# CHAPTER 88

## FIELD AND MODEL STUDIES FOR VISAKHAPATNAM HARBOR

by

Simon Ince* and W. W. Jamieson**

## ABSTRACT

Model studies and analysis of oceanographic and littoral drift data were undertaken to advise Howe India (Private) Ltd. on littoral drift, siltation and shore erosion problems to be encountered during and after the construction of Visakhapatnam Outer Harbor Project.

Distorted fixed-bed and movable-bed models with a horizontal scale of 1:300 and a vertical scale of 1:80 were calibrated to reproduce the integrated net effect of an average southwest and northeast monsoon season. Experiments were conducted to assess and predict seasonal changes resulting from the construction of the system of breakwaters under normal and extreme conditions. Recommendations were made concerning breakwater and sand trap location, shore protection, dredging and disposal of dredged material.

## INTRODUCTION

Visakhapatnam is situated in latitude 17°-41'-34", longitude 83°-17'-45" on the Bay on Bengal almost midway along the thousand mile length of coast between Calcutta and Madras (Fig. 1). Before 1933, a limited volume of sea trade was carried out by means of lighters plying between the shore and ships anchored offshore. This was a dangerous operation during the monsoon seasons due to waves breaking over the sandbar in front of the narrow entrance channel. In 1933, the existing harbor at Visakhapatnam was completed by dredging a 26 ft. outer channel through the sandbar. The depth of the entrance channel was increased over the years to 38 ft. The problem of maintaining the dredged depth was complicated by the existence of a large amount of littoral drift along India's coastline on the Bay of Bengal averaging about a million tons a year in a northerly direction. To prevent the silting of the entrance channel and the erosion of the shoreline north of the entrance channel, the following solution was evolved. An island breakwater of about 1000 ft. length on the southern side of the entrance channel was constructed by scuttling 2 merchant ships, filling them with sand, boulders and concrete and protecting them on the weather and lee sides by boulders. This breakwater was so aligned as to allow the littoral drift to pass through the gap between it and Dolphin's Nose and to settle in a sand trap in the lee of the breakwater, where a dredger could operate a good portion of the time during the southwest monsoon season. Part of the dredged material was discharged by means of a floating pipeline to the north of the entrance channel, thus maintaining continuity of littoral drift and the remainder was hoppered out to the dumping grounds. Figure 2 shows these two locations of sand disposal and the existing layout of approaches to Visakhapatnam Inner Harbor.

* University of Arizona, Tucson, Arizona, U.S.A., 85721.

