Chapter 2 Present Conditions of Main Ports in Sri Lanka

2.1 Port Development Policy

Ports sustain the economic and social activities of island countries like Sri Lanka. Almost all export and import cargo is transported through ports. Although air cargo volume is increasing rapidly, the share of it is marginal. Considering the importance of port and shipping sectors, Sri Lanka Government formulated the first national port development policy named "National Ports and Shipping Policy of Sri Lanka" in 1997.

The Ministry of Shipping, Ports, Rehabilitation & Reconstruction appointed a Task Force in late 1994. After long and comprehensive deliberations under the auspices of the Task Force, the Policy was finalized in 1997. The long term vision is for Sri Lanka to consolidate and further develop its position as a competitive shipping centre in the South Asia region which would result in the generation of economic activity, employment and income. Relating ports and infrastructure, macroeconomic objectives are as follows:

- Facilitate Sri Lanka's sea borne trade
- Generate economic activities and thereby enhance employment opportunities and income
- Ensure an adequate return on investment for the public sector and private sector investors

Based on the above overall objectives, development objectives of each port with the promotion of ancillary services are proposed as follows:

- Development of the Port of Colombo as a hub port in the region
- Development of the Port of Galle into a hub port with infrastructure facilities that would make it a multipurpose port.
- Development of the Port of Trincomalee to cater for bulk and break-bulk cargo and marine-related industrial activity
- Development of the Port of Kankesanthurai to handle bulk and break-bulk cargo, mainly to service the industries and the region's domestic trade
- The construction and development of a New Port at Oluvil as a coastal port to handle bulk and break-bulk cargo to meet the demands of domestic trade of the region
- The construction and development of a New Port in the vicinity of Hambantota to handle oil and dry cargo

Based on the development strategy of each port, Sri Lanka Government has been conducting construction works at Colombo Port and Trincomalee Port as described in 2.2.2 and 2.2.3. The feasibility study on Oluvil Port was already carried out and some preparation works for the construction of the Port are being done. As for Hambantota Port, the feasibility study has not been carried out yet and the Southern Development Authority is in charge of the project now. And Galle Port is now to be developed as a regional port rather than a hub port.

2.2 Colombo Port

Colombo Port is the largest port and the physical distribution center in Sri Lanka. It is famous as container hub port in South Asia.

Total container volume handled at the Port in 1999 was 1,704,000 TEUs of which 68% was transshipment containers. The total throughput of container decreased by 0.4% over 1998 and this marks the first decrease in the last 10 years. The main reason of the decline in throughput was that the SeaLand/Marsk line, which was the biggest user of the Port, shifted her container transshipment port from Colombo Port to Salalah Port in Oman, resulting in a loss of 224,000 TEUs. Nevertheless, other shipping companies such as Gold Star Shipping Line, ZIM and Evergreen increased their volume and the actual decline in container throughput was slight.

On the other hand, domestic container throughput has been increasing steadily because of the steady economic growth of Sri Lanka and the Sri Lankan Government's policy of encouraging foreign trade and foreign investment. The function of Colombo Port as the gateway of Sri Lanka and the physical distribution center is becoming more and more important.

Colombo Port also handled 6,676,000 tons of non-container cargo in 1999 including bagged sugar, bagged fertilizer, cement, iron/steel and crude oil, which are indispensable for daily life and economic activities.

Table 2.2.1 shows the cargo throughput at Colombo Port in the last 10 years and Table 2.2.2 shows that of container cargo.

To meet the increasing cargo traffic demand, Colombo Port has been continuously developed and redeveloped. Recent examples include dredging of the North Channel, construction of new CFS, redevelopment of feeder container berth and redevelopment of North Pier. Main purpose of such development is to meet the rapid increase of container traffic within the existing port boundary surrounded by breakwaters.

The first BOT project has already started, namely, the redevelopment of Queen Elizabeth Quay. The concession agreement was signed in August of 1999 after a 4-year negotiation between the Sri Lankan Government and South Asia Gateway Terminals (SAGT), which is a joint venture of SLPA, John Keells Holdings, P&O Netherlands, P&O Nedlloyd of Holland, Evergreen Group Taiwan, Asian Development Bank and the Commonwealth Development Plc. The quay will be expanded 100m toward the inner harbour side giving it a total length of 1000m and this will make it possible to accommodate 3 container vessels at once. The construction work has already started in the southern part of QEQ and SAGT started terminal operation of Queen Elizabeth Container terminal in September of 1999.

At present a feasibility study on the Southern Harbour Development of Colombo Port is being carried out with financial assistance from ADB. The project calls for the construction of Container Terminals outside the SouthWest Breakwater. The study will be completed in January of 2001.

Figure 2.2.1 shows the berth layout of Colombo Port and Table2.2.3 lists the berthing facilities of the Port.

Table 2.2.1 Cargo Throughput of Colombo Port

('000 Tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Tonnage Discharged										
1.Containerized										
(1)Containerized Local	933	973	1,176	1,400	1,628	1,847	2,018	2,450	2,806	2,866
(2)Containerized T/S	2,482	2,587	2,556	3,411	3,930	4,142	5,622	7,262	6,816	6,568
(3)Re-stow	48	42	51	59	67	81	97	155	165	129
(Sub-total)	3,463	3,602	3,783	4,869	5,625	6,070	7,737	9,867	9,787	9,563
2.Break Bulk										
(1)Cement Bags	121	161	88	216	223	516	326	409	376	446
(2)Fertilizer Bags	497	428	338	460	411	508	430	364	432	494
(3)Flour Bags	335	239	237	243	218	188	155	135	97	84
(4)Lentils Bags						35	8	7	5	
(5)Onions Bags	30	44	35			32	59	70	28	9
(6)Rice Bags	198	127	228	234	210	3	206	84	81	46
(7)Sugar Bags	287	388	372	382	343	431	385	547	333	472
(9)Iron/Steel						167	216	204	251	225
(10)M/Vehicle						54	43	54	77	71
(12)Other Break Bulk	436	467	490	514	555	249	215	195	283	227
(Sub-total)	1,904	1,854	1,789	2,049	1,960	2,183	2,043	2,069	1,963	2,074
3.Dry Bulk										
(1)Cement	304	201	322	333	403	438	535	490	515	622
(2)Clinker				10	55	48	10	44	105	113
(3)Fertilizer				17	28	15	42	31	48	32
(4)Gypsum				15	14	22	25	30	37	17
(5)Wheat	29	28				29	9			
(6)Maize						62	77	72	107	106
(7)Other Dry Bulk	111	388	177	217	103	18	6		60	11
(Sub-total)	444	617	499	592	603	632	704	667	872	901
4.Liquid Bulk										
(1)Crude Oil	1,717	1,637	1,304	1,800	1,857	1,872	2,041	1,822	2,092	1,898
(2)Fuel Oil	146	214	682	314	363	540	748	1,072	762	1,296
(3)LP Gas	17	18	31	38	51	67	70	86	99	126
(4)Palm Oil	23	28	2	66	31	22	52	57	59	60
(5)Other Liquid Bulk	5	6	0	6	8	4	5	6	13	11
(Sub-total)	1,908	1,903	2,019	2,223	2,309	2,505	2,916	3,043	3,025	3,391
TOTAL DISCHARGED	7,719	7,975	8,090	9,733	10,497	11,390	13,400	15,646	15,647	15,929
Tonnage Loaded										
1.Containerized										
(1)Containerized Local	821	844	887	1,031	1,193			1,681	1,706	1,816
(2)Containerized T/S	2,477	2,573	2,527	3,356	3,861	4,100	5,557	7,243	6,828	6,641
(3)Re-stow	47	41	50	60	62	81	98	154	162	129
(4)T/S Break Bulk	36	28	4	12	32	18	9	8	4	3
(5)T/S Dry Bulk	15									
(6)T/F Cement Bulk	40	213		90					55	
(Sub-total)	3,436	3,700	3,468	4,549	5,149	4,199	5,664	9,086	8,755	8,589
2.Break Bulk										
(1)Tea	145	170	106	89	105	45	45	39	59	24
(2)Rubber	44	21	13	11	13	3	1	1		
(3)Coconut Prod.	75	26	7	6	7	2				
(4)Coastal Service						85	2	116	92	66
(5)Other Break Bulk	109	163	116	97	115	95	124	28	63	102
(Sub-total)	373	379	241	203	240	230	172	184	214	192
3.Dry Bulk										
(1)Wheat Bran										
(Sub-total)	0	0	0	0	0	0	0	0	0	0
4.Liquid Bulk										
(1)Refined Fuel	98	98		67	90	96	79	80	20	21
(2)Naptha	75	99	77	118	97	110	112	93	128	82
(3)Coastal Service		25	41	43	33	1	1	29	20	12
(4)Other	2					26	20			
(Sub-total)	175	222	117	228	221	233	212	202	168	115
TOTAL LOADED	3,983	4,300	3,826	4,980	5,609	4,662	6,048	9,472	9,137	8,896
TOTAL TONNAGE	11,703	12,275	11,916	14,713	16,106	16,052	19,448	25,118	24,784	24,825

Source: SLPA

Table 2.2.2 Trends of Container Cargo Throughtput at Colombo Port

(TEUs)

	1985	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Import		87,917	95,197	107,033	127,405	146,636	165,158	179,632	209,973	237,570	256,776
T/S		205,525	234,791	226,489	297,051	333,529	350,865	492,455	617,652	592,647	577,805
Re-stow		5,780	5,903	6,340	7,919	8,650	10,155	13,229	19,013	21,600	19,984
DischargeTotal		**299,222**	**335,891**	**339,862**	**432,375**	**488,815**	**526,178**	**685,316**	**846,638**	**851,817**	**854,565**
(increase rate)			1.123	1.012	1.272	1.131	1.076	1.302	1.235	1.006	1.003
Export		85,122	92,986	104,898	124,494	142,839	163,096	170,168	206,824	241,128	254,842
T/S		205,247	234,728	224,724	293,603	332,311	349,627	487,427	615,033	598,510	575,123
Re-stow		5,765	5,883	6,292	7,926	8,677	10,143	13,390	18,689	22,622	19,859
Load Total		**296,134**	**333,597**	**335,914**	**426,023**	**483,827**	**522,866**	**670,985**	**840,546**	**862,260**	**849,824**
(increase rate)			1.127	1.007	1.268	1.136	1.081	1.283	1.253	1.026	0.986
Domestic Total	**103,313**	**173,039**	**188,183**	**211,931**	**251,899**	**289,475**	**328,254**	**349,800**	**416,797**	**478,698**	**511,618**
(increase rate)			1.088	1.126	1.189	1.149	1.134	1.066	1.192	1.149	1.069
T/S Total	**112,563**	**410,772**	**469,519**	**451,213**	**590,654**	**665,840**	**700,492**	**979,882**	**1,232,685**	**1,191,157**	**1,152,928**
(increase rate)			1.143	0.961	1.309	1.127	1.052	1.399	1.258	0.966	0.968
Re-stow Total	**4,331**	**11,545**	**11,786**	**12,632**	**15,845**	**17,327**	**20,298**	**26,619**	**37,702**	**44,222**	**39,843**
Total	**220,207**	**595,356**	**669,488**	**675,776**	**858,398**	**972,642**	**1,049,044**	**1,356,301**	**1,687,184**	**1,714,077**	**1,704,389**
Total (excl. restowing)	**215,876**	**583,811**	**657,702**	**663,144**	**842,553**	**955,315**	**1,028,746**	**1,329,682**	**1,649,482**	**1,669,855**	**1,664,546**
(increase rate)			1.127	1.008	1.271	1.134	1.077	1.293	1.241	1.012	0.997

Source: SLPA

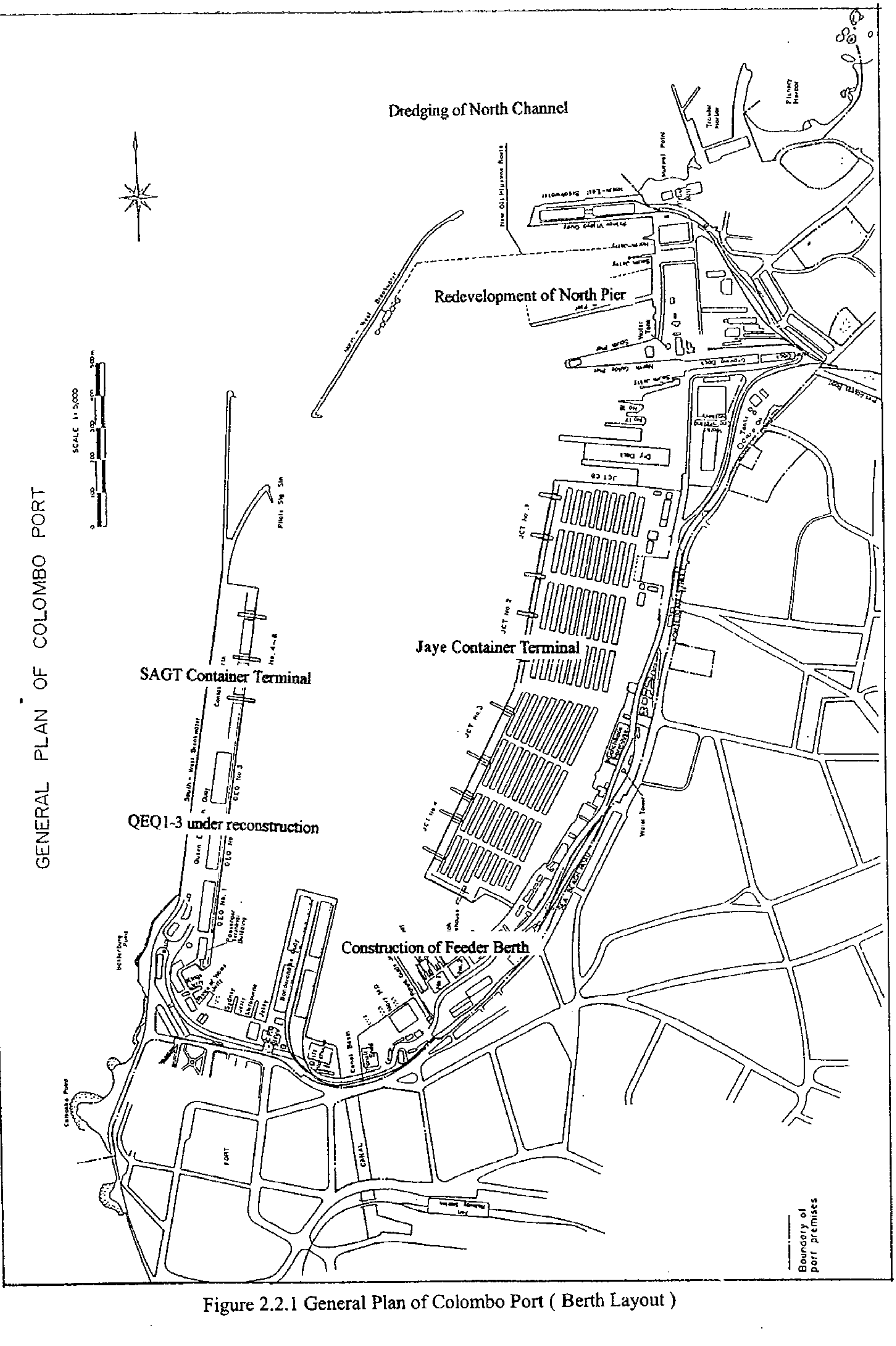


Figure 2.2.1 General Plan of Colombo Port (Berth Layout)

Table 2.2.3 Berthing Facilities at Colombo Port

Quay		Length (m)	Draft (m)	Remarks
Queen Elizabeth Quay	1	200	9.2	Under reconstruction
(SAGT)	2	200	9.8	ditto
	3	192	10.1	ditto
	No.4/5	190	9.8	3 Quay Cranes
	No.5/6	243	10.8	(No.4-6 Berths)
Bandaranayake Quay	1	163	6.5/8.5	
	2	181	9.5	
	2A	125	10.0	
	3	194	9.0	
	4	194	8.5	
	CB1	99	6.1	
	CB2	94	4.8	
Jaya Terminal	No.1	300	12.0	3 Quay Cranes
	No.2	332	13.0	3 Quay Cranes
	No.3	330	13.5	3 Quay Cranes
	No.4	330	14.0	3 Quay Cranes
	EX(N)	172	9.0	
	EX(S)	180	9.0	2 Quay Cranes
Guide Pier	1	196	7.9	
	2	167	9.2	
North Pier	1	200	9.5	
	2	165	11.0	
South Pier		234	9.5	
Prince Vijaya Quay	1	150	9.2	
	2	188	9.5	
Single Point Buoy			28.0	Offshore
Total		5,019		

Source: SLPA

2.3 Trincomalee Port

Trincomalee Port, located on the East Coast of Sri Lanka facing the Bay of Bengal, is situated at lat. 8° 31'E. long. 81° 15'E. Trinclmalee Port is a good natural harbour in the innermost part of the Trincomalee Bay. The Port has a land area of 2,036 ha and water area of 5,261 ha. Major facilities are positioned in Cod Bay, China Bay, Clappenburg Bay and Malay Cove.

Trincomalee Port is the second largest port in Sri Lanka in terms of cargo throughput. The volume of cargo handled in 1999 was 1,731,000 tons of which imported wheat represented half. Other main cargoes are imported clinker and flour and wheat barn for domestic export. Table 2.3.1 shows the cargo throughput at the Port from 1990 to 1999.

Table 2.3.2 shows the berthing facilities of the Port. At present there is no public berth. All berths are privately owned and operated. SLPA is now constructing the first public berth which will have a water depth of 13m, a berth length of 252 m and be capable of berthing 40,000 D.W.T. vessels. The berth is expected to be completed in June of 2001.

Table 2.3.2 Berths of Trincomalee Port

	Length	Draught
Prima Outer	200m	13.0m
Prima Inner	122m	5.0m
Oil Jetty	198m	9.3m
Tokyo Cement	155m	8.7m
Multipurpose	252m	13.0m

Table 2.3.1 Cargo Throughput of Trincomalee Port

(000 tons)

Commodity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Tonnage Discharged										
2.Break Bulk										
(12)Other Break Bulk	6	7	8	5	6	6	8			12
(Sub-total)	6	7	8	5	6	6	8			12
3.Dry Bulk										
(2)Clinker				204	244	224	267	326	348	437
(4)Gypsum				6	11	10	14		5	
(5)Wheat	655	670	707	830	864	1,061	871	779	892	861
(7)Other Dry Bulk	75	92	172							
(Sub-total)	730	762	879	1,040	1,119	1,295	1,152	1,105	1,245	1,298
4.Liquid Bulk										
(2)Fuel Oil				24	30	34	36	45	75	27
(Sub-total)				24	30	34	36	45	75	27
TOTAL DISCHARGED	736	768	887	1,069	1,155	1,335	1,196	1,150	1,320	1,337
2Break Bulk										
(4)Coastal Service	268	153	285	275	293	271	214	194	159	176
(Sub-total)	268	153	285	275	293	271	214	194	159	176
3.Dry Bulk										
(1)Wheat Bran	140	168	160	187	201	257	190	188	171	217
(Sub-total)	140	168	160	187	201	257	190	188	171	217
TOTAL LOADED	408	321	445	462	494	528	404	382	330	393
TOTAL TONNAGE	1,144	1,089	1,332	1,531	1,649	1,863	1,600	1,532	1,650	1,730

Source: SLPA

Chapter 3 Natural Conditions of Coastal Area Adjacent to Galle Bay

3.1 Natural Characteristics of Southern Area

This section outlines the natural characteristics of the Southwest Region of the country and compares them with the general features of other parts of the country.

3.1.1 Topography

Sri Lanka is divided topographically into four district regions: the Central Highlands ranging in elevation from 1,000 to 2,500 m; the relatively gently sloping Northern Lowlands; and the rather steep Southwest and Southeast regions.

The Southwest Region is well watered and has a topography characterized by elongated parallel ridges which are asymmetrical, that is, gently sloping toward the east and steep on the seaward side (west). The pattern of streams is similar to trelliswork and thus the system of drainage is called rectangular.

3.1.2 Soils

In Sri Lanka, the soils are grouped broadly into reddish brown earth, red-yellow podzolic soils and other soils. With the exception of the Southwest Region consisting of red-yellow podzolic soils, all the other regions are composed of reddish brown earth and other soil groups.

The red-yellow podzolic soils are well-drained, reddish to yellowish, moderately fine-textured and strongly acid soils formed on less steep slopes of mountainous terrain suitable for tea and plantation forestry serving as adequate erosion control measures.

3.1.3 Mean Temperature

The annual mean temperature in the lowlands is about 27°C with the mean daily range of 7°C to 3°C. Generally, the mean temperature tends to be higher in the northern part of the country. In the Southwest Region, the mean temperature is about 1°C lower than that in the other parts of the country during the Southwest monsoon period, the mean daily variations being as small as 3°C. Obviously, the annual rainfall pattern (Refer to 3.1.5 Annual Rainfall) of this region may influence these temperature characteristics.

3.1.4 Winds

Sri Lanka comes under the influence of the two monsoon systems in according with the formation of the Siberian High during the northern hemisphere winter, the formation of the Mascarene High during the southern hemisphere winter and the seasonal oscillation of the Equatorial Trough of low pressure. From December to February when the Equatorial Trough of low pressure is to the south of the island, Sri Lanka is under the influence of the northeast monsoon winds (Northeast Trades). From May to September when the Equatorial Trough is to the north, the Southeast Trades from the southern hemisphere cross the equator and sweep across Sri Lanka as the southwest monsoon winds. During this period relatively strong winds blow in nearly all parts of the country.

In March-April and October-November, in the coastal area mild winds blow from the sea to land (sea breeze) during the day, while mild winds blow from land to the sea (land breeze) during the night.

