CHAPTER 70

STUDY OF DURBAN HARBOR SILTING AND BEACH EROSION[1)]

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Abstract

A 1 : 300 vertical, 1 : 100 horizontal scale model of seven miles of coastline, including the major area of the port limits and the inner harbor, was constructed to study combined wave, tide and wind action on transport of sand along the coast.

The effects of three predominant conditions of swell and wind-waves on the state of the ocean front beaches were studied by observing relative changes in shoreline contours. Fluorescent-dyed sand tracers were also used in the model. The accumulation and dredging of sand near the harbor entrance was reproduced in the model and various dredging and storage proposals were carried out to scale on the model.

The model study enabled the cause of beach erosion to be attributed to the existence of an offshore shoal produced by the localized dumping of sand dredged from the harbor approaches. This shoal caused selective wave action along the coastline, which was reproduced to scale in the model. It was found that wind and tidal action had a major effect on the redistribution of sand on the beaches as modeled but a minor effect on the permanence of the harbor entrance channel. Apart from the interaction of dredged sand at times being fed to the beaches, the problem of beach erosion could be studied independently of that of harbor silting on the same model. Sand was fed to maintain a state of equilibrium on the southern approach beach to the harbor to simulate the littoral supply.

The northern beach downdrift of the harbor entrance, where the erosion problem existed, was found to be essentially starved of littoral supply, due to maintenance of the harbor entrance by dredging and offshore dumping.

The requirements of the model study also gave rise to a program of field data collection on the governing environmental factors, which in itself aided considerably to the diagnosis of the causes of the state of unbalance in the shoreline. The model study led to several proposed remedial schemes, certain of which have been adopted since completion of the model study. The model study was conducted by the South African Council for Scientific and Industrial Research, for the South African Railways and the City Council of Durban.

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1) This work was conducted by the author while a Senior Research Officer of the Nat. Mech. Engrg. Res. Inst., South African Council for Scientific and Industrial Research, under contract with the South African Railways and the City Council of Durban.

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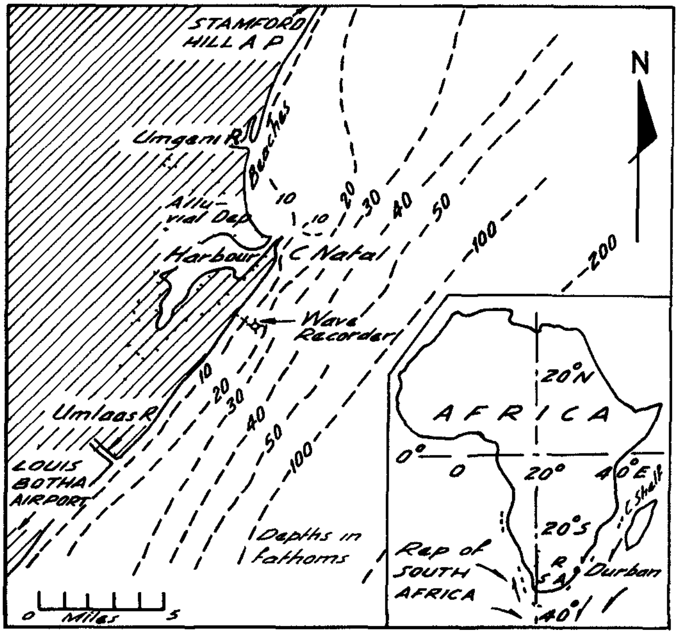


Figure 1 Plan of Vicinity and Location.

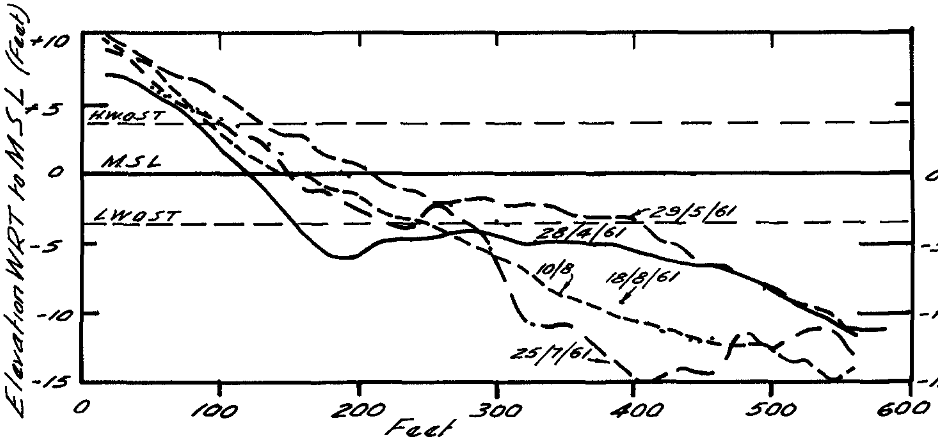


Figure 6. Variability of beach profiles at West Street Jetty, South Beach.

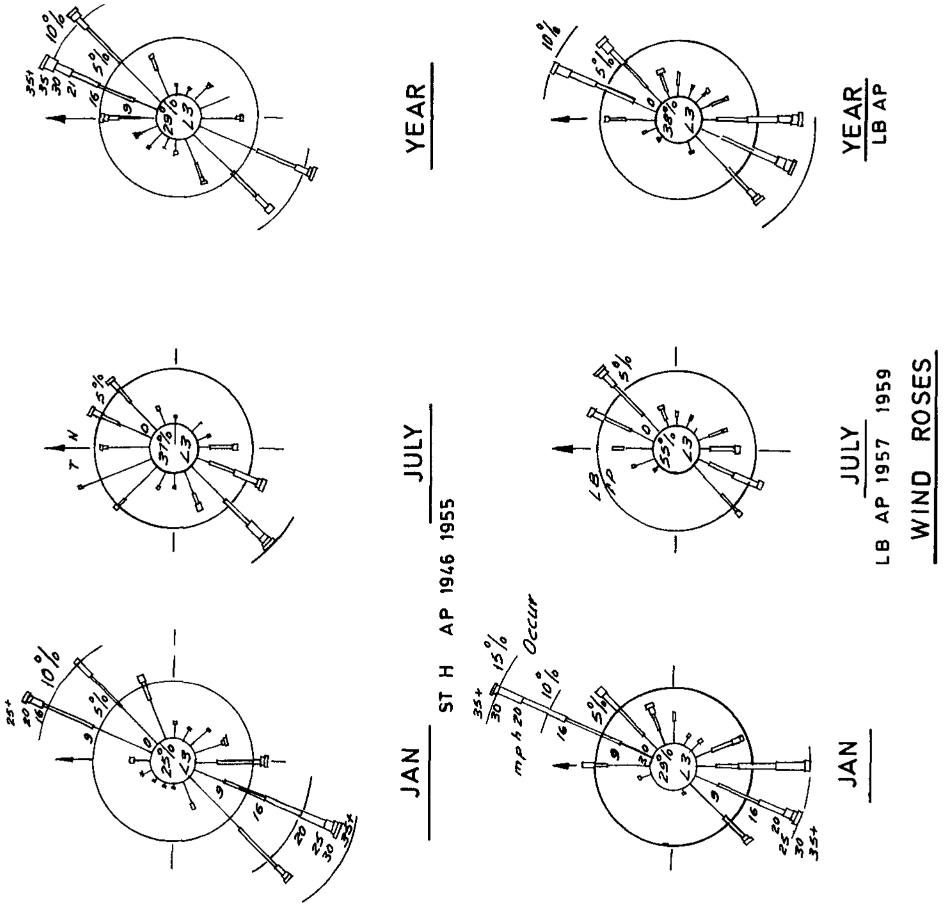


Figure 2. Wind roses for Stamford Hill and Louis Botha Airports, Durban.

