CHAPTER 76

BEACH DEVELOPMENT BETWEEN HEADLAND BREAKWATERS IN A LOW WAVE ENERGY ENVIRONMENT, PASIR RIS, SINGAPORE

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INTRODUCTION

One of the function of the offshore breakwater is to protect the coast from wave action. By dissipating the wave energy along its entire length, the breakwater causes sediments in its lee to deposit and a shore salient is formed. If the offshore breakwater are placed in a series along a coast with a gentle offshore slope and a substantial littoral drift tombolo will form behind the breakwaters between which bays will be sculptured by waves to form stable shapes (1). These attached breakwater would thus form a series of artificial headlands.

In nature, beaches between headlands are influenced by the position of the headlands. Where the headlands are closely spaced and a limited sediment supply exists, small pockets beaches are formed. Where the headlands are far apart and an adequate sediment supply exists, long and wide beaches are formed. Generally, between these two extremes most beaches between natural headlands take a shape that is related to the predominant wave approach; on the downcoast sector is a long and straight beach, while on the upcoast end is curbed beach. Silvester (2) in his model study established a relationship between the logarithmic spiral constant (α) and the angle of predominant wave approach (β). A quasi-permanent shape was reached when waves broke simultaneously around the model bay. As it is difficult to measure the curve sector in nature, Silvester and Ho (3) suggested the use of an indentation ratio to relate the bay's shape to wave approach.

The afore-mentioned concepts of headland breakwaters and beach formation between them were applied in 1968 along the Southeast Coast of Singapore (Fig. 1), where a series of headland breakwater are used to protect about 14 km of the newly reclaimed land (4,5) under the East Coast Reclamation Scheme (Phases I to VII) where 1525 hectares of foreshore was reclaimed at a total cost of $613 million from 1966 to 1985. Rip Rap headland breakwaters of length varies from 55 m to 67 m and spaced at 300 m to 360 m were constructed in series along the edge of the fill. Under wave action, the fines are removed leaving behind sand and gravels to form sandy bay beaches between the headland breakwaters. (see Figs. 2a, 2b and 2c).

The successful implementation of the headland breakwater concept at the Southeast Coast lead to similar technique being used for the reclaimed land at Pasir Ris. Between 1978 and 1980 Housing and Development Board reclaimed 44 hectares of the shallow foreshore at Pasir Ris and Loyang areas in two separate parts on both sides of Sungei Tampines on the northeast coast of Singapore to provide additional land for a park (Figs. 1 and 3). Approximately 2.4 million cu m of earth excavated from existing hills about 6 km away was utilised for the reclamation. The fill material, which is a semi-consolidated mass of gravel, sand and clays, disintegrates rather easily in contact with water. The fines are removed by wave action and coarser material is left behind for beach formation.

PASIR RIS RECLAMATION

The existing coast at Pasir Ris prior to reclamation was a relatively flat muddy coast with pockets of sandy beaches, the entire shallow foreshore up to a distance of 150 m from the existing shore was exposed during low tide.

To provide recreational facilities for residents around the area, it was decided to reclaim the shallow foreshore to creat land for the development of a park. In 1978 Housing and Development Board proceeded with the reclamation of 44 hectares of the foreshore at Pasir Ris and Loyang in two separate parts on both sides of Sungei Tampines and works was completed in 1980 (Fig. 3). The extent of the reclamation was confined mainly to the shallow area which was exposed at low tide. The profile of the reclamation was determined using the existing offshore topography as a guide, ie the edge of the reclaimed area was more or less parallel to the existing offshore contour (see Figs. 4a, 4b and 4c). The concept of rip-rap headland breakwaters which had been successfully implemented at the East Coast Reclamation was adopted for Pasir Ris Reclamation. A series of 10 numbers rip-rap headland breakwater was constructed along the edge of the reclaimed area to creat sandy bay beaches.

The fill material for the reclamation was excavated from existing hills some 6 km away from the reclamation site. The fill material is of Quarternary age and consists of semi-consolidated gravels, sands and clay. Boreholes carried out at the cut site showed that the material was dense to very dense medium to coarse silty clayey sand. Mechanical analysis showed approximately 75% was sand and gravel and 25% was silt and clay.