The main tracks of depressions and storms run on the northern sea or across the northern part of Sri Lanka and seldom pass through the southern region. The more they veer toward the south, the less they become in energy. For this reason, they usually have a minor impact on the vicinity of Galle Port.

3.1.5 Annual Rainfall

The annual amount of rainfall in the Southwest Region is much larger than the annual mean value of 1,500 mm in the northern part of the country. In the inner part of this region, in particular, the annual rainfall runs as much as 4,000 to 5,000 mm and is concentrated in the periods immediately before and after the southwest monsoon season.

3.1.6 Tides

The spring tidal range in Galle Port is 54.2 cm as against 59.0 cm in Colombo Port. The time difference in tide in relation to Colombo Port is +15 minutes. The ratio of tidal ranges between two ports is 0.92.

3.1.7 Waves

Field wave data available at Colombo Port and Galle Port since 1980 indicated that wave heights in Galle are generally about 40 cm higher than at Colombo.

The greater wave height in Galle Port presumably is attributable to swells of 1.0 to 1.5 m in height and about 15 second in period which come from S to SSW directions all year round, while in Colombo Port, located on the west coast of the country, the swells presumably are attenuated due to reflection and diffraction caused when they advance almost parallel to the coastline of the port.

3.2 Meteorology

Field observation records obtained by the Galle Observatory of the Department of Meteorology (located at lat. N 06°02 and long. E 80°13) have been analysed to compile the necessary meteorological data noted below.

3.2.1 Winds

Location of Observation:	Premises of Galle Observatory
Instrument Used:	3-cup type anemometer (manufactured by Casella)
Height of Instrument:	6 m above the ground level, which is 20 m above the Mean Sea Level

At the observatory, mean wind speeds in knots from three-minutes wind runs and eight wind directions were recorded manually by the observer every day at three-hour intervals from 0530 to 2030 hours (six times a day).

The field wind observations by the Galle Observatory of the Department of Meteorology were carried out at three different locations, and the observation records obtained are largely incomplete except 1986 to 1988.

For this reason, wind data covering the 3-year period noted were selected for the purposes of analysis on grounds that these data are derived from the same location and are relatively complete.

Frequencies of wind speed occurrence by direction have been complied for the wet and dry seasons from the field data obtained four times during the daytime. The data derived from the field observations made once each in the morning and in the evening are not used, since they are largely incomplete.

The prevailing wind direction is SW in the two monsoon seasons and this direction accounts for 56.6 % of all wind directions observed all year round and as high as 69.2 % during the southwest monsoon months. (See Table and Figure A.3.2.1)

Strong winds with speeds in excess of 20 knots have occurred in the southwest monsoon season only with a frequency of no more than 0.2 %. Annual frequencies of winds with speeds of over 10 knots and over 20 knots in the Port of Galle and Colombo are compared below.

	Over 10 knots	Over 20 knots
Galle Port	10.5 %	0.1 %
Colombo Port	38.0 %	1.0 %

Note: Observation at Colombo Port

Location of Observation:	Pilot station, Southwest Breakwater in the Port of Colombo
Instrument Used:	Electric anemograph (self-recording type)
Height of Instrument:	17.6 m above sea level

3.2.2 Temperature

The highest mean maximum daily temperature of 30.9°C is registered in March and April and the lowest value of 28.4°C in August. The lowest mean minimum daily temperature in each month varies moderately from 23.2°C to 25.7°C and the insignificant variations are comparable to those seen in the highest daily temperature.

The daily differences between the maximum and minimum temperatures are about 3.0°C to 7.0°C with the annual average difference of 5.0°C. The widest daily difference between the extremes is seen in February and March. (See Table A.3.2.2)

3.2.3 Humidity

Humidity is 80% during the daytime, however, increases to 88.6% at night. In monthly terms, daytime humidity is 72.8% in February and increases to 85.8% in August with a variation of 13%, while nighttime humidity varies from 86% in February to 91.3% in December with a variation of no more than 5%. (See Table A.3.2.2)

3.2.4 Rainfall

The annual total amount of rainfall ranges from about 1,550 mm to 2,560 mm with an annual mean value of 2,154.3 mm.

Viewed seasonally, rainfall is concentrated in April-June and September-November, that is, the periods immediately preceding and following the southwest monsoon season. These six months account for as much as 68% of the total annual amount of rainfall.

The maximum average monthly value of 304.1 mm has been registered in November as against the lowest average value of 50.7 mm in February.

The average annual number of rainy days is 174 days (approx. 48%) and the number varies from 14-20 days/month during the southwest monsoon season and periods immediately before and after it to 5-11 days/month during the northeast monsoon season. (See Table A.3.2.3)

3.3 Oceanography

3.3.1 Waves

(1) Wave Data

The following wave observation records are available for the Port of Galle and adjacent areas.

1) Offshore Wave Observation Records

Requesting agency : Coast Conservation Department (CCD)
Performed under : Joint Sri Lankan-German technical cooperation program

Period covered	: February 1989-September 1992, August-November 1993, and May 1994-September 1995
Items recorded	: Wave height, period and direction (at 3-hour intervals; 8 times/day)
Water depth of observations	: -68 m

2) Inshore Wave Observation Records

Requesting agency	: CCD and SLPA
Performed by	: Lanka Hydraulic Institute (LHI)
Period covered	: May 1984-December 1986, September 1988-December 1991, and January 1993-September 1995
Items recorded	: Wave height and period (at 3-hour intervals; 8 times/day)
Water depth of observations	: -23 m

Figure 3.3.1 shows the points where both the offshore and inshore wave observations were carried out. Of the wave measurements made during these field observations, those up to 1991 were obtained by the JICA feasibility study team for the year 1991. Hourly wave measurements after 1991 were obtained and stored on floppy discs by the current Study Team in addition to the field data up to 1991.

(2) Compilation of Field Data

1) Offshore Wave Measurements

A directional wave measurement programme was conducted along the Southern Coast of Sri Lanka during the period February 1989 to September 1995. A pitch-and-roll buoy was deployed off Galle Harbour at a depth of 70 m.

The sea climate was characterized by bimodal spectra with an all-year-round rather strong long-period swell wave component and a sea wave component. Both wave systems have different deepwater wave directions.

The wave height, period and direction data collected by the Study Team are compiled by LHI in the following way:

HMO	: Overall significant wave height in meters
HMOL	: Swell significant wave height in meters
HMOR	: Sea significant wave height in meters
DIR	: Overall wave direction (no separation between sea and swell)
DIRL	: Energy weighted mean direction of swell

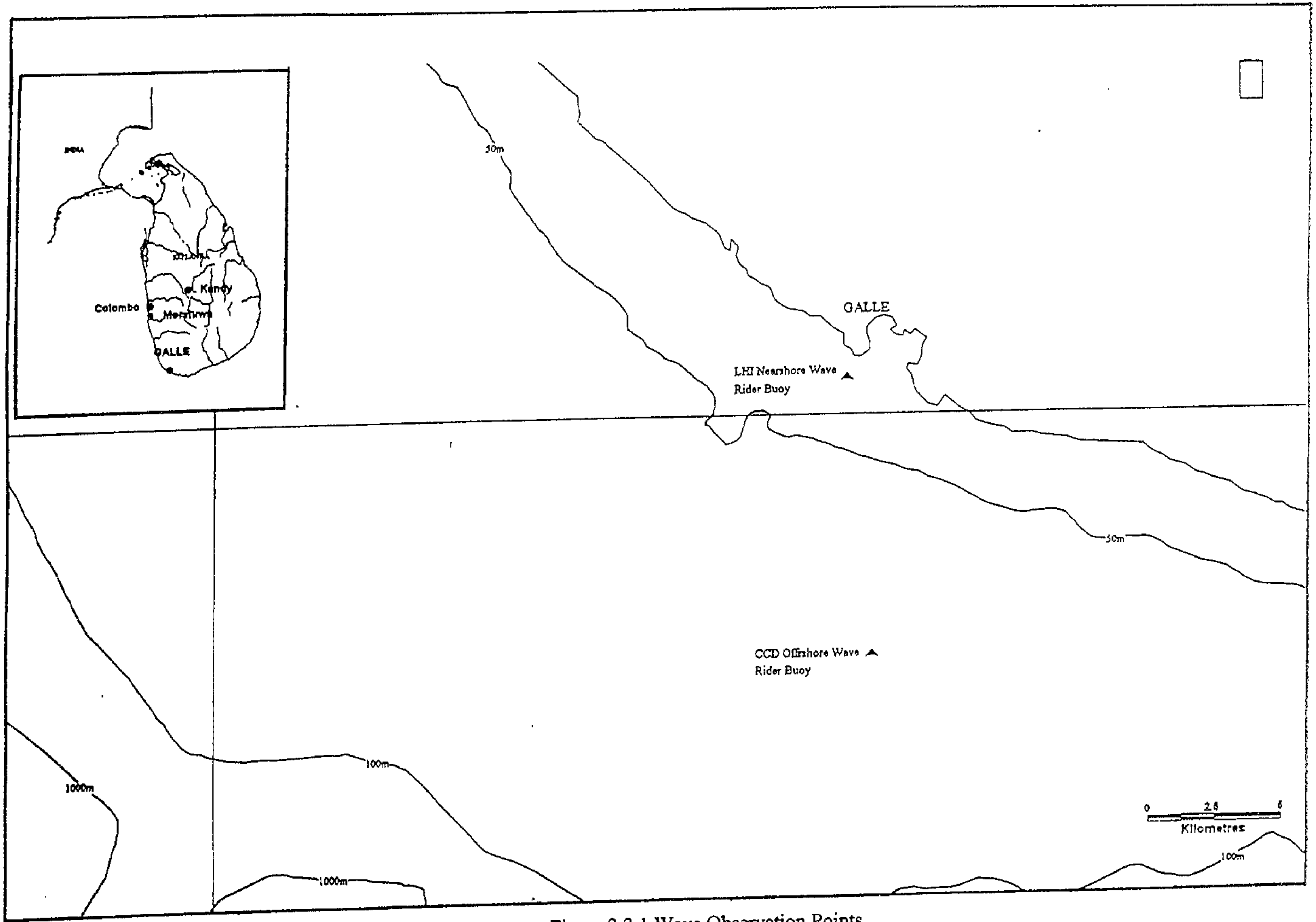


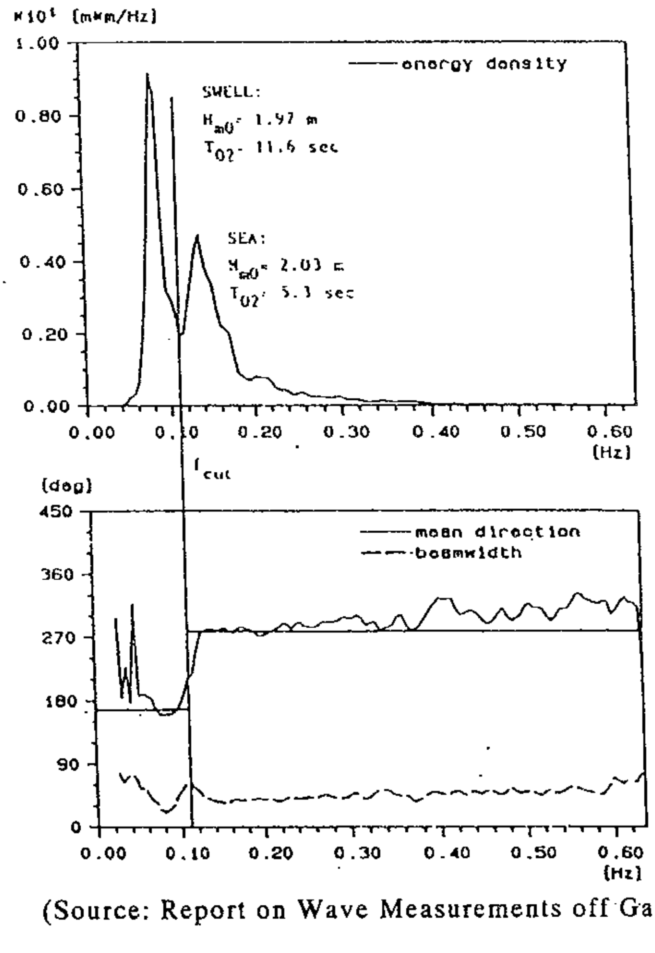
Figure 3.3.1 Wave Observation Points

DIRR : Energy weighted mean direction of sea

PKL : Mean wave frequency $1/T_{02}$ of swell in Hz

PKR : Mean wave frequency $1/T_{02}$ of sea in Hz

The method of wave data compilation as used by LHI is characterized by the separation of sea wave and swell wave components. Figure 3.3.2 gives a typical example of wave spectrum analysis made with respect to the wave data collected by the Study Team. The figure clearly shows twin-crest spectra having two predominant wave periods. From the spectra wave frequencies (periods) separating sea waves and swell waves were determined and using these wave frequencies (periods) as boundary conditions, significant wave heights, directions and average periods of wind sea and swell sea were obtained from spectral values.



(Source: Report on Wave Measurements off Galle)

Figure 3.3.2 Typical SW Monsoon Wave Spectra

2) Inshore Wave Data

The inshore wave measurements made by LHI at the request of CCD and SLPA were non-directional, and these measurements contain hourly recorded significant wave heights and average wave periods.

(3) Frequency of Wave Occurrences

From the field wave data collected by the Study Team, monthly frequencies of wave occurrences were obtained and compiled in the form of wave roses and charts.

1) Offshore Wave Data

From the significant wave heights of the overall sea state, wind sea and swell sea, wave roses showing frequencies of directional wave height occurrences have been obtained as in Figures 3.3.3, (A3.3.1 and A.3.3.2) and wave roses showing frequencies of directional wave period occurrences in Figures 3.3.4, (A.3.3.3 and A.3.3.4). With respect to wave periods, the field wave measurements showed average values, but for the purpose of the present Study the following conversion was made pursuant to the Japanese standards (Technical Standards for Port and Harbour Facilities in Japan, April 1999), since it is general practice in the Japanese profession to express wave periods in significant wave periods.

$$T_{1/3} = 1.2\ T_{02} \text{ (average wave period)}$$

The wave period of the overall sea state was obtained by the following equation in compliance with the Japanese standards.

$$T_{1/3}=k\{(H1^2+H2^2)/(H1/T1)^2\}^{0.5}$$

$$k=1.0+\alpha\,(R_H/\mu)-9.121A\ln(R_H/\mu)$$

$$\alpha=0.08(\ln R_T)2-0.15\ln R_T$$

$\mu=0.0632+0.144\ln R_T$	:	$0.1\leqq R_T\leqq 0.8$
0.6	:	$0.8\leqq R_T< 1.0$
$A=13.97+4.33\ln R_T$	:	$0.1\leqq R_T\leqq 0.4$
10.0	:	$0.4\leqq R_T< 1.0$

$R_H = H_1/H_2$

$R_T = T_1/T_2$

where			
	$T_{1/3}$	:	Composite wave period
	H_1, H_2	:	Significant wave height of wave group 1 and wave group 2 (m)
	T_1, T_2	:	Significant wave period of wave group 1 and wave group 2 (s)

For year-round overall sea waves, the frequency of occurrences was 85% for wave heights of 1 m or more, about 33% for wave heights of 2.0 m or more, and about 2% for wave heights of 3.0 m or more. In terms of wave directions, SSW had the highest frequency of occurrences, followed by SW and S in that order. W and S showed greater frequencies of occurrence of high waves. Wave periods of in the neighbourhood of 8.0 sec showed a higher frequency. Considered on a monthly basis, basis, SSE waves were

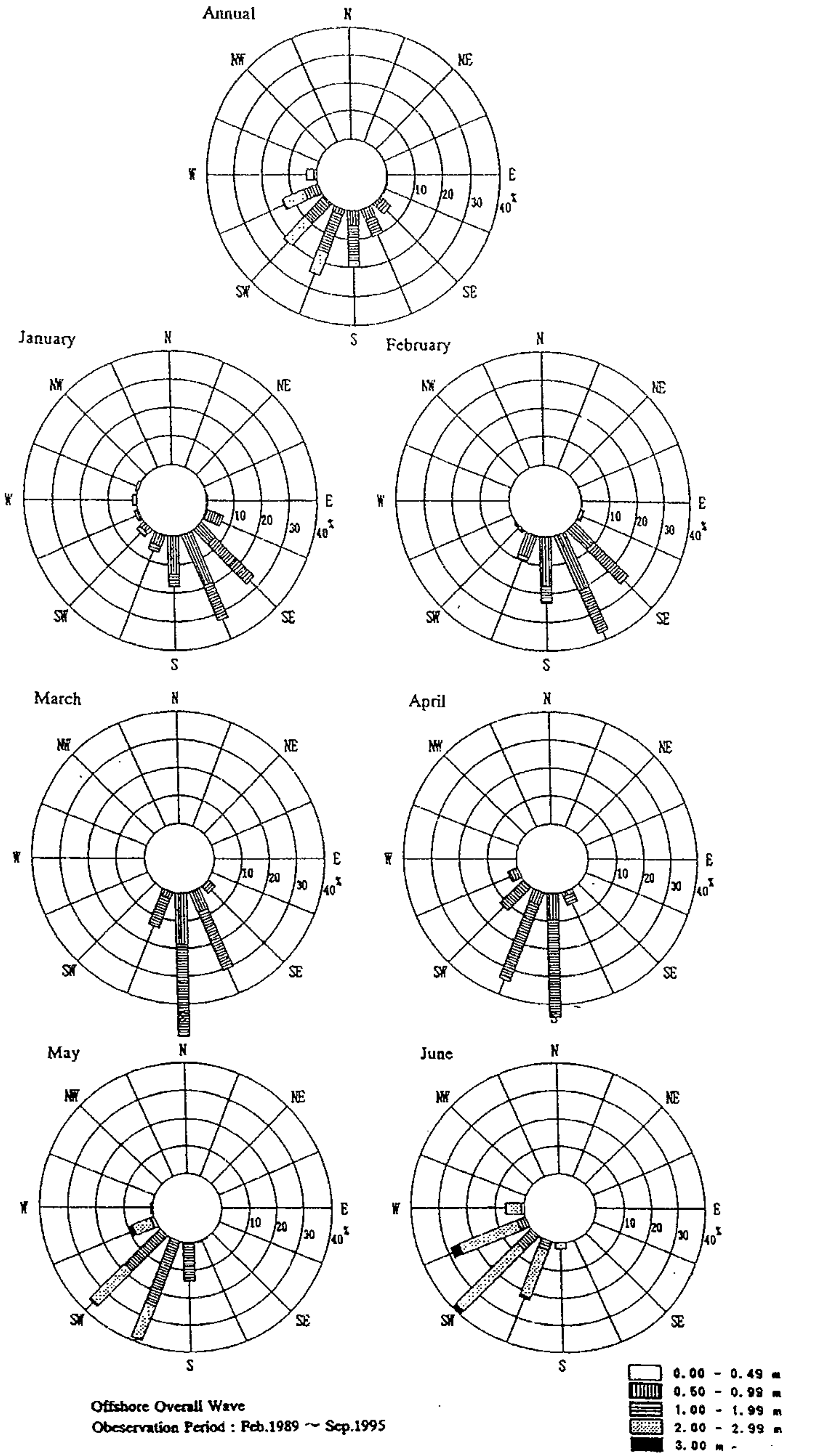


Figure 3.3.3 (1) Distribution of Significant Wave Height and Direction (Offshore Overall Wave)

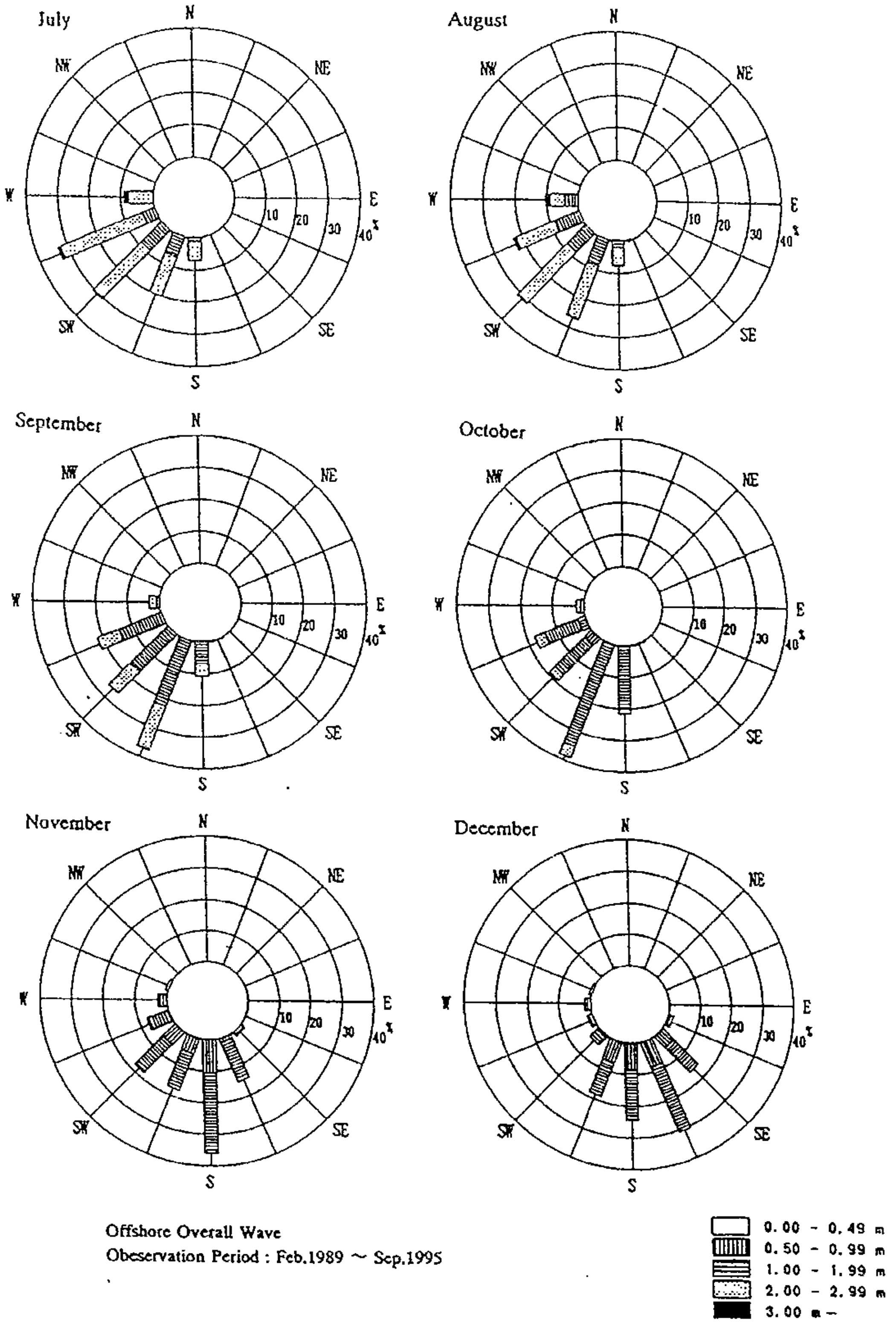


Figure 3.3.3 (2) Distribution of Significant Wave Height and Direction (Offshore Overall Wave)

