

DEVELOPMENT OF THE PORT OF CUDDALORE HYDRAULIC MODEL STUDY

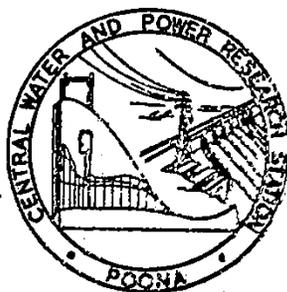
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PREFACE

The natural growth of ports along the east coast of India is inhibited due to heavy sand drift caused by breaking of waves at an angle to the coast. The south-western waves, which predominate over the north-eastern waves, both in strength and frequency, are mainly responsible for the enormous sand movement along the coast. The net littoral drift is, therefore, from south to north. Activities of the Port of Cuddalore, one of the most important intermediate ports on the east coast and situated about 120 miles south of Madras, are hindered due to this intense littoral drift. The depths at the entrance to the port deteriorate while the entrance itself moves towards north over a distance varying between 3000 to 4000 ft (914.4 to 1219.2 m) in a period of about 8 to 10 years. The entrance is not allowed to occupy a position close to the light house on account of latter's safety, and an artificial cut is made on the south side to divert the flow.

In order to develop the port it was necessary to stabilise the entrance and maintain adequate depths in the entrance channel. Experiments were conducted in a hydraulic model to length and depth scales of 1/200 and 1/50 to study various proposals. Two layouts for maintaining 9 and 17 ft (2.74 and 5.18 m) depths below LWOST in the navigation channel during first and second stages of development respectively have been recommended. First stage envisages construction of breakwaters 1300 and 900 ft (396.24 and 274.32 m) in length on the southern and northern sides of the gut respectively and sand trap behind the southern breakwater. It has been suggested that breakwaters for the first stage might not be extended in the beginning of the

second stage of development. Instead, only a sand trap may be extended upto 17 ft(5.18 m) contour in the sea, and periodic dredging carried out in the sand trap. Extensions of breakwaters to the final lengths of 1900 and 1700 ft(579.12 and 518.16 m) of the southern and northern breakwaters respectively, might be carried out in stages after watching conditions in the prototype in regard to silting in the entrance channel.

These investigations brought to light the following points :

i) An effective way of dealing with littoral drift consisted of obstructing it in a sand trap and dredging and dumping it on the down-drift side.

ii) An entrance channel if inclined in the direction of predominant littoral drift functioned better than the one at right angles to it.

iii) Vertical type of breakwater was not considered suitable in this case as the wave disturbance was continued in the navigation channel. It was further subject to very high dynamic pressures due to the location of the breakwater in shallow waters.

The investigations were carried out at the instance of the State Port Officer, Madras. The permission kindly granted by the Ministry of Transport, New Delhi, to publish the memorandum is gratefully acknowledged.

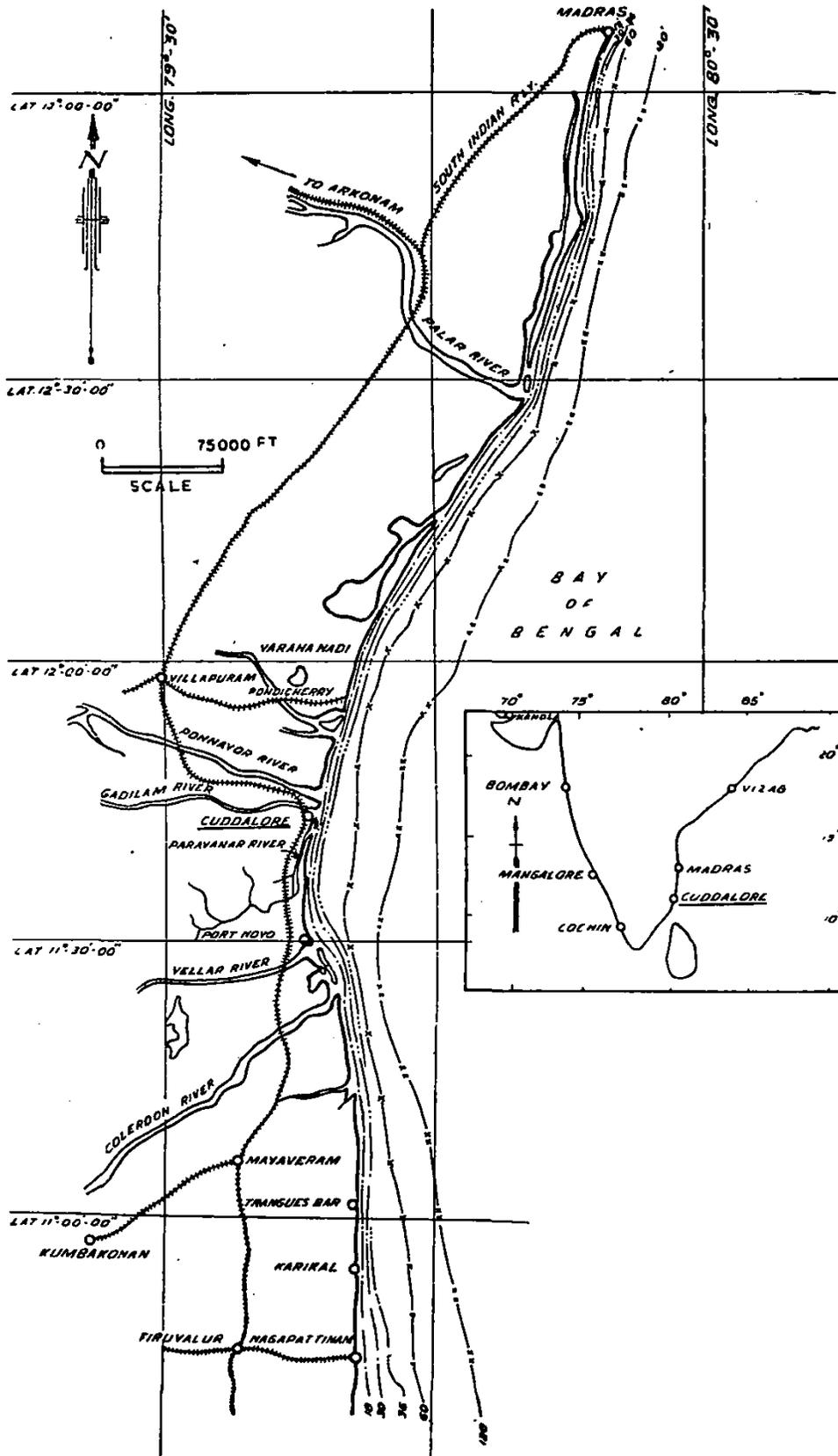


Fig 1 : Index plan of Cuddalore Port

DEVELOPMENT OF THE PORT OF CUDDALORE
Hydraulic Model Study

The Port of Cuddalore, about 120 miles (193.12 km) south of Madras is one of the most important intermediate ports of Madras State. It is situated at the confluence of the rivers Paravandar and Gadilam (fig 1). The Port facilities are located along the right bank of the Uppanar cross-channel connecting the two rivers: Paravandar and Gadilam. The Cuddalore is the main port of entry for coal required by the Southern Railway and export of iron ore to Japan and handles about 2,00,000 tons annually.

Had it not been for the existence of a bar in the sea at the entrance to the port, the traffic would have steadily increased and the port would have flourished. The port entrance also shifts northwards at an average rate of about 400 ft (121.92 m) per year, mainly due to preponderance of the northerly littoral drift of about 5,00,000 tons per annum. The entrance to the port moves northwards over a distance varying between 3000 and 4000 ft (914.4 and 1219.2 m) in a period of about 8 to 10 years, depending on meteorological conditions. The mouth is not allowed to occupy a position close to the light house as the Paravandar has a tendency to open a channel through the lagoon which may endanger the safety of the light house. An artificial cut is made on the south side for diverting flow of the rivers. The northernmost mouth then gets silted due to the intensive littoral drift. In due course of time this mouth shifts and again occupies the northernmost position near the light house. Such artificial cuts were made in the years 1936, 1942, 1949 and 1959 at the positions shown in fig 2. In order to develop the port it was necessary to stabilise the entrance channel and maintain adequate depths.

Advice of the CWPRS was sought by the State Port Officer, Madras, to

evolve suitable training measures for the same. A hydraulic scale model was, therefore, constructed to study the problem.

2. The object of the hydraulic model investigations was

i) to investigate the most suitable position of the entrance to the port and evolve training measures for guiding flow of Paravanar and Gadilam rivers.

ii) to evolve suitable measures to arrest shift of the gut, and

iii) to develop the port in stages and provide minimum depths of 9 ft and 17 ft (2.74 and 5.18 m) below LWOST in the navigation channel in the first and second stages of development respectively.

3. HISTORICAL, GEOLOGICAL AND PHYSICAL FEATURES

Old town of Cuddalore continues to be a trade centre, while the new town contains all the Government Offices. The historical importance of Cuddalore is very great. The port became a trade centre with the advent of the East India Company which conducted its dealings in Fort St David, the ruins of which still exist. Old records reveal that entrance to the port was previously through St David's Bar.

Greater part of the area is covered with archaeous rocks of the gneiss family. These are covered by sedimentary rocks belonging to different geological periods and overlying in regular succession. Enormous quantities of gneiss are quarried in Mailam and Tirukkoilur. Near Pánruti on the south bank of Gadilam, clay suitable for brick making is found. Sea shore is fringed with a belt of sand dunes. The country near about the port is formed by sandy lagoons. The country gently slopes from west to east and from north to south.

The Paravanar river originates at latitude $11^{\circ} 31' 0''$ and longitude $79^{\circ} 34' 6''$ as the surplus of Walajah tank of Sethiatope anicut system. The Walajah tank has a catchment area of 74 square

miles(196.82 sq Km) and the entire surplus discharge is carried by the Paravanar river through two surplus escapes at the left flank of Walajah tank. The surplus water flows along northeasterly direction and empties into Perumal tank after traversing a distance of about 6 miles(9.65 Km). Catchment area of Perumal tank is 216 sq miles (560 sq km). The surplus water from the Perumal tank finds its way through a natural ground escape, one by-wash and two surplus weirs in the lower reach of Paravanar ~~Port~~. The river at its mouth has a flat slope of 1' in 9000. The tidal limit extends 14 miles(22.53 km) from the sea. The reach below the railway line about 9 miles(14.48 km) from the sea is used for navigation of small craft.

The Gadilam river has its origin in the reserve forest limits of Sevanimalai in Tirukkoilur at latitude 12° 55' and longitude 79° 5'. It starts as a small stream having a width of about 10 ft(3.05 m) and serves as a supply channel to various diversion works constructed on the river as given below.

TABLE 1

Sl No	Name of the diversion work	Distance from Gadilam Mouth (in miles)	Year of construction	Length of weir in ft	Depth of water(ft) over crest during flood
Supply Channels					
1	Kattu Edayar Tank	51	*	-	-
2	Mémalur Tank	49	*	-	-
3	Alur Tank	46	*	-	-
4	Anenervkkai Tank	44	*	-	-
Anicuts					
5	Damal	41	1936	451	8.5
6	Puthanandal	37	1955	371	*
7	Tiruveđi	15	1848	524	15.1
8	Vanamadevi	9	1826	512	12.4
9	Tiruvendipuram	6	1837	436	12.6
* not available					

The Uppanar cross-channel

The Gadilam river is connected to the Paravanar river by Uppanar channel about 2 miles (3.22 km) in length. It takes off from the Gadilam river near Fort St David and joins the Paravanar river at Gori Point. The Cuddalore Port is located on the right bank of the channel. The channel has to be occasionally dredged for maintaining 6 ft (1.83 m) depths below LWOST. The dredged material is dumped on the banks, and consequent narrowing of the channel helps to maintain adequate depths. When the Paravanar and Gadilam rivers are in spate, a strong return flow develops at their confluence where considerable dredging is required to be done. The Paravanar river alone in flood causes severe erosion at the Gori point and its recession northwards.

4. ANALYSES

Data in respect of rainfall, freshet discharges, waves, tides etc, at the Cuddalore Port were collected by various agencies such as the State Port Officer, Madras, the Indian Navy, the Madras State PWD and the Indian Meteorological Department, etc. Analyses of the data are presented below.

i) Rainfall data for stations Kuringipadi, Ulundurpet and Cuddalore, representing catchment areas of the Paravanar, Gadilam and for the area near the Cuddalore Port respectively, was analysed. Heavy rains in both the catchment areas occur simultaneously during November and December. The average rainfall in catchment areas is about 46 inches (1168.4 mm) 70 percent of which is received from October to December. Further, the rainfall above average seems to repeat at an interval of about four to seven years. A severe storm occurred near Cuddalore in 1884 when 15.4 inches (392.16 mm) of rain-

fall was observed in a day on 19th December 1884. The maximum rainfall for the month in that year was 44 inches (1117.6 mm) in November, the total rainfall in the year being 102 inches (2590 mm). This rainfall has never exceeded, though about 90 to 95 inches (2286 to 2413 mm) of rainfall was observed in 1887 and 1913 respectively.

ii) The maximum freshet discharge during the period 1951 to 1957 in the Paravanar river was observed to be about 11,223 cfs (316 m³/s) on 19-9-53, while the calculated value from the catchment area works out to 58,000 cfs (1642 m³/s). As already mentioned the main source for this river is the surplus discharges from the Walajah and Perumal tanks. The freshet discharge of this river may not, therefore, represent the actual run-off from the catchment. Practically no freshet discharge was observed in the river during fair weather i.e. from January to August.

The average maximum freshet discharge in the Gadilam river during 1951 to 1957 was observed to be about 24,353 cfs (689 m³/s) on 7.12.52. The estimated value of the freshets from the catchment area works out to 65,000 cfs (1839 m³/s). The freshet discharge of this river also may not represent the actual run-off from the catchment due to diversion of discharges. Practically no freshet discharge was observed in the river during fair weather.

iii) Influx in both the rivers for a tide observed on 29.3.56 having a range of 2.42 ft (0.74 m) with HW and LW at +3.18 ft and +0.76 ft respectively has been worked out by Kilford's method. The influx in Paravanar works out to 65.7 million cft (1.86 million m³) while in Gadilam to 20.9 million cft (0.582 million m³); corresponding maximum tidal discharges being 4,405 and 1,319 cfs (125 and 37.3 m³/s) respect-

ively and 5,724 cfs (162.3 m³/s) at the entrance.

(iv) Survey plans supplied upto 1956 provided information in respect of cross-sectional areas and depths at the gut and monthly and yearly shift of the entrance as given below.

Depths and Cross-sectional areas at the gut

During fair weather the rivers do not carry any appreciable freshet discharge. Moreover, during this period there is an intensive northerly littoral drift. A bar develops at the entrance as the tidal influx is too small to produce adequate scouring velocities in the channel resulting in progressive deterioration of depths at the entrance. In September, just before the break of NE monsoon the bar is generally at its worst when depths are only about 2 ft (0.60 m) below LWOST and lighters drawing 3 to 4 ft (0.91 m to 1.21 m) are required to be pulled through. The average cross-sectional area below LWOST during fair weather is about 1000 sq ft (93 sq m). Due to freshets in the two rivers, depths in the channel improve. By the end of December a depth of 6 to 7 ft (1.83 m to 2.13 m) below LWOST is obtained at the entrance to the port. The average cross-sectional area below LWOST also increases to about 1400 sq ft (130 sq m). The variation in the cross-sectional areas and depths at the entrance worked out from the survey data made available since 1951 are shown in fig 3 and table 2.