1. Historical resume and statement of the problem

Durban is situated on South Africa's east coast around a natural bay which was first settled in 1824. It has since grown to become the country's largest port and most popular seaside resort (Fig. 1).

The Durban port is located at a geological irregularity of the otherwise straight coastline. The harbor entrance channel is formed between the 300 ft high projecting spur "The Bluff" and the 20 ft high estuarine formation "The Point". The nearshore area and the beaches are referred to as the Bluff side and the Bight respectively.

Before 1851 the estuarine channel remained open naturally, mainly as a result of tidal action and the protection afforded by the Bluff from SW to SE storms. The depth over the bar was, however, only about 6 feet at that time. In 1851 the harbour entrance-channel works were commenced. Breakwaters were built and extended at intervals on both the north and the south sides of the entrance, until the present state was reached in 1952 (Moffatt, 5).

At present the entrance channel is dredged to a width of 650 feet and is kept 42 feet deep in the channel proper and 48 feet deep at the bar. Maintenance dredging, which consists mainly of keeping the sand trap just south of the entrance approximately 54 feet deep, has steadily increased and now amounts to approximately 800,000 cubic yards a year (Fig. 5). One of the main aims of the investigation was to find means of reducing this amount.

The material which was dredged was mainly dumped offshore, in the earlier years up to 1938 in an area about 1½ miles east of the entrance and thereafter at various distances south-east of the entrance. During more recent years, however, some of the material has been supplied for pumping to the beaches (Fig. 7a).

The second main task of the investigation was concerned with stabilizing Durban's ocean beaches (Fig. 6). The beaches are located between the Point and the Umgeni River mouth on Durban Bay which forms part of a concave portion of coast stretching north from Cape Natal (Fig. 1). In the past, due to this particular location, a rather stable condition must have existed (4). Due to the harbor entrance improvements the equilibrium of the sand movements was disturbed (3). During the earlier stages of breakwater building (1851-1903) large deposits, a result of greater protection against SW to SE swells, caused the beaches to progress generally seawards a distance of about 800 feet.

From 1938 until 1949 some 5 million cubic yards of sand was pumped to Vetch's Bight (Fig. 9) by S.A. Railway dredgers moored at the North Pier through a 42" dia. pipe (4).

From 1950 to 1953 sand was pumped from a suction plant just south of the South Breakwater directly to Vetch's Bight through a 16" dia. submarine pipeline across the entrance channel. Because insufficient sand collected near the suction plant in the Cave Rock Bight, after 1953 the original system with the Railway dredgers delivering sand to Vetch's Bight was resumed. It was presumed that initially 600,000 cubic yards of sand per annum would be pumped and,

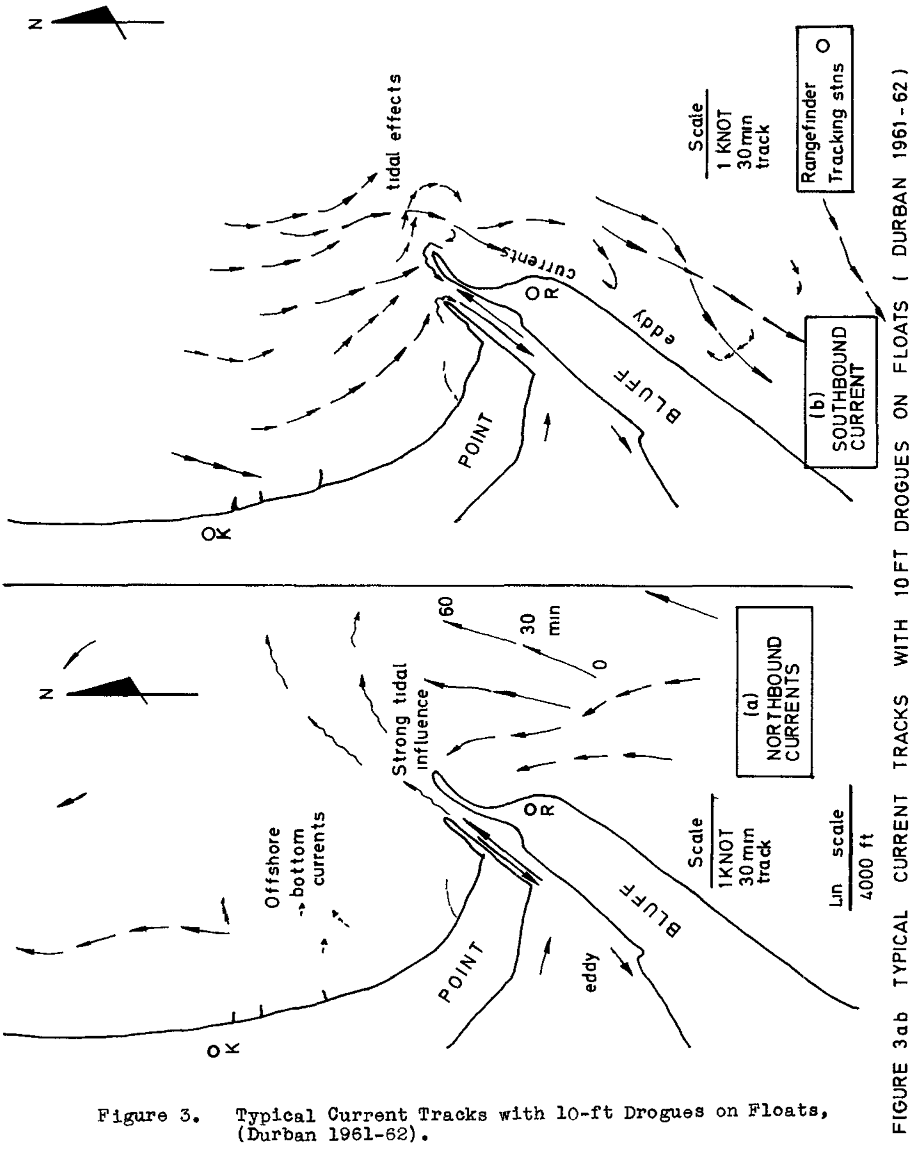


Figure 3. Typical Current Tracks with 10-ft Drogues on Floats, (Durban 1961-62).

after a period of building up, 300,000 cubic yards of sand would be available for maintenance. Moreover, two groins or breakwaters (Paterson Groynes) were built between 1954 to 1956 in order to stabilize the sand supplied to the Central Beach.