The material for reclamation was conveyed from the cut site to the reclamation site by lorry. An earth bund of approximately 20 m width was constructed initially along the perimeter of the reclamation site commencing from the existing shoreline and proceeded toward the sea by direct dumping from the lorries. Upon completion of the perimeter bund, filling within the bunded area was then proceeded, an opening in the bund was constructed to facilitate the inflow and outflow of sea water, area around the opening was reclaimed last. The level of the fill was 102.70 m or approximately 4.7 m above the existing seabed level.

Rip rap headland breakwaters constructed dry in the fill material along a near straight edge of fill and subsequently become wet (Fig. 5). The area upon which each rip-rap structure is to be constructed is first overfilled, compacted and thereafter excavated in stages to form an earth mound with a seaward slope of 1:2 and a landward slope of 1:1 1/2. A non-woven filter cloth of thickness 3.5 mm was used as a filtering medium to prevent removal of fill material by wave action was then spread loosely over the entire mound. On top of it were placed 0.1 m of 0.05 to 0.1 m stones, a second 0.25 m layer of 0.1 m to 0.15 m stones and lastly a layer of 0.40 m stone properly pitched. The rip-rap structure extends 1.18 m below LWOST to 1.5 m above HWOST. Subsequent wave action removes the fill materials which was overfilled and exposed the rip-rap breakwater which are spaced at about 200 m. Under wave action, the fines are removed leaving behind sand and gravels for beach formation between the headland breakwaters. The length of the rip rap breakwater is 25 m which has to be such that it would not subsequently become an "offshore island". This can be predetermined using Silvester's relationship between logarithmic spiral constant (α) and the predominant wave approach angle (β). The maximum limit of fill seaward of the rip-rap breakwater was 25 m from the centre of the breakwater. The overfilled material was removed and spread onto the seaward face of the rip-rap headland breakwater upon completion of construction to provide a gentle sloping seaward appearance.

COASTAL ENVIRONMENT

The northeast coast of Singapore is relatively clam as it is located at Johore Strait bound by the southern boundary of Johore and northern boundary of Singapore. Johore Strait is a long and narrow strait with a length of 30 km and an average width of 2 km. Winds from the north during the northeast monsoon do not have a large influence except through refracted swell from South China Sea which enter the Johore Strait from the east. It is essentially a low energy environment throughout the year with refracted waves coming from the northeast quadrant, so that westward littoral drift is present (see figure 3).

WINDS

The wind conditions in Singapore are governed by the two monsoon seasons. The SW-monsoon season prevailing in the months June through Sept. The NE-monsoon season prevailing in the months December through March. Separating these monsoon seasons there are two inter monsoon periods.

Winds were records at the Paya Lebar Airport at a point about 2 km from the sea and 28.0 m above mean sea level and at Changi Airport at a point 1.2 km from the sea and 13.0 m above mean sea level. Sharp contrasts in direction and velocity of winds were recorded for the northeast monsoon (December to March) and the other periods. Long term wind frequency data obtained from Meterological Services Singapore at Paya Lebar Airport from 1956 to 1980 and at Changi Airport from 1972 to 1982 were used to produce the wind rose for the annual average wind speed and direction (Fig. 6a). Southwest monsoon during the period June to September (Fig. 6b) and northeast monsoon during the period December to March (Fig. 6c) for Paya Lebar Airport and the annual average wind speed and direction for Changi Airport (Fig. 6d).

Winds during the northeast monsoon are predominantly from N-NNE and are less than 5.4 m/sec. Wind speed exceeding 10 m/sec only 2 - 3% of the time. Wind during other period are from S-SSE with speeds of less than 3.3 m/sec. The annual wind rose showed a similar pattern to that of the northeast monsoon which indicated that the predominant wind is from the north quadrant.

TIDES

The tides are essentially a combination of diurnal and semi-diurnal (ie a high tide is followed by a not so high tide) with a range of approximately 2.3 m during spring tide, 1.0 m during neap tide and a mean range of 1.7 m. The typical tidal velocity is 0.7 m/sec during spring tide and 0.4 m during neap tide based on information available from Admiralty Chart.

TIDAL CURRENTS

A non-contact current meter manufactured by Koyowa Shoko Co Ltd Japan was installed at the study area at 3 m below surface during the period 7.2.86 to 10.3.86. The current meter is able to measure both the direction and mean current velocity continuously. Current velocity, however, is counted for three minutes at every twenty minutes striped graphically on scratch paper. Measuring range for current velocity is 0.05 - 3 m/sec as mean current velocity with one constant-pitched impeller.