** National Research Council of Canada, Ottawa, Canada

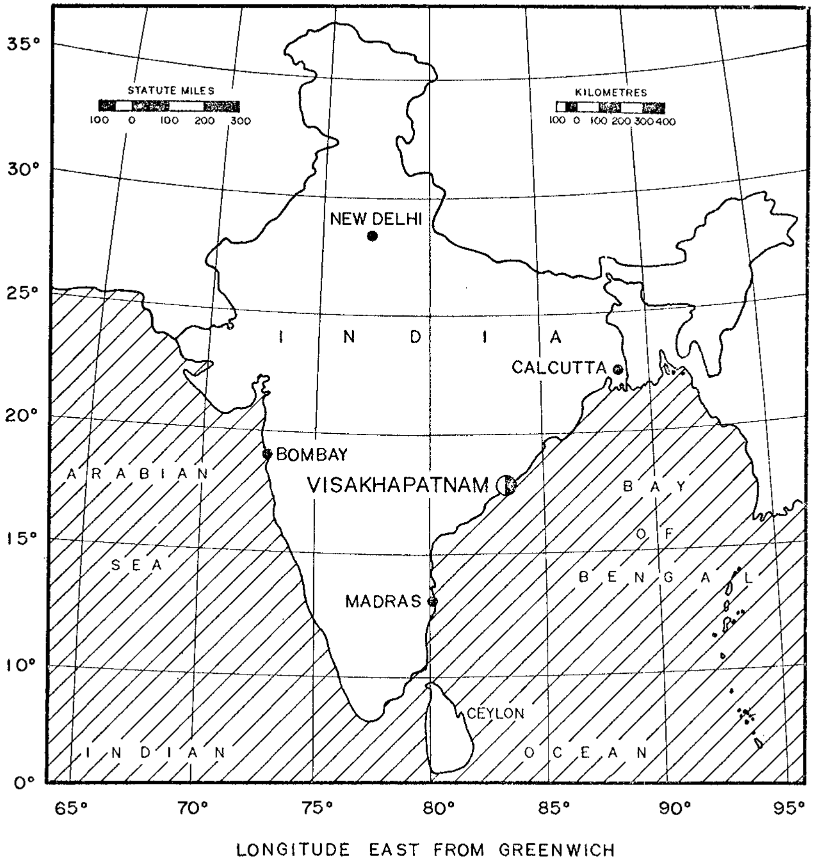



FIG. I LOCATION MAP

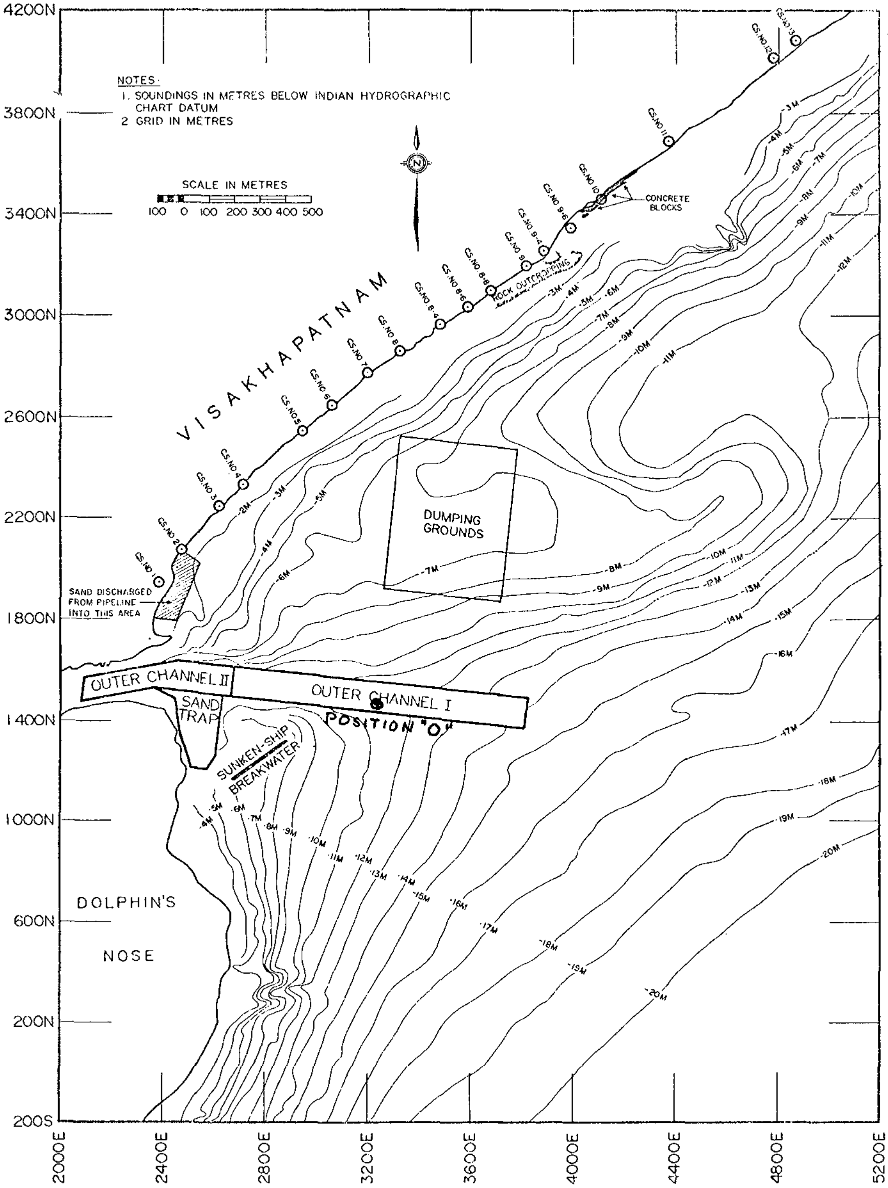



FIG. 2 EXISTING CONDITIONS AT VISAKHAPATNAM

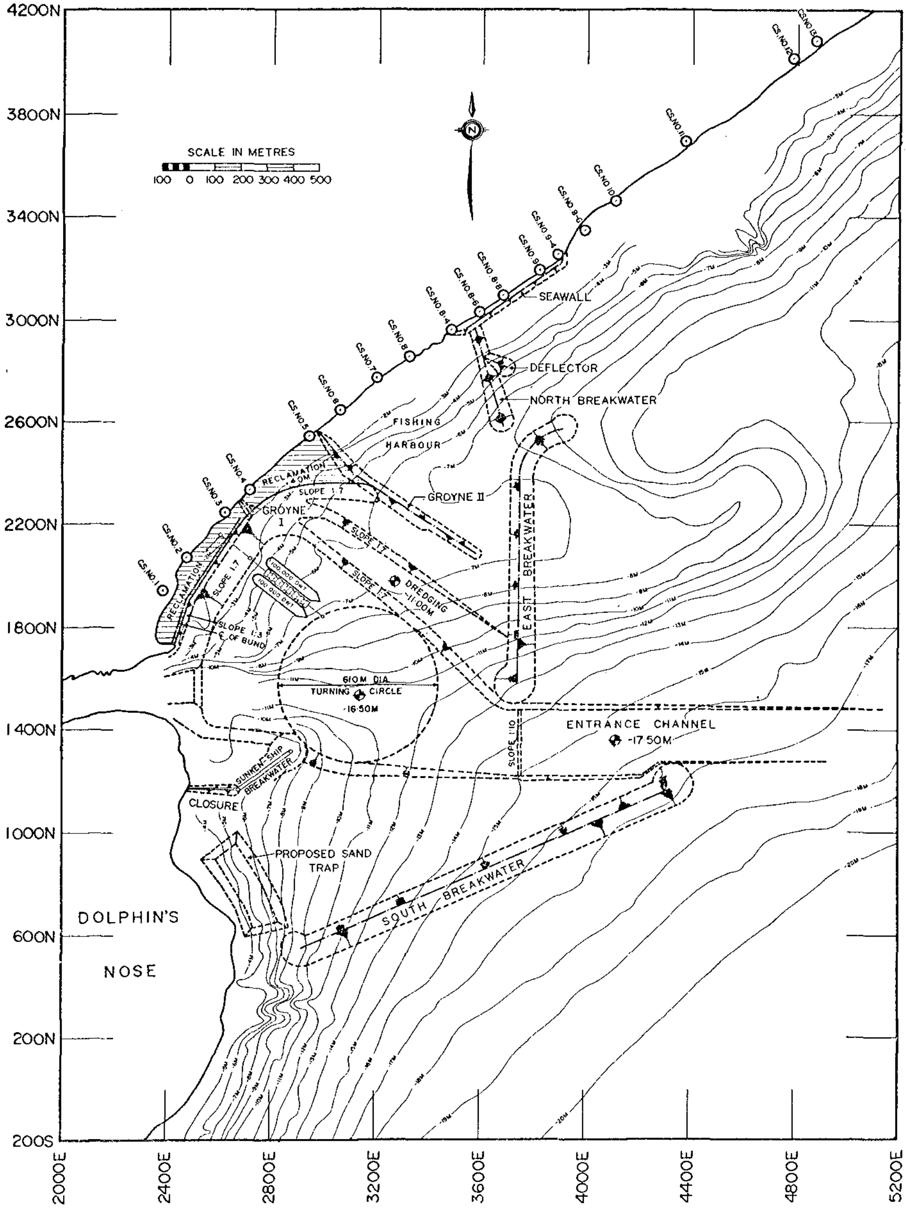



FIG. 3 FINAL LAYOUT OF VISAKHAPATNAM OUTER HARBOUR

## VISAKHAPATNAM OUTER HARBOR PROJECT

Over the years the volume of cargo handled through the Port of Visakhapatnam has gradually increased, and the export of ore through the Port of Visakhapatnam is expected to reach 12 million tons annually. The maximum ship size which can be accommodated at the existing loading facility is 33,000 DWT. From an economic point of view it has become essential to use ore carriers of 100,000 DWT and larger.

In accordance with these requirements, the consulting engineers, Howe India (Private) Ltd., prepared plans for an Outer Harbor Development which could eventually provide berthing and loading facilities for ore carriers up to 200,000 DWT. The final layout is shown in Fig. 3.

Since the problems of littoral drift, channel siltation and shore erosion arising from the effects of the cyclic southwest and northeast monsoon seasons were well known, the consulting engineers asked the Hydraulics Section of the National Research Council of Canada to conduct - in collaboration with the Central Water and Power Research Station in Poona - oceanographic data analysis and hydraulic model studies concerning the Visakhapatnam Outer Harbor Project. The studies provided answers to the following points:

1. Determination of the optimum clearance between the coast and the head of the south breakwater considering passage of littoral material, the deposition in the sand trap and wave energy through these gaps.
2. Location and configuration of new sand trap.
3. Quantity of sand deposited in the sand trap and the interior of the harbor under various conditions.
4. Suitable dumping grounds for dredged material.
5. Quantity of sand which will have to be dredged and pumped to the northern shore on the average and during extreme conditions.
6. Optimum discharge zone for the sand-bypass pipeline.
7. Quantity of sand which may be deposited in the entrance channel on the average and during extreme conditions.
8. Effect of the Outer Harbor Construction on the coastline north of the North Breakwater.

Some of the problems are discussed in this paper.

## METEOROLOGICAL AND OCEANOGRAPHIC CONDITIONS

The climate of Visakhapatnam is dominated by the monsoons, which divide the year approximately into four seasons:

a) The northeast monsoon from the end of November to the end of February with predominantly northeasterly winds.
b) The premonsoon period from March to May when the winds have shifted to a southwesterly direction and cyclones are frequent.
c) The southwest monsoon from the middle of May to the middle of October with predominantly southwesterly winds.
d) The postmonsoon period from the middle of October to the end of November with variable weather and greatest frequency of cyclones.

