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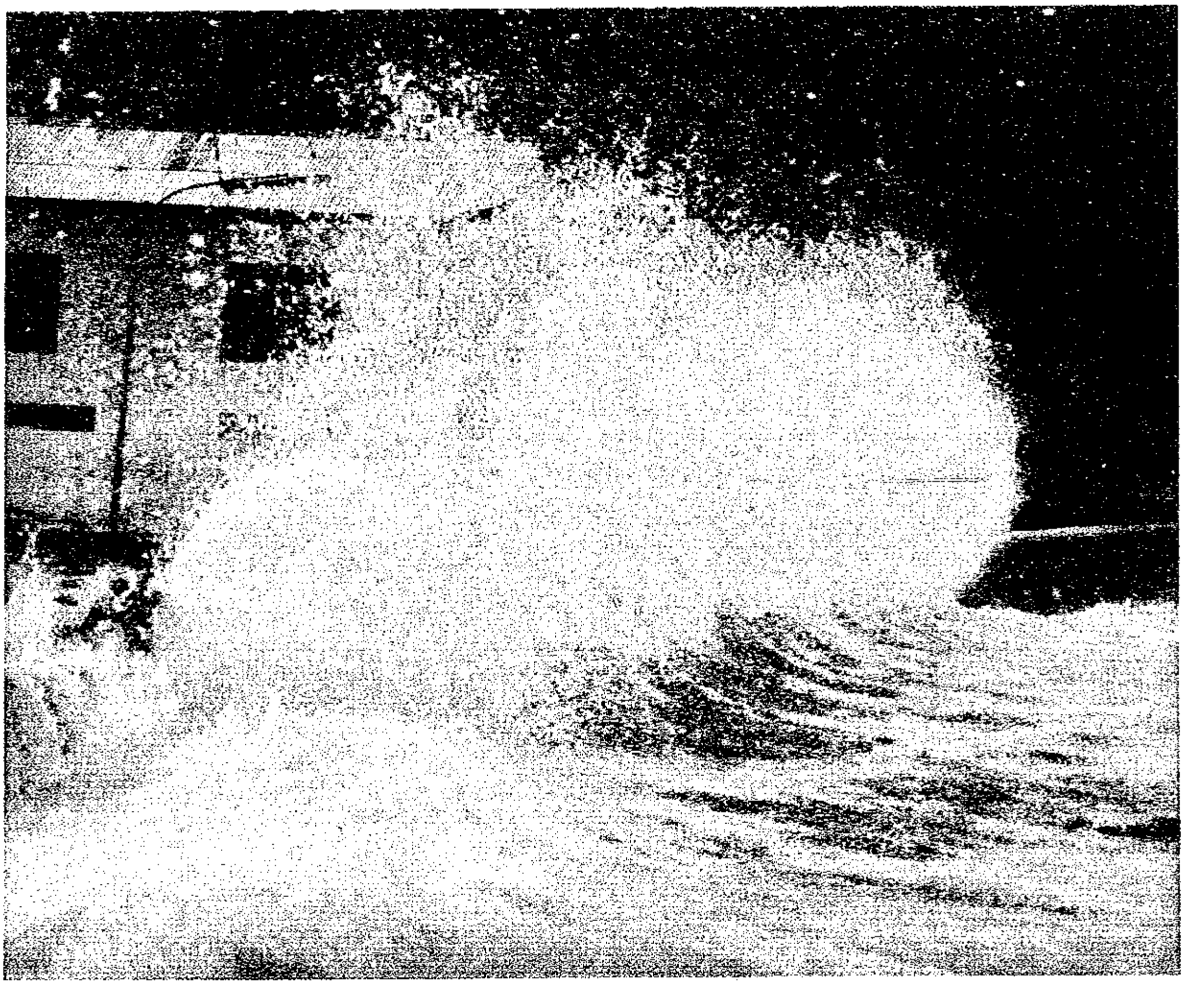
No. 52

THE DEVELOPMENT STUDY ON THE SEAWALL CONSTRUCTION PROJECT FOR MALE' ISLAND IN THE REPUBLIC OF MALDIVES

SUPPORTING DATA II



DECEMBER 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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THE DEVELOPMENT STUDY
ON
THE SEAWALL CONSTRUCTION PROJECT
FOR
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Composition of the Report

This report consists of six volumes as follows;

①	Summary Report	:	Summary
②	Main Report I	:	Report for Male'
③	Main Report II	:	Report for Funadhoo
④	Supporting Report	:	Supplementary Study Report
⑤	Supporting Data I	:	Topo/Hydrographic Maps
⑥	Supporing Data II	:	Oceanographic Survey Data

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Supporting Data II

Chapter 1. SOIL DATA

1.1 Geology of the Maldives Islands

(1) Formation of Maldive Islands

The Maldive Islands form the main part of the Maldive Ridge which extends from the Laccadive Islands into the Chagos Archipelago in the north-south direction. The Maldive Ridge lies between the Arabian Basin and the Mid-Indian Basin and is a chain between the Indian Continent and the Carlsbery-Mid Indian Ridge. (Refer to Figure 1.1)

According to the theory of plate tectonics, the Carlsbery-Mid Indian Ridge is a mid-oceanic ridge which is a spreading center of ocean plates. While the Maldive Ridge divides both the ocean plates of the Arabian and the Mid Indian Basin, and originated from a transformed fault resulted in a different moving velocity of the both ocean plates. According to Purdy, E.G. (1981), the results of a deep sea drilling by Esso Exploration Inc. Indicated more than 2,100 m of shallow-water carbonate sediments overlying the Eocene volcanic rocks, in the Maldives Islands. Therefore, the Maldive Ridge consists of the thick shallow-water carbonate sediments and the under lying volcanic rocks which erupted along the transformed fault. (Refer to Figure 1.2)

The shallow-water carbonate sediments having a thickness of about 2,100 m were mainly made up of coral and grew continuously up over the shallow submarine volcanic mountain ridge formed in the Eocene age (38 to 55 million years ago). Therefore, it is estimated that the shallow submarine volcanic mountain ridge submerged at least to a depth of 2,100 m during 38 million years and the carbonate sediments consisting mainly of coral grew up 0.06 m/m per year in ratio.

(2) Atolls and Faros

Large or very large atolls in the Maldive Islands are 30 to 80 km long, the lagoons of which being generally 35~70 m deep. Between these atolls are channels generally more than 400 m deep. The large or very large atolls contain many faros in their lagoons in addition to those occurring on their outer edge. A faro which indicates the unique features of Maldive atolls, consists of a small circular coral reef and shows a double circular structure together with a large atoll. Some of faros are 10 km or more in length, but the majority are smaller. The smallest are almost circular, but others are elongated parallel to the edges of the large atolls. Their lagoons vary in depth between 4~6 m and almost 40 m.