A scatter plot of current speed against direction (Fig. 7a) for all recordings indicated that the current is mainly in the southeast and northwest direction. A cumulative current speed distribution curve (Fig. 7b) showed that 85% or more of the current speed is less than 0.3 m/sec. A plot of west going and east going current together with hourly tide observation for 8.2.86 were shown in Figs. 8a and 8b. From these two figures it can be seen that during ebb tide the current is east going and during flood tide the current is west going. In general, the tidal elevation curve lead the velocity curve by about 3 hours which is approximately one-quarter of the semi-diurnal period. This is an expected observation because it shows that during extremes of tides, ie when the tides are about to change direction, the velocity are almost zero. Also, when the tides are flowing in or ebbing out of the strait, ie at mean sea level, the velocities are maximum.

WAVES AND WAVE REFRACTION

Pasir Ris Reclamation was along a coastline facing north which is subject to refracted swell wave from South China Sea arriving the beach from the north east direction. This results in a net littoral draft from east to west (as indicated by the offshore topography in Fig. 3) whether the waves are generally locally or are swell from South China Sea, they entering the Johore Strait from the east (Figs. 9a and 9b). The wind rose for the area indicates a predominance of winds from NE quadrant. The largest proportion of these are wind of less than 5.4 m/sec. Winds in excess of this velocity from this NE quadrant occur for less than 4% of the time.

The major wave incidence would therefore appear to be swell arriving from South China Sea. The predominance of this wave and current action is indicated by the offshore contour. These clearly indicate an east to west drift of sediment. Considering the general orientation of the bed contour at the study area, a refraction computation indicates a deepwater approach from a north easterly direction, S.Y. Chew (4) measured the waves at Southeast Coast of Singapore, the result indicated that during the northeast monsoon the highest value of H_{max} was 1.1 m and for more than 65% of the time, H_{max} did not exceed 0.6 m. During other period H_{max} exceed 0.6 m for less than 10% of the time. 90% of T_z fell between 2.5 and 4 seconds during northeast monsoon while T_z was predominantly around 3 seconds during other period. A wave period of 4 seconds was used for the plotting of the wave refraction diagram in Figs. 3, 9a and 9b. The wave period is close to that reported in South China Sea of 4 to 7 seconds. Such swell is predominant in the months from December to March when northeast monsoon exist in the area. Figs 10a and 10b showed the wave height exceedence distribution curves and H_s - T_p relations for prevailing system off Changi coast respectively.

IMPLICATION AND EFFECTS OF PROCESSES ON RECLAMATION PROJECT

The northeast coast of Singapore is a sheltered area and local winds do not have a large influence except through refracted swell from South China Sea. It is essentially a low wave energy environment throughout the year with waves coming from the northeast, so that a westward littoral drift is present.

The swell from South China Sea enter the Johore Strait from the east after travelling through the deep water, the waves are refracted toward the reclaimed area, as the offshore topography is almost parallel to the coast, the refracted waves reach the coastline almost perpendicular, this together with the fact that the tidal current is flowing westward during flood tide and eastward during ebb tide with a duration of approximately 15 hours during flood tide and 9 hours during ebb tide, there is a tendency for a net movement toward the westward. In view of the almost perpendicular approach of the wave orthogonal and the weak current, the movement of the sediment is a very slow processes as indicated by the slow beach formation at Pasir Ris Beach. The formation of the beach between the headland breakwaters is slower when it is compared to the coast at East Coast which is more exposed than the beach at Pasir Ris.

GRAIN SIZE DISTRIBUTION OF BEACH MATERIAL

The fill material, which is a semi-consolidated mass of gravels, sand and clays, disintegrates rather easily in contact with water. The fines are removed by wave action and coarser material is left behind for beach formation.

The grain size characteristic of the beach material varied from 0.06 mm to 10 mm. The median size (D50) varied from 0.4 mm to 1.1 mm and the average median size was 0.68 mm (Figs. 11a and 11b). There is a systematic variation of mean grain size normal to the beach, from medium sand at the berm to coarse sand at the step. The average mean grain size is 0.39 m for berm samples, 0.59 m for foreshore samples and 0.88 mm for step samples.

