URBAN TRANSPORT STUDY

IN

GREATER METROPOLITAN AREAS

OF

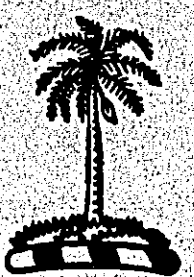
GEORGETOWN, BUTTERWORTH AND BUKIT MERTAJAM

MALAYSIA

SOIL INVESTIGATION

OUTER RING ROAD PROJECT (PHASE II)

TECHNICAL REPORT - 03



MARCH 1981

JAPAN INTERNATIONAL COOPERATION AGENCY

GOVERNMENT OF MALAYSIA

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. FIELD SURVEY

1.1 Outline of Works Performed

1) Geotechnical Investigation

Geotechnical investigation was started on 17th April, 1980 and completed on 30th June, 1980.

This geotechnical investigation consisted of:

a. Exploratory drilling with Standard Penetration Test and undisturbed sampling.

b. Laboratory tests on soil and material samples obtained from the site.

c. Study for coarse and fine aggregates and embankment material.

Drilling works were performed by Geotechnique (Malaysia) Sdn. Bhd. in Kuala Lumpur.

Almost all laboratory tests on soil and material samples were carried out at the laboratory of Kiso-Jiban Consultants Co., Ltd. in Singapore. Los Angeles Abrasion tests were conducted at JKR laboratory in Kuala Lumpur. The standards used for this study were the Japanese Industrial Standard (JIS) and American Association of State Highway and Transportation Officials (AASHTO). Investigation works performed are listed in Table 1.1 and Table 1.2.

Table 1.1 INVESTIGATION WORKS PERFORMED

Bore Hole Number	Drilling Length (m)			Standard Penetration Test	Sampling U-4 Sampler	Notes
	Offshore	On Land				
		Soil	Coring			
BH-1	40.0	-	-	26	9	Offshore Drilling by Percussion rig
BH-1'	21.7	-	-	14	3	- Ditto -
BH-2	40.0	-	-	27	5	- Ditto -
BH-3	21.7	-	-	15	1	- Ditto -
BH-4	-	46.15		25	4	On Land by Percussion rig
BH-5	-	5.2	11.6	3	0	On Land by Rotary rig
BH-6	-	5.8	11.0	3	0	- Ditto -
BH-7	-	15.9	7.0	12	1	- Ditto -
BH-8	-	25.3	-	18	2	- Ditto -
TOTAL	123.4	98.35	29.6	143 Nos.	25	
	251.35m					

Table 1.2 INVESTIGATION WORKS PERFORMED

Bore Hole And Site No.	Laboratory Test												
	Water Content	Specific Gravity	Atterberg Limits LL,PL	Unit Weight	Grain Size	Unconfined Compression	Triaxial Compression	Consolidation	Compaction		CBR (Modified)	Specific Gravity And Absorption	Los Angeles Abration
									T99 D	T180 D			
BH-1	7	7	7	4	6	4	2	2	-	-	-	-	-
BH-1'	6	7	6	2	7	3	3	3	-	-	-	-	-
BH-2	9	9	3	2	9	2	2	2	-	-	-	-	-
BH-3	5	5	2	1	5	1	0	-	-	-	-	-	-
BH-4	9	9	7	3	9	2	2	3	-	-	-	-	-
BH-5	1	1	1	-	1	-	-	-	-	-	-	-	-
BH-6	-	-	-	-	-	-	-	-	-	-	-	-	-
BH-7	5	5	2	1	5	1	1	1	-	-	-	-	-
BH-8	7	7	4	2	7	2	1	2	-	-	-	-	-
Fine Aggregate	-	7	-	-	7	-	-	-	-	-	-	7	-
Coarse Aggregate	-	3	-	-	3	-	-	-	-	-	-	3	3
Earth Work Material	4	4	4	-	4	-	-	-	4	4	4	-	-
Total	53	64	36	15	63	15	11	13	4	4	4	10	3

NOTE: Triaxial Compression Test is U-U Type

1.2 Geotechnical Investigation

1.2.1 Field Investigation and Laboratory Soil Tests

The alternative road alignments and drilling holes are shown in Fig. 1.1, Geological Map with Location of Drilling Holes.

1) Geological Reconnaissance

Geological reconnaissance along the alternative road alignments was conducted. Strikes and dips of joints of rocks were recorded at quarry sites and outcrops. Probable geological profiles and cross-sections were plotted based on drillings and geological reconnaissance and these are illustrated in Fig. 1.2 to Fig. 1.4, Geological Profile, Fig. 1.5 to Fig. 1.8, Typical Geological Cross-Section. Other geological information is shown in Fig. 1.1, Geological Map with Location of Drilling Holes.

2) Exploratory Drillings

(1) Drilling Works

Five (5) exploratory drillings were performed on land along alternative road alignments.

Four (4) of these were performed by rotary boring rigs, and one (1) was done by a percussion rig.

Four (4) offshore exploratory drillings were carried out by a percussion rig fixed on a pontoon. A steel boiler with an outside diameter of 140mm was used as a cutting tool and steel casings with an outside diameter of 165mm were used for drillings by percussion rigs to prevent collapse of bore-hole walls. Two rotary boring rigs were used for the drilling at hilly areas. Diamond bids with an inner diameter of 55mm were used for coring rocks and boulders. Steel casings with outside diameters of 114mm and 89mm were used for drilling by rotary machines to prevent the collapse of the bore-hole walls and the cuttings of soil or rock were washed out by circulating water.