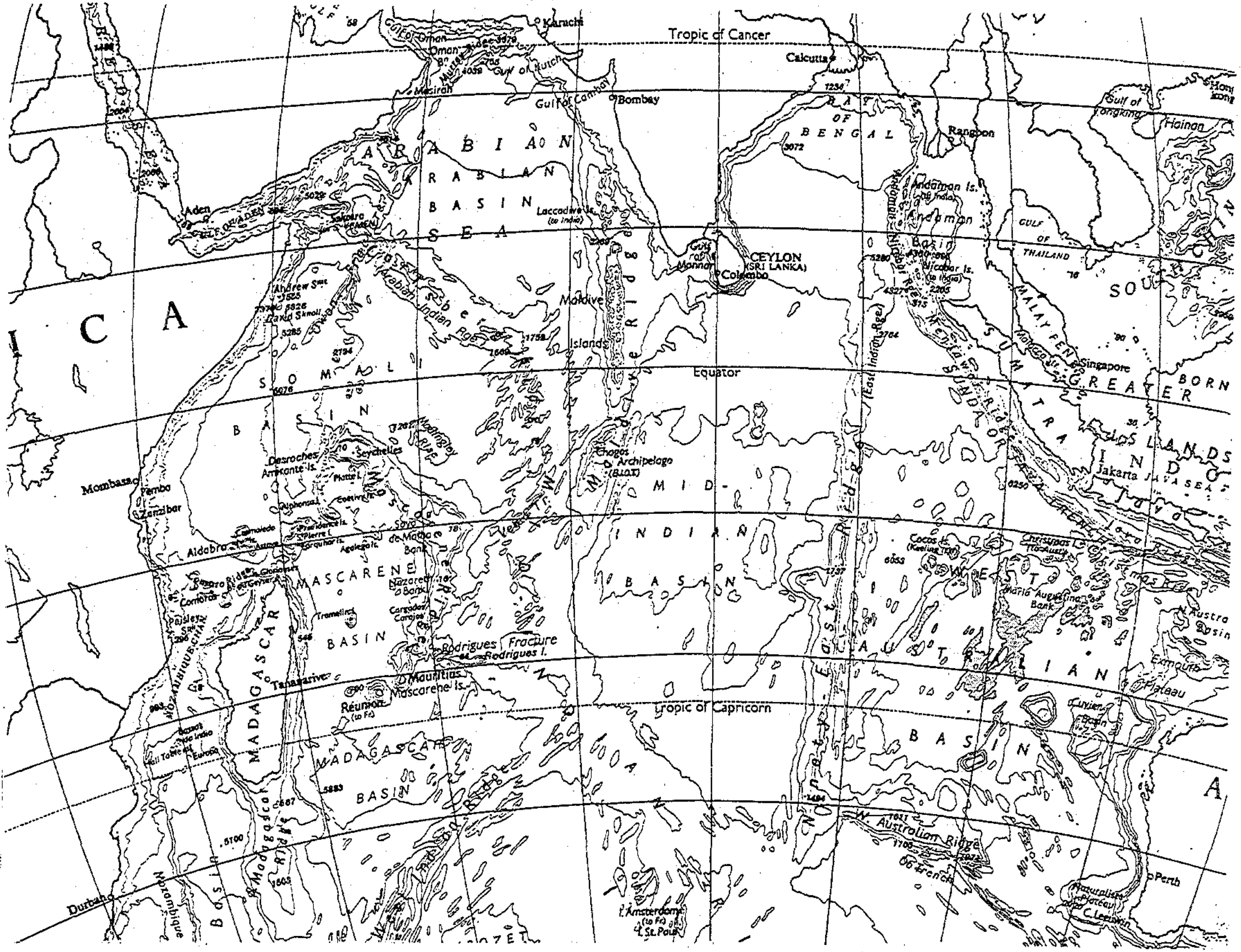


Figure 1.1 Submarine Topographical Map of Indian Ocean

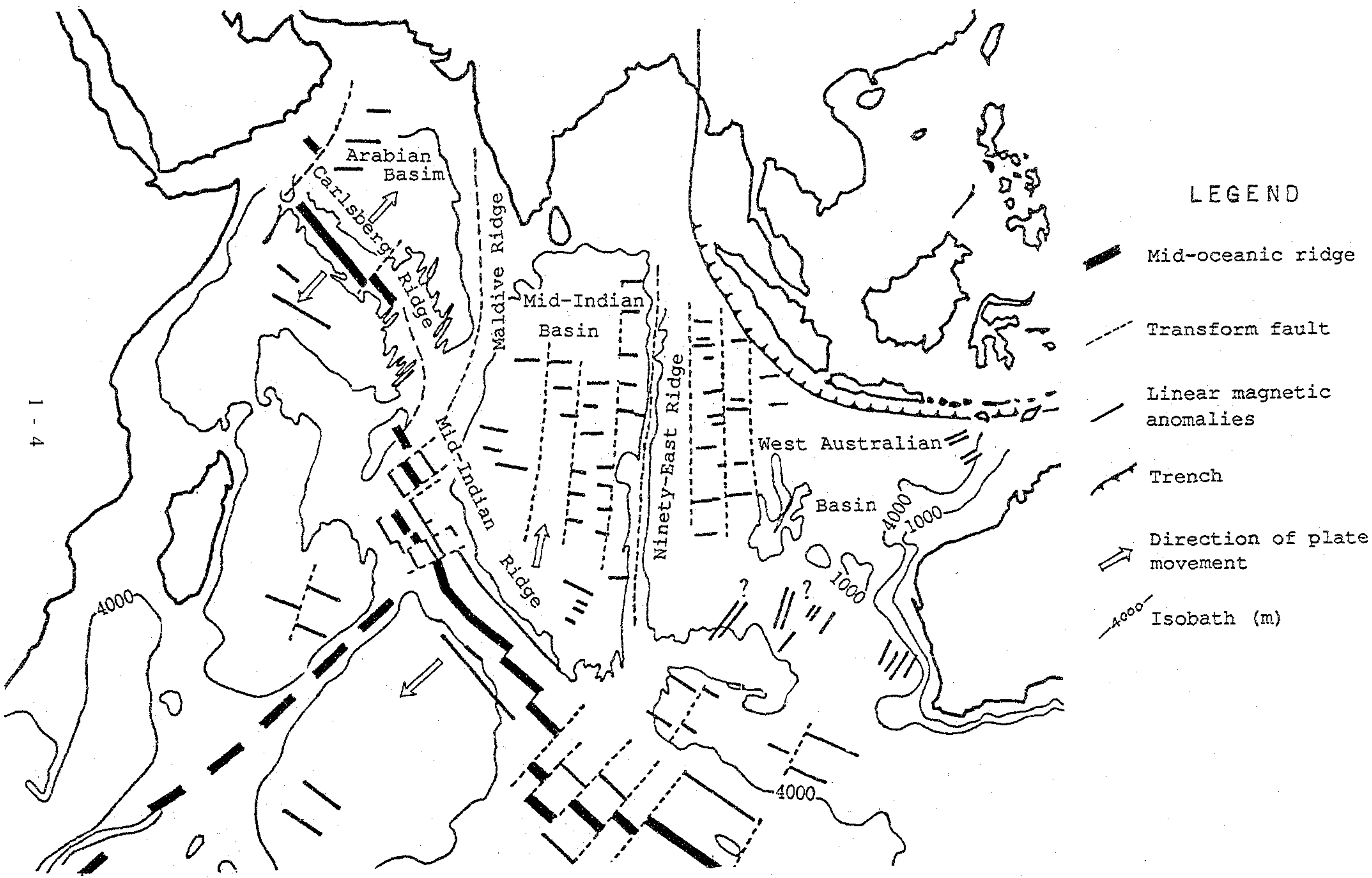


Figure 1.2 Direction of Plate Movement

The lagoons of atolls having depths 35~70 m can be explained by the glacial control theory. During the Last Glacial Stage, the floors of the present lagoons were erosion surface as the result of sea-level falls. Having emerged above the surface, the floors become karstified by rainfall and percolating water. Subsequent submergence of such a structure resulted in revival of coral growth at the knolls and along the outer edges of the lagoons. While the lagoons in faros having a depth of 4~6 m, are explained by the sea level change during Holocene age (10,000 years before~present) after the Last Glacial Stage. The lagoon floors in the faros become erosion surface as the result of sea level stop and fall, at a point of time during Holocene age. After that, coral reefs grew up along the edges of faros as the result of subsequent rise in the sea level. (Refer to Figure 1.3)

1.2 Geology of Male' Island

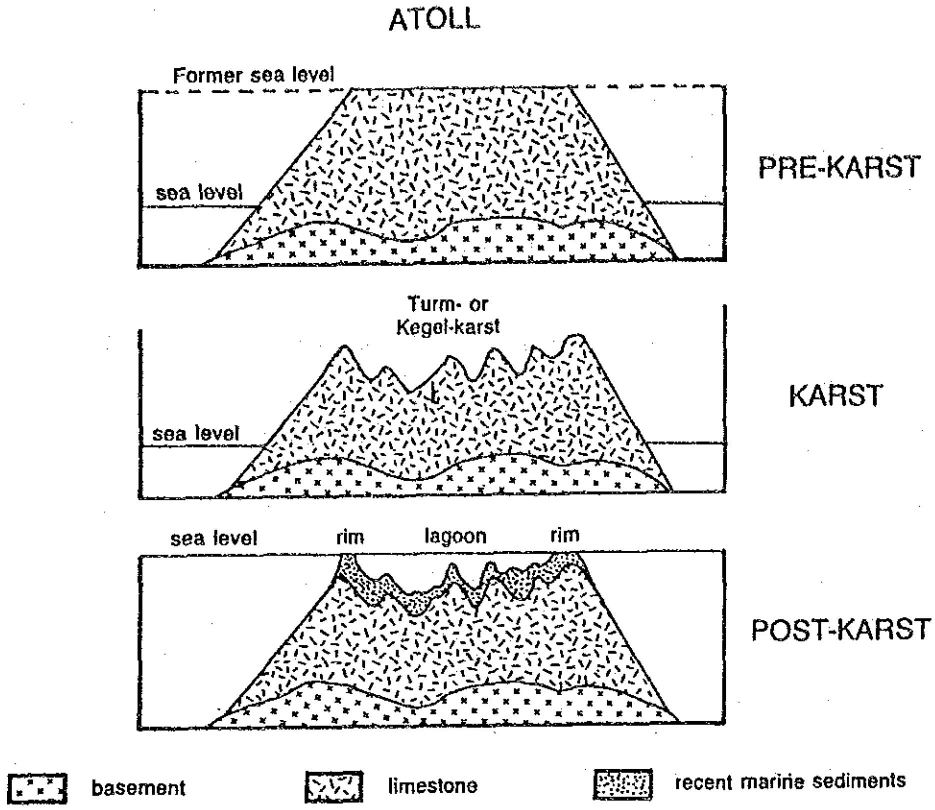
Male' Island is a faro which is located at the southeastern end of the North Male' Atoll. The faro of Male' Island is composed of a horseshoe shaped coral reef, a lagoon enclosed with the reef, and an island in the lagoon. (Refer to Figure 1.4)

The coral reef is made up of submarine outer edges, detrital outer ridges with coral detritus which are indicated by breaker zone, and reef flats in the inside of outer ridges.

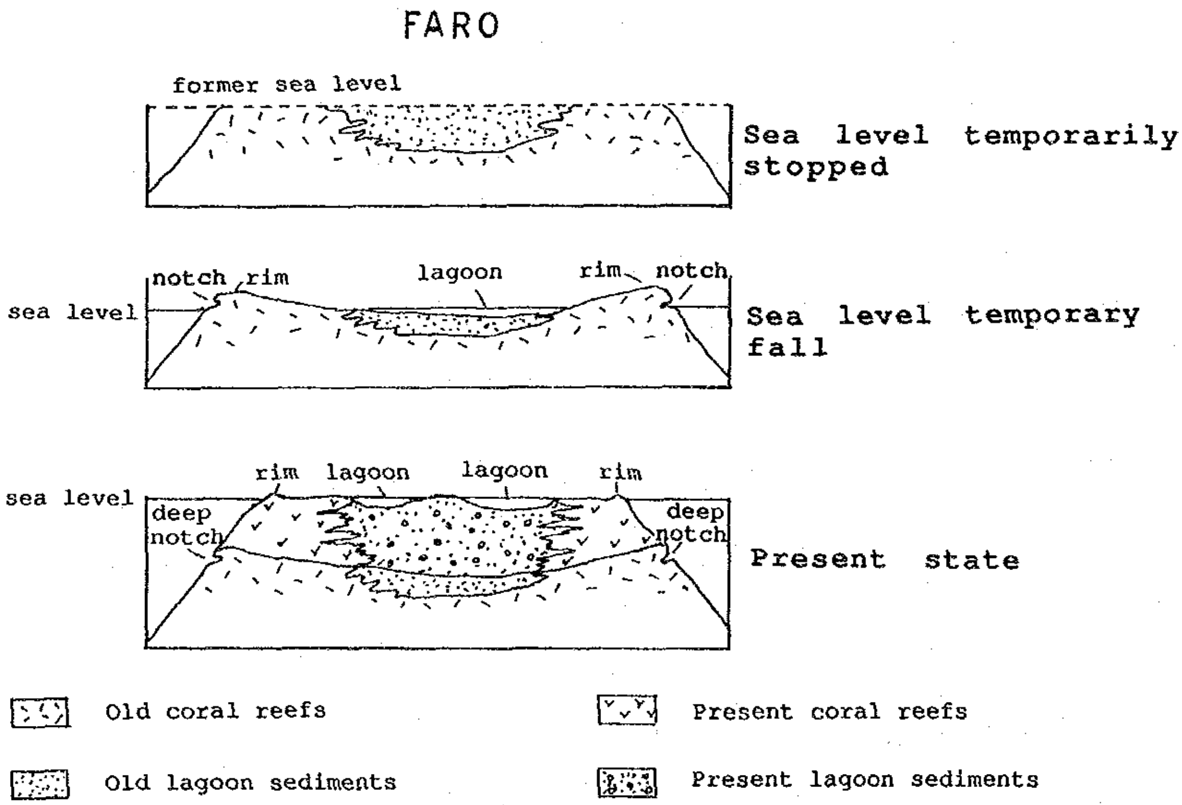
The horseshoe shape of the coral reef in Male' Island probably resulted from contrasts in the rates of reef growth, which are related to the waves generated by the south-east monsoon wind. Therefore the coral reef grew up well at the southeastern outer edges, but developed poorly along the northern outer edges.

The inner reef flats having many deep wave furrows, were found between the outer ridge and the lagoon as shown in Photographs 1.1 and 1.2 taken in 1980~1982. At the present time, the lagoon naturally remains along the east coast only. On the other coasts, the lagoon changes into the northern harbor and the southwestern domestic harbor as a result of the reclamation.