In 1960, at the start of this investigation, the supply of only one-third of the annual quantity of sand required for maintenance purposes could be realized, so that the Central Beach in particular was badly starved of sand. In addition, scour holes developed near the tips of the Paterson groins, causing a steep beach slope and dangerous swimming conditions near the groins.

2. Data Collection

In order to successfully perform a hydraulic model study such as the Durban investigation, a complete set of field data, covering both oceanographic, topographic and geomorphological aspects must be obtained. Oceanographic data were collected over a period of 26 months from October 1960 until November 1962.

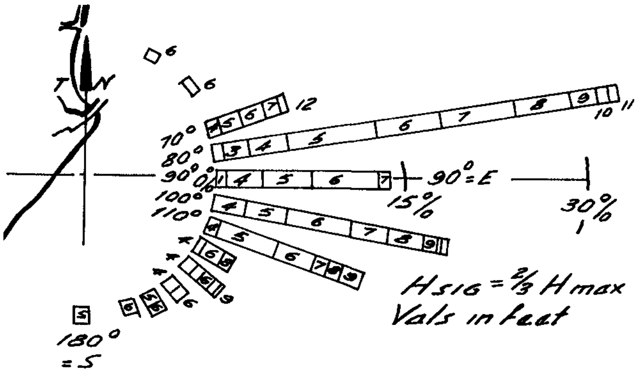
Wind. The result of the analyses of wind records taken over ten consecutive years at Stamford Hill Airport and over three years at Louis Botha Airport are shown in Figure 2. The predominance of strong winds from north-easterly and south-westerly directions is striking. This fact was made use of in the layout of the model.

Waves. Long period waves (swell) and storm waves cause rapid migration of sand directly and also indirectly by wave-induced currents. Sand movements can be correlated with incoming wave energy. Proper wave records are therefore essential for the analysis of sand movement. Waves can be fully described by their direction of approach, height and period. Because wave patterns are often very complex the above values have to be expressed statistically.

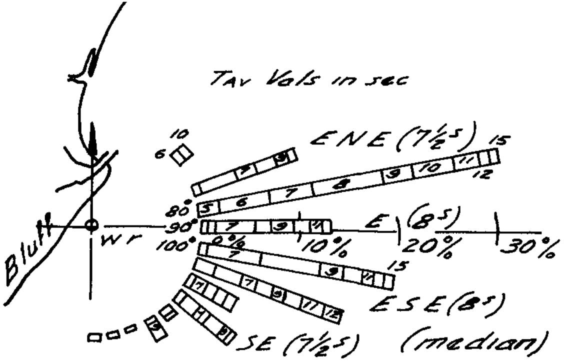
Wave characteristics have been recorded over various periods at the beach front (West Street Jetty), at the harbor entrance and by inverted echo-sounder recorder 1 mile off the Bluff (2). Wave direction, refraction and diffraction were successfully recorded by means of aerial photography for three typical weather conditions. It is clear from Figure 9 that wave direction in the Bight area is very much affected by wave refraction, while in the Vetch's Pier area, diffraction plays an important role.

The six months echo-sounder records have been supplemented and combined with Pilot Boat logs and clinometer readings to give the wave energy roses shown in Figure 4. These wave roses are fully representative for an average year (6). A very severe storm occurred from 24th to 30th August, 1962 when the recorder was inoperative. Stereo-photo pairs of the waves during the peak of the storm were obtained from an aircraft and these, together with visual estimates of wave heights, led to the conclusion that waves up to 20 feet high and of 11 to 12 seconds period occurred near the harbor entrance. The persistence of swell from any one direction has been determined as normally three to four days. A persistency of seven days was never exceeded.

Currents. Even fairly weak currents can cause substantial sand



WAVE HEIGHT ROSE (Bluff)



WAVE PERIOD ROSE (BLUFF)

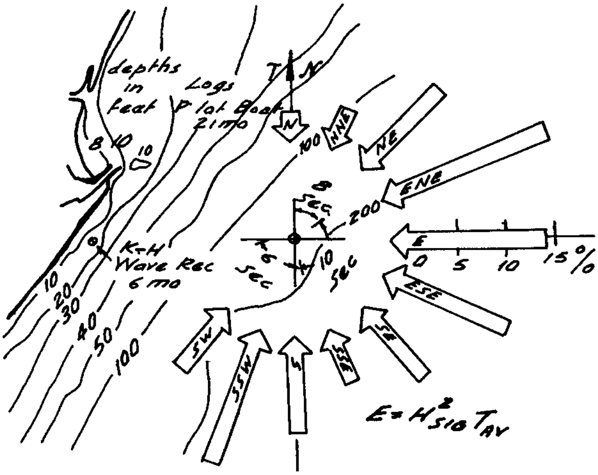


Figure 4. Wave Energy Distribution, offshore locations, Durban.