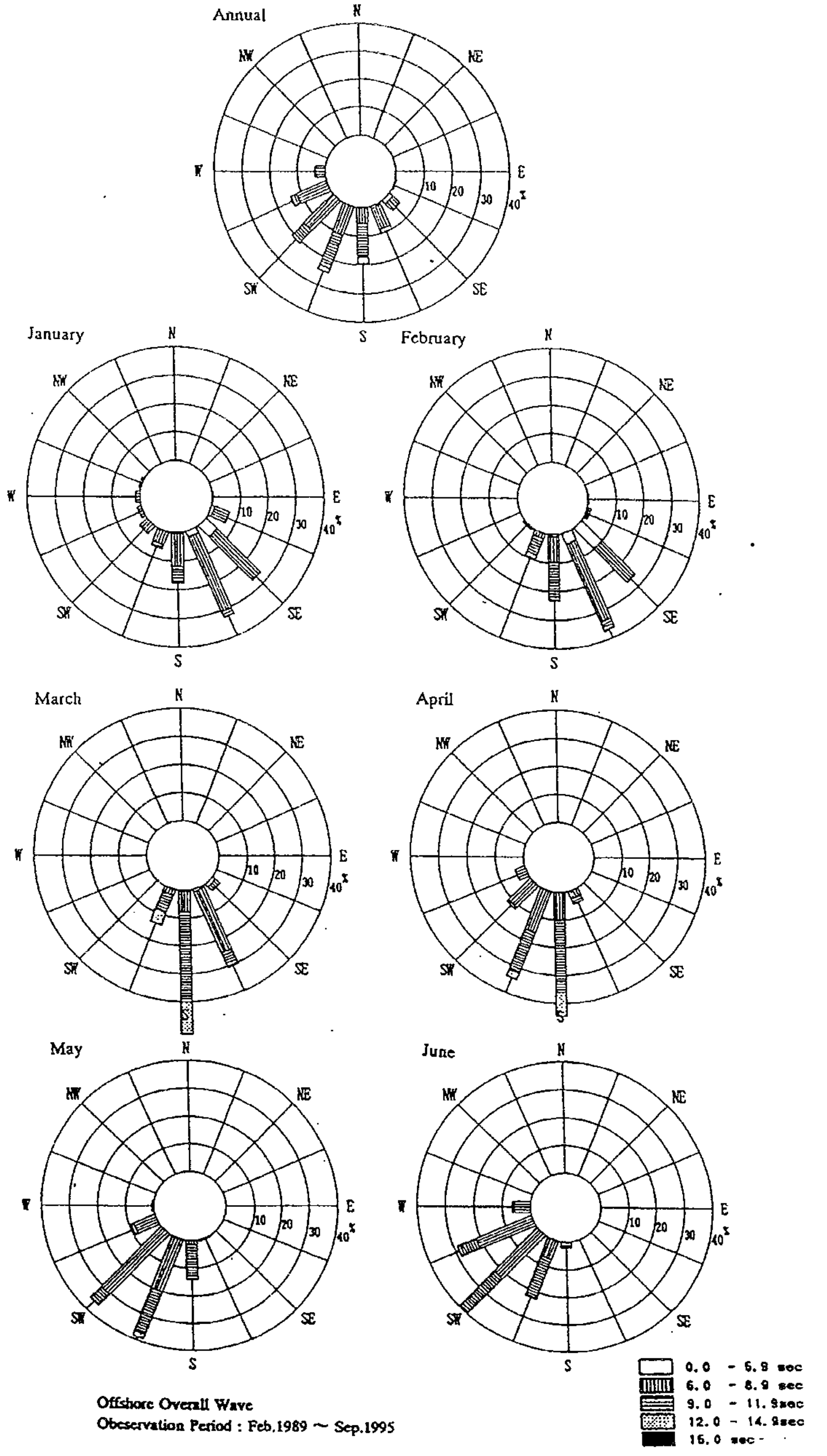


Figure 3.3.4(1) Distribution of Significant Wave Period and Direction (Offshore Overall Wave)

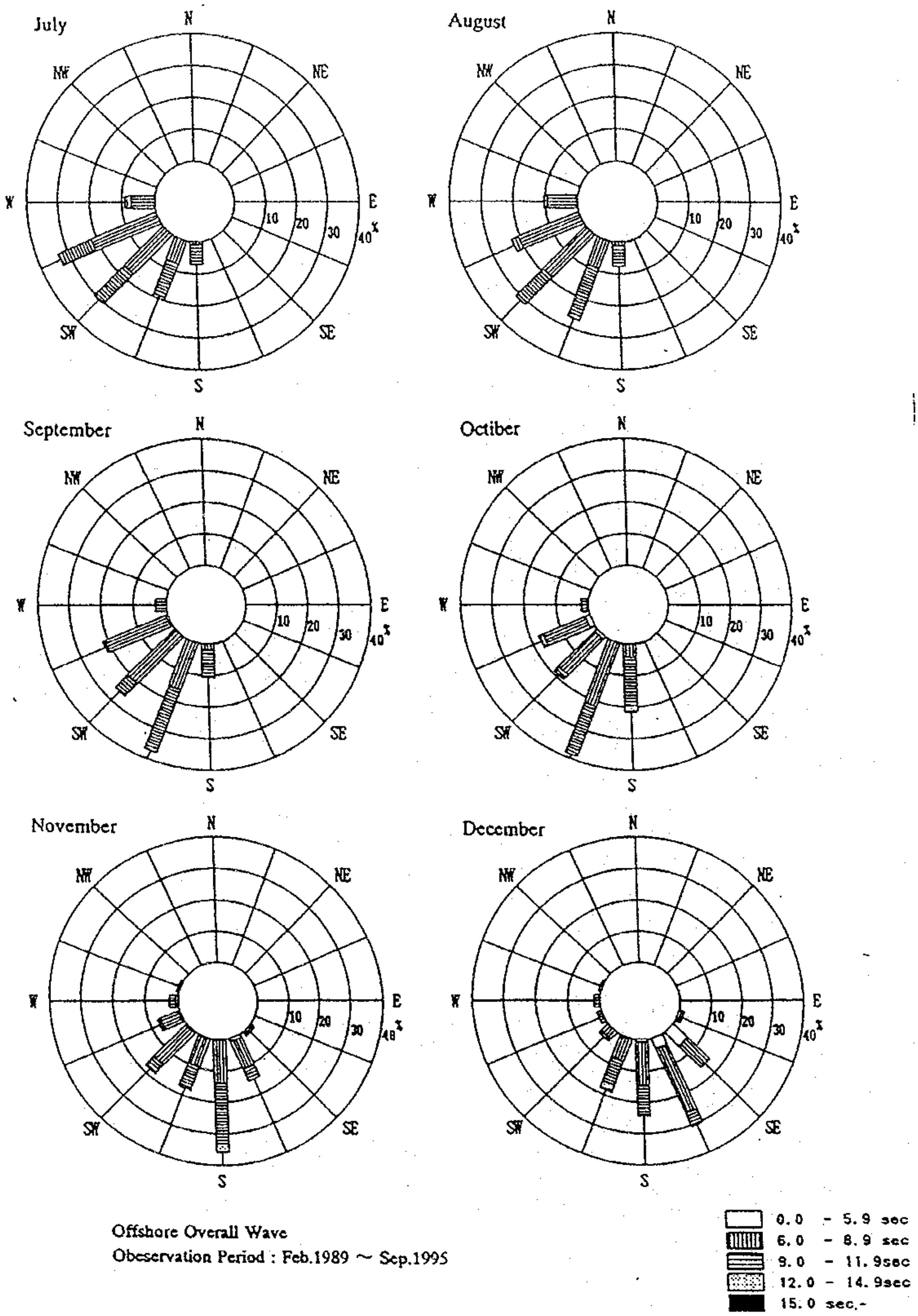


Figure 3.3.4(2) Distribution of Significant Wave Period and Direction (Offshore Overall Wave)

prevailing during the December-February period, but they were generally less than 2.0 m in height. Over the May-October period, waves higher than 3.0 m were recorded from W to SSW directions.

For wind waves all year round, the frequency of occurrence was about 57% for wave heights of 1.0 m or more, about 11% for wave heights of 2.0 m or more, and about 0.6% for wave heights of 3.0 m or more. In terms of wave directions, WSW showed the highest frequency of occurrence, followed by W and SW in the order mentioned. High waves were recorded from W and WSW. Wave periods of about 5.0 sec registered higher frequencies of occurrences. Taken on a monthly basis, SE and ESE waves were prevailing, but with a height of less than 2.0 m. Over the May-October period, waves higher than 3.0 m were recorded from W to WSW.

For swell waves all year round, the frequency of occurrences was approximately 53% for wave heights of 1.0 m or more and about 6% for wave height of 2.0 m or more. Higher swell waves than 3.0 m or more were not recorded. With regard to wave directions, S showed the highest frequency of occurrences, followed by SSW. The wave directions ranged from SW to SSE with S in the middle. The most frequent wave period was 14.0 sec. Taken on a monthly basis, the wave directions did not vary from month to month. With regard to wave height, however, higher waves were recorded during the June-August period.

2) Inshore Wave Data

Significant wave heights and average wave periods were the main items of the inshore wave measurements compiled by LHI. Figures 3.3.5 (A.3.3.5) present monthly frequencies of wave height and period occurrences compiled from the inshore measurements. The wave period values are converted to significant wave periods as in the case of the offshore wave data.

Considered on an annual basis, the frequency of occurrences was approximately 62% for wave heights of 1.0 m or more, about 6% for wave heights of 2.0 m or more, and about 0.2 % for wave heights of 3.0 m or more. The inshore wave data showed a lower frequency of high waves than the overall sea waves recorded in the offshore measurements. The most frequent wave period was in the neighbourhood of 7.0 sec. Taken on a monthly basis, wave heights were smaller over the December-February period, but tended to increase during the May-October period --- the same trend as seen from the offshore wave data.

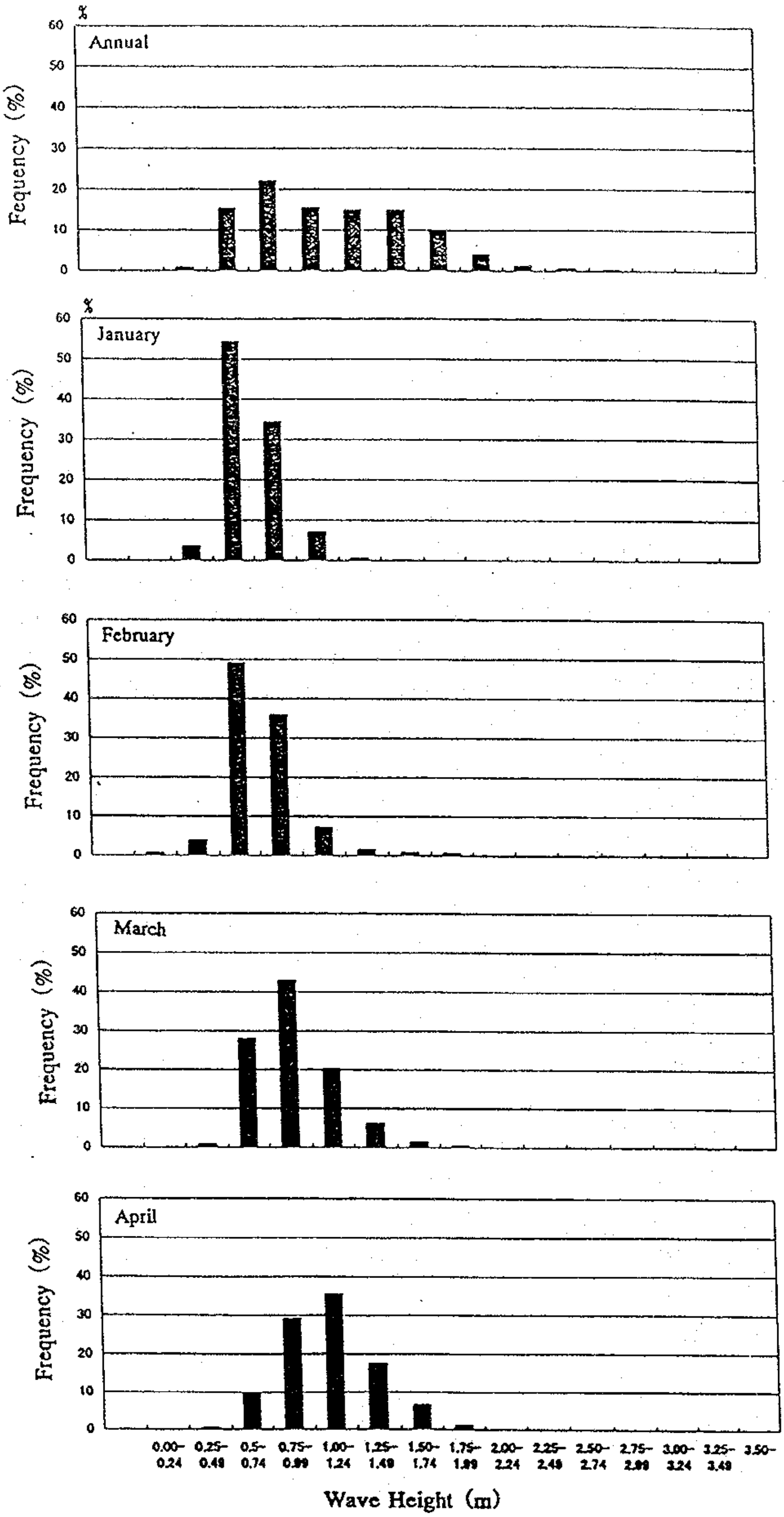


Figure 3.3.5(1) Distribution of Significant Wave Height (Nearshore Wave)

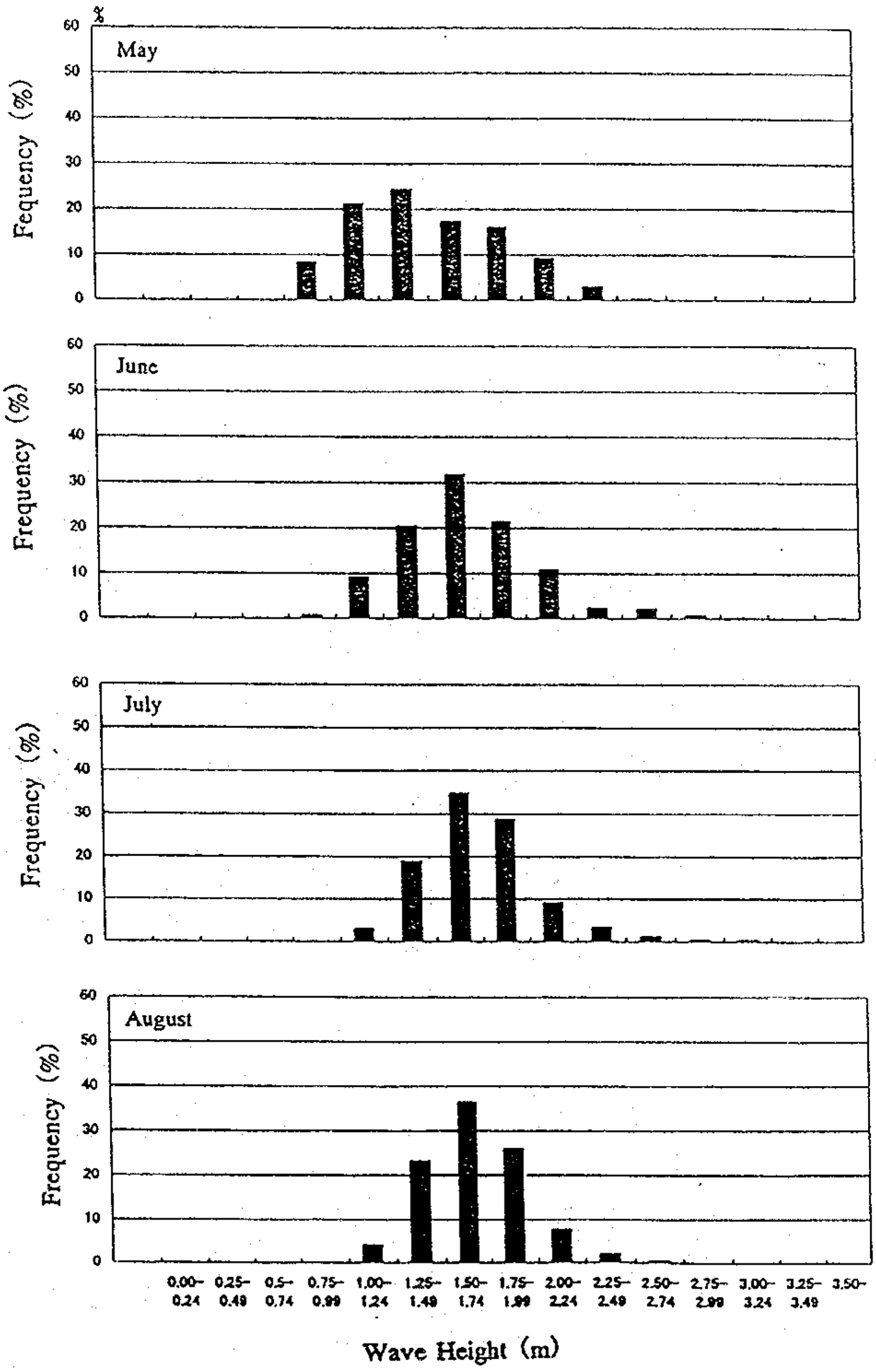


Figure 3.3.5(2) Distribution of Significant Wave Height (Nearshore Wave)

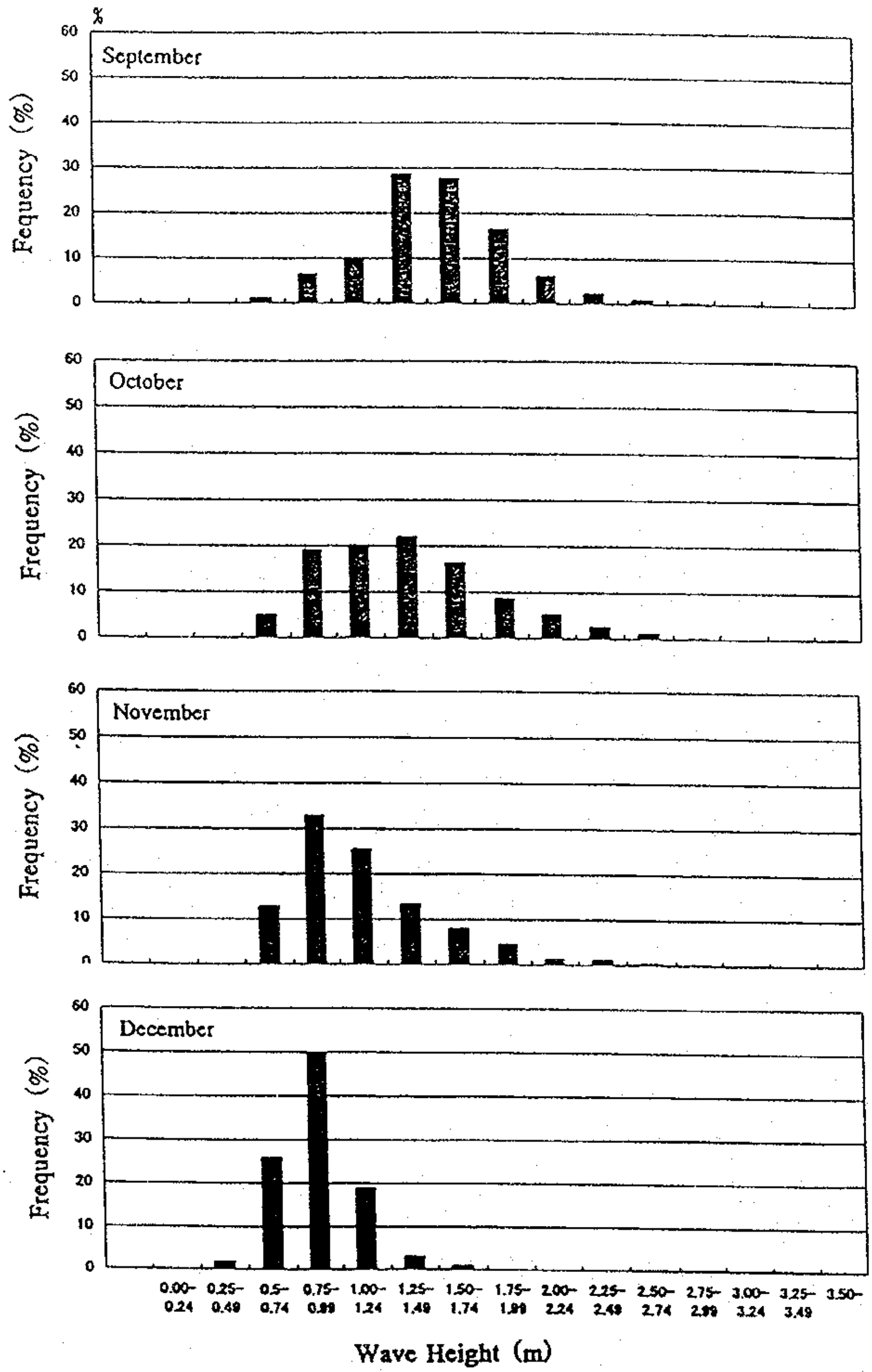


Figure 3.3.5(3) Distribution of Significant Wave Height (Nearshore Wave)

(4) Establishment of Design Wave Parameters

1) Calculation of Deepwater Wave Height with Exceedance Probability

a) Selection of Wave Data for Calculation

The Technical Standards for Port and Harbour Facilities in Japan (April 1999 edition), copyrighted by the Ports and Harbours Bureau, Ministry of Transport, and the Port and Harbour Research Institute, MOT, recommends the use of field wave data covering a period of 10 years or more for determining design wave parameters. The offshore wave measurements obtained during the present Study covers a period of about 6.5 years, while the inshore wave measurements made during the same study pertain to a period of about 9.5 years. By the MOT technical standards the inshore wave measurements are preferable for the purpose of establishing the design wave parameters. However, since these measurements do not include wave direction data essential for the purpose mentioned, both the offshore and inshore wave measurements have been used for computing design wave parameters with exceedance probability.

b) Selection of Maximum Wave

i) Offshore Wave Data

From the offshore wave measurements were picked out for different wave directions the maximum waves in which significant wave heights were in excess of a reference value. The wave directions chosen from the direction-wise wave height frequency distribution chart of Figure 3.3.3 are W, WSW, SW, SSW, and S, all of which showed a greater frequency of occurrence of high waves. The following were taken for reference wave heights from the frequency of wave height occurrences in the field wave measurements.