Wave observations were made by the Visakhapatnam Port Trust from 1934 onward at position 0 marked on Fig. 2. During the months of November, December and January the predominant direction of approach of waves at position 0 is from the sector E to ESE, whereas during March, April, May, June, July, August and September the predominant direction is from the sector S to SSE. The predominant period of the waves, disregarding the 0-2 sec. periods, is between 8 and 10 seconds. The average yearly wave height rose is shown in Fig. 4.

The currents which are of concern to construction problems at Visakhapatnam are the longshore currents in the surf zone. The general circulation in the Bay of Bengal and tidal currents are of minor importance.

The longshore currents at Visakhapatnam are in a northerly direction during the southwest monsoon season, and in a southerly direction during the northeast monsoon as indicated by measurements and observations of beach changes due to littoral drift. This is a confirmation of results obtained from wave refraction diagrams, where the angle between the wave front in the breaker zone and the shoreline gives an indication of the direction of the longshore currents.

Of particular interest are currents in the existing sand trap region, where they are not only a function of waves breaking at an angle with the shoreline but are also influenced by wave reflection and diffraction, partly due to the rocky shoreline, but in large measure due to the presence of the sunken-ship breakwater. Moreover, the intensity and direction of currents are greatly influenced by the amount and configuration of the accumulated sand. It has been observed by personnel of the Visakhapatnam Port Trust, for example, that currents across the entrance channel increase in magnitude as the sand trap fills up, and currents of 1 to 2 ft./sec. exist when the sand trap is nearly full. Measurements on the fixed-bed model have indeed confirmed these observations.

The littoral drift and shore erosion problems were briefly touched on earlier. The harbor layout with the sand trap and the floating pipeline sand by-passing scheme has been quite successful in maintaining the required depths in the entrance channel. Over the years this depth has been increased from 26 ft to 38 ft.

The problem of controlling shore erosion north of the entrance channel, however, has not been as successful. The reason for this is simply that the sand by-passing scheme, which as a principle of maintaining the mass continuity of the natural littoral drift is an excellent idea, has not been fully and continuously utilized. With the increase in ship traffic the floating pipeline has been disconnected for extended periods. Thus pumping of the sand to the north of the entrance channel (Fig. 2) has decreased considerably due to these frequent interruptions. Instead, the sand settling in the sand trap and O.C.II has been more and more hoppered out to the dumping grounds.

Over the years, there has been a gradual cutback of the shoreline north of the entrance channel, much of it taking place since 1933. In some places the shoreline recession is as much as 100 meters. It is, of course, not always easy to separate shoreline changes due to natural causes from those

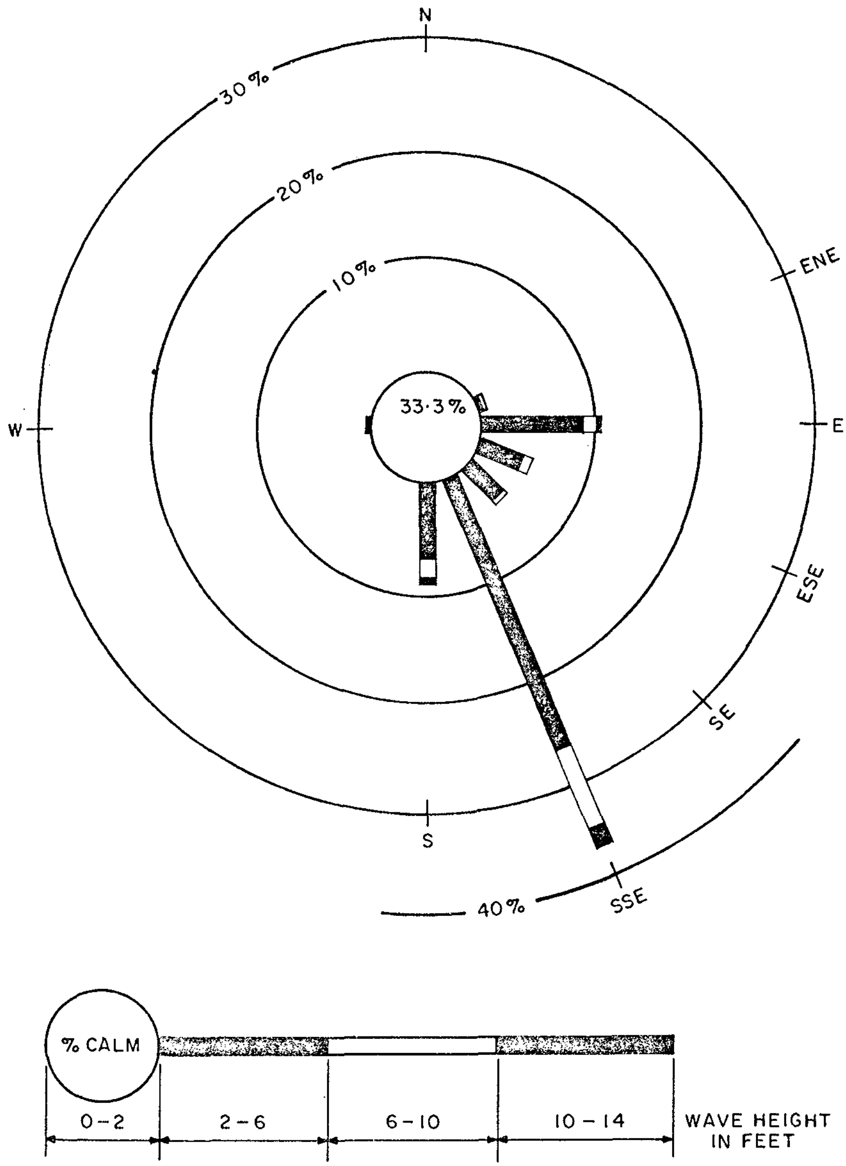



FIG. 4 AVERAGE YEARLY ROSE DIAGRAM FOR WAVE HEIGHTS AT POSITION O

occurring as a result of man-made interferences. On a geological time scale nearly all beaches are in an evolutionary stage, whereas on a human time scale they appear to be in quasi-equilibrium. Even so, a few very stormy years can and do cause appreciable changes in the shoreline lasting for a number of years, while over a longer period the original conditions might be nearly restored without apparent change. There are also the seasonal changes affecting the shoreline and the beach profiles. At Visakhapatnam, for example, the shoreline at C.S.9 varies by about 50 meters during one year

Having said all this, the inescapable fact still remains that erosion of the shoreline north of the entrance channel has taken place since the construction of the harbor above and beyond the measure that might have occurred naturally, since the sand by-passing has not been complete and the beaches to the north have been starved over the years. Observations by the Visakhapatnam Port Trust indicate that when the quantity of sand pumped to the north of the entrance channel remained constant for a few years, the shoreline assumed a new average equilibrium position. As the quantities of sand by-passing decreased, however, it became necessary to protect an extending porti of the shore by dumping large quantities of rock and concrete blocks (Fig. 5).

Thus, it becomes absolutely imperative in the planning of the Outer Harbor Project, to evaluate the quantities of littoral drift at Visakhapatnam and to design an effective sand by-passing system which can maintain the continuity of littoral drift across the harbor. In this manner one can be sure that at least no adverse effects will be caused by the construction of the Outer Harbor.