While size variation normal to beach is present, the material is not well sorted. The average berm sample is moderately sorted (0.96) whereas the foreshore and step samples are poorly sorted (1.22 and 1.23 respectively). Poor sorting is attributed to the incomplete process of selective removal of fine grains under low wave energy environment and the short period of beach development (1980 - 84).

There is no systematic alongshore variation of mean grain size and sorting. The lack of alongshore variation in grain size characteristics is due to low wave energy and absence of littoral currents to sort out the beach material.

BEACH PROFILES

The formation of beaches along the reclaimed Pasir Ris coast is essentially similar to a situation where the scarp retreat along the fill will not produce a seaward concave curve until the strip of fill between the headland breakwaters and the sea is removed and the seaward sides of the breakwater are exposed to wave action. The berm is of fairly uniform width along the entire shore in the model proposed for beach formation along reclaimed Southeast Coast of Singapore (8). Basically, a strip of fill material placed seaward of a pair of breakwaters retreats under wave action; as the shoreline retreats in form of a scarp, a sloping abrasion ramp is left behind; the clastic deposits which is derived from the fill covers the abrasion ramp. The extent of development of clastic deposits in form of a beach between a pair of breakwaters varies from cell to cell (See Figure 3 showing cells along Pasir Ris reclaimed coast).

Beach profiles were taken at the upcoast, midcoast and downcoast ends of cells at the Pasir Ris coast (see Figure 12 showing profiles from cells A and F). They are slightly concave and represent profiles of under-nourished beach based on Bruun's (9) classification of beach profiles. The beaches are poorly formed because of an inadequate supply of clastic material from the fill.

The backshore (berm) is present at parts of the cells and is very narrow, averaging 2.4 metres wide. The landward ends of the profiles are marked by active scarp erosion. The foreshore average 7.8 metres wide and consists of a thin layer of clastic material that gets progressively thinner towards the step. The foreshore slope ranges from 4°10' to 8°40'. Exposed abrasion ramps are found mainly in the foreshore zone; generally, they have a sparse cover of pebbles, cobble-sized and boulder-sized pieces of Old Alluvium. The slope of the abrasion ramp is less than that of the foreshore.

Certain features on beach profiles display consistent pattern: the upcoast fill scarp is usually inactive whereas ongoing erosion marks the fill scarps at the midcoast and downcoast sections. The berms are usually located at the upcoast ends and occasionally in the midcoast sections.

BEACH PLANS

With reference to position of the step, most of the beach planforms display a slight seaward concave curvature with an almost straight downcoast sector and a more indented upcoast sector. With development of berms in the upcoast sector, the step at that part of the cell is prograded and straightened.

Active scarps characterized almost the entire length of the cells, with most scarp height between 0.25 and 0.75 metres. The persistence of these active scarps indicates that beaches are still retreating. Small lengths of inactive scarps are found in the upcoast sectors of cells A, C, E, F and G and the downcoast sectors of cells B and C. They occurred at locations where they are protected by berms, bars or mangroves. The height of active scarps tend to increase progressively with distance from monactive scarp until the highest scarp height in the cell is reached (usually in the middle of the cell).

For planning purposes, Silvester's (2) criterion of the logarithmic spiral to determine the maximum position of the beach between the breakwaters was adopted.. These lines of maximum positions are based on a logarithmic spiral of 1.05 with a constant agnel (α) at 72° to a wave approach (β) of 10°. (See Figs 13a and 13b showing lines of maximum positions compared with planform of the scarps of all the cells).

BEACH DEVELOPMENT

Beach platform and changes at cells A and F are shown in Figs 13a and 13b. The profile indicated that there is minor variation of the beach profile between high and low water where a accretion and erosion have occurred. From Fig. 3 it can be seen that the offshore profile is more or less parellel to the edge of the reclamation profile and the wave direction is almost perpendicular to the beach, this together with the weak current resulted in slow erosion and minimum littoral drift which explain the slow formation of the beach development between the rip-rap headland breakwaters. Although the changes is slow, there is still a tendency for westward movement as the duration of the current flowing eastward is generally shorter than the westward movement. For land use purposes, it is necessary to determine the limit of erosion. Silvester (7) has suggested that the relationship between logarithmic spiral constant and the wave obliquity can be used to determine the equilibrium shape of the beaches between headland breakwaters.. The probable shapes based on this criterion of the three bays for wave approach from north are given in Figs 13a and 13b. This assume that the westward drift is reduced or cut off. From Figs 13a and 13b it can be seen that further erosion is expected to take place especially around the curved portion.