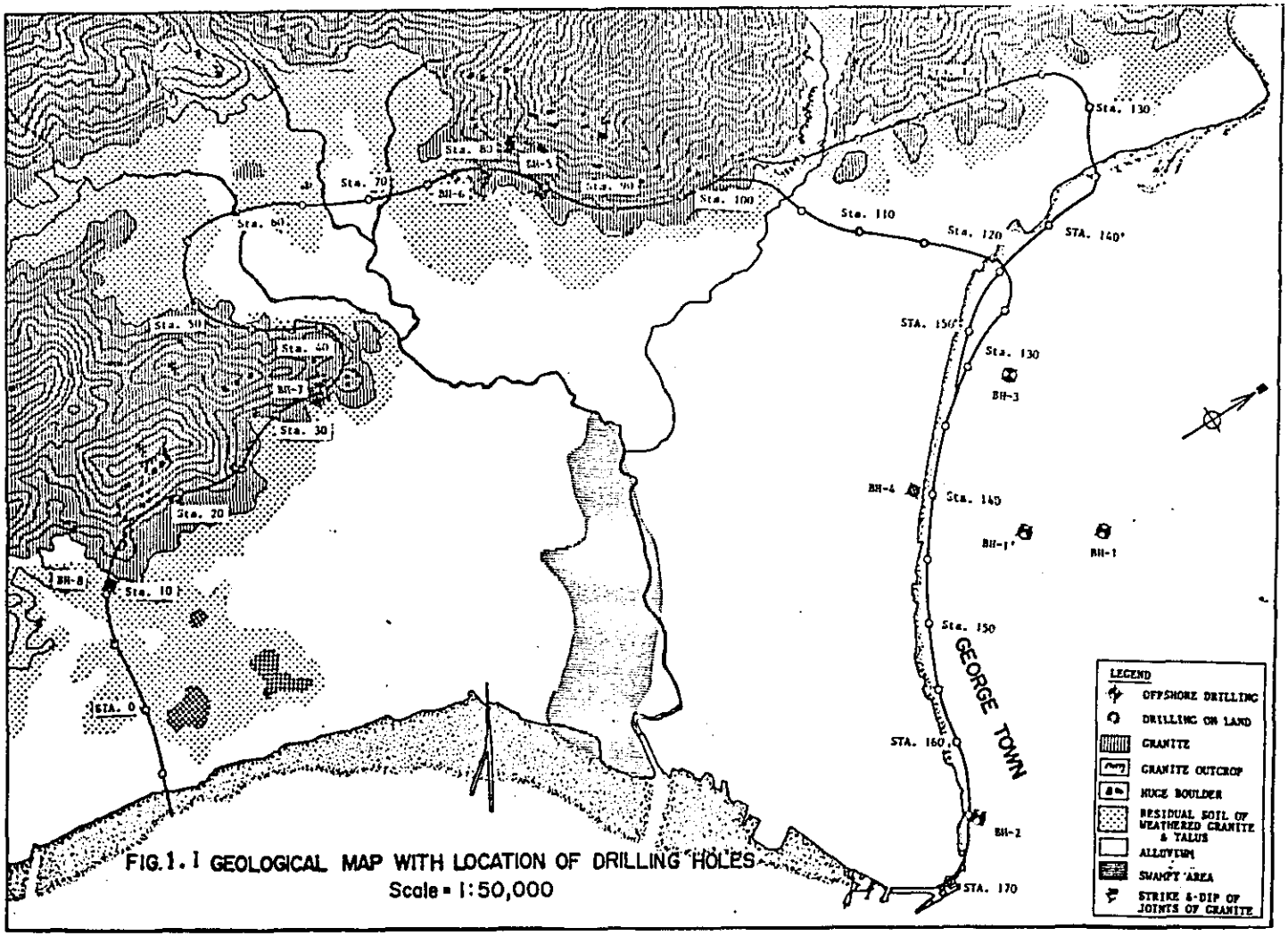


FIG. 1.1 GEOLOGICAL MAP WITH LOCATION OF DRILLING HOLES

Scale = 1:50,000

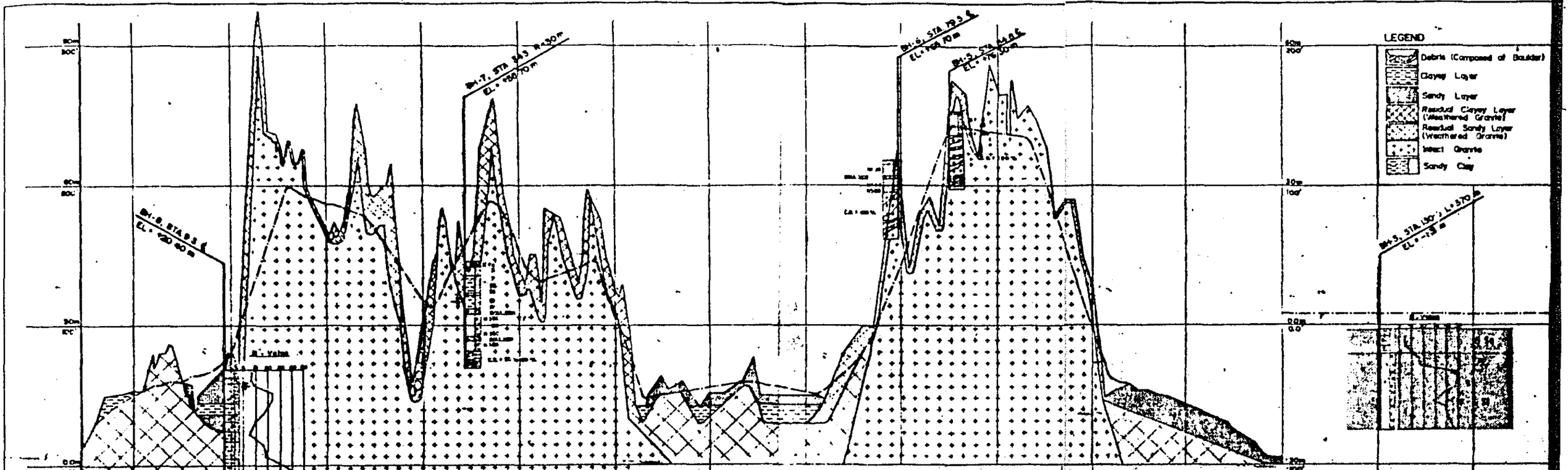


FIG. 1.2 GEOLOGICAL PROFILE ALONG ALTERNATIVE ROAD ALIGNMENT A

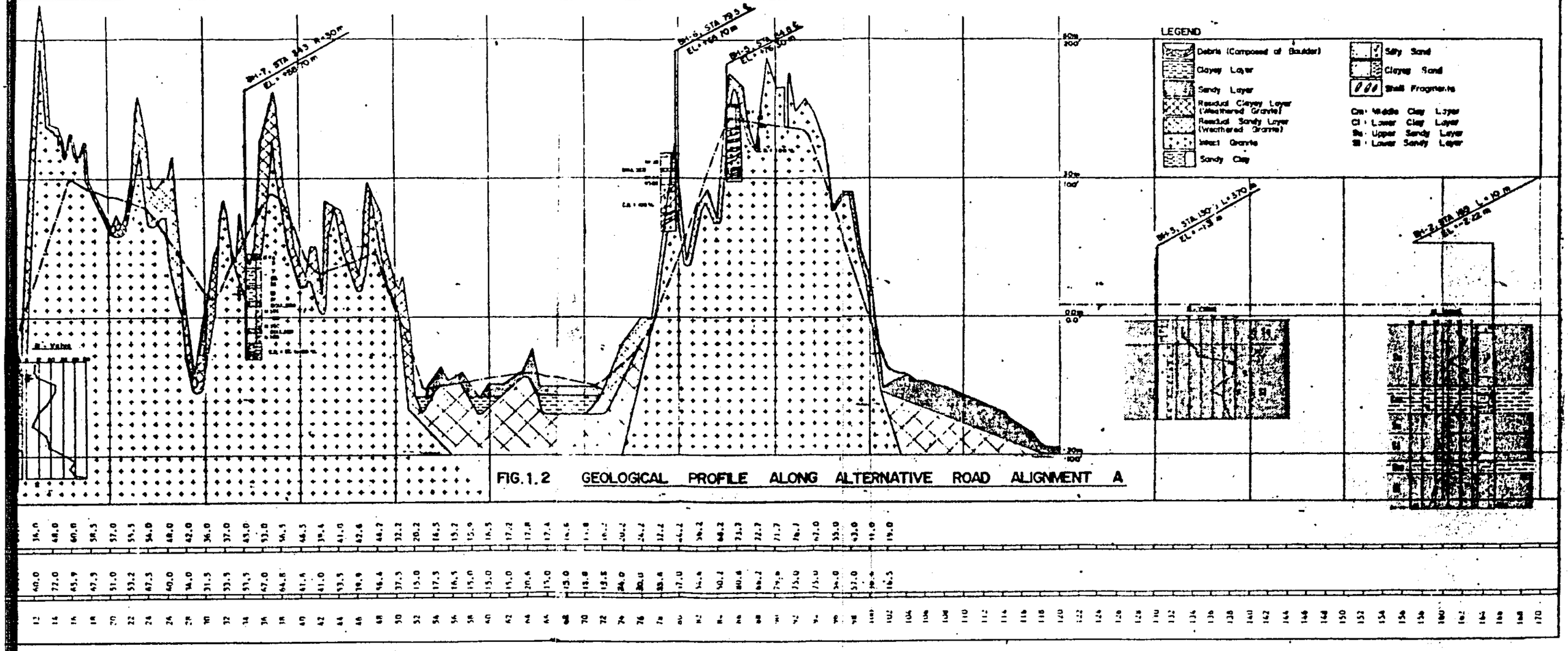


FIG. 1.2 GEOLOGICAL PROFILE ALONG ALTERNATIVE ROAD ALIGNMENT A

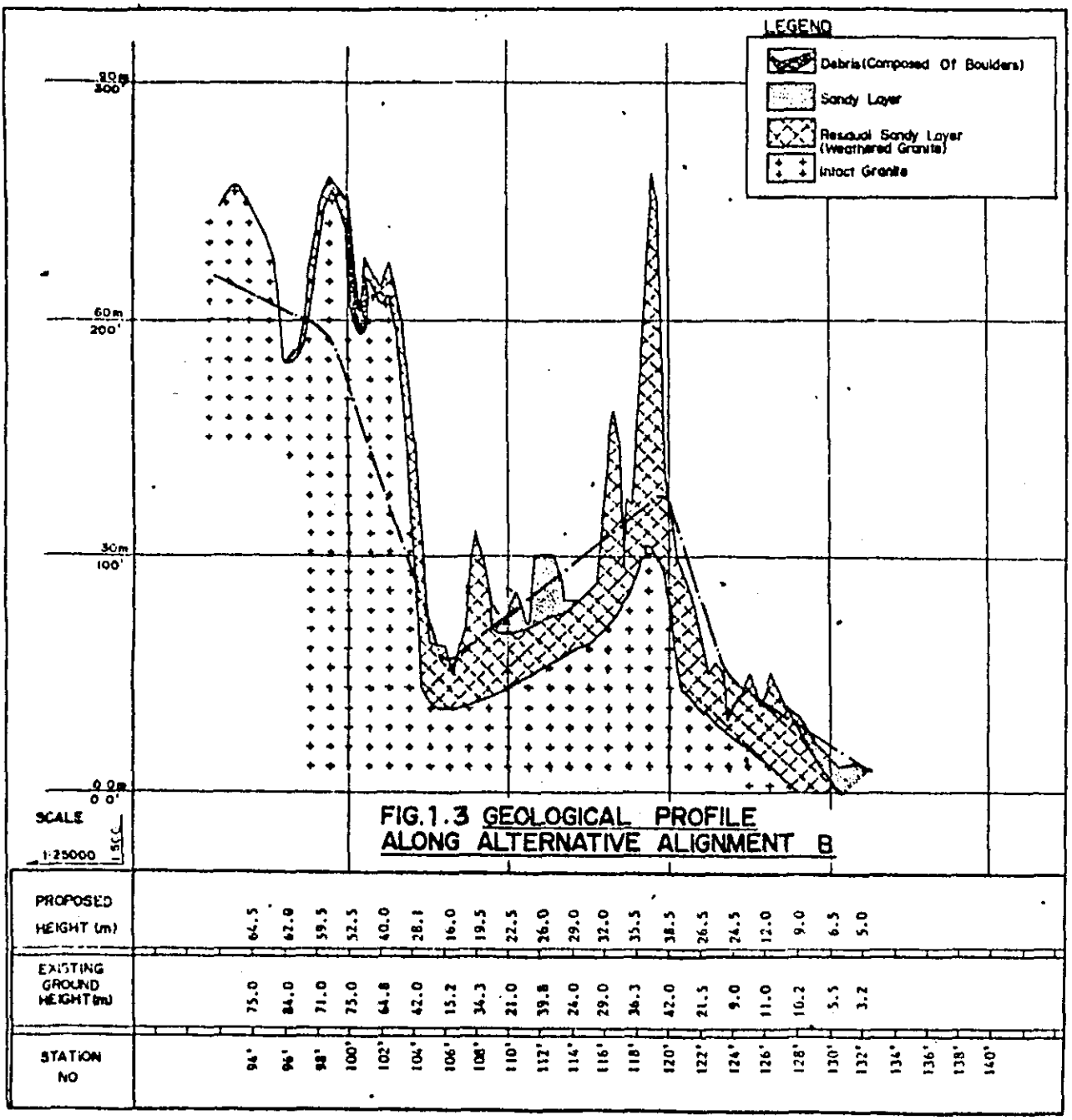


FIG.1.3 GEOLOGICAL PROFILE ALONG ALTERNATIVE ALIGNMENT B

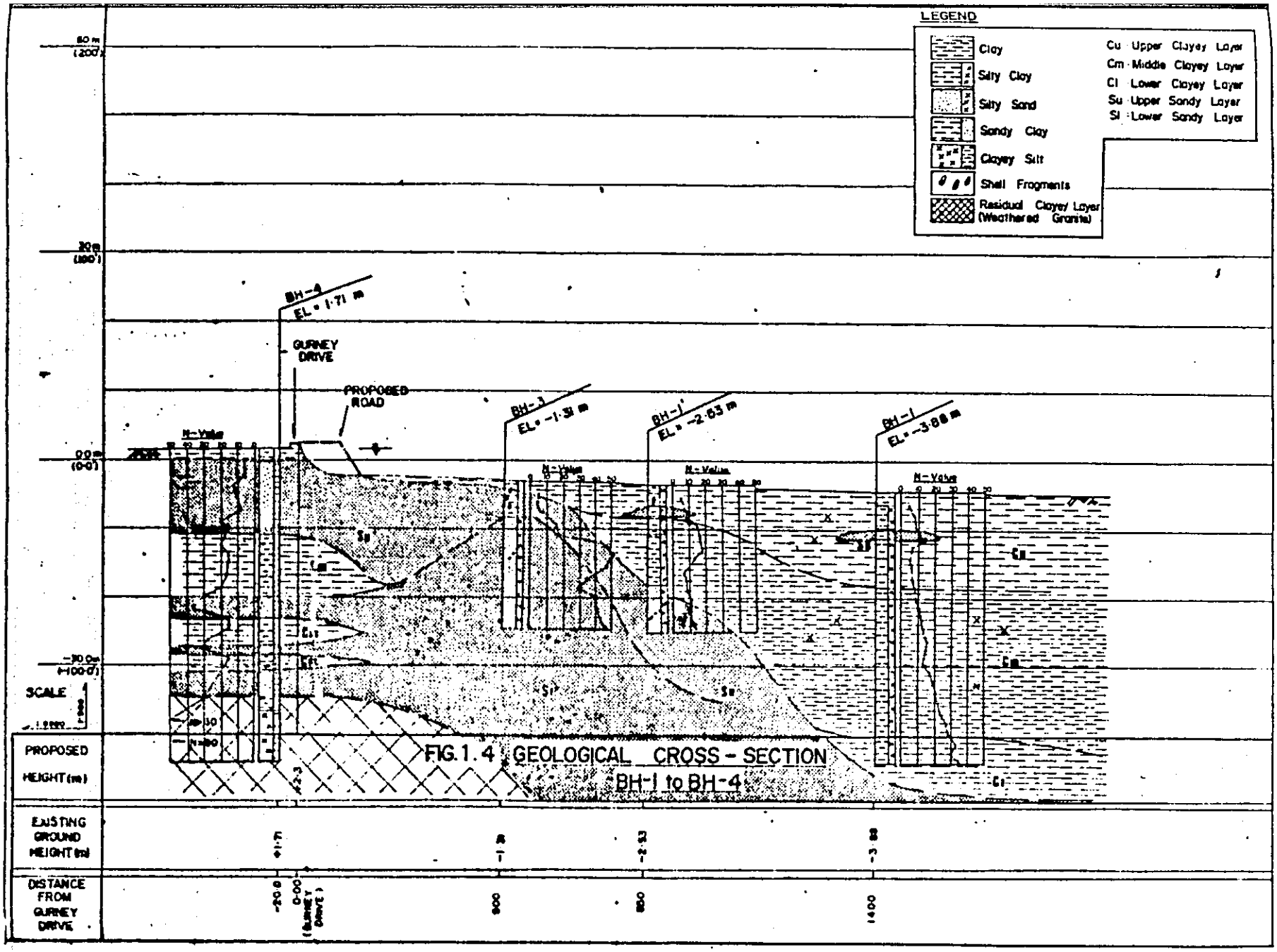


FIG. 1.4 GEOLOGICAL CROSS - SECTION BH-1 to BH-4

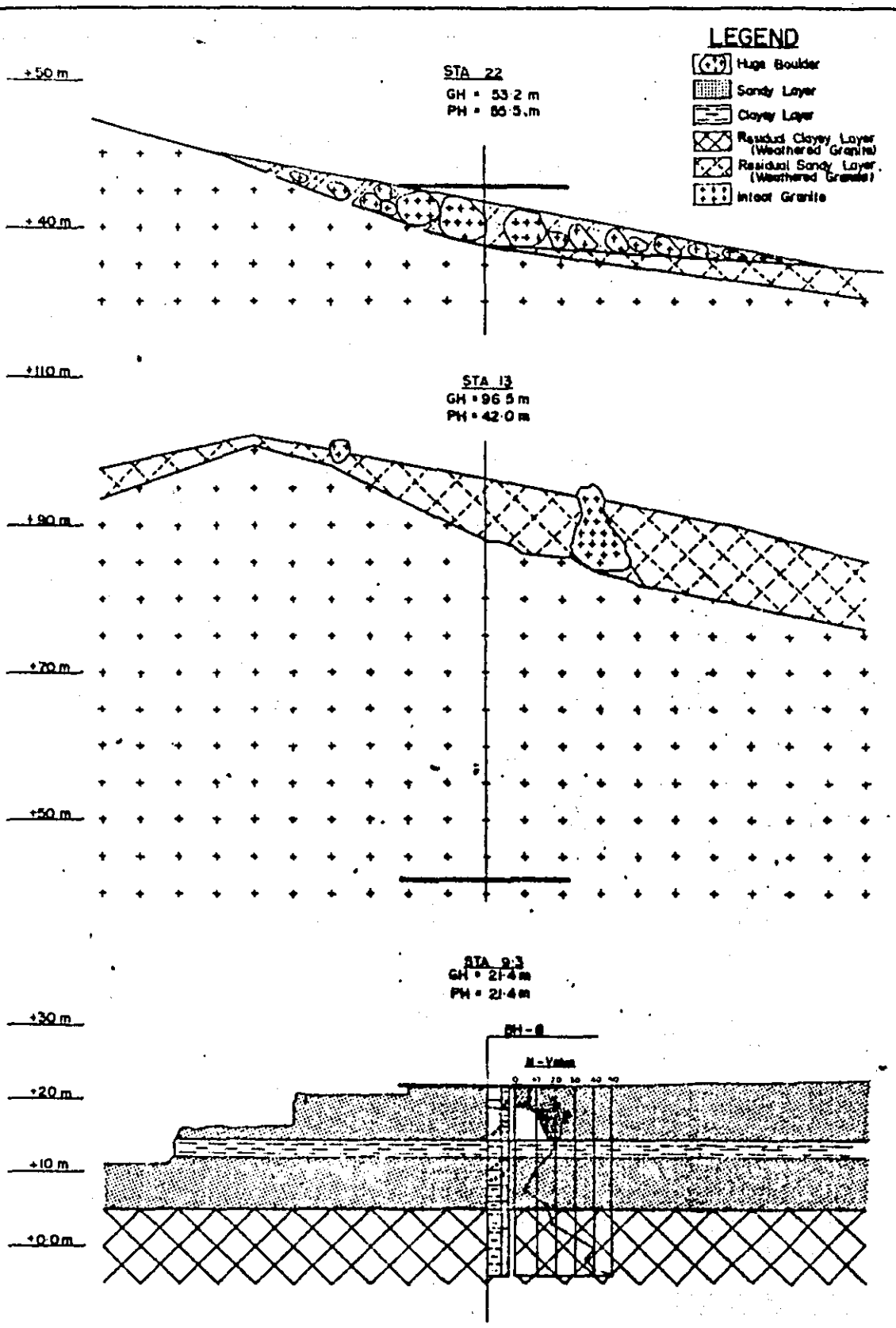


FIG. 1.5 TYPICAL GEOLOGICAL CROSS-SECTION (ALTERNATIVE ALIGNMENT A) Scale = 1:500

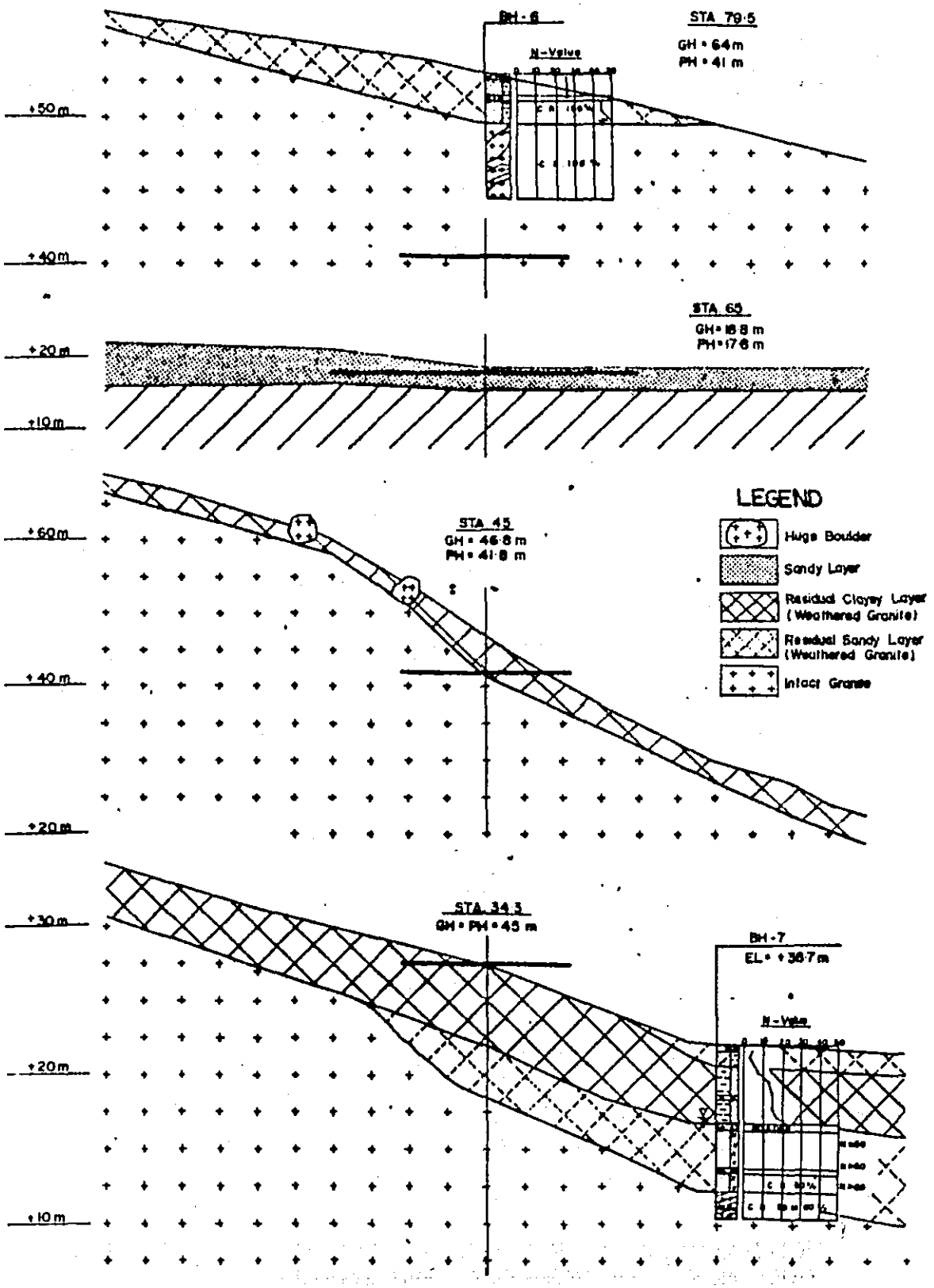


FIG. 1.6 TYPICAL GEOLOGICAL CROSS-SECTION
(ALTERNATIVE ALIGNMENT A) Scale = 1:500

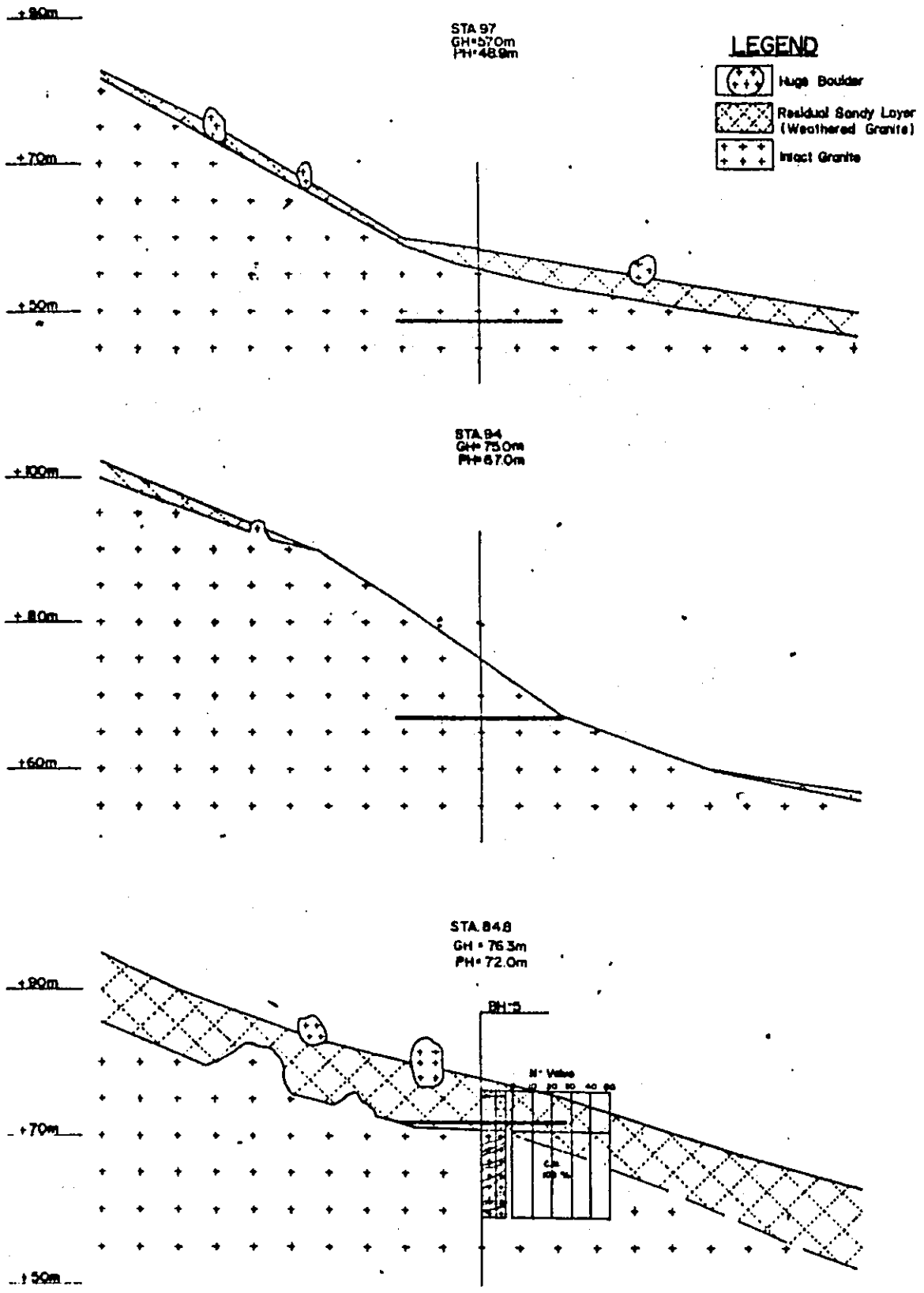


FIG. 1.7 TYPICAL GEOLOGICAL CROSS-SECTION (ALTERNATIVE ALIGNMENT A) Scale=1:500

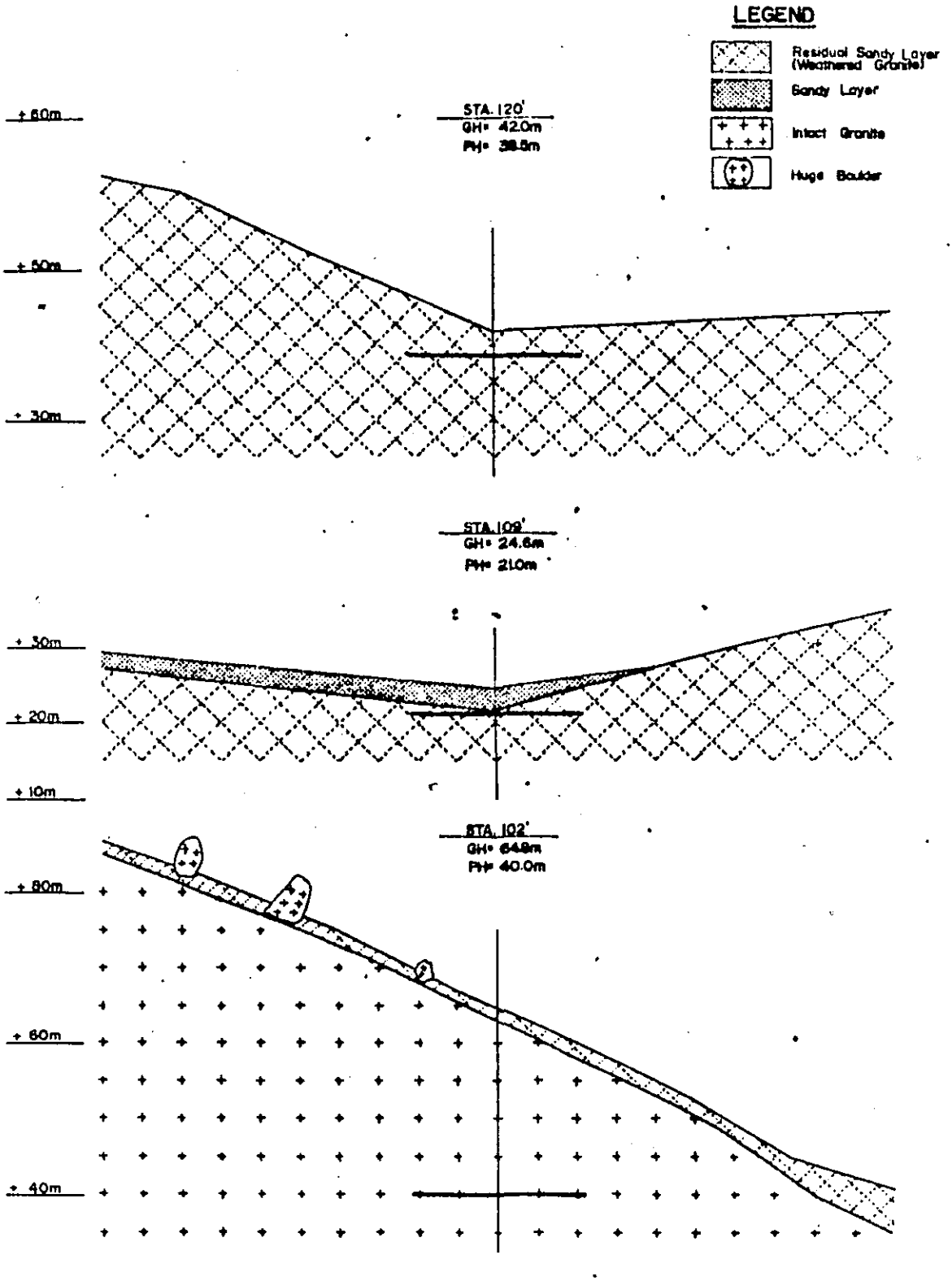