The main source of qualitative and quantitative information about littora drift is the extensive dredging records maintained by the Visakhapatnam Port Trust. The records over the years 1941 to 1965 show that on the average, the yearly quantity of sand dredged from the sand trap, O.C.I and O.C.II is approximately 725,000 cu. yd.

Dredging is done throughout the year and does not, therefore, reflect the seasonal accumulation in the sand trap and the outer channels I and II. It was thought useful to analyze 6 years' (1964-1969) records and sounding charts in greater detail to determine at what times and where deposition took place in the sand trap and outer channel II. The resulting mass curve for 1969 is shown in Fig. 6. The most salient feature of this plot is the obvious fact that almost all the material is settling in the sand trap and outer channel II during the period from April to November, which is essentially the southwest monsoon period. The conclusion can be drawn, then, that nearly all the quantities dredged from the sand trap and outer channel represent the littoral drift resulting from wave action during the southwest monsoon season. The mean annual dredging quantity of 725,000 cu. yd. represents the proportion of mean annual northerly littoral drift settling in the S.T., O.C.I, and O.C.I The mean annual southerly littoral transport is estimated at 165,000 cu. yd., and the average annual net drift may be estimated to be around 560,000 cu. yd. to the north.

The seasonal changes in the direction of the littoral drift with the southwest and northeast monsoons causes cyclic variations all along the beach, more obvious at some points than at others. The monthly variation of the

FIGURE 5

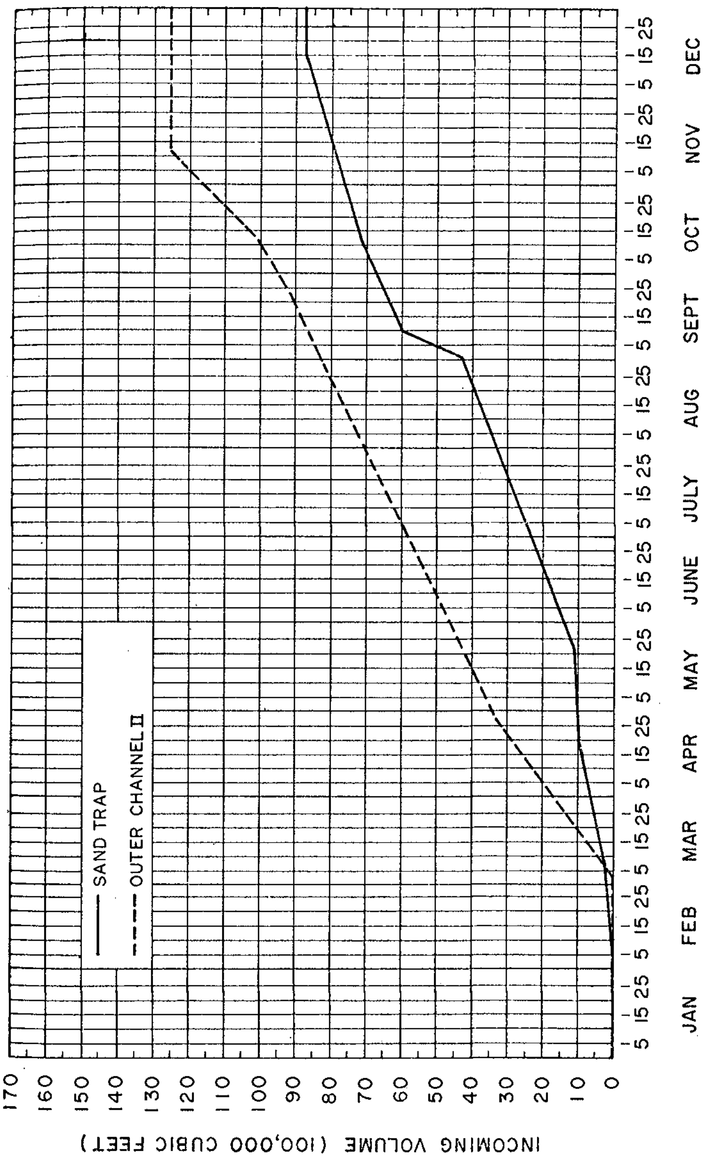
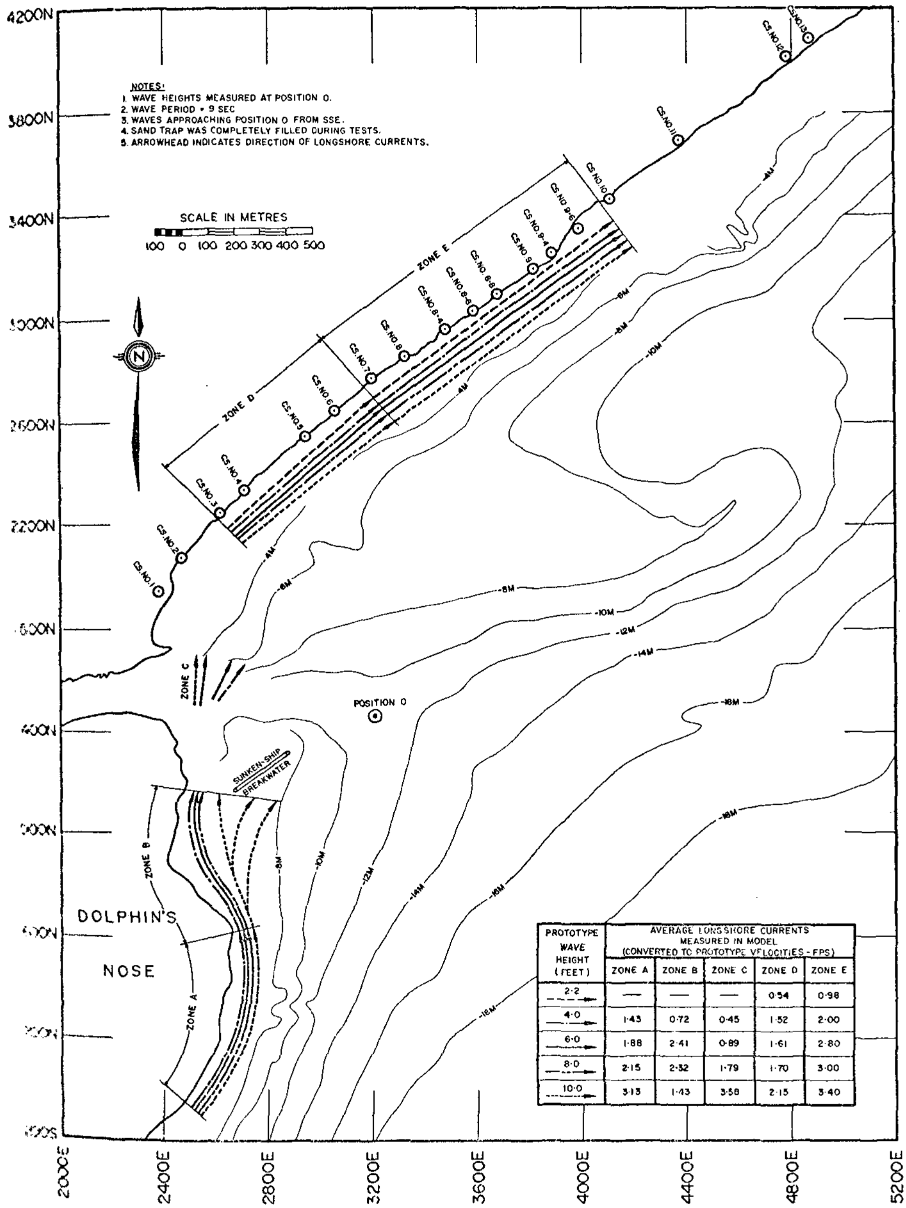