Shift of the port entrance

Comparison of shoreline plans (fig 4) available for the years 1949 to 1958 shows a northerly shift of the gut due to intense littoral drift on this coast. The shift mainly takes place during fair weather. During NE monsoon, though littoral drift is southwards, the

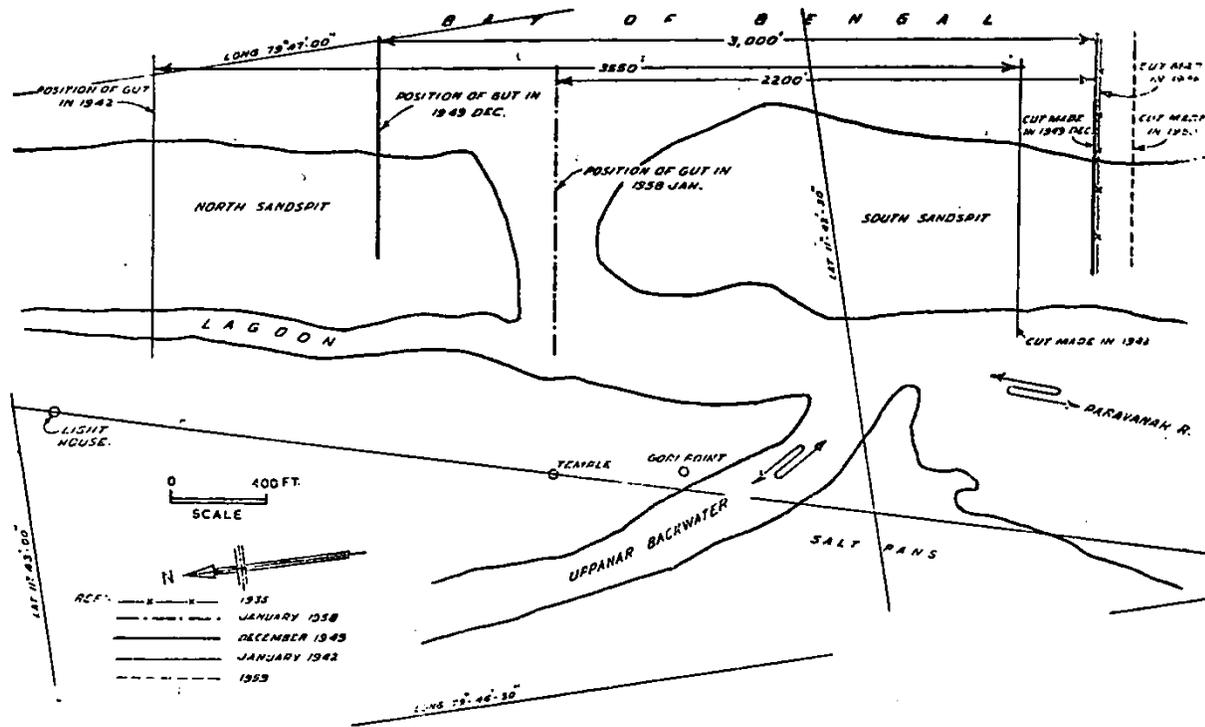


Fig 2 : Plan showing positions of guts in various years

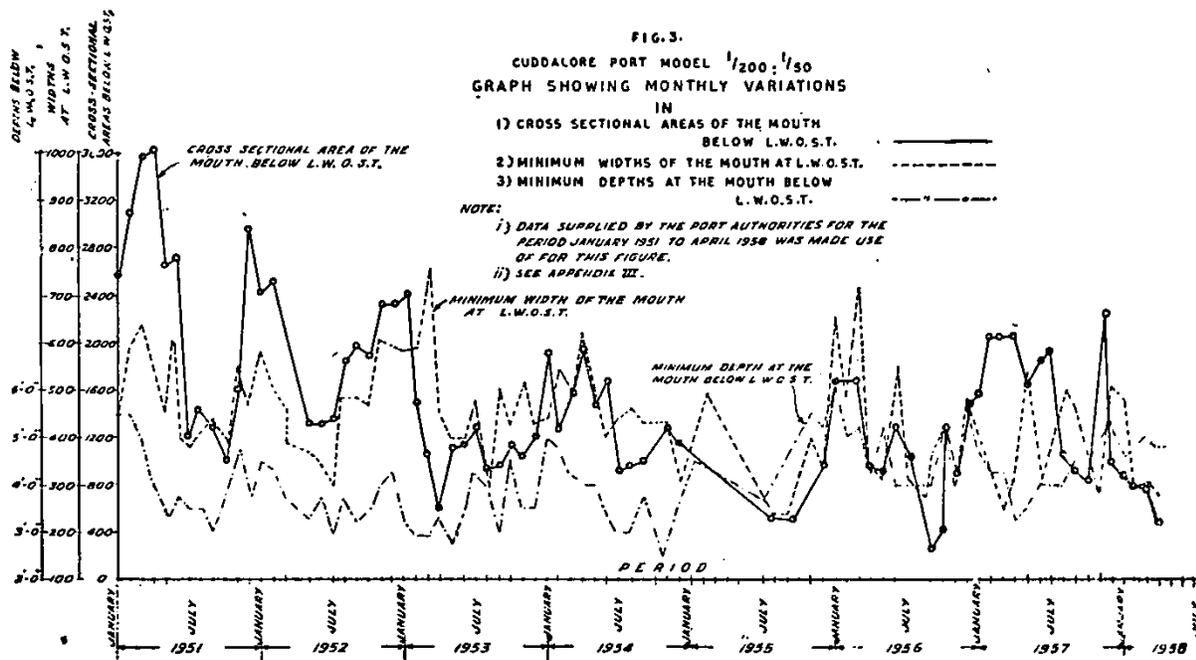


Fig 3

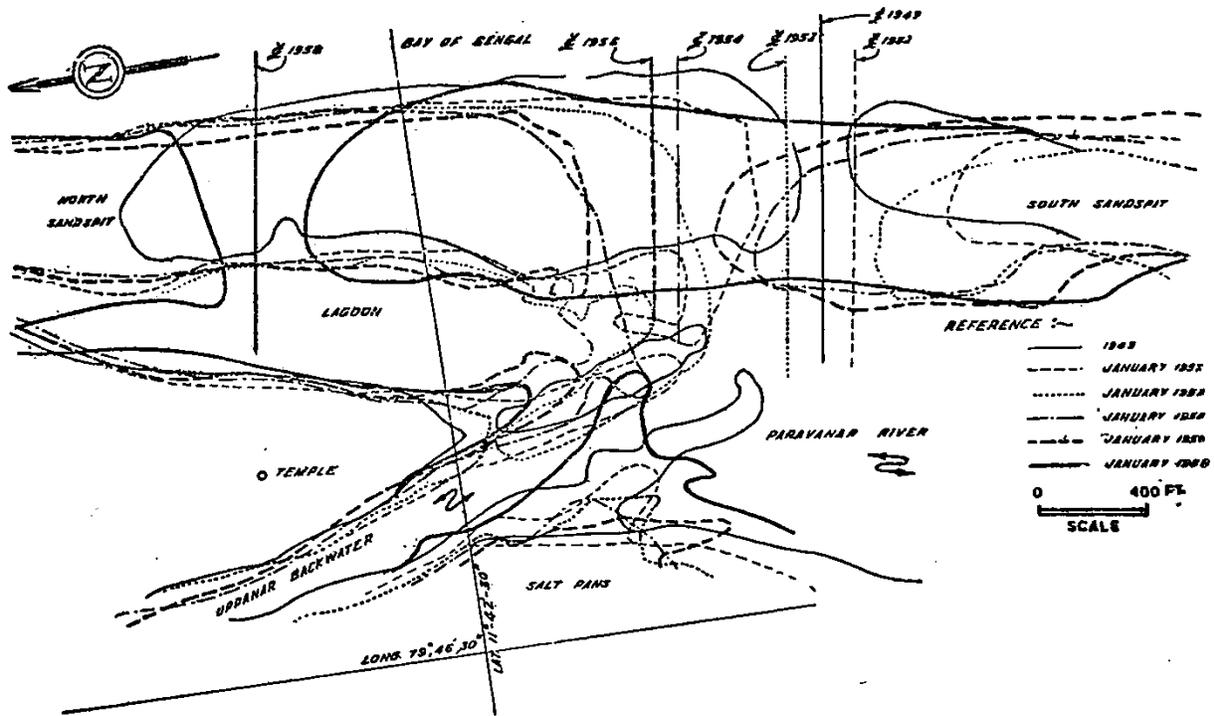
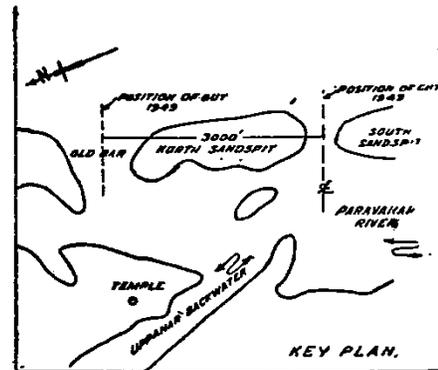
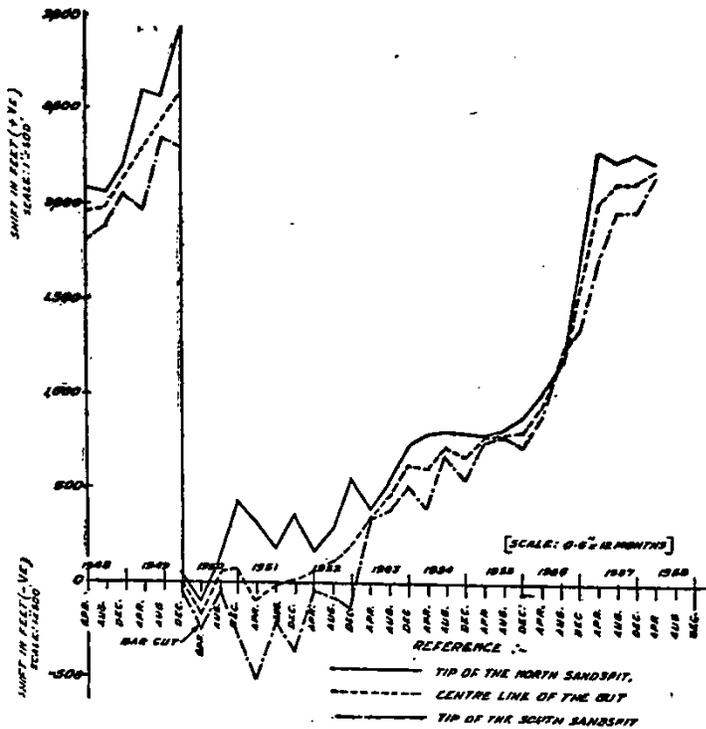


Fig 4 : Superimposition of HW Lines of surveys of various years



- NOTE:-
- (1) Shifts worked out from the surveys supplied by the State Port Officer, Madras
 - (2) Positive sign indicates shift of the mouth towards north & negative sign indicates shifts of the mouth to the south side.
 - (3) The tips of the North & South sandspits and the centre line of the cut in December 1949 are taken as the reference for finding out the cumulative shifts.

Fig 5 : Cumulative shifts of north and south sandspits and the centre line of the gut during various years

TABLE 2

 Year: Jan :Feb :Mar :Apr :May :June :July :Aug :Sept:Oct :Nov :Dec

Minimum widths(ft) of the month at LWOST

1951	450	600	640	-	450	610	400	380	440	390	545	470
1952	580	500	560	380	370	350	300	490	490	475	610	590
1953	585	590	760	450	400	400	480	300	500	430	520	430
1954	440	540	500	620	500	400	440	460	435	435	435	300
1955	380	-	490	-	-	-	-	240	240	-	400	320
1956	650	490	710	340	310	550	310	270	360	430	320	480
1957	400	250	320	340	540	310	360	500	460	360	280	510
1958	480	300	310	275	-	-	-	-	-	-	-	-

Cross-sectional areas of the mouth(sq ft)
 below LWOST

1951	2560	3100	3570	3620	2640	2720	1200	1440	1280	1000	1600	2960
1952	2440	2520	-	-	1320	1320	1360	1840	1960	1880	2320	2320
1953	2400	1480	1060	550	1120	1150	1280	950	960	1120	1040	1200
1954	1920	1280	1560	1920	1480	1680	920	960	1000	1280	1160	-
1955	-	-	-	-	-	-	-	520	-	500	-	960
1956	1680	1680	1680	960	920	1280	960	-	260	1280	880	1440
1957	1560	2040	2040	2040	1640	1840	1920	1040	920	830	2240	1000
1958	880	800	760	480	-	-	-	-	-	-	-	-

Minimum depths at the mouth(ft) below LWOST

1951	5.50	5.50	5.50	4.0	3.25	3.75	3.50	3.50	3.00	3.75	4.70	3.75
1952	4.50	4.35	3.75	-	3.30	3.75	3.00	3.75	3.20	3.50	4.00	4.25
1953	3.25	2.90	2.90	3.25	2.75	3.50	4.25	3.90	3.00	4.50	3.50	3.50
1954	5.00	4.75	4.25	4.00	4.00	3.25	3.00	3.00	3.75	2.50	3.50	3.75
1955	-	3.75	-	-	-	-	3.75	-	-	-	5.50	5.25
1956	6.00	5.00	5.25	4.25	5.25	4.00	4.00	4.00	4.00	5.25	4.00	5.50
1957	4.75	4.25	4.25	3.25	3.50	4.00	4.00	4.00	4.50	4.50	4.75	5.25
1958	4.50	4.75	5.00	4.80	-	-	-	-	-	-	-	-

 mouth does not recede southwards as the drift is very small during
 this period and whatever material is brought is carried away by the
 freshets. Thus the yearly net shift is northwards. Cumulative shift
 from December 1949 when a cut was made upto December 1957 was
 2625 ft(800 m) thus giving an average shift of 320 ft(97.54 m) per

year. Yearly shifts of the north and south sandspits and the distances of centre line of the gut observed since December 1949 are tabulated below and plotted in fig 5.

TABLE 3

Year and month:	Cumulative shift in ft of		
	: Tip of north : sandspit	: Centre line of gut	: Tip of south : sandspit
December 1949	0	0	0
" 1950	+ 430	+ 65	- 300
" 1951	+ 370	+ 10	- 350
" 1952	+ 540	+ 210	- 120
" 1953	+ 730	+ 620	+ 510
" 1954	+ 840	+ 665	+ 550
" 1955	+ 860	+ 785	+ 710
" 1956	+1790	+1565	+1340
" 1957	+2250	+2100	+1950

+ northerly shift - southerly shift

It will be seen that rate of shift of the gut varies from year to year depending on various meteorological conditions. The yearly shift, so far observed, ranges from minimum of 45 ft(13.72 m) in 1954 to a maximum of 780 ft(237.77m) in 1956. Further analysis of the monthly shift(fig 6) of the gut reveals that the maximum shift during a year takes place between the period March to June.

v) Sea Bed Contours : Comparison of Admiralty charts of 1929 and 1956 indicates that the sea bed contours as well as the shore lines in the region of Cuddalore Port entrance are stable(fig 7). The slope of the sea bed near the gut has been worked out from both the 1929 and 1956 Admiralty charts. The bed slope at sections taken on both the sides of the gut at a distance of 1500 ft(457.2 m),

