Chapter II Natural Conditions in and around MBPT

2.1 Geographical Conditions

2.1.1 Geological Characteristics

Earlier discoveries indicate that Mumbai harbour was once a thickly wooded valley which subsided below the sea due to tilting of the landmass. The origin of rocks in Mumbai region is that of the Deccan traps. Although the strata over the Deccan plateau formed by series of vast lava flow have remained nearly horizontal, they are found to be inclined by about 15 degrees towards west in the Mumbai area. The type of rock is mainly basalt, showing different grades of weathering. Earlier bore hole investigations have revealed the presence of tuffaceous breccias and volcanic ashes, which are much softer than the basalt traprock. There is also the presence of murrum, with its properties varying in hardness and thickness according to the degree of disintegration. The layer of weathered rock is overlain by residual soil which in turn is overlain by silty marine clay. The sub-soil conditions in the harbour have been further dealt with under section 2.3.

2.1.2 Geography of the Port and Surrounding Area

Mumbai region has a varied topography. Most part of the mainland is a flat coastal plain with adjoining islands both flat and hilly. The western ghats which rise sharply to heights of over 600 m are located about 50 km to the east of Mumbai.

Mumbai harbour located at latitude 18^{0} 57' N and longitude 72^{0} 51' E is protected by the mainland to its east and Mumbai peninsula to its west. The entrance to the harbour is from the south west between Prongs reef at the southernmost tip of Mumbai and Thal reef lying off the mainland to the south east. The mainland to the east of the harbour is dominated in the foreground by the hills of Karanja. Mumbai City lies to the west, the harbour being about 8 km in width at this point. The docks namely Indira, Prince's and Victoria are located on the east of the harbour. These docks have an impounded water area of 20 hectares, 12 hectares and 10 hectares respectively. The approach to Indira dock is by a branch taking off from the main channel east of the middle ground. For Victoria and Prince's docks, the approach is from North of the Cross Island.

Two islands namely, Jawahar (Butcher) and Elephanta are located to the North East of the harbour. The Marine oil terminal (MOT) berths 1, 2 & 3 project from Butcher island towards East. The fourth oil berth is connected by an approach trestle originating from Butcher Island in a southward direction, with the berthing structure located alongside the main channel. Elephanta Island is about 2 km East of Butcher Island and South of Trombay. To the northern extremity of the harbour is Pir Pau Pier. Approach to Pir Pau Pier is by way of the northern reach of main channel, leading towards Thane creek. West of this is a natural deep which has been further dredged to the required levels. The new Pir Pau Pier is 2 km offshore of the old Pir Pau Pier. Approach to new Pir Pau Pier is an extension of the channel leaving off from the MOT berths (Jawahar Dweep). East of Pir Pau are two large tidal creeks, Panvel and Thane joining the harbour. Moving further East along the main channel leads to Nhava Sheva port. This port was commissioned only in 1989, mainly to cater for container and bulk cargo.

Layout of Mumbai harbour is represented in Figure 5.1.1. The built up area of the port is generally flat. The major docks and berths extend for a distance of about 3 km from Ballard pier to the Ferry jetty, with cope levels of the quay varying from +6.71 m CD at Ballard Pier to +5.73 m CD at the Ferry terminal.

2.1.3 Seismic Conditions

Maharashtra region has experienced three earthquakes since 1967 with intensities varying from 4.6 to 6.7 on the Richter scale. The region around Mumbai experienced shock waves of intensities less than 4 on the Richter scale from earthquakes at Koyna (about 200 km from Mumbai) and Latur (about 400 km from Mumbai) in 1967 and 1993 respectively. Intensities of earthquake recorded at Koyna and Latur were 6.7 and 6.3 on the Richter scale respectively. As per the Indian Government's criteria for earthquake design of resistant structures (IS 1893 4^{th} revision) issued in 1984, Mumbai is classified under zone - III.

2.2 Meteorological Conditions

2.2.1 Climate

The climate of Mumbai region has a regular seasonal variation determined by the occurrence of two annual monsoons namely, the South West and North East monsoon. South West monsoon extends from June to September. The fair weather period is from October to May when it is generally sunny and dry. November to March is the North East monsoon period. Although occasional high wind speeds are experienced during the North East monsoons, rainfall is negligible. The West Coast is subject to occasional severe cyclonic storms. These storms normally occur in the period May / June and October / November. The last cyclonic storm was experienced in 1995. However, it was not as severe as the cyclonic storm of 1982.

2.2.2 Humidity and Temperature

The relative humidity ranges from 61% to 87% in the monsoon period. Between November to January i.e., in the winter months, the relative humidity varies from 57% to 72%. Based on thirty years data, the mean daily temperature during the year varies from 24°C to 33°C. Highest recorded temperature during this period was 40.6°C. The monthly mean, maximum and minimum temperatures observed for the year 1996 is given in Table 2.2.1. As indicated in Table 2.2.1, the maximum and minimum temperatures observed were 36°C and 15°C respectively. On analysis of raw data it is observed that the warmest months were May and June and the coolest month January.

2.2.3 Rainfall

Most of the annual rainfall occurs during South West monsoon. Rainfall during North East monsoon is of hardly any significance. Table 2.2.2 shows the average rainfall during South West monsoon season for the period 1992-96 measured at Colaba station, Mumbai. The following can be inferred from data furnished in Table 2.2.2, which pertains to the south west monsoon period:

1) Average annual rainfall is 1780 mm.
2) Average monthly rainfall is nearly 450 mm.
3) Maximum rainfall normally occurs in the month of July, followed by September and August.
4) Number of annual rainy days is 91.
5) Average number of days rainfall exceeds 30 mm is 20.

An analysis of day to day records for the last 5 years reveals that it is only during South West monsoon that the rainfall normally exceeds 30 mm in one day. The total number of days rainfall actually exceeds 30 mm is for about 20 to 25 days in a year, which is distributed over a period of 4 months i.e., June to September. Hence it can be assumed that under normal circumstances i.e., excluding cyclonic storms, the possibility of construction activities getting disrupted due to inclement weather conditions is for about a maximum of 30 days in a year.

2.2.4 Wind

(1) Wind Roses.

Monthly wind rose diagrams from 1978 to 1989 for both, morning and afternoon are illustrated in Figure 2.2.1. From the rose diagrams it can be inferred that intensity of wind is substantially higher during the afternoons at Mumbai harbour area. The predominant direction of wind during October to May is from North East in the mornings and North West during the afternoons. However, during the monsoon months i.e., June to September, the wind is predominant from the South West quarter both, in the morning as well as afternoon.

(2) Characteristics of Strong winds.

Daily maximum wind speeds and direction observed by Indian Meteorological department (IMD) at Colaba for the period 1990 to 1996 were obtained. Unfortunately, IMD was not able to furnish complete data on wind records for the above period. However, with the available information, "Monthly maximum of winds" and "Wind direction with maximum speed" in each month has been analysed and given in Table 2.2.3 and 2.2.4, respectively. From Table 2.2.3 it can be inferred that the maximum wind speeds for most of the time during the year is from North West quarter, with strong winds predominant during the South West monsoon period. From Table 2.2.4 the maximum wind speed is observed to be 54-km/ h, from North West direction.

Table 2.2.1 Maximum Monthly Temperatures During 1996

Month	Max.(^0C)	Min.(^0C)	Avg. Max.(^0C)	Avg. Min.(^0C)
Jan	33	15	29.40	19.55
Feb	35	19	31.07	20.73
Mar	35	21	32.54	23.90
Apr	35	23	33.23	25.10
May	35	25	34.09	26.80
Jun	36	24	32.89	26.51
Jul	33	24	29.98	25.53
Aug	31	23	29.51	24.93
Sep	33	23	30.42	24.85
Oct	36	22	32.10	24.29
Nov	36	21	33.10	22.34
Dec	35	19	33.23	21.23

Source: Indian Meteorological Department

Table 2.2.2 Average Rainfall at Mumbai for the Period 1992-96

Month	Average Rainfall (mm)	No. of Rainy Days	No. of Days RF>30mm
Jun	250	16	3
Jul	687	28	7
Aug	383	27	5
Sep	460	20	5
Total	1780	91	20

Source: Indian Meteorological Department

Table 2.2.3 Monthly Maximum Wind 1990-96

	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Year	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed	Dir	Speed
1990	NNW	18	E	20	NW	20	NW	19	NW	20	NW	23	WNW	25	W	24	W	18	SSE	30	NNW	15	NNW	18
1991	NW	20	NNW	20	NW	16	*	*	*	*	W	26	W	28	NW	26	NNW	24	NNW	24	WNW	32	E	15
1992	NNW	24	NNW	29	NNW	30	NNW	34	WNW	20	WNW	40	WSW	26	NW	30	W	30	NNW	24	ENE	24	NE	10
1993	NNW	18	NNW	20	WNW	33	NW	24	NW	38	WNW	41	W	23	WNW	44	NW	54	*	*	NE	30	NE	28
1994	NNW	32	NW	34	*	*	*	*	*	*	*	*	SW	35	W	25	W	20	ESE	23	E	17	*	*
1995	NW	16	NW	20	*	*	NW	22	*	*	S	32	W	35	W	24	WNW	26	SE	25	WNW	14	NW	14
1996	NNW	18	WNW	16	NW	21	WNW	17	WNW	22	SSE	48	W	33	W	24	W	23	SSE	29	N	19	NNW	13

* Data Not available

Table 2.2.4 Wind Direction with Maximum Speed in Each Month 1990-96

	NW	NNW	WNW	WSW	N	S	E	W	ENE	ESE	SW	SSE	SE	NNE	NE	SSW
Jan	28	32	14	14	17	-	-	10	12	10	10	16	12	-	-	-
Feb	34	29	13	10	22	-	20	17	-	8	-	-	-	-	-	-
Mar	21	30	33	10	**	**	**	13	**	**	12	**	**	**	**	**
Apr	24	34	24	13	19	**	**	15	**	**	7	**	**	**	**	**
May	38	10	28	22	16	9	**	16	**	**	11	12	15	**	**	**
Jun	30	20	41	16	8	32	**	30	**	**	36	48	38	**	**	**
Jul	23	-	25	30	15	12	-	35	-	11	35	32	18	-	-	13
Aug	30	17	44	36	-	10	-	36	-	-	14	15	15	-	-	9
Sep	54	24	44	32	22	10	16	36	-	12	20	18	26	12	11	-
Oct	19	24	20	**	13	12	16	8	22	27	11	30	25	**	13	**
Nov	30	22	32	8	19	5	30	18	24	20	20	-	8	9	30	20
Dec	26	18	16	8	12	**	34	11	18	10	**	**	9	**	28	**

"-" Calm
** Data not available

Source: Indian Meteorological Department

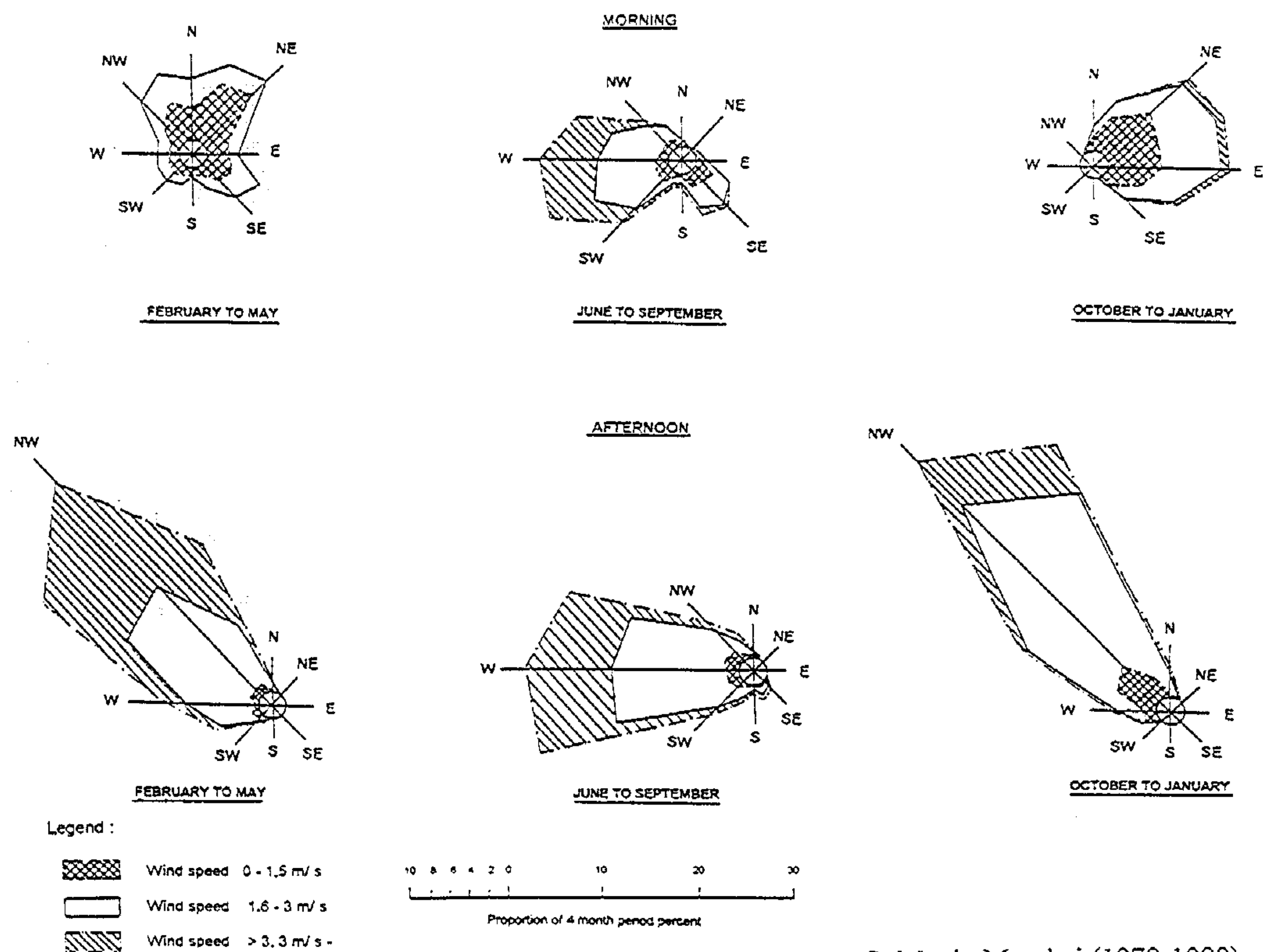


Figure 2.2.1 Wind Rose at Colaba in Mumbai (1978-1989)

2.3 Previous Observation of Natural Conditions

2.3.1 General

A very detailed study on natural conditions was made by Bertlin and Partners, herein after referred to as B&P, between 1964-68, during the preparation of a Master Plan report for the port of Mumbai. Field studies included the following:

1) Topographic surveys.

2) Aerial Photographs.

3) Bathymetric survey and probing.

4) Sub-Soil investigations.

5) Wave recording.

6) Current measurement and

7) Sediment transport measurements.

The field observations have been analysed in detail by B&P and included in their comprehensive report. Some of the results of field surveys made by B&P has been incorporated in this report to provide a better understanding of the overall status of natural conditions.

2.3.2 Waves

A detailed study of waves was carried out by B&P in order to determine the relative wave height in various parts of Mumbai harbour. In addition to visual observations, wave measurements were made using Ospos & Kelvin Hughes wave recorders. Figure 2.3.1 gives the location of the wave recorders installed in the harbour and their period of operation. Based on studies made by B&P, waves are substantially attenuated by the time they reach berthing facilities in the harbour. Figure 2.3.2 shows the 10% wave heights at various points inside and outside the harbour.

By combining the theoretical refraction analysis with statistical analysis of measured heights, a forecast of probable wave heights which could occur once in one, ten and hundred years was made by B&P. These are shown in Figure 2.3.3.

However as stated by B&P in their report, the wave height probability shown in Figure 2.3.3 does not take into account the effect of the following:

i) Wave reflection in the harbour depending on angle of approach.

ii) Cyclonic storms that occasionally hit Mumbai.

Mumbai harbour is not subject to any abnormal wave conditions. The predominant direction of wave is from South West. These waves arise mainly just before and during monsoons with wave heights reaching a maximum of 1.5 m under normal conditions and wave period ranging from 6 to 10 seconds, although the wave heights can be much higher during cyclonic storms. Since wave height in Mumbai region is not exceedingly high and adequate information is available, no further observations on waves were felt necessary for this study.

2.3.3 Tides

The tide levels at Mumbai port are shown in Table 2.3.1.

Table 2.3.1 Mumbai Port Tide Levels

Tide	Elevation (meter)
MHWS	+4.42
MHWN	+3.32
Highest LW	+2.74
MSL	+2.51
Lowest HW	+2.48
MLWN	+1.85
MLWS	+0.76
Chart Datum	+0.00

Source : B&P Master Plan Report.

MHWS - Mean High Water Spring

MHWN - Mean High Water Neap

MSL - Mean Sea Level

MLWN - Mean Low Water Neap

MLWS - Mean Low Water Spring

Statistical studies made for the Master Plan by B&P indicate that :-

i) All high tides exceed + 2.7 m.

ii) About 5% of all high tides would be less than +3.2 m.

iii) About 5% of lower high tides (LHW) would be less than +2.85 m.

The tidal variation at Mumbai is mainly diurnal. Regular tide observations are carried out by Survey of India with the help of an automatic tide gauge installed at Apollo Bunder, near Gate Way of India.

2.3.4 Currents

The currents in Mumbai harbour are mainly due to tidal ebb and flow. However, during South West monsoon, due to heavy rainfall, run off from rivers / creeks could considerably alter the flow pattern.

Current observations were made by B&P during 1965 - 67. Results of these observations illustrating the normal maximum current distribution in the harbour during both, ebb and flood tides are presented in Figure 2.3.4 and Figure 2.3.5, respectively. It may be noted that the maximum normal currents inside the harbour range from 2 to 3 knots. However, it was observed that the combination of ebb tide and heavy discharge from creeks during wet weather, at times, resulted in currents of up to 4 knots.

2.3.5 Bathymetry

Although the port area is located in a protected bay, the natural depths in the harbour are quite shallow. The entire navigable area of the port requires to be dredged for maintaining required depths. The Marine Survey department of MBPT conduct survey of areas within the harbour all round the year to assess accumulation of silt, in order to plan the maintenance dredging. Although these surveys are not carried out at regular frequencies or as planned, the results of all surveys are recorded and maintained. These survey drawings, along with those prepared by respective dredging companies during the annual maintenance dredging, have been extensively used for studying annual rate of siltation in the harbour.

2.3.6 Sub-Soil Conditions

A number of geotechnical investigations at various locations in the harbour have been conducted in the past. Investigations made in 1963 by Bertlin and Wilton and Bill provide information on soil conditions near Ballard Pier Extension, East of Indira dock East arm and the Ferry terminal area. From available data it can be inferred that hard tuff and / or weathered Basalt was generally encountered at - 5 m CD near the Ferry terminal area, at depths varying from - 7 m to - 10 m CD in the area surrounding East of Indira Dock East arm and finally at depths between - 15 m to - 17 m CD at the Ballard Pier area.

Another set of bore holes were drilled during the Master Plan Study in 1968, which covered various parts of the harbour. Areas of investigation included, the main channel, South of Ballard Pier Extension, Sewri mud flats, mouth of the creeks namely Nava-Sheva, Panvel, Thana and Dharmtar and offshore at Sassoon Docks. A total of 92 marine and 10 land soil borings were made for obtaining information to assist in the studies connected with siltation, reclamation and development of new structures in the port. Results of the soil investigation revealed soft clay in the top layers followed by Murum and then Basalt rock. However, the level of hard layer/ rock varied from shallow depths averaging -6 m CD at Sewri mud flats to -18 m CD at a few locations along the main channel.

In addition to the above investigations, seismic surveys of the main channel was carried out during 1978. Drawing prepared by MBPT (Drg. No. BH 1489/ 1979) indicates that the bed rock contours along the length of main channel vary from -12 m to -20 m CD. The bed rock contours mainly run across the channel except at certain locations where the contours run along the length of the channel.

2.3.7 Siltation

It is a well known fact that Mumbai harbour is prone to siltation. Although the rate of siltation is not alarming, it is quite substantial and cannot be ignored. The problem of siltation is mainly due to tidal action which creates the movement of large water mass to fill and empty the creeks, resulting in the influx of silt. In addition to the tidal activity, other factors such as strength and direction of currents, river discharges, wave action, flow conditions, salinity changes and nature of bed contribute to the amount of siltation in the harbour. Current pattern plays an important role in transporting sediments and redistributing the bed material within the harbour. The bed material, being very fine in nature, is easily brought to suspension by the slightest disturbance and is transported depending on the direction and speed of current. The moment currents become weak, the material in suspension begin to settle rapidly.

A number of siltation studies have been carried out in the past by various organisations. Several model studies have also have been conducted by CWPRS Pune. The Master Plan report prepared by B&P includes results or extracts of some of the earlier studies carried out within Mumbai harbour.

Site observations made by B&P for siltation studies during the Master Plan Study included the following:

1) Measurement of silt concentration and flow speed at short time intervals during typical spring, mean and neap tides in both pre-monsoon and monsoon seasons.

2) Flow gauging of Thane and Panvel creeks.

3) Wave and wind observations and sampling of bed material.

4) Current measurements.

5) Temperature and salinity.

6) Silt concentration.

7) Bathymetric surveys.

Sediment transport measurements were carried out at locations shown in Figure 2.3.6. Based on sediment measurements in the harbour, sediment discharge as analysed by B&P at three locations are given in Table 2.3.2(1), (2) & (3) respectively and represented graphically in Figures 2.3.7. to 2.3.10.

Siltation studies carried out by B&P are quite detailed and many of the observations made in their report will be of considerable use while conducting further analysis during the course of this Master Plan study. B&P in their report had recommended a regular annual check of depth in the main channel by taking soundings under closely similar condition each year during post monsoon period. We learn from MBPT that no such systematic surveys have been carried out. Also, there has been no systematic survey carried out for the entire harbour each year which could otherwise have greatly assisted in the analysis of siltation pattern studies.

Table 2.3.2 Sediment Discharge (1)

R/D	=	Tidal Range (in rise or fall) / Duration (hrs)
10^3 kg/m	=	total discharge of solids per metre width during rising or falling tide
10^3 kg/m^2	=	total discharge of solids per sq. metre during rising or falling tide
u	=	typical maximum velocity at height h above bed, measured during rising or falling tide
u^2/h		is measure of local force acting on the stream bed.

Locations 13 and 13A.

Date	R/D	10^3kg/m	10^3kg/m^2	u^2/h	Remarks
	Location 13		Flood tide		
6/6/66	0.52	14.9	2.61		
10/6/66	0.28	2.7	0.43		
16/6/66	0.30	2.6	0.42		
23/6/66	0.52	18.3	3.01		
29/6/66	0.30	4.1	0.61		In 1966 observations with bottle sampler
7/7/66	0.41	7.2	1.20		could not be obtained close to the sea-bed
22/7/66	0.56	32.3	5.16		and were only at hourly intervals
	Location 13		Ebb tide		
6/6/66	0.41	9.4	1.51		
16/6/66	0.33	3.7	0.58		
23/6/66	0.52	19.6	2.97		
29/6/66	0.35	5.5	0.84		
7/7/66	0.39	5.3	0.86		
22/7/66	0.62	23.4	3.67		
	Location 13A		Flood tide		
29/3/67	0.74	40.4	4.61	2.8	High silt contents
26/4/67	0.79	13.8	1.56	2.6	at all levels
26/6/67	0.41	3.9	0.42	0.83	
5/7/67	0.21	1.8	0.20	0.30	Low silt content. Early freshet.
10/7/67	0.58	7.9	0.91	0.83	
26/7/67	0.42	4.4	0.50	0.30	
1/8/67	0.12	0.27	0.03	0.38	
11/8/67	0.44	25.2	2.67	0.16	High silt content (>700 ppm) near bed
	Location 13A		Ebb tide		
29/3/67	0.58	39.8	4.35	1.40	High silt contents at all levels
26/4/67	0.61	9.0	0.97		C.M. Failed. Mostly v. low silt contents
5/7/67	0.29	2.0	0.21	0.58	Unusually low silt content. Early freshet.
10/7/67	0.48	5.5	0.63	0.48	
1/8/67	0.15	0.76	0.08	0.07	
22/8/67	0.54	21.0	2.25	1.63	
24/8/67	0.51	11.8	1.34	0.87	

Table 2.3.2 Sediment Discharge (2)

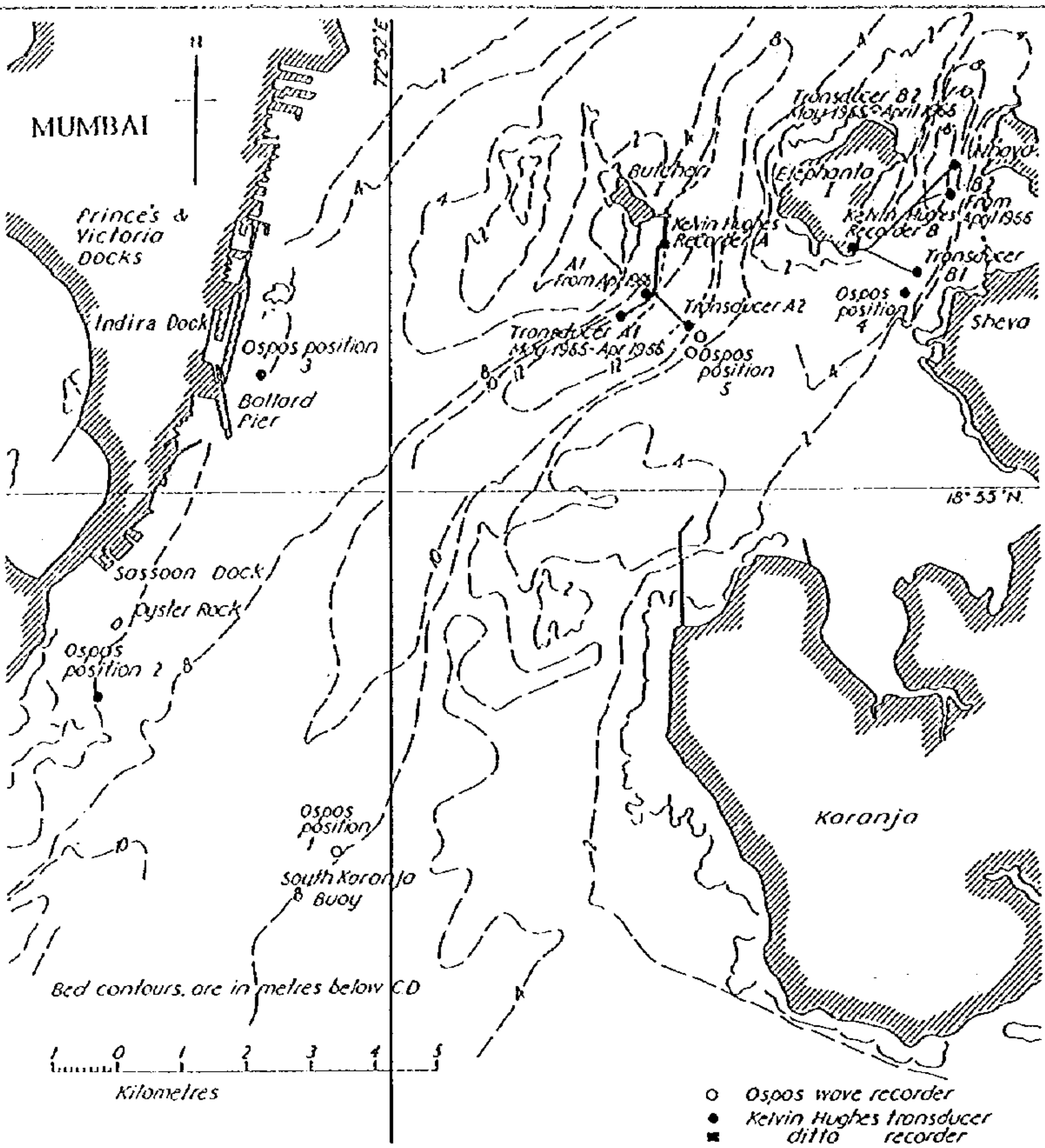
Locations 22 and 22A

Date	R/D	10^3Kg/m	10^3Kg/m^2	u^2/h	Remarks
Location 22	Flood tide				
25/5/66	0.45	14.7	2.51		
27/6/66	0.29	8.2	1.22		
5/7/66	0.51	24.5	3.70		
20/7/66	0.65	12.3	1.74		In 1966 observations with bottle sampler could not be obtained close to the sea-bed and were only at hourly intervals
Location 22	Ebb tide				
25/5/66	0.42	6.4	1.01		
27/6/66	0.30	6.8	1.02		
5/7/66	0.42	12.6	1.77		
20/7/66	0.58	26.5	3.63		
Location 22A	Flood tide				
11/4/67	0.52	7.4	1.07	0.45	
12/4/67	0.52	10.1	1.72	0.36	
30/6/67	0.19	3.3	0.50	0.53	First freshet
11/7/67	0.61	10.7	1.91	0.43	
13/7/67	0.41	5.2	0.72	0.12	High silt charge near bed. 800/1300 ppm near HW slack
24/7/67	0.54	7.4	1.11	0.45	
2/8/67	0.12	0.33	0.04	0.19	
Location 22A	Ebb tide				
11/4/67	0.47	6.8	0.90	0.15	
12/4/67	0.48	7.2	1.14	0.76	
16/6/67	0.29	1.3	0.16	0.01	
30/6/67	0.12	2.0	0.30	0.26	First freshet
11/7/67	0.42	11.7	1.83	0.13	Mud layers near bed >1500 ppm.
19/7/67	0.37	2.7	0.44	0.02	
24/7/67	0.47	17.3	2.54	0.41	Strong W. wind Silt content 1000 ppm near bed.
2/8/67	0.22	0.52	0.06	0.06	
18/8/67	0.42	4.9	0.59	0.75	