FIG. 6 MASS CURVES FOR 1969




| PROTOTYPE WAVE HEIGHT (FEET) | AVERAGE LONGSHORE CURRENTS MEASURED IN MODEL (CONVERTED TO PROTOTYPE VELOCITIES - FPS) | | | | |
|---|---|---|---|---|---|
| | ZONE A | ZONE B | ZONE C | ZONE D | ZONE E |
| 2·2 | — | — | — | 0·54 | 0·98 |
| 4·0 | 1·43 | 0·72 | 0·45 | 1·52 | 2·00 |
| 6·0 | 1·88 | 2·41 | 0·89 | 1·61 | 2·80 |
| 8·0 | 2·15 | 2·32 | 1·79 | 1·70 | 3·00 |
| 10·0 | 3·13 | 1·43 | 3·58 | 2·15 | 3·40 |

FIG. 7 LONGSHORE CURRENTS

shoreline (MHWST) at C.S.9 and C.S.10 is shown in Fig. 8. C.S.9 and C.S.10 show a most interesting feature beyond the annual cycle of cutback and build-up, which ordinarily would not be as pronounced. The effects of the southwest and northeast monsoons are magnified due to the existence of the rock outcropping between C.S.9 and C.S.10 (Fig. 2). This rock outcropping has beei exposed more and more over the years as the quantity of sand pumped to the foreshore has decreased, and acts now as a groyne. During the southwest monsoon season accretion occurs on the updrift side (C.S.9) and erosion takes place on the downdrift side (C.S.10). During the northeast monsoon season the conditions are reversed. This point of discontinuity plays an important role in the coastal regime at Visakhapatnam.

## MODEL INVESTIGATIONS

Fixed-bed and movable-bed model tests were undertaken to assist the consulting engineers with design information according to the terms of reference. Phase I of the investigation was conducted on a fixed-bed model in order to verify the general littoral drift current magnitudes and directions, the zone of effective littoral movements, and the general pattern of depositi( in the sand trap and entrance channel.

The fixed-bed model was constructed to a horizontal scale of 1:300 and a vertical scale of 1:80. The limits of the model were chosen to reproduce correctly the refraction phenomena of waves approaching the shoreline from any direction. The length of shoreline reproduced on the model was long enough to give a reasonable representation of the longshore current pattern.

The longshore current measurements done on the model and in the field agreed reasonably well. (Fig. 7)

The comparison of current measurements in the area of the sand trap and O.C.II show a greater variability in both direction and magnitude (Fig. 9). This is essentially due to conditions in the sand trap. When the sand trap i: full, there are strong currents across the entrance channel whereas with completely dredged sand trap these currents are small. Since an exact comparison of currents would depend on the condition of the sand trap at the tim( of the measurements, these differences are to be expected. The overall patte\ of currents is in line with the observations.

Although the fixed-bed model gave a good indication of the currents in the littoral transport zone, the complete study of erosion and deposition problems for the Visakhapatnam Outer Harbor required the use of a movable-bed model.

The fixed-bed model with a horizontal scale of 1:300 and a vertical scale of 1:80 was converted to a partially movable-bed model of the same scales by excavating the cement and molding the submarine topography with crushed bakelite in the areas along the beach. Experiments with a number of model bed material samples with different $D_{50}$ values and distributions indicated that the crushed bakelite ($D_{50}$ = 0.7 mm) gave the most reasonable calibration conditions.

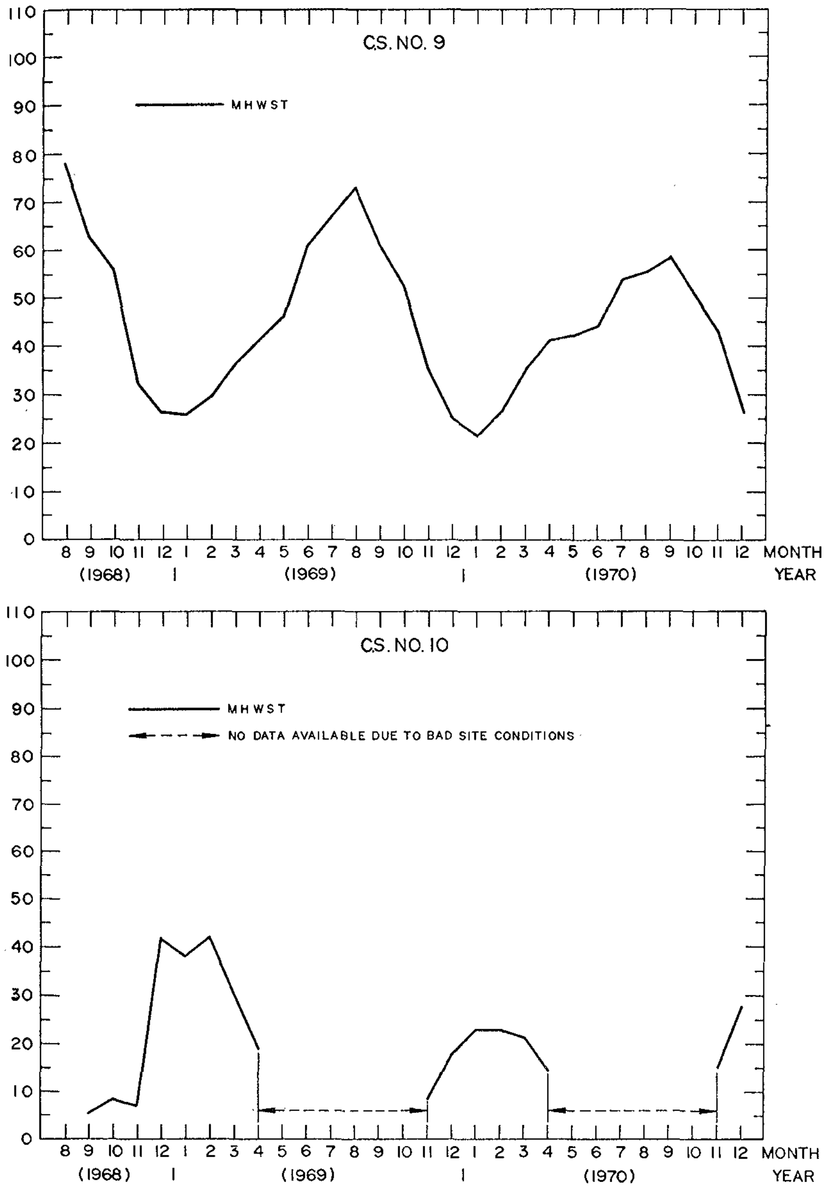
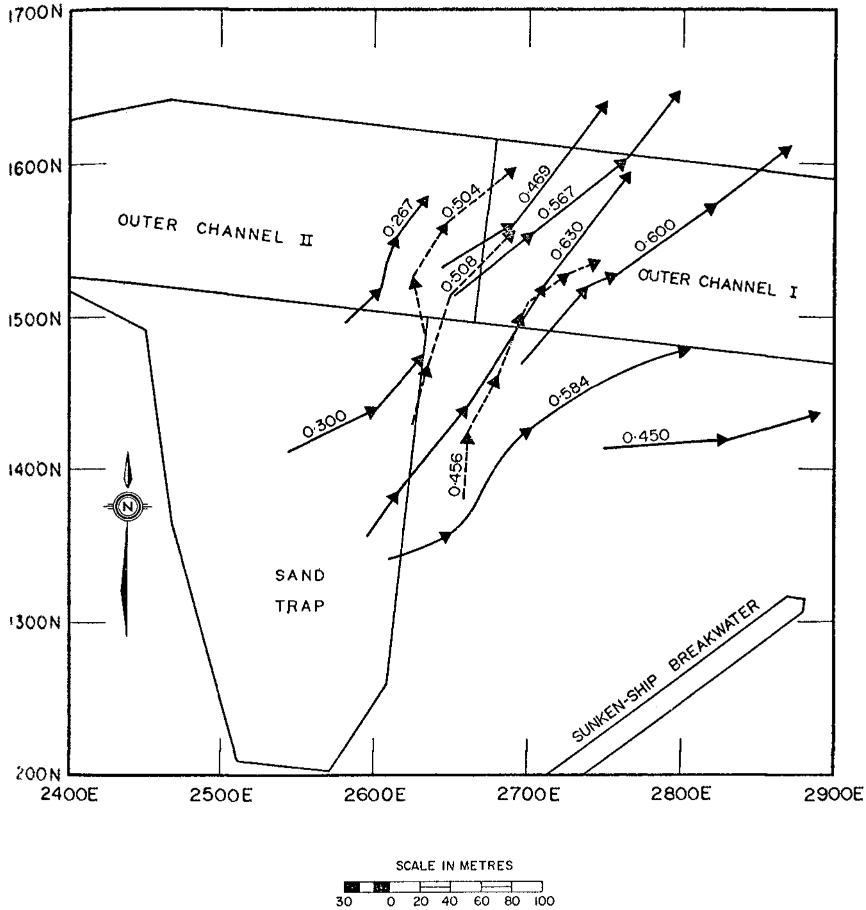