The original island having a 2 m height, is made up of the lagoon sediments (coral silt, sand and gravel) and the accumulation of coral detritus resulting from transportation by wave action.



(By Guilcher, A.; 1988)



(prepared by JICA study team)

Figure 1.3 Formation of Atoll and Faro

1.3 Geology of Funadhoo Island

Funadhoo Island is a small faro which is located about 700 m northeast of Male' Island. Funadhoo Island consists of a circular shaped coral reef with a diameter of about 400 m, an island having a diameter of about 200 m and lagoons between them. (Refer to Photograph 1.3 and Figure 1.5)

The coral reef is composed of submarine outer edges extending to the southeast, and detrital outer ridges which are indicated by breaker zones resulting from the southeast monsoon winds. The reef flats and the lagoons were disturbed by the breakwater construction and the dredging for the two boat harbors, but the reef flats are widely exposed along the south and the east coast of the island. The sandy beaches are scattered around the island. The island is made up of a sand cay covering the reef flats and has vegetation of coconut.

1.4 Soil Investigation, Male'

(1) Previous Investigations

The bore holes and the test pits for the previous foundation investigation are shown in Table 1.1. Also, the locations of the bore holes are shown in Figure 1.10 mentioned later. Both tables and figures include the three bore holes of this soil investigation for the Seawall Construction Project. The previous bore holes totalled 44 holes and 719 linear-meters. Their drill logs are summarized in Figure 1.6.

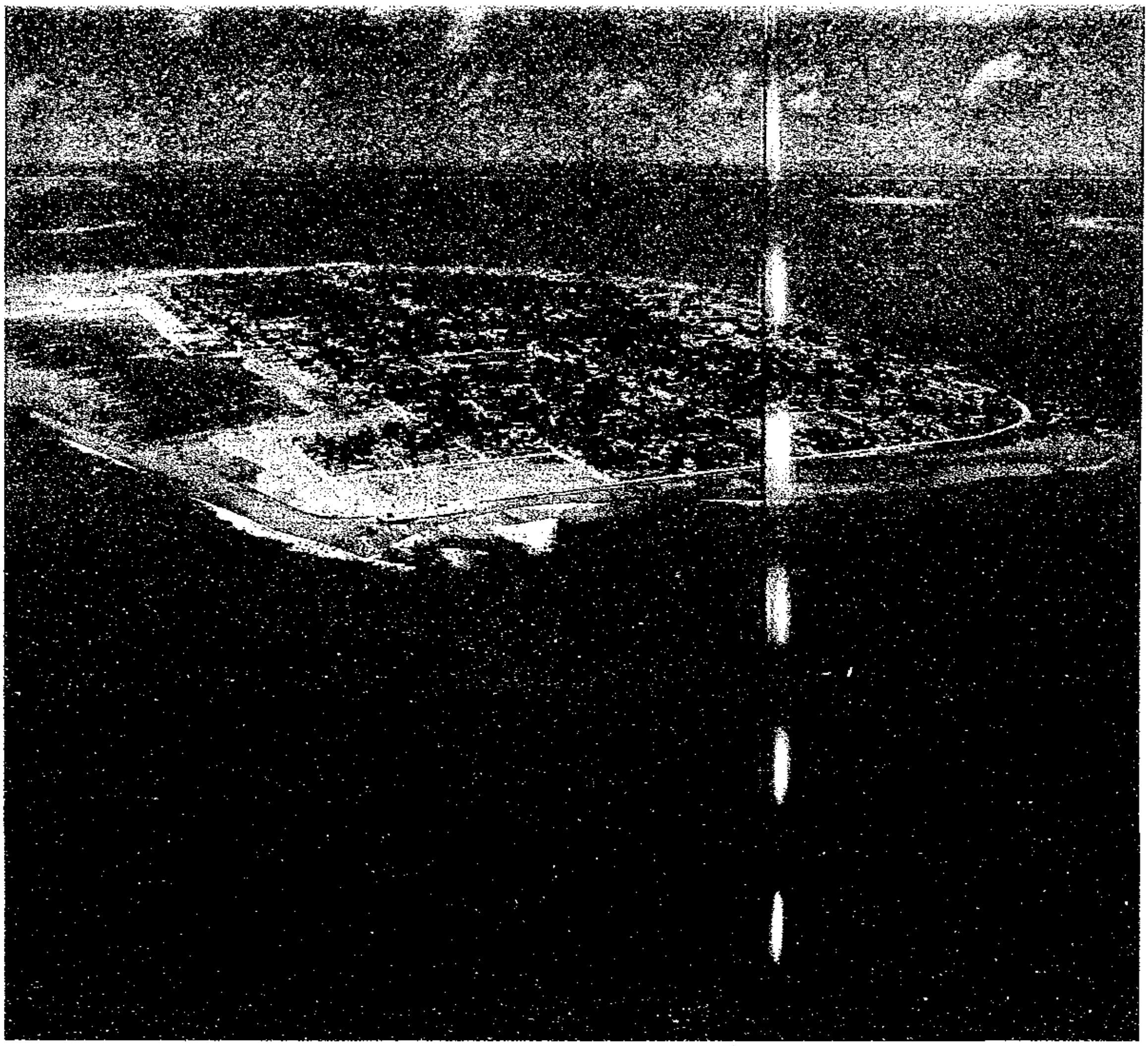
(2) Field Work and Laboratory Tests

The core drilling with a standard penetration test (S.P.T.) were performed for the purpose of obtaining geotechnical and soil data about sub-surface conditions along the proposed seawall alignments. The three bore holes (SDH 1, SDH 2, and SDH 3) were drilled by a hydraulic feed, rotary type core drilling machine at the east coast, the south coast and the west coast of Male'.

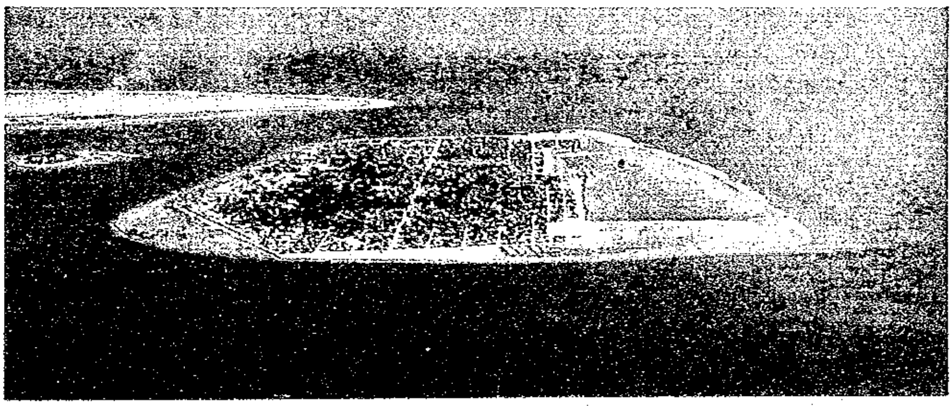
Their locations are shown in Figure 1.10 mentioned later. The depth and the number of S.P.T. of each bore hole are shown in Table 1.2. Also, the drilling log of each bore hole is shown in Figure 1.7 t o 1.9.

The unconfined compression test and the unit weight test concerning the nine core samples taken from the bore holes, were carried out in accordance with JIS and test standards based thereon at the laboratory in Singapore. These core samples were

Figure 1.4 Reef Pattern in Male' Island



Photograph 1.1　The East Coast and the South Coast View
taken in 1980 ~ 1982



Photograph 1.2　The South Coast and the West Coast View
taken in 1980 ~ 1982

Photograph 1.3 Bird's Eye View of Funadhoo Island
at the Present Time

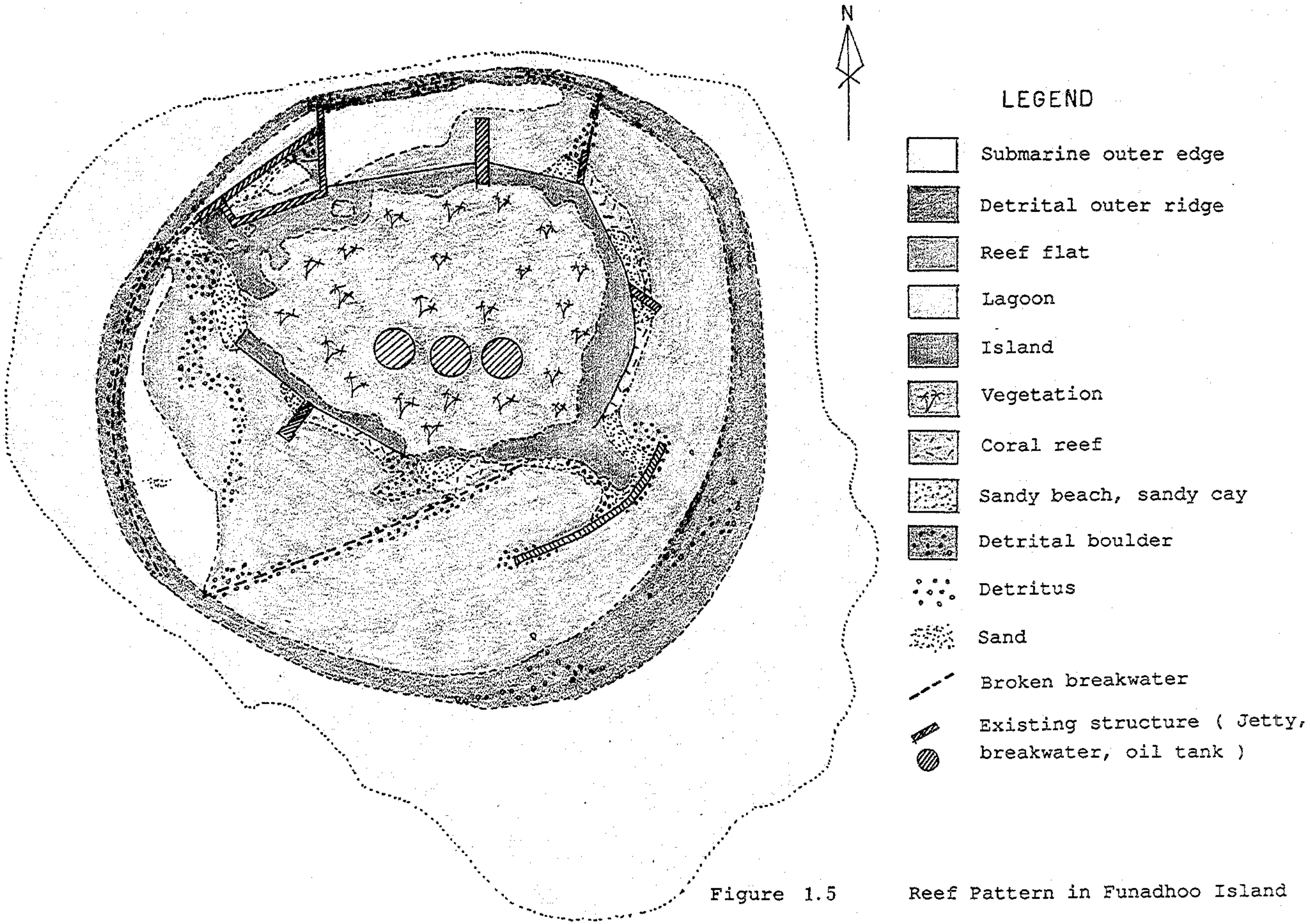


Figure 1.5 Reef Pattern in Funadhoo Island

Table 1. 1 *List of Bore Holes and Test Pits excavated for Foundation Investigations, Male'*