Table 2.3.2 Sediment Discharge (3)

Locations 27 and 27A

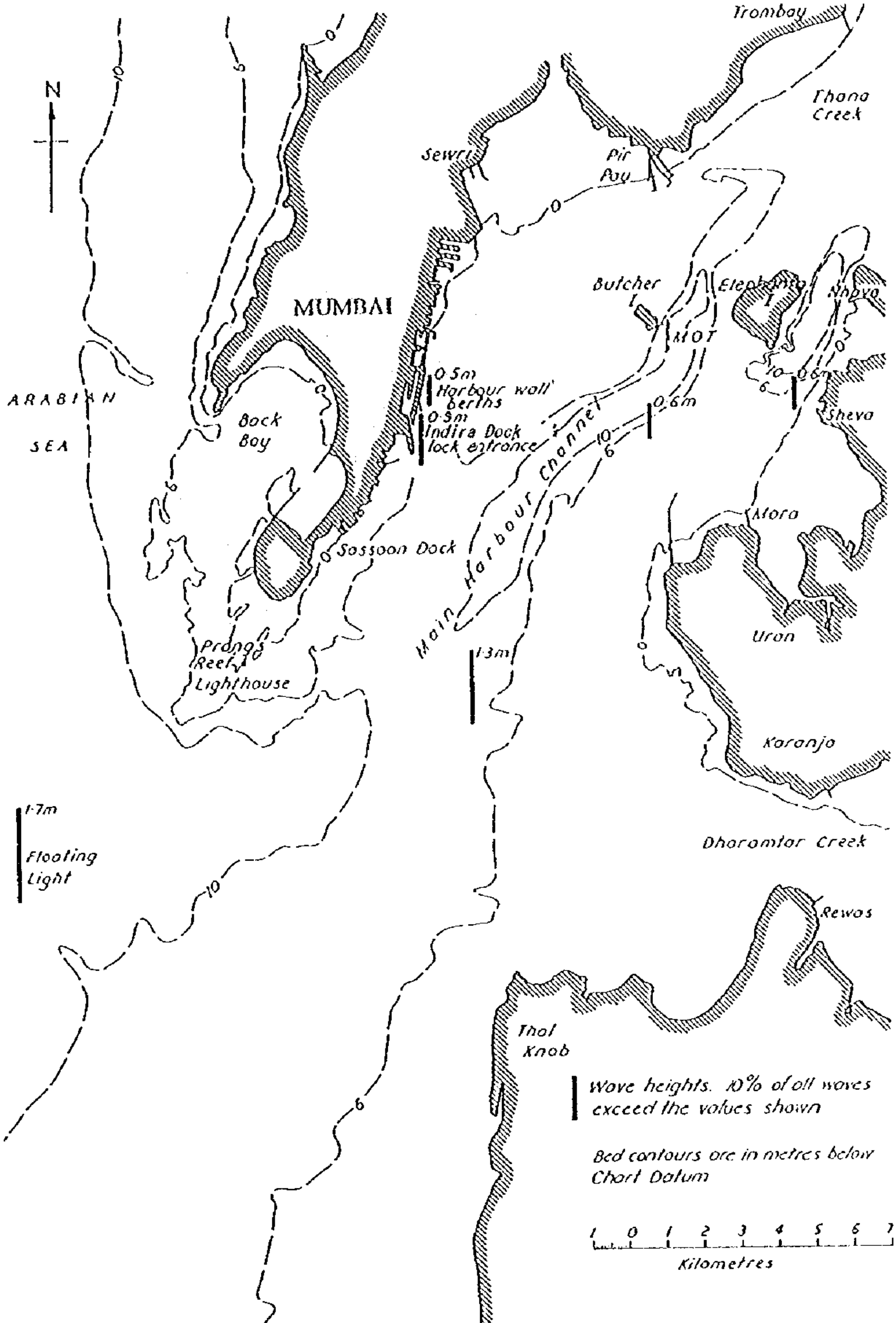
Date	R/D	10^3Kg/m	10^3Kg/m^2	u^2/h	Remarks
Location 27 Flood tide					
30/5/66	0.40	16.1	0.77		
10/6/66	0.27	5.2	0.25		
16/6/66	0.31	3.2	0.16		
23/6/66	0.46	50.0	3.10		
29/6/66	0.29	10.3	0.62		
7/7/66	0.41	22.0	1.55		In 1966 observations with bottle sampler could not be obtained close to the sea-bed and were only at hourly intervals
22/7/66	0.54	71.5	4.45		
Location 27 Ebb tide					
30/5/66	0.38	20.2	0.96		
10/6/66	0.25	6.3	0.30		
23/6/66	0.52	65.0	4.48		
29/6/66	0.34	25.9	1.53		
7/7/66	0.39	14.0	0.92		
22/7/66	0.62	126.0	8.40		
Location 27A Flood tide					
27/4/67	0.70	11.8	0.92	0.83	
28/4/67	0.61	7.1	0.54	0.80	
15/6/67	0.37	24.8	1.92	0.22	High silt content at all depths. S Wind. 1.75 m waves at Prongs Lt. see Fig. D.3.
29/6/67	0.22	7.9	0.63	0.15	
6/7/67	0.26	1.1	0.10	0.16	First freshet.
12/7/67	0.50	23.0	1.63	0.54	High silt charge near bed HW slack.
25/7/67	0.47	14.4	1.11	0.50	
3/8/67	0.19	0.9	0.07	0.075	
23/8/67	0.47	19.9	1.42	0.83	
Location 27A Ebb tide					
27/4/67	0.56	8.1	0.61	0.54	
28/4/67	0.46	4.0	0.29	0.51	
29/6/67	0.38	10.0	0.83	0.58	
6/7/67	0.32	7.2	0.67	0.42	First freshet.
12/7/67	0.50	23.0	1.70	0.50	High silt charges >600 ppm over bottom 12' at HW Slack.
21/7/67	0.47	12.1	1.14	0.53	W wind. See Fig. D.3.
25/7/67	0.48	14.6	1.24	0.29	Strong WSW wind. See Fig. D.3.
3/8/67	0.29	1.4	0.10	0.065	
23/8/67	0.54	22.0	1.54	1.05	W wind. See Fig. D.3.



Instrument	Position 1		Position 2		Position 3		Position 4		Position 5	
	From	To	From	To	From	To	From	To	From	To
Ospos No. 7172	17-6-64	22-10-64			22-10-64	4-12-64				
	20-5-65	10-8-65								
	14-6-66	3-8-66								
	13-8-66	9-9-66	9-9-66	21-9-66						
	16-6-67	17-7-67							22-7-67	8-8-67
	24-8-67	18-9-67								
Ospos No. 7173							18-6-64	3-9-64		
					3-9-64	14-10-64				
	22-10-64	4-12-64								
					21-6-65	9-7-65				
			13-7-65	8-9-65						
			21-6-66	3-8-66						
	3-8-65	23-11-65								
	30-5-67	11-8-67								

SOURCE : B&P MASTER PLAN

Figure 2.3.1 Mumbai Harbour - Location of Wave Recorders



SOURCE : B&P MASTER PLAN

Figure 2.3.2 Mumbai Harbour - Comparative Wave Heights

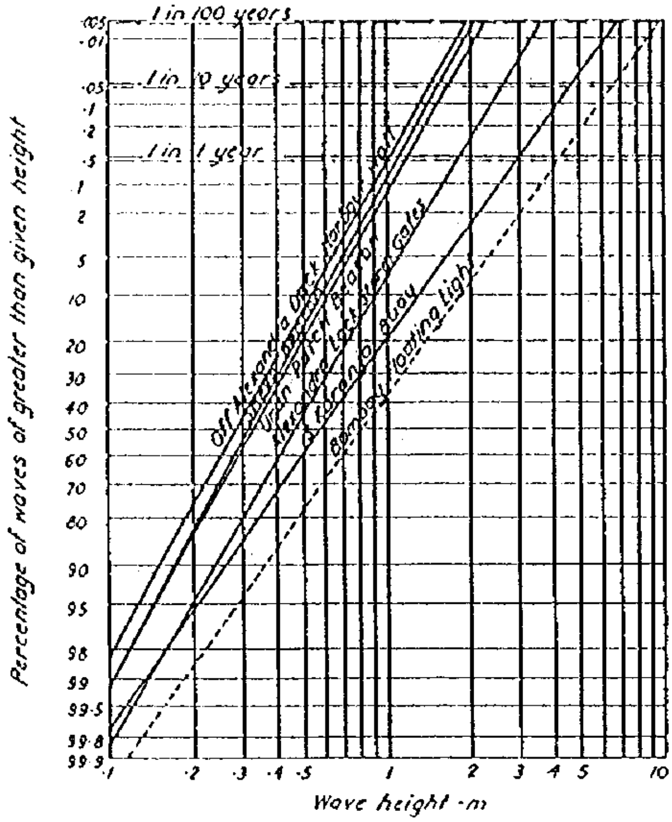
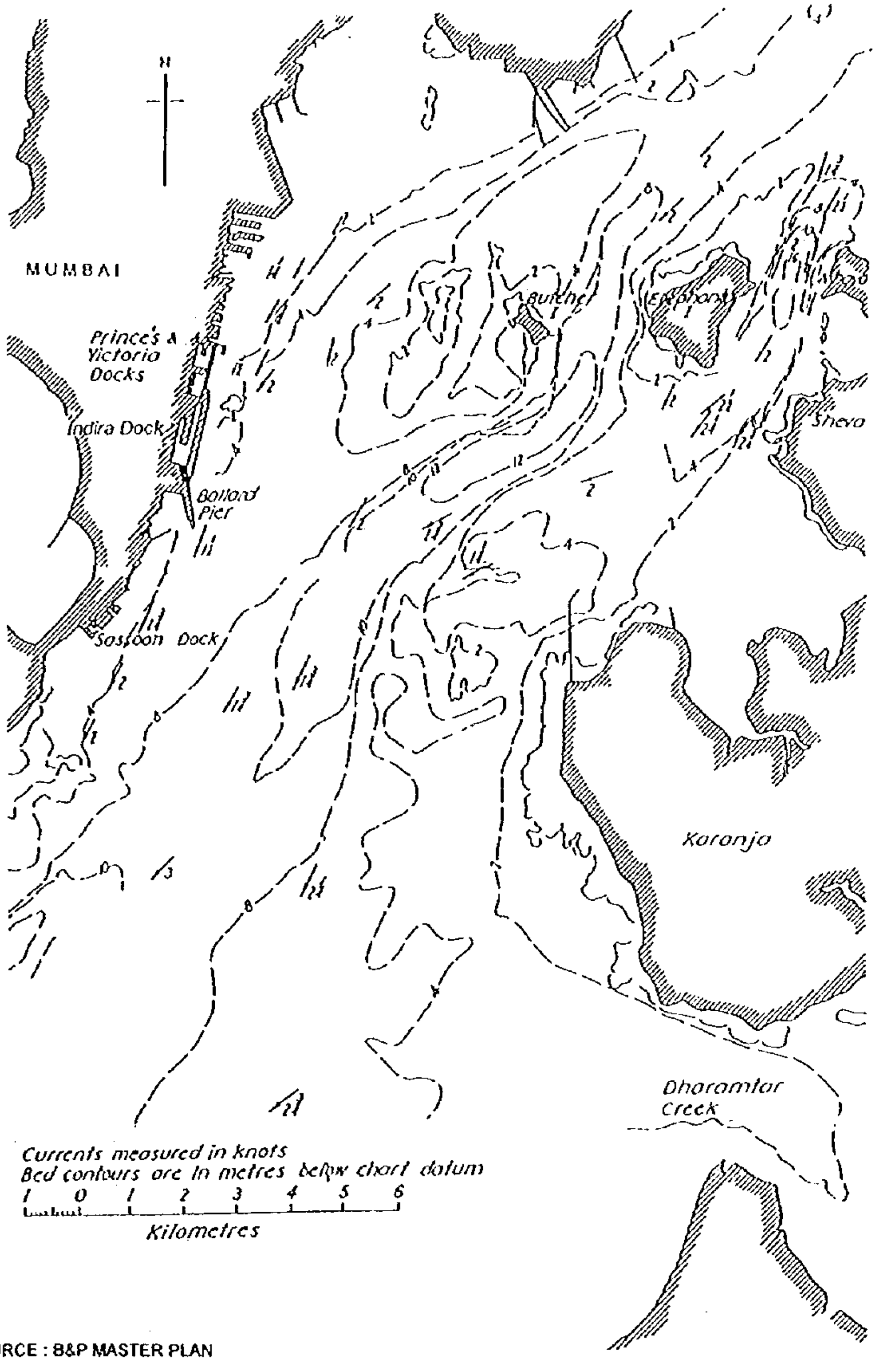
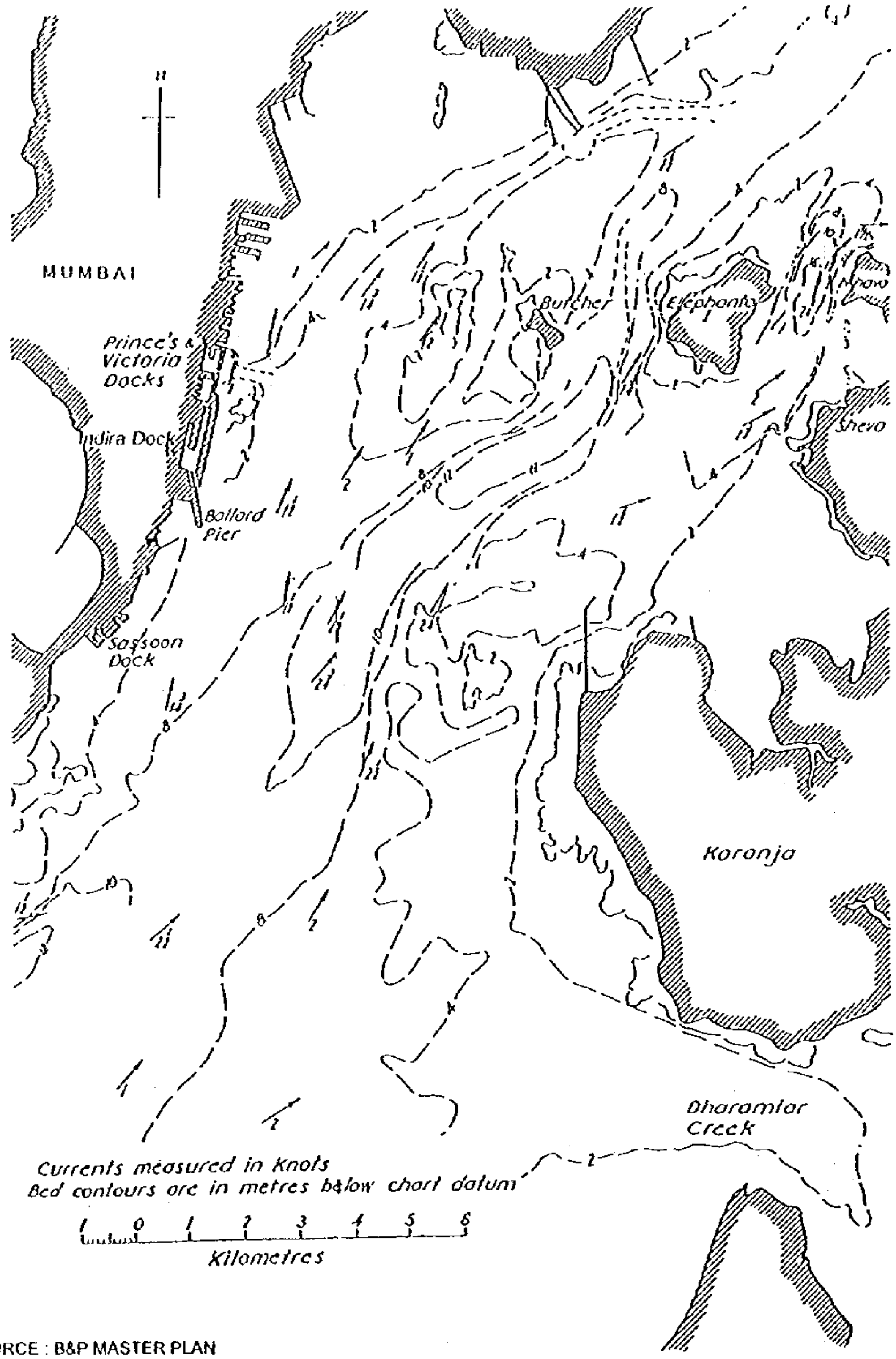