FIG. 1.8 TYPICAL GEOLOGICAL- CROSS SECTION (ALTERNATIVE ALIGNMENT B) Scale = 1:500

(2) Sampling and Standard Penetration Tests

Undisturbed sampling was performed using steel tubes with an inner diameter of 100mm and a length of 450mm (U4 tube). The tubes were advanced by means of a hydraulic jack or drop hammer.

After the tubes of undisturbed samples were sealed with paraffin at both ends, they were well packed in foam rubber cushions to avoid any disturbance during transportation, and were sent to Singapore by air. Standard Penetration Tests were conducted at intervals of approximately 1.5m or 3.0m for each drilling hole except at the depths where boulders or rocks were encountered. Disturbed samples taken from split tube samplers of Standard Penetration Tests were packed in plastic jars as observational samples, and remaining samples were sealed in plastic bags and sent to Singapore for the laboratory soil tests.

The results of drilling are summarized in Figs. 1.9 to 1.17. Drilling Logs, and shown in Figs. 1.2 to 1.3, Geological Profile and Fig. 1.4, Geological Cross-Section.

3) Laboratory Soil Tests

Laboratory soil tests were performed in Singapore on selected disturbed and undisturbed samples.

The results of the laboratory soil tests are summarized in Tables 1.3 to 1.9, "Summary of Soil Test", and discussed in this section.

(1) Physical Property Tests

a) Natural Water Content (Wn) and Atterberg Limits (LL, PL)

The results of natural water content and Atterberg Limits tests are shown in Figs. 1.18 to 1.19, Engineering Properties of Soil vs Depth, and summarized in Table 1.10, Natural Water Contents and Atterberg Limits.

FIG. 1 9 DRILLING LOG

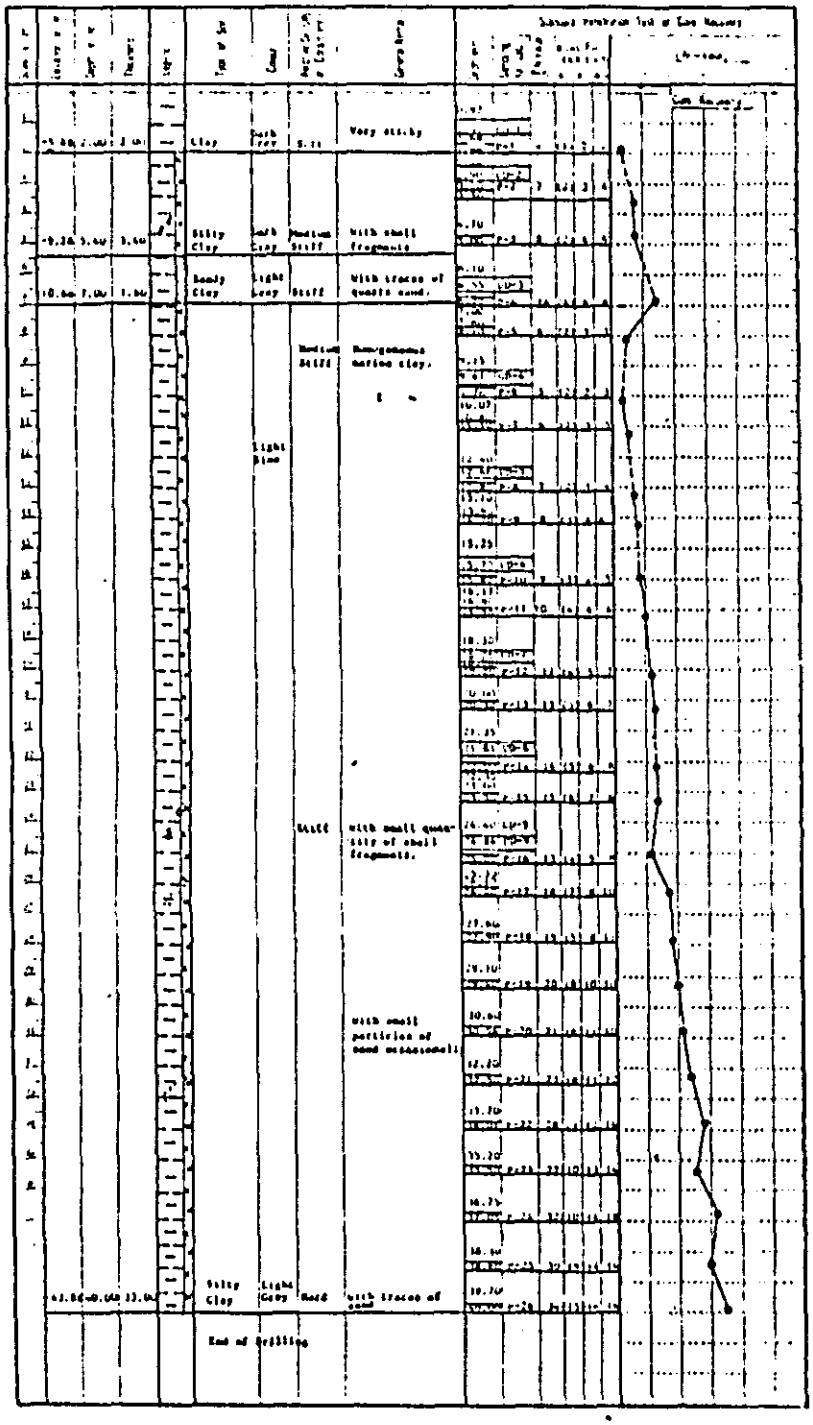


FIG. 1.10 DRILLING LOG

Remarks

Offshore Drilling

Name of Project URBAN TRANSPORT STUDY — Type of Drilling : PERCUSSION

Hole Number No. BH-1' — Elevation : - 2.53 m — Date : May 29 to 31, 1980.