For wave directions W and S: $H_{1/3}$ = 2.0 m or more

For wave directions WSW, SW, and SSW: $H_{1/3}$ = 2.5 m or more

With respect to the offshore wave measurements, overall, sea and swell wave conditions were analysed to define the characteristics of the waves observed at the observation station. The analysis indicated the tendency of swells to show relatively large values. The study of Tanimoto et al. concerning the method of calculating the force and design period of twin-crest spectrum wave acting on composite breakwaters (Port and Harbour Research Institute Bulletin Vol. 25, No. 2, 1986) is available for analysing the characteristics of the twin-crest spectrum waves of overall sea state (wind sea and swell sea) in relation to breakwater stability. The study just mentioned shows that once an appropriate composite wave period is determined, the wave height of overall sea state (wind sea and swell sea) indicates that in this case the same wave force as ordinary waves acts.

As discussed above, in selecting maximum wave parameters from the available field wave data to establish design wave parameters for analysis of breakwater stability, the wave height of overall sea state (wind sea and swell sea) was used and a composite wave period was also taken for that purpose.

Table 3.3.1 presents the characteristics of maximum waves chosen from the field wave measurements for the 1989-1995 periods and collated according to wave directions. The maximum wave parameters are the peak wave values attained during the period when significant wave heights exceeded a predetermined reference wave height.

ii) Inshore Wave Data

Selection of maximum waves was made in respect of the inshore wave measurements taken during the current Study.

Table 3.3.2 gives the maximum wave characteristics selected from the inshore wave measurements for the 1984-1995 periods in the same way as in the case of the offshore wave measurements. The reference wave height taken for the selection was assumed as follows:

All inshore wave data: $H_{1/3} = 2.0$ m or more

c) Calculation of Probability Wave Parameters

i) Method of Calculation

Appropriate probability wave parameters were calculated through statistical processing of maximum wave values chosen from the field wave measurements. The calculation procedure involved fitting the Gumbel and Weibull probability distribution functions to a long-term wave height distribution to find the function best fit to the input data and extrapolating an estimated relational equation to determine probability wave heights with different return periods.

ii) Calculation Results

Tables 3.3.3 to 3.3.7 give the probability wave heights according to different wave directions calculated on the basis of the offshore wave measurements. Table 3.3.8 presents the direction-classified probability wave heights determined on the basis of the inshore wave measurements. The wave period values for the probability wave parameters obtained were computed from the correlations between the heights and periods of the maximum waves chosen.

The wave direction generating the greatest wave height among the probability waves determined from the offshore observation records was WSW and the 50-year wave had the following characteristics:

$H_{1/3} = 6.5$ m

$T_{1/3} = 12.3$ sec

Table 3.3.1 (1) Extreme Waves of Offshore Wave Data

Year/Month/Day	Extreme Waves									
	W		WSW		SW		SSW		S	
	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$
1989/04/27-04/27									2.34m	10.2s
05/20-05/25			3.12m	8.1s	2.99m	8.3s				
05/28-05/31			3.30	7.9	2.82	9.6				
06/03-06/06			2.65	8.4	2.59	8.6				
06/11-06/14			3.64	10.1	2.70	10.5				
06/17-06/18	2.18m	7.4s								
06/22-06/25					2.73	10.4	2.90m	11.9s		
07/01-07/03					2.76	9.4	2.76	10.0		
07/07-07/07									2.19	9.3
07/10-07/28	3.49	9.1	3.49	9.2	3.22	9.7	2.93	11.5		
08/04-08/04									2.05	8.8
08/05-08/06							2.52	9.1	2.41	9.3
08/10-08/12	4.27	8.9	4.17	8.7						
08/14-08/15					2.53	9.5	2.62	9.8		
08/19-08/25	2.77	8.2	2.89	7.5	2.87	10.9	3.16	12.1		
09/08-09/10										
09/11-09/21	2.59	7.7	2.83	7.8	3.07	8.5				
09/25-09/25									2.13	8.5
10/05-10/07			2.90	7.7	2.88	8.2	2.58	9.0		
1990/01/06-01/06	2.01	6.7								
05/16-05/18							2.69	9.2	2.45	9.0
05/19-05/25	2.52	10.3	2.79	10.9	3.33	7.2	2.58	11.2		
06/01-06/05	3.13	8.3	2.96	7.8						
06/07-06/10			3.14	9.0	3.64	10.8	3.16	10.8		
06/12-06/12									2.54	10.1
06/13-06/16					2.66	8.5	2.51	9.9		
06/18-06/24			2.60	8.8	2.91	11.2	2.52	10.7		
06/30-07/04	2.96	7.0	3.20	7.3						

Table 3.3.1 (2) Extreme Waves of Offshore Wave Data

Year/Month/Day	Extreme Waves									
	W		WSW		SW		SSW		S	
	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$
1990/07/06-07/08	2.23m	8.8s								
07/16-07/20									2.39m	12.2s
07/29-08/03	2.72	9.3	2.84m	9.3s						
08/05-08/08			2.57	9.3	2.87m	8.6s				
08/13-08/16			2.71	7.5			2.58m	9.7s		
08/23-08/25							2.51	10.3	2.46	10.8
08/27-08/27	2.50	8.0								
09/02-09/02									2.35	11.4
09/19-09/19	2.21	7.4								
09/21-09/21	2.15	7.5								
1991/05/29-06/08			5.51	10.0	4.93	9.8				
07/05-07/08									2.59	11.8
07/10-07/12							3.12	12.0	2.32	10.0
07/19-07/22	3.25	9.0	2.73	9.2						
07/25-08/06			3.76	8.0	3.10	8.7	2.67	8.4	2.64	10.9
08/16-08/20	2.92	7.5	2.87	7.6	2.67	7.8				
08/22-08/25					2.89	7.2	2.59	9.7	2.57	10.2
08/29-08/29	3.26	7.7	2.74	6.8						
09/08-09/09					2.51	9.8				
09/14-09/15									2.11	12.1
09/17-09/19									2.29	10.6
10/04-10/04									2.14	8.3
10/06-10/08									2.46	13.1
10/27-10/31	2.99	7.4	2.70	7.4	2.57	7.5				
1992/05/11-05/11					2.53	8.5				
05/18-05/20					3.19	9.2	3.33	9.1		
05/21-05/22							2.60	11.2		
06/02-06/03					2.87	7.5				

Table 3.3.1 (3) Extreme Waves of Offshore Wave Data

Year/Month/Day	Evtreme Waves									
	W		WSW		SW		SSW		S	
	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$
1992/06/12-06/14	2.91m	8.3s	2.66m	8.3s						
06/16-06/18			2.90	8.7	2.87m	9.4s				
06/20-06/27	2.83	8.1	2.60	9.1	2.79	11.3	3.08m	12.5s		
07/02-07/02			2.51	7.0						
07/15-07/17	3.24	7.8	3.08	8.6						
07/18-07/23	2.85	8.7	2.85	10.3	3.11	11.1				
07/25-08/01	2.51	7.9	3.61	12.6	3.94	12.8	2.64	9.7		
08/04-08/10	3.52	10.0	3.06	10.1						
08/22-08/23	2.14	7.6								
08/29-09/03			3.02	7.9	2.70	8.2	2.63	8.1		
1993/08/29-08/30	2.22	7.0								
10/08-10/09			2.54	7.0						
11/08-11/09			4.67	9.5						
1994/05/20-05/22							2.72	10.7		
05/24-06/11	3.66	7.4	3.07	8.6	3.33	8.9	2.90	9.3		
06/14-06/16	2.38	9.8								
06/18-06/25					3.55	9.5	2.98	13.0	2.20m	8.8s
06/30-07/05			2.72	9.1	2.58	9.7	2.69	10.0		
07/12-07/16									2.66	9.8
07/17-07/17	3.40	7.1								
07/23-07/24					2.66	11.2	2.59	11.4		
07/27-07/28			2.58	7.6	2.63	8.5				
07/28-08/08	4.45	8.1	3.13	8.2	3.19	11.8	3.23	12.5		
08/10-08/15							2.60	12.8	2.40	11.3
09/02-09/07			2.59	7.6	2.51	7.8			2.45	12.0
09/09-09/10					2.64	9.1	2.70	9.9		
09/14-09/17							3.35	11.7		
09/23-09/24									2.25	11.6

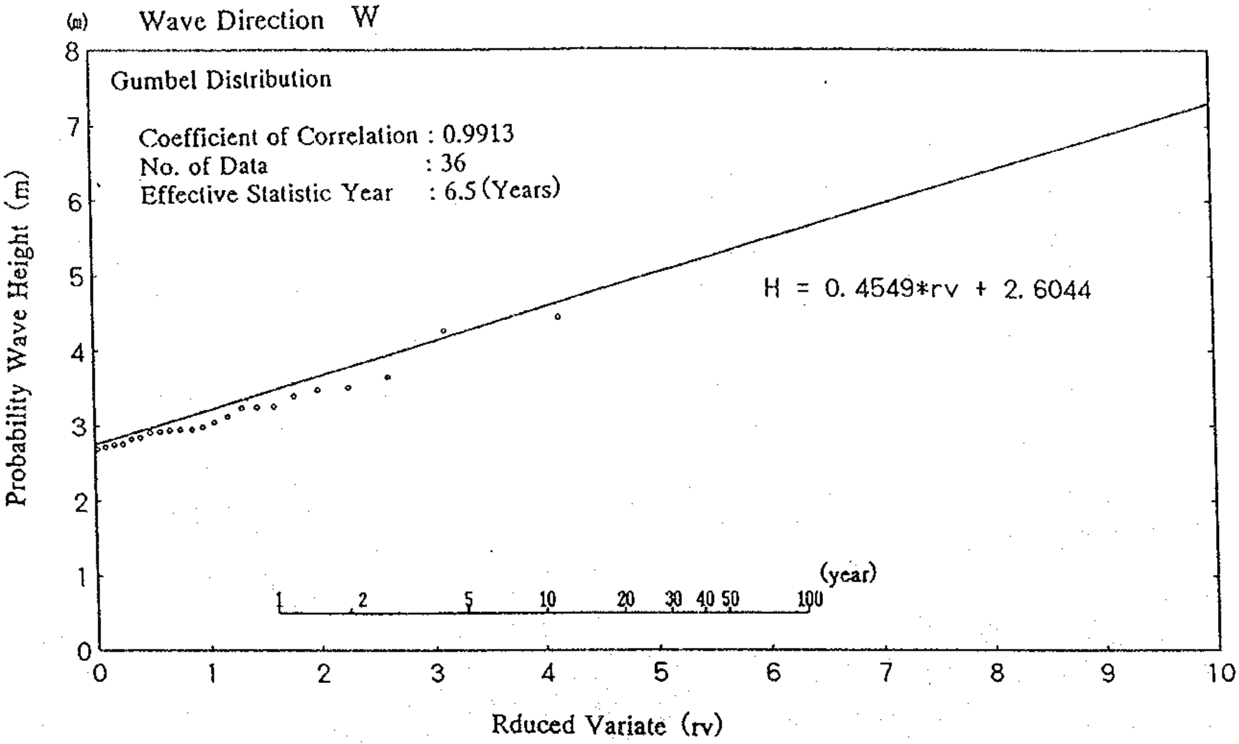
Table 3.3.1 (4) Extreme Waves of Offshore Wave Data

Year/Month/Day	Extreme Waves									
	W		WSW		SW		SSW		S	
	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$	$H_{1/3}$	$T_{1/3}$
1994/10/14-10/16									2.38m	11.6s
11/07-11/09									2.17	14.1
1995/04/14-04/15									2.18	11.2
05/06-05/13			3.21m	7.4s	3.32m	7.9s				
05/14-05/17					2.92	7.2	2.57m	7.9s		
06/02-06/06					3.20	9.3	2.74	9.3		
06/06-06/18	3.05m	7.9s	3.35	8.5	3.09	9.9	3.22	11.5	2.82	9.8
06/18-06/19	2.34	7.4								
06/21-06/22					2.58	9.0	2.57	9.9		
06/29-07/03			3.28	7.9	3.22	9.2	2.51	8.1	2.10	9.9
07/06-07/19	2.69	8.6	3.13	9.9	2.97	9.6	2.98	10.6		
07/21-07/26			2.74	10.3	2.84	11.9	2.66	10.3	2.33	10.2
07/30-07/30			3.22	7.6	2.75	6.9	2.56	7.2		
08/07-08/13							2.50	10.3	2.68	10.8
08/14-08/16							2.78	9.0		
08/17-08/27			3.16	9.6	3.27	9.8	3.03	9.4		
08/28-08/30	2.76	8.3								
08/30-09/02	2.96	8.7								
09/03-09/05	2.95	8.2								
09/08-09/10							2.93	11.3		

Table 3.3.2 Extreme Waves of Nearshore Wave Data

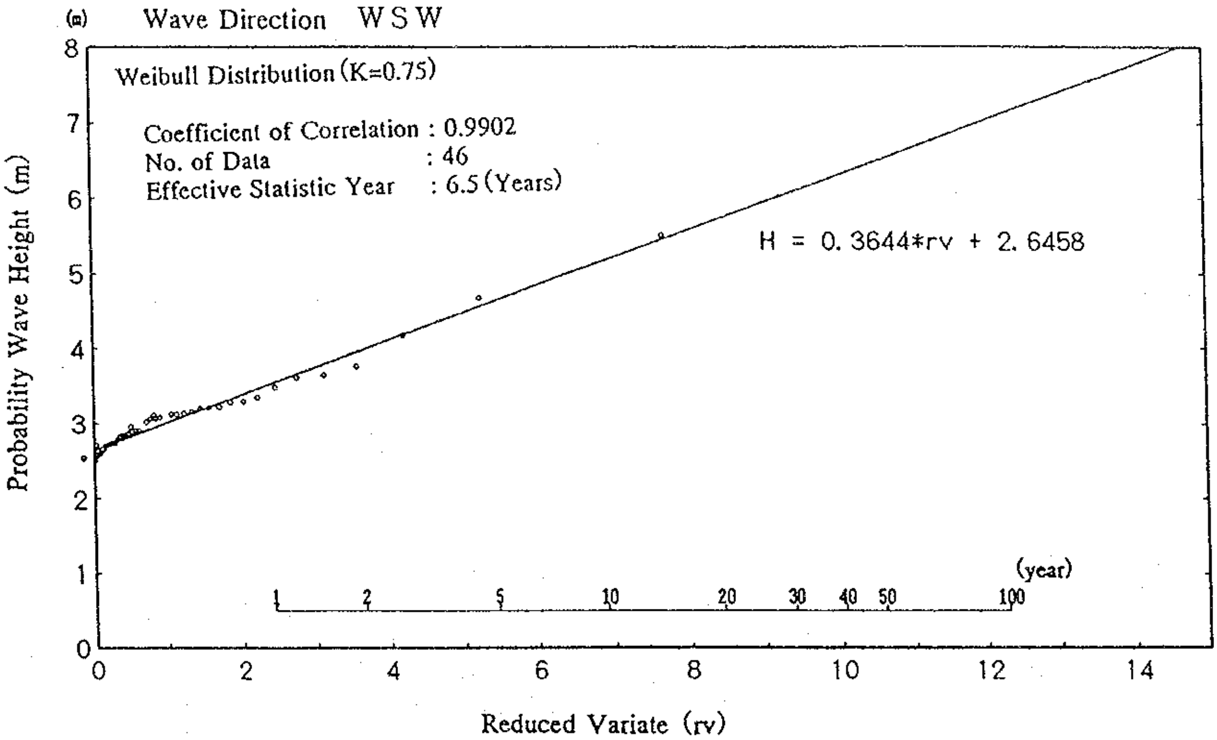
Year/Month/Day	Extreme Waves		Year/Month/Day	Extreme Waves		Year/Month/Day	Extreme Waves		Year/Month/Day	Extreme Waves	
	$H_{1/3}$	$T_{1/3}$		$H_{1/3}$	$T_{1/3}$		$H_{1/3}$	$T_{1/3}$		$H_{1/3}$	$T_{1/3}$
1984/06/01-06/04	2.41m	7.3s	1985/10/09-10/10	2.39m	9.8s	1990/06/16-06/16	2.16m	9.0s	1991/09/28-09/30	2.37m	8.5s
06/11-06/17	2.69	9.2	10/16-10/16	2.18	7.9	06/19-06/23	2.45	9.8	10/06-10/07	2.46	9.5
06/21-06/23	2.11	8.7	11/07-11/07	2.03	8.1	07/01-07/04	2.42	7.6	1993/05/30-05/31	2.53	8.0
07/01-07/03	2.32	7.4	11/11-11/12	2.91	7.8	07/08-07/13	2.61	6.9	06/03-06/03	2.17	7.9
07/06-07/06	2.18	8.7	1986/05/01-05/04	2.46	8.4	07/29-07/30	2.15	7.8	06/27-06/30	2.59	7.4
07/11-07/13	2.66	7.4	08/03-08/04	2.61	7.8	08/04-08/04	2.06	11.7	07/03-07/03	2.04	6.8
07/28-07/31	2.47	9.5	08/22-08/25	2.11	8.3	08/07-08/07	2.19	9.9	07/15-07/16	2.59	8.2
08/05-08/10	2.33	10.0	09/26-09/26	2.05	7.2	08/15-08/15	2.01	8.4	07/18-07/21	2.55	10.5
09/02-09/04	2.09	8.7	09/29-09/30	2.14	6.7	08/23-08/23	2.08	9.4	08/10-08/10	2.01	9.4
09/26-09/30	2.33	7.7	10/25-10/26	2.25	11.1	08/27-08/31	2.37	9.8	08/31-08/31	2.02	8.2
10/01-10/06	2.81	8.7	10/28-10/28	2.40	9.1	09/05-09/05	2.11	9.6	10/07-10/09	2.49	7.5
10/08-10/10	2.92	10.1	1988/09/02-09/04	2.20	5.8	09/13-09/14	2.21	8.7	10/11-10/11	2.07	7.2
1985/04/21-04/21	2.16	12.4	09/07-09/08	2.73	6.4	09/25-09/26	2.14	8.4	10/27-10/27	2.06	12.7
05/29-05/30	2.12	8.7	09/14-09/22	2.99	7.1	10/03-10/03	2.02	10.5	11/07-11/09	3.68	10.0
06/05-06/05	2.18	8.4	09/30-10/04	2.61	5.8	10/19-10/19	2.14	12.8	1994/05/15-05/16	2.26	9.4
06/10-06/10	2.10	9.7	10/06-10/08	2.14	4.2	10/22-10/24	2.27	9.4	05/20-05/29	2.39	9.2
06/14-06/14	2.14	7.5	11/10-11/10	2.25	7.6	11/01-11/04	2.51	8.5	06/27-07/04	2.59	7.4
06/19-06/25	2.63	7.7	1989/05/23-05/24	2.35	8.6	1991/04/11-04/11	2.02	12.0	07/21-07/24	2.63	10.3
06/28/07/02	3.68	12.3	06/03-06/03	2.11	8.3	05/26-06/08	4.32	10.5	07/27-08/03	3.07	7.9
07/08-07/08	2.10	9.7	06/12-06/14	2.59	9.8	06/12-06/13	2.61	10.4	08/05-08/07	2.82	9.9
07/14-07/14	2.07	7.6	06/22-06/24	2.27	10.3	07/06-07/07	2.43	10.3	08/10-08/12	2.56	11.7
08/06-08/07	2.33	8.1	07/17-07/19	2.34	8.7	07/19-07/21	2.10	7.0	1995/05/07-05/11	2.39	7.3
08/11-08/12	2.04	8.0	08/20-08/21	2.44	9.9	07/26-07/29	2.19	9.2	06/04-06/04	2.14	6.9
08/20-08/23	2.30	8.4	1990/05/16-05/18	2.25	7.5	08/17-08/25	2.23	7.4	06/08-06/09	2.13	7.2
08/25-08/26	2.06	9.0	05/19-05/24	2.41	11.0	08/29-08/29	2.49	8.3	07/18-07/20	2.17	8.6
09/16-09/16	2.09	9.3	05/26-05/28	2.61	11.7	09/08-09/09	2.35	9.1	07/30-07/30	2.52	6.4
09/24-09/24	2.25	7.9	06/02-06/04	2.54	7.7	09/14-09/14	2.09	11.7	08/23-08/23	2.13	7.4
10/01-10/03	2.22	7.1	06/07-06/10	2.88	9.2	09/17-09/17	2.17	9.4	09/17-09/17	2.03	7.0
10/05-10/06	2.22	8.4	06/14-06/14	2.08	8.9	09/19-09/19	2.10	8.7			