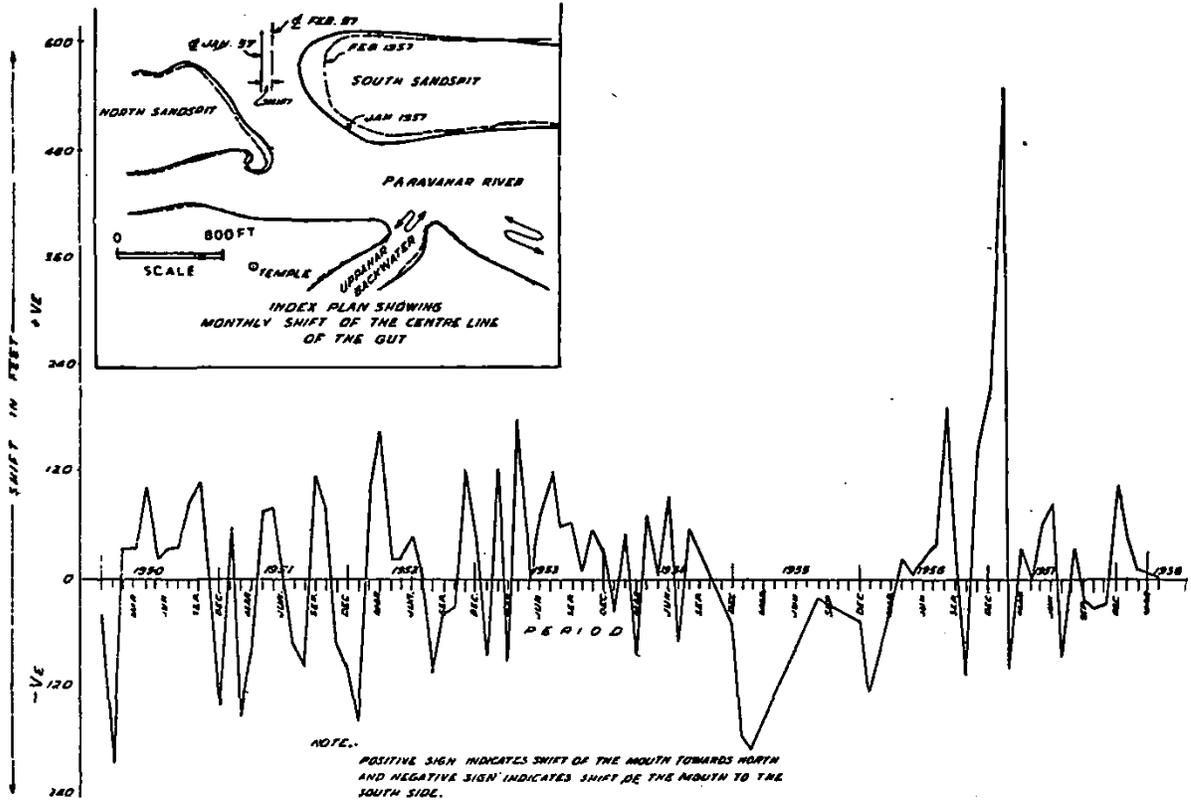


Fig 6 : Monthly shifts of centre line of gut during various years

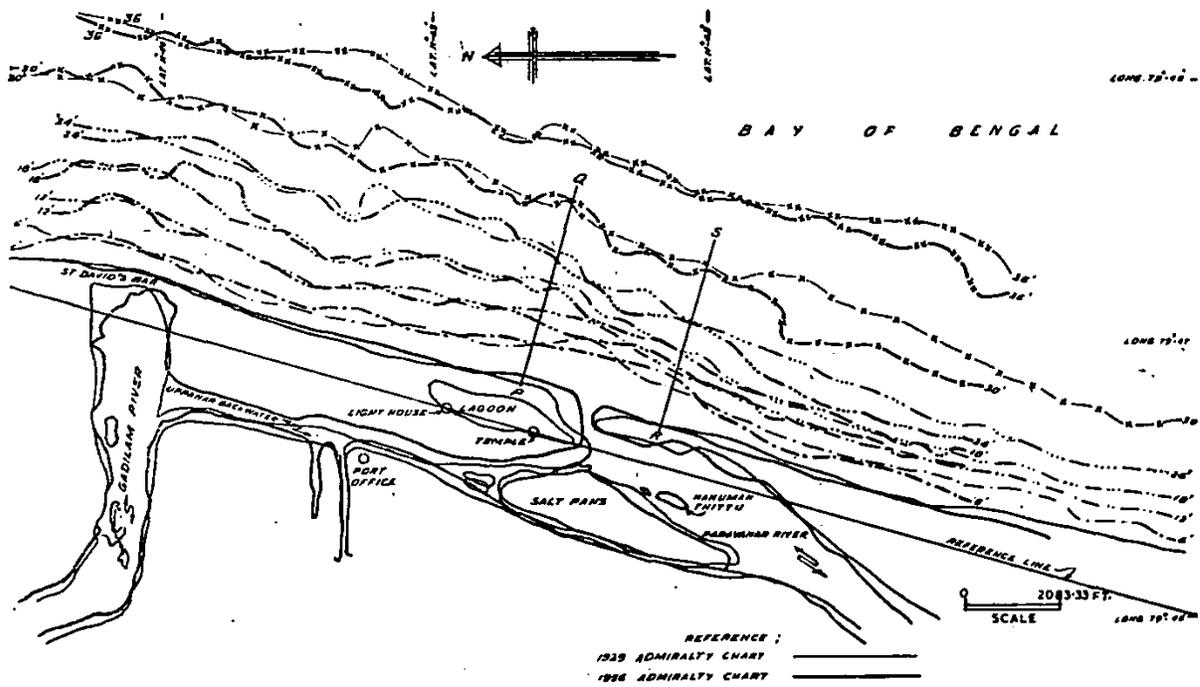
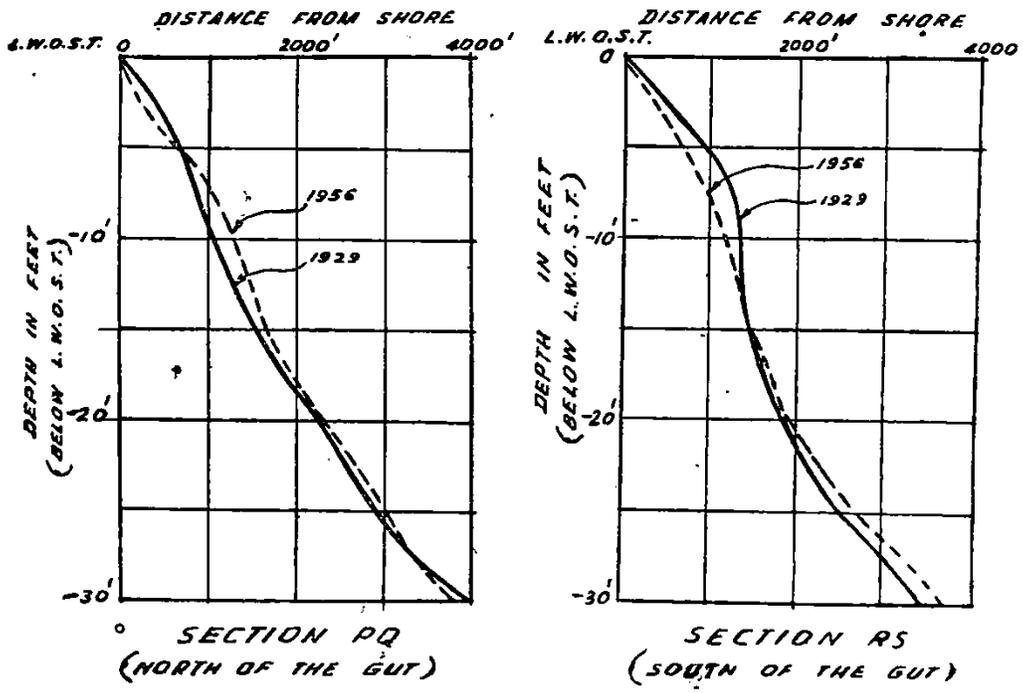


Fig 7 : Comparison of 1921 and 1956 hydrographic surveys



Note : Sections PQ and RS along which the slopes are circulated are shown in Fig 7
 Fig 8 : Slope of the sea bed near gut

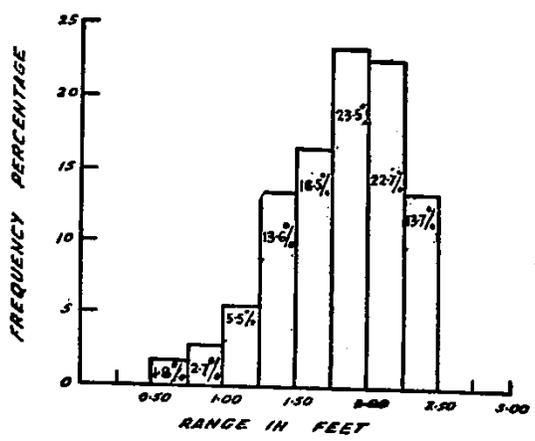


Fig 9 : Frequency of tidal ranges at Cuddalore port office

is plotted in fig 8. The average slope of the sea bed works out roughly to 1 in 100, which indicates a fairly stable slope.

vi) Bed samples collected from Paravanar river at a distance of about 800 ft(243.84 m) from the mouth were analysed. The results are given below.

Median diameter	0.17 mm
Specific gravity	2.63
Composition : Quartz	94.47%
Carbonate	4.1 %

Bed samples collected from Uppanar Channel about 500 ft(152.4 m) from the mouth were also analysed. The results are given below.

Median diameter	0.358 mm
Specific gravity	2.59
Composition : Quartz	95.47%
Carbonate	4.07%
with a small percentage of other impurities.	

Bed samples from the sea in this area were also collected from 0, 6, 12, 18, 24 and 30 ft contours. Results of the mechanical analysis, given below, show that the material becomes finer towards the deeper contours.

Ft below LWOSt	0	6	12	18	24	30
Mean size in mm	.257	.176	.165	.122	.140	.105

vii) The littoral drift at Cuddalore is estimated to be of the order of 5,00,000 tons per annum. Littoral current observations carried out in 1924 near Cuddalore Port indicated southerly currents with a wind direction between ENE and WNW and northerly currents for a wind direction between ESE and WSW. From January to August the direction of the littoral drift is northwards and from September to December, it is southwards.

viii) The tide pole data collected in connection with the hydrographic survey was available for the period 23.3.56 to 20.4.56.

The range at springs was 2.6 ft(0.79 m) and that at neaps 0.6 ft(0.18 m). The histogram for the tidal data shows that the tide with a maximum range of 2.5 ft(0.76 m) has a frequency of 13.7%, while the tide observed on 20.4.56 with a range of 2 ft(0.61 m) with HW and LW at +3.01 ft and +1.01 ft respectively at the port office, has a maximum frequency of 23.5%(fig 9) and that 65% of the observed tides fall below the range of this tide. This tide having a flooding and ebbing period of $6\frac{1}{2}$ hrs and 5 hrs 40 mins respectively was selected for reproduction in the model.

ix) Wave observations reported by ships plying in the Bay of Bengal, were analysed for the area between latitudes 15° to 20° and longitudes 80° to 85° for the years 1949 to 1953. A study of these data revealed that waves during March to September are predominantly from south to south-west with wave height and period varying between 4 to 5 ft(1.22 to 1.52 m) and 4 to 5 seconds respectively. During October to February, predominant direction is from north-east with the wave heights and period of about 4 ft and 4 seconds respectively. These waves were, therefore, chosen for reproducing in the model.

A detailed analysis of the data of storms experienced in the Bay of Bengal in the years 1930 to 1958 was made to assess intensity of wave action at the Cuddalore Port. Hindcasting for wave characteristics was made for storms considered to have affected Cuddalore(Appendix). The maximum wave might have occurred on 30.11.52, with a height of 18 ft(5.50 m) and 10.7 seconds period generated due to wind blowing at a speed of 30 knots, the storm being located at Cuddalore.

x) A graph of movement of sea bed sand at 0, 6, 12, 18, 24, 30

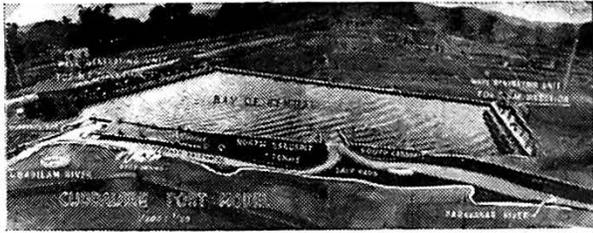


Photo 1 : General view of Cuddalore Port Model

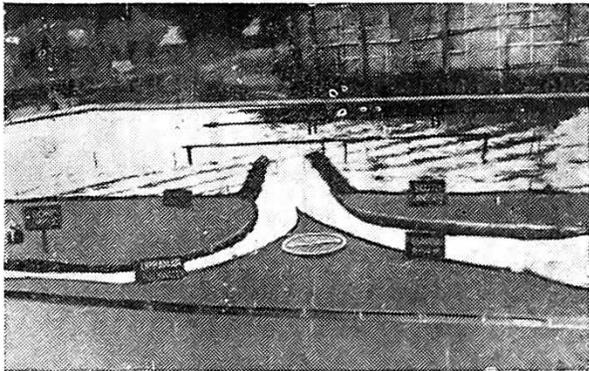


Photo 3 : Reduction in wave disturbance in the entrance due to rubble mound breakwaters (I Stage)

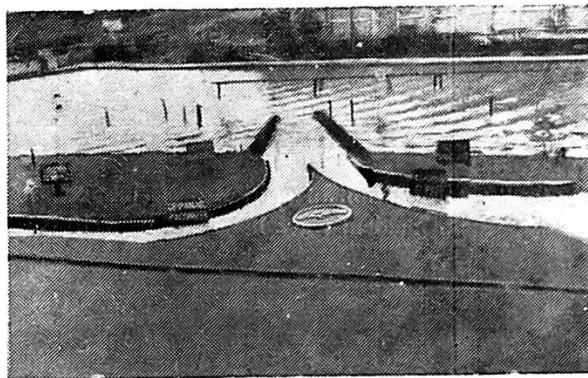


Photo 4 : Reduction in wave disturbance in the entrance due to rubble mound breakwaters (II stage)

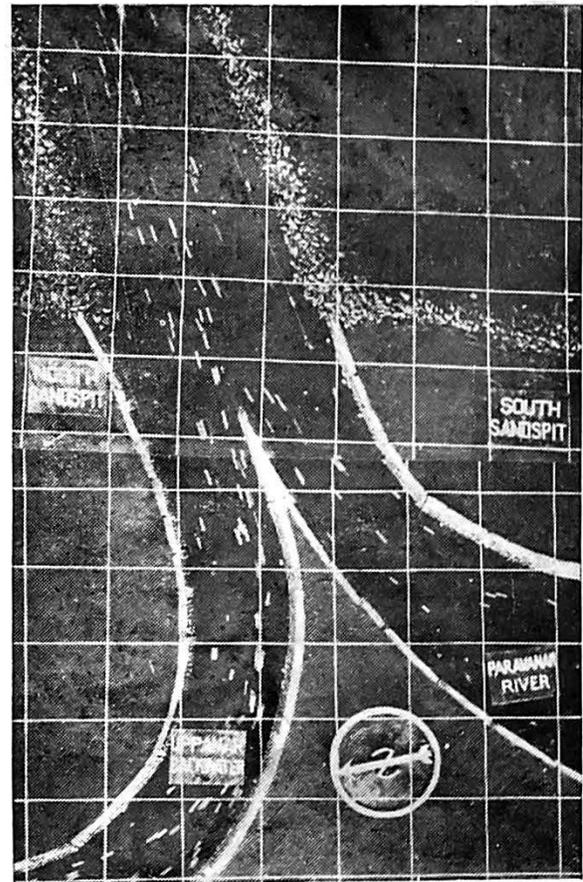


Photo 2 : Flow pattern in Paravanar and Uppanar channels and in entrance formed by breakwaters (I stage - Proposal C)

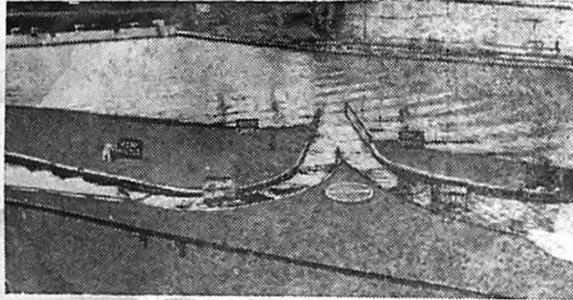


Photo 5 : Wave disturbance in Uppanar and Paravanar channels with breakwaters (I Stage) with vertical sides

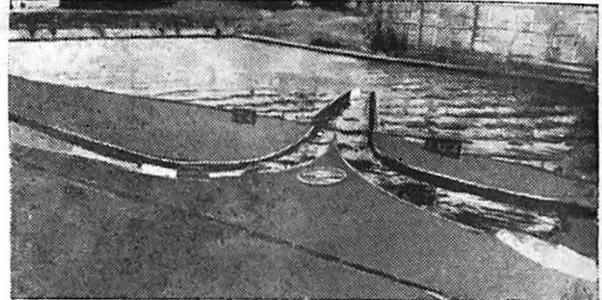


Photo 6 : Same as photo 5 but with II stage of breakwaters and wave height of 9 to 10 ft.

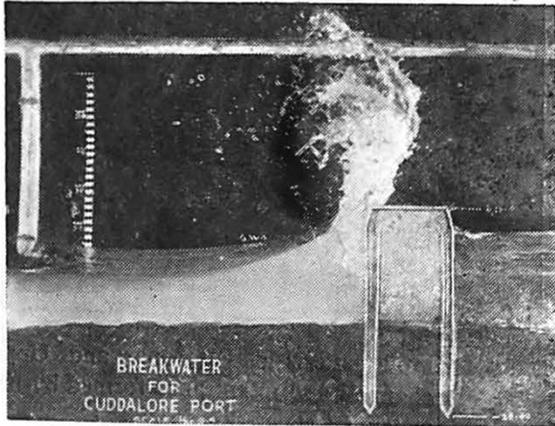


Photo 7 : $\frac{1}{30}$ Scale geometrically similar sectional model of breakwater, breaking and overtopping of waves

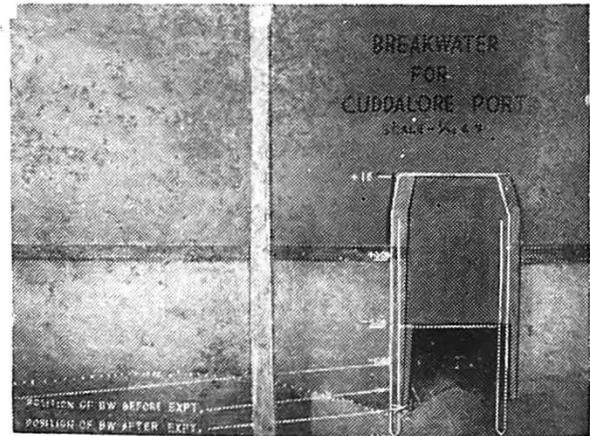


Photo 8 : Dislocation of section of a breakwater for an incident wave height of 9 to 10 ft.

and 36 ft contours for different wave heights and periods has been prepared (fig 10). It shows that maximum bed movement takes place upto 15 ft contour in the sea for wave heights between 4 and 5 ft with a period between 3 and 5 seconds.

5. MODEL

The model covered a sea portion upto 48 ft (14.63 m) contour, Paravanar and Gadilam rivers and Uppanar channel. The requisite capacity for absorption of tidal volume was reproduced by suitable lengths of labyrinths. A part of the sea portion upto 24 ft (7.3 m) contour was made mobile while the rest was made rigid. Length of the sea coast from St David's Bar to about $1\frac{1}{2}$ miles (2.41 Km) south of the 1956 position of the gut was included (fig 11 and photo 1). Tides were reproduced by letting out variable discharge from the tidal chamber. Tidal currents were reproduced from the NE direction in the model. Automatic water level recorder was installed at the Port Office for recording tides. Freshet discharges admitted in rivers were measured over V notches. Following model scales were adopted.

Length Scale	1/200
Depth Scale	1/50
Vertical Exaggeration	4
Velocity Scale	1/7.07
Discharge Scale	1/70,700
Time Scale	1/28.3

The tidal period in the model was 25.5 minutes. Vertical exaggeration of four was necessary to fulfil the requirements of simultaneous reproduction of tides and waves as well as to keep the ratio of model and prototype rugosity coefficients close to unity.

The model was proved in respect of tides, waves and bed changes observed at the gut during various years as described below:

i) The tide observed in the prototype on 20.4.56 at the Port Office was selected for reproduction in the model. It will be seen from fig 12 that the tidal curve obtained in the model was satisfactory in respect of its range and shape.

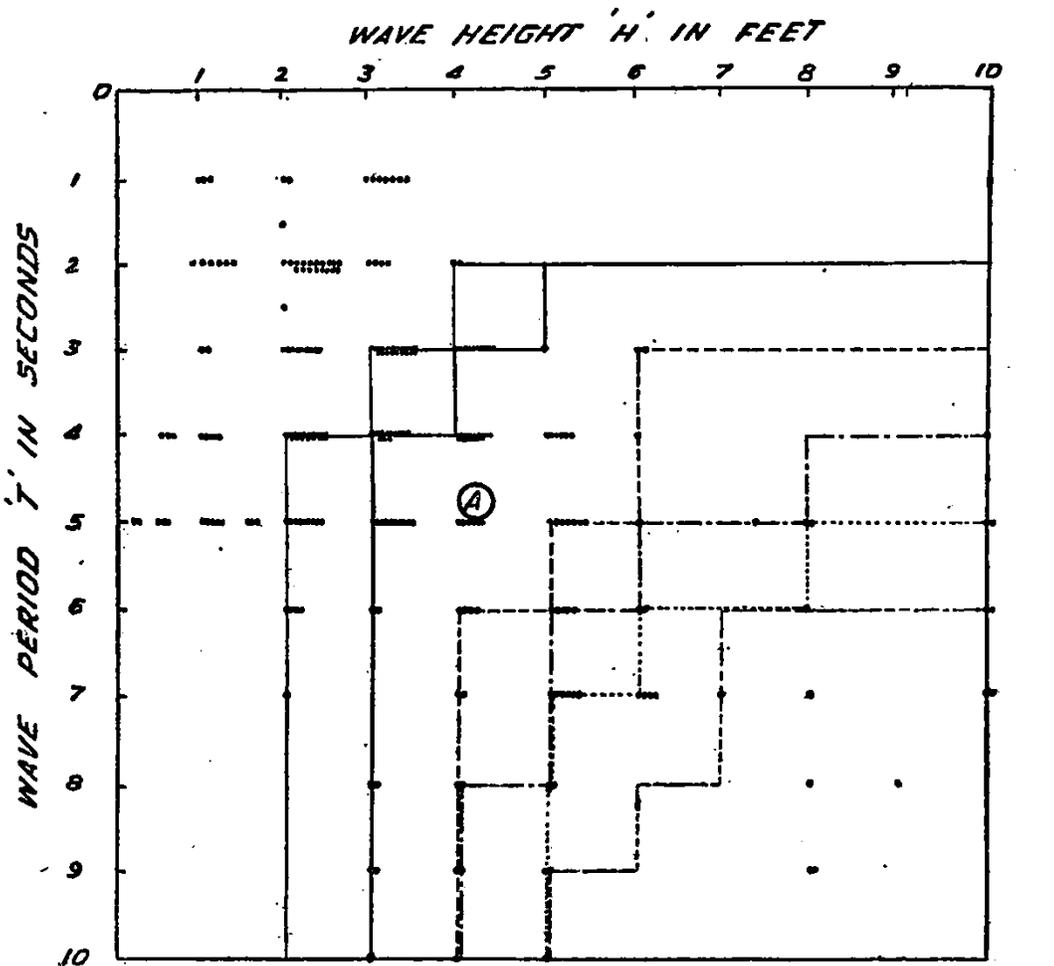
ii) Wave generating units were installed to generate waves from SSW during fair weather and from NE during monsoon. Eccentricity of the wave generating machine was so adjusted that waves of heights 4 to 5 ft (1.22 to 1.52 m) and 3 to 4 ft (0.91 to 1.22 m) were obtained for fair weather and monsoon conditions, respectively. The wave pattern was also correctly reproduced in the model.