Figure 2.3.3 Wave Height Probabilities



SOURCE : B&P MASTER PLAN

Figure 2.3.4 Mumbai Harbour - Maximum Currents of Ebb Tide



SOURCE : B&P MASTER PLAN

Figure 2.3.5 Mumbai Harbour - Maximum Current of Flood Tide

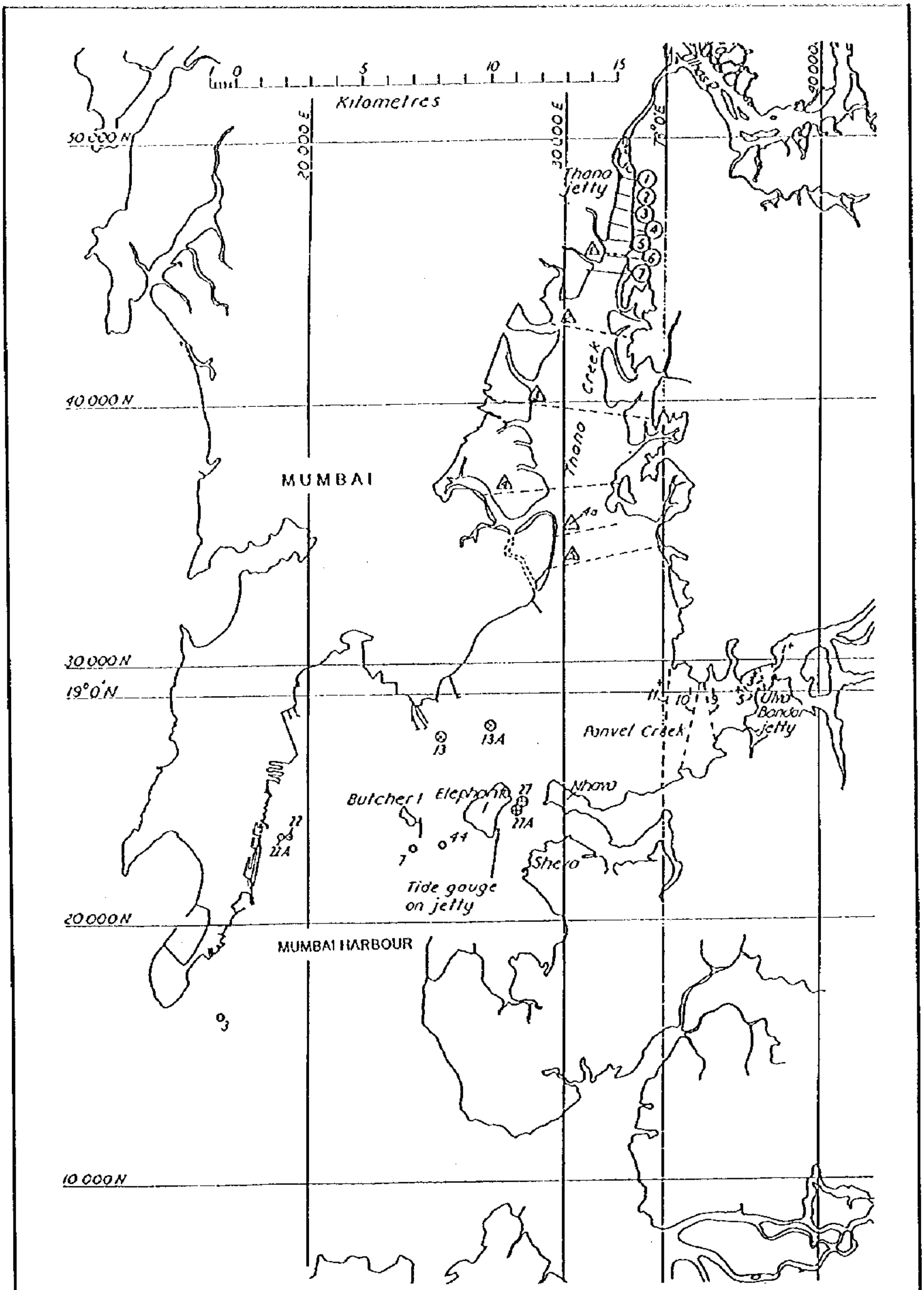


Figure 2.3.6 Location of Siltation Study Observation

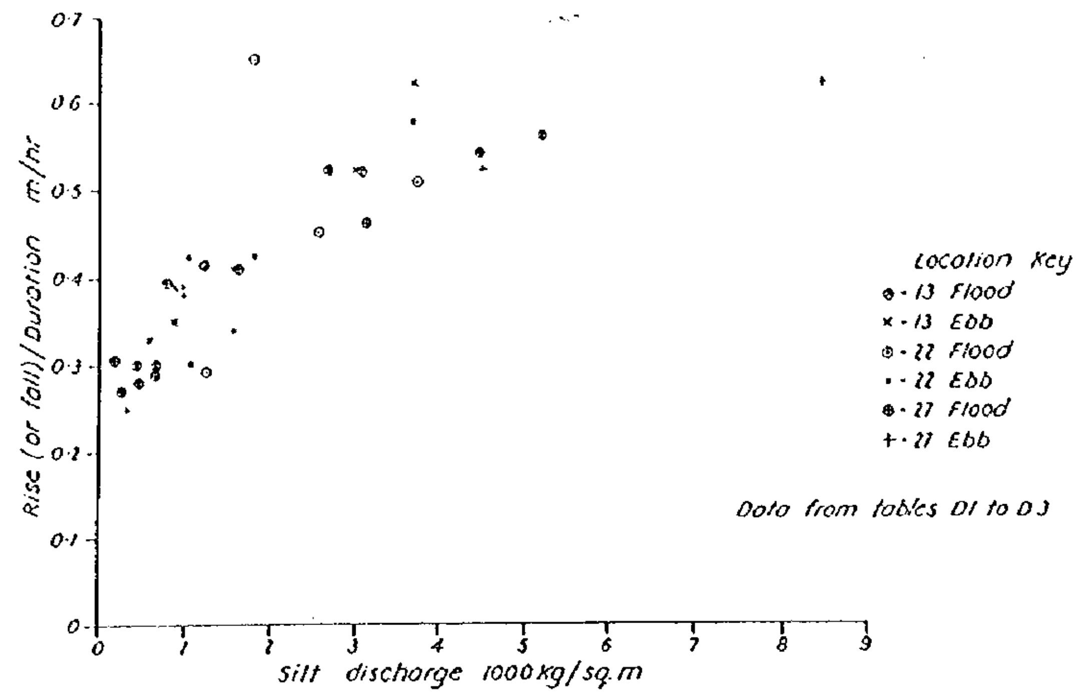


Figure 2.3.7 Variation of Siltation Discharge with Tidal Activity 1966

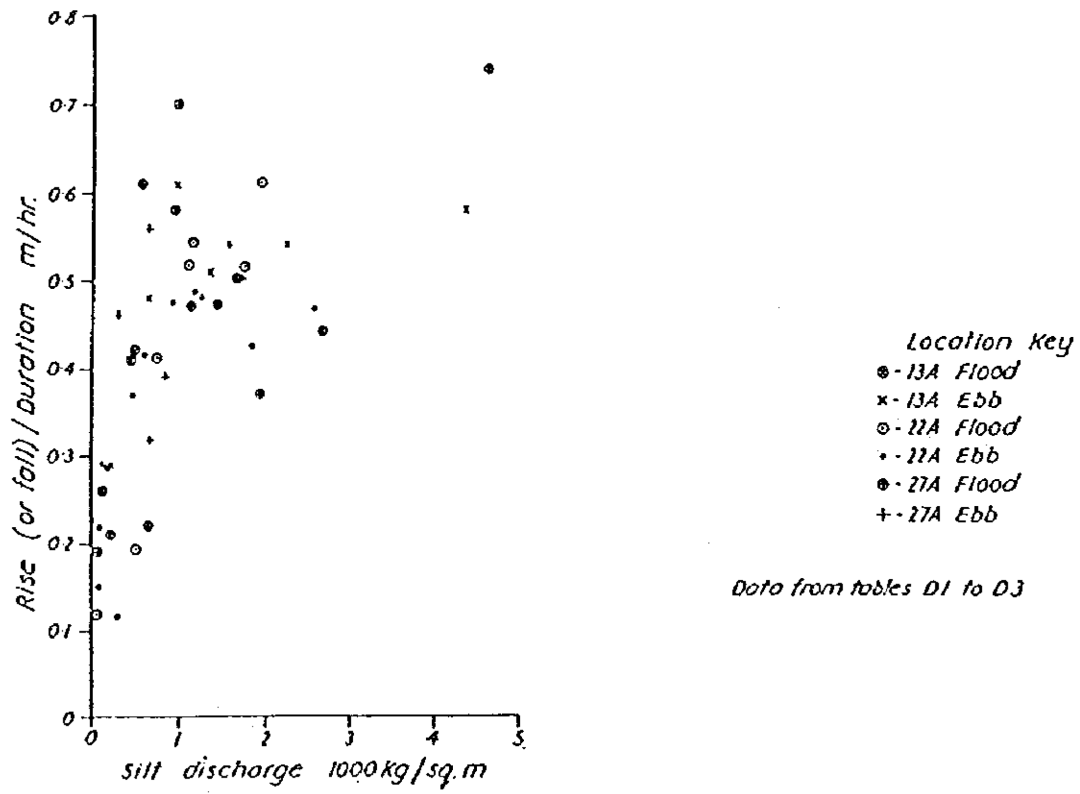


Figure 2.3.8 Variation of Siltation Discharge with Tidal Activity 1967

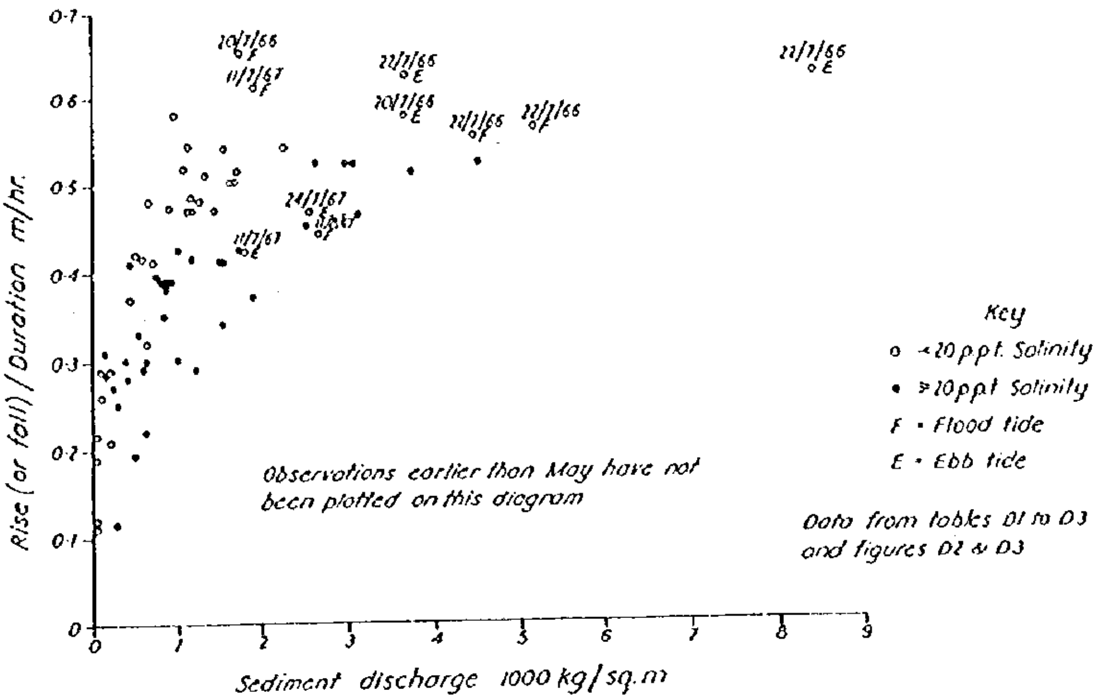


Figure 2.3.9 Sediment Discharge 1966 - 1967 Effect of Salinity

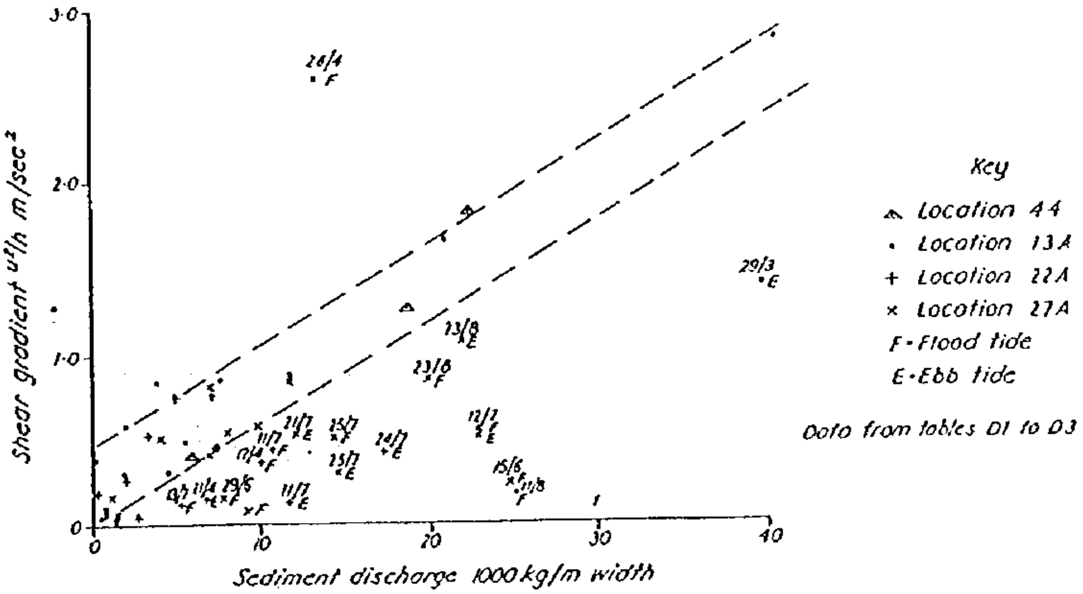


Figure 2.3.10 Variation of Discharge with Shear Gradient 1967

2.4 Field Investigation for Natural Conditions (Phase I)

2.4.1 General

In order to assist in planning / designing of port facilities, certain field investigations related to natural conditions were made during this study. These investigations were made in two phases. Although the nature of investigation was quite similar in both phases, the first phase investigations emphasised to a large extent on siltation aspects and the second phase concentrated more on subsoil information to help in deciding the proposed berth location and dredging requirements. Investigations made in both the phases and further analysis made on respective results are detailed in the following sections.

Field investigations in this phase were aimed to obtain information on the following natural conditions :-

1) Observation of tidal current at five locations distributed within the harbour area.
2) Bathymetric survey in navigable channels of Mumbai harbour and the water-front of outer harbour wall of Indira dock.
3) Sediment sampling of seabed at twenty locations distributed along the channels and analysis of samples collected.
4) Sub-soil investigation on land along Indira dock outer harbour quay.

2.4.2 Observation of Tidal Currents

(1) Outline of Observations

Four in number interocean S4 self-recording current meters and one in number direct reading current meter (DRCM) were deployed from 27th May to 11th June, 1997 to collect the tidal current data at 15 minutes interval for 15 consecutive days. The current meters were moored at location and positioned at 60 % of the available depth above seabed. The location of current meters deployed are indicated in Figure 2.4.1. Current velocity and direction recorded on the interocean S4 current meters were transferred to an IBM compatible computer using a serial interface.

(2) Summary of Data

The summary of observations made on current is given in Table 2.4.1.

Table 2.4.1 Summary of Observation on Current

Location	Coordinates	Water Depth (m)	Maximum Speed (knots)	Minimum Speed (knots)	Pre-dominant Direction
CM-1	N 2088081.268 E 273385.370	9.90	1.90	0.0	030 / 210°
CM-2	N 2091256.890 E 275267.973	10.20	1.60	0.0	040 / 220°
CM-3	N 2094744.008 E 279406.991	5.00	1.00	0.0	055 / 235°
CM-4	N 2093869.891 E 275358.065	7.00	1.80	0.0	040 / 220°
CM-5	N 2094750.043 E 273788.443	5.00	1.65	0.057	015 / 215°

Note : Current measurements were made at all locations from 27th May to 12th June 1997.

(3) Results of observations

a) Velocity and Direction of Current

Observations were carried out at five different locations, namely, CM-1 to CM-5. However, in order to obtain more reliable and consistent results, the observations made from one direct reading current meter was ignored and data collected from only four (4) self - recording current meters ie., at locations CM-1 to CM-4, were used for the purpose of consolidation and analysis.

i) Location CM-1

Frequency of direction and velocity of flow of current are shown in Figure 2.4.2 (1). Predominant directions of current were NNE and SSW. Velocity of flow of current in the range of 20 cm/s to 30 cm/s was dominant and the average velocity of flow was about 46 cm/s during the period of observations.

ii) Location CM-2

Frequency of direction and velocity of flow of current at Location CM-2 are shown in Figure 2.4.2 (2). Predominant directions of current were NE and SW, indicating a slight inclination towards E-W direction in comparison to that observed at location CM-1. Velocity of flow of current ranging from 40 to 50 cm/s was dominant and the average velocity was approximately 40 cm/s. The average velocity of current at this location is slightly less than what was observed at Location CM-1.

iii) Location CM-3.

Frequency of direction and velocity of current at Location CM-3 are shown in Figure 2.4.2(3). Predominant directions of current were ENE and SW, indicating a further inclination towards E-W than that observed at Location CM-2. Values of velocity of flow within a range of 20 cm/s and 30 cm/s were dominant and the average velocity observed during the period of measurements was approximately 20 cm/s, which is much less when compared with those values obtained at locations CM-1 and CM-2.

iv) Location CM-4

Frequency of direction and velocity of flow of current are shown on Figure 2.4.2 (4). Directions of current and velocity of flow as well were in close proximity of those values obtained at Location CM-2.

b) Results of Harmonic Analysis of Current

Harmonic analysis of current was performed by adopting the results of observations made at all the locations for 15 consecutive days. Calculated results of each constituent of tidal current at respective locations are shown in Tables 2.4.2 (1) to (4). Among these results, tidal current ellipses of M_2 component current (semidiurnal M_2 tidal component) that correspond to annual average currents are shown in Figure 2.4.3.

The results of harmonic analysis show that it is M_2 component currents that represents the maximum velocity of flow at each location. The next is S_2 component current, that is, semidiurnal currents are predominant. It is quite evident from the results of observations made that at locations further inside the bay, the current tends to alter its direction toward E-W, resulting in the decrease of velocity of flow.

2.4.3 Sediment Sampling and Analysis

(1) Sediment sampling

A total of Forty seabed sediment samples were collected (two samples at each point) from twenty locations distributed over the main channel, Indira dock channel and P&V channel. Figure

2.4.4 indicates the location of seabed samples collected. Samplings were made using a Veen-Van type grab sampler. Two sets of samples were collected from each location to analyse its characteristic features.

(2) Analysis of sediment samples

The following analysis were carried out on samples :-

a) Grain size analysis.

b) Colour and odour.

c) Mineral composition and settling velocity of sediment for 5 samples.

Table 2.4.3 represents the typical distribution curve of grain size of sediment. Table 2.4.4 details the colour and odour and Table 2.4.5 presents the results of analysis for the mineral composition and settling velocity. Based on the test results on sediment samples, the following conclusions can be drawn :-

1) It appears that the content of silt and clay is almost equal in the respective samples. More than ninety percent (90%) of each sample is a mixture of silt and clay and the remaining sand, implying that a substantial quantity of the sediment can be brought to suspension due to bed currents.

2) The grain size distribution is almost similar in all the samples obtained from different locations. This indicates that either the source of these sediments is the same or the prevailing current pattern is responsible in re-distributing the bed material within the harbour.

3) The dark grey / black colour of sample indicates the presence of marine clay.

2.4.4 Bathymetric Survey

(1) Positioning

The position fixing system employed during the survey was the Differential Global Positioning System (DGPS). The system comprised a fixed reference station with a GPS positioning unit and an UHF data link transmitter station and a mobile GPS positioning unit placed on board the vessel along with a UHF data link receiver.

(2) Survey Configuration

An Atlas Deso 22 Echosounder with an over the side mounted transducer was used to produce the seabed profile along each survey line. The echosounder was operated on dual frequency of 33 KHz and 210 KHz. The speed of the boat during the run along the line was kept constant at 4 Knots and fixes were recorded at 30 sec. intervals.

The survey area measuring about 22 square kilometers, divided in five suitable blocks A,B,C,D, and E was surveyed in grids of 100 meters. The survey results around water area in front of Wet Docks including the Indira dock Approach Channel are presented in Figure 2.4.5. Figure 2.4.6 (1) to (5) gives the sounding results along the Main Channel and other surveyed areas.

(3) Observations

The above survey was carried out just after maintenance dredging operations were completed in the channels. This is quite well reflected in the survey results which indicate the recorded depths almost equal to the original deepened depths. From Figure 2.4.6 (1), it is evident that except for a small stretch in front of outer harbour wall and approach to P&V docks, the rest of the area is quite shallow. Any future development in this area will require considerable capital dredging.

2.4.5 Sub-soil Investigations

(1) General

Previous soil investigation results, provide adequate data to understand the profile of hard strata to the North and South of Indira dock outer harbour wall. However, in order to re-confirm the results of earlier investigations along the outer harbour berths, and to get a better understanding of the profile of hard strata for the entire stretch from Ferry terminal to Ballard pier, two land bore holes were drilled during the first phase of this study. The location of bore holes is shown in Figure 2.4.7. The two boreholes on land were drilled upto 5 meter depth in good bed rock. These two boreholes were expected to give information about the existing bed rock profile as well as the characteristics of imported fill material behind the existing wharf structures and to assess their load bearing strength.

(2) Geotechnical Appraisal

Starting from the pavement / ground level, the following subsurface layers were identified in the two bore holes :-

1) Road pavement of thickness upto 0.7 meter.

2) Red gravely silty sand with occasional boulders.

3) Grey marine clay.

4) Highly Weathered basalt.

5) Moderately weathered to fresh basalt.

The stratification of area investigated as revealed by the soil borings is given in Table 2.4.6.

Table 2.4.6 Stratification of Area Surveyed

Stratum	N - Value	Thickness	Characterstics
Gravelly Silty Sand	11 To 40	9. 5 m	This strata is just below the road formation with Boulders and contains imported soil made up from a mixture of gravel, sand, silt and boulders.
Grey Marine Clay	No SPT	0. 5 m	This strata is observed in 2 layers at different depths in BH-1. In both the bore holes, it is observed that this layer is partly mixed with the soil layer above it.
Highly Weathered Basalt	Refusal	BH1 - 1.5m BH2 - 0.5m	This layer comprises of very weak rock with lot of fracture. The compressive strength is low due to high degree of weathering.
Moderately Weathered to fresh Basalt	--	--	In this layer, rock is moderately weathered and weak upto -16.25m. Below this is fresh Basalt and the rock strength increases.

Bore logs along with feature of each stratum are shown in Figure 2.4.8. The first layer ie.,road formation with a thickness of 0.7m is of heterogeneous material consisting of sub-base and soling, topped with asphalt. The second layer, about 9.5m thick is made up of silty sand and boulders which had probably been used for reclamation of the area. SPT values in this strata range between 11 to 40, with the lower values indicating loose to dense sand. The third layer consisting of grey marine clay with a shallow thickness of about 0.5m thick is immediately followed by highly weathered Basalt. This highly weathered Basalt layer is very weak, with a compressive strength of only 24 Kg/cm^2. The final layer of the two bore holes consists of moderately weathered to fresh Basalt with the compressive strengths varying from 26 to 76 Kg/cm^2 initially and increasing with depth to 203 and 507 Kg/cm^2 at bore hole BH-1 and BH-2 respectively.

Information available from earlier bore logs was utilised in plotting the rock profile starting from the Passenger jetty located north of these two bore holes to the Ballard pier at the south. The interpolated rock profile for this entire length along the outer harbour wall is indicated in Figure 2.4.9. As can be seen in Figure 2.4.9, the moderately weathered Basalt rock layer varies from a shallow depth of - 4.10m CD at Passenger jetty (F3) to - 17.87m CD at Ballard pier (B15).

(3) Soil Testing & Analysis

An analysis of SPT samples obtained from the second and third layer in the two bore holes was reported as Poorly graded sand (SP) and highly plastic clay (CH) respectively. The constituents of these soil samples are detailed in Table 2.4.7.

Table 2.4.7 Constituents of Soil in Bore Holes

Soil Constituents	Second Layer (in %)	Third Layer (in %)
Gravel	10 To 32	0
Sand	49 To 75	24
Silt	)	37
	) 14 To 20	
Clay	)	39

The percentage of sand and gravel is more when compared to silt and clay in the second layer due to the fact that it is basically fill material and hence containing a mixture of different soil. The third layer contains a large amount of marine clay and silt. But since this layer is made up of soft clay and is of very shallow depth, it has partly got mixed with the fill material over it.

The soil strata encountered in the two bore holes were unsuitable for collecting undisturbed samples and hence shear strength parameters of the soil, such as, cohesion and angle of internal friction could not be obtained in the laboratory.

Table 2.4.2 (1) Harmonic Analysis of Tidal Current

LOCATION C - 1

PERIOD OF OBSERVATION : 00:00hrs 28 May - 00:00hrs 12 June 1997

Constituents Name	N - Component		E - Component	
	Velocity (cm/s)	Phase Lag (g°)	Velocity (cm/s)	Phase Lag (g°)
MSf	1.1	170.6	1.0	294.1
O_1	3.5	328.9	2.1	345.4
K_1	11.5	327.2	6.9	327.4
M_2	55.3	275.8	32.7	264.8
S_2	14.3	297.7	9.7	288.0
M_3	1.3	19.9	1.4	356.2
SK_3	2.1	150.2	1.3	150.6
M_4	0.6	243.3	3.4	311.3
MS_4	1.9	47.5	2.6	353.7
S_4	0.4	96.3	0.5	50.4
$2MK_5$	1.2	354.4	2.0	318.9
$2Sk_5$	0.7	224.8	0.4	187.3
M_6	0.7	265.6	1.8	261.1
$2MS_6$	1.9	265.9	1.9	271.2
$2SM_6$	0.5	268.1	0.6	285.9
$3MK_7$	0.7	242.5	0.3	105.7
M_8	0.4	42.4	0.7	348.7
A0	-0. 8		-0.5	

Table 2.4.2 (2) Harmonic Analysis of Tidal Current

LOCATION C - 2

PERIOD OF OBSERVATION : 00:00hrs 28 May - 00:00hrs 12 June 1997

Constituents Name	N - Component		E - Component	
	Velocity (cm/s)	Phase Lag (g °)	Velocity (cm/s)	Phase Lag (g °)
MSf	0.6	69.3	1.1	191.8
O_1	3.9	325.4	3.5	349.8
K_1	7.4	327.0	6.9	312.2
M_2	41.0	268.2	34.7	275.0
S_2	11.4	293.2	10.4	294.0
M_3	2.5	330.9	0.3	299.6
SK_3	1.6	180.8	2.0	166.6
M_4	4.9	294.2	1.4	251.6
MS_4	2.6	338.3	1.8	33.7
S_4	0.5	314.7	0.3	94.7
$2MK_5$	1.7	348.4	0.4	347.2
$2SK_5$	0.7	211.5	0.7	209.6
M_6	1.7	247.6	0.6	224.7
$2MS_6$	2.1	286.8	1.5	259.1
$2SM_6$	0.4	322.6	0.5	152.1
$3MK_7$	0.7	166.4	1.1	231.4
M_8	0.4	28.3	0.7	86.8
A0	3.6		-2.3	

Table 2.4.2 (3) Harmonic Analysis of Tidal Current

LOCATION C - 3

PERIOD OF OBSERVATION : 00:00hrs 28 May - 00:00hrs 12 June 1997

Constituents Name	N - Component		E - Component	
	Velocity (cm/s)	Phase Lag (g °)	Velocity (cm/s)	Phase Lag (g °)
MSf	1.9	239.7	0.5	59.2
O_1	1.0	37.3	1.7	356.4
K_1	2.6	314.0	4.5	321.8
M_2	17.0	254.0	24.5	267.8
S_2	4.9	292.1	6.6	297.7
M_3	1.0	340.3	0.6	26.1
SK_3	0.9	152.3	1.3	154.6
M_4	0.6	35.7	1.6	59.6
MS_4	1.2	26.9	2.4	56.7
S_4	0.3	231.2	0.2	209.5
$2MK_5$	1.7	279.7	0.7	293.2
$2Sk_5$	0.5	195.6	0.4	197.2
M_6	1.9	235.3	0.7	254.3
$2MS_6$	1.7	256.4	1.0	274.6
$2SM_6$	0.4	48.8	0.0	50.1
$3MK_7$	0.2	293.4	0.6	215.5
M_8	0.4	102.8	0.4	113.6
A0	-2.4		-0.8	

Table 2.4.2 (4) Harmonic Analysis of Tidal Current

LOCATION C - 4

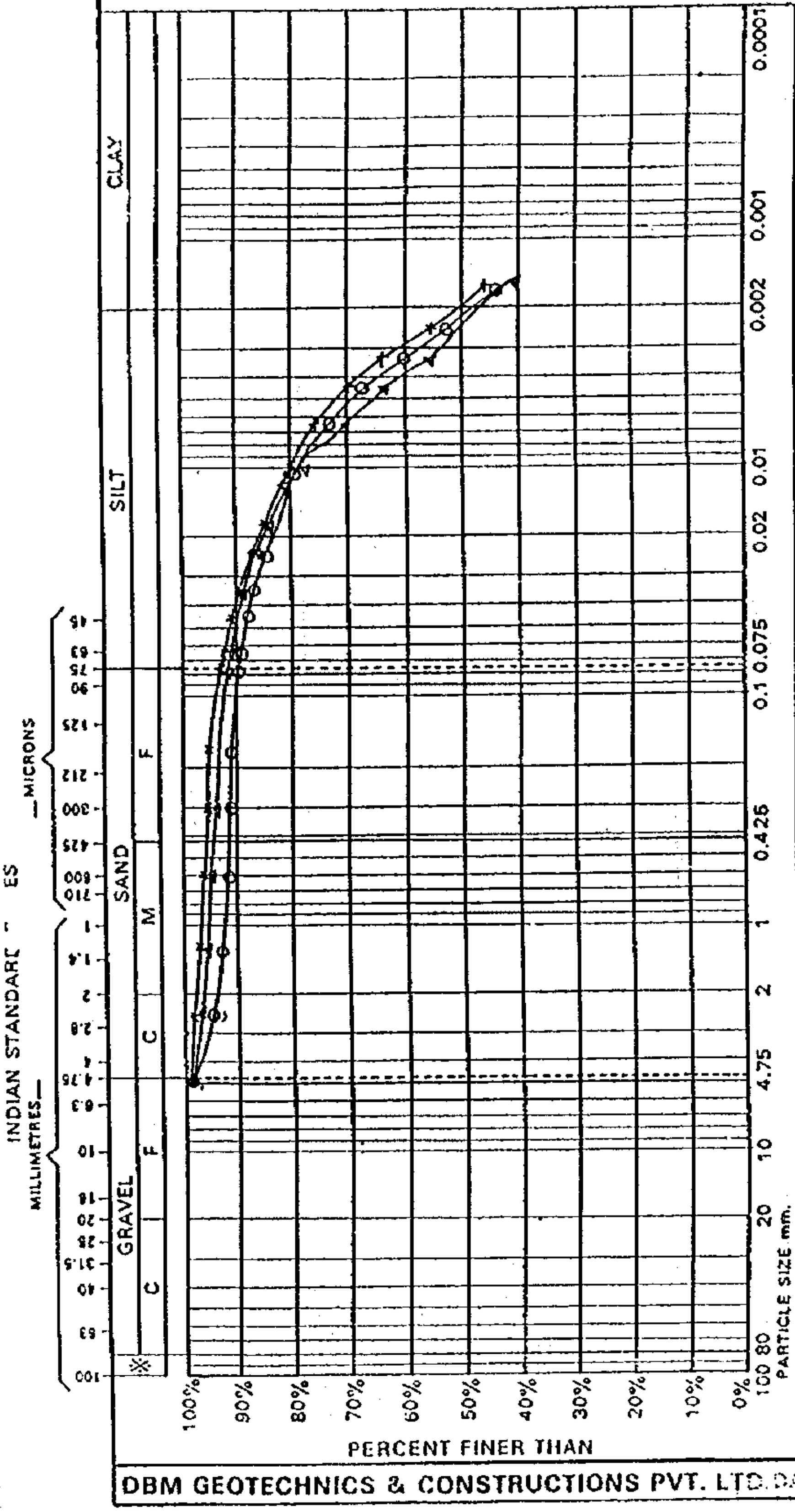
PERIOD OF OBSERVATION : 00:00hrs 28 May - 00:00hrs 12 June 1997

Constituents Name	N - Component		E - Component	
	Velocity (cm/s)	Phase Lag (g °)	Velocity (cm/s)	Phase Lag (g °)
MSf	0.7	69.3	1.2	191.8
O_1	4.1	325.4	3.7	349.9
K_1	7.8	327.0	7.3	312.2
M_2	43.5	268.2	36.8	272.0
S_2	12.1	293.2	11.1	294.0
M_3	2.6	330.8	0.3	299.3
SK_3	1.7	180.7	2.1	166.6
M_4	5.2	294.2	1.3	251.7
MS_4	2.7	338.3	1.9	33.7
S_4	0.5	314.7	0.3	94.6
$2MK_3$	1.8	348.4	0.4	347.4
$2Sk_3$	0.7	211.2	0.7	209.8
M_6	1.8	247.5	0.6	225.1
$2MS_6$	2.2	286.8	1.6	259.1
$2SM_6$	0.4	322.6	0.5	151.9
$3MK_7$	0.7	166.6	1.1	231.4
M_8	0.4	28.3	0.7	86.6
A0	3.9		-2.4	

Table 2.4.3 Distribution Curve of Grain Size of Sediment

SITE: ELCOME / JICA B.P.T.

GRAIN SIZE DISTRIBUTION



Symbol	LOCATION No.	Depth in Metre	Classification (I.S.)	* Cobble %	Grav. %	Sand %	Silt %	Clay %	φ 10% mm.	φ 30% mm.	φ 60% mm.	Cu	Cc	Remarks
o—o	17A	-	—		00	10	41	49	-	-	-	-	-	D
x—x	18A	-	—		0C	06	44	50	-	-	-	-	-	D
+—+	19A	-	—		00	06	45	49	-	-	-	-	-	D

DBM GEOTECHNICS & CONSTRUCTIONS PVT. LTD. DATE: DRG. NO.: L-75

Table 2.4.4 Colour and Odour of Sediment

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- DRILLING & GROUTING
- SOIL MECH. LABORATORY
- MICRO PILES

DBM

6, Coutinho House, Behind Roop Talkies, Santacruz (E), Bombay - 400 055.
Tel.: 6113121, [redacted], 6103945 Fax: 91-22-6104733 Telex: 011-78259
E. mail: [illegible]
Internet: http:// [illegible]

Lab/8160/95/Elcome

Date : 09/6/97

CERTIFICATE OF ANALYSIS

Client : M/S Elcome Surveys

Sample : Soil

Marks : –

Site : JICA, BPT.