Table 3.3.3 Probability of Significant Wave Height (Offshore Wave, Wave Direction W)



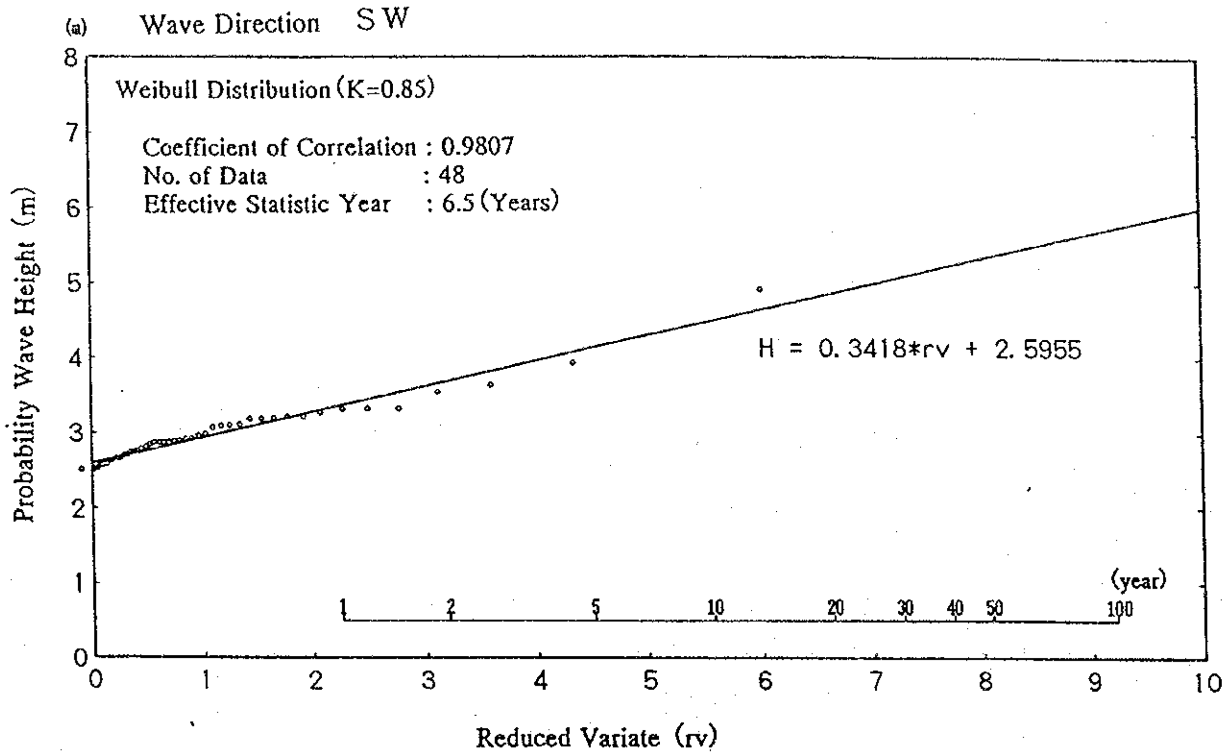
Return Period (year)	Non-exceeding Probability	Reduced Variate (rv)	Wave Height (m)	Wave Period (sec)
100	0. 99819	6. 3160	5. 5	11. 1
50	0. 99639	5. 6219	5. 2	10. 8
40	0. 99549	5. 3983	5. 1	10. 7
30	0. 99398	5. 1099	4. 9	10. 6
20	0. 99097	4. 7029	4. 7	10. 4
10	0. 98194	4. 0052	4. 4	10. 0
5	0. 96389	3. 3028	4. 1	9. 7
2	0. 90972	2. 3579	3. 7	9. 1
1	0. 81944	1. 6138	3. 3	8. 7

Table 3.3.4 Probability of Significant Wave Height (Offshore Wave, Wave Direction WSW)



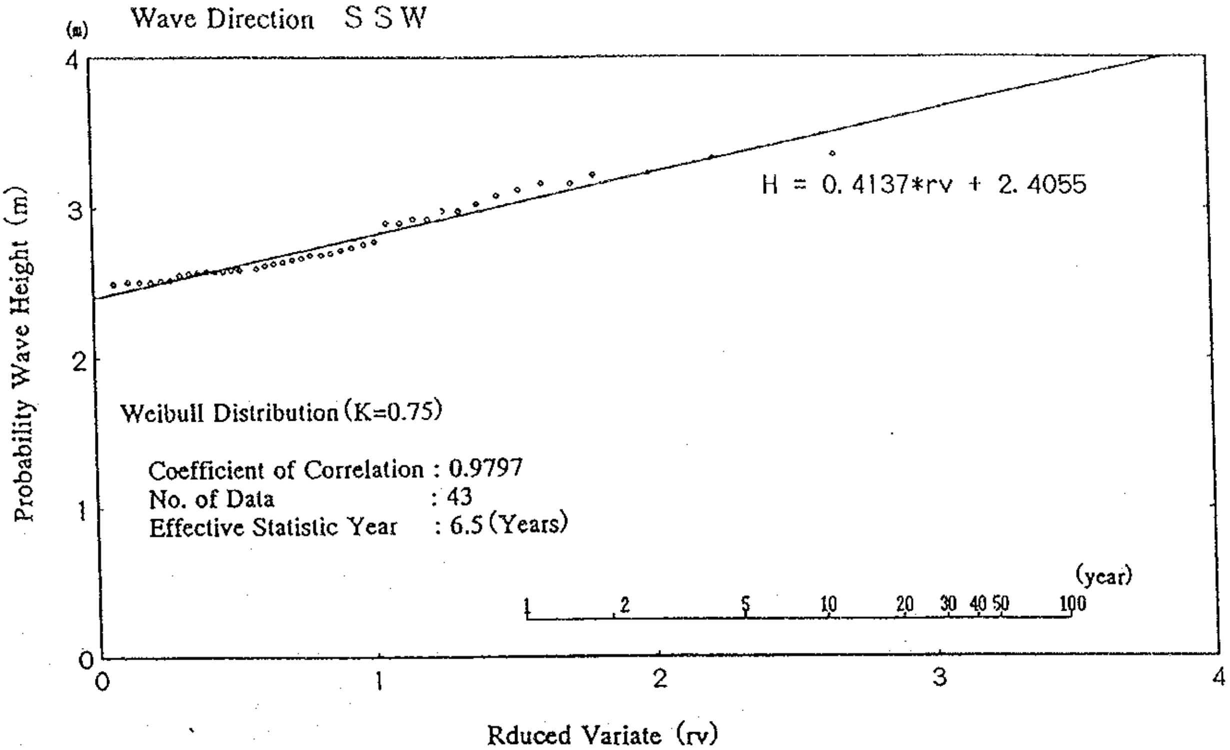
Return Period (year)	Non-exceeding Probability	Reduced Variate (rv)	Wave Height (m)	Wave Period (sec)
100	0.99859	12.2852	7.1	12.8
50	0.99717	10.5862	6.5	12.3
40	0.99647	10.0529	6.3	12.1
30	0.99529	9.3758	6.1	11.9
20	0.99293	8.4419	5.7	11.5
10	0.98587	6.9045	5.2	10.9
5	0.97174	5.4486	4.6	10.4
2	0.92935	3.6671	4.0	9.6
1	0.85870	2.4476	3.5	9.1

Table 3.3.5 Probability of Significant Wave Height (Offshore Wave, Wave Direction SW)



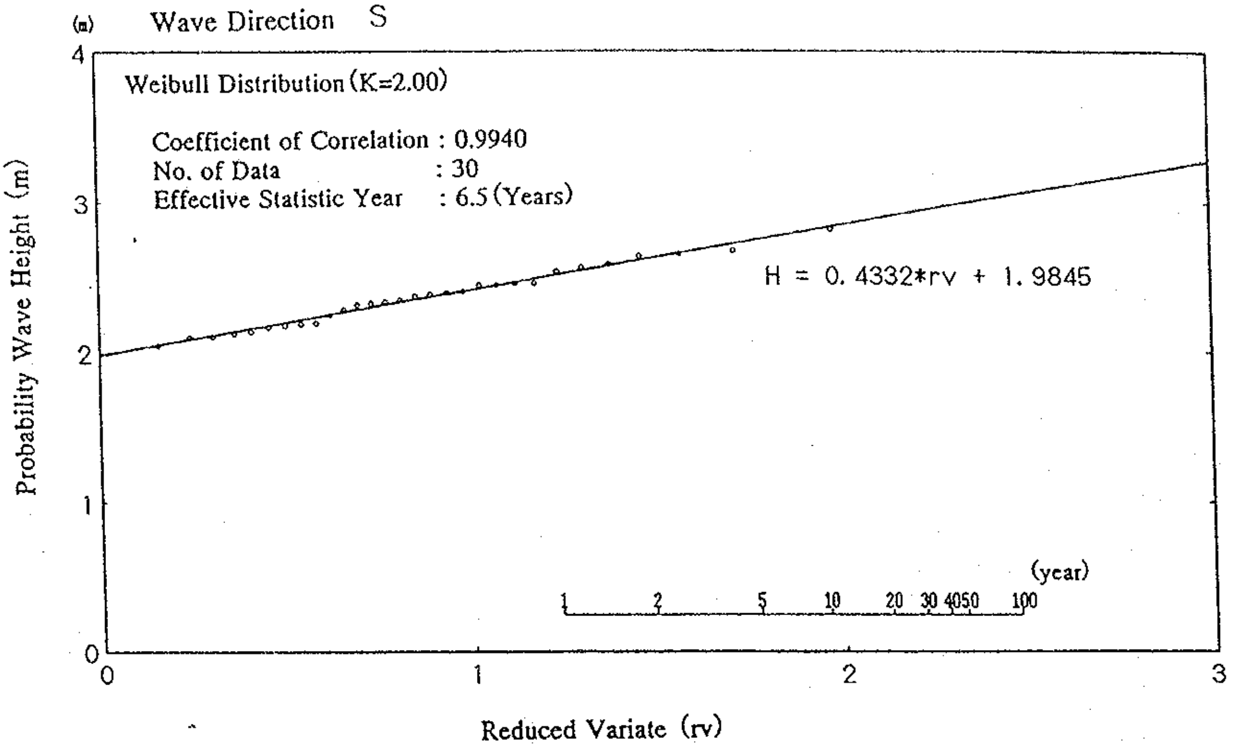
Return Period (year)	Non-exceeding Probability	Reduced Variate (rv)	Wave Height (m)	Wave Period (sec)
100	0. 99865	9. 2156	5. 7	12. 6
50	0. 99729	8. 0886	5. 4	12. 2
40	0. 99661	7. 7306	5. 2	12. 0
30	0. 99549	7. 2727	5. 1	11. 8
20	0. 99323	6. 6347	4. 9	11. 6
10	0. 98646	5. 5654	4. 5	11. 1
5	0. 97292	4. 5261	4. 1	10. 7
2	0. 93229	3. 2068	3. 7	10. 1
1	0. 86458	2. 2594	3. 4	9. 6

Table 3.3.6 Probability of Significant Wave Height (Offshore Wave, Wave Direction SSW)



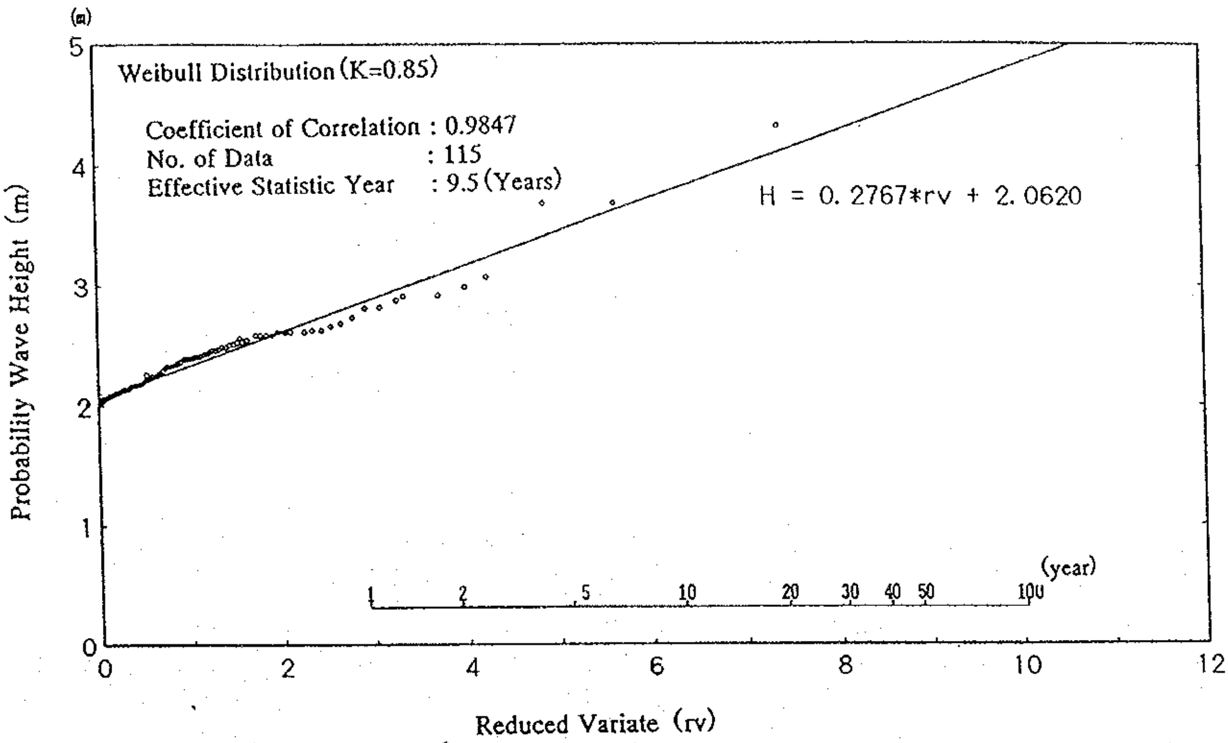
Return Period (year)	Non-exceeding Probability	Reduced Variate (rv)	Wave Height (m)	Wave Period (sec)
100	0.99849	3.4810	3.8	11.8
50	0.99698	3.2287	3.7	11.7
40	0.99622	3.1453	3.7	11.6
30	0.99496	3.0362	3.7	11.5
20	0.99244	2.8791	3.6	11.4
10	0.98488	2.5998	3.5	11.2
5	0.96977	2.3047	3.4	11.0
2	0.92442	1.8823	3.2	10.8
1	0.84884	1.5283	3.0	10.5

Table 3.3.7 Probability of Significant Wave Height (Offshore Wave, Wave Direction S)



Return Period (year)	Non-exceeding Probability	Reduced Variate (rv)	Wave Height (m)	Wave Period (sec)
100	0. 99783	2. 4768	3. 1	11. 8
50	0. 99567	2. 3327	3. 0	11. 7
40	0. 99458	2. 2844	3. 0	11. 6
30	0. 99278	2. 2205	2. 9	11. 6
20	0. 98917	2. 1272	2. 9	11. 5
10	0. 97833	1. 9575	2. 8	11. 3
5	0. 95667	1. 7717	2. 8	11. 2
2	0. 89167	1. 4908	2. 6	10. 9
1	0. 78333	1. 2367	2. 5	10. 7

Table 3.3.8 Probability of Significant Wave Height (Nearshore Wave)



Return Period (year)	Non-exceeding Probability	Reduced Variate (rv)	Wave Height (m)	Wave Period (sec)
100	0. 99917	10. 0322	4. 8	11. 9
50	0. 99835	8. 8899	4. 5	11. 5
40	0. 99793	8. 5267	4. 4	11. 4
30	0. 99725	8. 0619	4. 3	11. 2
20	0. 99587	7. 4136	4. 1	11. 0
10	0. 99174	6. 3250	3. 8	10. 6
5	0. 98348	5. 2639	3. 5	10. 2
2	0. 95870	3. 9100	3. 1	9. 6
1	0. 91739	2. 9300	2. 9	9. 2

iii) Comparison with Previous Probability Wave

Table 3.3.9 presents the probability wave parameters obtained during the JICA feasibility study in 1991 (refer to the Study on the Development of the Port of Galle in the Democratic Socialist Republic of Sri Lanka, November 1991, JICA). The wave values in this table were calculated on the basis of offshore wave measurements for the 1984-1990 periods.

The latest probability wave data, contained in the Development of the Port of Galle – Preliminary Design Report, June 1999, Posford Duvivier, are based on the offshore directional wave measurements carried out as part of a joint Sri Lankan-German technical cooperation study during the periods February 1989 to August 1992 and May 1994 to September 1995. Table 3.3.10 gives the probability wave parameters calculated from the field wave measurements.

Comparison of the probability wave parameters calculated during the current Study on the basis of offshore wave measurements with those given in the 1991 JICA feasibility study shows that the WSW wave height is greater than that given in the 1991 report. The wave measurements for the period 1989 to 1995 give the highest significant wave $H_{1/3}$ =5.5 m (WSW) recorded during the period May to June 1991. This highest significant wave height data was not included in the field measurements providing the basis for the parameter calculation in the 1991 JICA report. Obviously, this is the reason for the higher WSW probability wave height obtained during the current Study. The 50-year wave height of the overall sea state given in the Posford report is $H_{1/3}$ = 6.77 m, while the value obtained during the current Study is slightly lower. However, considering that the Posford value was based on wave measurements disregarding wave directions, the significant wave height value obtained for the Posford report and that derived during the current Study seem to be substantially the same. Thus the probability wave parameters obtained during the current Study are considered to be reasonable.

2) Establishment of Design Deepwater Wave Characteristics

For conservative considerations, the probability wave parameter calculations based on offshore wave measurements have been adopted as design deepwater wave parameters with a 50-year return period and a 10-year return period. The 50-year wave has been used for evaluating breakwater stability after the completion of the structures and the 10-year wave for evaluating their stability during their construction. Table 3.3.11 presents the design deepwater wave parameters referred to above.

Table 3.3.9 Probability of Significant Wave Height (JICA Study at 1991)

Return Period (year)	Non-excedding Probability	Reduced Variate (rv)	Wave Height (m)	Wave Period (sec)
50	0.99182	2.8478	5.0	8.5
40	0.98977	2.7590	5.0	8.4
30	0.98636	2.6423	4.9	8.4
20	0.97955	2.4732	4.8	8.4
10	0.95909	2.1699	4.6	8.3
50	0.91818	1.8436	4.5	8.3
2	0.79545	1.3605	4.2	8.2
1	0.59091	0.9279	3.9	8.1

Table 3.3.10 Recommended Extreme Offshore Wave Height (Posford Study at 1999)

Return Period (Years)	Overall	Sea	Swell
0.1	3.07	2.80	**
0.2	3.36	3.32	1.97
1	4.20	4.10	2.66
2	4.61	4.56	2.90
5	5.18	5.21	3.22
10	5.64	5.73	3.45
25	6.27	6.45	3.75
50	6.77	7.02	3.98
100	7.29	7.61	4.21

Table 3.3.11 Design Deepwater Wave Parameters

Probability Wave	Wave Direction	Wave Height (m)	Wave Period (sec.)
10-year wave (For analysis of breakwater stability during construction)	W	4.4	10.0
	WSW	5.2	10.9
	SW	4.5	11.1
	SSW	3.5	11.2
	S	2.8	11.3
50-year wave (For analysis of breakwater stability after construction)	W	5.2	10.8
	WSW	6.5	12.3
	SW	5.4	12.2
	SSW	3.7	11.7
	S	3.0	11.7

3) Calculation of Design Wave Height for Breakwaters

a) General

From the design deepwater wave parameters given in Table 3.3.11, shoaling wave deformation calculations were made in respect of the 50-year deepwater waves required for post-completion stability analysis for the breakwaters and the 10-year deepwater waves for during-completion stability analysis to obtain the design wave heights ($H_{1/3}$ and H_{max}) for the breakwaters planned.

b) Calculations for Shoaling Wave Deformations

Calculations for deformations due to refraction, diffraction, reflection, shoaling and other effects on deepwater waves during their inshore advance were made by the improved wave energy equalization equation developed by the Port and Harbour Research Institute, Ministry of Transport, Japan.

c) Conditions for Calculations

i) Waves

From the design deepwater wave parameters given in Table 3.3.11, three wave directions considered to generate relatively high waves along the planned breakwaters were selected as conditions for determining the design deepwater wave parameters for the proposed breakwaters. The selected conditions are as presented in Table 3.3.12.