DISCUSSION

Even with a longer time period, the beaches at Pasir Ris are unlikely to attain the equilibrium shape according to the logarithmic spiral criterion. This is confirmed by the presence of inactive scarps protected by berms along parts of the cell and the straightening and progradation of the shoreline with berm development. The logarithmic spiral criterion therefore cannot be used to determine beach equilibrium at the Pasir Ris coast because of the low wave energy and a very weak littoral drift. Given the low wave energy and a very gentle offshore gradient, beach type similar to East Coast of Singapore is unlikely to be attained by all the cells at Pasir Ris.

The slow progress in the development of the beach at northeast coast is due to weak current and almost perpendicular approach of the waves. It is most likely that the beach will only reach its anticipated platform after prolong period. Monitoring of the beaches will be carried out to observe the beach development.

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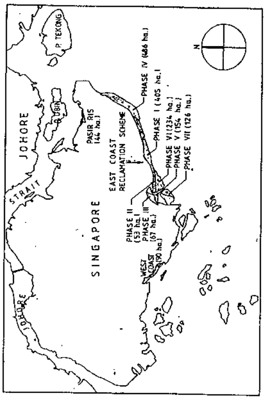
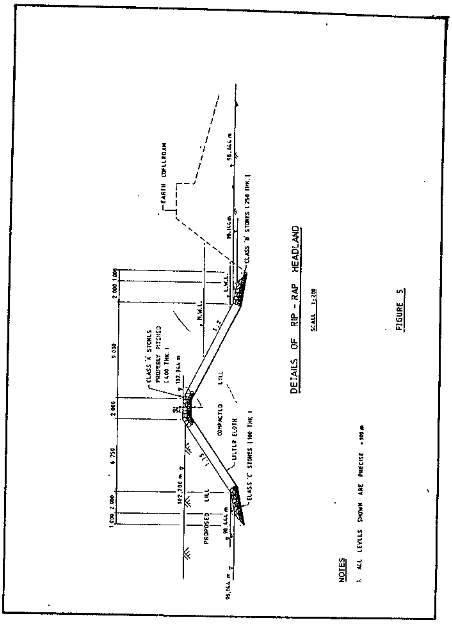