Water Table - - m — Driller : GEOTECHNIQUE (Hr. Chen)

Scale in m	Elevation in m	Depth in m	Thickness	Legend	Type of Soil	Colour	Relative Density or Consistency	General Remarks	Depth in m	Sampling by Tube	N-Value Wet	Blows Per each 15cm	Standard Penetration Test or Core Recovery (N—Value)
1								With decomposed organic matter	0.92				
						Bluish Grey to Dark Grey			1.37	UD-1			
2									1.83	P-1	4	(2) 2 2	
3	-5.58	3.05	1.55		Silty Clay		Soft	With shell fragments	3.05				
									3.51	UD-2			
4	-7.08	4.60	2.40		Sandy Clay	Light Grey	Medium	With gravel occasionally	4.57	P-2	8	(2) 4 4	
									4.57	P-3	8	(3) 4 4	
									5.80				
	-9.53	7.00	7.65		Silty Clay	Grey	Very Stiff	With some sand and gravel	6.10	P-4	16	(4) 7 9	
									7.33				
									7.62	P-5	17	(5) 7 10	
									9.30				
									9.60	P-6	18	(4) 8 10	
									10.37				
									10.67	P-7	14	5 6 8	
									12.20				
									12.49	UD-3			
									12.65	P-8	7	(2) 4 3	
									13.72	P-9	8	(3) 4 4	
	17.18	14.65	4.15		Silty Clay	Dark grey	Medium to Very Stiff	With laminates of fine sand.					
									15.40				
									15.70	P-10	9	(3) 5 4	
									16.47				
									16.77	P-11	11	(3) 5 6	
									18.45	P-12	10	(2) 4 6	
									18.75				
									20.00				
									20.30	P-13	11	(4) 5 6	
	-24.23	21.70	7.05		Silty Sand	Grey	Loose to Medium	With gravel in some parts	21.40				
									21.70	P-14	12	(5) 6 6	
					End of Drilling								

FIG. 111 DRILLING LOG

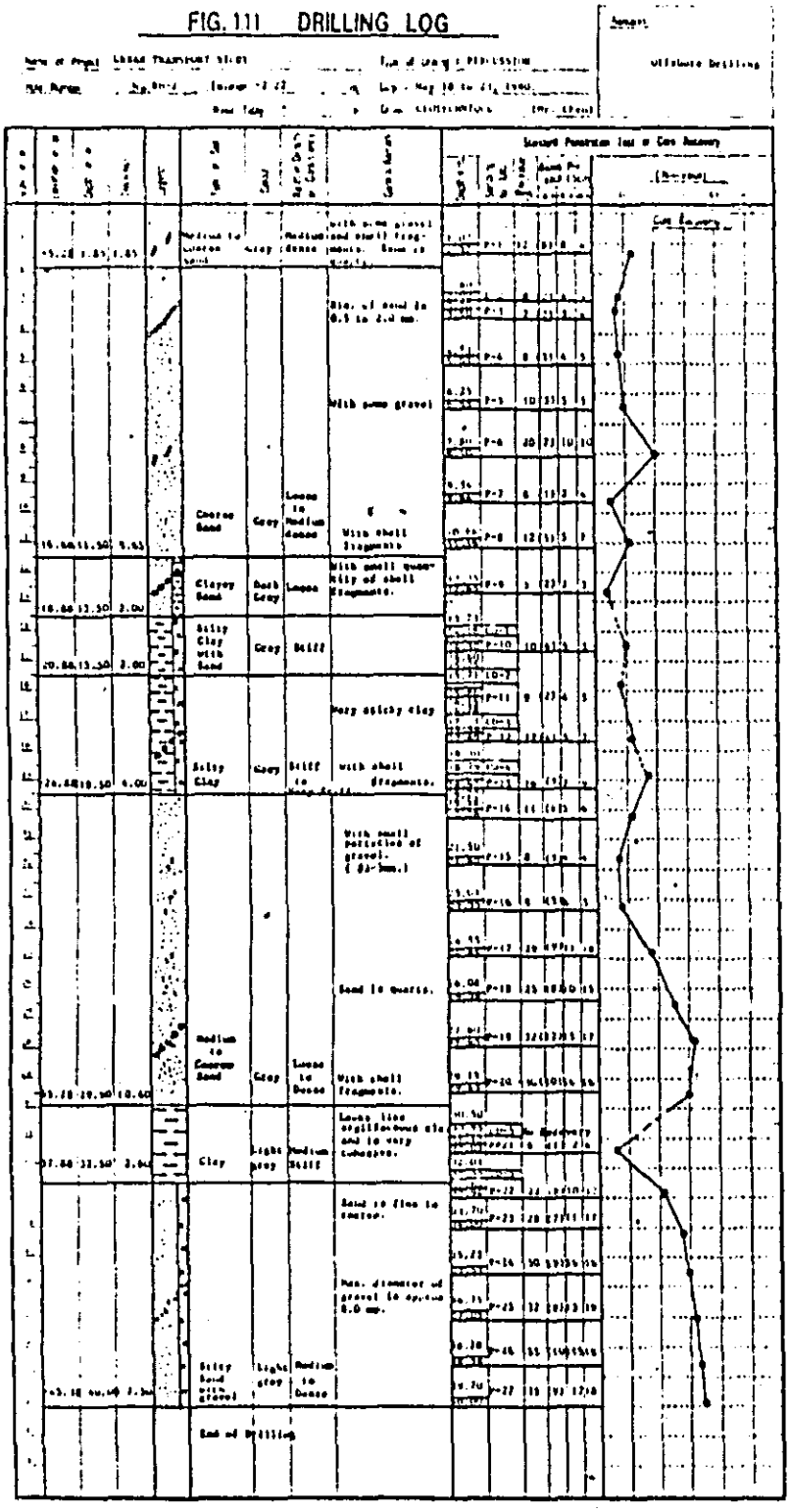


FIG. 1.12 DRILLING LOG

URBAN TRANSPORT STUDY — Type of Drilling : PERCUSSION

No. BH-3 — Elevation : - 1.31 m — Date : May 23 to 26, 1980

Water Table : - m — Driller : GEOTECHNIQUE . (Mr. Chen)

Remarks: Offshore Drilling

Scale	Elevation m	Depth m	Thickness	Legend	Type of Soil	Colour	Relative Density or Consistency	General Remarks	Depth m	Sampling by Lab	N-Value	Blows Per each 15cm	Standard Penetration Test or Core Recovery (N—value)
									0.00	UD-1			Core Recovery
									0.45				
									1.68	P-1	6	(2) 3 3	
								20% of the soil is sand.	2.60	P-2	5	(2) 2 3	
									4.00	P-3	6	(2) 2 4	
	-6.51	5.20	13.55		Sandy Clay	Bluish Grey	Medium Stiff	With some shell fragments.	4.73	P-4	8	(3) 4 4	
									6.26	P-5	17	(5) 7 10	
								With a lot of clay at 7.0 to 8.0 m.	7.78	P-6	18	(4) 8 12	
									9.38	P-7	50/23	(14) 27 23/10	N > 20
								With some gravel	10.80	P-8	50	(20) 23 27	
									12.36	P-9	47	(12) 22 25	
									13.90	P-10	35	(10) 15 20	
								With a lot of clay.	15.41	P-11	29	(13) 15 14	
									16.90	P-12	39	(11) 17 22	
									18.45	P-13	41	(12) 16 25	
									20.00	P-14	43	(15) 18 25	
	-23.01	21.70	16.50		Silty Sand	Reddish Light Grey	Medium to Very Dense		21.40	P-15	45	(17) 19 26	

(Note) Disturbed sample for testing was obtained by bailer at the depth of 5.5 to 8.0 m.

FIG. 113 DRILLING LOG

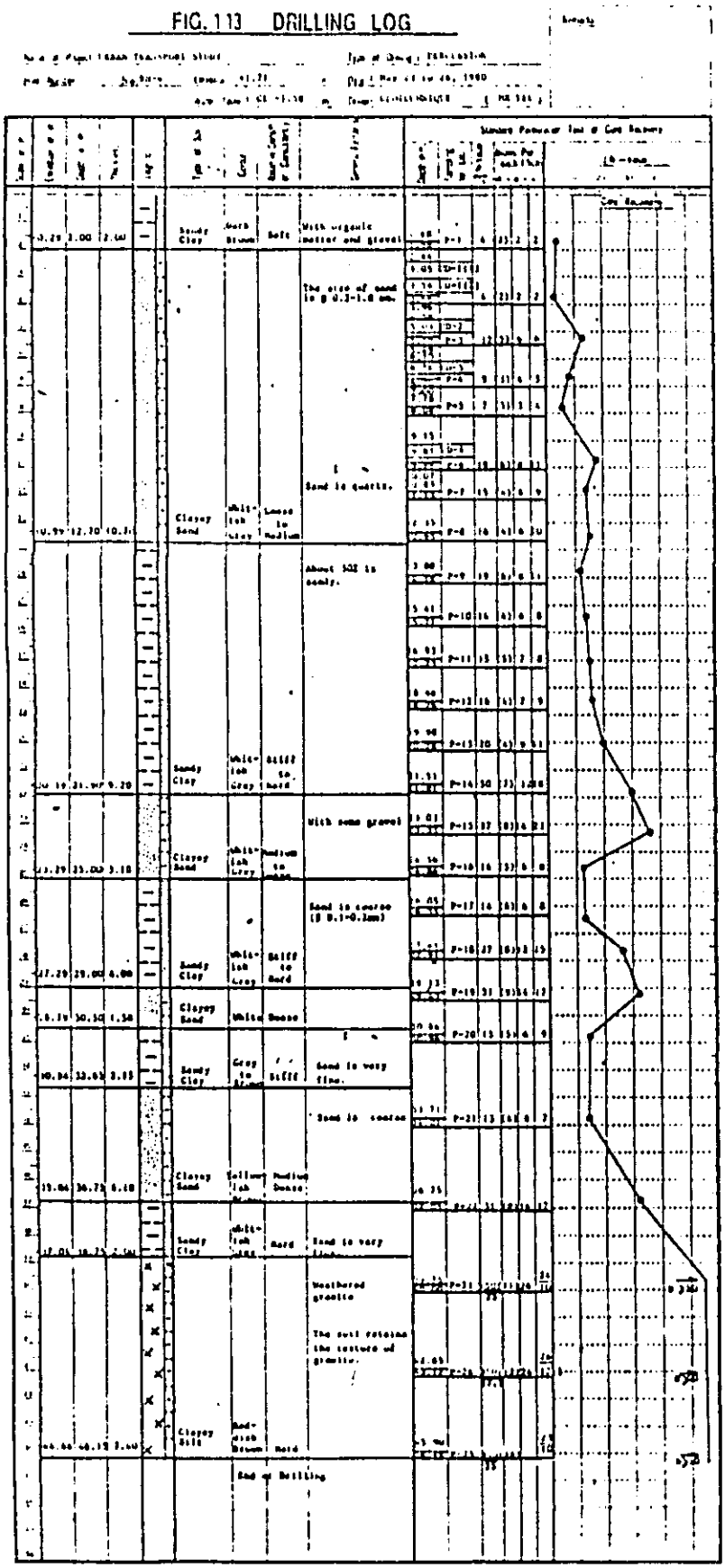


FIG. 1.14 DRILLING LOG

Remarks

Name of Project: URBAN TRANSPORT STUDY — Type of Drilling: ROTARY

Hole Number: No. BH-5 — Elevation: + 76.30 m — Date: May 18 to 21, 1980.