Table 3.3.12 Deepwater Wave Conditions for Determining Design Wave Parameters

Probability Wave	Wave Direction	Wave Height (m)	Wave Period (sec.)
10-year wave (For analysis of breakwater stability during construction)	W	4.4	10.0
	WSW	5.2	10.9
	SW	4.5	11.1
50-year wave (For analysis of breakwater stability after construction)	W	5.2	10.8
	WSW	6.5	12.3
	SW	5.4	12.2

ii) Tide

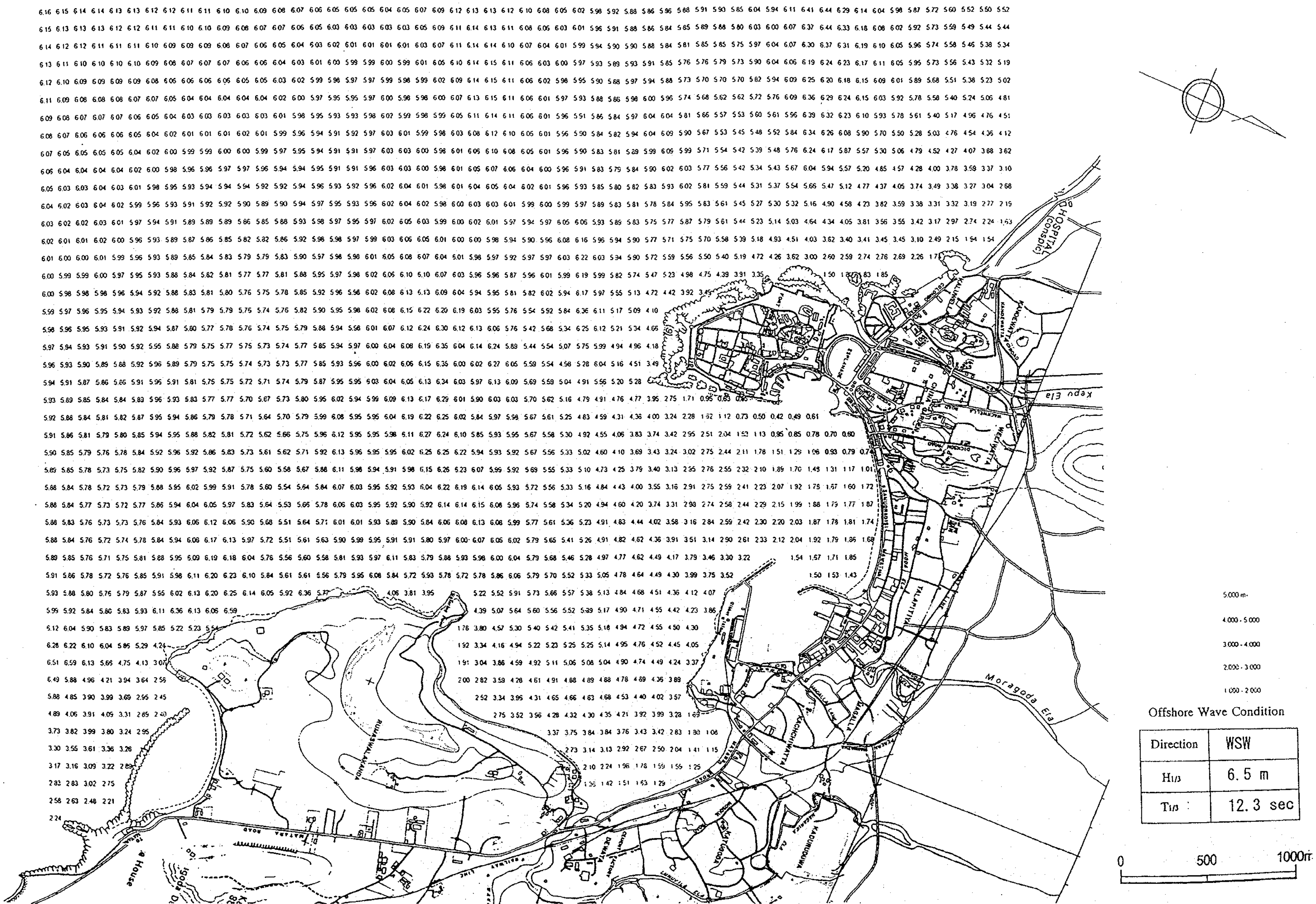
The tide level used for calculation of the design wave parameters is HWL = DL+0.6 m.

iii) Water Depth and Topographical Data

The water depth and topographical data used for the calculation purposes are derived from the available admiralty charts and bathymetrical survey results.

iv) Calculation Results

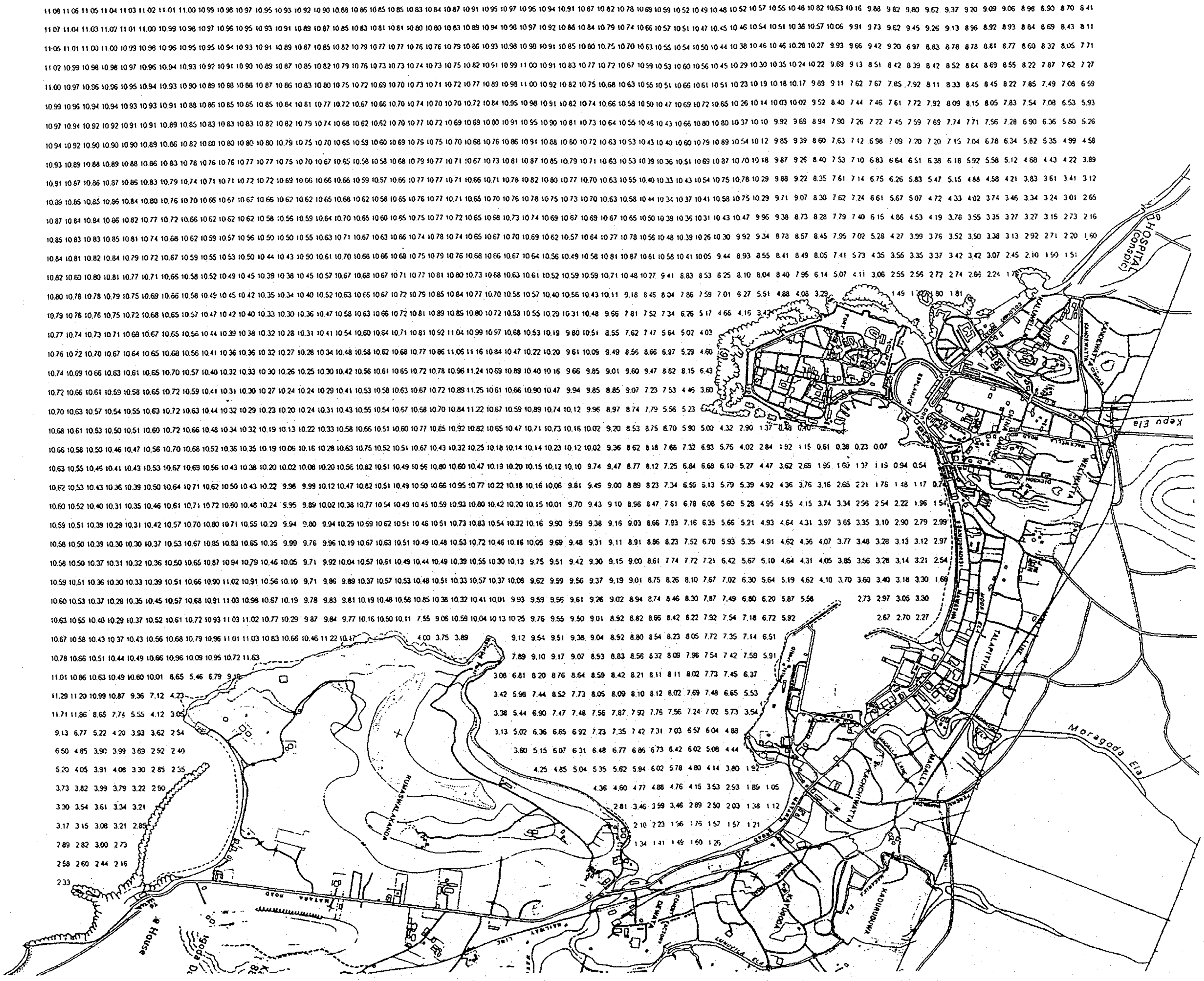
Figures 3.3.6 (A.3.3.6 and A.3.3.7) give the 50-year significant wave parameters for different deepwater wave conditions, 50-year maximum wave parameters in Figures 3.3.7 (A.3.3.8 and A.3.3.9) and wave vectors in Figures 3.3.8 (A.3.3.10. and A.3.3.11)

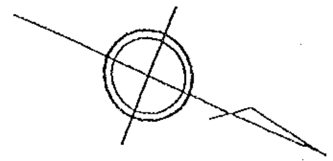


Offshore Wave Condition

Direction	WSW
$H_{1/3}$	6.5 m
$T_{1/3}$	12.3 sec

Figure 3.3.6 Significant Wave Heights (50Year Wave, Wave Direction WSW)





5.000m-
4.000 - 5.000
3.000 - 4.000
2.000 - 3.000
1.000 - 2.000

Offshore Wave Condition

Direction	WSW
$H_{1/3}$	6.5 m
$T_{1/3}$	12.3 sec

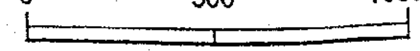
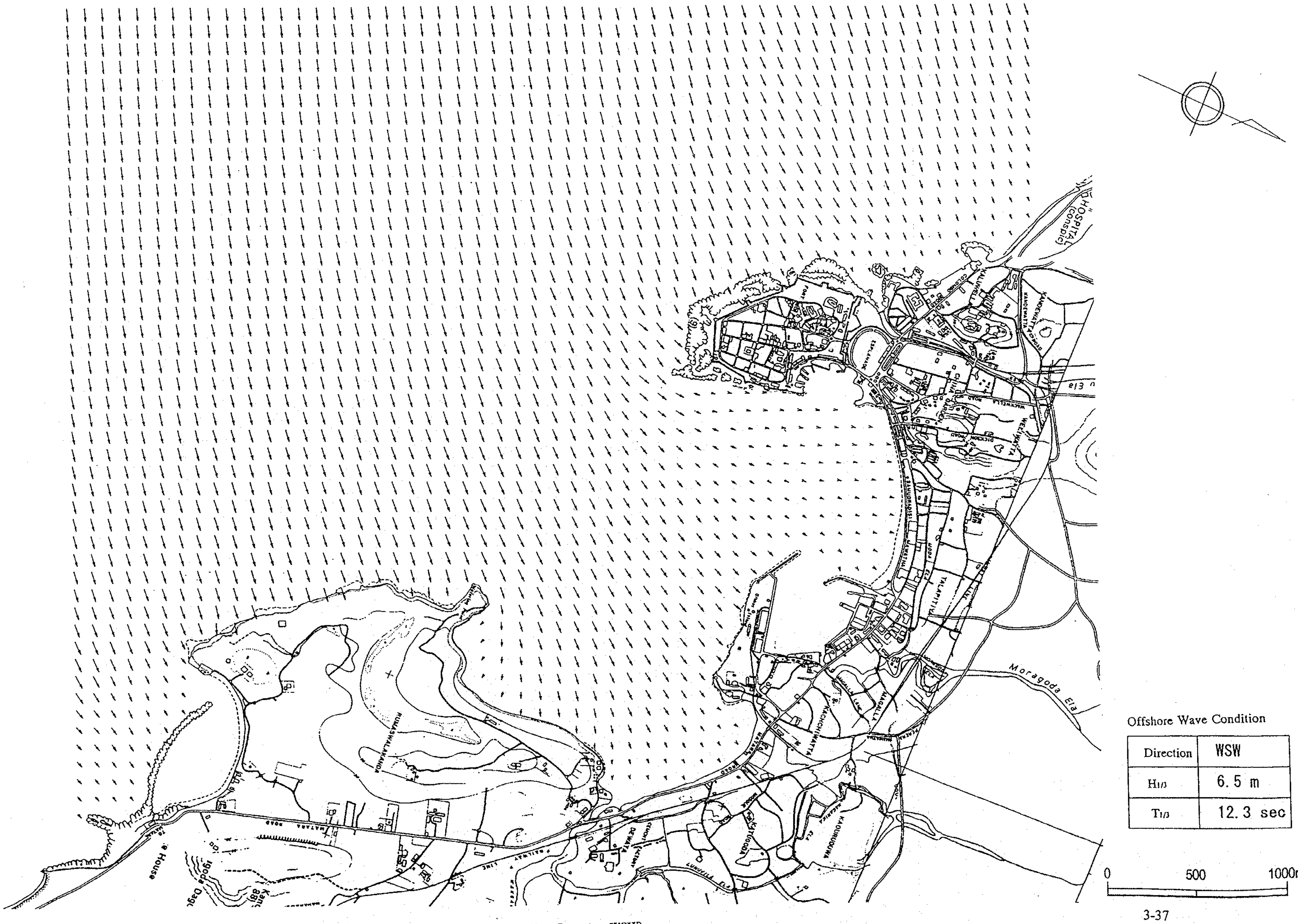


Figure 3.3.7 Maximum Wave Heights (50Year Wave, Wave Direction WSW)



Offshore Wave Condition

Direction	WSW
$H_{1/3}$	6.5 m
$T_{1/3}$	12.3 sec

Figure 3.3.8 Wave Vectors (50Year Wave, Wave Direction WSW)

3.3.2 Tidal Levels

The Indian Tide Table shows the following four main tidal constituents in Galle Port:

M_2	S_2	K_1	O_1
16.1 cm	11.0 cm	5.1 cm	1.4 cm

From these tidal constituents the tidal levels required for design purposes have been determined as follows:

H.W.O.S.T.(≒H.W.L)	0.607 m (0.6 m)
M.S.L	0.336 m
L.W.O.S.T.(≒L.W.L)	0.065 m (0.1 m)
D.L.	0.000 m

Note: Values in brackets are based on the chart.

The work datum level (W.D.L.) currently in use at Galle Port for construction purpose is 0.43 m below the Mean Sea Level (M.S.L.), or about 10 cm lower than the calculated datum level noted above.

H.W.O.S.T (≒H.W.L)	0.607 m	0.701m
M.S.L	0.336	0.430
L.W.O.S.T (≒L.W.L)	0.065	0.159
D.L.	0.000	
W.D.L.		0.000

3.3.3 Tidal Current

(1) Observation Records

Location of Observation:	Close to Data-well Wave-rider Buoy
Instrument Used:	Marsh McBirney 2-D Electromagnetic Current Meter
Recording Duration:	8 minutes every six hours

(2) Frequency Distribution of Current Speed According to Current Direction

The frequency distributions of current speeds according to current directions were studied.

The maximum current speed observed during June-September is 20.3 cm/sec. Current speeds of less than 10 cm/sec or less account for 71.2% of all the observations made. Thus it may safely be said that the current speeds in the vicinity of Galle Port are very insignificant.

The currents are distributed in nearly all directions, but the WNW to WSW and E to SE directions, which are more or less parallel to the coastline, are more frequent.

3.3.4 General Features of Coastline and Littoral Drift

Galle Bay, located at the southwestern tip of Sri Lanka, is oval-shaped and measures about 2.5 km southeast to northwest and about 1.5 km northeast to southwest and 1.8 km wide at the bay entrance. A plain continental shelf, formed at a depth of about 70m, extends nearly 20 km offshore.

The bay entrance opens to southwest and is dotted with reefs. On the west of the bay is located the Fort Area which rests on reefs and virtually forms a headland and the east side is surrounded by cliffs which also form a headland (Rumassala Hill).

Outside the bay the sea bottom slopes very gently on both the east and the west and the coastline forms beaches of fine sand.

The sea area abutting on the Fort Area on the west is enclosed by foreshore rocks (exposed at ebb tide) over a distance of about 150m offshore. Off these foreshore rocks the waters are generally shallow, but the depth varies widely and the bottom is scattered with reefs.

The existing facilities of Galle Port were completed in the centre of the bay in 1971. Beaches of fine sand are formed on both sides of the port and in front of the beaches the seabed slopes rather gently at 1/50 to 1/100 and this area forms a surf zone about 100m wide. Dredging data for the harbour basin indicate that the seabed is scattered with rolling stones.

On the east of the bay the coastline extending from Rumassala Hills is backed by cliffs about 15 to 20 m high and the shoreline is formed by rocks and gravels. In front of the shoreline the water is deeper than on the west and scattered with fewer reefs.

Data available at the Coast Conservation Department show that the southwestern coasts of Sri Lanka are eroded at an annual rate of about 30 cm. The prevailing wave direction is south to west and the coastlines in the vicinity of Galle Bay run in a NW direction on the west and in an ESE direction on the east. Judging from these facts, the littoral drift is presumed to branch off into the easterly and westerly directions in the neighbourhood of the bay. The littoral drift into the bay is intercepted by the east and west headlands.

Waves advancing toward the bay are either intercepted or broken by scattered reefs at the bay mouth, dispersing in the bay as diffracted waves and then gradually broken in the gently sloping surf zone. In consequence, the sand drift inside the bay is presumably limited in volume and the shoreline remains virtually unchanged. The front of the revetment for a coastal road built by filling up part of the west coastline area of Galle Port in 1968 is partly eroded. Obviously, this erosion has been caused by a scour in the revetment base and the sucking-out of backfill material behind the steep revetment structure as the consequence of its construction on the gently sloping natural beach.

Two small rivers with a total drainage area of nearly 50 km^2, namely, the Moragoda and Lunuvila, discharge into Galle Bay. They have a gently inclined bed and their mouths are completely closed in times of droughts. For these reasons, the sediment discharge into the bay is considered to be very limited, which is evidenced by the fact that the water depths of the inner and other harbours have remained virtually constant since the completion of dredging work in 1984.

3.4 Site Investigation

The purpose of the site investigations is to obtain information on the topographical features of the land and seabed, the submarine geology, and subsoil of the project site.

The investigations, carried out between early March and the end of April 2000, comprised the following activities.

- Soil Exploration
- Bathymetric Survey
- Sonic Prospecting
- Topographic Survey

The scope of investigation is summarized in Table 3.4.1 and survey locations are shown in Figure 3.4.1 and 3.4.2.

Table 3.4.1 Scope of Investigation

Items of Investigation	Scope
1. Soil Exploration	Soil investigation through borings at 9 points in Galle Bay
2. Bathymetric Survey	Providing oceanographic map through sounding survey in whole sea area of Galle Bay
3. Sonic Prospecting	Identifying bed rock location and depth through sonic prospecting in whole sea area of Galle Bay
4. Topographic Survey	Producing topographic map by through topographic survey of approximate 8 km^2 in the vicinity of Galle Port

3.4.1 Soil Exploration

A YBM 05 rotary drilling machine with necessary equipment and a drilling crew were mobilized on 3rd March, 2000 for the boring work. The boring operation was completed on 15th April, 2000.

The purpose of this offshore soil exploration was to investigate the overburden material and basement rock below the seabed in the outer Galle Port.

The boring work was carried out using a steel-structured 17m-high rig with a wooden platform atop. A crane barge supported by a tugboat was employed for moving the platform with the drill rig from one boring location to another.

Nine boreholes were drilled at nine locations. The coordinates of these boreholes are described in Table 3.4.2. The borehole location map is shown in Figure 3.4.1.