FIG. 1 - FORESHORE RECLAMATION BY HOUSING & DEVELOPMENT BOARD



DETAILS OF RIP - RAP HEADLAND

SCALE 1:200

FIGURE 5

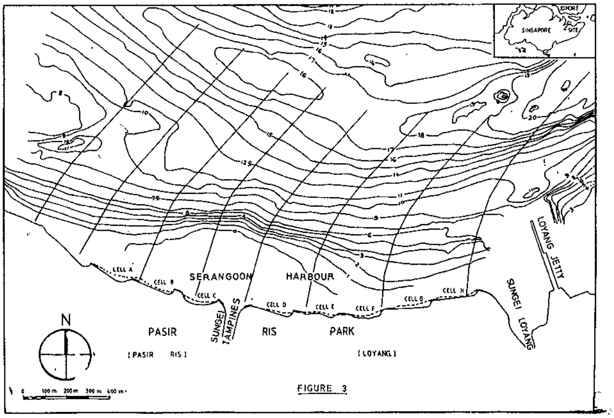


FIGURE 3

FIGURE 2a

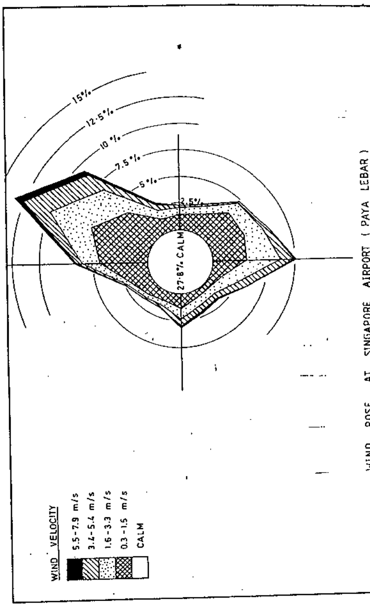
FIGURE 2b

FIGURE 2c

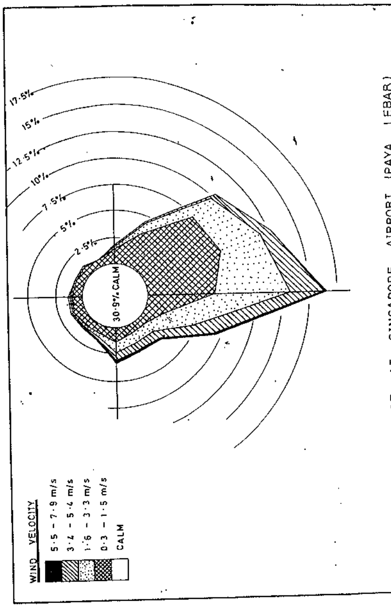
FIGURE 4a

FIGURE 4b

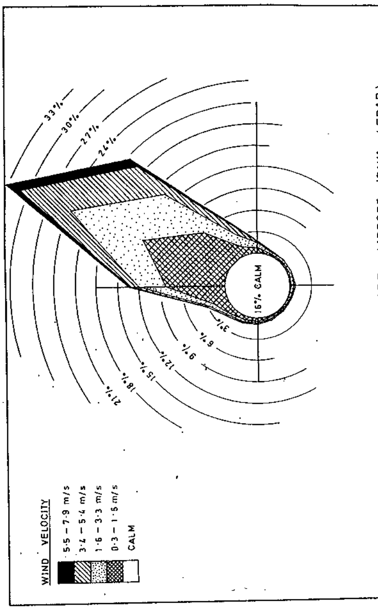
FIGURE 4c



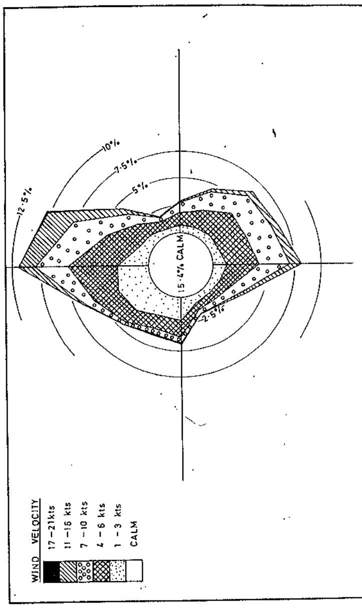
WIND ROSE AT SINGAPORE AIRPORT (PAYA LEBAR)
ANNUAL
FIGURE 6a



WIND ROSE AT SINGAPORE AIRPORT (PAYA LEBAR)
S. W. MONSOON
FIGURE 6b



WIND ROSE AT SINGAPORE AIRPORT (PAYA LEBAR)
N. E. MONSOON
FIGURE 6c



WIND ROSE AT SINGAPORE CHANGI AIRPORT
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FIGURE 6d

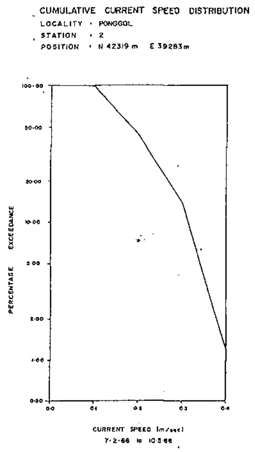


FIGURE 7b

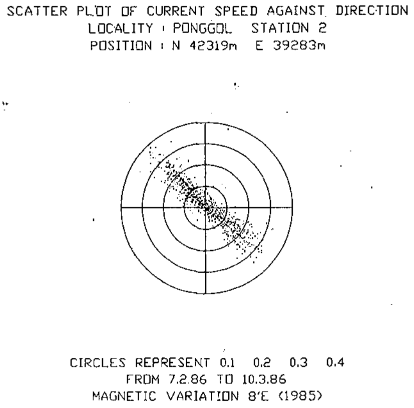
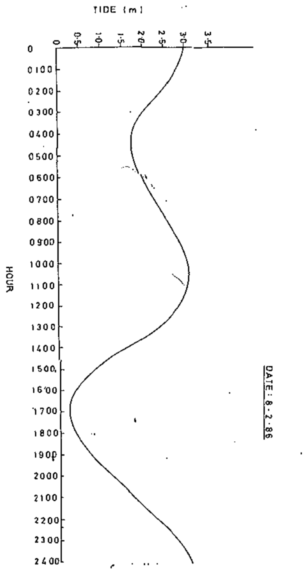