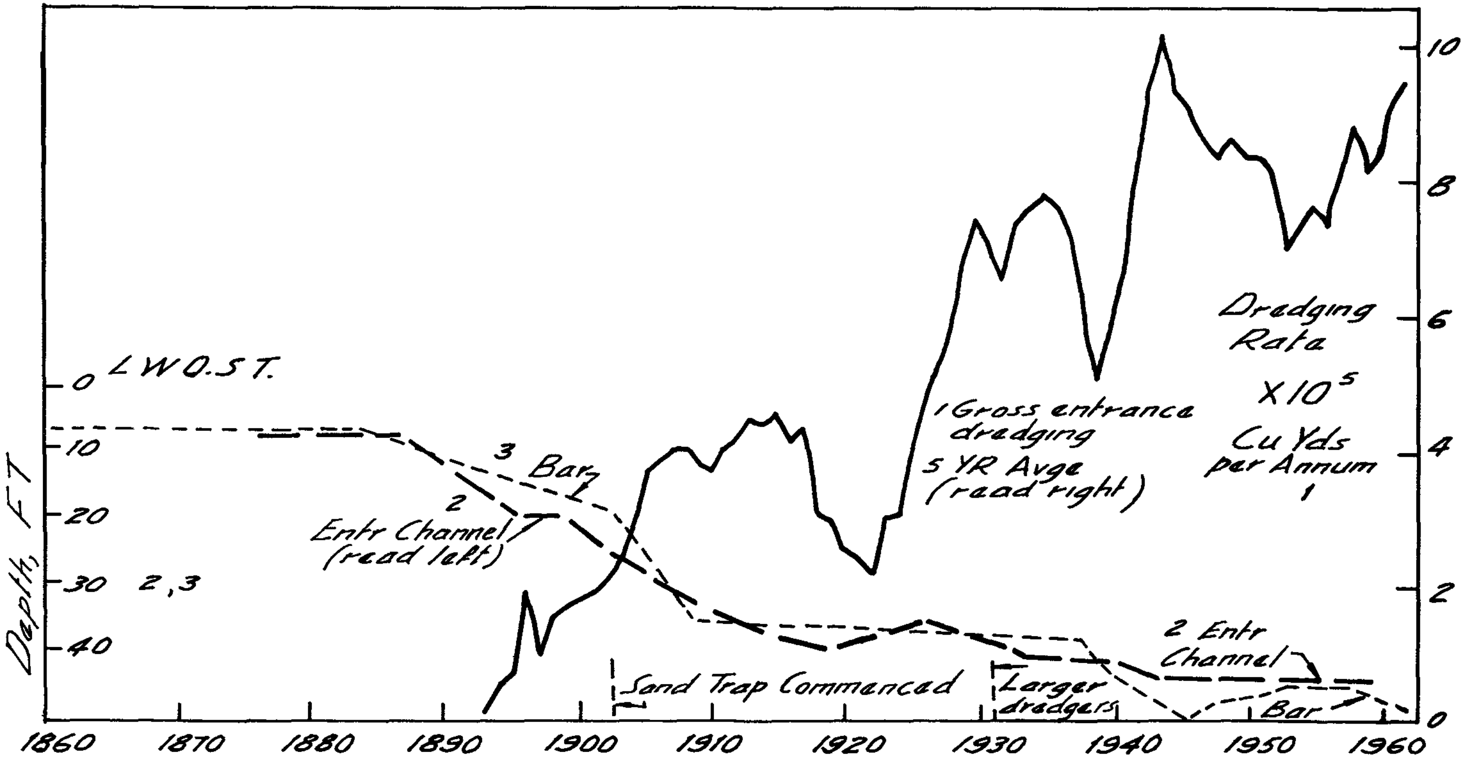


Figure 5. Dredging Rates per annum; entrance channel depths at various times.

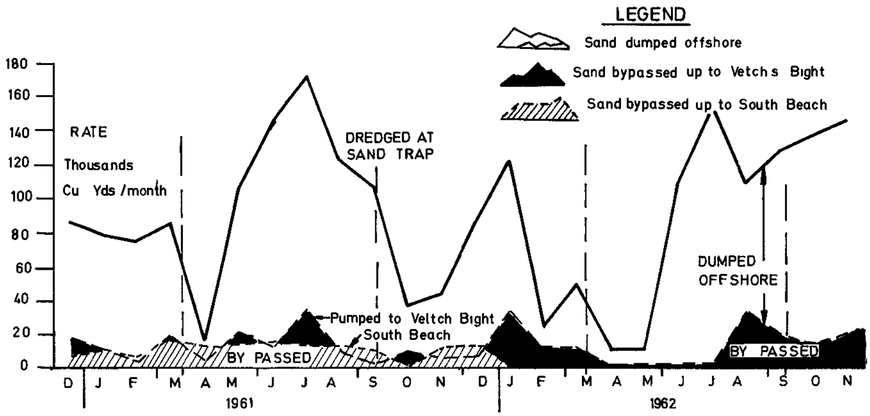


Figure 7a Distribution of Sand dredged, Sand dumped offshore and Sand pumped to Beaches (bypassed)

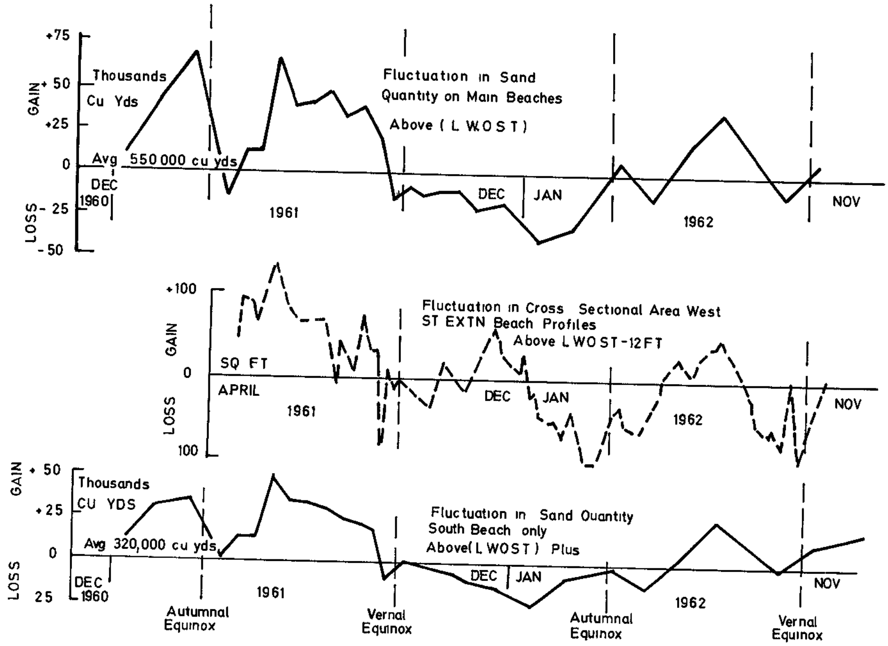


FIGURE 7 b Corresponding changes to beach sand quantities, mainly as affected by seasonal influence moving sand on- and offshore movements when occurring concurrently with waves of swell which stirs up the bottom material into suspension. On the other hand, current velocities have to be about 1.25 knots to be able to transport material not already in suspension. The south bound Mozambique current, which is in general not found within the 100 fathom line, creates a counter current from south to north along the coastline at Durban. The extent and strength of this counter current has been found to be extremely variable.

For correct reproduction of prototype conditions in the model a better understanding of the current system near Durban was therefore called for. Measurements, spread over a period of nearly two years, included earial photographic tracing of surface floats with drogues attached, propeller current meter measurements from a boat, tracking of floats with two rangefinders and measurements of bottom currents with jelly bottles.

3. Morphology

The quantities of sand in beaches above low water mark taken from regular fortnightly surveys made by the Durban Corporation are given in Figure 7b. The total and the South Beach quantities have also been plotted. A significant loss of sand is seen to have occurred at the equinoctial spring tides. A set of typical extremes in beach profiles taken along West Street Jetty over a period of eighteen months reflect the effects of various extreme conditions on underwater beach formation (Fig. 6). The maximum variation of beach level near mean sea level was found to be nine feet, corresponding to a beach width change of approximately 150 feet.

