub-division is made between beaches receiving full protection (south beaches), partial protection (Patterson Groynes area) and zero protection (northern beaches to Umgeni mouth) (see Figure 12)

Figure 13 shows the overall effect on the beaches since the construction of the mound started The 100 per cent is based on the average of the measured sand volumes on the beaches above mean sea level for the period November, 1965 to May, 1966 and all subsequent monthly measurements were compared with these values

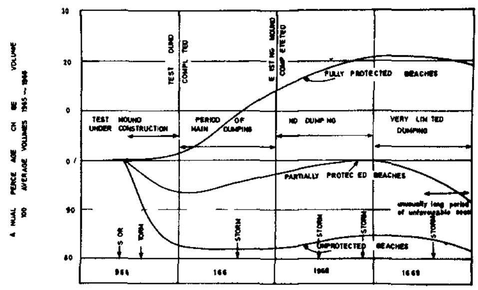

FIGURE 13 EFFECT ON BEACHES FOR VARIOUS DEGREES OF PROTECTION

Although even at the south end the mound has not yet reached its full design crest width, it is clear from Figure 13 that the fully protected beaches greatly benefited from the mound (about 20 per cent increase in sand quantities) whereas partially protected beaches show less improvement and those unprotected appear to loose sand

The partially protected beaches were close to equilibrium at the end of 1968 but they show a decline in beach volumes during 1969 This was caused by a severe storm with 4 5 m high SE'ly waves which occurred on the 22nd August, 1969 This was the most severe storm since the devastating storm in May, 1966 which caused severe erosion of the northern beaches (see Figure 13) and the first major test of the completed section of the mound The mound stood up to the test extremely well, hardly any loss of sand was recorded and crest levels remained within 0 5 m the same as before the storm

The effect of the storm on the beaches was serious, as can be expected from a storm of such magnitude The northern unprotected beaches showed a loss, compared with the condition just before the storm, of 21 per cent against 33 per cent for the May, 1966 storm, the partially protected central beaches lost 16 per cent, which is the same as in 1966, whereas the protected beaches lost only 8 per cent against 20 per cent in May, 1966

It is thus clear that the completed section of the underwater mound has considerably improved the beaches in its lee, as was predicted on the basis of the model tests

CONCLUSIONS

The following conclusions may be drawn from the Durban underwater mound studies

(a) An underwater mound of sand of the correct dimensions offers an effective beach protection scheme

(b) Such a mound of fine to medium sand may be expected to remain virtually stable under most wave conditions and if losses occur during severe storms, natural processes will re-build the depleted mound to its original size

(c) Reliable results, i e accurate predictions of prototype events, were obtained from movable bed models which were designed in accordance with the *shear-settling velocity* criterion

The entire mound will have to be built to provide protection to all the beaches between the harbour entrance and the Umgeni mouth It is expected that the mound will be completed in about 2 to 3 years, using sand from future harbour extension works in Durban Bay

ACKNOWLEDGEMENTS

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