<u>RESULTS OF ANALYSIS</u>

Sample	Colour	Odour	Sample	Colour	Odour
1 A	Black gray	Organic	2 A	Black	Muddy
3 A	Black	Organic	4 A	Black gray	Fishy
5 A	Black	Fishy	6 A	Dark gray	Muddy
7 A	Black gray	Organic	8 A	Dark Black	Fishy
9 A	Gray	Fishy	11 A	Black	Fishy
12 A	Dark gray	Muddy	13 A	Black Gray	Muddy
14 A	Dark gray	Fishy	15 A	Dark gray	Fishy
16 A	Black gray	Fishy	17 A	Dark gray	Fishy
18 A	Gray	Muddy	19 A	Black gray	Fishy
20 A	Dark Gray	Fishy			

Analysed By : [signature]

Table 2.4.5 Mineral Composition and Settling Velocity of Sediment

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Tel.: 6113121, [redacted], 6103945 Fax: 91-22-6104733 Telex: 011-78259
E. mail: [illegible]
Internet:- http: // www.dbmgeotech. com

Lab/8158/94/Elcome

Date : 09/6/97

CERTIFICATE OF ANALYSIS

Client : M/S Elcome Surveys

Sample : Soil

Marks : -

Site : JICA, BPT.

<u>RESULTS OF ANALYSIS</u>	7A	9A	11A	16A	19A
<u>Minerals</u>					
Calcium	4.41 %	2.00 %	2.40 %	1.64 %	2.39 %
Magnesium	2.70 %	1.25 %	1.30 %	1.06 %	1.40 %
Sodium	12.50 %	4.86 %	5.48 %	6.25 %	6.98 %
Potassium	1.00 %	0.90 %	1.20 %	1.34 %	1.28 %

	7A	9A	11A	16A	19A
Setting Velosity of Sediments	90%/Sec	92%/Sec	93%/Sec	91%/Sec	92%/Sec
	08%/4Sec	06%/5Sec	05%/3Sec	5%/2Sec	06%/2Sec
	02%/4Min	02%/4.2Min	02%/3Min	03%/4Min	02%/4.2Min

Analysed By : *(signature)*

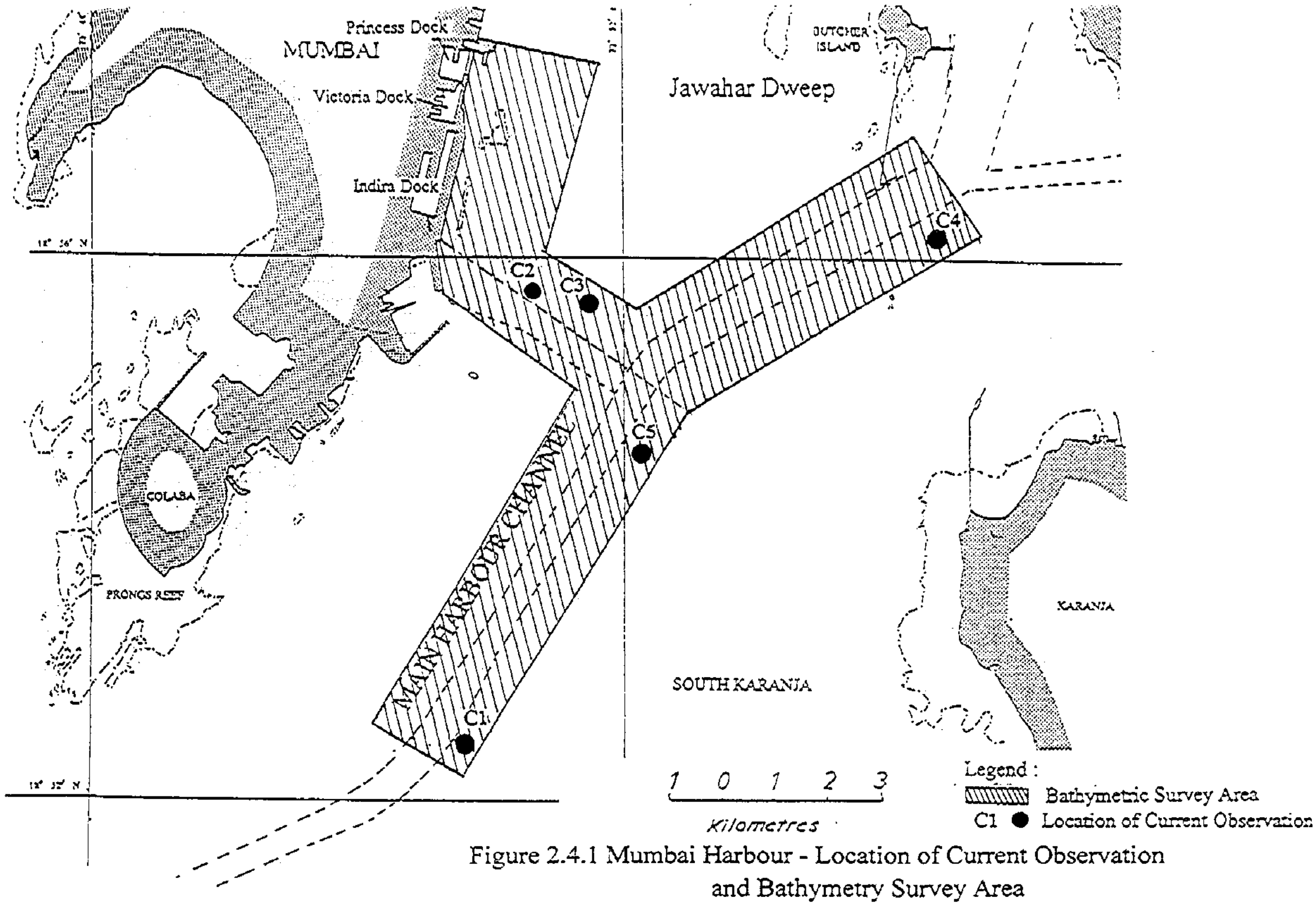


Figure 2.4.1 Mumbai Harbour - Location of Current Observation and Bathymetry Survey Area