Refraction of waves was theoretically calculated (fig 13) and the angle through which it turned measured. Actual turning of waves in the model was also determined by taking photographs and making computations therefrom. The observed angles in the model agreed fairly well with the calculated values.

Direction of incident waves	Angle through which waves refract near the gut	
	Calculated	Observed
North-east	14° 40'	15° 10'
South-south-west	44° 30'	45° 0'

The agreement obtained indicated that the model was behaving like the prototype in this respect also.

iii) The reproduction of bed changes was by far the most difficult task in proving the model. It was necessary to reproduce in the model the corresponding changes in the prototype during a known period.



REFERENCE

- 6' CONTOUR LINE - - - - - 30' CONTOUR LINE
- 12' CONTOUR LINE - - - - - 36' CONTOUR LINE
- - - - - 18' CONTOUR LINE " WAVE OBSERVATIONS
- - - - - 24' CONTOUR LINE

Note for using the chart : If a point with particular wave height and period falls above the contour line, movement at that particular contour is not likely to occur and vice-versa. eg. for a point (A) with wave height of 4 ft and period 5 sec bed movement will take place at 12 ft contour [since it lies below 12 ft contour] and bed movement may not take place at 18 ft contour [since the point lies above 18 ft contour line]

Fig 10 : Movement of sand due to waves of different periods and heights at various contours near gut

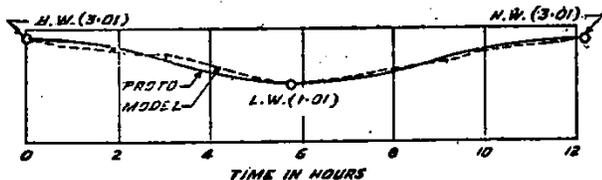


Fig 12 : Proving tidal curves at Port office (Proto and Model), Tidal range = 2 ft.

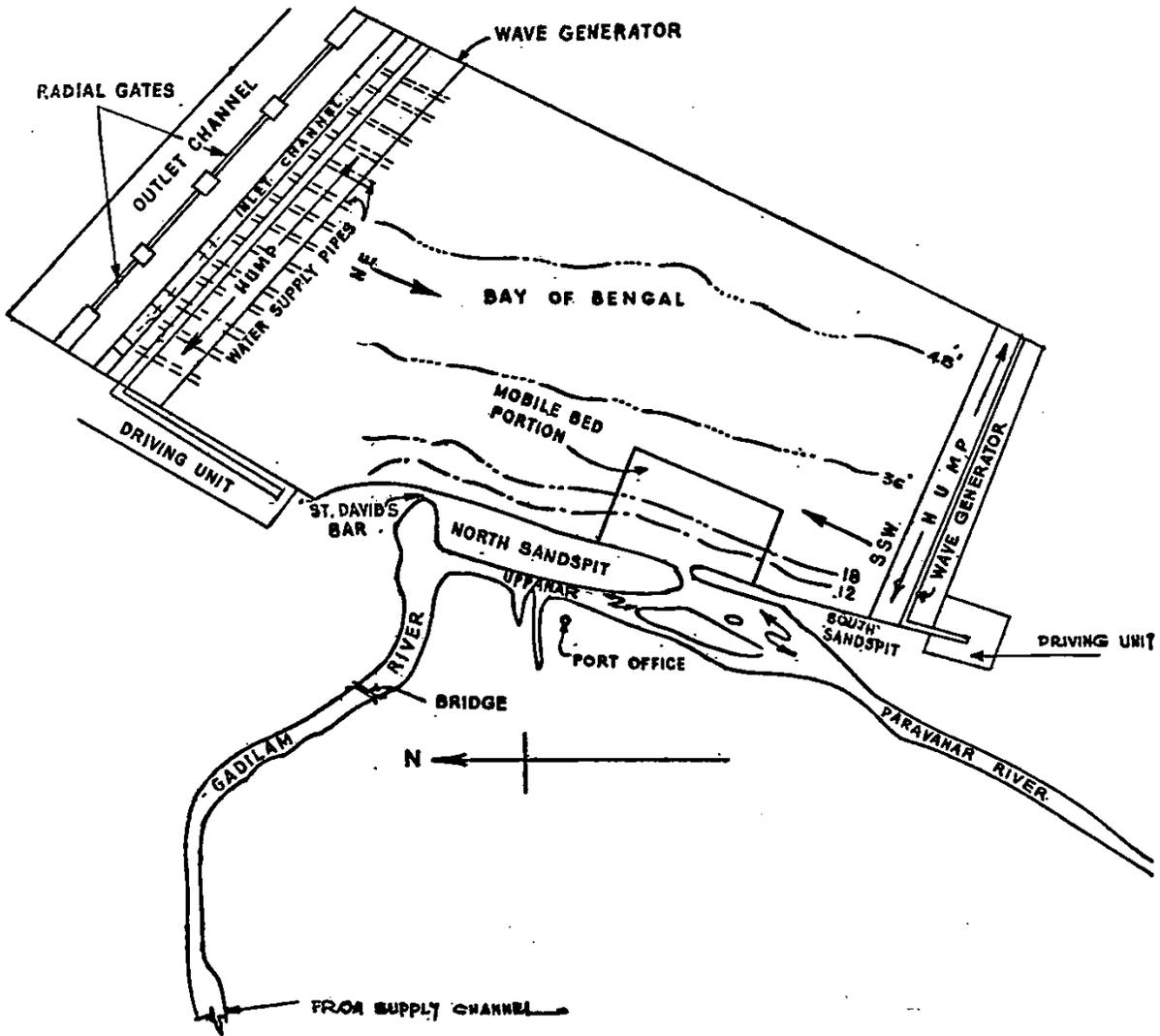


Fig 11 : Layout of Cuddalore Port Model

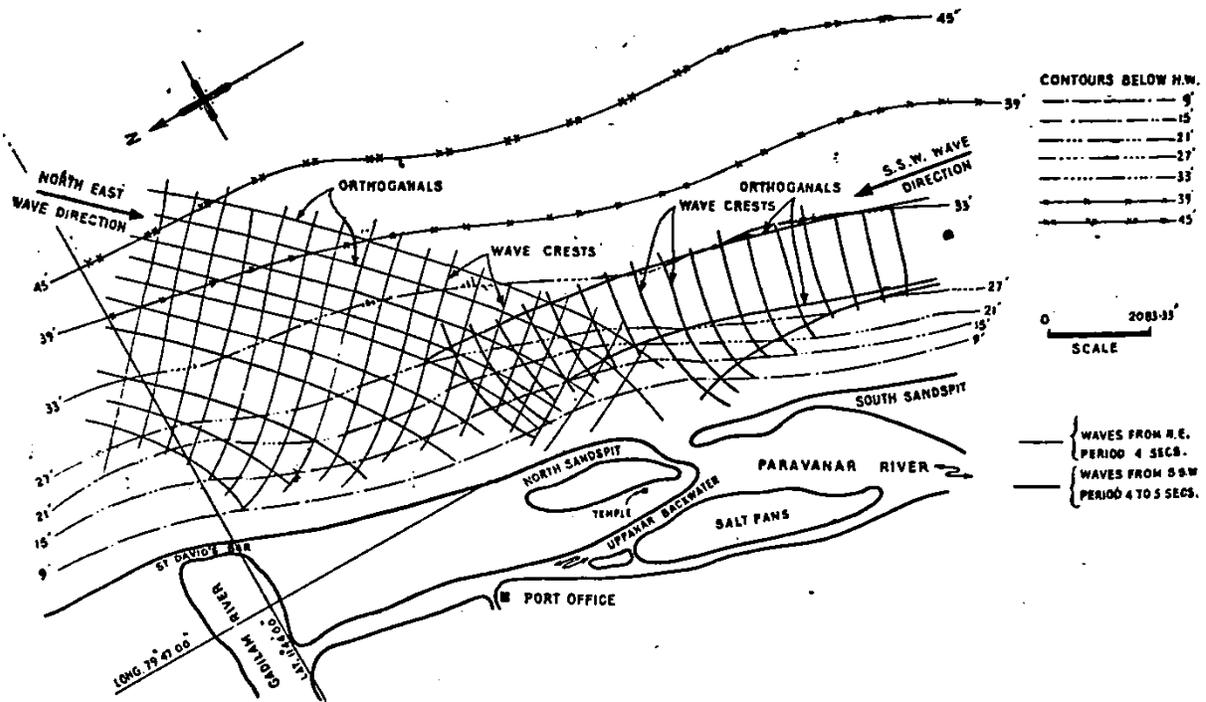


Fig 13 : Refraction diagram for waves from SSW and NE directions

A number of experiments were carried out to simulate the changes occurring in the entrance channel for the years 1951 to 1957 for which the relevant data was available. Experiments were done in three series for the periods January 1952 to December 1953, January 1954 to December 1955 and January 1957 to December 1957 under the following conditions.

Various bed materials such as sand, saw dust, coal powder, etc were tested as bed materials for the model. Eventually, bituminous coal powder was found suitable as it gave the required bed movement for the model velocities, depth of water and waves. Consequently, experiments were conducted with the coal powder having a mean diameter 0.4 mm and specific gravity 1.4.

About 0.15 cft(0.0043 m³) of coal powder was injected per hour in the sea to represent the littoral drift in the prototype. This quantity was arrived at by trial and error to get stable bed contours in the model in the reach under investigations. During fair weather and monsoon seasons this injection was done from SSW and NE directions, respectively. During freshets .037 cft(.0011 m³) of coal powder per hour was injected in each river. Since no data regarding silt concentration in the rivers was available, this quantity was arrived at by a number of trials so as to get a satisfactory reproduction of depths on the bar.

The discharges in the Gadilam and Paravanar rivers admitted were equivalent to those observed in the prototype in various years.

The time required for reproducing certain bed changes over a known length of time in the prototype was also found out after a number of trials. Thus about two hours and a half were required for

reproducing changes observed after one fair weather and monsoon season. A fairly satisfactory reproduction in respect of depths and widths was obtained in the model. The tendency of the depths in the entrance channel to reduce progressively from January to August and to increase from September to January was indicated in the model also. The prototype and model depths and widths have been compared in table 4 and the results presented in fig 14. The minimum widths obtained in the model agreed fairly well with these in the prototype.

The northward shift of the gut in various years was also obtained in the model(fig 14) with a fair degree of accuracy though the exact distance through which the north and south sandspits shifted every year could not be reproduced. However, the tendency to shift was obvious. Fig 15 has been included as an illustration of the model results. The model reproduced the changes satisfactorily within experimental limits. Experiments for testing various proposals for stabilising the entrance and maintaining adequate depths were, therefore, next taken up.

6. MODEL INVESTIGATIONS AND RECOMMENDATIONS

Experiments were first carried out for finalising proposals for the first stage of development. While finalising these proposals, it was borne in mind that it should be possible to evolve a layout for the second stage of development which would key in with the first stage without incurring any infructuous expenditure.

Test Conditions

Experiments with various proposals were carried out with two sets of freshet discharges

	Q Gadilam	Q Paravanar
I set	5,000 cfs	500 cfs
II set	2,000 cfs	1,000 cfs

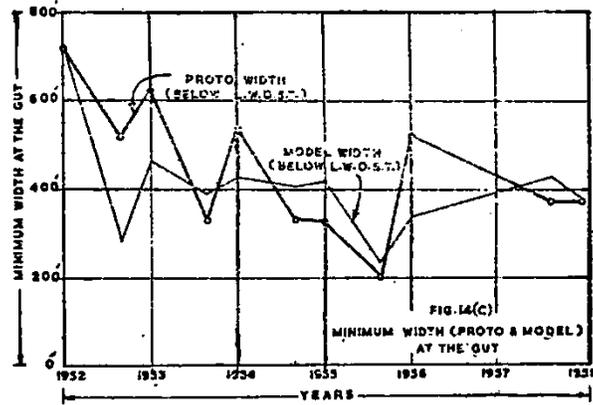
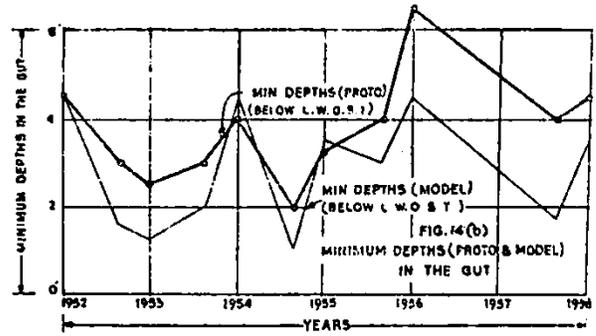
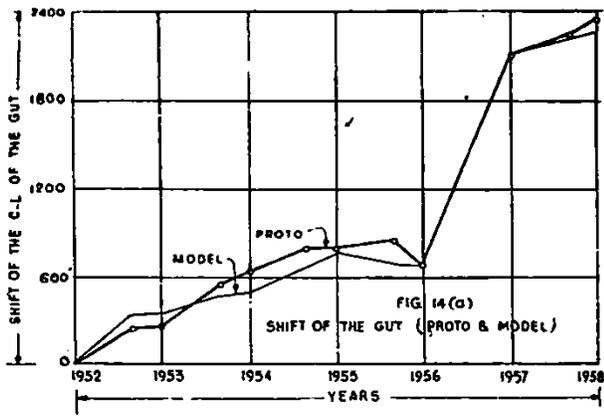


Fig 14

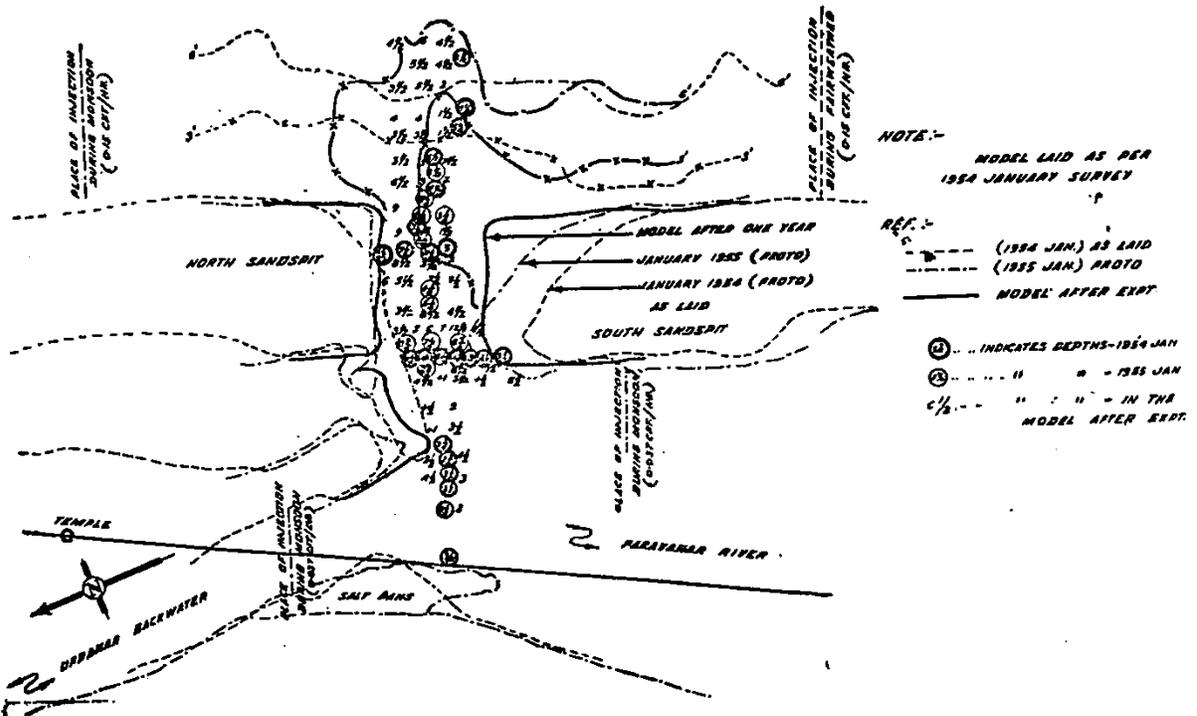


Fig 15 : Contours obtained in the model after an equivalent period of one year under existing conditions