Water Table: - m. — Driller: GEOTECHNIQUE (MR.LEE)

Elevation m	Depth m	Thickness m	Legend	Type of Soil	Colour	Relative Density or Consistency	General Remarks	Standard Penetration Test or Core Recovery: Depth m	Sampling No.	N-Value Blows	Blows Per each 15cm	(N—Value) / Core Recovery
+75.69	0.61	0.61		Silty Clay	Brown		With organic matter	1.00				
								1.30	D-1			
								1.71	P-1	14	(5) 7 7	
								1.98				
								3.30	P-2	23	(10) 11 12	
								3.51				
+71.10	5.20	4.59		Clayey Sand	Light Brown	Medium to Very Dense	With some gravel	4.95	P-3	64/25	(8) 14 50/10	N=64/25
								5.20				
							Generally, the granite is sound.	Core length is 200 mm to 300 mm. at 5.20 to 6.20 m.				
							Joints are generally 80° from the horizontal or are vertical.	Longest core is 1.0 m.				
								Core length is 250 to 1000 mm. at 6.20 to 10.40 m.				
							Vertical joints at 11.9-12.8 m.					Core recovery = 100%
							No clay at joints	Core length is 200 to 400 mm. at 10.40 to 14.85m.				
							Joints are vertical and the faces are yellow at around 15.30m.	Cores of gravel size (ø 20-50 mm.) were obtained.				
+59.5	16.80	11.60		Granite	Whitish Grey	Hard						
				End of Drilling								

FIG. 1.15 DRILLING LOG

Remarks

Name of Project URBAN TRANSPORT STUDY — Type of Drilling : ROTARY

Hole Number No. BH - 6 — Elevation : + 65.70 m. — Date : May 24 to 29, 1980.

Water Table : - m. — Driller : GEOTECHNIQUE (MR. LEE)

Scale in m	Elevation in m	Depth in m.	Thickness	Legend	Type of Soil	Colour	Relative Density or Consistency	General Remarks	Depth in m.	Sampling by Tube	Blow Value	Blows Per each 15cm	(N—Value)	Core Recovery
					Sandy Clay	Dark Grey		With organic matter.						
1	65.10	0.60	0.60											
2					Clayey Sand	Yellowish Brown	Medium Dense	With some gravel.	1.68 / 1.98	P-1	26	(7) 14 12		
	62.65	3.05	2.45											
	62.05	3.65	0.60		Boulder	Grey		Granite						100%
									4.73 / 5.03	P-2	44	(7) 22 20		
					Clayey Sand	Light Greyish Brown	Dense	With gravel (Ø20 -40 mm.) ; Weathered granite	6.10 / 6.40	P-3	50/15	18 50 -		
								Core length is 20 to 250 mm.		Joints are 45° from the horizontal and are brown in colour.				100%
								Core length is 200 to 500 mm.						
								No clay at joints.						
								The faces of the joints are fresh without any trace of other materials and are firmly in contact with each other.						
	48.90	16.80	10.40		Granite	Grey	Hard							
					End of Drilling									

FIG. 1.16 DRILLING LOG

Name of Project URBAN TRANSPORT STUDY — Type of Drilling : BBS 10

Hole Number No. BH - 7 — Elevation : +38.70 m — Date : May 27 to 29, 1980.

Water Table : GL - 9.50 m — Driller : GEOTECHNIQUE (Mr. Kho)

Remarks

Scale in m	Elevation in m	Depth in m	Thickness	Legend	Type of Soil	Colour	Relative Density or Consistency	General Remarks	Depth in m	Sampling by Tube	SPT-N Value	Blows Per each 15cm	Standard Penetration Test or Core Recovery (N—Value)
1	+38.80	0.90	0.90		Top soil Silty Sand	Brown	Loose	With some gravel	0.46 0.76	P-1	4	(1) 2 2	Core Recovery
2	+35.90	2.80	1.90		Clayey Sand with Gravel	Brown	Very Loose		1.68 1.98	P-7	3	(1) 2 1	
3									3.05	UD-1			
4						Reddish & Yellowish Brown			3.51 3.67	P-3	7	(3) 3 4	
5									3.97 4.73				
6					Sandy Clay		Medium to Stiff		5.03	P-4	13	(5) 6 7	
7	+32.0	6.70	3.90						6.26 6.56	P-5	14	(6) 6 8	
8	+30.45	8.25	1.55		Granite Boulder	Grey	Hard		7.05 8.25	P-6	15	(6) 7 8	100%
9									8.55				
10	+28.60	10.10	1.85		Sandy Clay	Brown	Medium	Residual soil of granite.	9.31 9.61	P-7	17	(7) 8 9	
11	+27.40	11.30	1.20		Granite Boulder	Grey	Hard						100%
12													
13						Yellowish Brown with Red Patches		Weathered granite	12.36 12.66	P-8	52	(10) 25 27	
14	+24.50	14.20	2.90		Silty Sand		Very Dense		13.88 14.18	P-9	50	(10) 24 26	
15													
16	+22.50	16.20	2.00		Silty Sand	Yellowish Brown	Very Dense	Weathered granite	15.40 15.70	P-10	50 15	- - -	N > 50
17	+21.60	17.10	0.90		Granite Boulder	Light Grey			Core size is about 40mm. 50%				
18													
19								Weathered Granite	18.09 18.39	P-11	50 10	- - -	N > 50
20	+19.15	19.55	2.45		Silty Sand	Light Grey			19.55	P-12	50 10	(Rebounded)	
21													50%
22													
23	+15.80	22.90	3.35		Granite	Grey	Hard	Cores of gravel size (15-40 mm) were obtained.	Cracks intervals are 15 to 40 mm. Vertical cracks were found.				60%
24					End of Drilling								
25													

FIG. 1.17 DRILLING LOG

Remarks

Name of Project: URBAN TRANSPORT STUDY — Type of Drilling: ROTARY (B.B.S.10)

Hole Number: No. BH-8 — Elevation: +20.40 m. — Date: May 20 to 23, 1980.

Water Table: GL-3.97 m. — Driller: GEOTECHNIQUE (Mr. Kho)

Scale m	Elevation in m	Depth in m	Thickness	Legend	Type of Soil	Colour	Relative Density or Consistency	General Remarks
	+18.55	1.85	1.85		Clayey Sand	Dark Grey	Medium	With roots of trees.
	+17.35	3.05	1.20		Silty Sand	Brown	Loose	With traces of gravel.
	+13.10	7.30	4.25		Clayey Sand	Greyish Brown / Light Grey	Loose to Medium	With some gravel.
	+10.65	9.75	2.45		Sandy Clay	Yellowish & Reddish Brown	Very Stiff	With a lot of sand.
	+9.10	11.30	1.55		Clayey Sand with Gravel	Light Greyish Brown	Loose	Size of gravel is 2-5 mm.
	+7.15	13.25	1.95		Clayey Sand	Yellowish & Whitish Brown	Loose	With some gravel.
	+4.70	15.70	2.45		Sandy Clay	Yellowish Brown	Medium	With red patches.
	+1.20	19.20	3.50		Sandy Clay	Reddish Brown	Medium Dense	With some gravel / Weathered granite
	-4.40	25.30	0.92		Sandy Clay	Reddish & greyish Brown / Dark Brown	Hard	The soil retains the texture of granite. / Highly decomposed granite.
					End of Drilling			

Standard Penetration Test or Core Recovery

Depth in m	Sampling by Lab	N-Value	Blows Per each 15 cm			
0.46	P-1	7	(2)	4	3	
1.53						
1.98	UD-1					
2.44	P-2	6	2	2	4	
3.20						
3.50	P-3	9	(2)	4	5	
4.73	P-4	23	(5)	11	12	
5.03						
6.25						
6.55	P-5	23	(5)	11	12	
7.78						
8.08	P-6	20	(5)	9	11	
9.30						
9.60	P-7	16	(6)	8	8	
10.83	P-8	10	(3)	4	6	
11.13						
12.20						
12.70	UD-2					
12.82						
13.12	P-9	6	(4)	3	3	
13.88						
14.18	P-10	5	(5)	2	3	
15.25						
15.71	UD-3					
15.86	P-11	16	(9)	9	7	
16.16						
16.93	P-12	17	(7)	8	9	
17.23						
18.45	P-13	18	(9)	8	10	
19.75						
19.98						
20.28	P-14	30	(8)	15	15	
21.50	P-15	40	(7)	17	23	
21.80						
23.03						
23.33	P-16	35	(7)	17	18	
24.55						
24.85	P-17	40	(8)	19	21	
25.30	P-18	50	(10)	20	30	

(N—Value) 10 20 40

Core Recovery

Table 1.3 SUMMARY OF SOIL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.		BH-1								
Sample No.		UD-2	UD-3	UD-5	UD-7	P-16	P-20	P-24		
Sample depth		2.44 m ~ 2.90 m	6.10 m ~ 6.56 m	12.2 m ~ 12.6 m	18.3 m ~ 18.8 m	25.0 m ~ 25.3 m	30.6 m ~ 30.9 m	36.75 m ~ 37.05 m	m ~ m	m ~ m
Condition of sample		Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed
Natural water content, %		76.4	12.6	78.1	76.5	78.4	57.1	47.6		
Specific gravity		2.568	2.617	2.671	2.664	2.638	2.636	2.642		
Wet density, g/cm³		1.52	2.14	1.54	1.55	-	-	-		
Dry density, g/cm³		0.87	1.90	0.87	0.88	-	-	-		
Natural void ratio		1.961	0.377	2.089	2.034	-	-	-		
Degree of saturation , %		100.0	87.5	100.0	100.0	-	-	-		
Atterberg limits	Liquid limit , %	129.0	42.1	119.2	117.2	88.5	101.1	74.0		
	Plastic limit , %	51.5	14.0	35.7	37.6	28.2	31.5	23.2		
	Plasticity index	77.5	28.1	83.5	79.6	60.3	69.6	50.8		
Grain size analysis	Gravel , %	0	18	0	0	0		0		
	Sand , %	3	29	1	3	16		12		
	Silt , %	21	19	31	27	15		30		
	Clay & colloid , %	76	34	68	70	69		58		
	Max. diameter, mm	0.84	4.76	0.42	0.84	2.00		4.76		
	Diam. at 60%	0.0018	0.52	0.0029	0.002	0.0018		0.0065		
	Diam. at 10%	-	-	-	-	-	-	-		
Visual soil description		Silty Clay	Sandy Clay	Silty Clay	Silty Clay	Silty Clay		Silty Clay		
Unified soil classification		-	-	-	-	-	-	-		
Unconfined compression test	Undisturbed sample, kg/cm²	0.38	1.09	0.58	0.20	-	-	-		
	Remoulded sample, kg/cm²	-	-	-	-	-	-	-		
	Sensitivity ratio	-	-	-	-	-	-	-		
	Strain at failure,%	(20)	9.2 ~14.2	2.0 ~5.9	3.5 ~12.0	-	-	-		
Triaxial compression test	Angle of internal friction	0°	-	-	0°	-	-	-		
	Cohesion, kg/cm²	0.15	-	-	0.14	-	-	-		
	Condition of drainage	U-U	-	-	U-U	-	-	-		
Consolidation test	Preconsolidation pressure, kg/cm²	0.95	-	3.0	-	-	-	-		
	Compression index	0.81	-	1.75	-	-	-	-		

Remarks:

Table 1.4 SUMMARY OF SOIL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.		BH-1'								
Sample No.		UD-1	UD-2	UD-3	P-1	P-2	P-6	P-12		
Sample depth		0.92 m - 1.37 m	3.05 m - 3.51 m	12.20 m - 12.69 m	1.53 m - 1.83 m	3.66 m - 3.96 m	9.30 m - 9.60 m	18.45 m - 18.75 m	m - m	m - m
Condition of sample		Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed
Natural water content, %		110	25.2		102	30.3	36.1	13.3		
Specific gravity		2.648	2.596	2.637	2.619	2.591	2.654	2.619		
Wet density, g/cm³		1.64	2.02		-	-	-	-		
Dry density, g/cm³		0.70	1.61		-	-	-	-		
Natural void ratio		2.747	0.609		-	-	-	-		
Degree of saturation , %		100.0	100.0		-	-	-	-		
Atterberg limits	Liquid limit , %	88.9	47.4	99.0	128.8	-	85.5	32.8		
	Plastic limit , %	30.8	21.7	30.8	41.1	-	25.9	13.8		
	Plasticity index	58.1	25.7	68.2	87.7	-	59.6	19.0		
Grain size analysis	Gravel , %	0	23	0	1	6	9	17		
	Sand , %	4	49	2	4	55	23	47		
	Silt , %	8	7	26	3	13	6	11		
	Clay & colloid , %	88	21	72	92	26	62	25		
	Max. diameter, mm	2.00	9.52	0.42	4.76	4.76	4.76	4.76		
	Diam. at 60%	-	0.87	0.0014	-	0.44	0.0034	0.61		
	Diam. at 10%	-	-	-	-	0.0098	-	-		
Visual soil description		Silty Clay	Clayey Sand	Silty Clay	Silty Clay	Clayey Sand	Silty Clay	Clayey Sand		
Unified soil classification										
Unconfined compression test	Undisturbed sample, kg/cm²	0.054	0.144	0.639	-	-	-	-		
	Remoulded sample, kg/cm²	-	-	-	-	-	-	-		
	Sensitivity ratio	-	-	-	-	-	-	-		
	Strain at failure,%	(20.0)	14.5 ~ 20.0	2.0 ~ 3.5	-	-	-	-		
Triaxial compression test	Angle of internal friction	0°	0°	0°	-	-	-	-		
	Cohesion, kg/cm²	0.04	0.12	0.32	-	-	-	-		
	Condition of drainage	U-U	U-U	U-U	-	-	-	-		
Consolidation test	Preconsolidation pressure, kg/cm²	0.15	-	0.5	-	-	-	-		
	Compression index	1.20	0.11	1.29	-	-	-	-		

Remarks:

Table 1.5 SUMMARY OF SOIL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.		BH-2								
Sample No.		P-1	P-4	P-8	UD-1	UD-3	P-15	P-18	P-21	P-25
Sample depth		1.05 m - 1.35 m	4.7 m - 5.0 m	10.8 m - 11.1 m	13.7 m - 14.2 m	16.8 m - 17.2 m	20.0 m - 20.3 m	26.1 m - 26.4 m	31.0 m - 31.3 m	35.2 m - 35.5 m
Condition of sample		Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed
Natural water content, %		9.72	14.3	14.4	77.3	78.1	17.6	12.6	39.9	14.5
Specific gravity		2.609	2.611	2.619	2.646	2.642	2.606	2.641	2.612	2.611
Wet density, g/cm³		-	-	-	1.60	1.53	-	-	-	-
Dry density, g/cm³		-	-	-	0.90	0.86	-	-	-	-
Natural void ratio		-	-	-	1.932	2.075	-	-	-	-
Degree of saturation , %		-	-	-	100.0	100.0	-	-	-	-
Atterberg limits	Liquid limit , %	-	-	-	126.1	130.5	-	-	42.1	-
	Plastic limit , %	-	-	-	44.2	50.5	-	-	22.6	-
	Plasticity index	-	-	-	81.9	80.0	-	-	19.5	-
Grain size analysis	Gravel , %	25	35	13	0	0	22	31	0	11
	Sand , %	71	63	84	1	1	73	67	1	80
	Silt , %	4	2	3	9	7	5	2	39	9
	Clay & colloid , %				90	92			60	
	Max. diameter, mm	4.76	9.52	4.76	0.25	0.25	9.52	4.76	0.25	4.76
	Diam. at 60%	1.40	1.80	1.30	-	-	1.50	1.70	0.0053	1.10
	Diam. at 10%	0.55	0.85	0.65	-	-	0.52	0.50	-	0.15
Visual soil description		Sand	Sand	Sand	Silty Clay	Silty Clay	Sand	Sand	Silty Clay	Silty Sand
Unified soil classification										
Unconfined compression test	Undisturbed sample, kg/cm²	-	-	-	0.77	0.70				
	Remoulded sample, kg/cm²	-	-	-	-	-				
	Sensitivity ratio	-	-	-	-	-				
	Strain at failure,%	-	-	-	1.7 ~ 3.0	2.0 ~ 3.8				
Triaxial compression test	Angle of internal friction	-	-	-	0°	0°				
	Cohesion, kg/cm²	-	-	-	0.50	0.45				
	Condition of drainage	-	-	-	U-U	U-U				
Consolidation test	Preconsolidation pressure, kg/cm²	-	-	-	2.7	3.4				
	Compression index	-	-	-	1.31	1.35				

Remarks:

Table 1.6 SUMMARY OF SOIL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.		BH-3								
Sample No.		UD-1	P-2	P-5	P-7	P-12				
Sample depth		0.00 m - 0.45 m	2.60 m - 2.90 m	6.26 m - 6.56 m	9.38 m - 9.63 m	18.45 m - 18.75 m	m - m	m - m	m - m	m - m
Condition of sample		Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed
Natural water content, %		63.6	32.2	19.6	15.3	19.1				
Specific gravity		2.639	2.624	2.606	2.597	2.594				
Wet density, g/cm³		1.66	-	-	-	-				
Dry density, g/cm³		1.02	-	-	-	-				
Natural void ratio		1.601	-	-	-	-				
Degree of saturation , %		100.0	-	-	-	-				
Atterberg limits	Liquid limit , %	51.0	47.8	-	-	-				
	Plastic limit , %	20.8	19.2	-	-	-				
	Plasticity index	30.2	28.6	-	-	-				
Grain size analysis	Gravel , %	9	19	8	16	10				
	Sand , %	26	38	55	46	61				
	Silt , %	18	11	2	2	10				
	Clay & colloid , %	47	32	35	36	19				
	Max. diameter, mm	4.76	9.52	4.76	9.52	4.76				
	Diam. at 60%	0.038	0.33	0.55	0.66	0.60				
	Diam. at 10%	-	-	-	-	0.0011				
Visual soil description		Sandy Clay	Sandy Clay	Silty Sand	Clayey Sand	Silty Sand				
Unified soil classification										
Unconfined compression test	Undisturbed sample, kg/cm²	0.03	-	-	-	-				
	Remoulded sample, kg/cm²	-	-	-	-	-				
	Sensitivity ratio	-	-	-	-	-				
	Strain at failure,%	(20)	-	-	-	-				
Triaxial compression test	Angle of internal friction	-	-	-	-	-				
	Cohesion, kg/cm²	-	-	-	-	-				
	Condition of drainage	-	-	-	-	-				
Consolidation test	Preconsolidation pressure, kg/cm²	-	-	-	-	-				
	Compression index	-	-	-	-	-				

Remarks:

Table 1.7 SUMMARY OF SOIL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.		BH-4								
Sample No.		UD-1 (1)	UD-1 (2)	UD-3	P-6	P-11	P-15	P-18	P-21	P-23
Sample depth		2.6 m - 3.1 m	3.1 m - 3.6 m	6.26 m - 6.55 m	9.8 m - 10.1 m	16.9 m - 17.2 m	23.0 m - 23.3 m	27.6 m - 27.9 m	33.7 m - 40.0 m	39.8 m - 41.1 m
Condition of sample		Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed
Natural water content, %		44.1	27.4	16.9	17.8	22.2	20.3	27.2	15.9	29.8
Specific gravity		2.567	2.612	2.603	2.584	2.584	2.593	2.602	2.614	2.622
Wet density, g/cm³		1.74	1.94	2.12	-	-	-	-	-	-
Dry density, g/cm³		1.21	1.52	1.81	-	-	-	-	-	-
Natural void ratio		1.126	0.715	0.435	-	-	-	-	-	-
Degree of saturation , %		100.0	100.0	100.0	-	-	-	-	-	-
Atterberg limits	Liquid limit , %	49.0	75.3	80.1	82.6	80.3	-	60.5	-	54.7
	Plastic limit , %	21.9	23.3	23.5	29.9	28.9	-	23.1	-	34.1
	Plasticity index	27.1	52.0	56.6	52.7	51.4	-	37.4	-	20.6
Grain size analysis	Gravel , %	3	11	26	10	8	3	1	15	2
	Sand , %	25	23	43	33	42	29	53	61	40
	Silt , %	12	8	6	31	22	36	10	2	31
	Clay & colloid , %	60	58	25	26	28	32	36	22	27
	Max. diameter, mm	4.76	4.76	4.76	4.76	9.52	4.76	4.76	9.52	4.76
	Diam. at 60%	0.0053	0.011	1.1	0.12	0.44	0.0062	0.17	1.15	0.11
	Diam. at 10%	-	-	-	-	-	-	-	-	-
Visual soil description		Sandy Clay	Sandy Clay	Clayey Sand	Clayey Sand	Clayey Sand	Clayey Sand	Sandy Clay	Clayey Sand	Sandy Clay
Unified soil classification										
Unconfined compression test	Undisturbed sample, kg/cm²	0.20	-	0.30	-	-	-	-	-	-
	Remoulded sample, kg/cm²	-	-	-	-	-	-	-	-	-
	Sensitivity ratio	-	-	-	-	-	-	-	-	-
	Strain at failure,%	14 ~(20)	-	5.1 ~9.0	-	-	-	-	-	-
Triaxial compression test	Angle of internal friction	-	0°	24°, 0°	-	-	-	-	-	-
	Cohesion, kg/cm²	-	0.18	0.15, 1.14	-	-	-	-	-	-
	Condition of drainage	-	U-U	U-U	-	-	-	-	-	-
Consolidation test	Preconsolidation pressure, kg/cm²	0.57	(1.25)	(>2.0)	-	-	-	-	-	-
	Compression index	0.41	0.16	0.08	-	-	-	-	-	-

Remarks:

Table 1.8 SUMMARY OF SOIL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.		BH 5		BH-7						
Sample No.		D		UD-1	P-2	P-3	P-5	P-7		
Sample depth		m-m	m-m	3.05 m-m 3.50	1.68 m-m 1.98	3.67 m-m 3.97	6.26 m-m 6.56	9.31 m-m 9.61	m-m	m-m
Condition of sample		Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed
Natural water content, %		22.6		14.8	14.3	24.5	18.1	17.9		
Specific gravity		2.579		2.610	2.588	2.601	2.600	2.609		
Wet density, g/cm³		-		2.00	-	-	-	-		
Dry density, g/cm³		-		1.74	-	-	-	-		
Natural void ratio		-		0.498	-	-	-	-		
Degree of saturation , %		-		77.5	-	-	-	-		
Atterberg limits	Liquid limit , %	62.7		58.9	-	-	57.6	-		
	Plastic limit , %	30.7		22.0	-	-	22.4	-		
	Plasticity index	32.0		36.9	-	-	35.2	-		
Grain size analysis	Gravel , %	8		8	22	3	11	7		
	Sand , %	43		44	45	49	47	38		
	Silt , %	12		7	3	5	5	18		
	Clay & colloid , %	37		41	30	43	37	37		
	Max. diameter, mm	4.76		4.76	4.76	4.76	9.52	4.76		
	Diam. at 60%	0.22		0.29	0.64	0.27	0.36	0.15		
	Diam. at 10%	-		-	-	-	-	-		
Visual soil description		Clayey Sand		Sandy Clay		Sandy Clay	Sandy Clay	Sandy Clay		
Unified soil classification										
Unconfined compression test	Undisturbed sample, kg/cm²			0.85	-	-	-	-		
	Remoulded sample, kg/cm²			-	-	-	-	-		
	Sensitivity ratio			-	-	-	-	-		
	Strain at failure,%			1.2	-	-	-	-		
Triaxial compression test	Angle of internal friction			10°	-	-	-	-		
	Cohesion, kg/cm²			0.36	-	-	-	-		
	Condition of drainage			U-U	-	-	-	-		
Consolidation test	Preconsolidation pressure, kg/cm²			(>1.5)	-	-	-	-		
	Compression index			(0.14)	-	-	-	-		