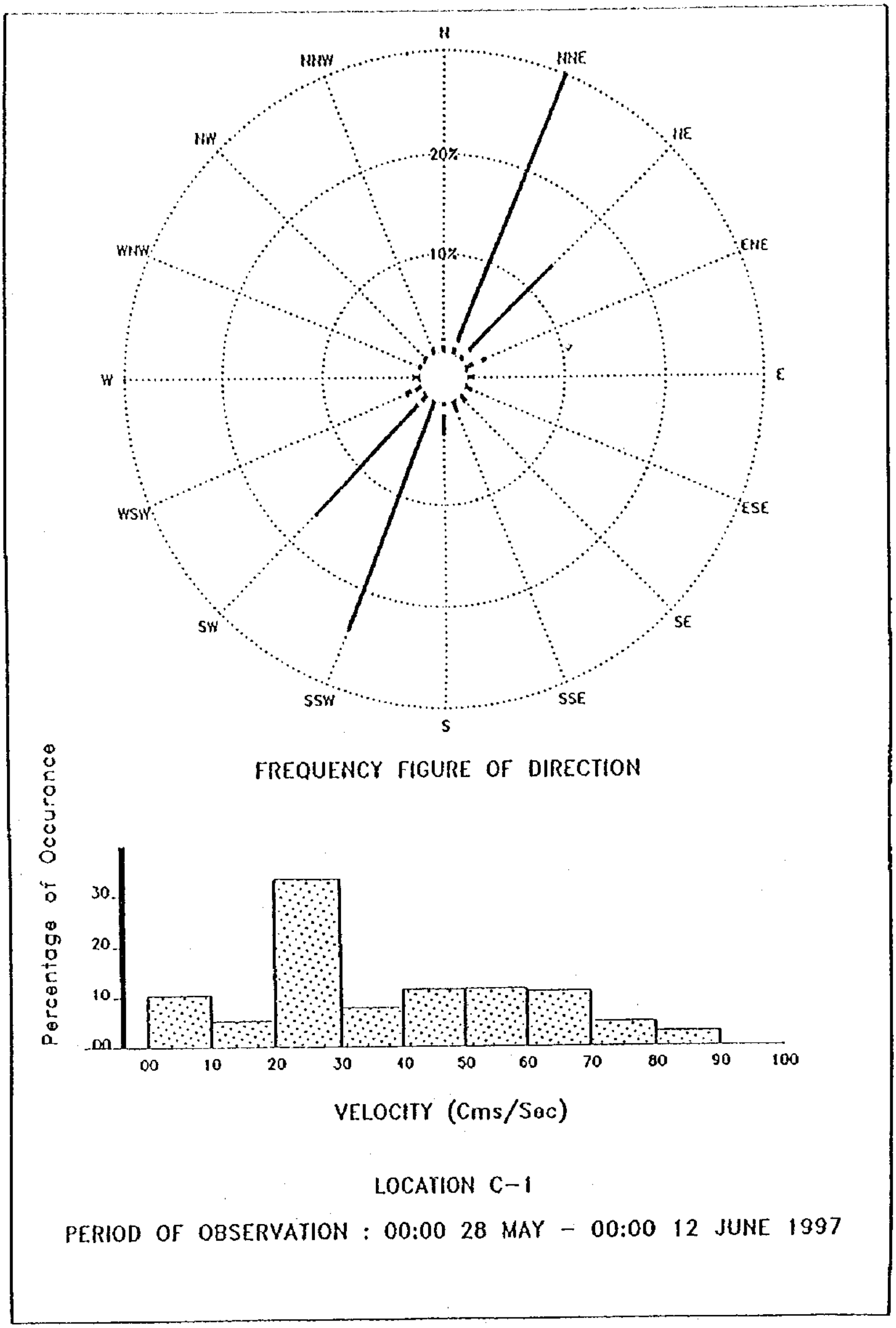


Figure 2.4.2 (1) Frequency of Direction and Velocity of Flow of Current

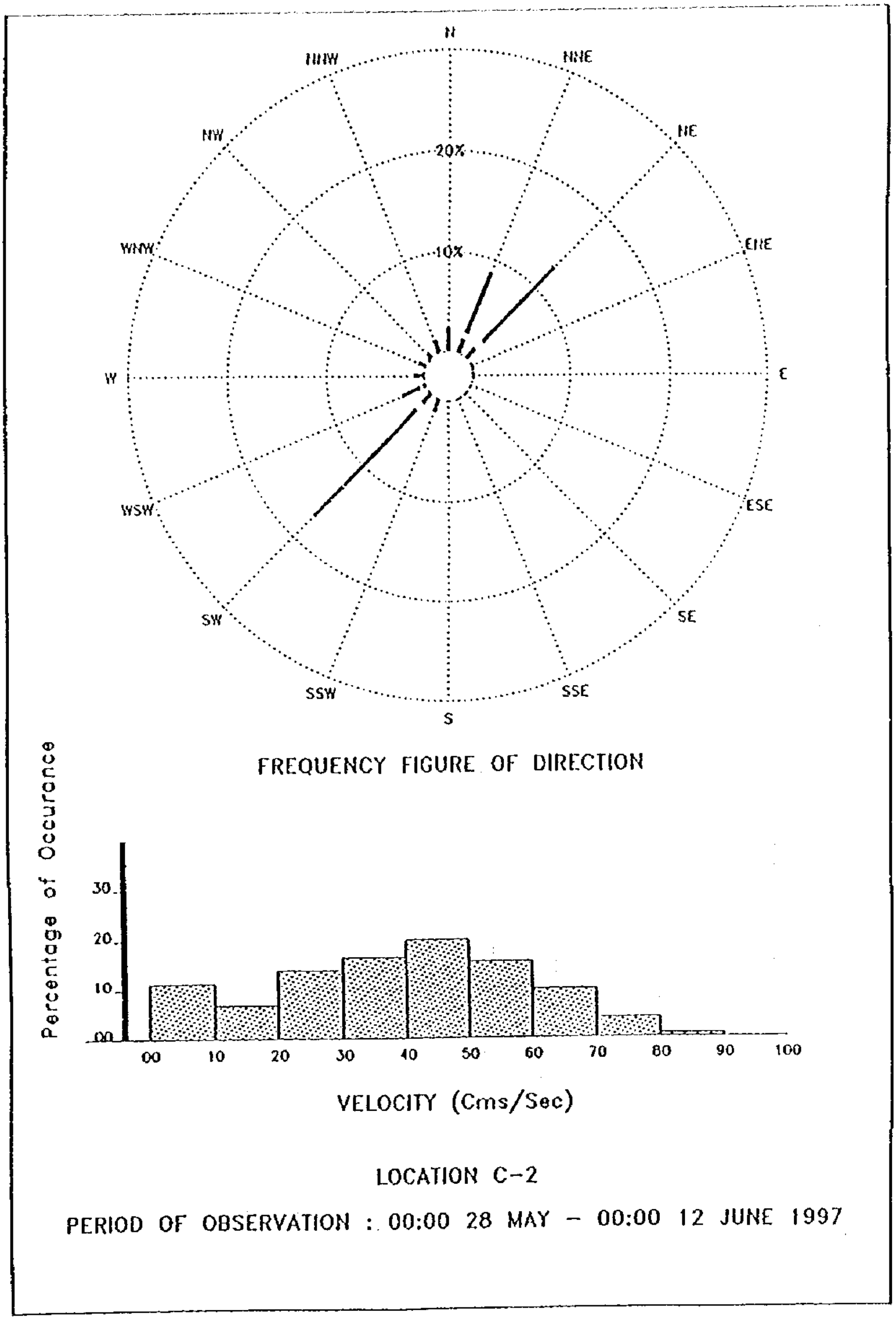


Figure 2.4.2 (2) Frequency of Direction and Velocity of Flow of Current

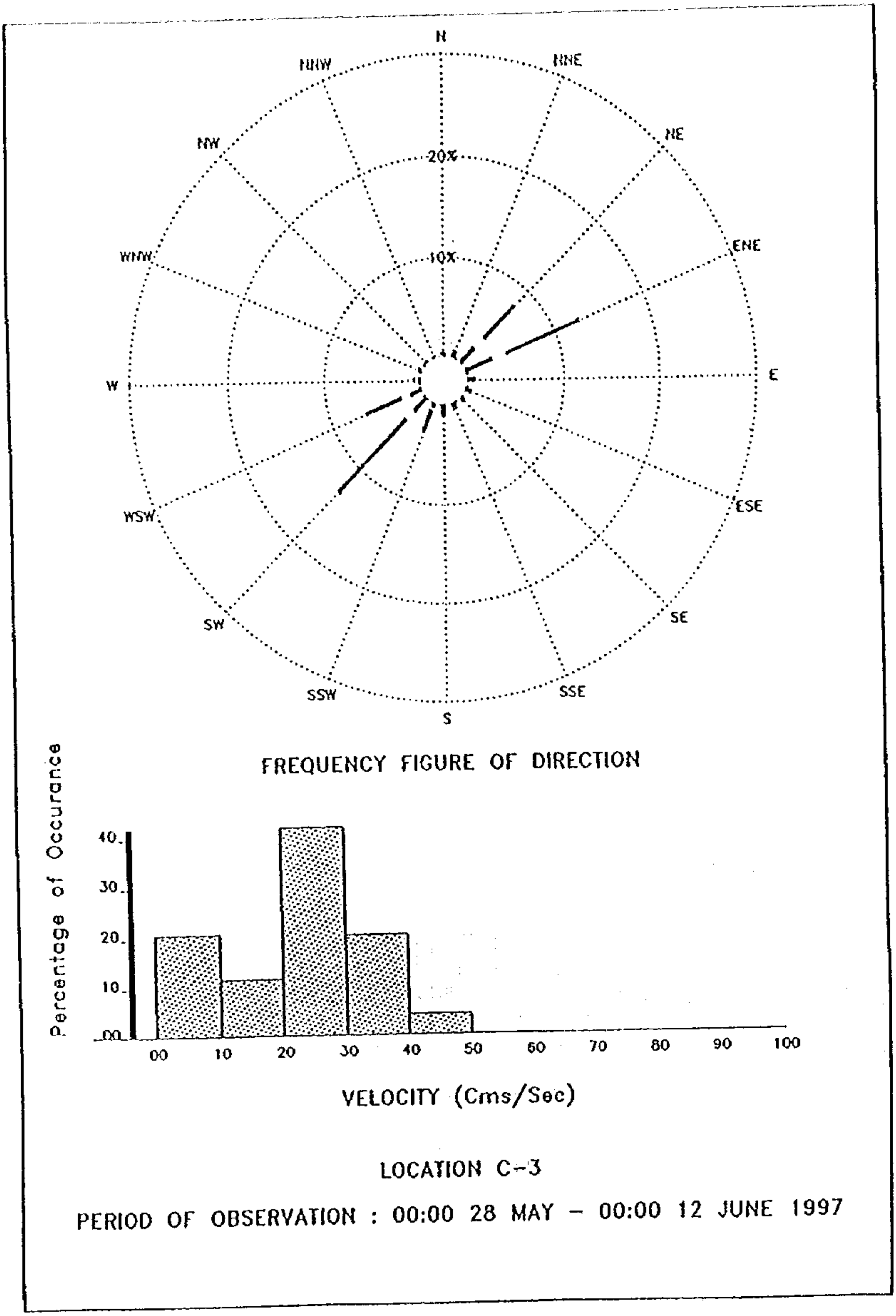


Figure 2.4.2 (3) Frequency of Direction and Velocity of Flow of Current

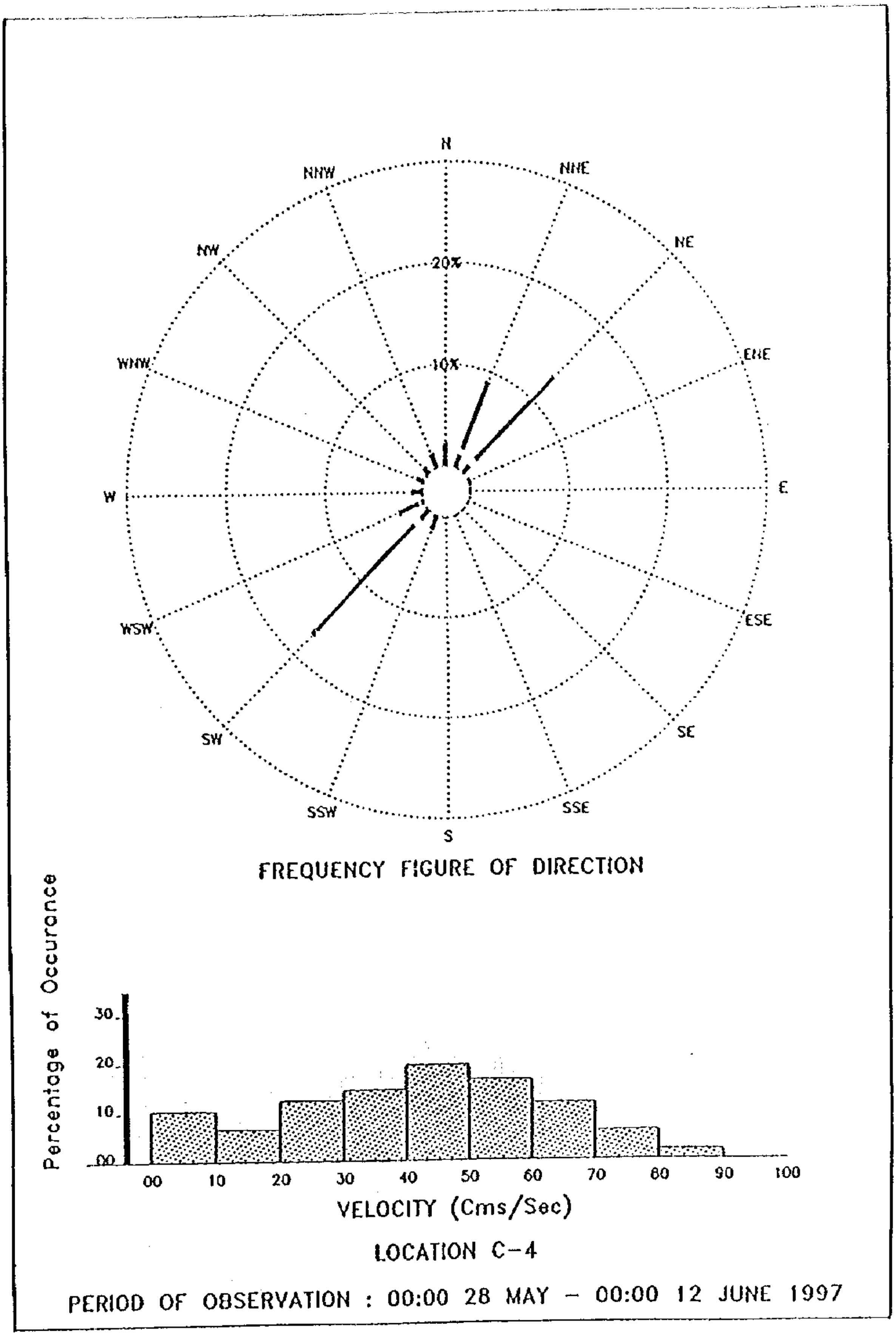


Figure 2.4.2 (4) Frequency of Direction and Velocity of Flow of Current

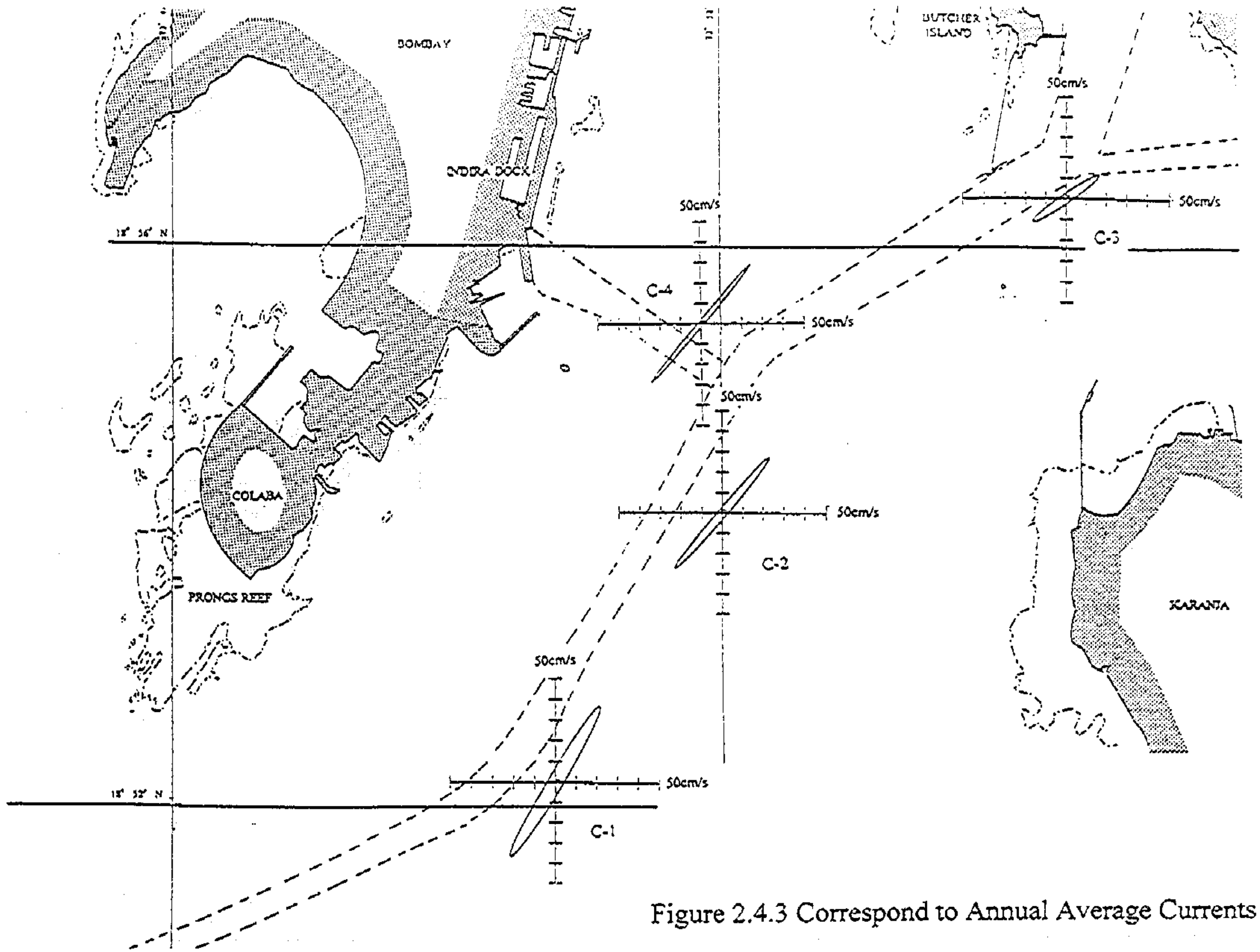


Figure 2.4.3 Correspond to Annual Average Currents

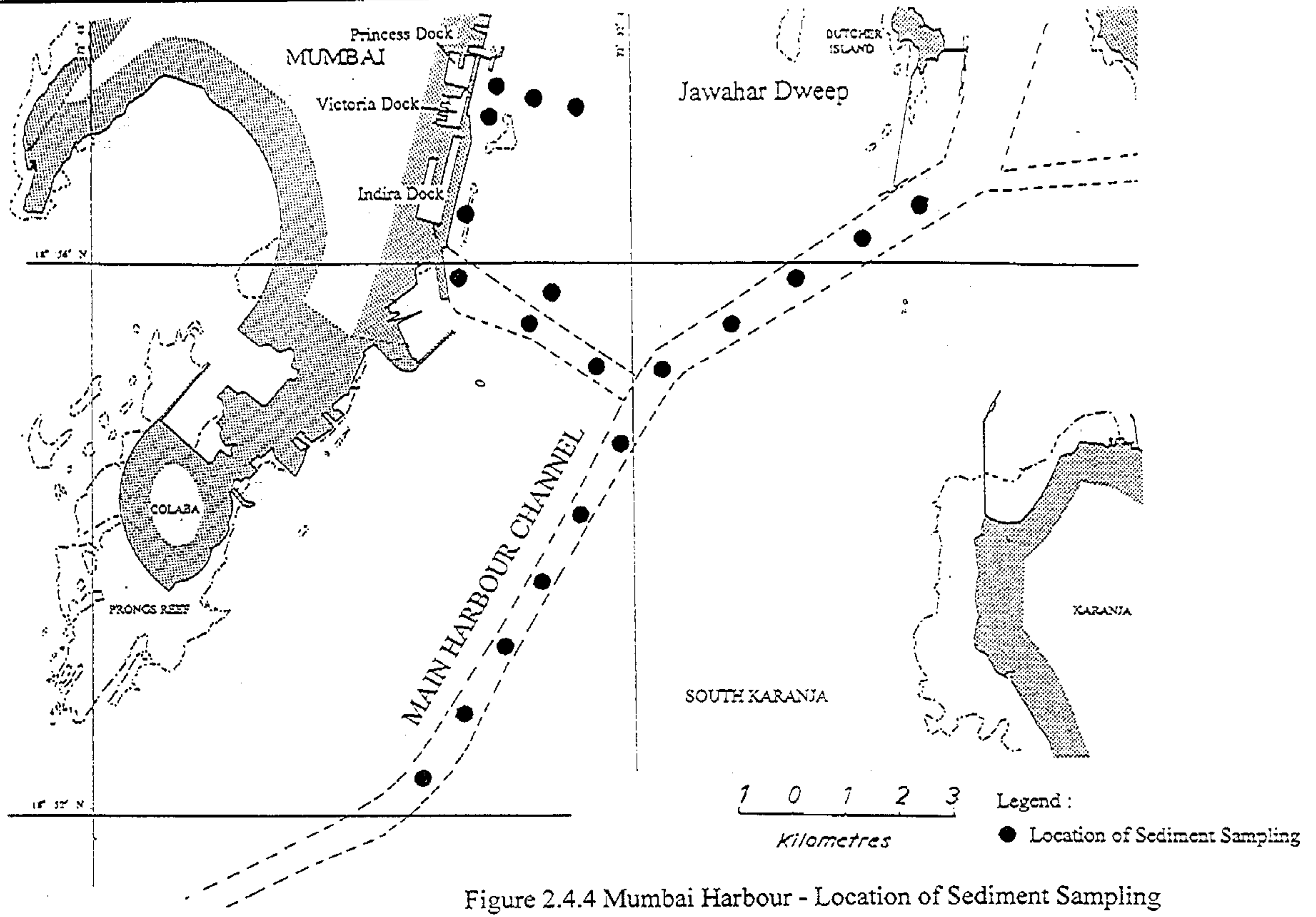


Figure 2.4.4 Mumbai Harbour - Location of Sediment Sampling

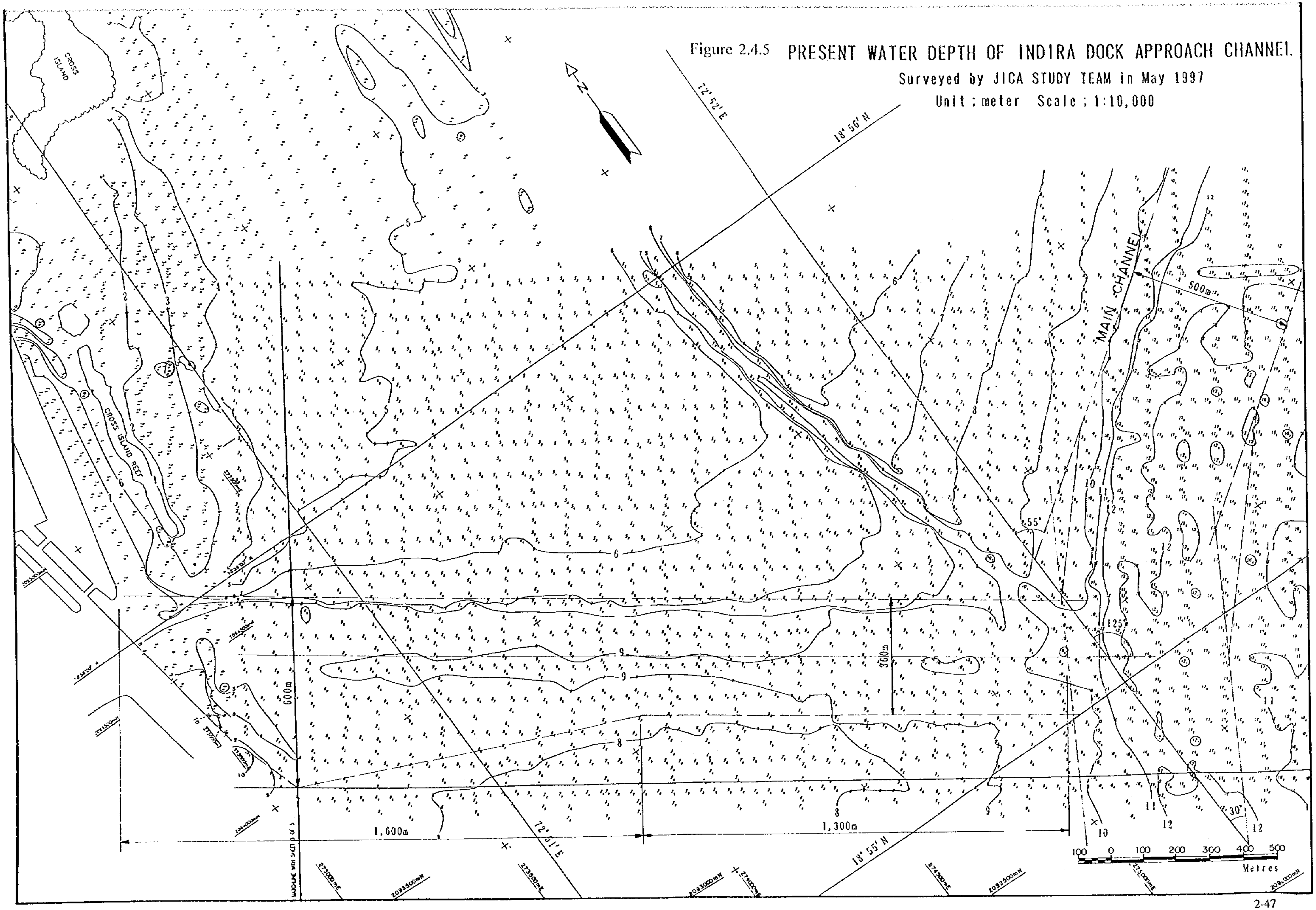


Figure 2.4.5 PRESENT WATER DEPTH OF INDIRA DOCK APPROACH CHANNEL

Surveyed by JICA STUDY TEAM in May 1997

Unit : meter Scale ; 1:10,000

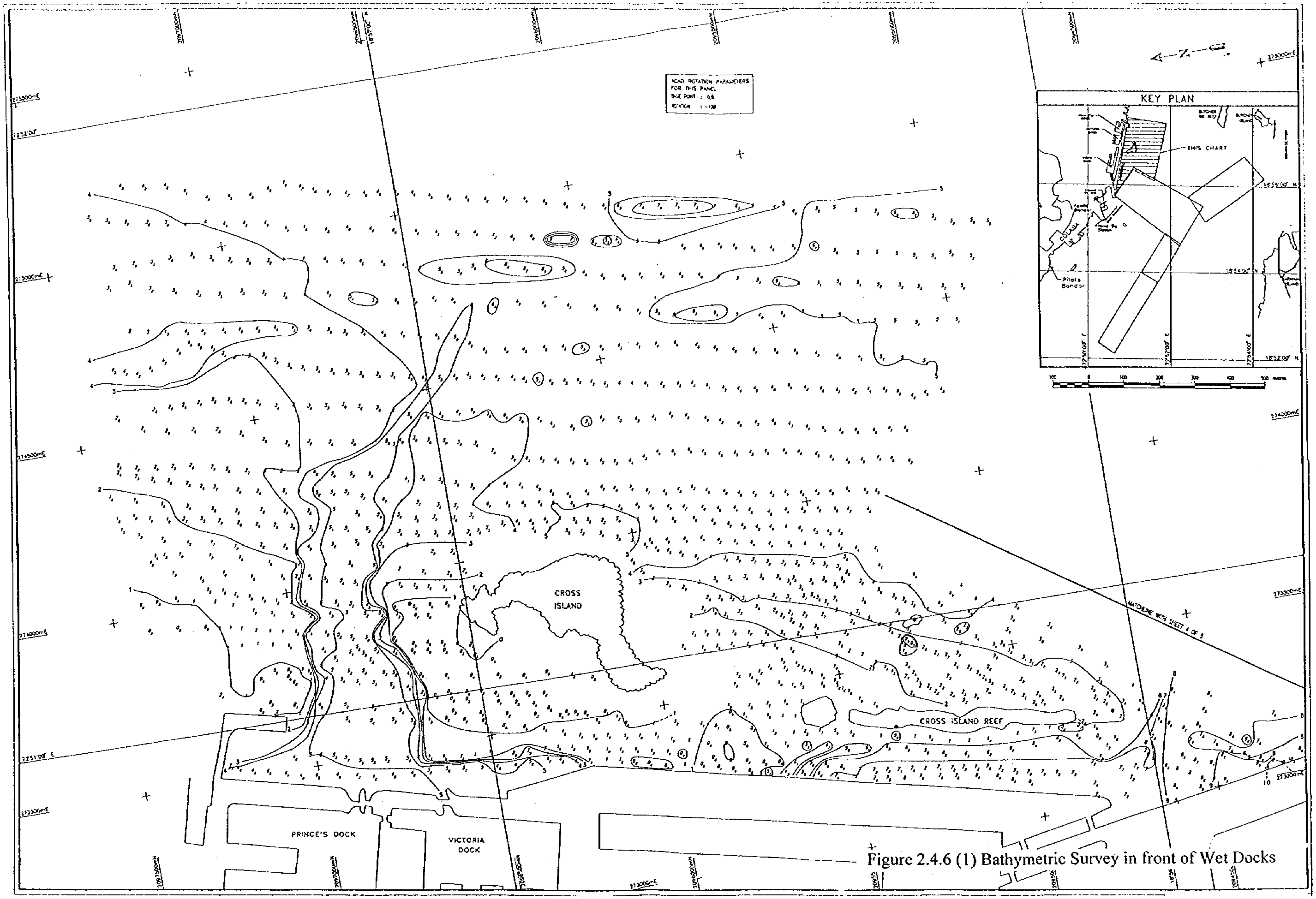


Figure 2.4.6 (1) Bathymetric Survey in front of Wet Docks

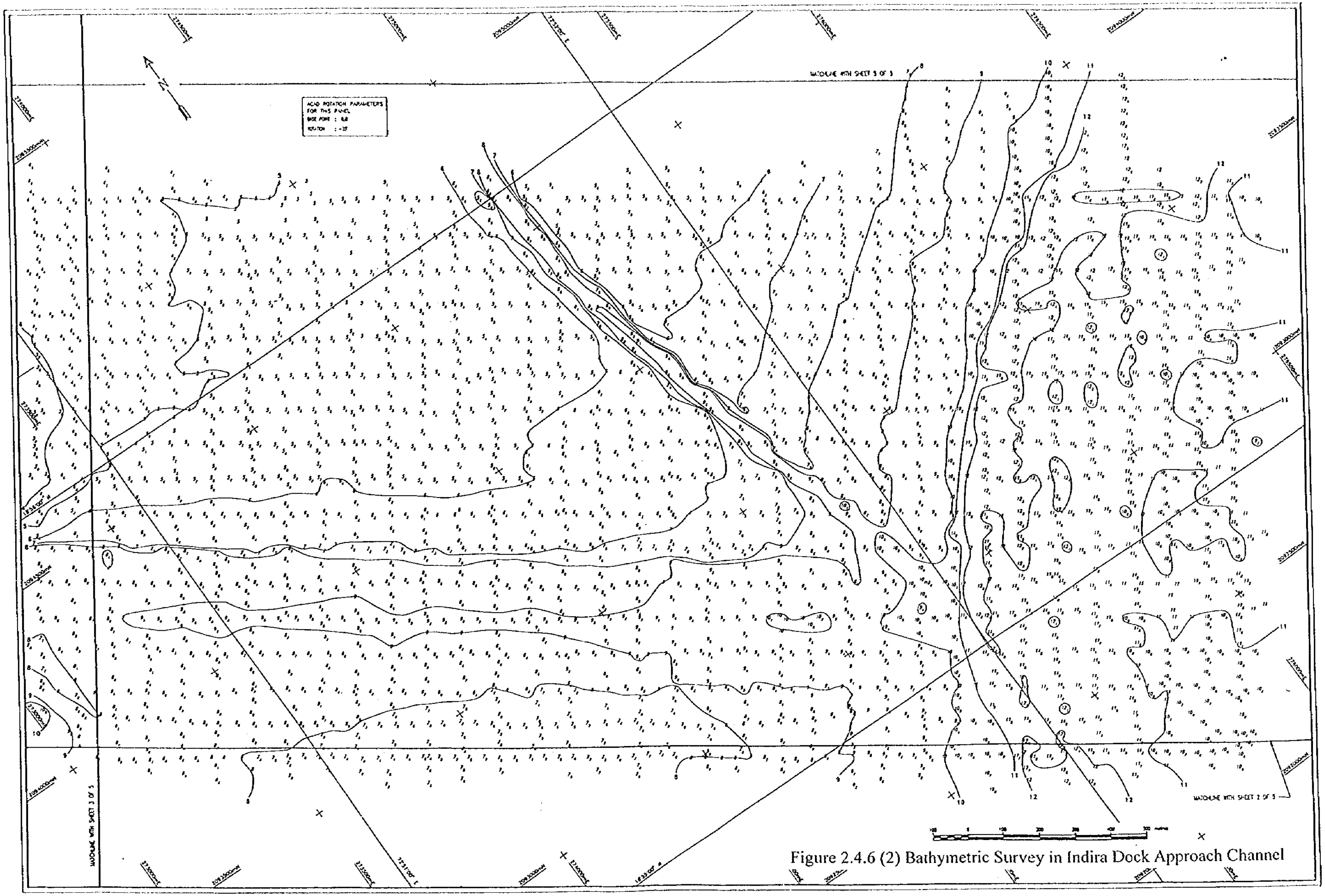


Figure 2.4.6 (2) Bathymetric Survey in Indira Dock Approach Channel

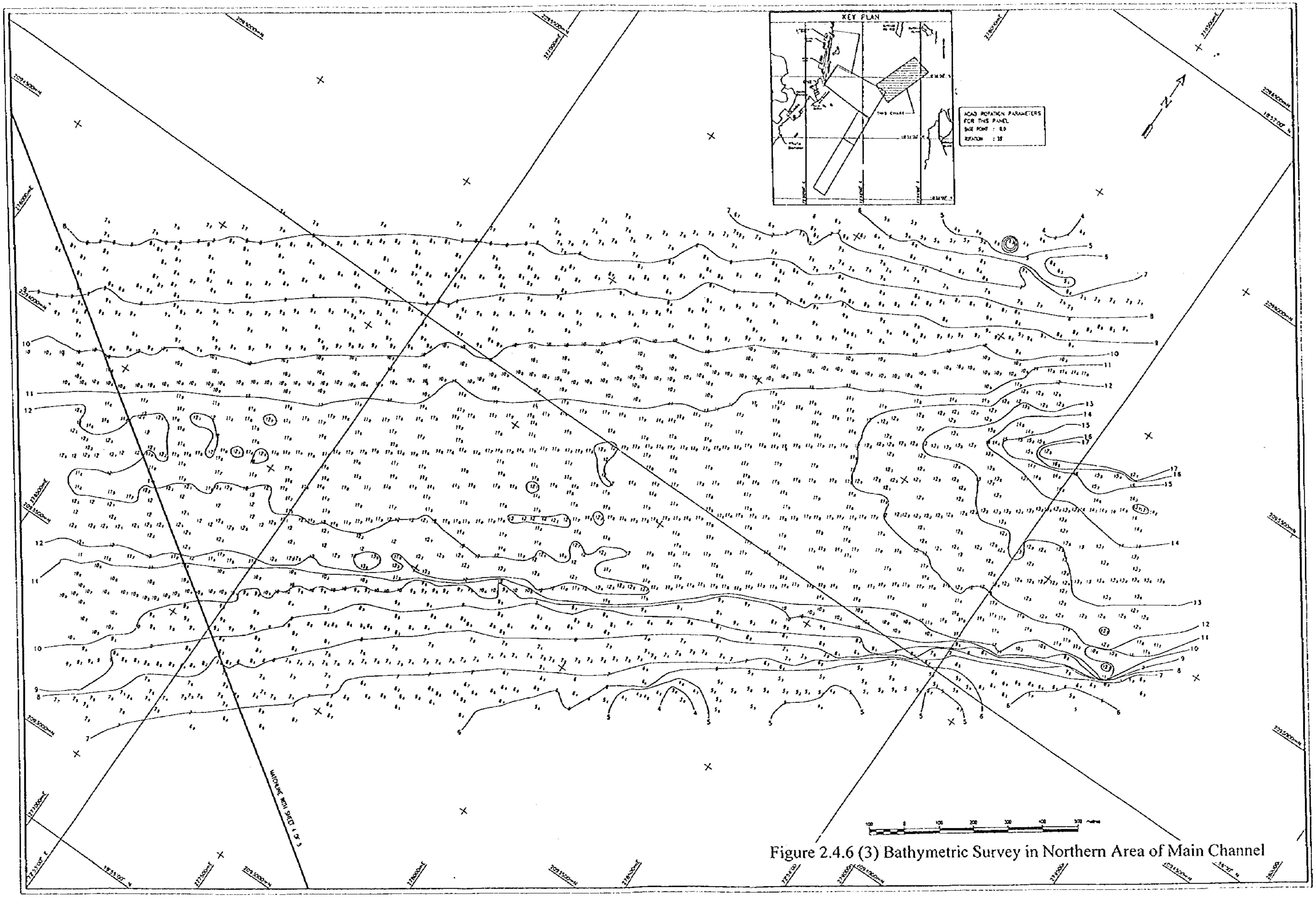


Figure 2.4.6 (3) Bathymetric Survey in Northern Area of Main Channel

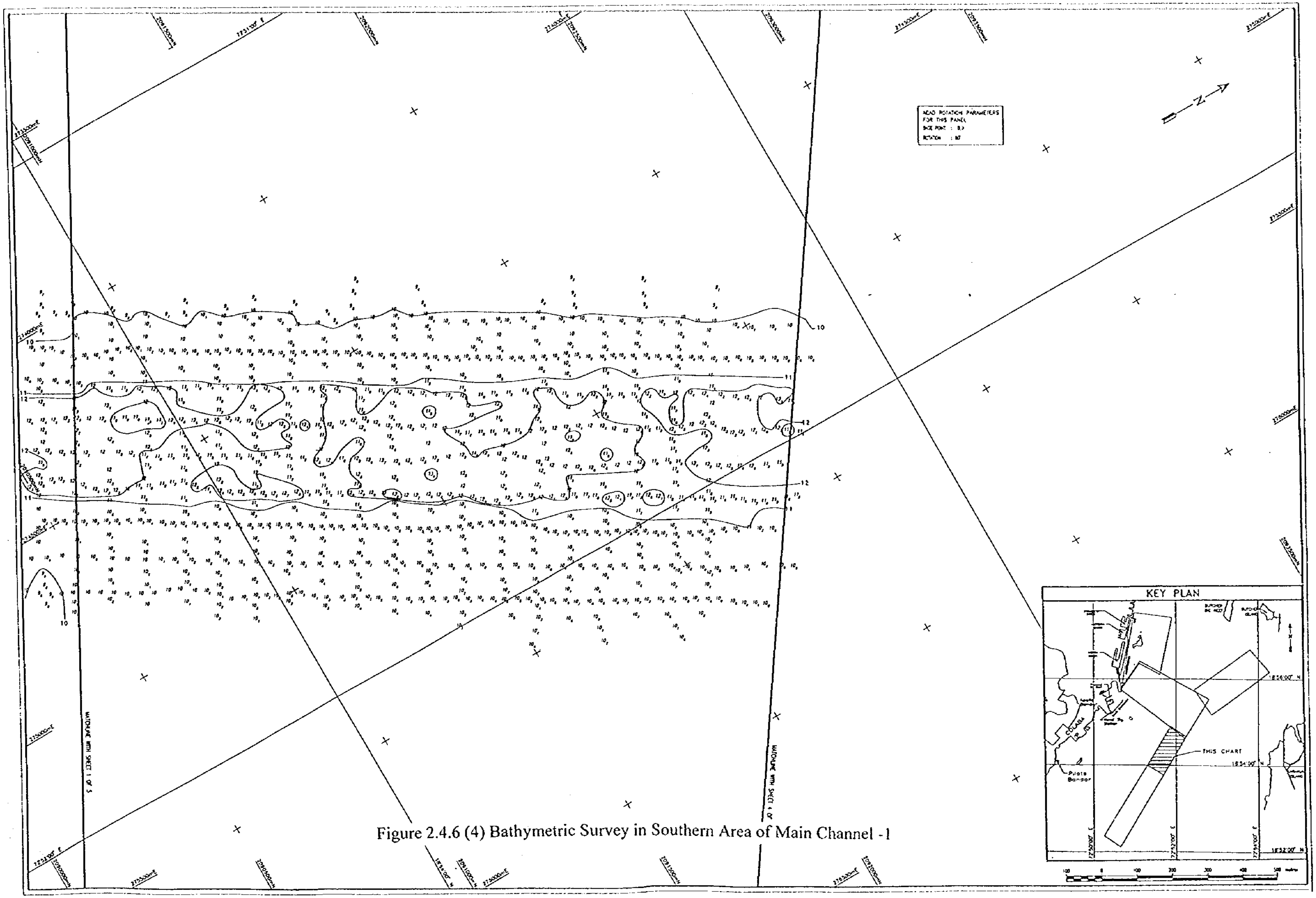


Figure 2.4.6 (4) Bathymetric Survey in Southern Area of Main Channel -1

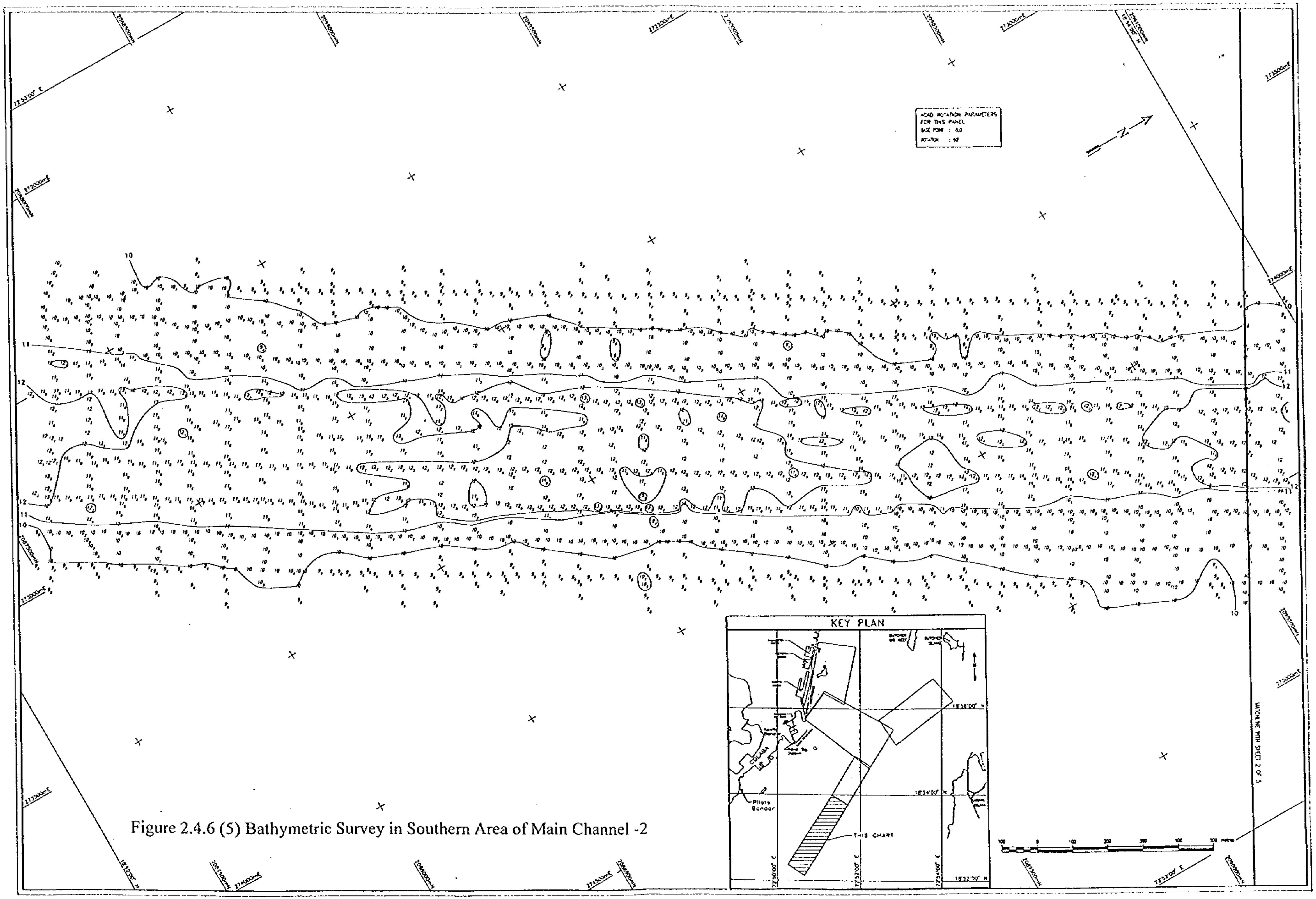
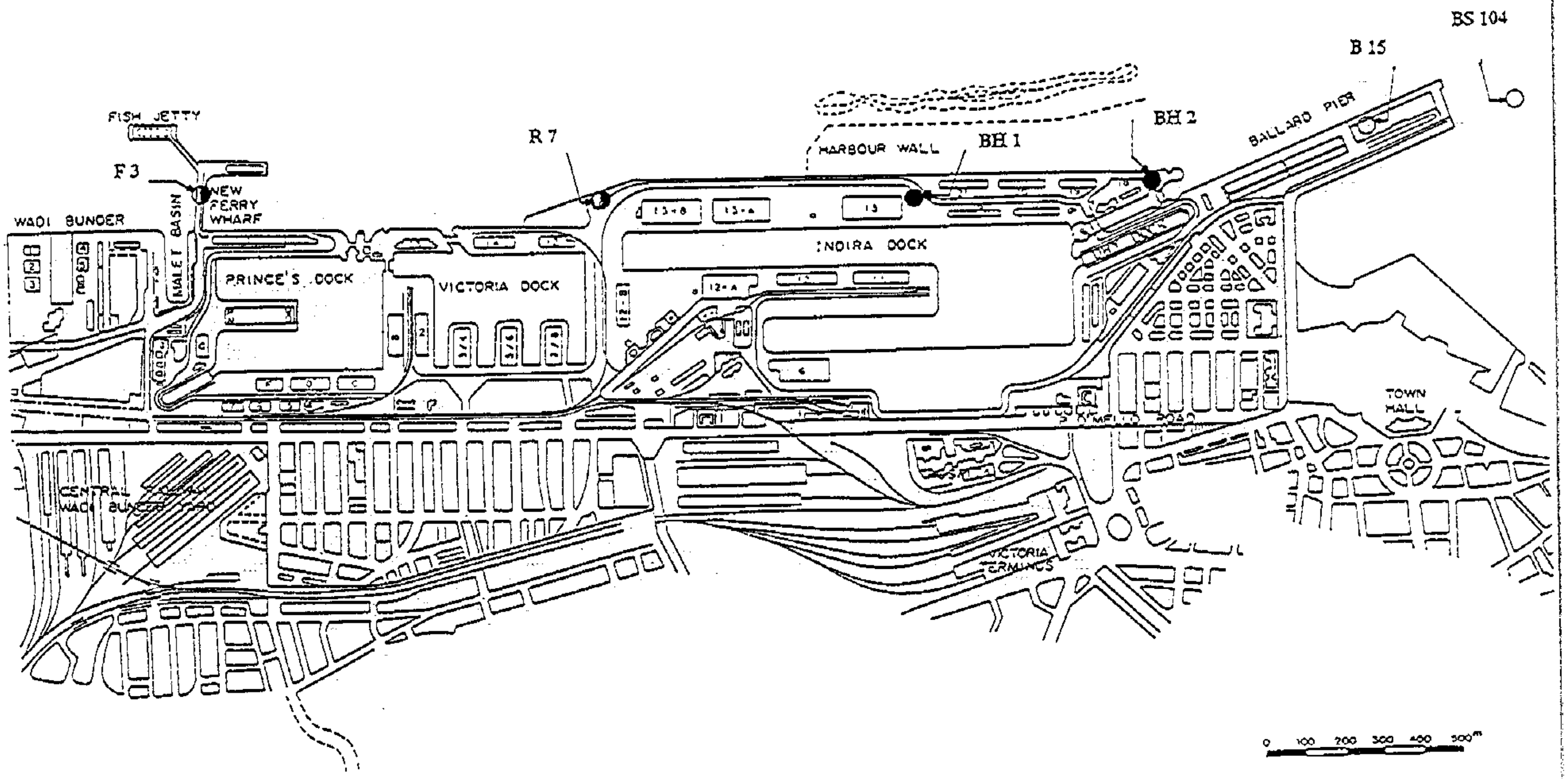