Dredging at Durban harbor started in 1884 in the entrance channel and in 1893 on the bar. From 1903 onwards dredging was concentrated more in the sand trap area. The data for floating five-year averages of annual dredging outside the harbor basin are plotted in Figure 5. Available records of channel and bar depths have been plotted as well. The correlation between dredged quantities, channel and bar depths can readily be seen from the figure. For the past several decades the South African Railways (S.A.R.) have made available to the Durban Corporation (D.C.) a certain quantity of sand per annum for beach renourishment. This sand is pumped by the S.A.R. and discharged just north of Vetch's Pier where it is retrieved by the D.C. pumping plant and discharged just north of West Street Jetty via booster stations. Records made available by the S.A.R. and D.C. for the two years 1961 and 1962 are presented in Figure 7a. The various monthly quantities dredged and pumped via the various pipe lines are shown.

Sand samples were taken at various places along the beaches and from the sea bottom in the area represented in the model (1). They showed significant differences in size distribution, hue and texture. The results yielded a basis for classifying the sand by size as well as by color and permitted interpretation to be made of the pattern of sand movement. This made the use of special tracer experiments unnecessary. The sand south of the Umgeni River down to the harbor entrance is rather fine, well-sorted

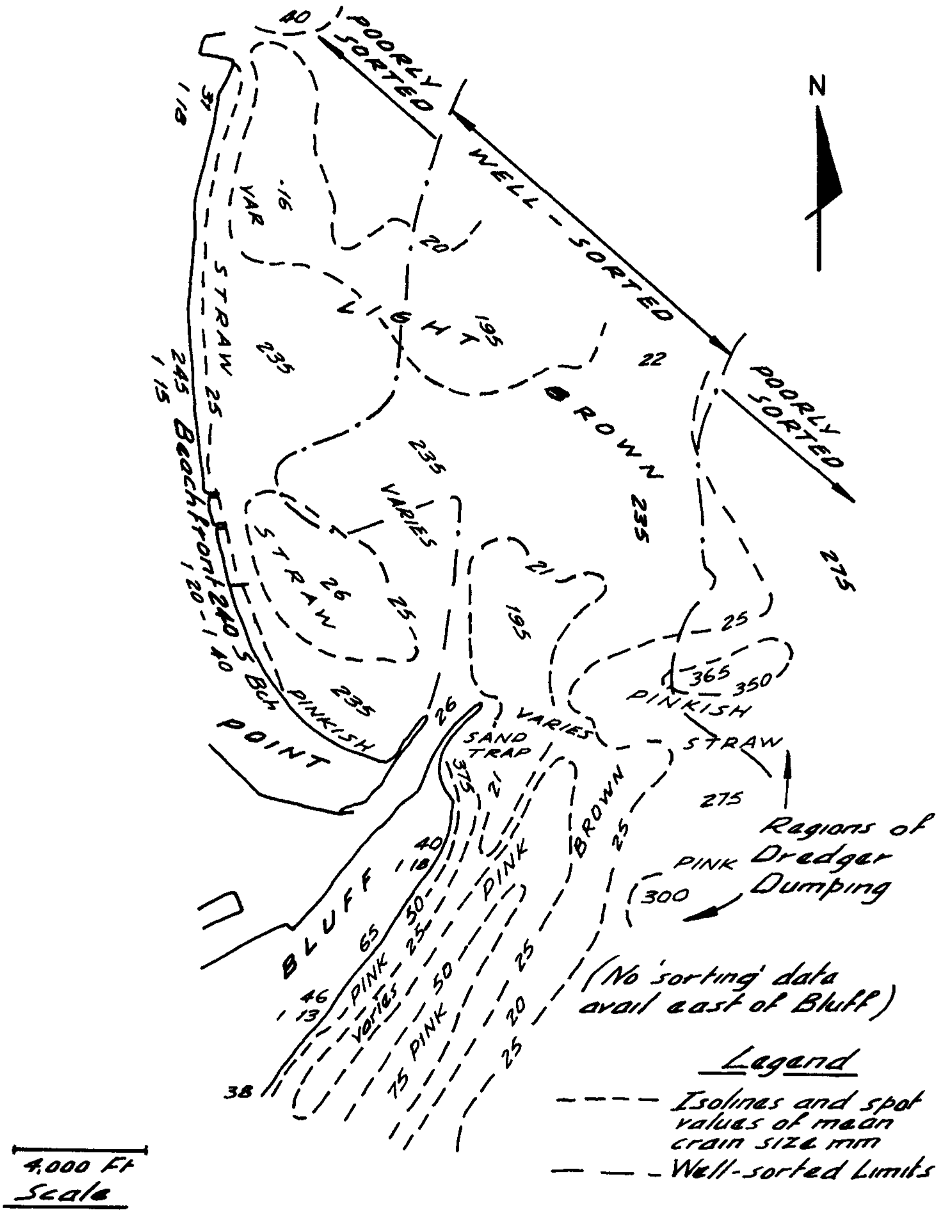


Figure 8. Sand size and color distribution, Durban 1961 - 1962.

DURBAN 1961 - 62

(closely sized) and rounded in shape. South of the harbor entrance on the Bluff beaches, the sand is very coarse, irregular in shape and it occurs in a wide band of sizes (Fi. 8). The most important observation is that the Bluff sands are distinctively colored - pink or red - compared to the Bight sands which are straw-colored. The presence of the pink color points to the fact that "The Dump" consists of Bluff sand dredged from the sand trap and dumped offshore. A remarkable finding was the close correlation between sand size and color. As a result of this correlation, Bluff sands could be identified elsewhere in the sampling area, both by color and by size.

4. The Model

Although theoretical considerations combined with an extensive measuring campaign in nature, can often yield an evaluation of the existing hydrological and morphological conditions, changes to the existing status can only be evaluated economically in a hydraulic model. More often than not, a distorted model, with vertical heights accentuated, is used as the most expedient solution. The Durban sand movement problem therefore called for a movable bed model. In order to reproduce the natural forces in the model as correctly as possible, besides the usual waves, current and tides, wind was also reproduced. This was quite unusual in a three-dimensional model. The model was built in Durban for reasons of convenience and suitable control. A Belman Hangar, belonging to the S.A.R. was made available for this purpose.

Model Scales. A 6.5 mile stretch of coastline, by 4 mile offshore distance had to be reproduced in the available space of the hangar-120 by 96 feet. Furthermore, a model wave height of about 1 inch minimum is required in order to avoid unscalable influences such as surface tension and viscosity effects. The following scale ratios were consequently selected:

Horizontal scale (except wave length): $L_r = 300$
Vertical scale (including wave length): $h_r = 100$

Further scale ratios follow from the Froude similitude law:-
Velocity scale (currents): $V_r = \sqrt{h_r} = 10$
Hydraulic time ratio (tides): $t_r = L_r/V_r = 30$
Celerity scale (shallow water): $C_r = \sqrt{h_r} = 10$
Wave period scale (for $\lambda_r = h_r$) $T_r = \lambda_r/C_r = 10$

Satisfactory results were obtained with fine beach sand as movable bed material, with specific gravity of 2.65 and a medium diameter of 250 microns.