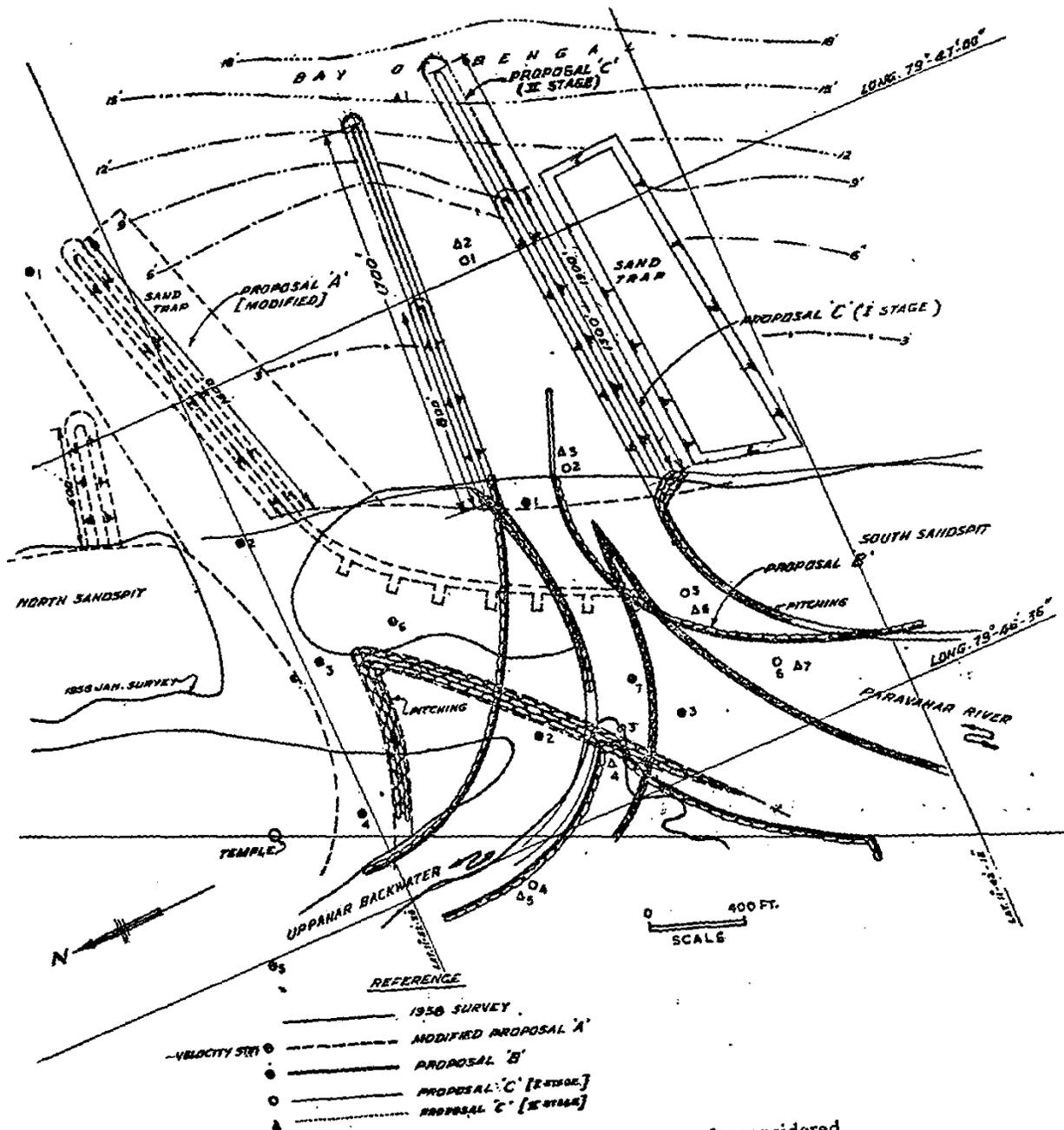


Fig 16 : Plan showing various proposals considered

TABLE 4

Expt	Corresponding type	months	Shift of the entrance channel		Minimum to maximum depths in ft below LOWST in		Minimum width in ft at the entrance	
			Proto	Model	Proto	Model	Proto	Model
1	2	3	4	5	6	7	8	
1952 Jan laid								
Fair-weather	I	Jan-Aug '52	250	340	3 to 10 $\frac{1}{2}$	1 $\frac{1}{2}$ to 5	540	280
Monsoon	I	Sep-Dec '52	250	340	2 $\frac{1}{2}$ to 9 $\frac{1}{2}$	1 $\frac{1}{4}$ to 10 $\frac{1}{2}$	640	480
Fair-weather	II	Jan-Aug '53	540	460	3 to 6 $\frac{1}{2}$	2 to 8 $\frac{1}{2}$	330	390
Monsoon	II	Sep-Dec '53	625	480	4 to 8 $\frac{1}{2}$	4 $\frac{1}{2}$ to 11	540	440
1954 Jan laid								
Fair-weather	I	Jan-Aug '54	780	660	2 to 8 $\frac{1}{2}$	1 to 8	350	420
Monsoon	I	Sep-Dec '54	780	750	3 $\frac{1}{4}$ to 8 $\frac{1}{4}$	3 $\frac{1}{2}$ to 9	350	440
Fair-weather	II	Jan-Aug '55	850	660	4 $\frac{1}{2}$ to 9	3 to 8 $\frac{1}{2}$	210	230
Monsoon	II	Sep-Dec '55	675	660	6 $\frac{1}{2}$ to 12 $\frac{1}{2}$	4 $\frac{1}{2}$ to 8 $\frac{1}{2}$	520	340
1957 Jan laid								
Fair-weather	I	Jan-Aug '57	2250	2220	4 $\frac{1}{2}$ to 8 $\frac{1}{2}$	1 $\frac{1}{4}$ to 5 $\frac{1}{2}$	360	425
Monsoon	I	Sep-Dec '57	2340	2250	4 to 10 $\frac{1}{2}$	3 $\frac{1}{2}$ to 6	360	365
For shift 1952 Jan was taken as reference								

These were considered to represent the predominant conditions of freshets. Following sequence of waves and freshets was operated in the model.

Equivalent prototype period(months)	Waves from	Discharge conditions
9	SSW	no freshets
1	NE	no freshets
1	NE	freshets
1	NE	no freshets

Three proposals(fig 16) were tested in the model for the first stage of development with an entrance channel dredged to 9 ft(2.74 m)

below LWOST from 9 ft contour in the sea to the Port Office.

Proposal A

The curvature provided for diverting the flow of the Uppanar channel appeared to be sharp. It was, therefore, apprehended that flow conditions would not be smooth and conducive to self-maintenance of the channel. Observations were carried out in the model in respect of flow pattern, velocities and bed changes after an equivalent period of five years in the prototype. These revealed

i) The sharp curvature given to the training wall along the Uppanar channel at the Gori point appeared to cause return flow during flood tide along its left bank near Gori temple and also along the western bank immediately after its confluence with the Paravanar river.

ii) Further, at the confluence slack water region was observed and velocities dropped considerably. This was considered undesirable from the point of view of siltation.

iii) Experiments with sea side works revealed that depths in the navigation channel upto the confluence of the two rivers would be maintained. There would, however, be heavy silting in the entrance and in the navigation channel between the breakwaters. The alignment of the channel which was directly exposed to the wave disturbance during monsoon was mainly responsible for this deterioration. The material, agitated by waves, was, therefore pushed in by waves during flood tide and this could not be flushed out by the ebb tidal currents.

The proposal A was not, therefore, considered promising.

Proposal B

It envisaged

i) Training flow of Uppanar and Paravanar rivers(fig 16).

ii) Constructing an open type jetty from the foreshore to one fathom line in the sea, so as to take sand pump approximately of the type and capacity as the one at the Port of Madras. The spoil discharge of the sand pump could be utilised for reclaiming the lagoon area on the northern side of the entrance for at least some 8 to 10 years.

The model was laid according to the latest available survey of 1958. The entrance channel was dredged to 9 ft below LWOST and the

pitching provided(fig 16). As mentioned above, observations were taken in respect of surface flow pattern, surface velocities at representative stations and the bed contours after each fair weather and monsoon conditions. A study of these results indicated

i) Since Paravanar has a bigger tidal absorption capacity, the flow instead of following the straight navigation channel, was slightly inclined towards north and south during ebb and flood respectively. During freshets also, this tendency persisted, indicating that instead of having a straight entrance channel it would be desirable to make it slightly inclined towards north. Some return flow was also observed in the Paravanar channels.

ii) Velocities increased uniformly from the confluence towards sea indicating that both the discharges were guided properly.

iii) Bed contours observed after running the model without any sea side works or operations showed that the entrance channel silted up very rapidly as expected.

iv) Further experiments performed with sea side works consisting of two breakwaters and a sand trap, in combination with river training works showed considerable improvement over(iii). The improvement was however, not as complete as desired.

Proposal C

From the foregoing it was observed that in order not to impede navigation, the alignment of training works should be such that navigation channel would be, as far as possible, free from any return flow or eddies and that the flow should be guided smoothly. The axis of the channel if made to coincide with predominant direction of flow would be conducive to self-maintenance of the channel. Finally, the entrance formed by the breakwaters should not be unduly exposed to the disturbance from predominant waves.

Keeping this in view, several experiments were conducted till a satisfactory layout(fig 16) was evolved. Flow pattern observed during both fair weather and freshet conditions showed no eddies and return flow anywhere in the navigation channel between the breakwaters and in

the Uppanar channel(photo 2). A slight return flow was observed on the convex side near the apex of the northern breakwater and in the Paravanar river for some length. The former was however, not considered as a drawback since a navigation channel 200 ft(60.96 m) in width and clear of any return flow, eddies, etc, could be obtained at the entrance of Uppanar channel.

With the layout of training works as described, following proposals were tested for stabilising the entrance channel to sea and maintaining a 9 ft(2.74 m) depth in it.

i) An approach channel only, dredged to 9 ft depth below LWOST from the Port Office to 9 ft contour in the sea;

ii) An approach channel, as above, with a southern breakwater 1300 ft(396.24) in length.

iii) An approach channel as in(i), with two breakwaters, one on the southern side 1300 ft in length and the other on the northern side 600 ft(182.88 m) in length;

iv) An approach channel as in(i) with a southern breakwater 1300 ft in length and a northern breakwater 800 ft(243.84 m) in length;

v) An approach channel as in(i) with a sand trap only;

vi) Same as in(v) with a southern breakwater 1300 ft in length only;

vii) Same as in(v) with a southern breakwater 1300 ft in length and a northern breakwater 800 ft in length.

All the proposals were examined under the test conditions. The model, prior to commencement of every test was laid to 1958 survey and then run for both the fair weather and monsoon conditions.

Proposal No(vii) with an approach channel upto 9 ft contour and two breakwaters, one on the southern side 1300 ft in length and the other on the northern side 800 ft in length, with a sand trap behind the southern breakwater was found satisfactory. Long period tests were,

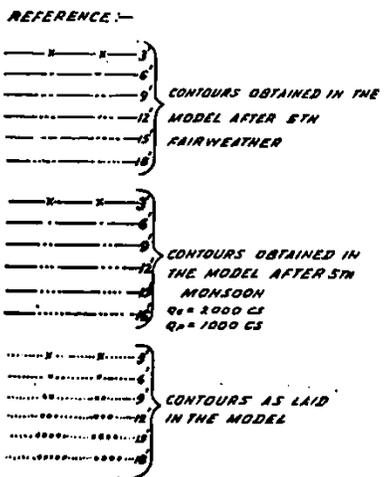
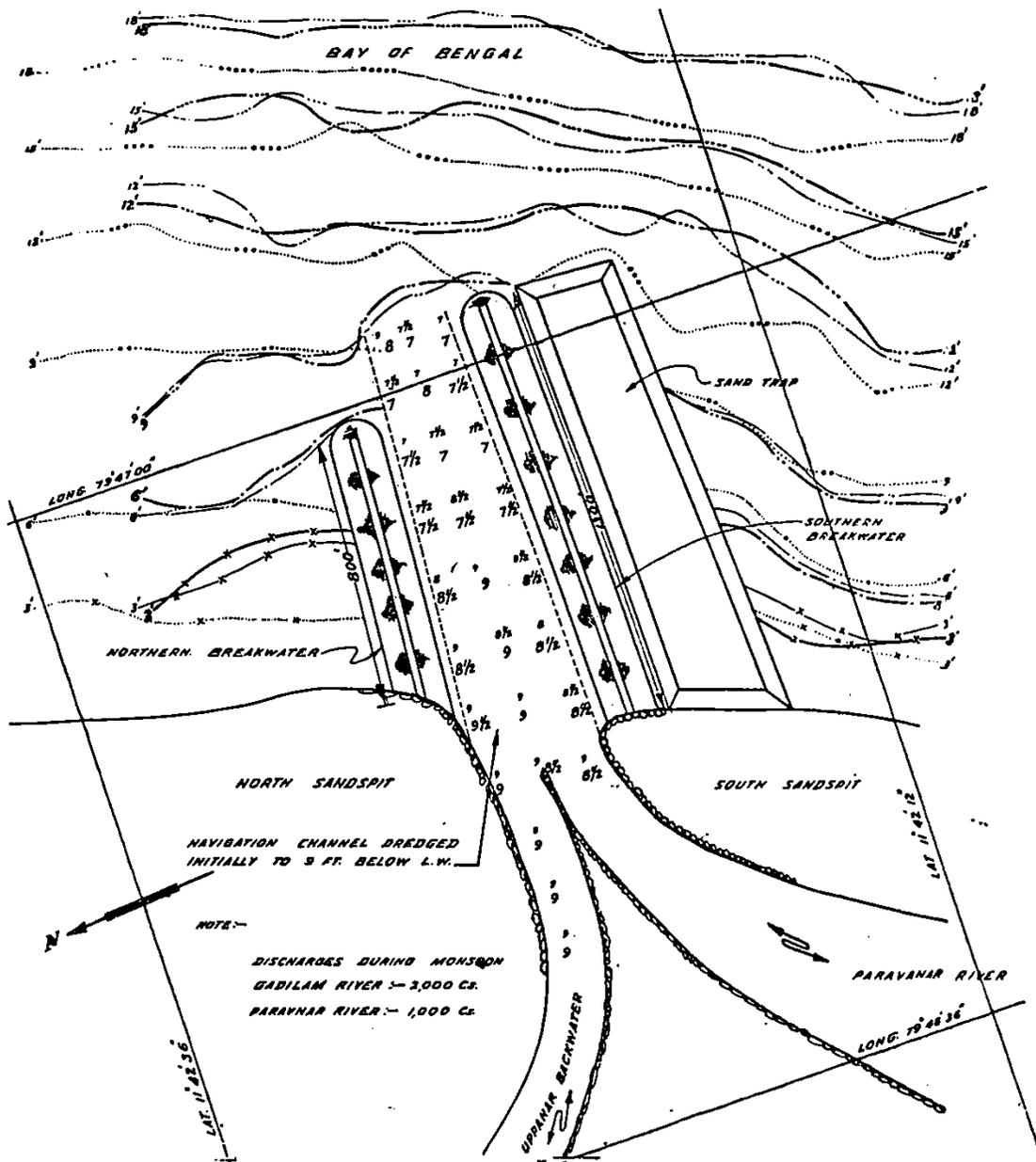
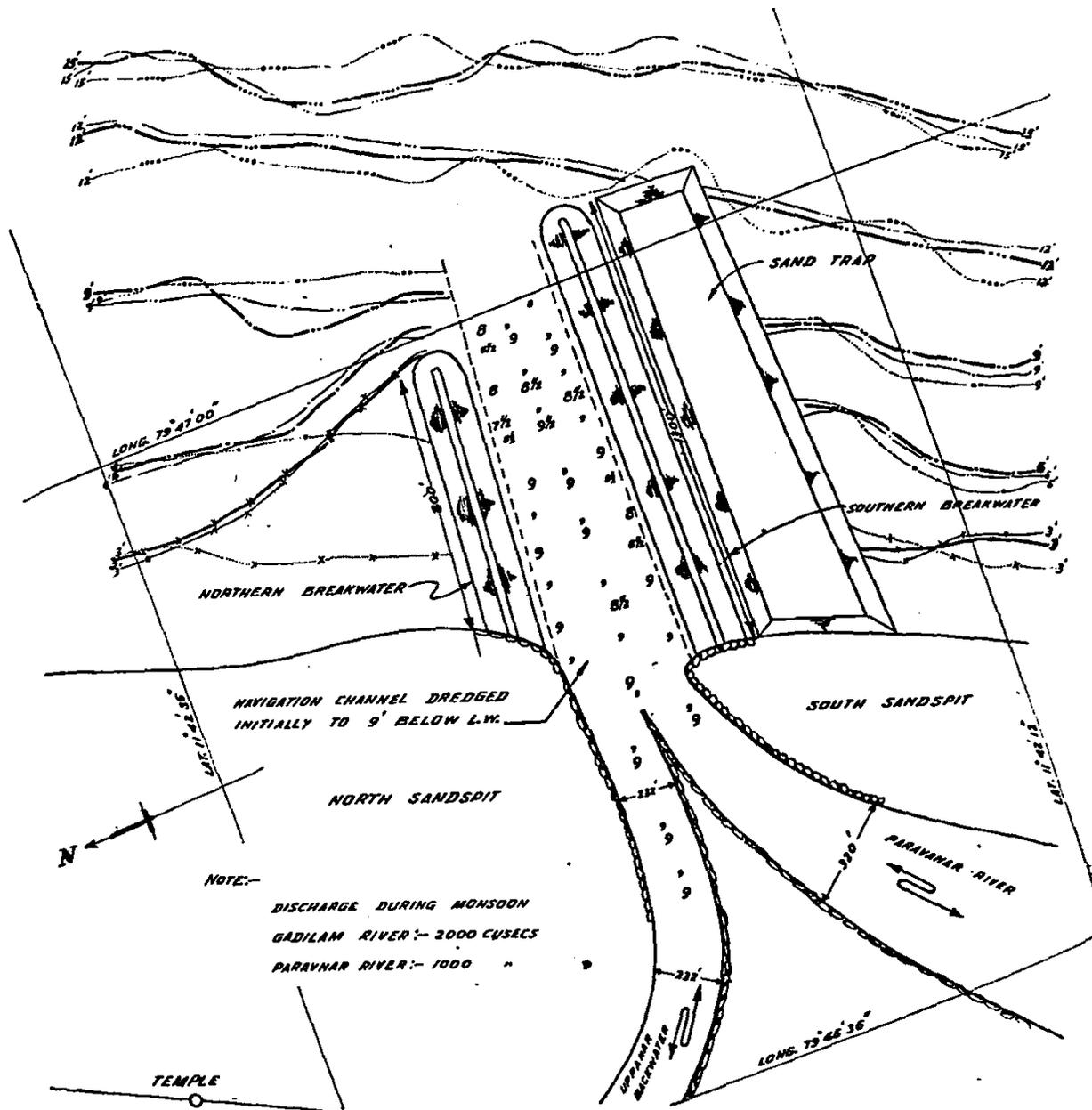


Fig 17 : Contours obtained in the model with proposal C (I stage) for an equivalent period of five years

Note : Width of the uppanar channel at — 9 = 232 ft. Experiment conducted without periodic dredging of sand trap.