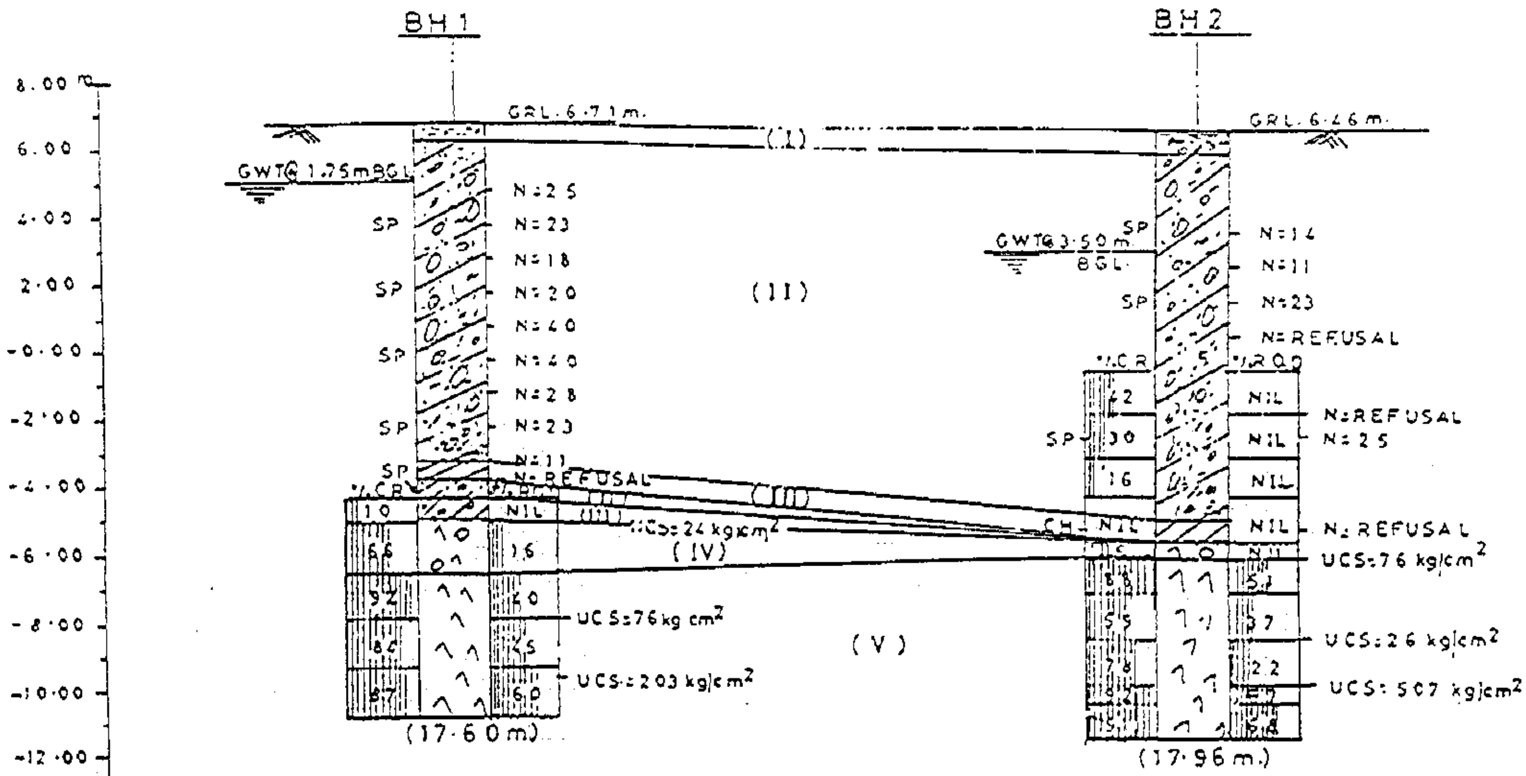
Figure 2.4.6 (5) Bathymetric Survey in Southern Area of Main Channel -2



Legend :

- ● Bore Hole - April 1997
- ◑ Bore Hole - Feb 1966
- ○ Bore Hole - Dec 1963

Figure 2.4.7 Location of Onshore Bore Holes



LEGEND:
LAYERS-(I) ROAD FORMATION
(II) GRAVELLY SILTY SAND WITH BOULDERS
(III) GREY MARINE CLAY
(IV) HIGHLY WEATHERED BASALT
(V) MODERATELY WEATHERED TO FRESH BASALT

CLIENT: JAPAN PORT CONSULTANTS LTD. MUMBAI			
SUB SURFACE PROFILE THOU' BORE HOLES			
DBM GEOTECHNICS & CONSTRUCTIONS P.LTD. SANTACRUZ (E), MUMBAI-400 055.	DRN. BY TELANG	DATE MAY. 97	SCALE 1:200
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Figure 2.4.8 Bore Logs along with Feature of Each Stratum

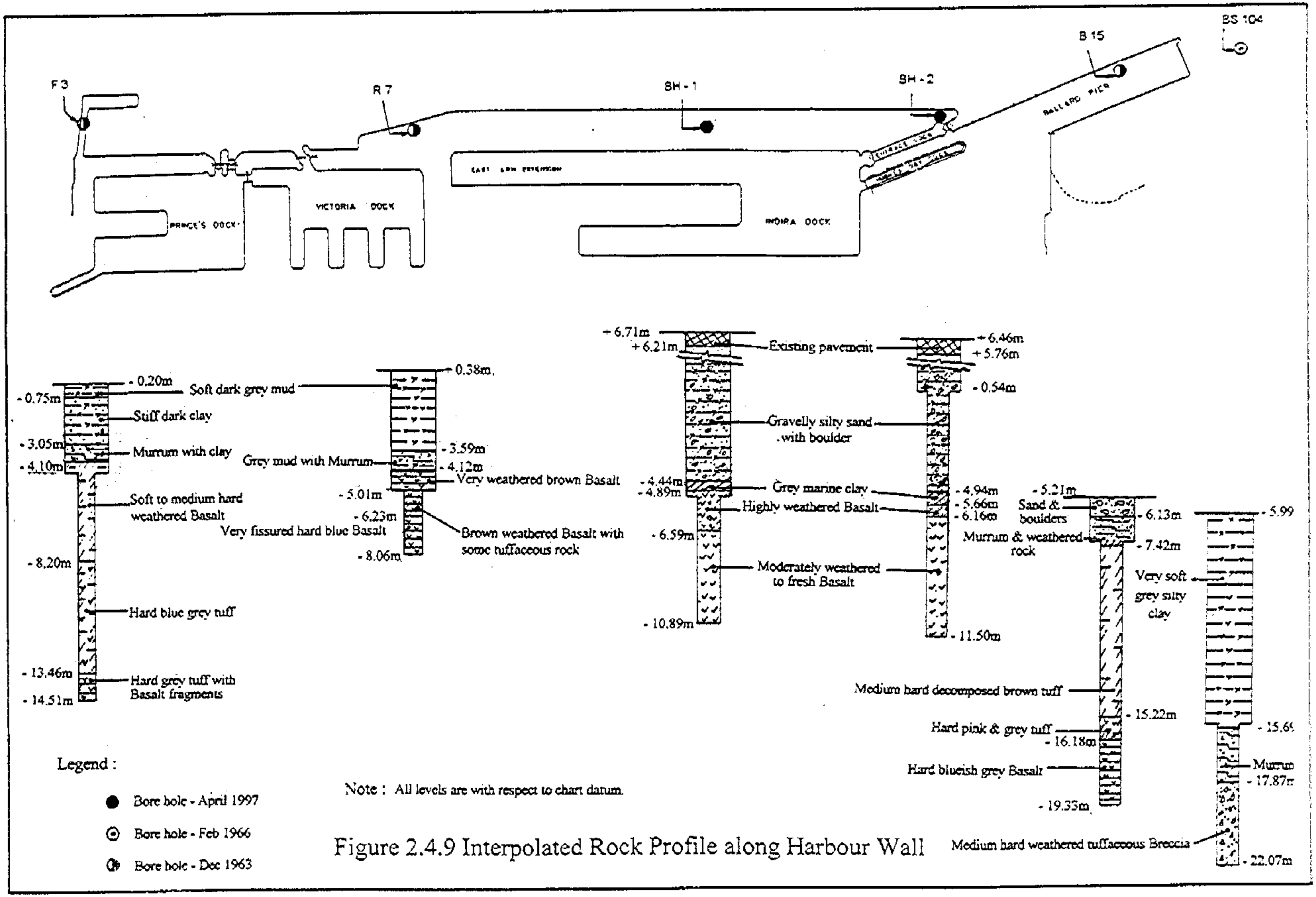


Figure 2.4.9 Interpolated Rock Profile along Harbour Wall

2.5 Field Investigations for Natural Condition (Phase II)

2.5.1 General

Earlier investigations made in Phase I was concentrated mainly on siltation aspects in the channels and to confirm the sub-soil conditions along Indira dock outer harbour wall, keeping in view that one of the alternative proposals at that stage was to utilise the harbour wall for developing additional container berths by extending the harbour wall seaward. However, during the preparation of Interim report for this study, one of the most ideal alternatives proposed was to provide container berths about 900m offshore of the outer harbour wall and connected by an approach trestle to the shore. Accordingly, the field investigations in this phase were planned to obtain information on the sub-soil condition at the location of proposed container berths and dredging areas. In addition, to assist in estimating the siltation in the harbour, certain surveys were also carried out during Phase II.

The following field investigations were made in this phase :-

1) Shallow seismic survey of sea bed to acquire sufficient knowledge on the distribution and depth of rock ground at the location of proposed berths and areas to be dredged.
2) Three in number marine bore holes along the proposed berths to identify the depth of bed rock.
3) Observation of direction and velocity of tidal current at two locations .
4) Sediment sampling of seabed at four locations to analyse the grain size distribution, specific gravity and settling velocity of sediments.
5) Suspended sediment sampling, in order to obtain the vertical distribution of suspended sediment density.

The details of investigations made and analysis of results are further described in this section.

2.5.2 Shallow Seismic Survey

(1) Equipment

For mapping the shallow geology of the survey area, an ORE pipeliner / sub-bottom profiling system was used. As the name suggests, this device identifies the profile of shallow sub-seabed strata. The ORE system comprises of an underwater over-the-side transducer unit which is connected to the transceiver control and recorder units mounted on the deck. After some sea trials and having caliberated the equipment with respect to the results of bore logs in the same area, it was found that optimum results were obtained when the system was set at a frequency of 3.5 kHz.

In order to establish the sea bed profile along each survey line, an Echotrack, model 3100 single frequency echosounder with an over-the-side mounted transducer was used. The echosounder was operated on a single frequency of 200 kHz.

(2) Survey Configuration

The area surveyed is presented in Figure 2.5.1 The survey area was divided into two blocks. Block-I, 600m wide and 3 Km in length, enclosing the Indira dock approach channel area was surveyed with survey lines running at 100m spacing. Block-II, surrounding the proposed berth and channel and covering an area of about 1.5 Km^2, was surveyed with a line spacing of 140m. In addition, to obtain a better understanding of the rock profile in the survey area, lines were run across both the blocks at about 500m intervals. The entire survey was done using Echotrack echosounder & ORE pipeline and the positioning / tracking of the vessel by DGPS with UHF data link receiver. The fixes were recorded at every 30 seconds interval with the boat running at a constant speed of 4 knots.

(3) Interpretation of data and analysis of results

During the survey period, tides were observed at 15 minutes interval and these tidal values, used for preparing the tidal curves for reduction of soundings below chart datum. The reduced bathymetric data was plotted and the contours drawn at 1m intervals. It is observed that in the respective blocks, the sea bed is generally regular and any changes in depths are only gradual. The reduced levels of seabed within the survey area is given in Figure 2.5.2.

The sub-bottom profiler records indicate two clearly distinguishable layers :-

Layer-I - The uppermost layer varying in thickness between 3m to 18m at different locations in the survey area. This layer is interpreted to be made of soft silty clay, very soft at the top and becoming stiffer with depth.

Layer-II - The acoustic basement beyond which the acoustic signals do not penetrate. This very irregular surface underlying Layer-I is interpreted to be the top of weathered Basalt bedrock.

At certain stretches, the interface between Layer-I and Layer-II is not clearly defined possibly due to the bottom of the clay containing loose pebbles or the presence of murrum/ very highly decomposed rock. A zone of signal masking also occurs at a few locations within the survey area, preventing any further penetration of acoustic signal. These signal masking rise abruptly to the sea bed in patches possibly due to certain volatile matter finding escape routes in the clay.

Earlier records of similar surveys carried out by other agencies in Mumbai harbour area reveal identical masking and hence this phenomenon is not unusual.

The isopach of bedrock and sections showing profiles of strata along a few relevant survey lines are presented vide Figures 2.5.3 (1) and 2.5.3 (2), respectively. Comparisons were made between results of shallow seismic survey and bore logs of the three bore holes executed within the survey area. The bore hole location and the depth at which rock was met in the respective bore holes is superimposed on the sectional profiles in Figures 2.5.3 (2). Although the bore holes are located close to the survey tracks and not exactly on them, keeping in view the rock levels in the vicinity of the respective bore holes, it is observed that the depth of acoustic base obtained by shallow seismic survey compares well with the results of bore hole investigation.

Based on survey results plotted in Figures 2.5.3 (1) & (2) and the analysis made above, the following inferences can be made :-

i) The rock contours do not follow any specific pattern, implying there exists a lot of undulation in the rock profile along both directions ie., seaward as well as parallel to the docks. .

ii) For the area proposed for constructing new container berths and creating navigational channel, rock dredging will have to be carried out for a depth of 2m to 3m in certain stretches. However, due to the rock levels being below -13m CD along the Indira dock approach channel (for nearly 2.5 Km length when measured from the main channel), no rock is expected to be encountered if the channel requires deepening, for accommodating ship sizes envisaged to visit the proposed new container berths.

iii) In Figure 2.5.3 (1), rock profile along Line 23, there is difference in rock level between the results of shallow seismic survey and bore hole investigations. This difference could be due to the fact that the acoustic pulses were not able to penetrate 2m to 3m thick layers of packed boulders underlying the soft clay. The presence of these boulders is clearly established in the respective bore log.

iv) Along Indira dock approach channel, the acoustic base has an undulating pattern with the rock level commencing at -9m CD from near Ballard Pier and dipping to -25m CD at midway of the channel and again rising to -13m CD, before dropping to -26m CD as it approaches the main channel.

2.5.3 Marine Soil Investigation

(1) General

During this study, three marine bore holes were investigated along the proposed new container berth. The main purpose was to identify the depth of bedrock to help in deciding the foundation details for the berth. The location of these three bore holes are shown in Figure 2.5.4 Earlier marine bore holes investigated by B&P were spread all over Mumbai harbour. The present area planned for development is away from the earlier bore hole locations and hence the results of those investigation are not very helpful for this study.

(2) Geo-technical Appraisal

Bore logs of the three bore holes are presented in Figure 2.5.5 The maximum depth to which investigations were made in the bore holes and the depth of bed rock met at the respective bore holes are given in Table 2.5.1.

Table 2.5.1 Depth of Bore Hole and Bedrock

Bore Hole No.	Seabed Level RL (m)	Bore Hole Depth RL (m)	Bed Rock Depth RL (m)
MBH-1	- 4.57	- 17.02	- 14.07
MBH-2	- 4.65	- 11.15	- 09.20
MBH-3	- 4.80	- 18.40	- 14.85

The sub-surface layers in MBH-1 and MBH-2 are quite identical. The first layer commencing at the seabed consists of soft marine clay followed by a layer of completely weathered Basalt which is underlain by moderately weathered Amygdaloidal Basalt. The only additional layer found in MBH-3 was a 3m thick layer of boulders. The various strata encountered in the bore holes are briefly summarised below :-

i) In all the three bore holes, the first layer is quite consistent. Laboratory test on undisturbed samples (UDS) indicate that 90% of it contains a mixture of equal quantities of silt and clay and the balance 10% sand.

ii) The second layer in MBH-3, consists of densely packed boulders nearly 3m thick. Similar boulders in loose form can be seen at the foot of the Cross Island located close to MBH 3 site. It appears that these boulders are spread over the seabed for a small area around the Cross Island.

iii) A layer of completely weathered rock is present just above the bedrock in all the three bore holes. The thickness of this layer is 0.25m, 1.4m and 1.8m in MBH-1, MBH-2 and MBH-3 respectively. No core recovery was possible from this layer. However, SPT tests indicate refusal in MBH-1 & MBH-3 and N values of 21 & 64 in MBH-2.

iv) The last layer in the subsurface upto the depth of investigation is made up of highly to moderately weathered Basalt. Core recoveries in this layer varied between 50 to 100%. The Rock Quality Designation (RQD) varies from zero to 79% indicating very poor to good state of fracture in bedrock.

(3) Soil Testing and Analysis

Compression tests were carried out on rock core samples recovered from the bore holes at different depths. The test results have been summarised in Table 2.5.2.

Table 2.5.2 Compressive Strength of Rock Core Samples

Bore Hole. No.	Depth Below CD (m)	Dry Density (gm/cc)	Compressive Strength Kg/cm^2
MBH-1	- 14.72 to - 15.02	2.58	532
MBH-1	- 16.02 to - 17.02	2.35	197
MBH-2	- 9.20 to - 9.85	2.37	205
MBH-2	- 9.85 to - 10.65	2.12	28
MBH-3	- 16.30 to - 17.40	2.82	1024
MBH-3	- 16.30 to - 17.40	2.80	426

Within the area of investigation, the compressive strength of rock varies between 197 to 1024 Kg/cm^2. This indicates that the rock is moderately strong to very strong. However, the low value of failure (28 Kg/cm^2) reported on one of the samples in MBH-2, is due to the presence of a joint plane in the sample and hence to be ignored.

A total of six (6) UDS were obtained from three bore holes. Results of consolidation and triaxial tests made on these samples are given in Table 2.5.3.

Table 2.5.3 Results of Consolidation and Triaxial Tests

Bore Hole No.	Depth of Sample RL (m)	Triaxial Test Cohesion (Kg/cm^2)	Triaxial Test Phi (Degree)	Consolidation Test (Cc/1+eo)	Consolidation Test Pc (Kg/cm^2)
MBH-1	-07.570	0.09	1.00	0.292	0.85
MBH-1	-12.570	0.14	4.00	0.182	0.88
MBH-2	-06.650	0.11	1.50	0.238	0.32
MBH-3	-08.805	0.16	2.00	0.244	0.37

Shear strength of clay was determined by conducting unconsolidated undrained triaxial test. Cohesion values range from 0.09 Kg/cm2 to 0.16 Kg/cm2. These values confirm very soft to soft consistency of clay. The values of internal friction are small and should not be considered for design. Compressibility characteristics were obtained from consolidation tests in the laboratory. Ratio Cc/1+eo ranges from 0.182 to 0.292. Pre-consolidation pressure (Pc) varies from 0.32 Kg/cm2 to 0.88 Kg/cm2. These values when related with depth indicate clay layer to be normally consolidated. The two results when viewed together imply that on application of load, this clay layer will undergo longtime dependant settlement.

2.5.4 Observation of Currents

(1) Out Line of Observation

It is observed that, in addition to normal tidal currents during the wet season, the inflow from various creeks entering the bay of Mumbai not only discharge more sediment into the bay but also affect the current velocity. In order to further help in siltation studies, it was felt necessary to acquire additional information on the post monsoon current pattern in the bay preferably at two (2) locations along the main channel.

During the first phase in June 1997, current observations were made at five locations distributed along different approach channels. In order to make a comparison of current velocities between pre and post monsoon, in Phase-II, current measurements were made at two of the five locations measured in first Phase. Figure 2.5.6 shows the location of the two current meters (C-1 & C-2) deployed along the main channel.

The current meters deployed were of type Interocean S4 self recording units. Current meters were positioned at 60 % of the available water depth above seabed. Observations were made simultaneously at both locations from 28th October to 30th October 1997. Current velocity and measurement at 15 minute intervals were recorded for 2 consecutive days.

(2) Summary of Data

The summary of results on current observation is given in Table 2.5.4.

Table 2.5.4 Summary of Current Measurements

Location	Coordinates	Water Depth (m)	Maximum speed (Knots)	Minimum speed (Knots)	Direction
C-1	N 2091256.890 E 275267.973	10.20	1.3	0.1	025 / 205°
C-2	N 2094744.008 E 279406.991	5.00	0.7	0.0	055 / 235°

(3) Analysis of Observations

a) Velocity and Direction of Current

i) Location C-1

Polar plot and Histogram of velocity of flow of current are shown in Figure 2.5.7 (1). Predominant directions of current were observed to be NNE and SSW. Velocity of flow of current in the range of 45 to 50 cm/s was dominant and the average velocity of flow was about 35 cm/s during the period of observation.

ii) Location C-2

Figure 2.5.7 (2) shows polar plot and histogram of velocity of flow of current at Location C-2. At this location, the predominant directions of current were observed to be ENE and WSW, indicating a slight inclination towards E-W direction in comparison to that observed at location C-1. The pre-dominant velocity of current was in the range of 25 to 30 cm/s and the average velocity about 20 cm/s during the period of observation. The average velocity at this location is observed to be less than what was observed at Location C-1.

(4) Conclusion

A realistic comparison cannot be made between the results of current measurements made at similar locations in Phase-I and Phase-II due to the fact that in Phase-I measurements were made for a period of 15 days where as for only 2 days in Phase-II. However, in order to find the possibility of any appreciable changes in the characteristics of the current, the results were analysed and the following observations made :-

i) The predominant direction of currents is quite similar, except for a marginal difference in Location C-1. This is understandable since there has been no change in the overall geographical features or construction of new structures / obstructions in the vicinity of observations being made during the period between Phase-I and Phase-II surveys.

ii) There is no appreciable change in the velocity of flow of current. Infact, the measurements made in Phase-II indicate that current velocities are slightly less than that observed in Phase I for both locations. This could be due to any of the following possible reasons :

- The period of observation was inadequate to reflect the actual conditions in the wet season.
- The observations were made at nearly the end of wet season and hence the period when maximum changes in current velocities occur was probably over.

2.5.5 Sediment Sampling and Analysis

(1) Sediment Sampling

During this phase, sediment samples were collected from near the mouth of two main creeks viz., Thane and Dharamtar and also at two locations near the entrance of Bay of Mumbai. Figure 2.5.8 shows the location of seabed samples collected. Two sets of samples were collected from each of the above locations using a Veen-Van type grab sampler. The main purpose of collecting sediment samples from these locations was to have a better understanding of the characteristics of material flowing from these creeks during the wet season and also to confirm whether the same material after entering into the bay infiltrates upto the entrance of bay of Mumbai.

(2) Analysis of Sediment Samples

The following analysis was made on the seabed samples :-

a) Grain size analysis.

b) Specific gravity.

c) Settling Velocity.

Table 2.5.5 (1) - (2) represent the typical distribution curve of grain size contained in the sediment at Thane and Dharamtar creek respectively. Table 2.5.5 (3) shows the typical distribution curve of grain size contained at the entrance of Bay of Mumbai. The specific gravity and settling velocity of sediments is summarised in Table 2.5.6 Test results for grain size and specific gravity indicate the soil to be generally clayey silty sand with a specific gravity of around 2.6. Analysis made on samples indicate that the bed material at the mouth of creeks contain a comparatively higher percentage of silt and clay. The slightly higher content of sand at the entrance of bay of Mumbai could be possibly due to the movement of littoral sand getting drifted into the channel during strong currents. The percentage distribution of grain size in the sediment samples is summarised in Table 2.5.7.

Table 2.5.7 Percentage Distribution of Grain Size in Sediments

Location	Grain Classification & Content (%)			Specific Gravity
	Sand	Silt	Clay	
	16	41	43	2.62
	18	42	40	2.61
	20	41	39	2.63
	12	44	44	2.61
	10	46	44	2.62
	13	42	45	2.62
	13	42	45	2.61
	11	46	43	2.62

It is observed that the grain size distribution in samples collected from within the harbour area in Phase-I, compare quite well with the grain size in samples obtained from the mouth of creeks in Phase-II. Infact, sediment samples from the harbour area contain marginally less content of sand than those samples obtained from near the creek mouths due to the fact that unlike silt, sand being heavier, it does not easily come to suspension to be transported for very long distances.

2.5.6 Suspended Sediment Analysis

(1) Water Sampling

Sea water samples were collected at the same five (5) locations where current measurements were made during the first phase of this study. These locations were specifically chosen in order to assist in obtaining a better understanding for estimating the siltation in channels (where maximum siltation occurs) since the currents have a direct effect on movement of suspended sediment and current measurements at these locations had been made earlier. Figure 2.5.9 shows the locations of sampling. The water samples were collected using a Niskin sampler at depths of 0.5m, 2m and 5m above seabed level. One sample at each specified depth was collected at these five (5) locations at one hour intervals for twelve (12) consecutive hours on two (2) subsequent days.

(2) Analysis of suspended sediment

Sea-water samples were analysed to obtain the quantum of suspended sediments (in terms of weight) present in it at three (3) different depths. The procedure adopted was Standard gravimetric method as described below :

a) 50ml of water sample is evaporated. The residue is weighed and it is the total solids (W1).

b) After filtering 50ml of water sample, it is evaporated. This residue is weighed and it is the dissolved solids (W2).

c) Total solids (W1) - Dissolved solids (W2) x 20 = Suspended solids / liter.

Results of tests made on samples is given in Table 2.5.8 The following observations / analysis can be made from these results :

I. At Locations 1, 2 and 3, which are on the main channel, the quantum of suspended solids is more than at locations 4 and 5 (along approach channel to Indira dock). This could be due to the following reasons :

i) The orientation of main channel is along the same direction as the flow of water mass during flooding and ebbing. Due to the tidal currents being stronger in this stretch, the seabed material is easily brought to suspension during flushing action.

ii) The seabed material is made up of fine silty clay. With the slightest turbulence, this material is brought to suspension. Since the frequency of vessel movement is more in the main channel, there is a greater possibility of material being brought to suspension.

II. The suspended sediments are more during Flooding at Locations 1, and 2. However, at Locations 4 and 5 there is no appreciable difference in the volume of suspended sediments between flooding and ebbing.

III. At Locations 1 and 2, suspended sediments are found to be in larger quantities at 0.5m and 5m above seabed, when compared to 2m above seabed. This could be due to variation in current velocity at different depths.

IV. The quantum of suspended samples are comparatively more at 0.5m depth above seabed at Locations 2 and 3 probably due to density currents, which appear to reduce by the time they reach Location 1.

V. At Locations 4 and 5, except for few periods when the suspended sediment is concentrated at lower depths, the suspended sediment is quite equally distributed in the water column at most of the times during the observation, which could be attributed to the following reasons:

1) The depths being shallow, any disturbance of the seabed will create almost an equally dense water column.
2) There may be no major variation in current velocity along the water column height.
3) Due to comparatively less movement of vessels in the Indira dock approach channel, occurrence of major turbulances of the seabed sediments are few.
4) Effect of freshet must be insignificant and hence the possibility of density current is remote.