Construction. The construction of the model was a joint undertaking of the CSIR, the D.C. and the S.A.R. and took 9 months from October, 1960 to June, 1961. The main model structure consists of level concrete floor approximately 3 inches thick and a surrounding concrete wall 2'3" high, forming a watertight basin. The model topography was moulded in concrete using asbestos templates, according to the 1960 offshore survey (Fig. 9).

Wind generation. To be able to reproduce wind effects from the predominant directions - NNE and SSW - a bank of 20 inch diameter axial flow fans was installed along the NE and SW boundaries of the model (Fig. 9). Each fan produced some 5000 cubic feet per minute free air which was blown horizontally over the model. The opening of the converging duct which covered the fans was 15 inches high. With the aid of guide vanes the air jet could be deflected at will. The maximum air velocity ranged from about 35 ft/s at the jet outlet to 6 ft/s at the beach front. More realistic, irregular and steep, wave shapes were obtained when using wind as well, than by the use of the wave generator alone.

Wave generation. Waves were created to scale in the model by three banks of unique pneumatic wave makers, oriented perpendicular to the three main directions of wave approach, viz. NE, ESE and SE (Fig. 9). The wave generators were made up of two-foot air-dome elements, surge chambers and diverging underwater nozzles. Air let into the domes periodically depresses the water surface, thus creating a wave at the nozzle outlet. The surge chambers were connected via four-arm rotary valves alternately to the suction and the compression ducts of a common blower. All four-arm valves, fitted on to a common rotating shaft. By turning each valve housing through a pre-determined angle, the phase between the individual 2-ft sections of the wave-maker could be set. In this way waves could be produced in any required direction, from 0.4 to 1.2 sec. in period and up to 2" high. The two separate drives for the shaft allowed the creation of a typical "sea" and swell combination coming from two different directions.

Currents. For the reproduction of currents axial-flow propeller pumps of 12" and 6" diameter were used to circulate the water.
Tide Generation. The tides in the model were created by admitting water to and withdrawing water from the model according to a preset program controlled by a tidal synthesizer which produced a saw-tooth-shaped tidal curve.
Operation. As a result of the analyses of wave records it was found that three basic sea conditions, viz. NE, ESE and SSE and combinations thereof could be used to represent natural conditions. Quantitative measurements of loss and gain were obtained by measuring the change in the depth of sand over the fixed concrete bed, as well as by photographing contour strings from a traversing gantry tower spanning the model. Quantitative measurements of dredging rates were made by continuously weighing accretions "dredged" with a centrifugal pump and suction hose, the discharge of which was admitted under water into a constant volume skimming weighing tank.
Sedimentological time scale. Tests showed that the equivalent of the 3/4 million cubic yards sand dredged annually can be moved from one area into another with SSE conditions in about

four hours when the bed material consists of 250 micron sand. In nature SSE stormy conditions only occur during about three per cent of the time, i.e. 260 hours per year. An approximate value of the sedimentological time scale, for SSE conditions is thus about 65.

Verification. Because a satisfactory correlation was found between model and prototype phenomena (wave, current and sand transport patterns), predictions made from the model regarding changes which might result from the coastal engineering structures envisaged in this investigation, may be regarded with confidence.

5. Results of Model Tests.

Littoral Drift. When not affected by dredging, the north bound littoral drift will encroach into the harbor entrance and eventually form a bar across, thus creating much the same conditions as existed in 1851, but shifted 3000 ft out to sea. Dredging is therefore necessary to prevent the siltation of the harbor entrance. It is the reduction of the necessary maintenance dredging which was aimed at with the testing in the model of the various remedial schemes.

From the diagnostic studies it was clear that with the present sand trap dredging technique, the gross northerly drift is removed (3). The main aim of the investigation was therefore to provide conditions which would ensure that only the net northerly drift will have to be dredged.

Standard Test Cycle. The conditions producing littoral drift to the north are SSE swell by itself or in combination with ESE swell, south-to-north current and S'ly wind. Under these storm conditions a yearly accrual in the sand trap of some 800,000 cubic yards, could be simulated in the model in about four hours.

Conditions under which a reduction of deposits in the Cave Rock Bight can be expected are NE swell with NE wind. These two storm conditions were applied in the model in such a way that the energy distribution corresponded as near as possible to that found in nature.

Phase	Swell direction	Period in sec.	Approximate duration, days (storm)	Wind direction
I	SSE	10	1	SW
	NE	8	1	NE
	ESE	8	1	-
II	SSE	10	2.5	SW
	NE	8	4.5	NE
	ESE	8	2.5	-
III	SSE	10)	combined	
	ESE	7)	4.5	SW
	NE	8	2.5	NE
IV	SSE	10	2.5	SW
	NE	8)	combined	
	ESE	8)	4.5	NE

The foregoing test sequence consisting of four phases was used for most of the remedial scheme tests, the times given being as for nature, the cycle representing approximately one year's storm conditions in nature, (6).

Harbor Silting Prevention

A 1000-foot long mole off Cave Rock gave very promising results when tested in the model. To the north of the mole, an oscillation basin is formed between the mole and the South Breakwater which is well protected for SSE conditions.

Some 2.5 million cubic yards can be stored in the Cave Rock Bight before bypassing of the breakwater starts under prolonged SSE swell. Moreover, some 1.5 million cubic yards can accumulate south of the mole, bringing the total possible accumulation before there is any encroachment into the channel to some 4 million cubic yards, or 5 to 7 years storage capacity for the entire northerly littoral drift.

Due to NE'ly conditions, some sand will be moved out of the basin to the south again. Moreover, a large portion of the sand accumulated to the south of the mole is moved south, thus creating new storage capacity for SSE conditions, (Fig. 11), (6).

Beach improvement structures tested

A system of Y-groynes with intermediate straight groynes, and the addition of spurs to the Paterson Groynes, yielded positive results in maintaining a beach everywhere except at the southern portion of the Lower Marine Parade, where a beach could only be maintained by intermittent sand renourishment or with offshore protection (Fig. 10).

Offshore breakwaters were investigated with the object of protecting existing and artificially created beaches and of building up new beaches in the lee of the structures. Solid reflecting and semi-solid partly-absorbing structures were tested in the model in a number of positions. A good build-up of the sheltered beaches was generally obtained and the initial fill was satisfactorily protected.

The optimum solution was found to be two 1000 foot long parallel breakwaters, approximately 2000 feet offshore. Two floating rafts, 900 by 300 feet in the same positions, tested as alternative measures, resulted in as good a protection of the beaches as the offshore breakwaters would give.