NOTE:-
 DISCHARGE DURING MONSOON
 GADILAM RIVER:- 2000 CUSECS
 PARRYNAR RIVER:- 1000 "

NOTE:-
 (i) WIDTH OF THE UPPANAR CHANNEL
 AT 9' = 232'
 (ii) EXPT. CONDUCTED WITH PERIODIC
 DREDGINGS OF THE SAND TRAP.

REF:-

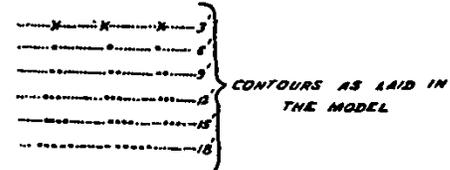
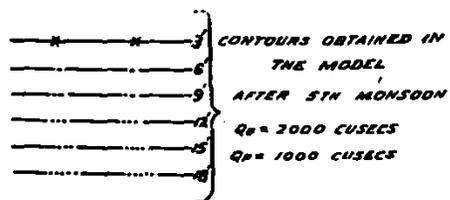
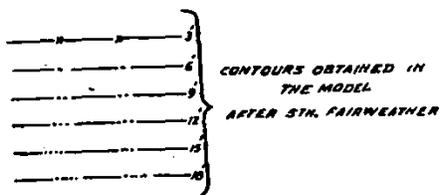
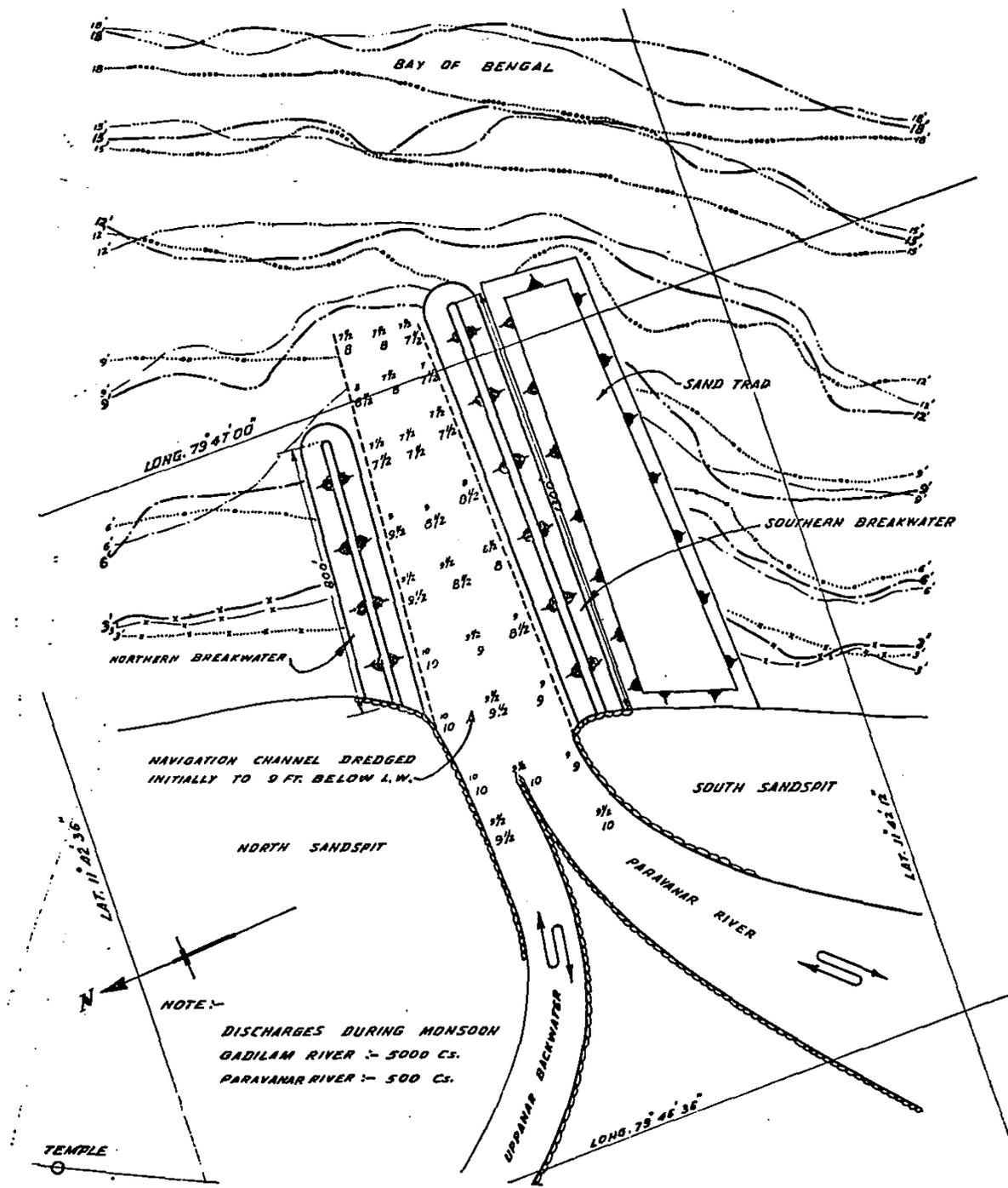


Fig 18 : Contours obtained in the model with proposal C (I stage) after an equivalent period of five J



NOTE:-
 DISCHARGES DURING MONSOON
 GADILAM RIVER :- 5000 CFS.
 PAPANAR RIVER :- 500 CFS.

Note : Experiment conducted without periodic dredging of the sand trap. Width of the uppnar channel at -9 = 232 ft

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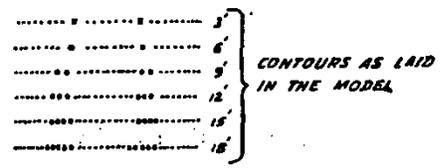
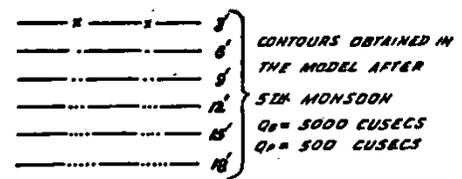
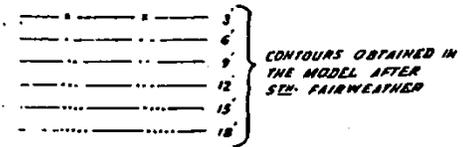
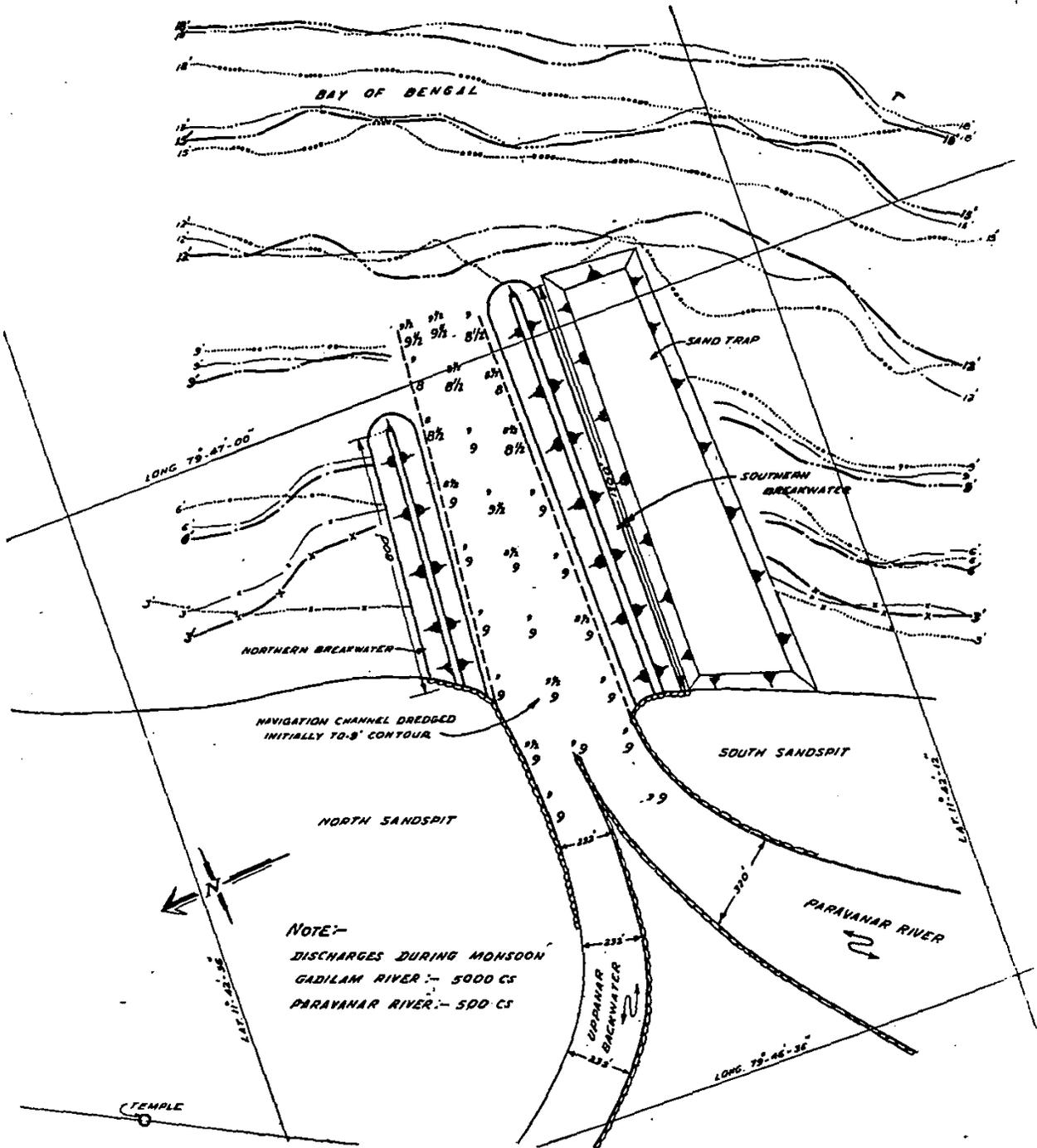


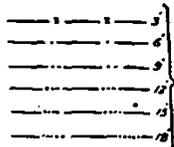
Fig 19 : Contours obtained in the model with proposal C (I stage) after an equivalent period of five years



NOTE:-
 DISCHARGES DURING MONSOON
 GADILAM RIVER :- 5000 CS
 PARAVANAR RIVER :- 500 CS

Note : Experiment conducted with periodic dredging of the sand trap and nourishing the coast on the northern side. Width of the uppanar channel at -9 = 232 ft

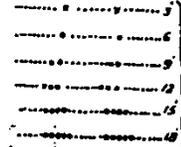
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CONTOURS OBTAINED IN THE MODEL AFTER 5TH FAIRWEATHER.



CONTOURS OBTAINED IN THE MODEL AFTER 15TH MONSOON
 QG = 5000 CUSECS.
 QP = 500 "



CONTOURS AS LAID IN THE MODEL

Fig 20 : Contours obtained in the model with proposal C (I stage) after an equivalent period of five years

therefore, conducted with this layout under two sets of river discharges with periodic dredging of the sand trap and nourishing coast on the northern side and without any dredging for five years. The results obtained after an equivalent period of five years are presented in figs 17 to 20.

These tests showed that with periodic dredging the desired depths are likely to be maintained throughout the length of navigation channel. Dredging would also be required at the point of bifurcation of discharges between the Paravanar and the Uppanar channels, where the deterioration might be more than in the rest of the channel. Periodic dredging at these places was, therefore, indicated. In case no dredging was done, there might be silting at the entrance which would reduce the efficiency of the port. The layout was, therefore, considered suitable for the development of port for maintaining 9 ft depths below LWOST.

The surface velocities were observed during fair weather and freshet conditions with the final layout at various stations shown in fig 16. Velocities increased gradually from the confluence towards the sea indicating that discharges through both rivers were guided properly. Maximum surface velocities obtained during monsoon (with Q Gadilam = 5,000 cfs ($141.5 \text{ m}^3/\text{s}$) and Q paravanar = 500 cfs ($14.15 \text{ m}^3/\text{s}$) were 3.55 ft/sec ($1.07 \text{ m}/\text{sec}$) and 1.80 ft/sec ($0.55 \text{ m}/\text{sec}$) in the Gadilam and Paravanar rivers respectively. The velocities obtained in the model were well within the permissible range of velocities of 5 ft/sec ($1.52 \text{ m}/\text{sec}$) for lighters and boats using this port. Hence, the alignment of breakwaters needed no change and could, therefore, be considered satisfactory.

In order to see the wave disturbance in the area enclosed by breakwaters, test was carried out by maintaining water level in the model at HW and waves of equivalent predominant height of 4 to 5 ft and 3 to 4 ft were generated in the model from SSW and NE directions respectively. Wave heights in the area under consideration were recorded with and without breakwaters for both the wave directions. Observations with rubble mound breakwaters are presented in figs 21 and 22 which showed that there was a considerable reduction in height of waves inside the area included by breakwaters(photo 3). Maximum wave height was only one foot(0.31 m) which was considered quite safe for the lighters using the port. The lengths and alignment of breakwaters were therefore, considered suitable from this aspect also.

7. SECOND STAGE OF DEVELOPMENT FOR 17 FT DEPTHS BELOW LWOST

The layout finalised for 9 ft depths below LWOST was maintained and the lengths of southern and northern breakwaters were increased in steps with the channel dredged upto 17 ft(5.18 m) contour. The following combinations of lengths(ft) of breakwaters were tested with a sand trap behind the southern breakwater.

Northern	1150	1400	1500	1500	1700
Southern	1400	1600	1800	1900	1900

The combination of southern breakwater 1900 ft(548.64 m) and the northern one 1700 ft(518.16 m) in length with a sand trap behind the southern breakwater was found to give satisfactory results.

Long period tests were conducted with two sets of discharges mentioned above and with and without periodic dredging of the sand trap. Results of bed changes obtained after an equivalent period of five years, plotted in figs 23 to 26, showed that since the cross-sectional

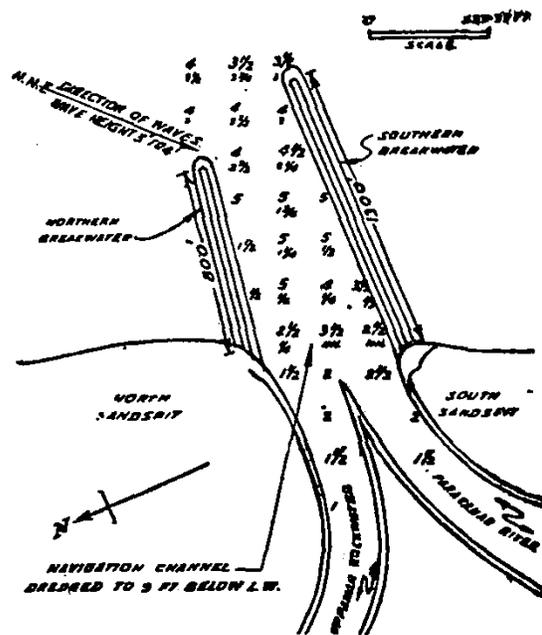
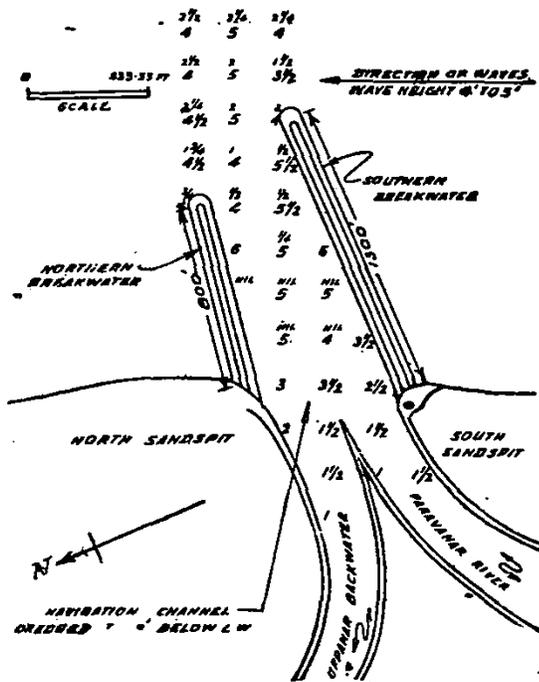