FIGURE 7a



HOURLY TIDE OBSERVATION

FIGURE 8b

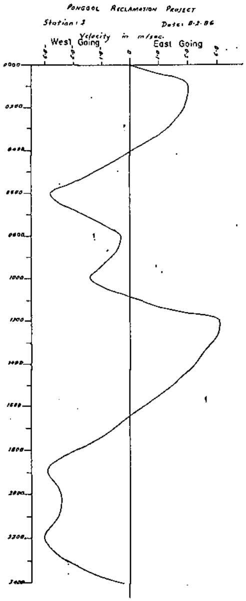


FIGURE 8a

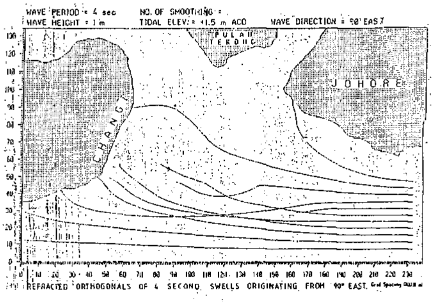


FIGURE 9b

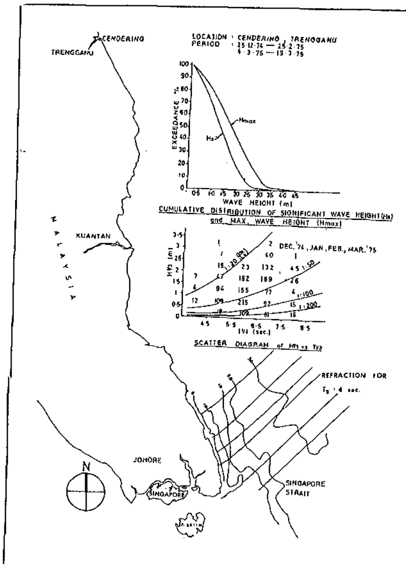


FIGURE 9a

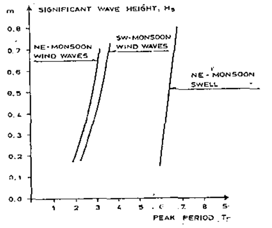


FIGURE 10b

H_s-T_p relations for prevailing wave systems off the Changi Coast.

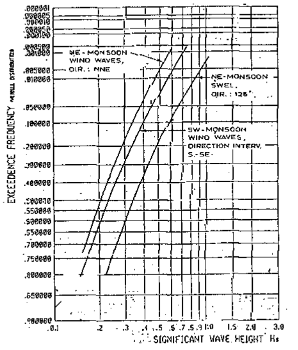


FIGURE 10a

Wave height exceedence distribution curves for the prevailing wave systems off the Changi Coast.