Project Name	Date	Bore Holes: Symbol & Consecutive No.	Bore Holes: Hole No.	Bore Holes: Depth	Test Pits
Male' Harbour	Mar. 29 ~ Apr. 1 1973	◑		(m)	
		1	BH 2	4.50	
		2	3	4.50	
		3	4	4.50	
		4	5	4.50	
		5	6	4.50	
		6	7	4.50	
		7	8	4.10	
		8	9	4.80	
		9	10	2.10	
		10	11	2.50	
		Total		40.50	
Grand Friday Mosque	Dec. 29 1982 ~ Jan. 11 1983	⊙		(m)	
		11	BH 1	38.10	
		12	2	30.48	
		13	3	29.57	
		Total		98.15	
Kalaafaanu Primary School	Jul. 18 ~ 21 1987	◓		(m)	4Pits, Depth; 1.5m each
		14	BH 1	15.00	
		15	2	15.38	
		16	3	15.00	
		17	4	15.00	
		Total		60.38	
Male' Port Development	Oct. 1987	⦶		(m)	
		18	BH 1	3.80	
		19	2	5.85	
		20	3	4.25	
		21	4	3.90	
		22	5	5.20	
		23	7	3.85	
		24	13	2.80	
		25	14	5.20	
		26	16	6.85	
		Total		41.70	
Electric Power Station	Oct. 1988				5Pits, Depth; 2.5m each

Project Name	Date	Bore Holes: Symbol & Consecutive No.	Bore Holes: Hole No.	Bore Holes: Depth	Test Pits
Indira Gandhi Memorial Hospital	Jun. ~ Jul. 1989	⊕		(m)	
		27	BH 1	20.40	
		28	2	19.85	
		29	3	40.15	
		30	4	20.50	
		31	5	40.15	
		32	6	40.20	
		33	7	40.30	
		34	8	18.80	
		35	9	40.30	
		36	10	39.85	
		Total		320.50	
Centre for Social Edication	Feb. 4 ~ 7 1990	◓		(m)	2Pits, Depth; 1.5m each
		37	BH 1	14.50	
		38	2	15.50	
		Total		30.00	
Private Client	Feb. 8 ~ 12 1990	⊖		(m)	
		39	BH 1	20.50	
		40	2	30.45	
		Total		50.95	
Male' Port Development	Feb. 18 ~ 21 1990				9Pits, Depth; 0.5m ~ 1.4m
	Nov. 28 1990 ~ Mar. 12 1991	◐		(m)	
		41	BH 1	18.00	
		42	2	20.35	
		43	3	17.46	
		44	4	21.00	
		Total		76.81	
Seawall Construction	Sep. 25 ~ Oct. 3 1991	◎		(m)	
			SDH 1	10.45	
			2	10.32	
			3	11.57	
		Total		32.34	

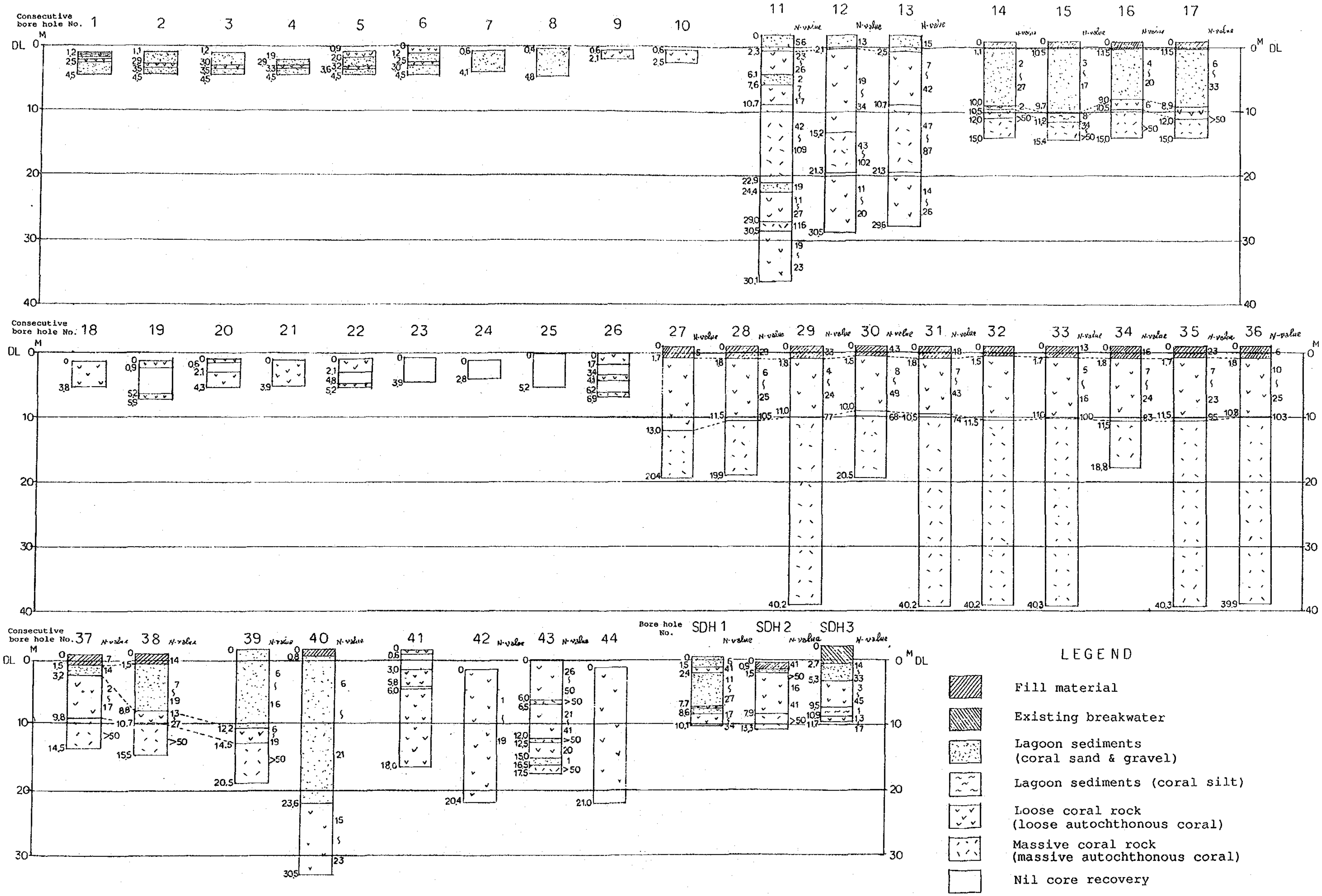


Figure 1.6 Columnar Sections of Bore Holes dilled for Foundation Investigation, Male'

Table 1.2 The Depth and the Number of S.P.T of Each Bore Hole

Bore Hole No.	Location	Depth (m)	Number of S.P.T.
SDH 1	East coast	10.45	10
SDH 2	South coast	10.32	10
SDH 3	West coast	11.57	10
Total		32.34	30

coated with paraffin on samples wrapped in transparent vinyl sheet, in order to keep the natural condition. The results of the above-said tests are shown in Table 1.3.

(3) Geological Classification

The geological classification which is summarized in the above-mentioned Figure 1.6, is defined as follows.

Fill material : The fill material consists of coral detritus including many kinds of rubbish.

Existing breakwater : The concrete body of the existing breakwaters located on the east, the south and the west coasts.

Lagoon sediments (coral sand and gravel) : The lagoon sediments consist of coral sand and gravel, including seashells in many cases. Sometimes, grading and sorting are found in the sediments. The N-values of S.P.T. in the sediments range from 3 to 33.

Lagoon sediments (coral silt) : The lagoon sediments consist mainly of coral silt, and include clay and fine coral sand. Seashells and organic materials are occasionally found in the sediments. the N-values of S.P.T. in the sediments range from 1 to 3.

Loose coral rock (loose autochthonous coral) : The loose coral rock is the reef building coral which grows up in-situ, with a many pores and cavities. therefore, its physical property is weak, the N-values of S.P.T in the loose coral rock range from 2 to 50 and the core recoveries are low. Based on the data of the previous and this investigations, the unconfined compressive strength on the core samples in the loose coral rock ranges from 5 to 135 kgf/cm^2, with an average of 70 kgf/cm^2. But the values may not be typical because the test was performed on the core samples only.

DRILLING LOG

Project No.	S03-31
Project	SEAWALL CONSTRUCTION - MALE
Type of Drilling	ROTARY
Hole Number	SDH-1
Elevation	DL +0.4 m.
Date	SEP 25 - 28, 1991
Water Table	At Sea Level m.
Driller	LOR (SHAH)

Remarks
P : Standard Penetration Test
C : Coring

Elevation in m	Depth in m	Thickness in m
0.40 / 0.20	0.00 / 0.20	0.20
-1.10	1.50	1.30
-2.00	2.40	0.90
-7.40	7.80	5.40
-8.20	8.60	0.80
-10.05	10.45	1.85

- END OF DRILLING -

Type of Soil	Colour	Relative Density or Consistency	General Remarks
Coral Gravel and Boulder	Grey to white	Very dense	Water transported well rounded well graded gravels and boulders of moderately strong coral rock.
Coral Sand	Yellowish gray	Loose	Well graded. With lot of seashell debris.
Coral Rock	Grayish white	Moderately weak to weak	Brecciated weakly cemented highly fractured. With well graded sand seams.
Coral Sand	Grayish white	Medium dense	Well graded with some medium to coarse gravels (Dia.max.=35mm; Calcareous and weak coral fragments.) Presence of silt (?). With red honeycombed coral rock at 2.40m.
Coral Rock	White	Weak	Fractured, weak, calcareous.
Coral Sand	Grayish white	Medium dense	Well graded. With some medium to coarse coral fragments (Dia.max.=30mm).
Coral Rock	White	Weak	Highly fractured calcareous coral. Presence of well graded coral sand pockets at top portion.