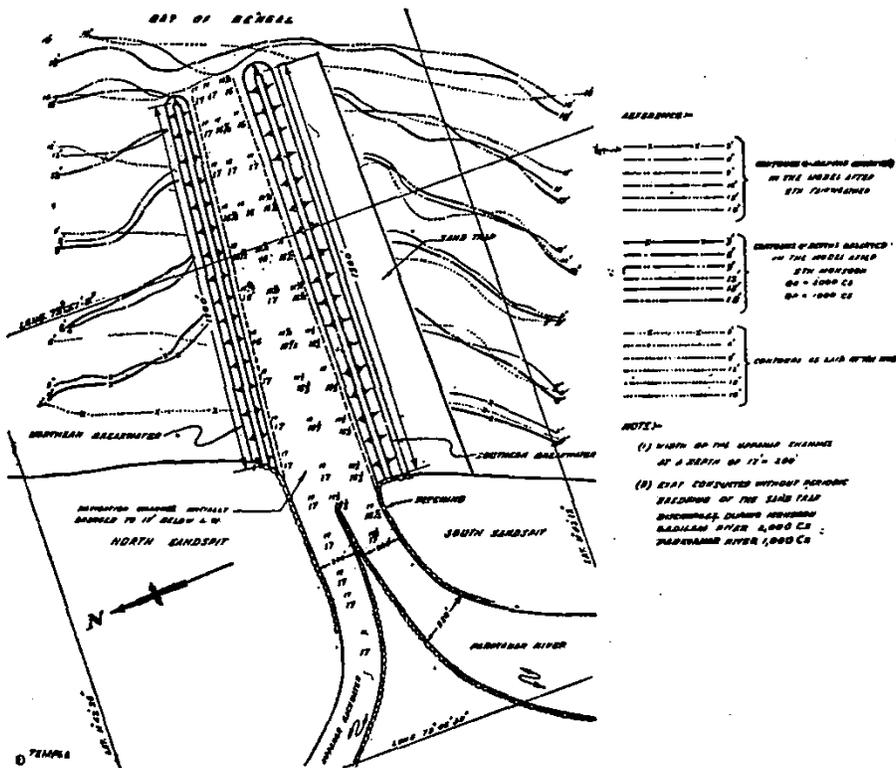
Fig 21 : Wave heights observed in the model with proposal C (I stage), waves from SSW

Fig 22 : Wave heights observed in the model with proposal C (I stage), waves from NE

Note : Wave heights observed at HW

Reference- Small figs : Wave heights with two rubblemound breakwaters

Bold figs : Wave heights without breakwaters and channel dredged



Note :

- (i) Width of the uppnar channel at a depth of 17 ft = 200 ft.
- (ii) Expt conducted without periodic dredging of the sand trap. Discharges during monsoon
Gadilam river 2,000 cfs
Paravannar river 1,000 cfs

Fig 23 : Contours obtained in the model with proposal C (II stage) after an equivalent period of five years

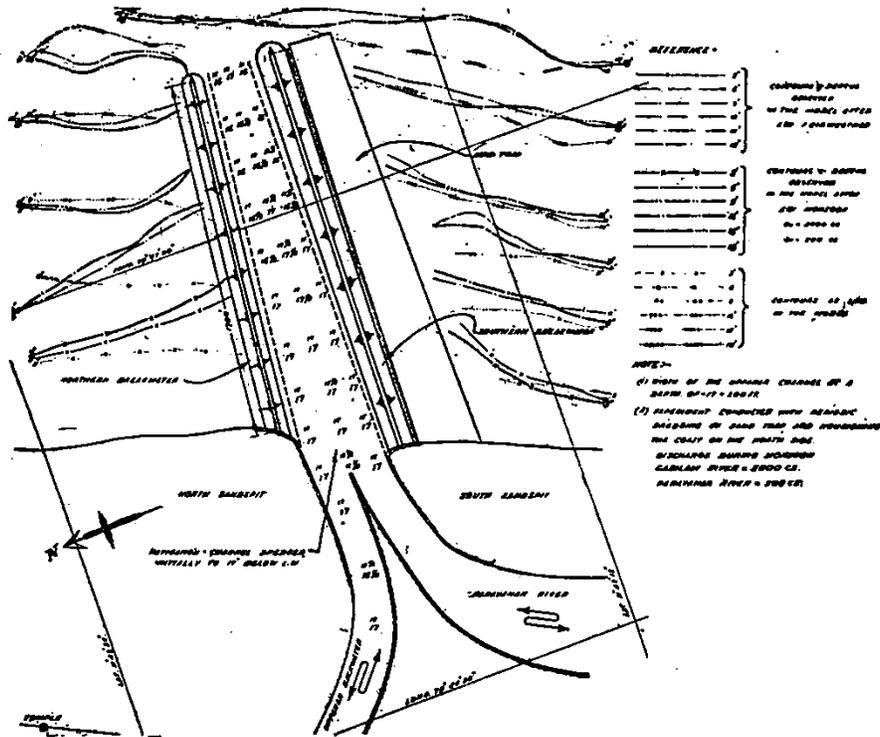


Fig 26 : Contours obtained in model with proposal C (II stage) after an equivalent period of five years

Note : (i) Width of the uppnar channel at a depth of $-17 = 200$ ft

(ii) Expt conducted with periodic dredging of sand trap and nourishing the coast on the north side. Discharge during monsoon Gadilam river = 5,000 cfs, Paravanar river = 500 cfs.

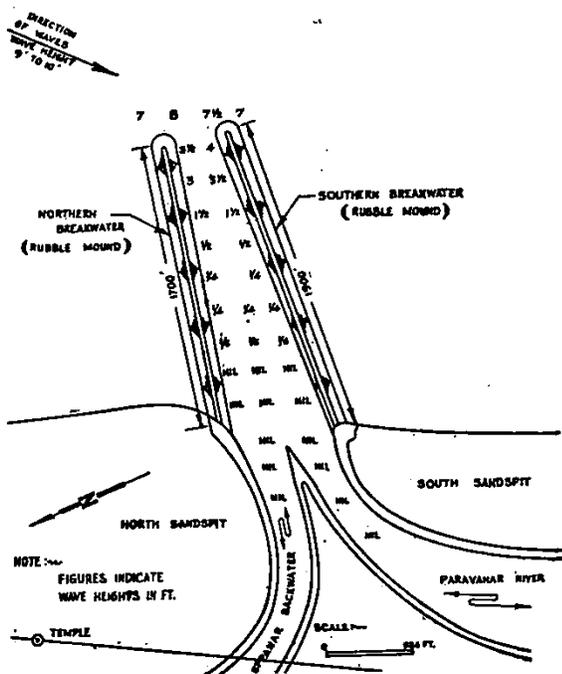


Fig 27 : Wave heights observed in the model with proposal C (II stage) with waves from NE

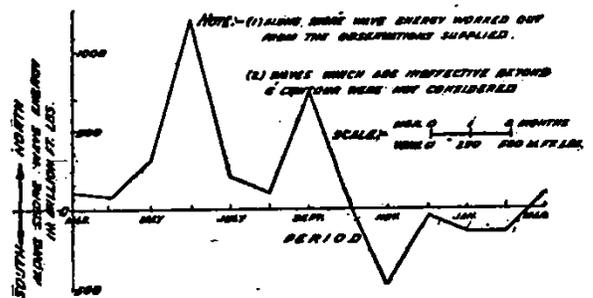


Fig 28 : Direction and magnitude of wave energy at Cuddalore

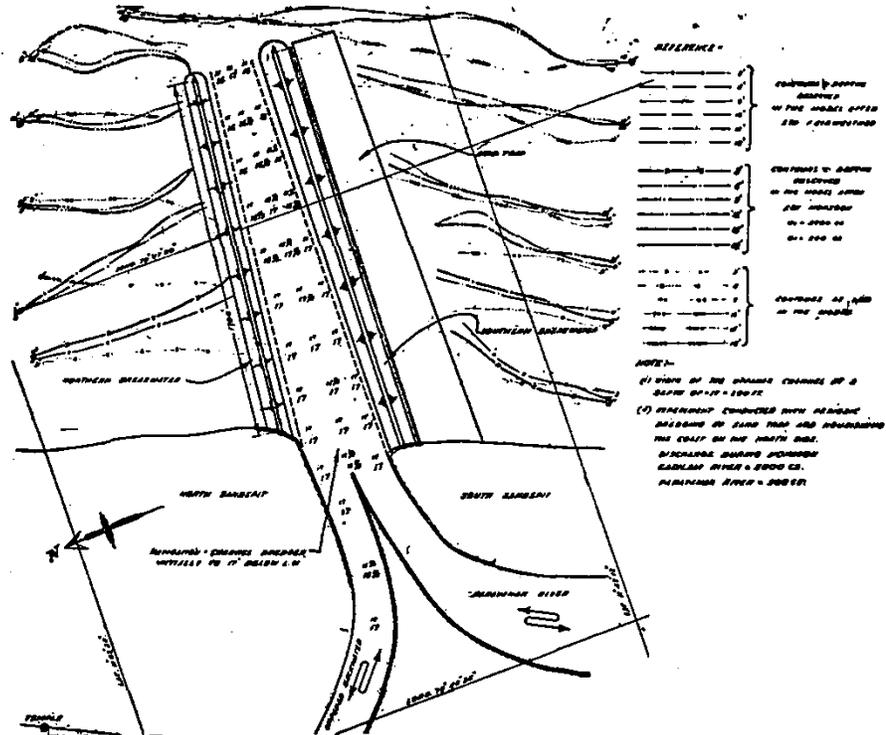


Fig 26 : Contours obtained in model with proposal C (II stage) after an equivalent period of five years

Note : (i) Width of the uppnar channel at a depth of $-17 = 200\text{ ft}$

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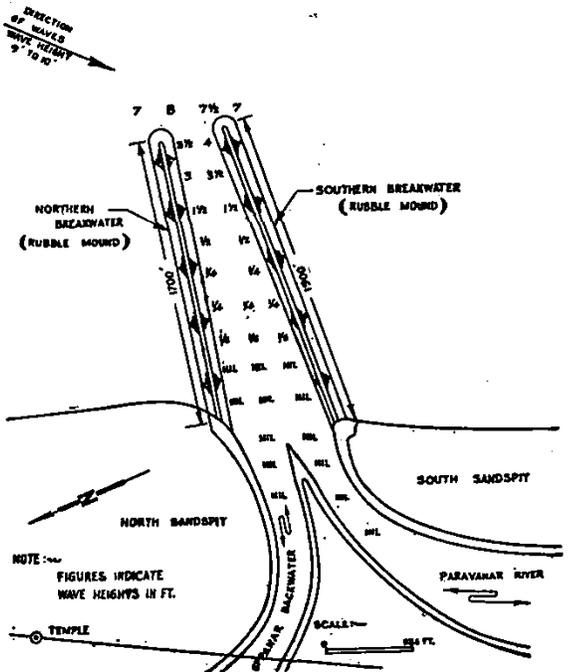


Fig 27 : Wave heights observed in the model with proposal C (II stage) with waves from NE

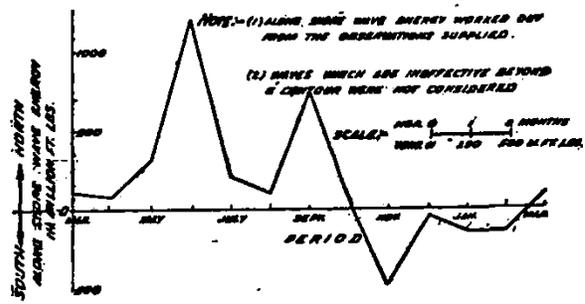
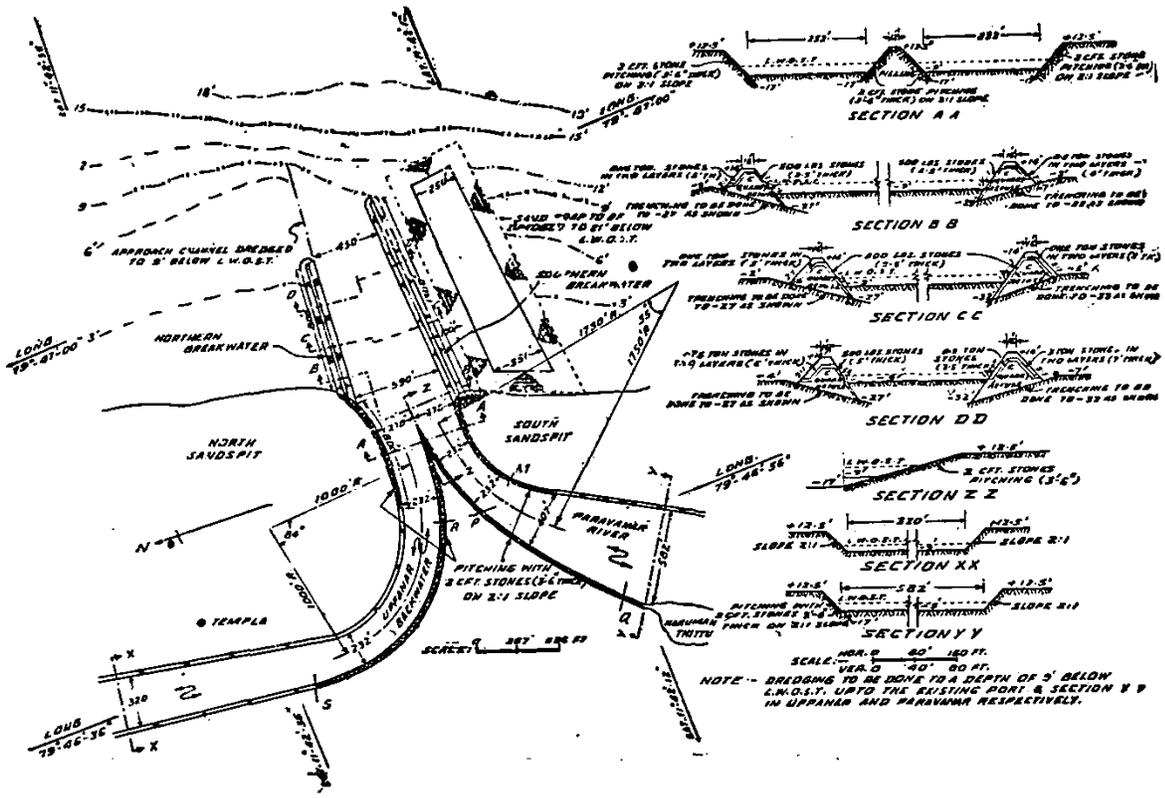


Fig 28 : Direction and magnitude of wave energy at Cuddalore



Details of trenching

Reach of breakwater between	Trenching ft below LWOST for breakwater	
	Northern	Southern
Sections BB and CC	27	29
Sections CC and DD	27	32
Sections DD and seaward end	27	32

Fig 29 : Layout of first stage of development

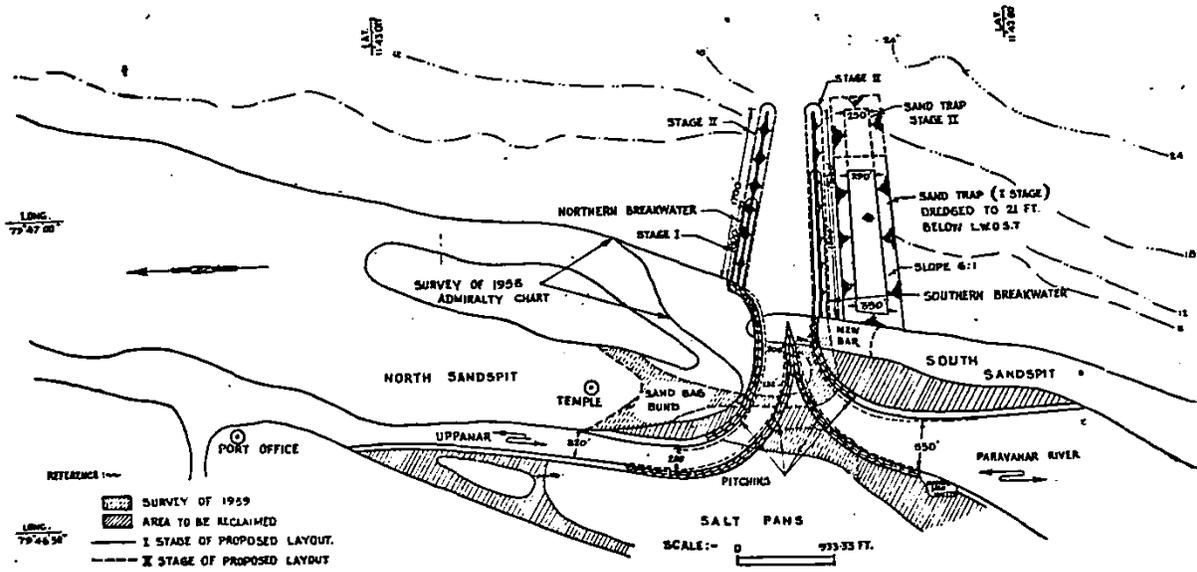


Fig 30 : Proposed layout of Cuddalore Port (superimposed on 1956 admiralty chart)

area provided was much more than the one commensurate with the tidal influx absorbed, flow would be very sluggish and thus might induce silting.

As in the first stage of development, flow pattern in the navigation channel between the breakwaters and through the Uppajar channel was observed to be satisfactory. A return flow, similar to the one described above, was observed in the Paravanar river but was considerably weak in strength.

The surface velocities at stations shown in fig 16 were also observed with this layout. The velocities in general were considerably less as compared to those in the first stage, due to which some more dredging might be necessary.

It would be seen from fig 21 that wave disturbance due to waves from SSW was negligible. Further, entrance formed by breakwaters was more open to wave disturbance from NE direction than that from SSW direction. Experiments with breakwaters in the second stage were, therefore, carried out with waves from NE only and of height 9 to 10 ft, which could be expected to reach breakwaters in this higher depth of water. Observations(fig 27) showed that the area inside breakwaters was adequately protected and the layout considered satisfactory(photo 4).

8. DISCUSSIONS OF RESULTS

Proposal A : Slight return flow was observed in the navigation channel for some period during flood tide. The curvature given to the navigation channel was much too sharp. This was an undesirable feature for development of the port for bringing in coasters. The flow at the confluence of two rivers was also observed to be slack which was not favourable for maintaining depths. Due to the alignment of breakwaters

and the navigation channel facing north-east, too much of wave disturbance was felt inside the channel resulting in deterioration of depths. The proposal A could not, therefore, be considered suitable.

Proposal B with breakwaters : The navigation channel was at right angles to the coast line. Past experience, again corroborated by the model, showed that a channel at right angles to the direction of predominant littoral drift was less efficient than the one inclined slightly in its direction. This was necessary since the alignment should give more consideration to the direction of flow from the Paravanar river which had a bigger tidal influx.