FIG. 8 MONTHLY VARIATION OF THE SHORELINE AT C.S. 9 AND C.S. 10




NOTES:

1. AVERAGE VELOCITIES IN FPS.
2. MODEL VELOCITIES HAVE BEEN CONVERTED TO PROTOTYPE VALUES.
3. MODEL CONDITIONS:
   (a) WAVE HEIGHT AT POSITION O = 6 FEET.
   (b) WAVE PERIOD = 10 SEC.
   (c) WAVES APPROACHING POSITION O FROM SSE.
   (d) SAND TRAP DREDGED.

CURRENT TRACKS USING SURFACE FLOATS:

←—— MODEL
←- - - PROTOTYPE (13 AUGUST, 1969)

FIG. 9 CURRENTS IN THE SAND TRAP AND THE OUTER CHANNEL

The period from April 20-September 9, 1969 was used for calibrating the model for the southwest monsoon. The April profiles of C.S.1 to C.S.13 were reproduced in the model to the -6 m depth. Wave direction, wave height and wave period were so adjusted that after a certain interval of time the erosion and deposition patterns and quantities in nature were reproduced in the model.

From the dredging records supplied by the Visakhapatnam Port Trust, it was calculated that in the period April 20 to September 9, the following quantities of sand were deposited in various locations in and south of the entrance channel (Figs. 6, 10 and 11):

| | | |
|---|---|---|
| Sand Trap | 180,000 cu. yd. | ( 43.5%) |
| O.C.II | 220,000 cu. yd. | ( 53.0%) |
| O.C.I | 14,000 cu. yd | ( 3.5%) |
| | 414,000 cu. yd. | 100.0% |

The quantity of sand pumped to the foreshore around C.S.1 during this period was about 120,000 cu. yd.

The erosion and buildup of the shore north of the entrance channel is given by the profiles at C.S.1 to C.S.13.

The calibration procedure consisted in finding a physically reasonable and acceptable combination of wave direction, wave height and wave period which, when applied over an interval of time would reproduce the natural events as observed at Visakhapatnam from April to September.

After a considerable number of calibration tests it was found that deep water waves of 7 ft. height and 8 sec. period (prototype values) approaching the harbor from SSE (H = 5.5 ft. at position 0 due to refraction and shoaling) and acting for 150 minutes reproduced reasonably well the sequence of events at Visakhapatnam during the 143-day period from April 20 to September 9.

The historical scale for the model was thus established at 150 minutes for the movement and deposition of around 420,000 cu. yd. of sand in the sand trap, O.C.II and O.C.I.

The April and September shorelines (MHWST) in the model were used as a base test with which results of other tests are compared. The repeatability of the calibration runs was in general quite good, except at C.S.8, C.S.9, C.S.9-6 and C.S.10 where variations of up to ± 25% were observed. This is essentially due to the sensitivity of the littoral processes to the influence of the rock outcropping.

Figure 12 shows the deposition pattern in the sand trap and in O.C.II. It should be noted that during the period April 20 to September 9, 1969, no substantial dredging took place in the sand trap until the first part of September; for obvious reasons, O.C.II was being continuously dredged during this period. The model results in Fig. 11 show no dredging in the sand trap and in O.C.II. Other tests have been performed where the movable-bed material was continuously removed from O.C.II corresponding to dredging in nature. It should be noted that the deposition pattern is similar in model and prototype. The dotted areas indicate the deposition of the finer sand.