Sampling / Standard Penetration Test & Core Recovery (CR)

Depth in m.: 0.0, 1.00, 1.15, 1.45, 1.50, 2.00, 2.15, 2.45, 3.15, 3.45, 3.50, 4.00, 4.15, 4.45, 5.15, 5.45, 5.50, 6.00, 6.15, 6.45, 6.50, 7.00, 7.15, 7.45, 7.50, 8.00, 8.15, 8.45, 8.79, 9.00, 9.15, 9.45, 9.70, 9.91, 10.15, 10.45

Sample No.	N-Value Blows/30cm	Blows Per Each 10cm: 10 cm	10 cm	10 cm
P-1	6	1	2	3
P-2	41	17	13	11
P-3	27	8	8	11
P-4	19	9	6	4
P-5	11	4	4	3
P-6	12	3	4	5
P-7	18	6	7	5
P-8	18	3	7	8
C-1				
P-9	34	11	15	8
C-2				
P-10	17	6	4	7

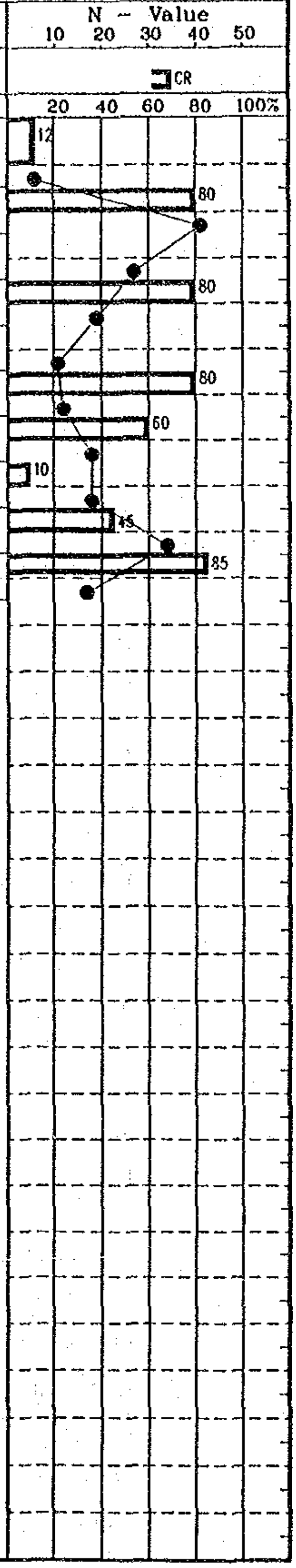


Figure 1.7 Drilling Log of SDH 1

DRILLING LOG

Project No. S03-31	Project SEAWALL CONSTRUCTION - MALE	Type of Drilling ROTARY	
Hole Number SDH-2	Elevation DL -0.4 m.	Date SEP.29 - OCT.01 1991	
Water Table At Sea Level m.		Driller LOR (SHAH)	

Remarks
P : Standard Penetration Test
C : Coring

Scale in m	Elevation in m	Depth in m	Thickness in m	Legend	Type of Soil	Colour	Relative Density or Consistency	General Remarks
	-0.40	0.00						
1	-1.00	0.60	0.60		Coral Boulder	Gray	Dense	Fill (Reclamation area). With concrete block, scrap iron, plastic refuse etc.
	-1.30	0.90	0.30					
	-1.90	1.50	0.60					
2–4					Silty Coral Gravel	Dark gray	Dense	Medium to coarse subangular gravels (Dia.max.=25mm). With some coral sand and lot of organic decays.
5					Coral Sand	Grayish white	Dense	Well graded. With some fine (Dia. max. = 6mm) coral gravels.
6–8	-8.30	7.90	6.40		Coral Rock	Grayish white to white	Very weak to weak	Weakly to moderately strong cemented, highly fractured. Disintegrated into well graded sand and gravels under hammer blows.
9–10	-10.72	10.32	2.42		Coral Rock	Grayish white	Weak to moderately strong	Moderately fractured. Occassionally with well graded sand seams.
11					- END OF DRILLING -			

Scale in m: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Sampling / Standard Penetration Test & Core Recovery (CR)

Depth in m: 0.0, 1.00, 1.15, 1.45, 1.50, 2.00, 2.15, 2.42, 2.50, 3.00, 3.15, 3.45, 3.70, 3.95, 4.00, 4.15, 4.45, 4.60, 4.75, 5.00, 5.15, 5.45, 5.50, 6.00, 6.15, 6.45, 6.50, 7.00, 7.15, 7.45, 7.50, 8.00, 8.15, 8.33, 8.50?, 8.75, 8.97, 9.15, 9.27, 9.98, 10.17, 10.32

Sample No.	N-Value Blows/30cm	Blows 10 cm	Blows 10 cm	Blows 10 cm
P-1	41	12	15	14
P-2	50/27	17	21	12/7
P-3	38	8	14	16
C-3				
P-4	41	12	11	18
C-4				
P-5	17	6	5	6
P-6	31	14	7	10
P-7	16	6	5	5
P-8	50/18	11	39/8	
C-5				
P-9	50/12	40	10/2	
C-6				
P-10	50/15	50/15		

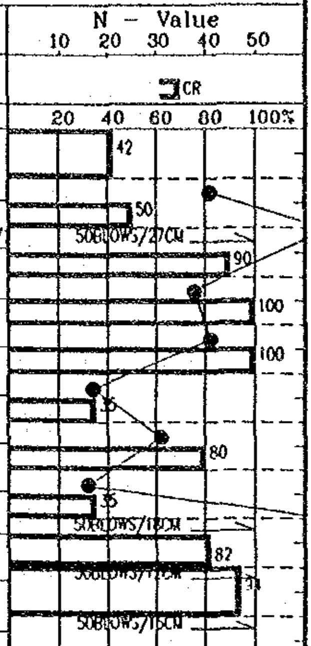


Figure 1.8 Drilling Log of SDH 2

DRILLING LOG

Project No.	S03-31	Project	SEAWALL CONSTRUCTION - MALE
Type of Drilling	ROTARY	Hole Number	SDH-3
Elevation	DL +2.2 m.	Date	2nd.- 3rd.OCT, 1991
Water Table	GL -1.5 m.	Driller	LOR (SHAH)

Remarks
P : Standard Penetration Test
C : Coring

Elevation in m	Depth in m	Thickness in m	Type of Soil	Colour	Relative Density or Consistency	General Remarks
2.20	0.00					
-0.50	2.70	2.70	Coral Boulder with Concrete	Greyish white to creamy white	Weak to moderately strong	Existing breakwater. Boulders of different sizes (Predominant dia. 15cm to 30cm). Cemented together with concrete mortar.
-3.10	5.30	2.60	Coral Sand	Greyish white	Medium dense to dense	Well graded sand with lot of coral gravels and some friable coral rock fragments. Occassionally with some seashells. Presence of plastic and clothes refuse between 1.70m to 1.80m
-7.30	9.50	4.20	Coral Rock	Creamy white to white	Very weak to weak	Highly fractured and partly porous. Disintegrated into well graded sand and gravels under hammer blows.
-8.70	10.90	1.40	Silty Coral Sand	Greyish white	Very loose	Sand is fine grained. (No recovery between 9.50m to 10.67m - Cavity (?)).
-9.37	11.57	0.67	Coral Rock	Greyish white	Very weak	Highly fractured.

- END OF DRILLING -

Sampling / Standard Penetration Test & Core Recovery (CR)

Depth in m: 0.0, 1.00, 2.00, 2.50, 3.00, 3.15, 3.45, ... 10.00, 10.67, 10.82, 11.12, 11.27, 11.57

Sample No.	N-Value Blows/30cm	10 cm	10 cm	10 cm
C-7				
P-1	22	9	7	6
P-2	33	9	16	8
C-8				
P-3	14	4	3	7
C-9				
P-4	3	2	1	0
P-5	9	5	2	2
P-6	5	0	1	4
P-7	45	25	7	13
P-8	1/67			
P-9	13	5	3	5
P-10	17	3	8	6

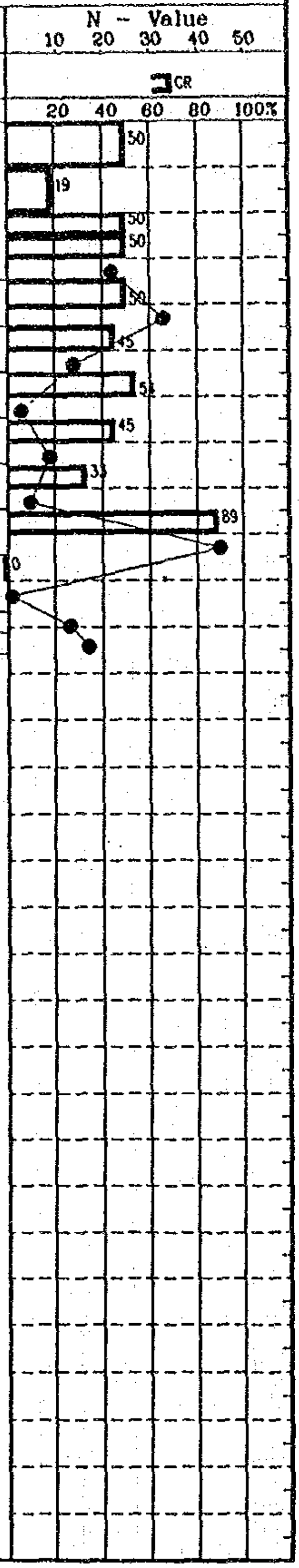


Figure 1.9 Drilling Log of SDH 3

Table 1.3 The Results of Unconfined Compression Test and Unit Weight Tetst on the Core Samples

Sample No.	Sample	Locality	S.P.T. N-value		Unconfined Compessive Strength kgf/cm²	Strain at Failure %	Water Content in Percent of Dry Weight %	Unit Weight Paraffin Method g/cm³
			Upper Level	Lower Level				
C-1	Loose coral rock	SDH1 8.79～9.00m depth	18	34	66.1	3.95	18.0	2.13
C-2	do	Do 9.70～9.91m depth	34	17	61.6	4.15	10.4	2.47
C-3	do	SDH2 3.70～3.95m depth	38	41	16.8	3.70	17.5	2.41
C-4	do	Do 4.60～4.75m depth	41	17	5.9	1.91	29.7	2.48
C-5	Massive coral rock	Do 8.75～8.97m depth	>50 (18cm)	>50 (12cm)	14.0	1.68	35.5	1.53
C-6	do	Do 9.98～10.17m depth	>50 (12cm)	>50 (15cm)	19.4	4.08	26.2	2.33
C-7	Loose coral rock	SDH3 3.98～4.00m depth	22	33	57.5	4.04	13.4	2.12
C-8	do	Do 4.87～5.00m depth	33	14	109.4	8.78	12.7	2.26
C-9	do	Do 5.90～6.00m depth	14	3	35.5	3.93	13.4	2.47

(   ): A penetration advance at 50 blows by S.P.T.