The proposal of a sand pump moving over a jetty as at Madras Port could not be studied in the model. It had inherent limitations. Firstly, the pump could not be designed for the maximum rate of littoral drift and for its economical running it had to be designed for the average rate of littoral drift. It is well known that the rate of littoral drift varies according to energy of waves and hence would obviously be different during different months(fig 28). Thus the pump would always have some backlog of littoral drift, which it would not handle. This quantity of littoral drift passing in the channel, would cause channel to silt and lose depths. This had been the experience at Durban Harbour in Africa. Relevant information in this regard was collected from the System Harbour Engineer of South African Railways(Harbours Department) at Durban. The plant when installed at the south breakwater had a limited if not almost negligible effect on the littoral drift. The sand pump at this harbour had, therefore, to be replaced by a suction dredger working in a sand trap and the former is now being used as a booster pump. The proposal of a sand pump and a jetty did not, therefore,

appear to be sound.

Proposal C : This proposal(fig 16) appeared satisfactory. The flow was observed to be smooth and without any return flow and the depths also maintained to reasonable expectations.

9. FINAL LAYOUT

The dimensions of the navigation channel were arrived at to meet the requirements of vessels calling at the port.

The finalised layout(fig 29) for first stage of development envisaged construction of two breakwaters, 1300 ft(396.24 m) long on the south side and 800 ft(243.84 m) long on the north side of the entrance and a sand trap behind the southern breakwater. A navigation channel commencing from the entrance formed by the breakwaters to the existing port on the Uppanar channel was dredged to a depth of 9 ft below LWOST upto the place known as Hanuman Thittu.

Fig 30 shows the same layout superimposed on the 1956 admiralty chart. The channel on the western side of the Hanuman Thittu should be closed and similar reclamations be carried out for training the Uppanar.

Though dredging was carried out upto the existing port, it was suggested that the port be shifted to a suitable place along the reach marked RS(fig 29) to reduce the to and fro distance appreciably from the present distance of 4.5 miles(7.24 km) and thereby increase the number of trips to obtain a quicker turnover of the cargo. This would further result in the reduction in length of the navigation channel to be maintained. The finalised layout(fig 31) for second stage of development has lengths of breakwaters 1900 ft(579.12 m) and 1700 ft(518.16 m) on the southern and northern side of the gut

respectively. They gave the least deterioration in depths at the entrance during second stage of development.

It was suggested that breakwaters of the first stage might not be extended in the beginning of the second stage of development. Instead, only the sand trap upto 17 ft(5.18 m) depth should be provided and periodic dredging carried out in the sand trap. Breakwaters should be extended only if silting in the navigation channel, was found to be excessive for dredging. This extension might be carried out in stages in lengths of 300 ft(91.44 m) or so and further additions decided after watching the conditions of the entrance in the prototype.

It was further suggested that the dredged material be dumped in the surf zone on the north side to maintain the material energy balance thereby preventing erosion on the north side of the gut.

10. DESIGN OF TRAINING WORKS

The Port authorities intimated that the maximum observed discharges of the Paravanar and Gadilam rivers were 36,292 cfs(1029 m³/s) and 34,871 cfs(989 m³/s) respectively. It was not known what percentage of discharge in the Gadilam river flowed through the Uppanar and through the St David's bar at this stage. It was also not known at what stage of discharges in the Gadilam river, an artificial cut was made through the St David's bar. In absence of this data, it was presumed on the basis of rational calculations from the available data, that maximum discharges of 10,000 cfs(283 m³/s) (allowing some factor of safety) might flow through the Uppanar channel and that, at worst, this would synchronise with the stated maximum discharge of the Paravanar River of 36,292 cfs. While determining the level to which trenching of the breakwaters should be carried out to pre-

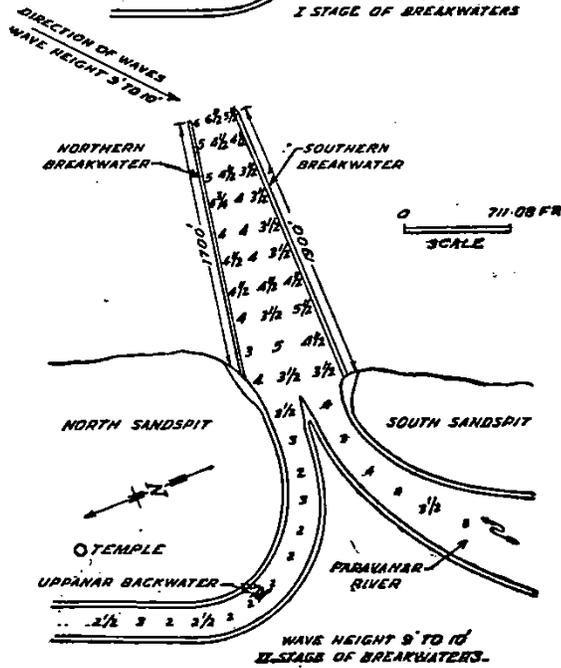
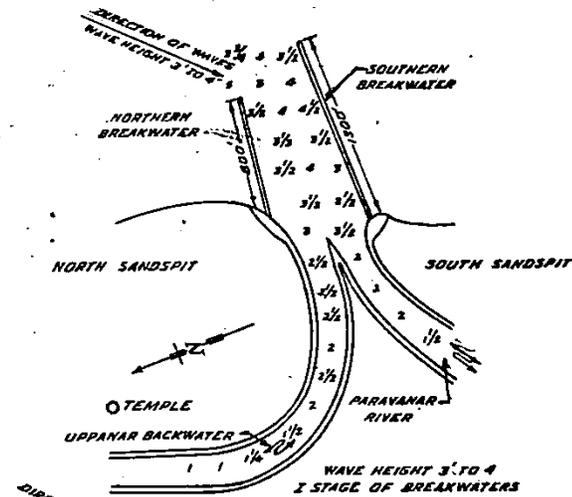


Fig 33 : Wave heights observed in the model with a design of breakwater with vertical sides waves from NE

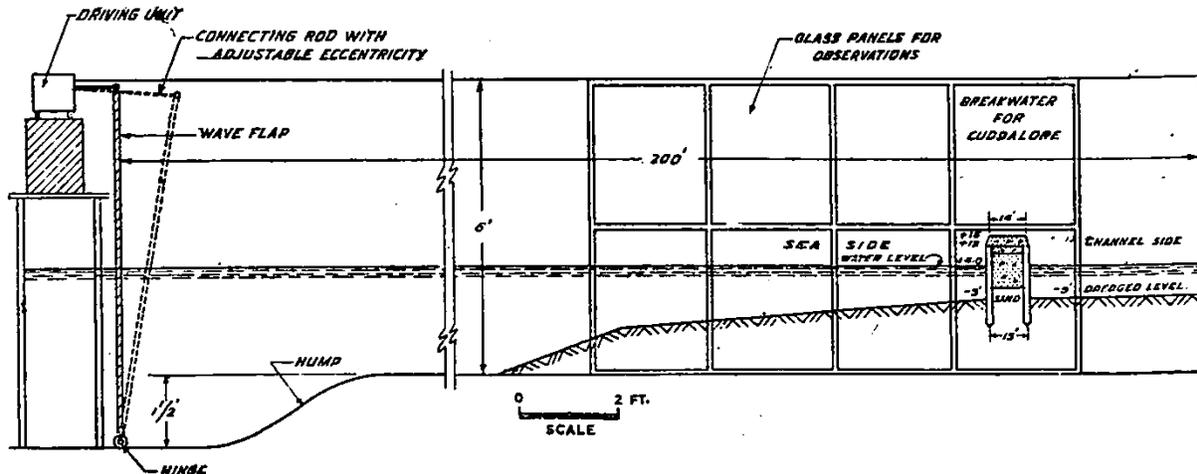


Fig 34 : Longitudinal section of 200 ft wave flume

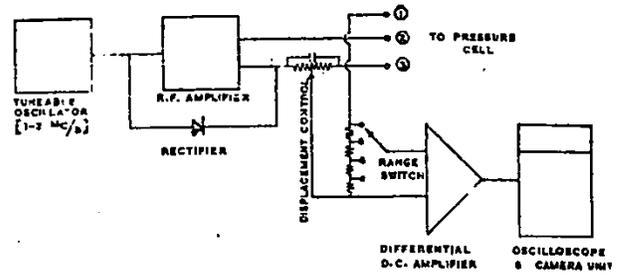


Fig 35 : Set-up for pressure measurements

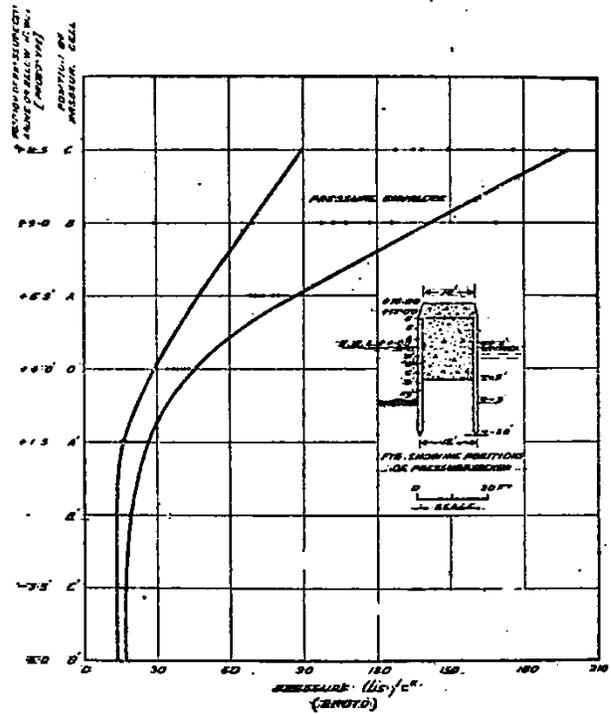


Fig 36 : Variation in pressure on the vertical side of a breakwater

vent undermining of breakwater due to scour, the combined discharge of 46,292 cfs (2018 m³/s) was therefore, assumed. The levels to which trenching should be carried out are shown in figs 29 and 31 along with details of breakwaters and training works for first and second stages of development.

11. STUDY OF THE DESIGN OF BREAKWATERS WITH VERTICAL SIDES

At this juncture, a design of breakwaters (fig 32) with vertical sides was proposed by the Port authorities.

Experiments were carried out in the composite model (1/200 : 1/50) to test the design of breakwaters (I stage) with vertical sides. It was observed that during the period when the wave approach is from north-east, which is predominant during October to February, wave heights in the navigation channel formed by the breakwaters were more than 3 ft (0.91 m) while in the Paravanar and Uppanar channels, they were more than 2 ft (0.61 m) for a predominant wave height 3 to 4 ft (0.91 to 1.22 m) generated in the deep sea. Observations are presented in fig 33. Photo 5 shows wave disturbance in the Uppanar and Paravanar channels under these conditions.

Experiments were continued to see the behaviour of breakwaters in the second stage. It was observed that when wave heights were of the order of 9 to 10 ft (2.74 to 3.05 m) in the open sea, wave disturbance in the navigation channel was more than 4 ft while in the Paravanar and Uppanar channels it was about 3 to 4 and 2 to 3 ft respectively (fig 33 and photo 6).

This disturbance as compared with that observed with rubble mound breakwaters (figs 22 and 27 and Photo 3 and 4) was not considered desirable. With so much wave disturbance, navigation in a channel of

restricted width would be difficult and hazardous. Further, if the port were shifted in the region RS(fig 29) this wave disturbance would be undesirable from the point of view of loading and unloading operations. Moreover, with deep water wave heights of as much as 18 ft(5.49 m) expected with the storm located at Cuddalore itself (Append. . conditions would be still worse.

Further experiments were conducted in a 200 ft(60.96 m) long and 4 ft(1.22 m) wide wave flume(fig 34) on a breakwater section constructed to a geometrically similar scale of 1/30 to test its stability. It was subjected to a wave height of 10 to 11 ft(3.05 to 3.35 m) which might be reasonably expected in 13 ft(3.96 m) depth of water. As will be seen in photo 7, waves after breaking on the vertical side of breakwater, would result in considerable overtopping and spray.

Pressures due to dynamic action of a breaking wave were observed at various elevations with respect to high water at +4 ft with a calibrated pressure pick up mounted in the vertical side of a breakwater. The sensitive diaphragm of a pick-up 15 mm in diameter, was flush with the surface of a breakwater. The pressure pick up designed and made at Technisch Bureau J.TH. Van Reijssen, Delft, Holland, consisted of two electrodes, the capacitance between which varied due to impact of breaking waves. The pressure variation thus picked up by the pick up was conveyed to an oscilloscope and camera unit through a capacitance displacement meter(fig 35).

Variation in observed pressures with respect to elevation of the pressure pick up above and below the high water level at +4 ft is shown in figure 36. It will be seen that pressures below the water surface were constant and well defined, whereas those above the water surface

showed much variation. This was probably due to air trapped between the breakwater and the breaking wave which in turn acted like a cushion thereby reducing or increasing the pressure intensity. The breaking pressure as recorded in the model by the pressure pick up was so high that the section of the breakwater was not stable and showed signs of overturning(photo 8). These results were corroborated by tests on a 1/15 scale geometrically similar model. Mathematical computations made to determine stability of the breakwater confirmed the above findings.

The design of the breakwater with vertical sides was not considered safe.

APPENDIX

Hindcasting for storm waves near Cuddalore

Wave data collected from the India Meteorological Department were for the years 1949 to 1953 supplied by the ships plying in the Bay of Bengal between latitudes 15° and 20° and longitudes 80° and 85° . Though this data is indicative of what was happening in the Bay of Bengal in various months and seasons, it was also considered essential to study in detail the waves that might have been generated due to the storms located in the Bay of Bengal and reaching Cuddalore. Wave characteristics were, therefore, hindcast for Cuddalore from synoptic weather charts of the Bay of Bengal for the years 1930 to 1958.

The weather maps prepared by the India Meteorological Department at 12 hours interval were utilised for the analysis of such storms. Fetch areas, wind speeds and their duration were determined directly therefrom. The equations and curves developed by Sverdrup and Munk and revised by Bretschneider were used to determine the hindcast significant characteristic of waves. The following points are worthy of mention

i) Computations of wave characteristics were made for moving fetches.

ii) The hindcast wave characteristics were for deep water and hence they must be used in conjunction with refraction theories to find out their shallow water characteristics.

The values of deep water waves obtained are given in Table A1. Only the waves of more than 5 ft height generated due to storms are incorporated in this table. The direction of storm waves is mainly between E and NE. The maximum wave height of 18 ft (5.49 m) with 10.7 seconds period might have occurred on 30th November 1952, due to wind blowing at a speed of 30 knots over a fetch of 247 nautical miles, the storm being located at Cuddalore itself.

TABLE A1

Analysis of storm data during 1930-1958 for Cuddalore Port

D = Decay distance(in N miles) U = Wind velocity(in knots)
 F = Fetch length(in N miles) T_m = Minimum duration(in hours)
 H_F = Wave height in ft at the end T_F = Wave period in seconds at
 of fetch area. the end of the fetch area.
 H_D = Deep water wave height in ft at T_D = Deep water wave period in
 the end of decay distance. sec at the end of decay dist.

Wave heights more than five feet are only reproduced in the table

Date	D	F	U	T _m	H _F	T _F	H _D	T _D	Direction of wave approach
1	2	3	4	5	6	7	8	9	10
23 10 30	0	322	21	12.0	8.2	7.1	8.20	7.1	E
17 11 30	300	311	27	25.5	15.2	10.5	7.51	12.29	NE
28 11 30	205	266	32	12.0	16.0	9.3	7.20	11.61	E
24 11 32	144	355	21	32.5	10.0	9.3	6.20	11.45	E
15 12 33	0	189	30	17.0	17.0	10.0	17.00	10.10	NNE
19 10 35	0	144	32	12.0	16.5	9.4	16.50	9.40	NNE
14 11 35	144	167	21	18.0	9.2	8.0	5.06	8.96	E
15 11 46	0	266	15	28.5	5.3	6.9	5.30	6.90	NE
26 10 49	371	194	30	17.5	17.0	10.3	7.32	12.87	NE
10 12 51	566	196	30	17.5	17.3	10.3	6.44	13.90	NE
21 5 52	93	103	25	12.0	11.0	8.0	6.05	9.60	NNE
28 11 52	330	330	25	19.5	13.0	9.3	6.59	11.62	E
28 11 52	422	247	30	20.5	18.0	10.7	7.83	13.40	E
29 11 52	242	227	30	19.0	17.8	10.5	9.43	12.60	E
29 11 52	165	175	30	16.0	16.5	9.9	8.58	11.87	NE
30 11 52	0	247	30	20.5	18.0	10.7	18.0	10.70	NE
5 11 55	288	124	30	12.0	15.0	9.1	5.85	11.72	NE
30 11 55	92	92	25	11.0	10.7	7.7	5.57	9.33	E
28 10 56	304	113	30	11.0	14.5	9.0	5.80	11.70	E
28 10 56	278	113	30	11.0	14.5	9.0	5.50	11.50	E
17 5 58	556	103	35	10.0	18.0	9.6	5.40	13.44	NE
21 11 58	144	134	30	13.0	15.2	9.3	7.92	11.15	NE

TABLE A2

Comparison of hindcast and observed wave heights*(ft)

Date	Hindcast	Observed
4 12 50	3.08	3.00
4 11 55	2.96	3.00
5 11 55	5.85	6.50
29 11 55	1.00	Less than 1
28 10 56	5.80	6.50
28 10 56	5.50	5.00
27 12 57	2.86	3.00

*Collected from India Meteorological Department, Poona.

These hindcast waves were verified from the actual data supplied by ships. Representative verified wave heights are given in Table A2, which show that hindcast wave heights agree fairly well with the observed ones.

CWPRS TECHNICAL MEMORANDUMS

SUBJECT CLASSIFICATION

Subject	Symbol
Water studies & Hydrology	HLO
Rainfall & Runoff	
Regeneration & Losses	
Quantity of Water	
Fluid Mechanics	FLM
Design of Hydraulic Structures	HYD
River Training & Flood Control	HYR
Irrigation, Drainage & Reclamation	IRD
Surface & subsurface irrigation	
Water requirements of crops	
Soil survey and crop pattern	
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Other miscellaneous	MIS

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