Table 2.5.5 (1) Distribution Curve of Grain Size in Sediment from Thane Creek

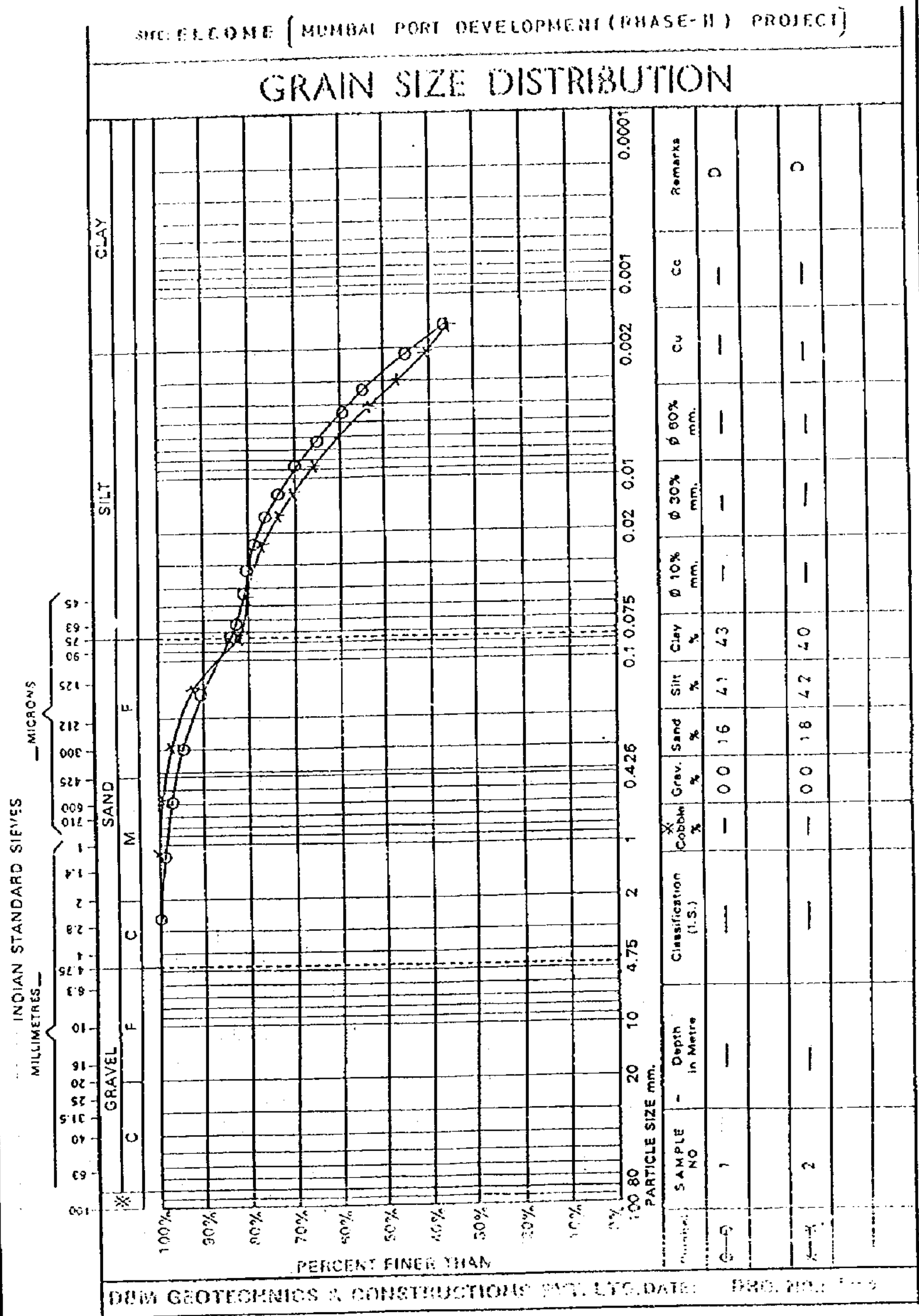
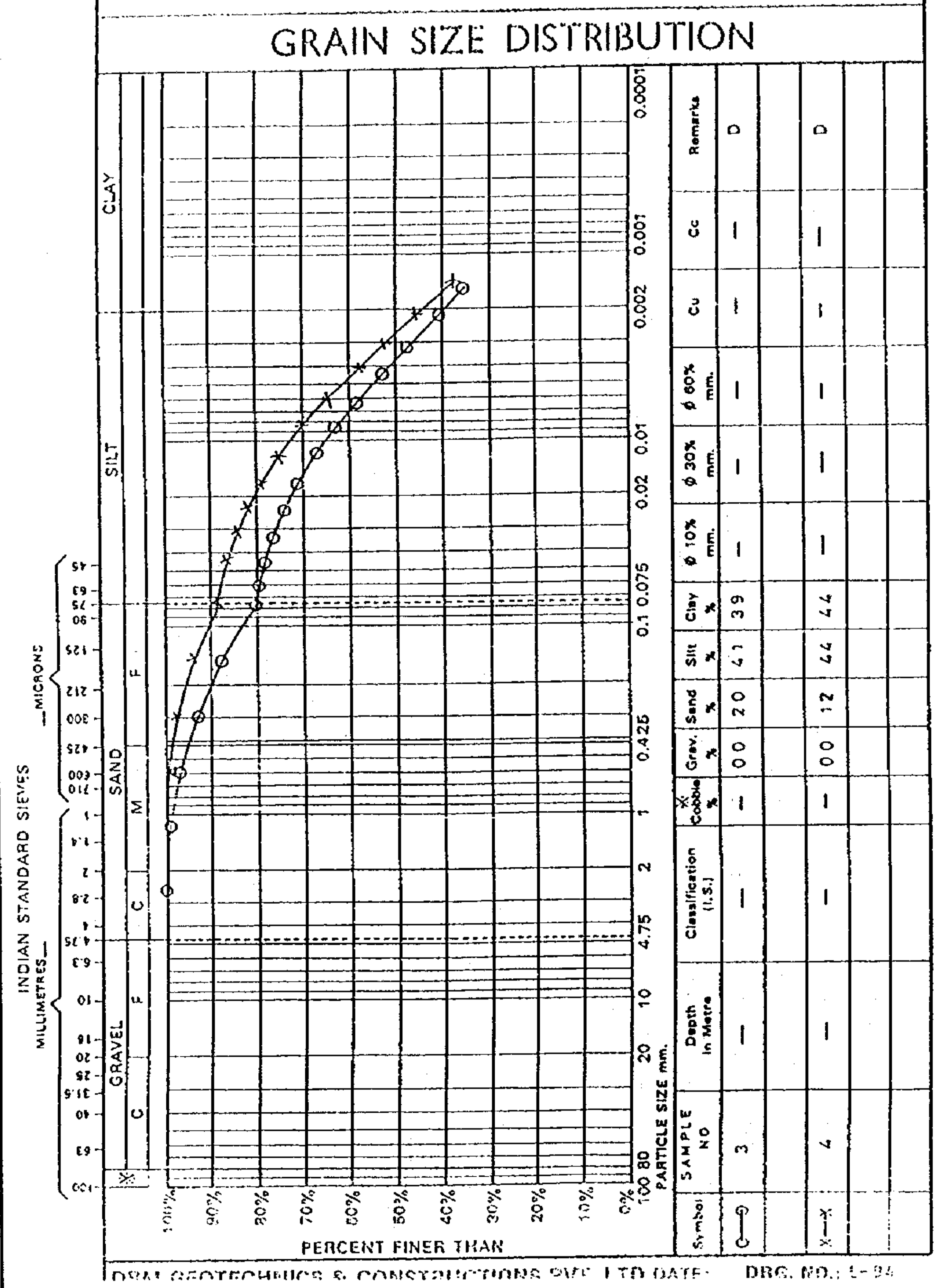


Table 2.5.5 (2) Distribution Curve of Grain Size in Sediment from Dharambar Creek

SITE: ELCOME [MUMBAI PORT DEVELOPMENT (PHASE-II) PROJECT]



Symbol	Sample No	Depth in Metre	Classification (I.S.)	Cobble %	Grav. %	Sand %	Silt %	Clay %	φ 10% mm.	φ 30% mm.	φ 60% mm.	Cu	Cc	Remarks
o—o	3	—	—	—	00	20	41	39	—	—	—	—	—	D
x—x	4	—	—	—	00	12	44	44	—	—	—	—	—	D

Table 2.5.5 (3) Distribution Curve of Grain Size in Sediment from Entrance of Mumbai Bay

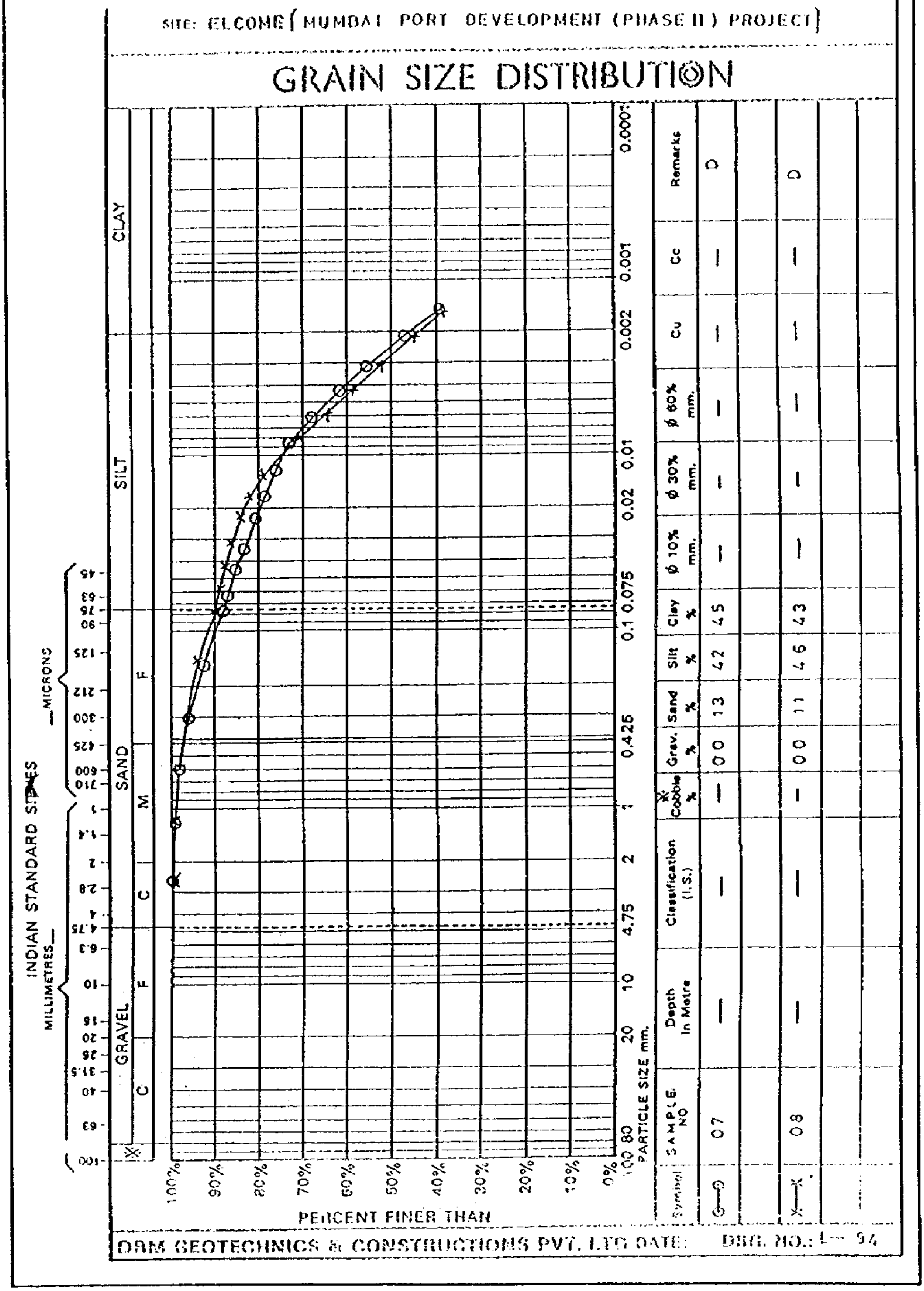


Table 2.5.6 Specific Gravity and Settling Velocity of Sediment

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CERTIFICATE OF ANALYSIS

Site : Mumbai Port Development (Phase II) Project

Sample : Soil

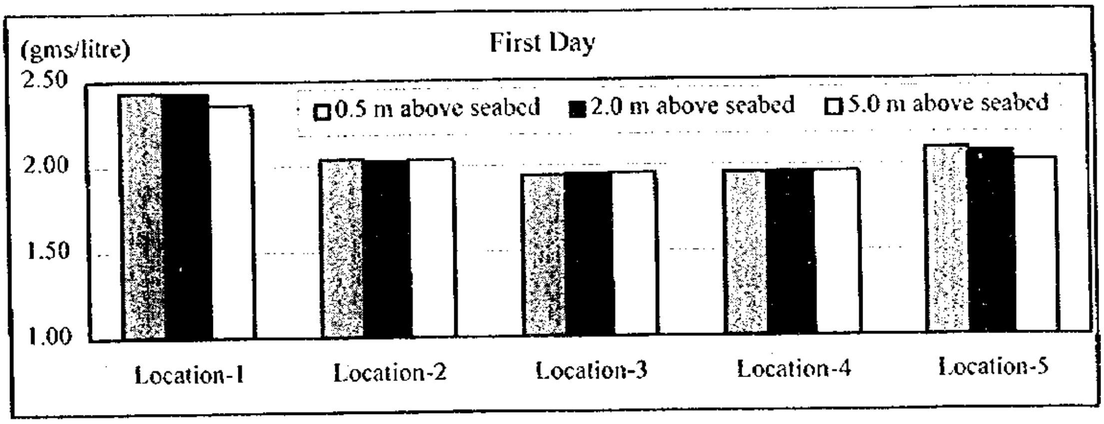
Result Of Analysis Sample	Settling Velocity of Sediments		
No. 1	80% / Sec.	15% / 5 Sec.	3% / 4 Min.
No. 2	75% / Sec.	20% / 5 Sec.	4% / 4 Min.
No. 3	90% / Sec.	5% / 5 Sec.	3% / 4 Min.
No. 4	85% / Sec.	10% / 5 Sec.	3% / 4 Min.
No. 5	80% / Sec.	15% / 5 Sec.	3% / 4 Min.
No. 6	85% / Sec.	10% / 5 Sec.	3% / 4 Min.
No. 7	80% / Sec.	15% / 5 Sec.	3% / 4 Min.
No. 8	90% / Sec.	5% / 5 Sec.	3% / 4 Min.

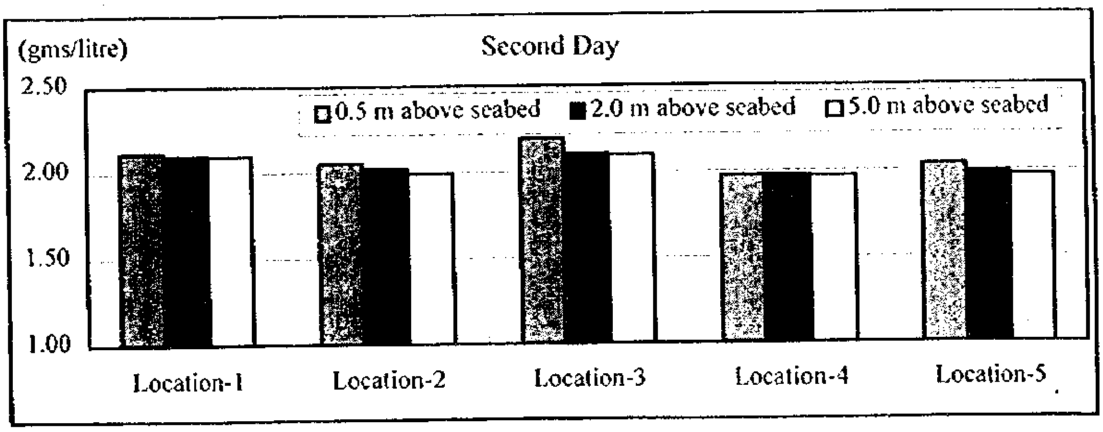
Analysed By [signature]

Table 2.5.8 Survey Results of Analysis for Suspended Sediment

Location	Depth (m)	First Day (gms/litre)	Second Day (gms/litre)	Remarks
1	0.5	2.4349	2.1138	
	2.0	2.4314	2.0994	
	5.0	2.3624	2.0963	
2	0.5	2.0413	2.0522	
	2.0	2.0267	2.0172	
	5.0	2.0357	1.9893	
3	0.5	1.9424	2.1912	
	2.0	1.9498	2.1038	
	5.0	1.9529	2.0955	
4	0.5	1.9554	1.9737	
	2.0	1.9566	1.9723	
	5.0	1.9580	1.9671	
5	0.5	2.0913	2.0349	
	2.0	2.0681	1.9904	
	5.0	2.0191	1.9715	