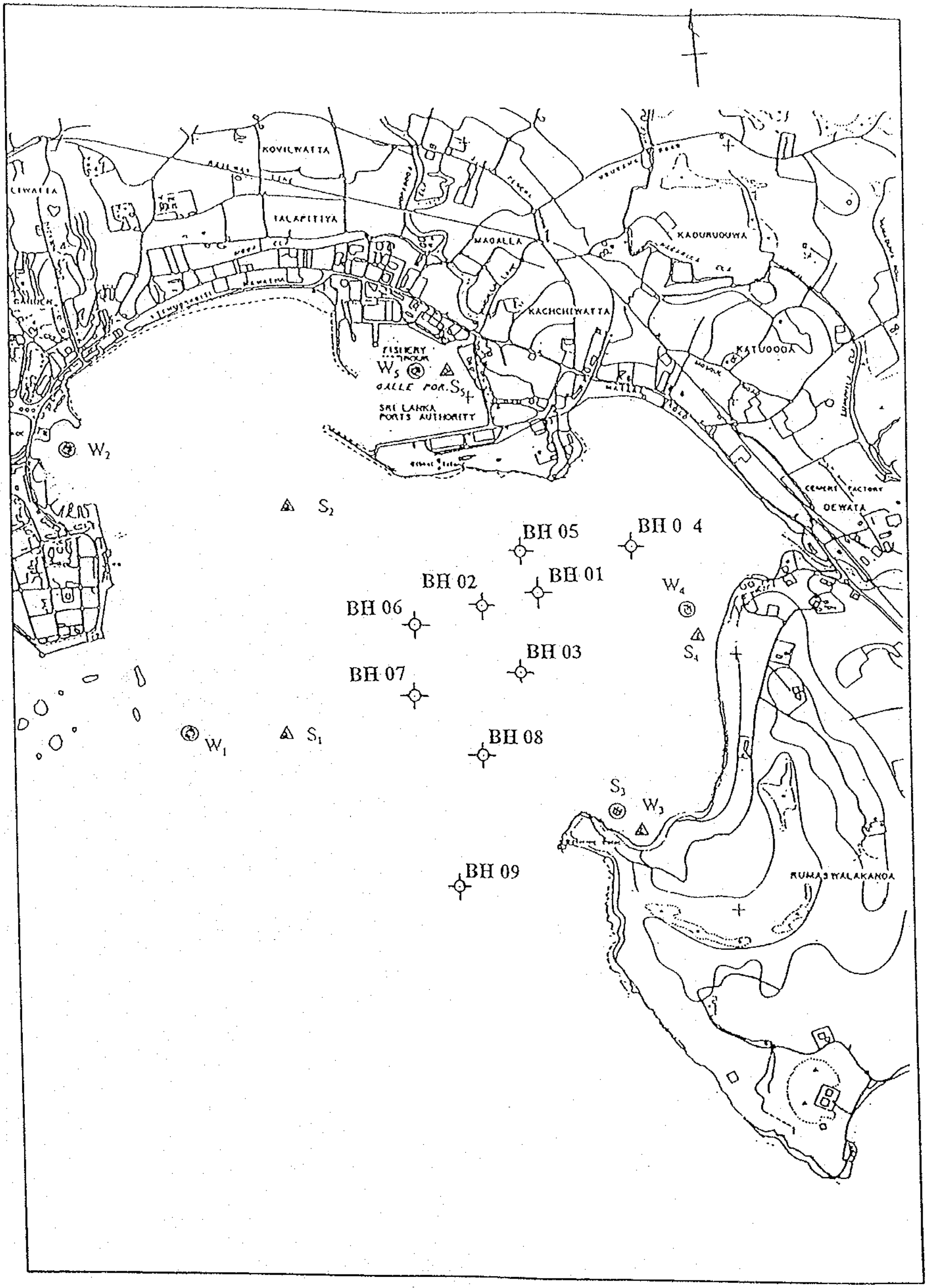


Figure 3.4.1 Boring Position

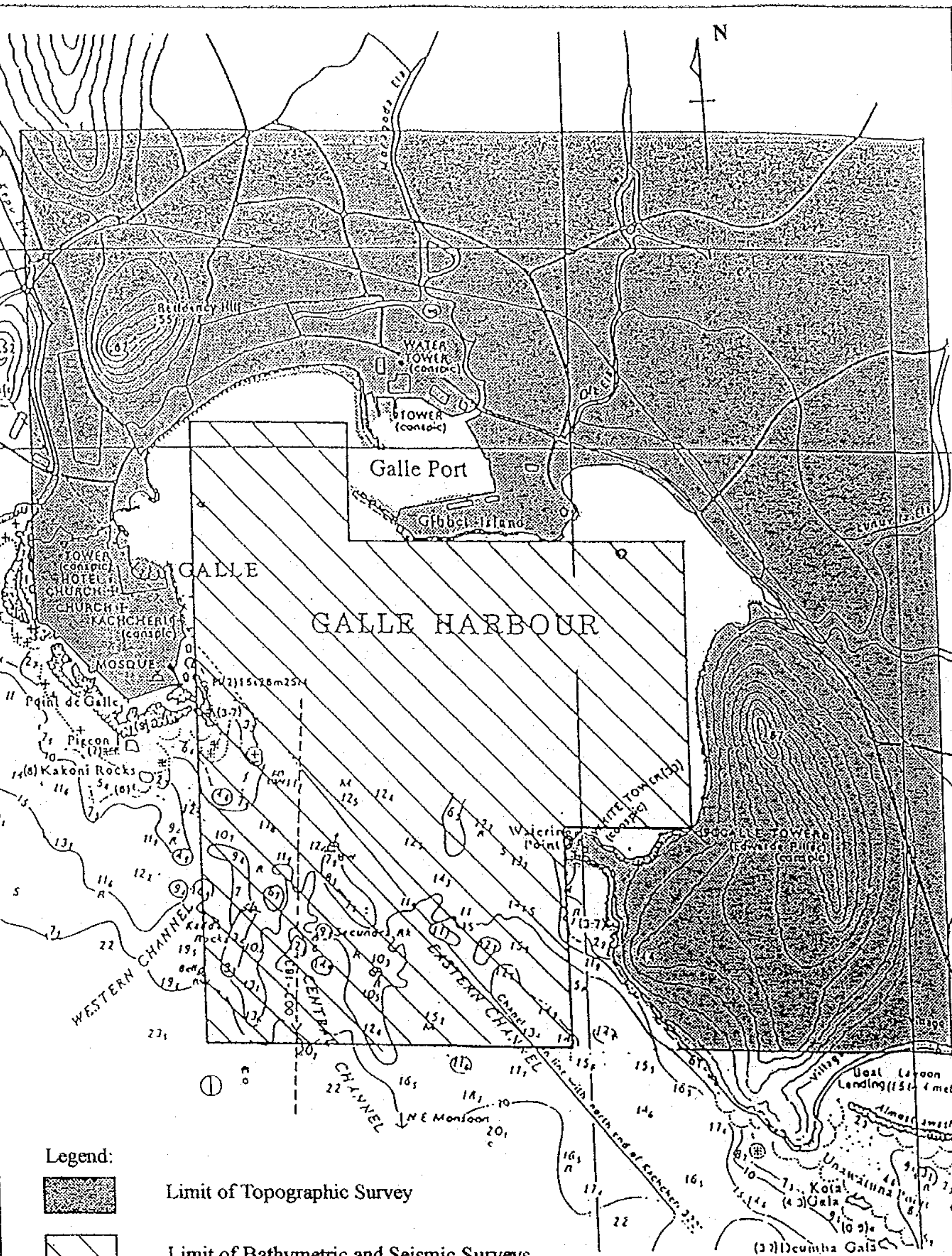


Figure 3.4.2 Location Plan of the Project Area

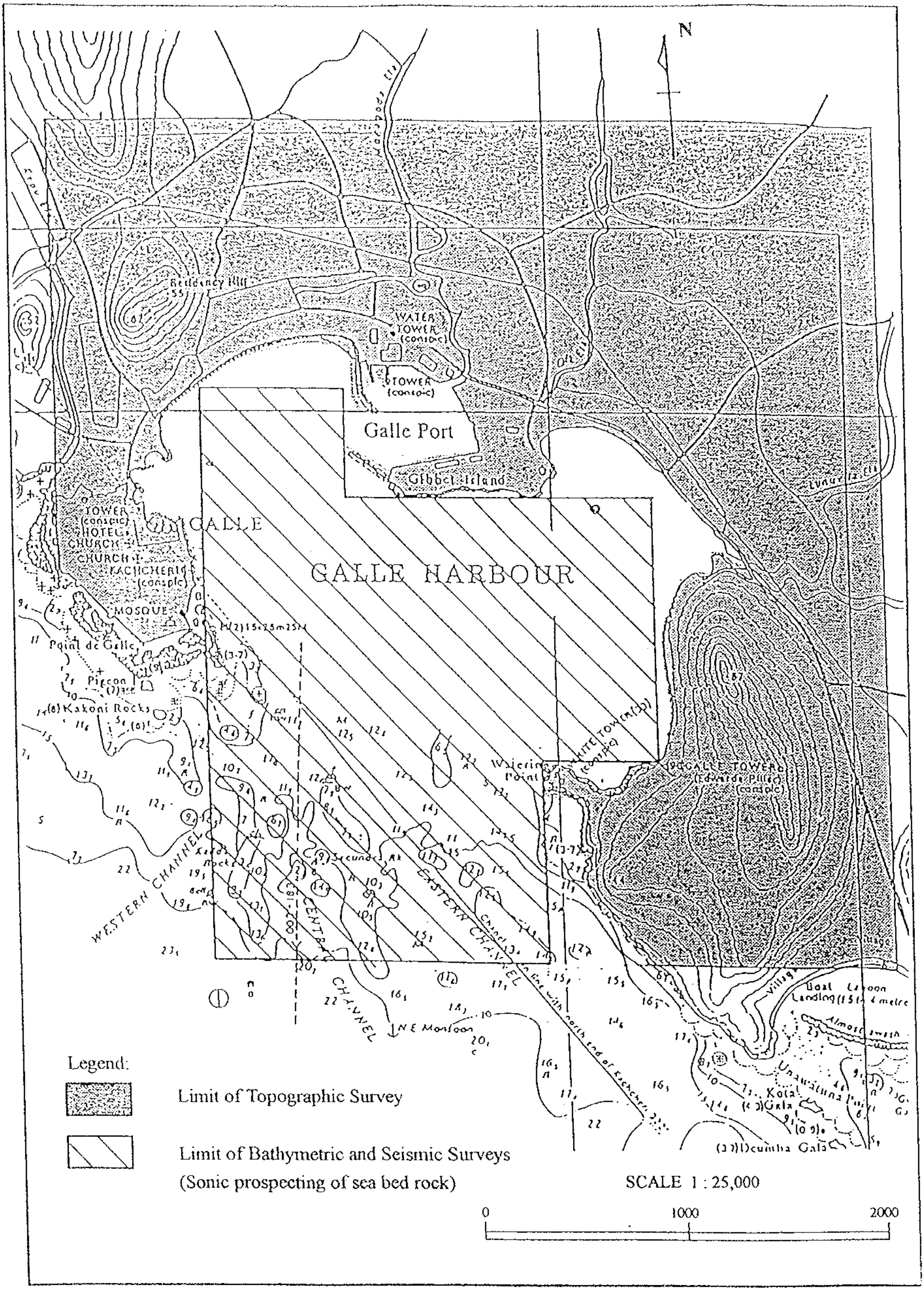


Figure 3.4.2 Location Plan of the Project Area

Table 3.4.2 Coordinates of Bore Holes

BH No.	Northing	Easting
01	06° 01' 33"	80° 13' 58"
02	06° 01' 26"	80° 13' 50"
03	06° 01' 23"	80° 13' 53"
04	06° 01' 38"	80° 14' 08"
05	06° 01' 38"	80° 13' 53"
06	06° 01' 28.5"	80° 13' 40.5"
07	06° 01' 18"	80° 13' 40.5"
08	06° 01' 12"	80° 13' 51"
09	06° 00' 51"	80° 13' 45.5"

The soil boring was carried out using the wash boring technique with standard penetration tests at every 1.0m of depth. The subsoil strata were recovered using a split spoon samples, thin walled tubes or by other dry blocking methods. Representative disturbed soil samples were collected from every 1.0m of depth.

The standard penetration tests were conducted inside the boreholes in accordance with ASTM-D-1586 at 1.0m intervals throughout the depth of overburden. The weathered rock foundation below the overburden soil was drilled through with tungsten carbide tipped starter bits and cuttings were recovered by water pressure. The bedrock formation was cored using "NX" size diamond coring bits and double tube core barrel, by which continuous coring was possible. The coring was carried out in all the nine boreholes. The soil samples were examined with a 10×1 magnifying glass and classified according to the Unified Soil Classification System.

The vertical profiles of subsoil and bedrock strata (Geological Record of Boring) are given in Appendix as Figure A.3.4.1 (2)-(10). Summary of those data is presented in Table 3.4.3.

Table 3.4.3 Summary of Vertical Profiles of Strata

BH No.	Depth of Overburden		Depth of Weathered Bedrock		Depth of Covering of Bedrock	
	From (m)	To (m)	From (m)	To (m)	From (m)	To (m)
01	-9.95	-18.95	-18.85	-19.71	-19.71	-22.15
02	-11.20	-26.15	-26.15	-36.61	-36.61	-37.61
03	-11.80	-25.70	-25.70	-33.02	-33.02	-35.60
04	-5.78	-9.68	-9.68	-11.78	-11.78	-12.78
05	-7.40	-14.85	-14.85	-15.25	-15.25	-16.20
06	-12.10	-21.90	-21.90	-23.64	-23.64	-24.70
07	-11.75	-16.41	-16.41	-19.62	-19.62	-20.67
08	-11.50	-12.70			-12.70	-13.70
09					-11.80	-12.80

All elevations were measured in the boreholes logs with respect to the Mean Sea Level. The depth is measured referring to the seabed level = 0.0m.

These generalised cross sections through the boreholes are shown in the following figures.

(1) Figure 3.4.3: Generalised vertical cross section through boreholes BH06, BH07 and BH09

(2) Figure 3.4.4: Generalised vertical cross section through boreholes BH05, BH01, BH03, BH08 and BH09

(2) Figure 3.4.5: Generalised vertical cross section through boreholes BH06, BH02, BH01 and BH04

3.4.2 Bathymetric Survey

Bathymetric survey of Galle Bay was conducted in order to determine the depth to the seabed and the overburden material. The area covered by the bathymetric survey is shown in Figure 3.4.2.

The field work was carried out from 7th to 8th and from 17th to 23rd April, 2000. The progress of survey was greatly affected by the inter-monsoon weather that prevailed during the survey period.

Position fixing was carried out using the Trimble Differential Global Positioning System (DGPS), which is capable of producing sub-metric accuracy. An ODOM echo sounder with a digitizer was used to measure the depths to the sea bottom. The results were obtained in digital format as well as in chart form. The outputs of the digitizer and DGPS were synchronized to permit a simultaneous digital recording of X, Y and Z coordinates. The frequency of echo sounder was 208 Hz. A fibreglass low-draught boat was used for the survey. Hydro Pro navigational software was used to survey along the predetermined survey lines, spaced at 50m apart.

For tide level corrections, a tide pole was established in Galle Bay and continuous recording of water levels was done during the survey. During the processing, field data were corrected for tides and pitching of the vessel.

Processed data were reduced to Chart Datum (CD), which is 0.38m below Mean Sea Level, and plotted to a scale of 1:20,000. Depth contours are indicated at 1.0m intervals. The bathymetric chart is shown in Figure 3.4.6.

The bathymetric survey indicates that the water depth of the Galle Bay increases gradually in the southerly direction from the innermost part of the Bay. The -10.0 m contour line runs approximately 200 m north of the tip of the Fort area to about 200 m west of Watering Point; the depth increases gradually with increasing distance in offshore direction to attain -13.0 m in the center of the bay mouth forming the Fort - Watering Point line and finally -20.0 m in the waters about 1,200 m south of the bay mouth center. However, the water area between the -10.0 m contour line and the

20.0 m line is scattered with rocks and the seabed is characterized by sharp rises and falls.