6. Summary of the main conclusions

a. Although conditions at Durban vary almost daily, neither seasonal nor yearly variations were found to be very significant. The field data collected over a period of two years could be considered representative.

b. Data collected over much longer recording periods than two years have to be processed when analysing geomorphological data. Nearshore surveys and dredging records extending many decades, proved an invaluable source of information. Color and size analysis and sand samples from the sea bottom yielded a method for classifying the sand which simplified the diagnosis of sand movement

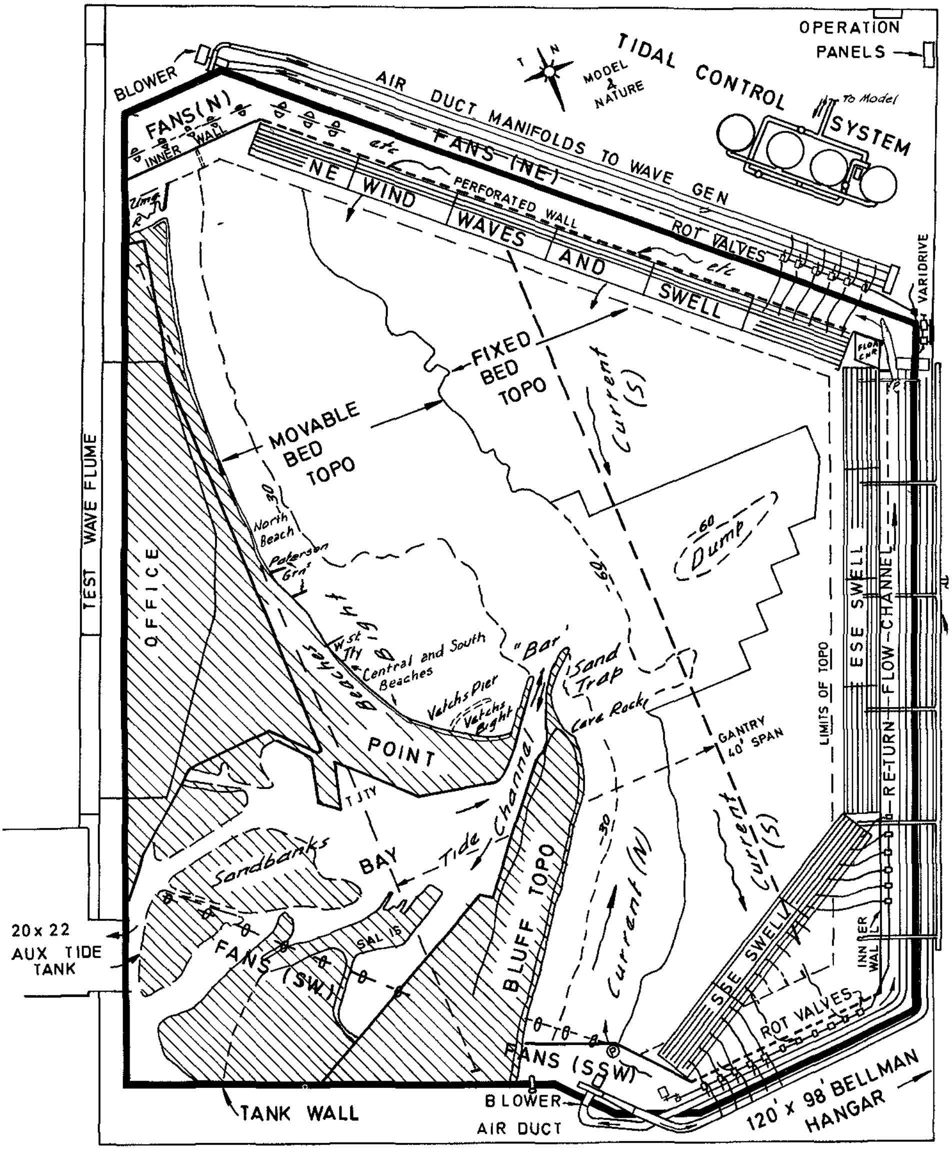


Figure 9 Plan of Durban Coastal Model

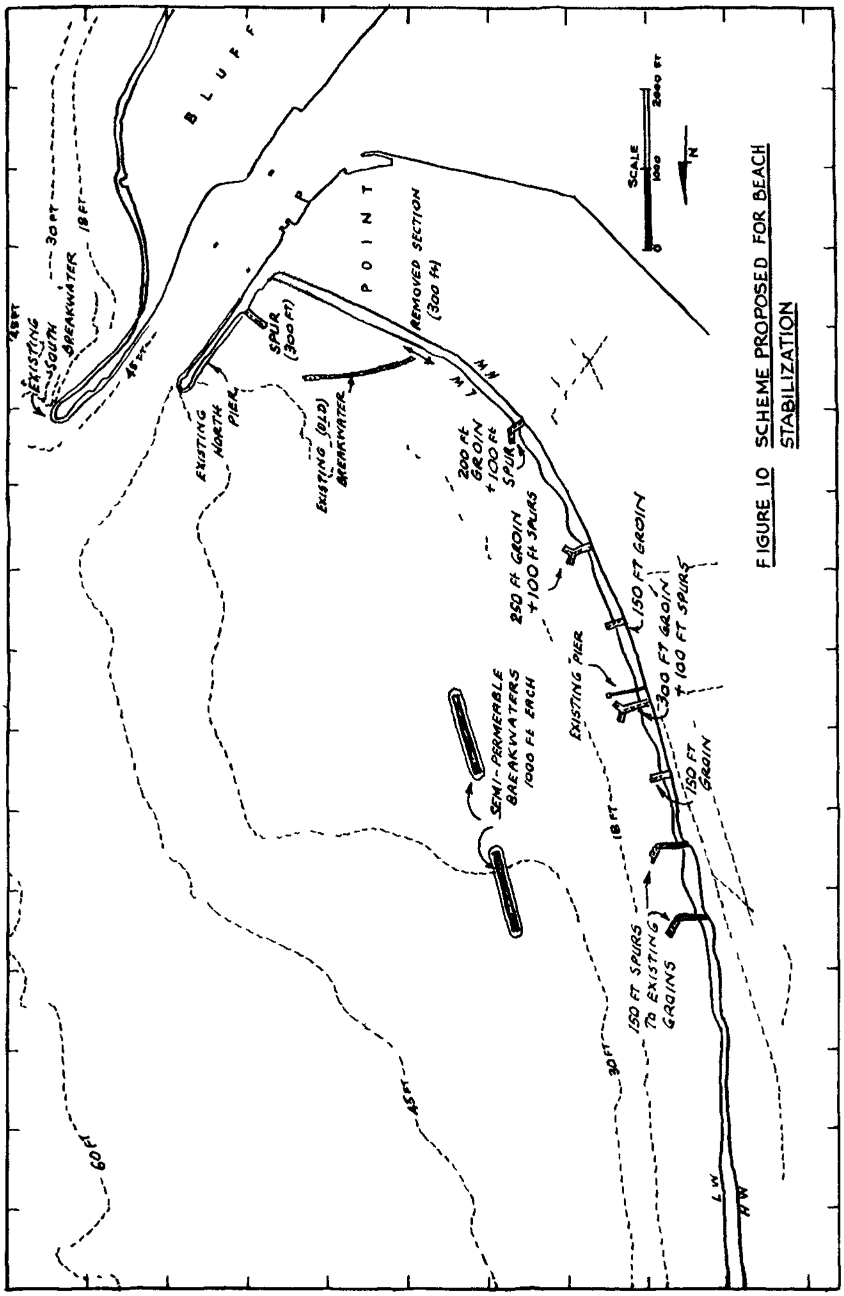


Figure 10. Scheme proposed for beach stabilization.