Massive coral rock (massive autochthonous coral) : The massive coral rock is the reef building coral which grows up in-situ too. But the massive coral rock is slightly more stronger than the above-said loose coral rock, because of the compaction by the load of upper sediments and the cementation resulting from the movement of calcareous matter by percolating water. The N-values of S.P.T. in the massive coral rock show a value above 50, and the core recoveries are higher than in the loose coral rock and sometimes reach 100 %. Based on the data of the previous and this investigations, the unconfined compressive strength on the core samples in the massive coral rock ranges from 14 to 210 kgf/cm^2, with an average of 90 kgf/cm^2. These values are slightly higher than those in the loose coral rock.

(4) Geotechnical Situation of the Foundation along the Proposed Seawall Alignments

The geological sections along the proposed seawall alignments and their cross sections are prepared on the basis of the reef pattern in Figure 1.4, the columnar sections in Figure 1.6 and the above-mentioned geological classification. The location of the geological section lines are shown in Figure 1.10 and the geological sections are shown in Figure 1.11.

a) The Gelogical Section A-A'

Based on the geological section A-A' along the proposed seawall alignment on the east coast, the foundation of the proposed seawall consists of the lagoon sediments in the northern side and the loose coral rock in the southern side. The lagoon sediments are distributed in the northern side from 75 m south of SDH 1 bore hole position, and mainly underlie the existing breakwater and occasionally intercalate thin fill material between both of them. While, the loose coral rock which forms the reef flat is extended in the southern side of the lagoon sediments. The loose coral rock underlies the existing breakwater and frequently includes an intercalated thin sandy sediment between both of them.

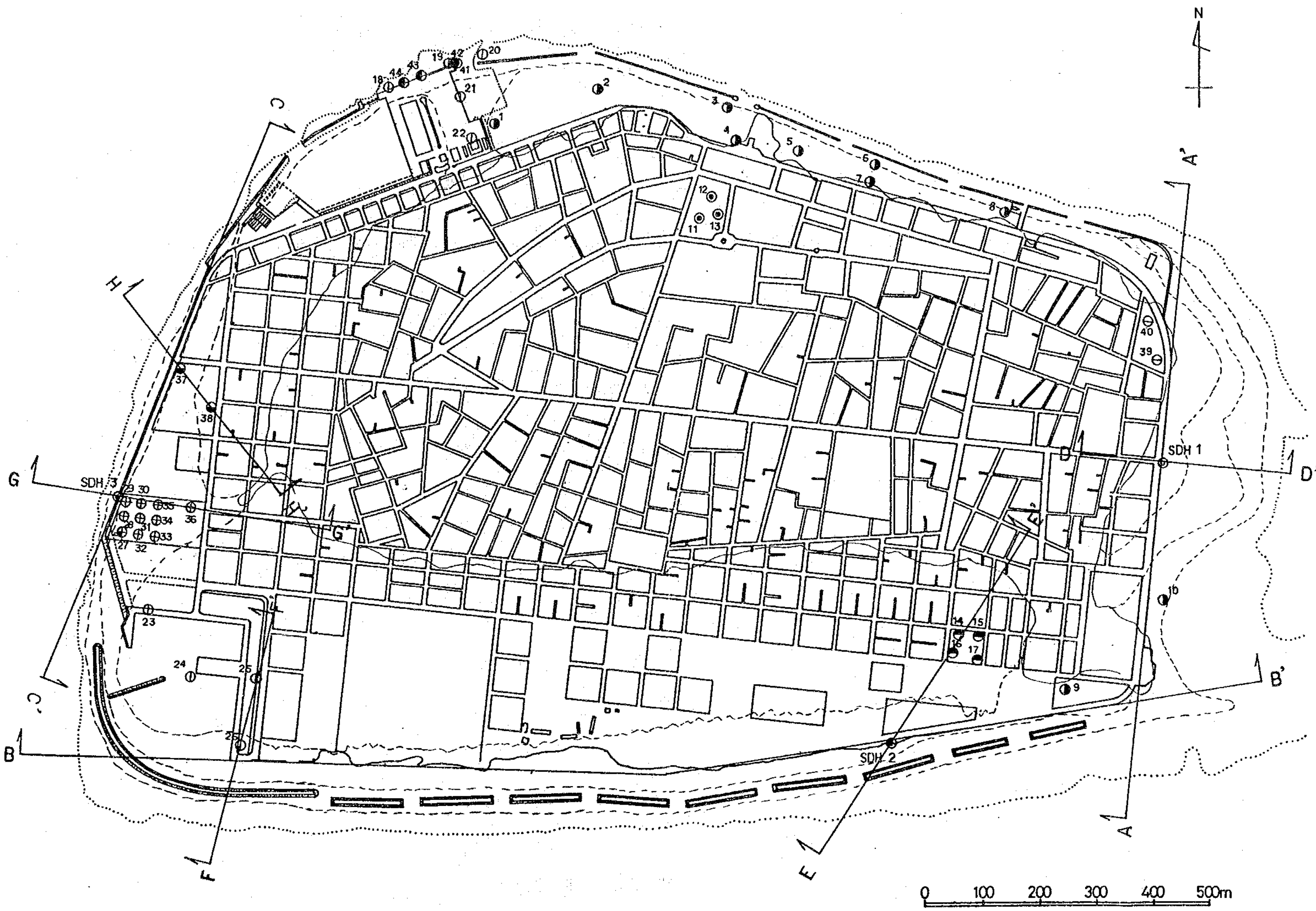


Figure 1.10 Location Map of Bore Holes drilled for Foundation Investigation and Geological Section Lines, Male'

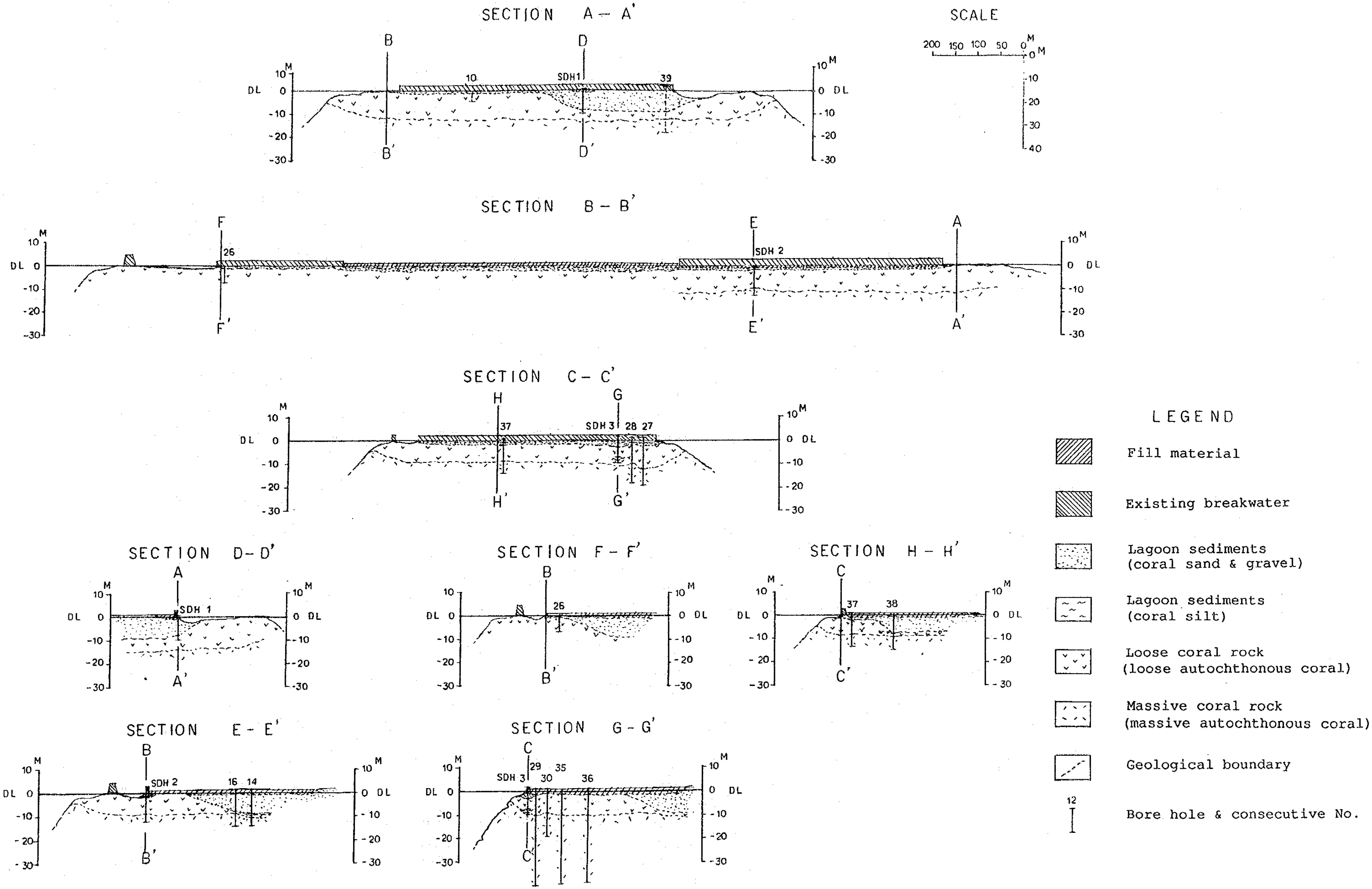


Figure 1.11 Geological Sections along the proposed Seawall Alignments and their Cross Sections

b) The Geological Section B-B'

Based on the geological section B-B' along the proposed seawall alignment on the south coast, the foundation of the proposed seawall is made up mainly of the loose coral rock which forms the reef flat. The loose coral rock underlies the existing breakwater in half of the section. SDH 2 bore hole intersected the fill material of about 1 m thick and the underlying sandy sediments of about 50 cm thick between the existing breakwater and the loose coral rock. Therefore, the fill material and the sandy sediment are intercalated between the existing breakwater and the loose coral rock, or cover on the loose coral rock. their thicknesses probably depend upon the surface shape (for example wave furrow) of the reef flat and the situation of reclamation.

c) The Geological Section C-C'

Based on the geological section C-C' along the proposed seawall alignment in the west coast, the foundation of the proposed seawall is composed mainly of the loose coral rock which forms the outer ridge. The loose coral rock underlies the existing breakwater and frequently includes an intercalated sandy sediment between both of them. SDH 3 bore hole intersected the sandy sediment of 2.6 m thick between the existing breakwater concrete body and the loose coral rock. The thickness of the sandy sediment at geological section H-H' is estimated to be from 1.5 m to 2.0 m. Such a thick sandy sediment may be caused by the sedimentation at deep wave furrow on the outer ridge.