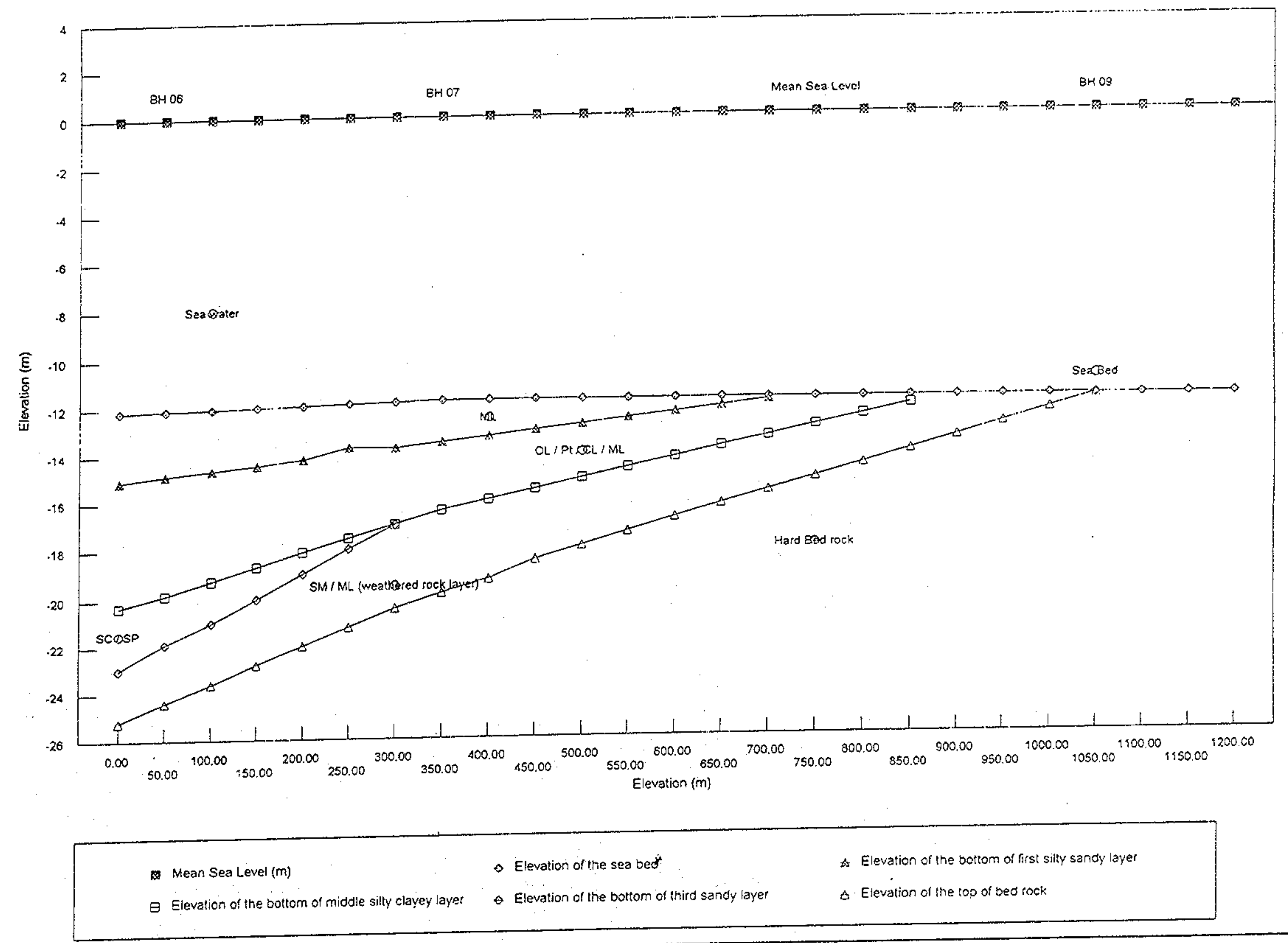


Figure 3.4.3 Generalised Cross Section through BH06, BH07 and BH09

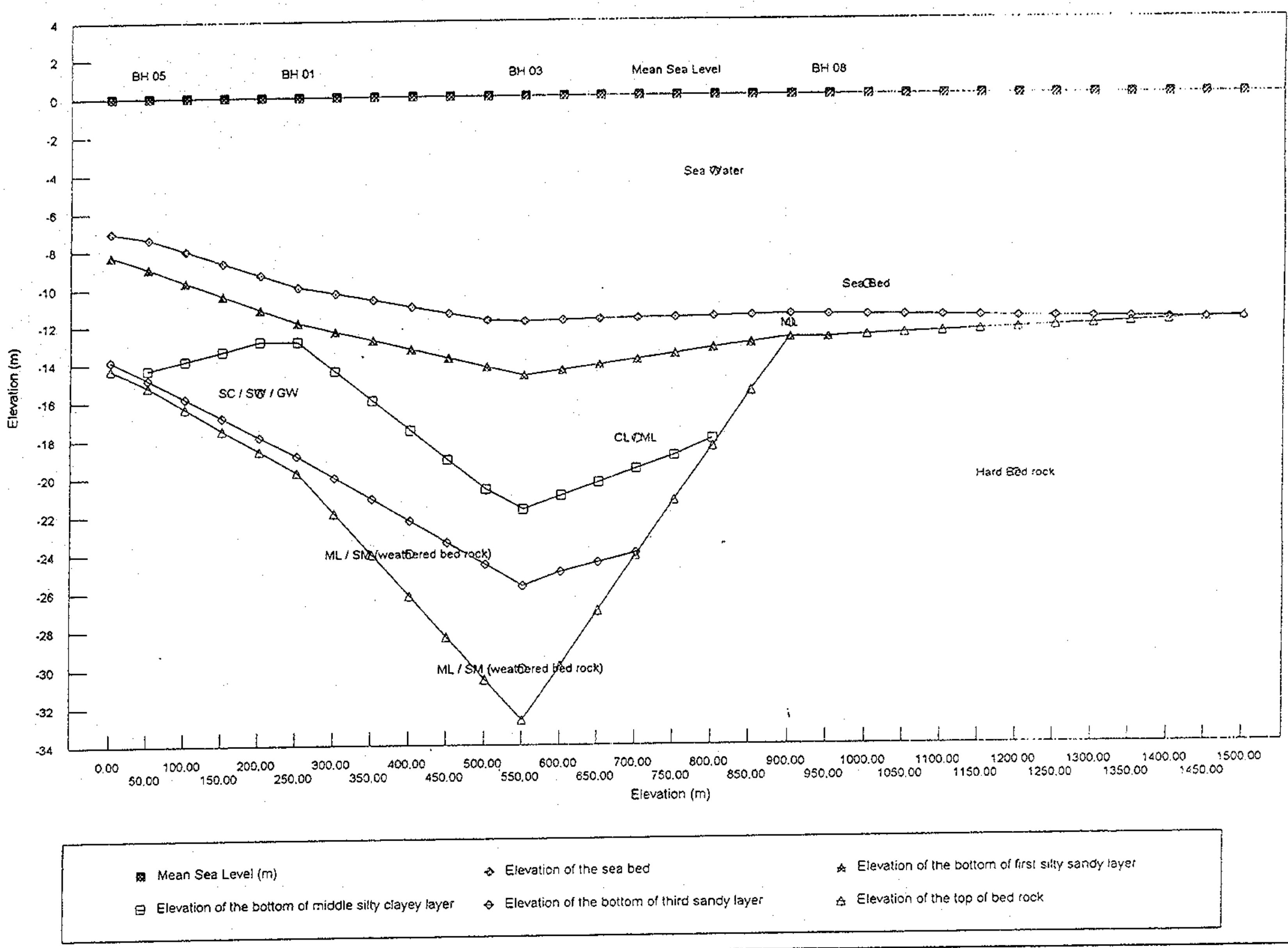


Figure 3.4.4 Generalised Cross Section through BH05, BH01, BH03, BH08 and BH09

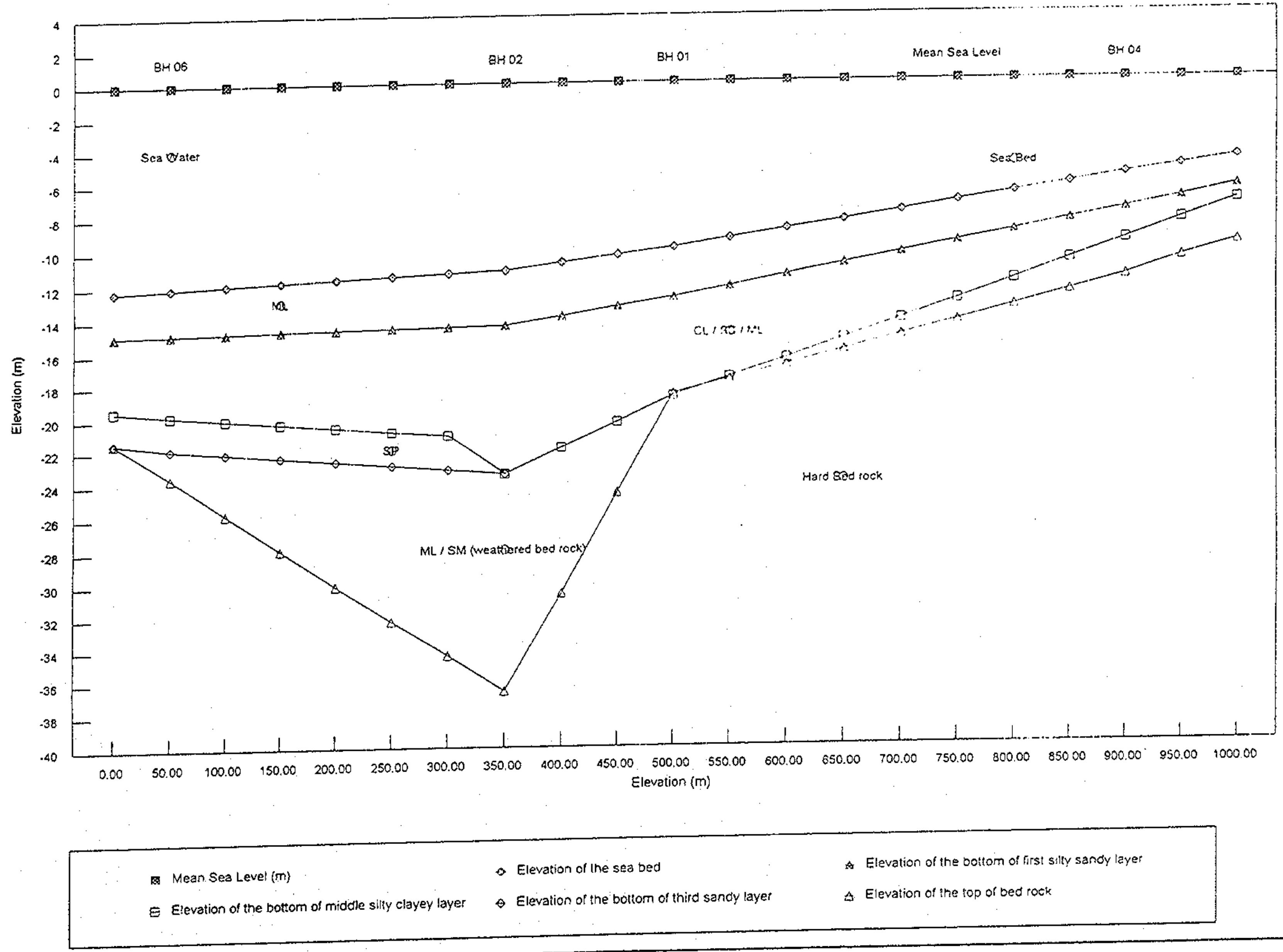


Figure 3.4.5 Generalised Cross Section through BH06, BH02, BH01 and BH04

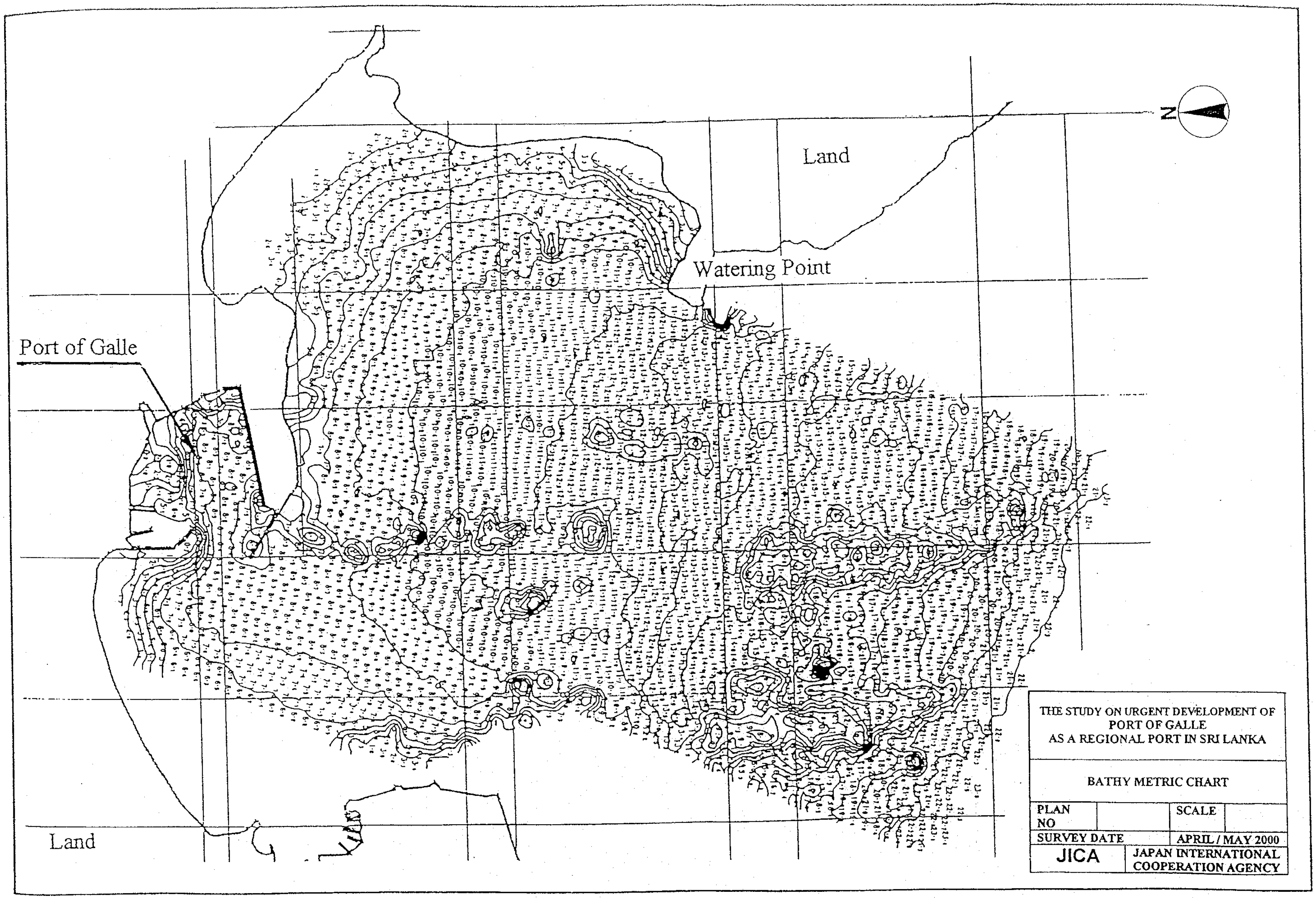


Figure 3.4. 6 Bathymetric Chart

3.4.3 Sonic Prospecting

Sonic prospecting of the seabed has been carried out in order to determine the depth to the bedrock surface in Gall Bay. The area covered by the sonic prospecting is shown in Figure 3.4.2.

The survey work was commenced on 27th March and completed on 26th April, 2000. CM800 Side Scan Sonar System with a digitizer was used for sonic prospecting purposes. Position fixing was carried out using the Trimble Differential Global Positioning System (DGPS) which is capable of producing sub-metric accuracy.

The results were obtained in chart form. The outputs of the digitizer and DGPS were synchronized to permit a simultaneous digital recording of X, Y and Z coordinates. A fibreglass low-draught boat was used for the survey. Hydro Pro navigational software was used to survey along the predetermined survey lines, spaced 50m apart.

For tide level corrections, a tide pole was established in Galle Bay and continuous recording of water levels was done during the survey.

During the processing, field data were corrected for tides and pitching of the vessel. Processed data were reduced to Chart Datum (CD), which is 0.38m below Mean Sea Level, and plotted to a scale of 1:10,000. Depth contours are indicated at 1.0m intervals. The results of survey data are as shown in Figure 3.4.7.

The sonic prospecting survey shows that the basement rock is encountered in the water depth range of -10.0 m to -14.0 m on the west of the existing access channel, while it is found at depths less than -10.0 m in the northwest of the innermost part of the Bay.

On the north of Watering Point the basement rock formation rises and falls sharply and is distributed in the depth range of 0 m to -20.0 m. The basement rock has a distribution at relatively greater depth (more than -20.0 m) behind the central to eastern part of Gibbet Island.

3.4.4 Topographic Survey

The topographic survey of land in the vicinity of Galle Port has was conducted in order to evaluate the land utilizing patterns and available infrastructures around the area. The surveyed area is as shown in Figure 3.4.8 (1). Also based on the output of this survey, a detailed topographic map of Galle Port has been produced as shown in Figure 3.4.8 (2).

The survey was performed with two units of Nikon Electric Total Station C100 with a digital data recorder, two units of Wild Nak Automatic Level and Hewlet Pakcard Design Jet 250 C plotter. It was based on the benchmarks fixed by the National Grid of Sri Lanka. These are described in Table 3.4.4.

The field work was commenced on 10th March, 2000 and completed on 20th April, 2000.

Table 3.4.4 Detail of Benchmarks

	Name of the Benchmark	N Code	E Code
1	Watering Point 78	91,382.50	140,405.48
2	Tong Joo 78	92,165.74	140,961.60
3	Marine Drive	93,408.66	139,149.43
4	Utrecht 78	92,041.64	138,651.57
5	Gibbet Island 78	92,730.33	139,815.40
6	Flagstaff Mark	92,563.70	138,633.34
7	Lighthouse	92,058.40	138,631.09
8	Clock Tower	92,661.60	138,160.16
9	All Saint's	92,378.02	138,409.65
10	Closen Burg	92,708.87	140,318.14

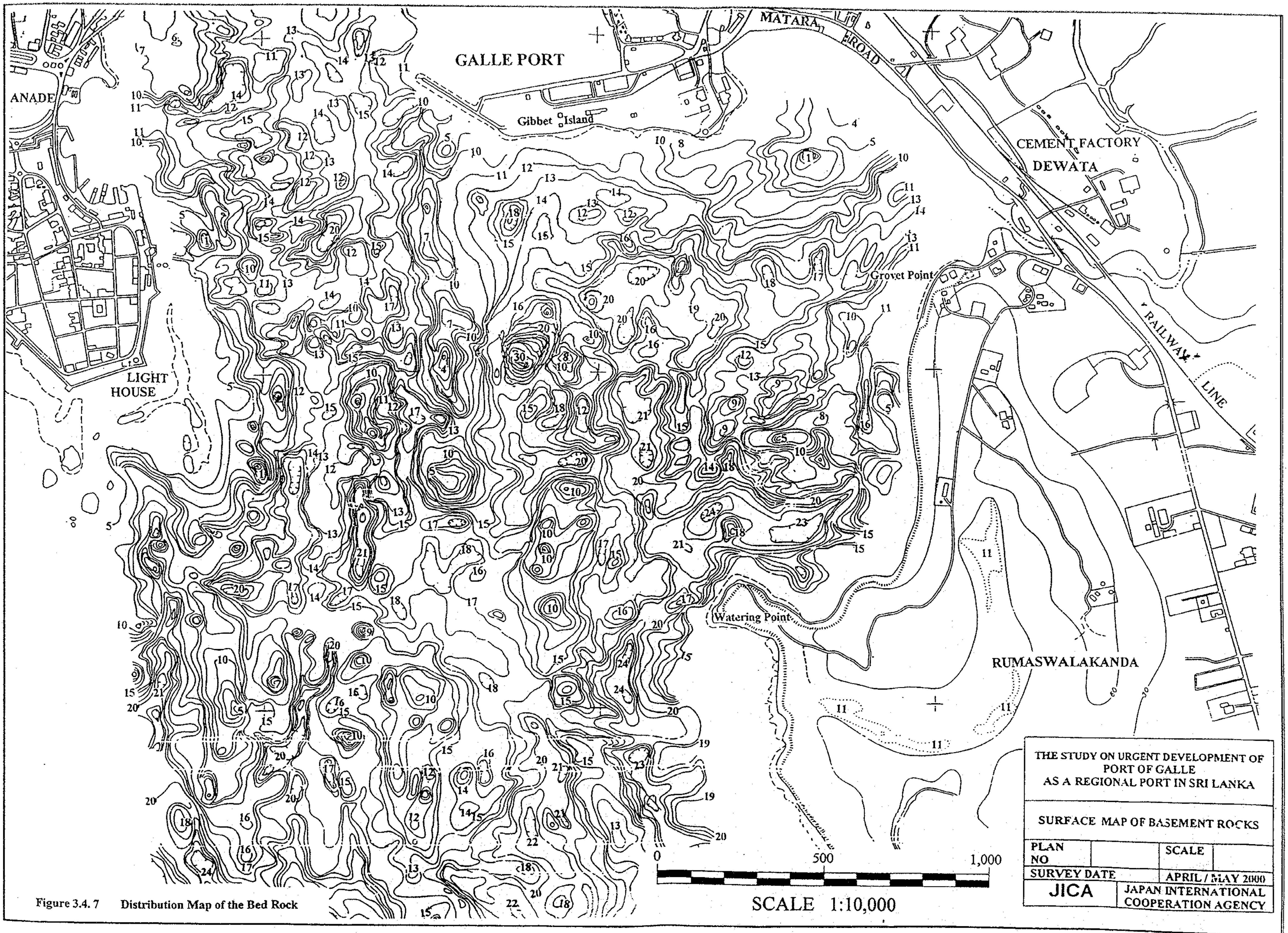


Figure 3.4. 7 Distribution Map of the Bed Rock

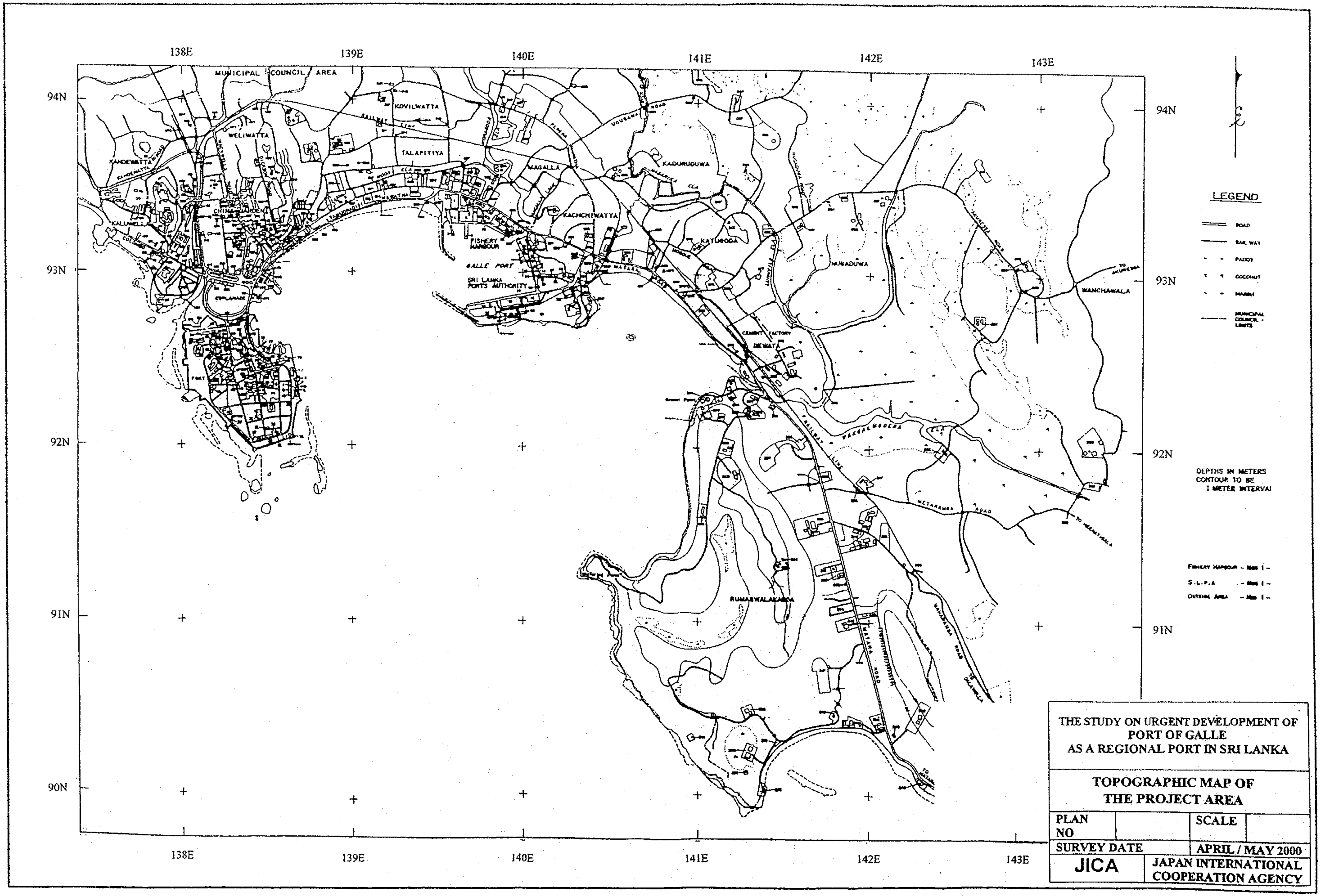


Figure 3.4. 8 (1) Topographic Map of the Project Area

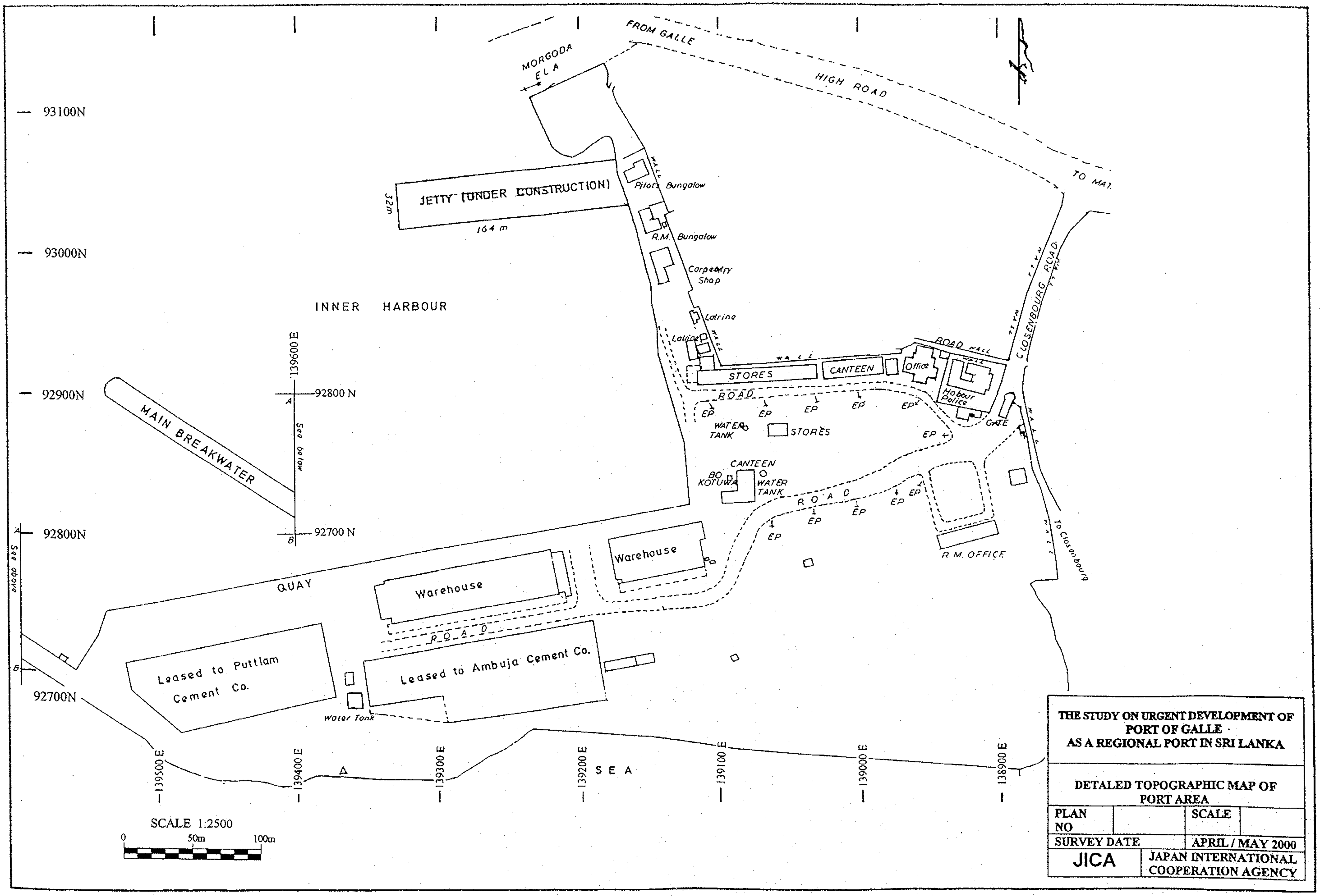


Figure 3.4. 8 (2) Topographic Map of the Port Area