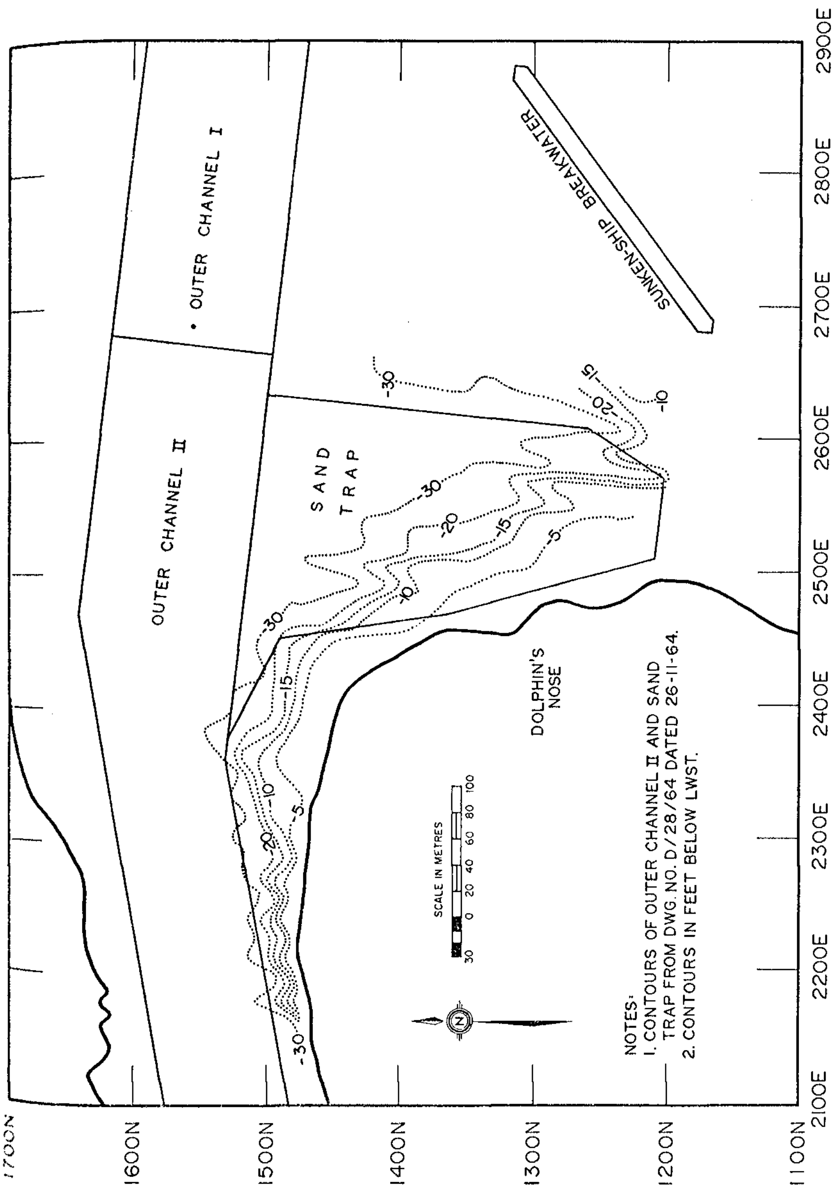



FIG. 10 DEPOSITION PATTERN IN THE SAND TRAP (PROTOTYPE)

To represent the 414,000 cu. yd. of sand deposited in the prototype, 1.6 cu. ft. of crushed bakelite (≈ 425,000 cu. yd.) was injected into the model along the 2300E coordinate line between the -6 m contour and the shore. After 150 minutes, the pattern shown in Fig. 11 was obtained with the following quantities:

| | | |
|---|---|---|
| Sand Trap | 170,000 cu. yd. | ( 40.0%) |
| O.C.II | 220,000 cu. yd. | ( 51.8%) |
| O.C.I | 10,000 cu. yd. | ( 2.4%) |
| | 400,000 cu. yd. | 94.2% |

The rest of the material is unaccounted for; some of the finer material deposited in the lee of the sunken-ship breakwater and the remainder was probably distributed in the region seaward around Dolphin's Nose.

The April and September profiles of C.S.1 to C.S.13 were reproduced in the model and compared with those of the prototype. The correspondence - although not perfect - was acceptable. It should be remarked that it is very difficult to match one season's profile in the model and prototype, because the model deals with average and uniform conditions over a season, while the prototype is subject to the non-uniform effects of storms.

The model was also calibrated for the northeast monsoon conditions for the period November 8, 1969 to February 8, 1970. After a considerable number of tests it was found that 2.5 ft., 6 sec. waves (prototype values) arriving at position 0 from S38E and acting for 40 minutes gave the best results. The repeatability was again reasonably good. However, at C.S.8, C.S.9 and C.S.11 there are discrepancies between model and prototype amounting to as much as 30% and the repeatability was no better than ±25%. All model results have therefore confidence limits of ±25%.

The new harbor layout is shown in Fig. 3. The starting point for all tests was the April 1969 conditions. The model was operated for 180 minutes for the southwest monsoon season corresponding to a slightly below average year for sand deposition in the sand trap, O.C.II and O.C.I (≈520,000 cu. yd.). For simulation of the northeast monsoon season the model was operated for 40 minutes corresponding to a southerly drift of 100,000 cu. yd. All resulting changes are compared to 1969 April and/or September conditions in the model.

The length and general alignment of the south breakwater was located by the consulting engineers in collaboration with the Central Water and Power Research Station Laboratories. While optimum harbor tranquility was one of the main considerations, it was required to adjust the gap between the shoreline at Dolphin's Nose and the head of the breakwater to achieve a trade-off between wave agitation in the harbor and effective longshore sand transport through the gap. The Hydraulics Section of the National Research Council was not involved in harbor tranquility studies, but did perform tests with various gap dimensions concerning trap efficiency. The gap location and width adopted by the consulting engineers shown in Fig. 3 was found to be satisfactory. The effect of a slightly wider gap was not discernible on the movable-bed model but would have injected more wave energy into the harbor. Placing the head of the breakwater closer to shore did interfere to some degree with the

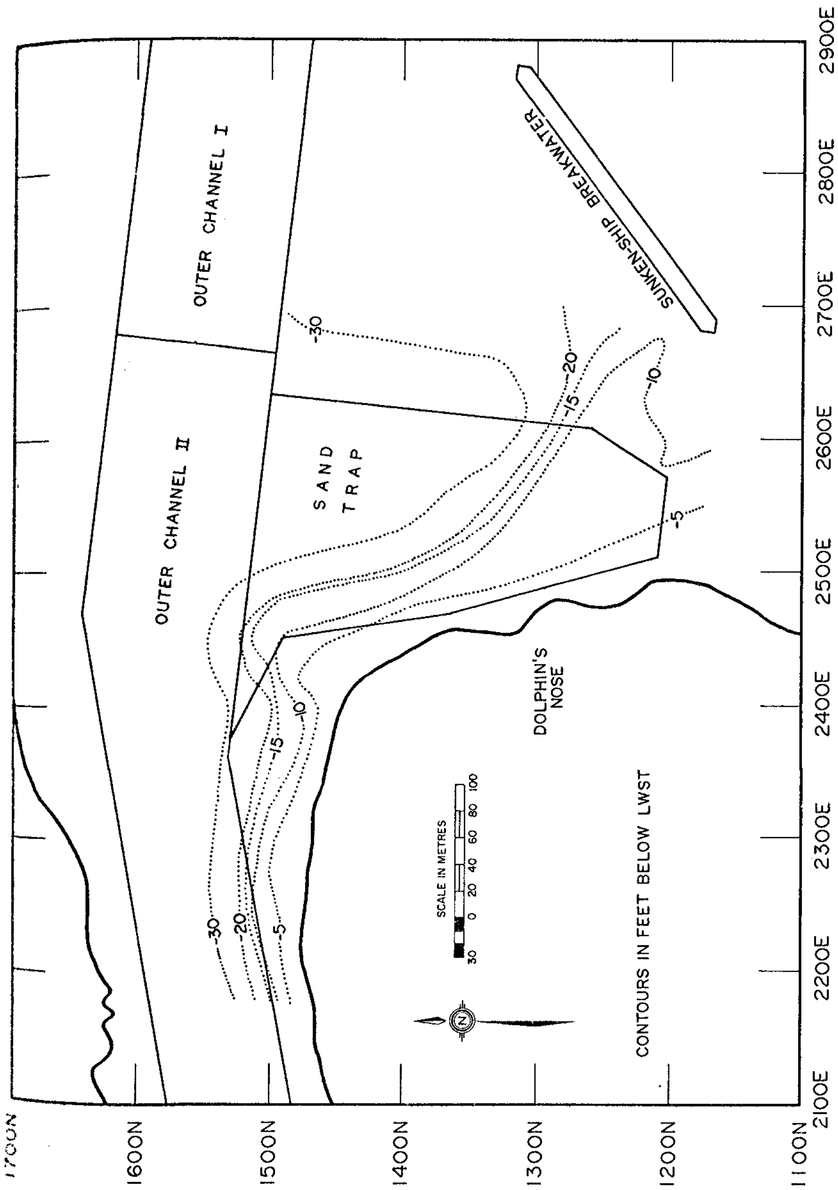



FIG. 11 DEPOSITION PATTERN IN THE SAND TRAP (MODEL)

sand transport, but not beyond the limits of accuracy of the experiments. In other words, the displacement of the breakwater head ±25 m in either direction did not indicate significant changes of littoral transport through the gap. The optimum location, size and dimensions of the new sand trap was established after considerable experimentation. The choice was dictated by conditions of littoral transport as well as limitations imposed by the rock contours. The bottom of the sand trap was set at an average of -18 m. Three fundamental tests were conducted to determine the efficiency of the sand trap and the conditions under which the gap would be blocked. Only one is reported here.