Depth (m) : Above Seabed





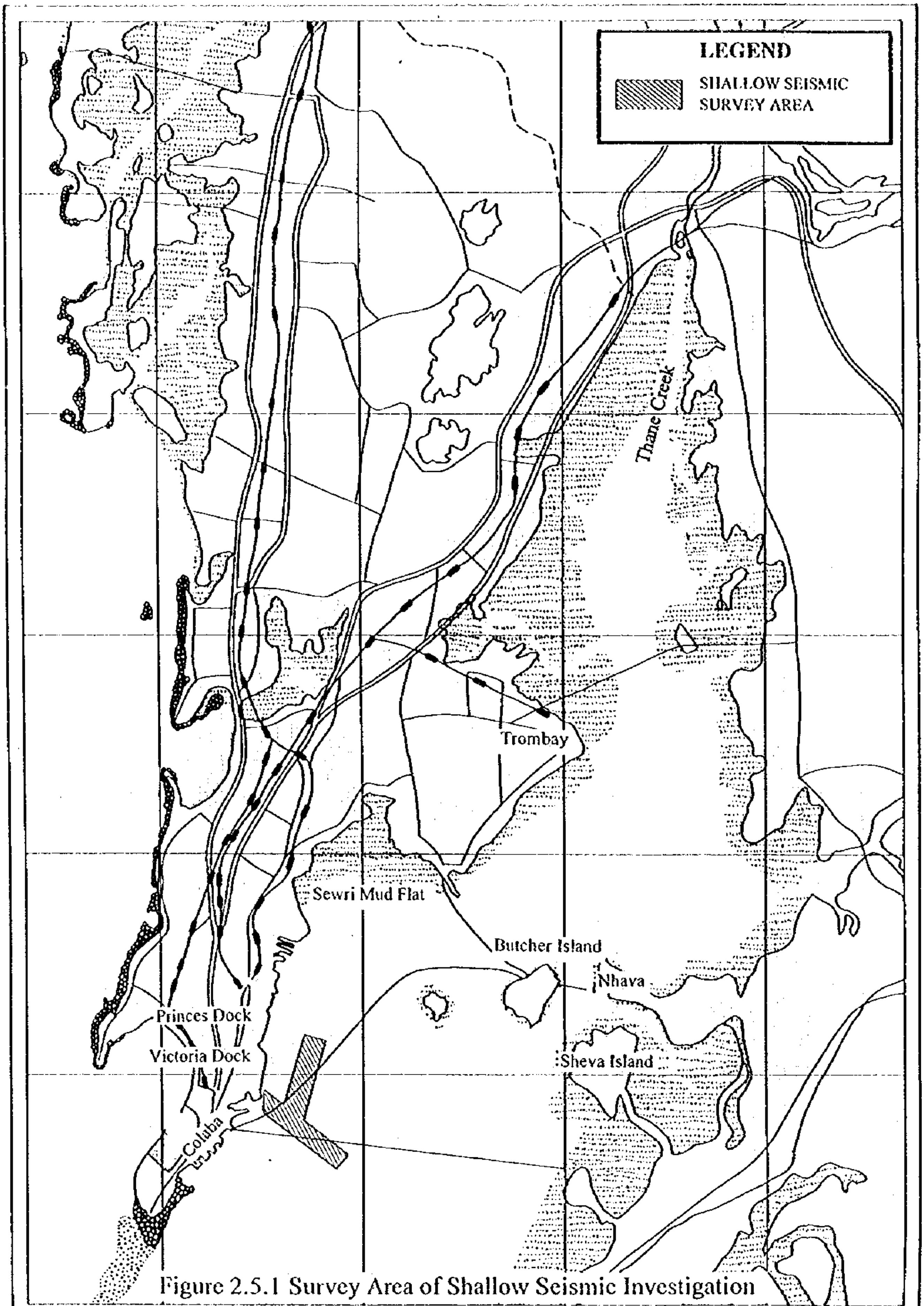


Figure 2.5.1 Survey Area of Shallow Seismic Investigation

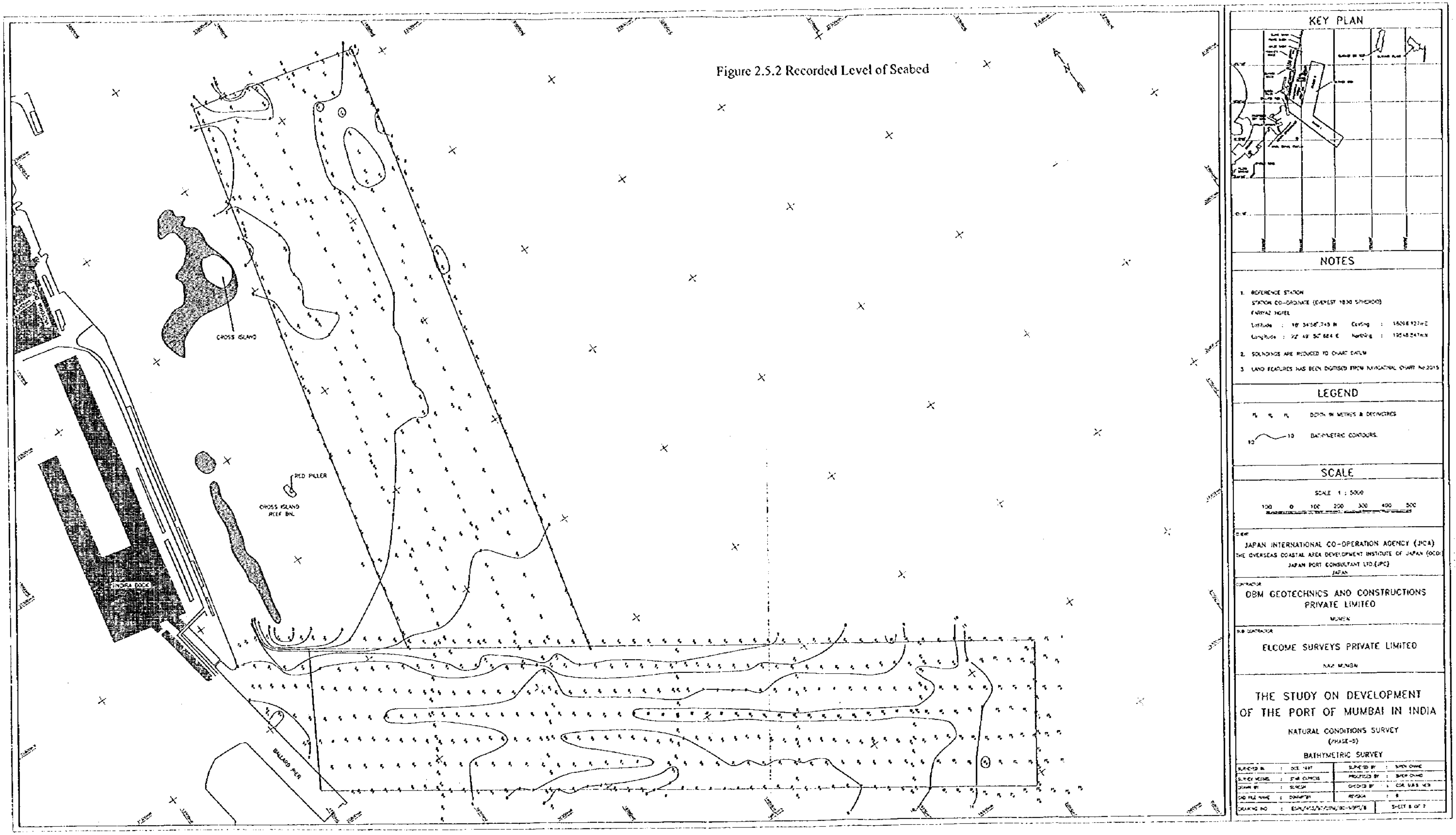


Figure 2.5.2 Recorded Level of Seabed

Figure 2.5.3 (1) Isopach of Bedrock and Profile of Strata

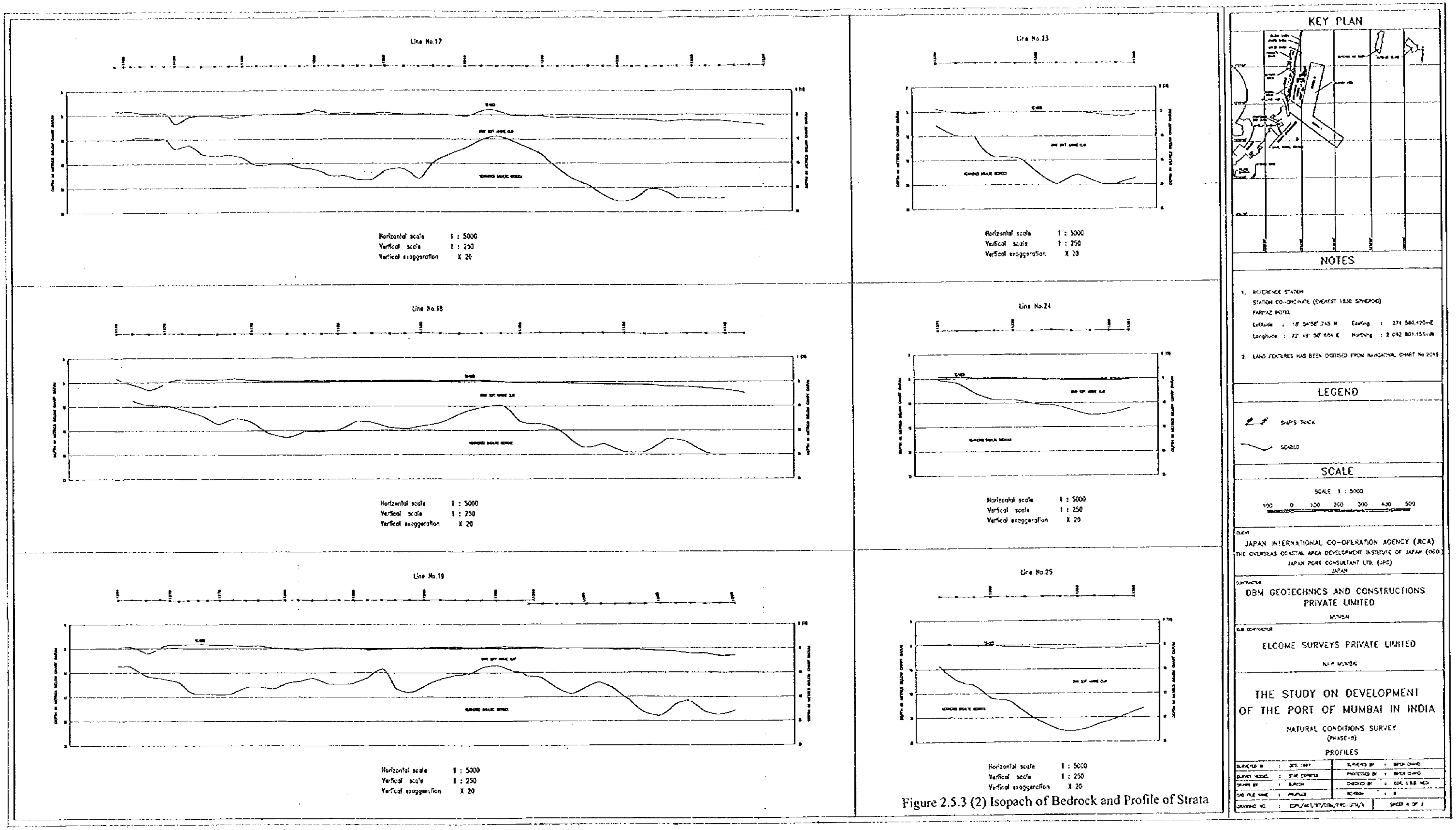


Figure 2.5.3 (2) Isopach of Bedrock and Profile of Strata

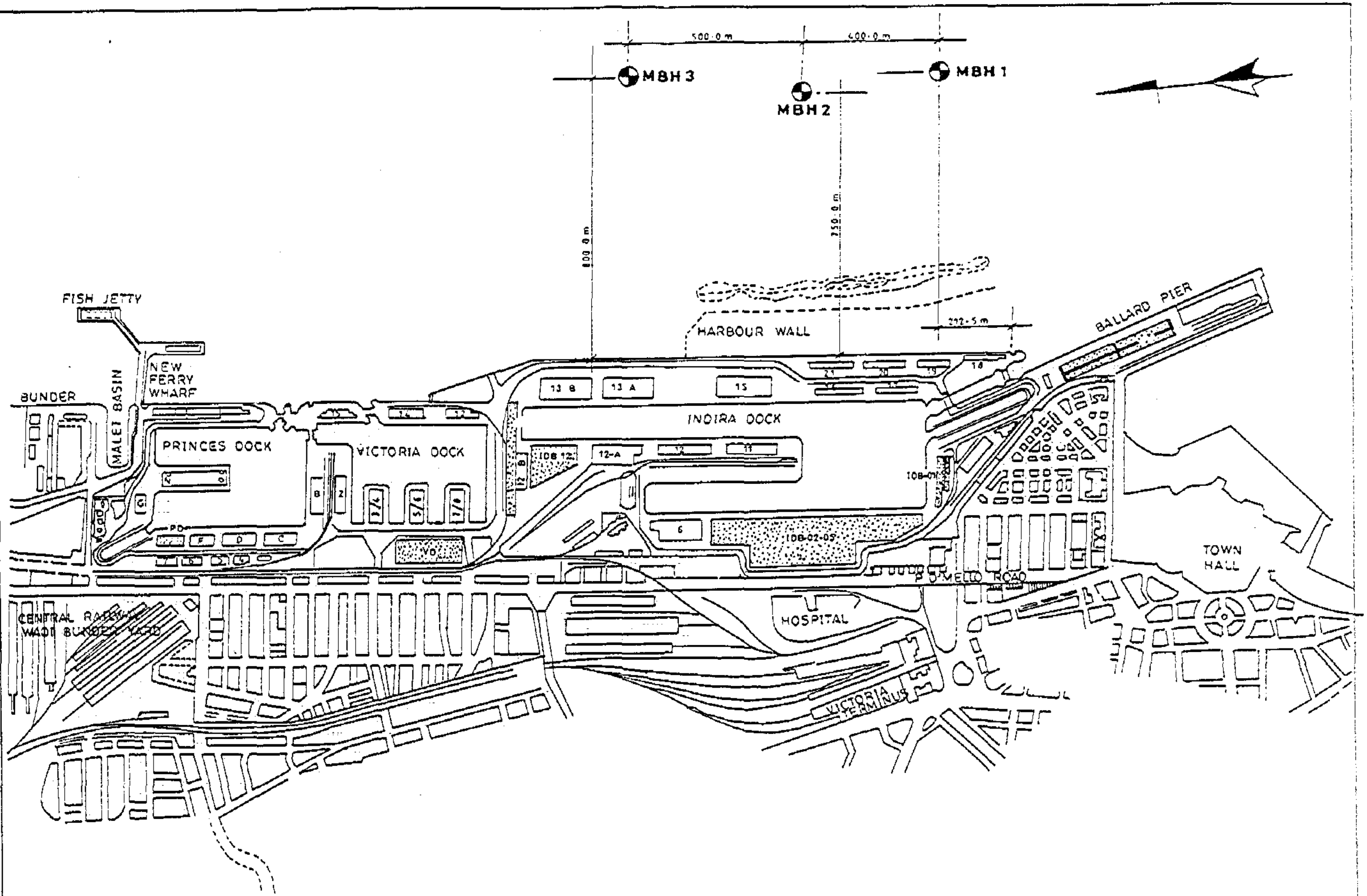


Figure 2.5.4 Location of Offshore Bore Holes

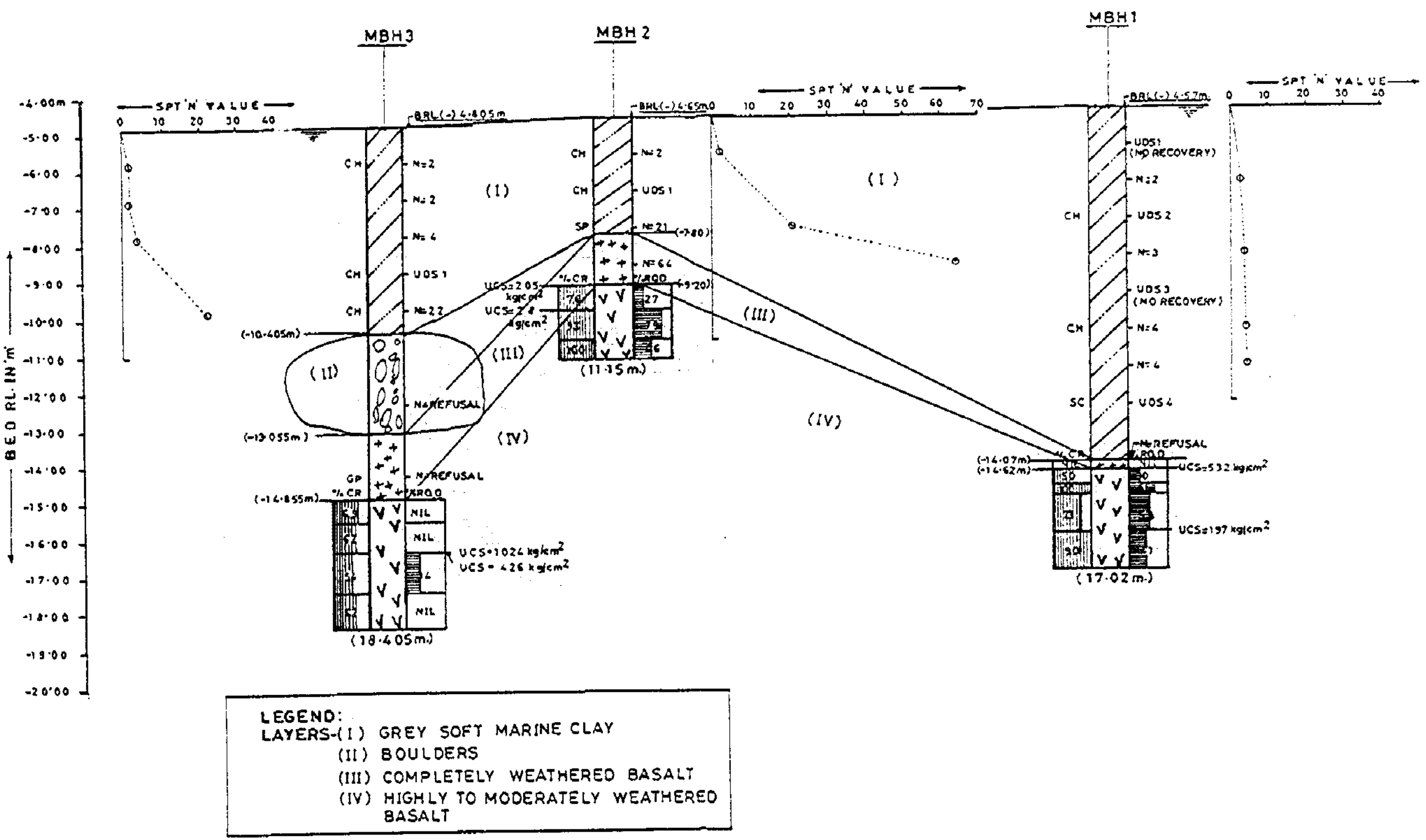


Figure 2.5.5 Bore Logs and Assumed Soil Profile

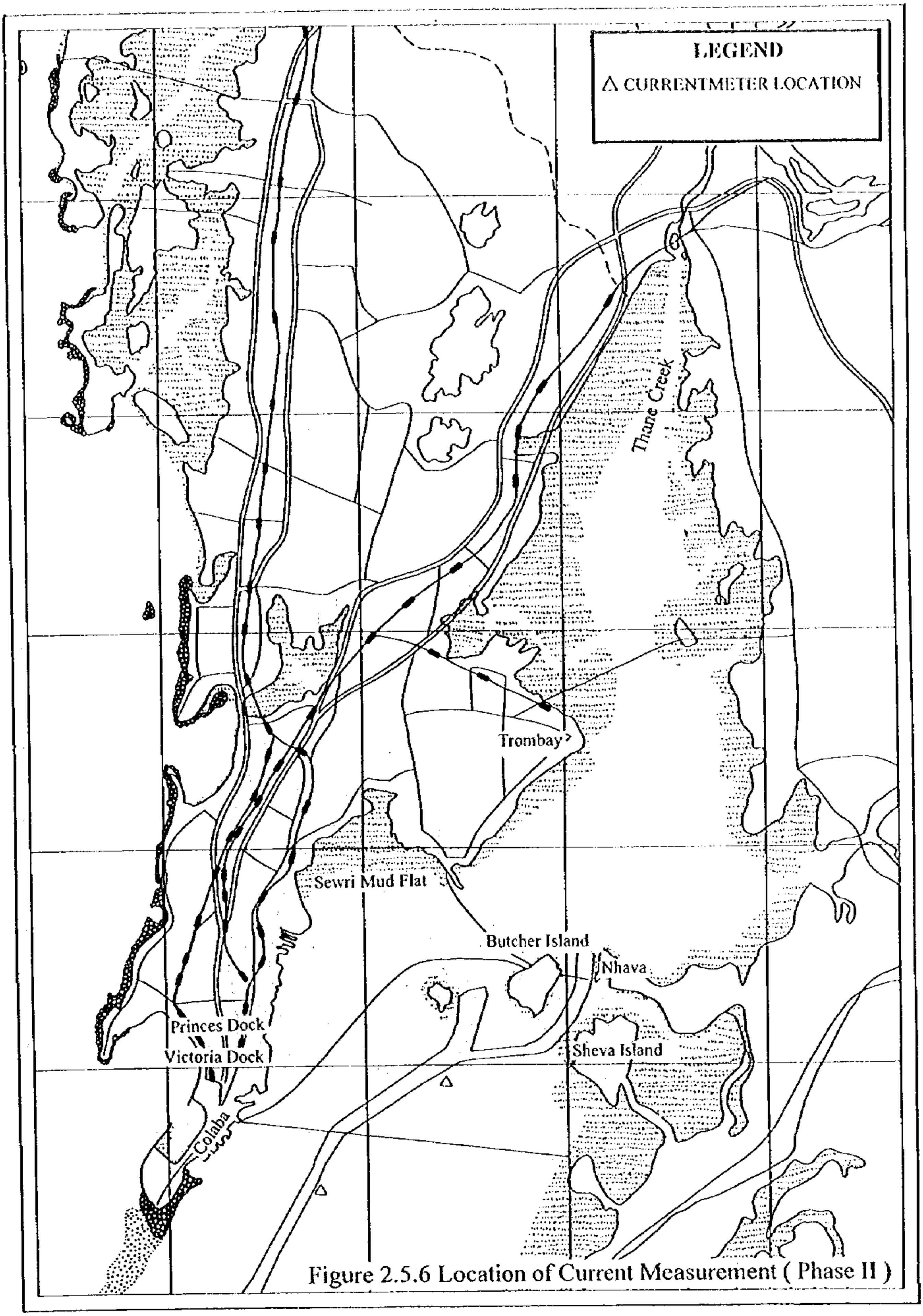
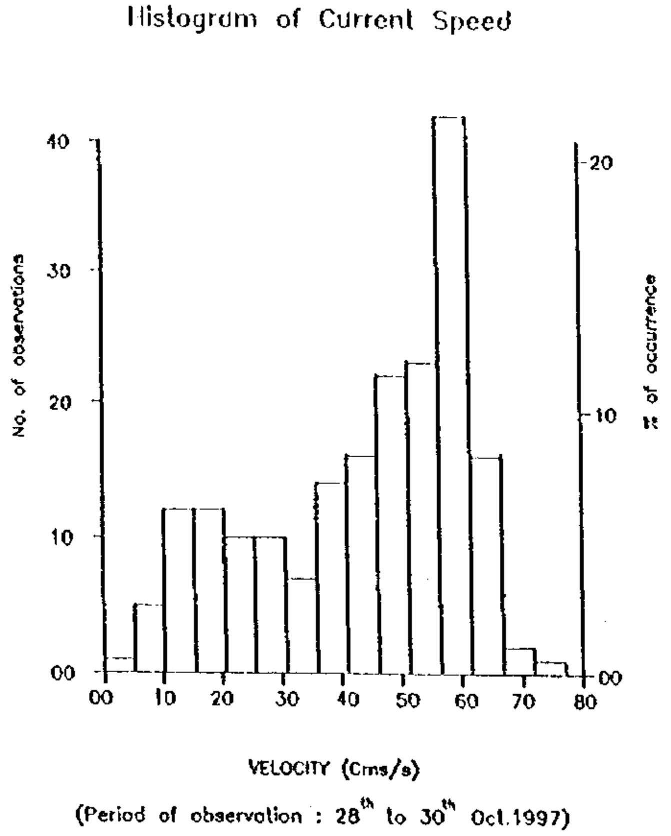


Figure 2.5.6 Location of Current Measurement (Phase II)



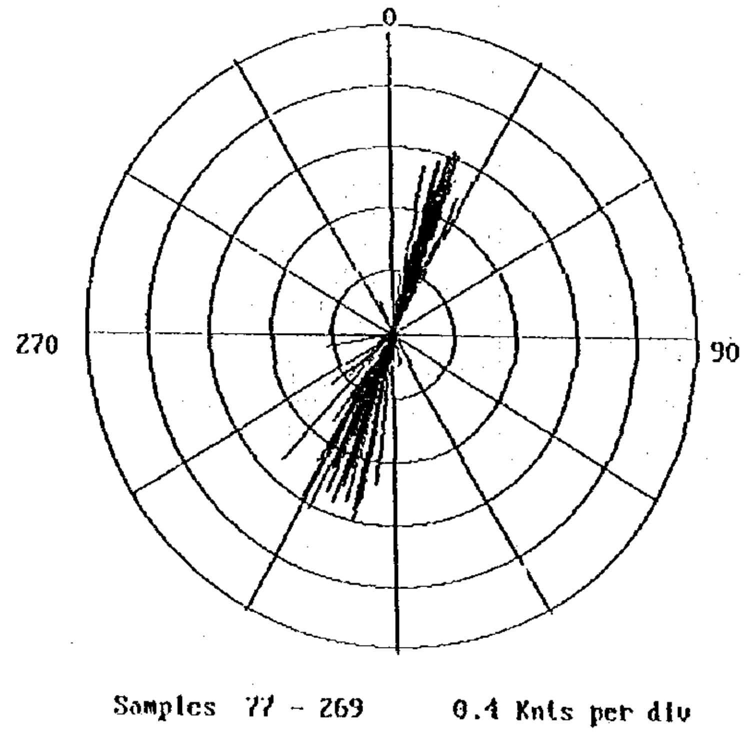
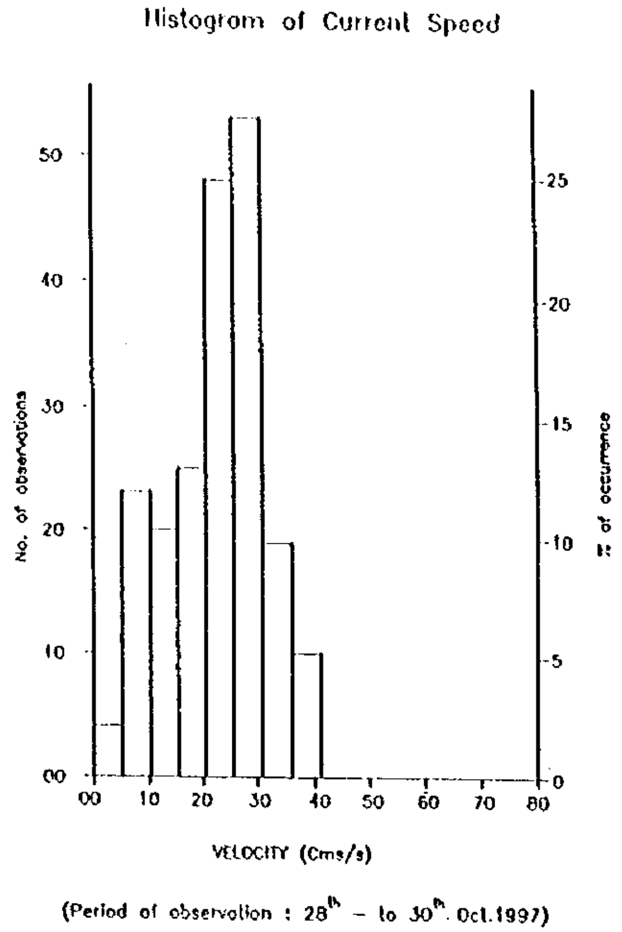


Figure 2.5.7 (1) Polar Plot and Histogram of Velocity of Current Flow



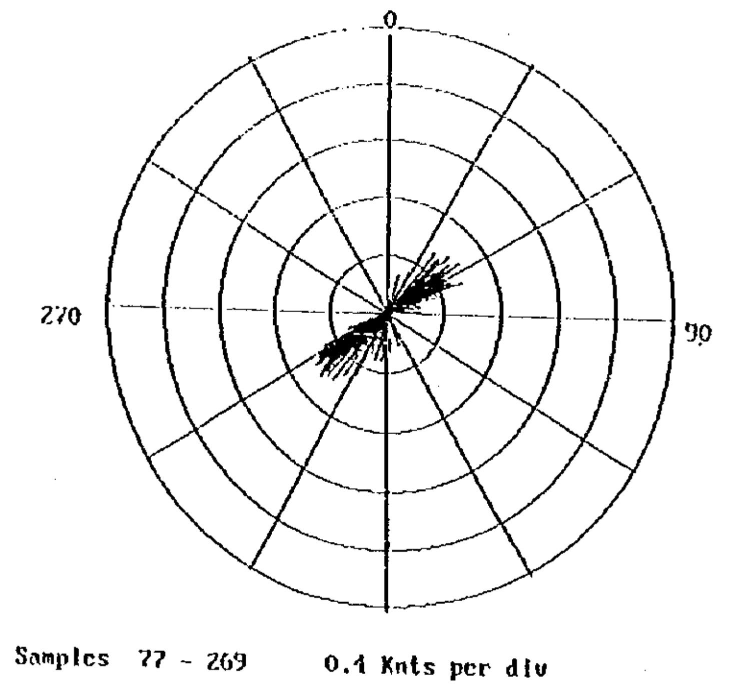


Figure 2.5.7 (2) Polar Plot and Histogram of Velocity of Current Flow

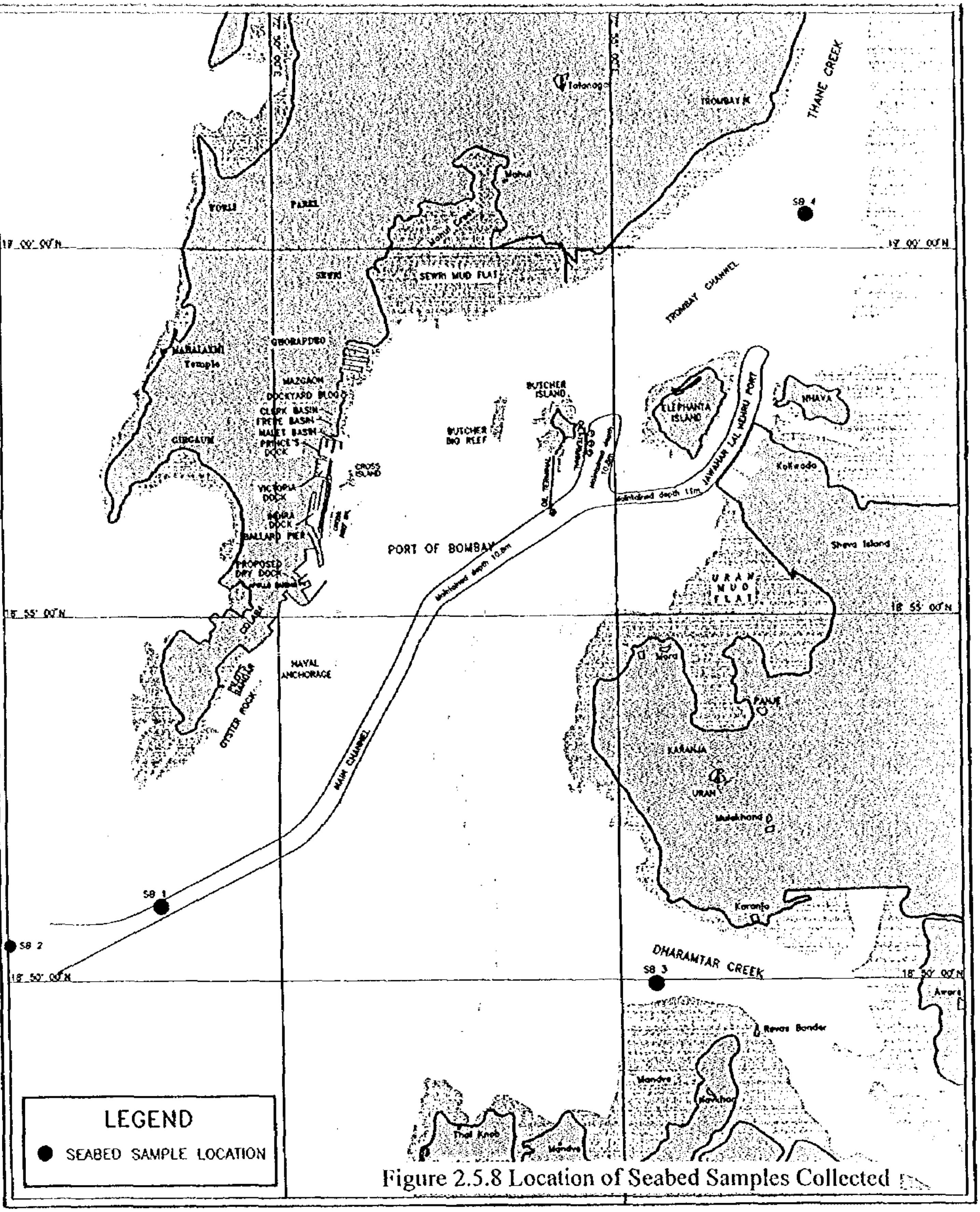


Figure 2.5.8 Location of Seabed Samples Collected

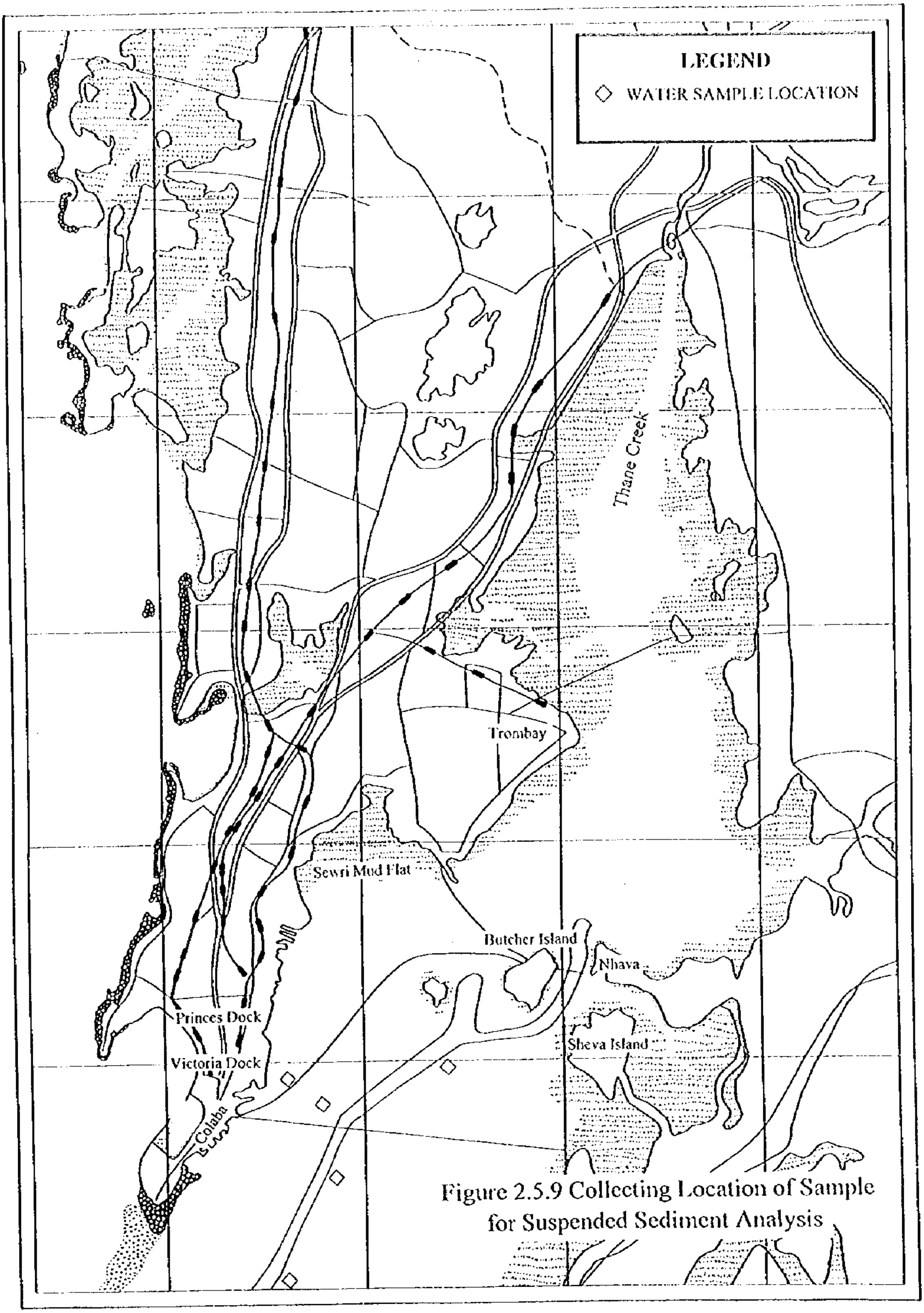


Figure 2.5.9 Collecting Location of Sample for Suspended Sediment Analysis