c. Progressive extension of the breakwaters and deepening of the harbor entrance, together with the associated maintenance dredging, resulted in a gradually increasing interception of the northerly littoral drift. The coastal areas north and south of the entrance channel can at present be regarded as two independent systems with reference to littoral processes. Observations indicate that the major movement of sand occurs close to the South Pier tip. Only relatively fine material can be carried in suspension across the harbor channel. The present state of the beaches is therefore not materially affected by the method of dredging south of the harbor entrance.

d. Nearshore bottom changes, mainly brought about by dumping of spoil, affect wave refraction in such a way that a concentration of wave energy in the Paterson Groyne area results for certain sea conditions(3). Partly due to this and partly due to the greater sheltering effect caused by the South Breakline has adapted itself into a new long-term equilibrium position, concave in plan compared with the 1851 conditions. Seasonal and short-term or storm effects can cause a redistribution of beach material in the beach and surf zones resulting in possible beach variations of up to 150 feet in width.

e. If dredging is interrupted altogether, the northerly sand drift eventually finds its way into the harbor entrance by creeping in, as a narrow band, around the South Pier tip. Dredging is therefore essential. A reduction in maintenance dredging rate can, however, be achieved when conditions are created such that only the net northerly littoral drift has to be coped with

It has been found in the model that this can be realised with various schemes, of which the one with a 1000 feet long mole off Cave Rock proved most advantageous. This scheme provides for an initial sand storage of some 4 million cubic yards, and anticipated reduction in maintenance dredging rate of some 25 per cent and a reserve storage volume of some 1.5 million cubic yards,(6).

f. As the present Bight beaches have been found to be not subject to progressive erosion, improvement schemes were directed towards the formation of beaches in those areas where there are none at present and the protection and stabilisation of newly formed and existing beaches.

A scheme including two 1000-foot long offshore breakwaters or floating rafts, as well as a system of Y-groynes and additional groynes has proved to be successful in maintaining a beach everywhere, after the initial fill (1 million cubic yards) had been brought in to form a beach in the Central and South Beach areas.

With a groynes-only scheme (Fig. 10) it has been established in the model that, after an initial fill of approximately 250,000 cubic yards and with a maintenance sand pumping rate of about 10,000 cubic yards per year, a mean beach width above HW of some 55 feet in the Central Beach area and 250 feet in the North and South Beach areas could be maintained. Moreover, the groynes and spurs could successfully reduce seasonal variations to a negligible amount,(6).

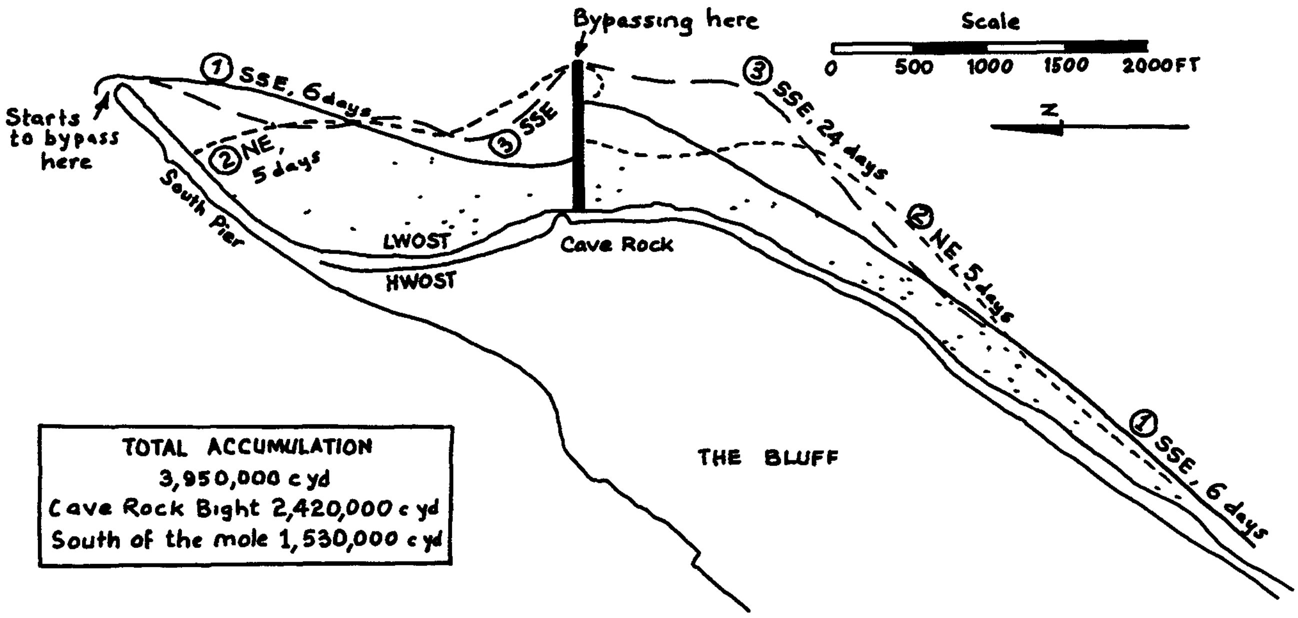


Figure 11. Fluctuation of accumulations, Mole (prop.) off Cave Rock.

An alternative scheme by which a continuous underwater sand mound be formed some 4000 feet offshore in the Durban Bight seemed to warrant further investigation, and was eventually adopted (7).

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ACKNOWLEDGMENTS

The author appreciates the encouragement and assistance from Mr. R.E. Jones, then System Harbour Engineer, Mr. A. Kinmont, then City Engineer, Durban, Dr. H.G. Denkhaus, Director CSIR National Mechanical Engineering Research Institute and other members of the Technical Committee and their organizations.

Mr. J.A. Zwamborn, Mr. W.G. van Lienden, Mr. J.B. FitzPatrick collaborated over long periods of time on this investigation and their unsparing efforts are greatly appreciated.

The author is indebted to all who contributed their time and efforts to the work herein reported.

Permission to present this paper was granted by the South African Railways Administration, the City Council of Durban, and the Council for Scientific and Industrial Research.