Southwest Monsoon Season

Northerly Littoral Drift: 650,000 cu. yd.

The deposition pattern around the gap, the head of the south breakwater, in the sand trap and in the harbor area is shown in Figs. 12 and 13. The types and quantities of sedimentary material deposited in various general regions are as follows:

| Zone | Type | Quantity (cu.yd.) | Percent of Total |
|---|---|---|---|
| I | Coarse) | | |
| | ) | 430,000 | 66.1 |
| II | Fine ) | | |
| III | Coarse-Medium | 40,000 | 6.2 |
| IV | Fine | 50,000 | 7.7 |
| V | Coarse-Fine | 90,000 | 13.8 |
| VI | Fine | 35,000 | 5.4 |
| | | 645,000 | 99.2 |

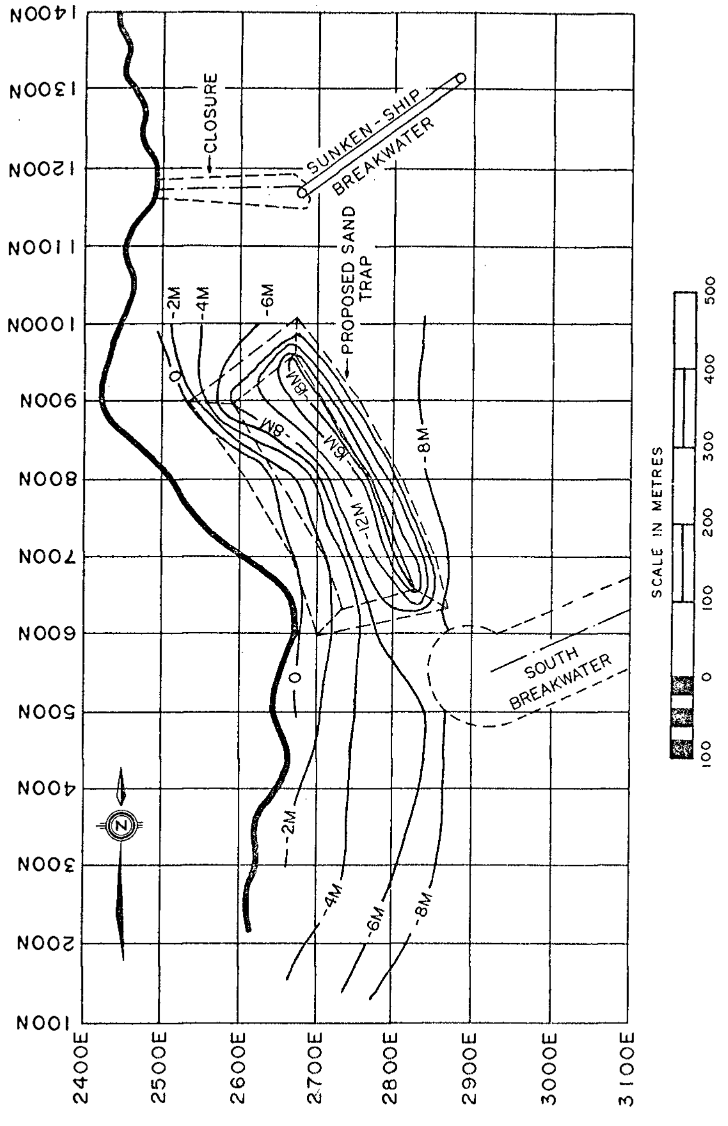



FIG. 12 DEPOSITION PATTERN AROUND THE GAP AND THE NEW SAND TRAP DURING THE SW MONSOON SEASON (LITTORAL DRIFT: 650,000 CU YD)

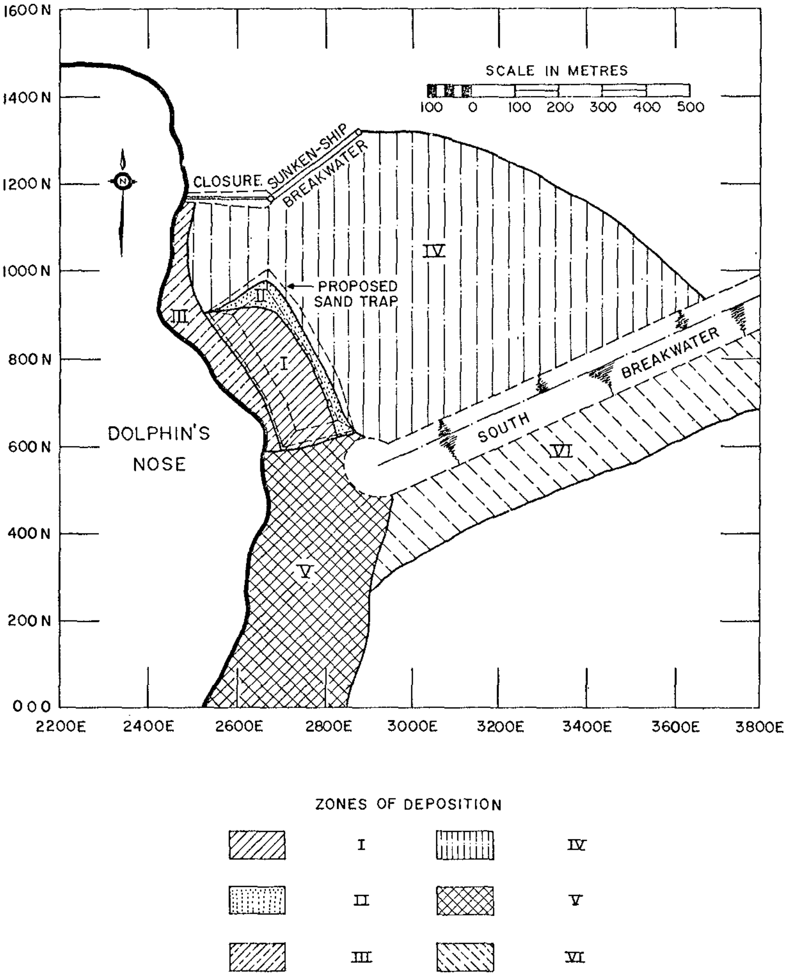



FIG. 13 ZONES OF DEPOSITION AROUND THE SOUTH BREAKWATER AND THE SAND TRAP