(5) Geotechnical Analysis

a) The Lagoon Sediments and the Loose Coral Rock

The foundation of the proposed seawall consists mainly of the lagoon sediments (in the north side of the east coast), the loose coral rock which forms the reef flat (in the south side of the east coast and the south coast) and the loose coral rock which forms the outer ridge (on the west coast).

The physical properties of the lagoon sediments and the loose coral rock are summarized in Table 1.4.

The ultimate bearing capacity of the lagoon sediments in the Table 1.4 was taken on the basis of the previous plate load test for the Kalaafanu Primary School

Project. Also, the ultimate bearing capacity of the loose coral rock in Table 1.4 was taken on the basis of the previous plate load test for the Indira Gandhi Memorial Hospital Project. Both plate load tests are performed on the lagoon sediments and on the loose coral rock respectively.

Table 1.4 The Physical Properties of the Lagoon Sediments and the Loose Coral Rock

Name of Fundation Rock	Description	N-value (S.P.T)	Unconfined Compressive Strength kgf/cm²	Ultimate Bearing Capacity t/m²
Lagoon Sediments	Coral sand and gravel, median grain size : 0.4~0.6 m/m	3 ~ 33	-	16 ~ 22
Loose Coral Rock	Leef building coral which grow up in-situ, with many pores and cavities	2 ~ 50	5 ~ 135 (average 70) The test was performed on core samples only	45 ~ 60

b) Damage of Coral Reef on the West Coast

The Proposed seawall alignment on the west coast is planned on the outer ridge of the coral reef, and it is not the same as on the reef flat or on the lagoon sediments in case of the east and the south coast. The alignment is very near from the outer slope of coral reef and its distance ranges from 7 m to 30 m.

It is estimated that the coral reef on the west coast is probably damaged by wave erosion and surface erosion during the period of sea level change, because the submarine notches are found on the outer slope at 5 m to 10 m depth from D.L.

SDH 3 bore hole intersected the sandy silt sediment of 1.4 m thick at 7.3 m to 8.7 m depth from D.L. The sandy silt sediment which underlies the loose coral rock having 45 in N-value (S.P.T.), shows a penetration advance of 67 cm at one blow by S.P.T. Therefore, the sandy silt sediment may be deposits in the cave.

1.5 Material Test

(1) Sample

Five coarse aggregate samples (E1~E5) which were taken from the concrete body of the existing breakwaters, were coated with paraffin on samples wrapped in transparent vinyl sheet, because to keep its natural condition. Ten dredged coral lump samples (R-1~R-10) were collected at the pile area of the domestic harbor. The unconfined compression test and the unit weight test concerning the above-mentioned fifteen samples were carried out in accordance with JIS and test standards based thereon, at the laboratory in Singapore. The results of the said tests are shown in Table 1.5.

Seven dredged coral sand samples for fine aggregate (S-1~S-7), were collected at the same pile area. Three river sand samples for fine aggregate (S-8~S~10), imported from Lumut Port, Malaysia, were collected at the pile area of the tetrapod plant. The grading analysis and the specific gravity test for the above-mentioned ten samples were conducted in accordance with the test standards based on JIS, at the same laboratory. The results of the said tests are shown in Table 1.6.

(2) The Coral Coarse Aggregate Samples Taken from the Existing Breakwaters.

As compared with JIS A 5005 for "crushed stone for concrete", the values of unit weight concerning the coral coarse aggregate samples range from 1.1 to 2.2, and all those values are lower than the specific gravity above 2.5 provided by the said JIS standard. The values of water content concerning the said samples range from 13 to 32 % in natural condition, but all those values are higher than the absorption value below 3 % prescribed by the said JIS standard.

The results of the unconfined compression test range from 6 to 56 kgf/cm^2 in unconfined compressive strength. All these' values are classified as "soft rock" (below 200 kgf/cm^2 in unconfined compressive strength). However, coarse aggregate for concrete should generally be "hard rock" (above 600 kgf/cm^2 in unconfined compressive strength). Therefore, because of "soft rock", lower unit weight and higher adsorption, all the said coral coarse aggregate samples taken from the existing breakwater are not suitable for structural coarse aggregates, but the coral coarse aggregate are sufficiently possible to be used as packing for the proposed seawall.

Table 1.5 The Results of Unconfined Compression Test and Unit Weight Test on the Coarse Aggregate Samples from the Existing Breakwaters and the Dredged Coral Samples

Sample No.	Sample		Locality	Unconfined Compressive Strength kgf/cm²	Strain at Failure %	Water Content in Percent of Dry Weight %	Unit Weight Paraffin Method g/cm³
E- 1	Coral Coarse aggregate from the existing breakwater	Bee hive-like coral	80m west from SDH2 position	6.4	2.50	17.3	1.08
E- 2		Massive porous coral	do	34.7	3.80	12.6	2.19
E- 3		Massive coral	SDH3, 0.88 ~1.00m depth in the existing breakwater body	56.1	5.00	31.9	1.93
E- 4		Bee hive-like coral	SDH3, 2.28 ~2.50m depth in the existing breakwater body	20.1	2.16	21.6	1.81
E- 5		Massive porous coral	10m south from SDH3 position	48.2	3.03	19.4	1.93
R- 1	Dredged coral Lump sample before screening	Bee hive-like coral	Taken by the domestic harbour dredging	9.5	1.11	1.9	1.85
R- 2		Massive coral	do	74.5	3.42	0.6	1.46
R- 3		Bar-like coral	do	135.5	4.93	1.2	2.25
R- 4		do	do	82.0	3.09	6.0	2.39
R- 5		Massive porous coral	do	31.2	3.62	6.5	1.98
R- 6	Dredged coral sample (40~100m/m in size) after screening	Bee hive-like coral	do	13.8	2.83	7.6	1.66
R- 7		Massive coral	do	46.6	3.79	0.6	1.74
R- 8		Bar-like coral	do	48.4	2.22	1.6	2.18
R- 9		do	do	57.6	3.13	1.8	2.35
R-10		Massive porous coral	do	47.3	4.42	2.0	2.10

(3) The Dredged Coral Lump Samples for Coarse Aggregate

As compared with JIS A 5005 for "crushed stone for concrete", the values of unit weight concerning the dredged coral lump samples range from 1.5 to 2.4, and all those values are lower than the specific gravity above 2.5 prescribed in the said JIS standard. The value of water content among the said samples are higher than the absorption value below 3 % provided by the said JIS standard.

The results of the unconfined compression test range from 10 kgf/cm^2 to 136 kgf/cm^2. All these values are classified as "soft rock" (below 200 kgf/cm^2 in unconfined compressive strength). However "hard rock" (above 600 kgf/cm^2 in unconfined compressive strength) is more suitable for coarse aggregate for concrete. So, by reason of "soft rock" and lower unit weight, all the said dredged coral lump samples are not suitable for structural coarse aggregate. But, these dredged coral lump samples are sufficiently possible to be used as packing for the proposed seawall.

(4) The Dredged Coral Sand Samples for Fine Aggregate.

As compared with JIS A 5004 for "manufactured sand for concrete", the four values of specific gravity among the dredged coral sand samples are lower in comparison with the specific gravity above 2.5 prescribed by the said JIS standard. While, all the values of adsorption regarding the said samples are lower than the absorption value below 3 % provided by the said JIS standard.

Compared with the river sand sample from Malaysia, the average values of specific gravity, absorption, median grain size and coefficient of uniformity concerning the dredged coral sand sample are as follows.

Specific gravity : Coral sand (2.50) is lower than the river sand (2.61)

Absorption : The coral sand (0.3 %) is the same as the river sand (0.3 %)

Median grain size : The coral sand (0.71 m/m) is smaller than the river sand (0.86 m/m)

Coefficient of uniformity : The coral sand (4.1) is higher than the river sand (2.8). It means that the uniformity of river sand is higher than that of coral sand, because of sorting by river water flow.

Table 1.6 The Results of Grading Analysis and Specific Gravity Test on the Dredged Coral Sand Samples and the River Sand Samples

Sample No.	Sample	Locality	Grading Analysis			Specific Gravity g/cm^3	Absorption %
			Median Grain size m/m	Coefficient of Uniformity	Coefficient of Curvature		
S- 1	Dredged coral sand (before screening)	taken by the domestic harbour dredging	0.64	4.3	0.93	2.51	0.3
S- 2	do	do	0.66	4.1	0.98	2.51	0.3
S- 3	do	do	0.54	3.9	0.70	2.55	0.3
S- 4	do	do	0.85	4.6	1.10	2.49	0.5
S- 5	Dredged coral sand (under 5m/m in size)	do	0.78	4.1	0.97	2.49	0.2
S- 6	do	do	0.76	4.1	0.94	2.47	0.5
S- 7	do	do	0.73	3.9	0.95	2.49	0.3
Average			0.71	4.1	0.94	2.50	0.3
S- 8	River sand (under 5m/m in size)	imported from Lumut Port, Malaysia	0.89	2.6	0.95	2.60	0.3
S- 9	do	do	0.90	3.1	0.85	2.61	0.3
S-10	do	do	0.80	2.6	1.04	2.61	0.2
Average			0.86	2.8	0.95	2.61	0.3

Note : Median grain size(m/m); 50% grain size(D_{50})
10% grain size(D_{10}), 30% grain size(D_{30}),
60% grain size(D_{60})

Coefficient of uniformity: D_{60}/D_{10}
Coefficient of curvature : $(D_{30})^2/D_{10} \times D_{60}$

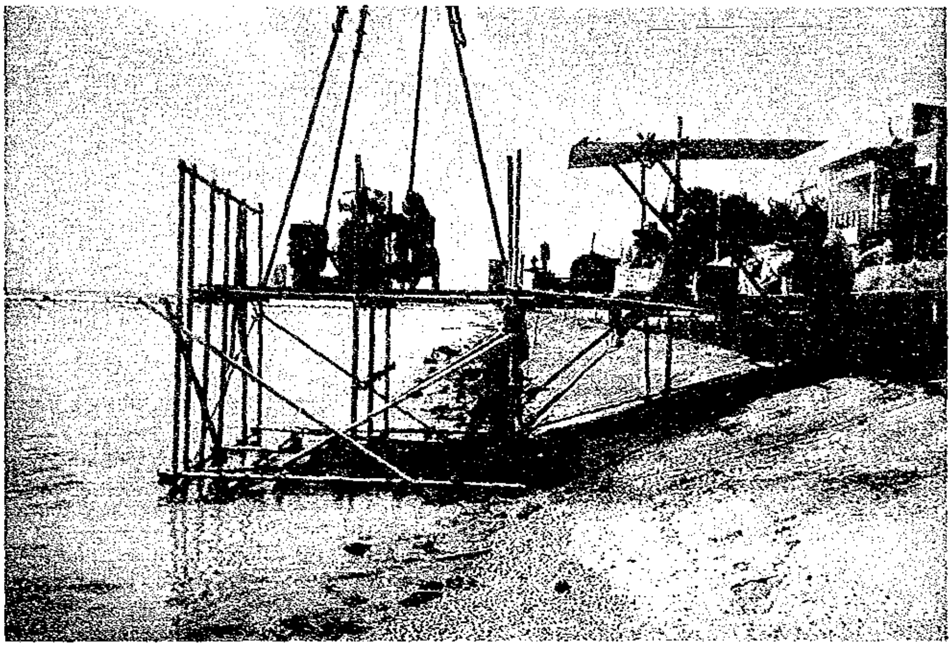
Because the coral sand has a softer grain and lower specific gravity than river sand from Malaysia, the coral sand is not so suitable for fine aggregate for concrete in comparison with the river sand from Malaysia.