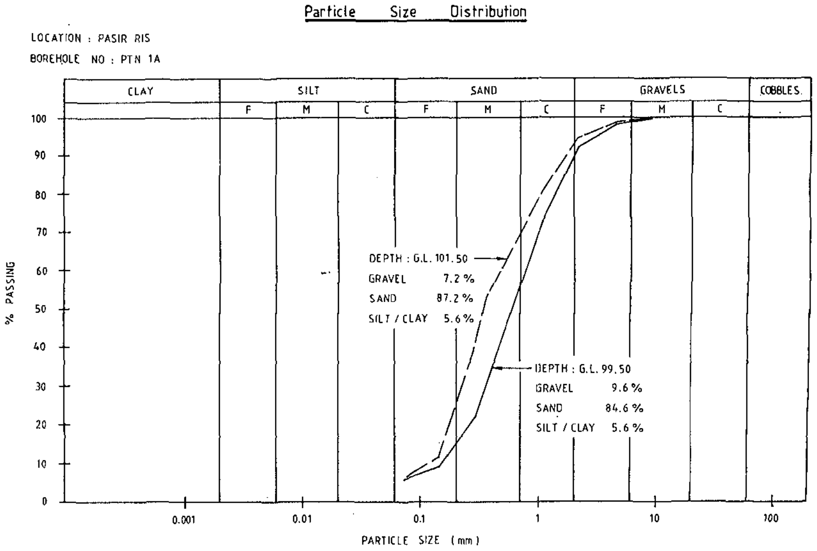


FIGURE 11a

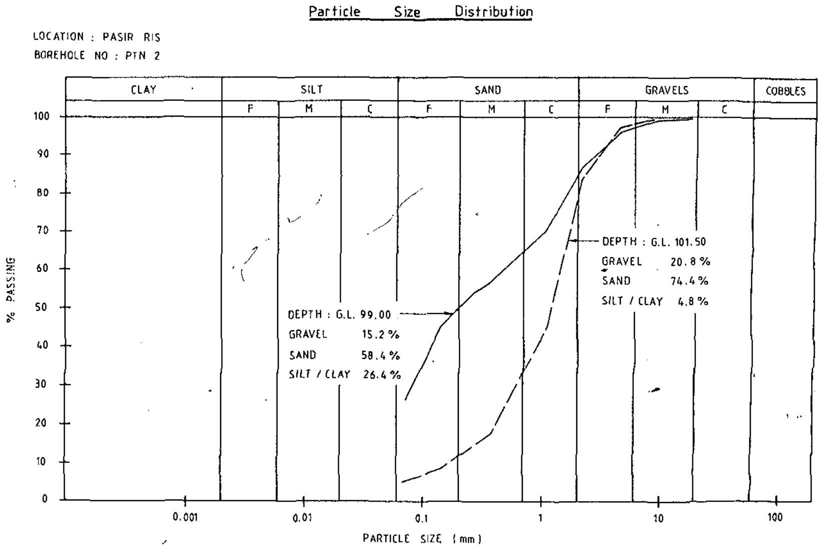


FIGURE 11b

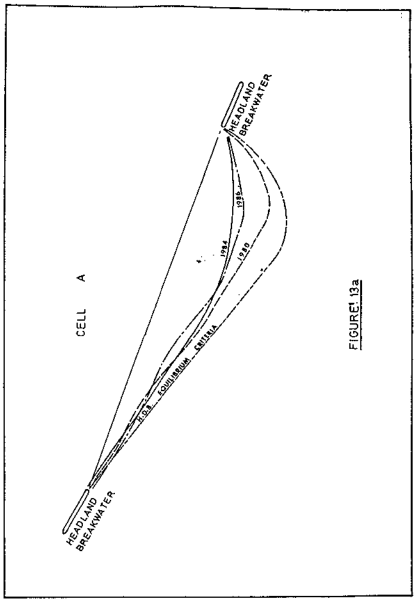


FIGURE 13a

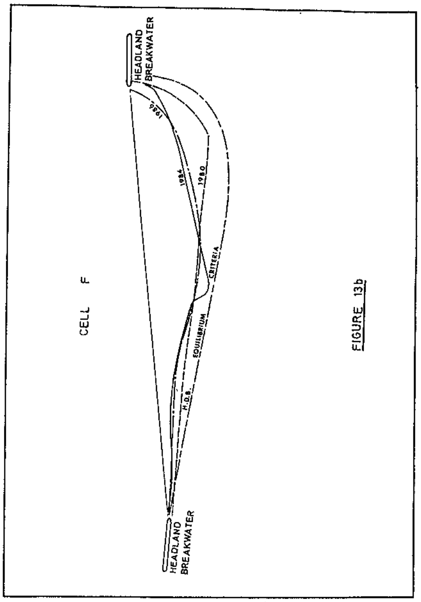


FIGURE 13b

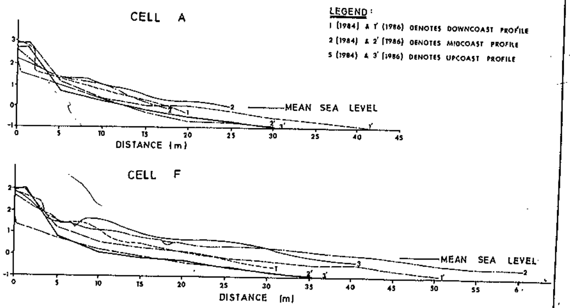


FIGURE 12

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