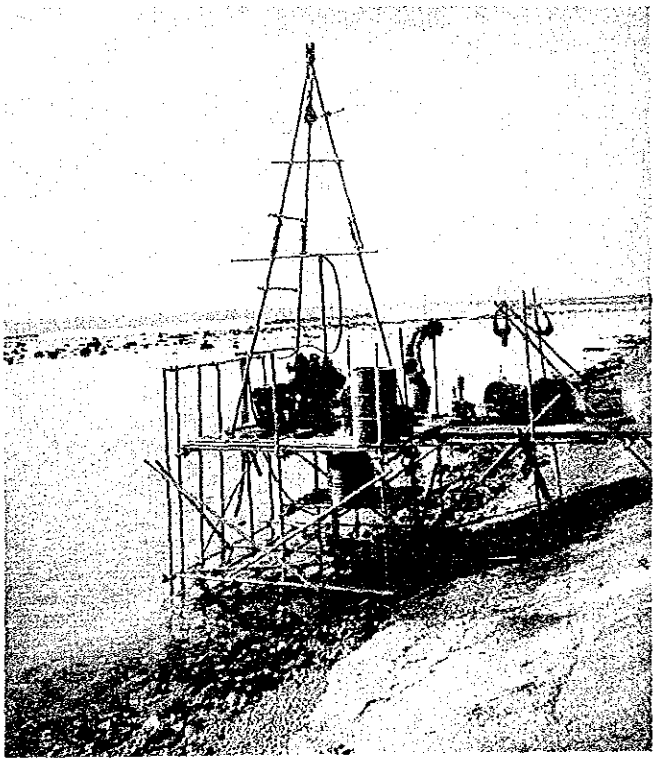
APPENDIX

(SOIL DATA)

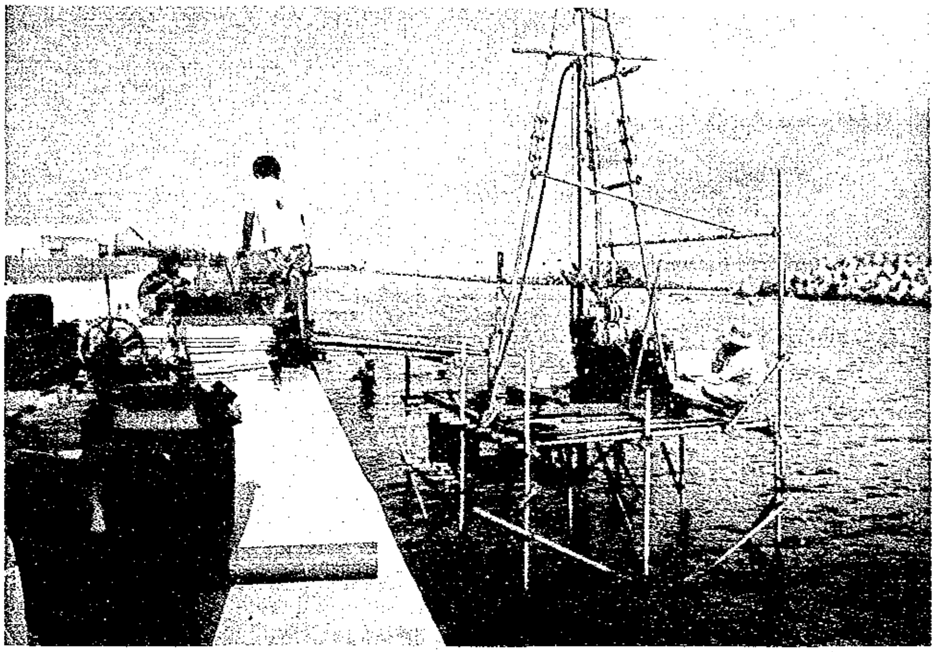
1. Photograph of Field Investigation

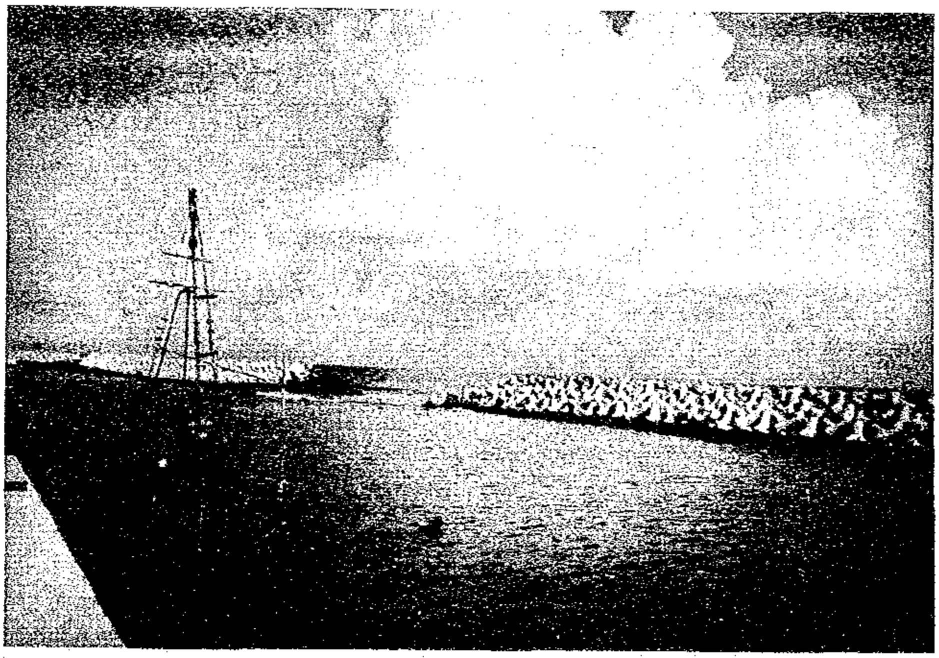
2. Photograph of Rock Cores



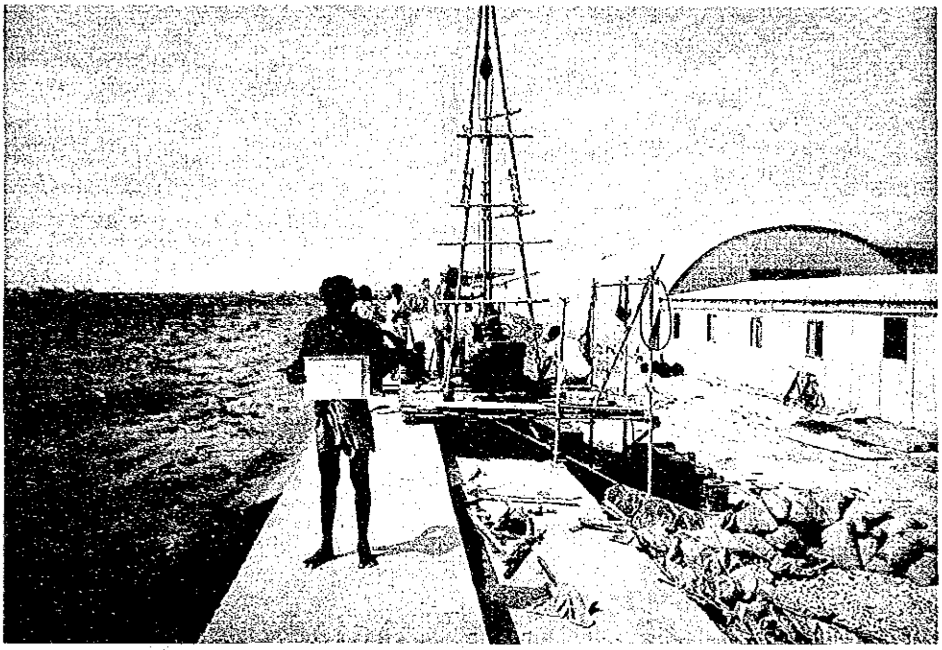


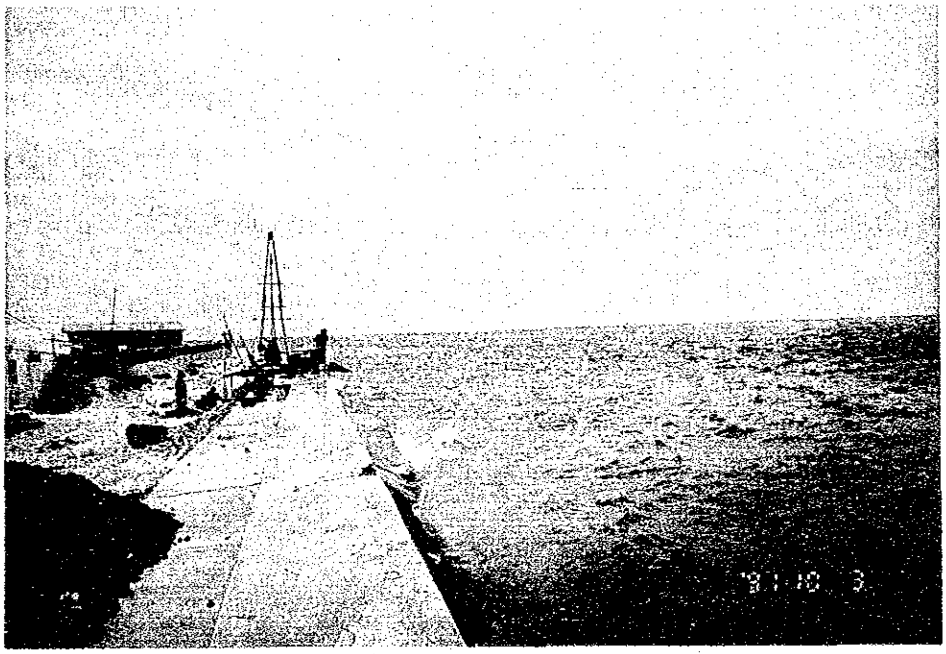
Set-up Drilling Machine at Borehole Location SDH-1





Set-up Drilling Machine at Borehole Location SDH-2





Set-up Drilling Machine at Borehole Location SDH-3