Remarks:

Table 1.9 SUMMARY OF SOIL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.		BH-8								
Sample No.		UD-2	UD-3	P-1	P-4	P-7	P-13	P-15		
Sample depth		12.2 m - 12.7 m	15.3 m - 15.8 m	0.5 m - 0.8 m	3.2 m - 3.5 m	9.3 m - 9.6 m	18.5 m - 18.8 m	21.5 m - 21.8 m	m - m	m - m
Condition of sample		Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed	Disturbed / Undisturbed
Natural water content, %		20.0	24.5	19.2	18.9	18.7	26.9	23.0		
Specific gravity		2.605	2.620	2.588	2.600	2.616	2.631	2.632		
Wet density, g/cm³		2.00	1.82	-	-	-	-	-		
Dry density, g/cm³		1.67	1.46	-	-	-	-	-		
Natural void ratio		0.563	0.792	-	-	-	-	-		
Degree of saturation , %		92.5	81.0	-	-	-	-	-		
Atterberg limits	Liquid limit , %	86.6	60.0	41.2	-	-	63.8	-		
	Plastic limit , %	29.1	37.1	19.7	-	-	36.1	-		
	Plasticity index	57.5	22.9	21.5	-	-	27.7	-		
Grain size analysis	Gravel , %	9	7	1	9	21	30	20		
	Sand , %	45	31	69	56	47	28	33		
	Silt , %	15	26	10	5	7	20	22		
	Clay & colloid , %	31	26	20	30	25	22	25		
	Max. diameter, mm	4.76	4.76	4.76	9.52	4.76	9.52	9.52		
	Diam. at 60%	0.48	0.28	0.63	0.85	1.25	1.40	0.64		
	Diam. at 10%	-	-	-	-	-	-	-		
Visual soil description		Clayey Sand	Sandy Clay	Clayey Sand	Clayey Sand	Clayey Sand	Clayey Sand	Sandy Clay		
Unified soil classification										
Unconfined compression test	Undisturbed sample, kg/cm²	0.97	1.05	-	-	-	-	-		
	Remoulded sample, kg/cm²	-	-	-	-	-	-	-		
	Sensitivity ratio	-	-	-	-	-	-	-		
	Strain at failure,%	1.4	2.9 ~8.9	-	-	-	-	-		
Triaxial compression test	Angle of internal friction	8.5°, 0°	-	-	-	-	-	-		
	Cohesion, kg/cm²	0.22,0.72	-	-	-	-	-	-		
	Condition of drainage	U-U	-	-	-	-	-	-		
Consolidation test	Preconsolidation pressure, kg/cm²	(1.8)	-	-	-	-	-	-		
	Compression index	0.21	0.30	-	-	-	-	-		

Remarks:

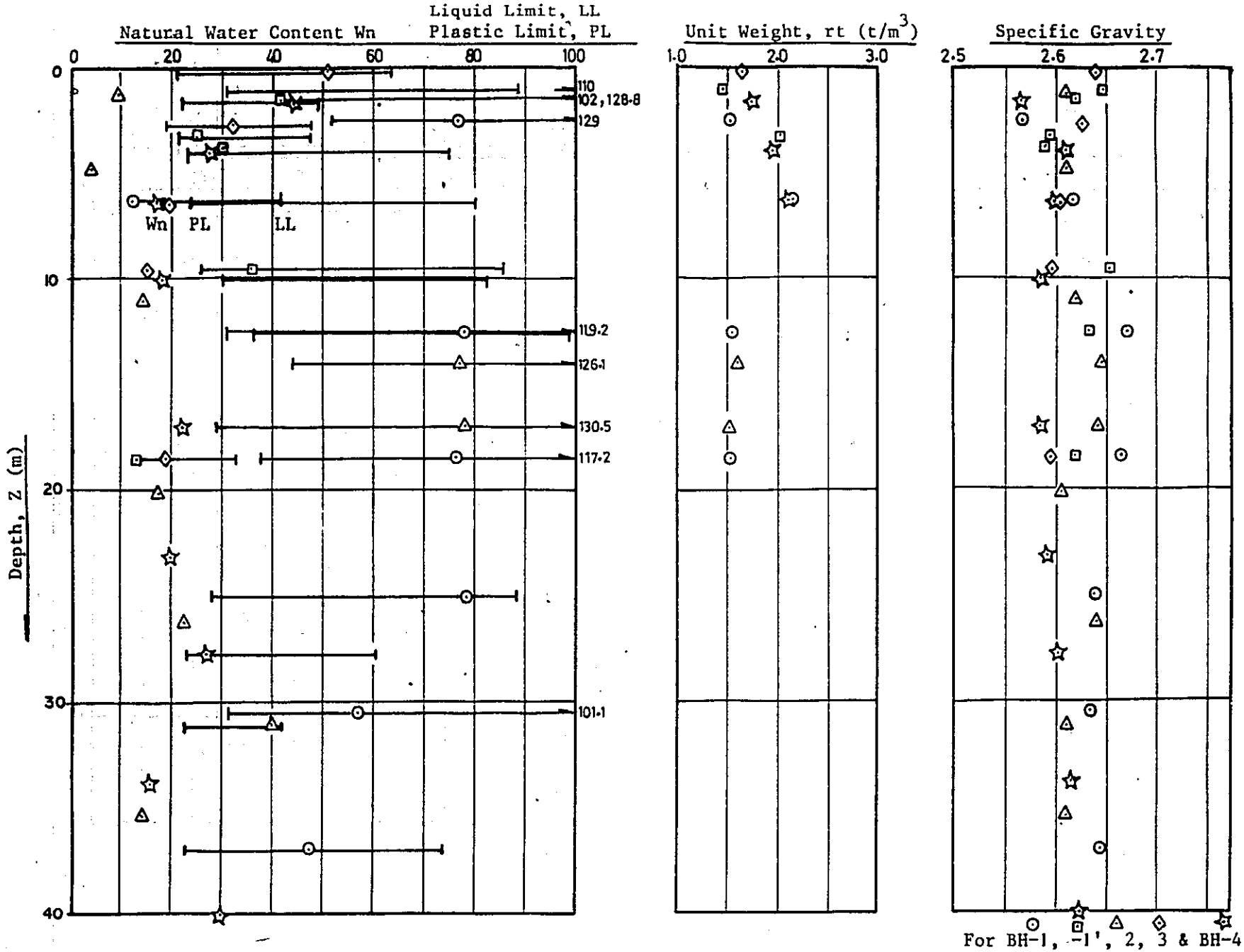


FIG. 1.18 ENGINEERING PROPERTIES OF SOIL VS. DEPTH

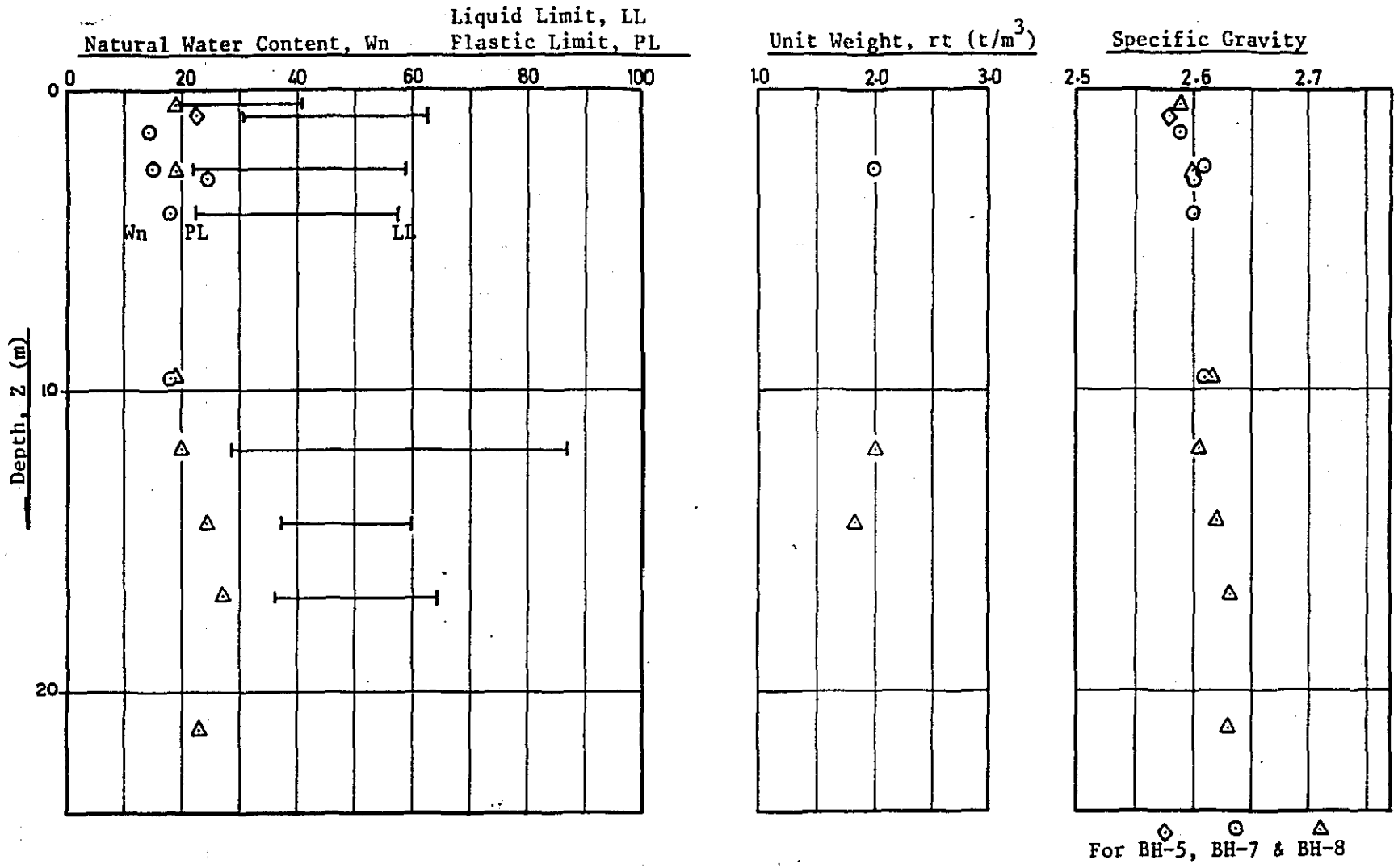


FIG. 1.19 ENGINEERING PROPERTIES OF SOIL VS. DEPTH

Table 1.10

NATURAL WATER CONTENT AND ATTERBERG LIMITS

Area	Layer	Natural Water Content	Atterberg Limits		
			Liquid Limit	Plastic Limit	Plasticity Index
Hilly Area	Clayey Layer	19-25%	60%	37%	23
	Sandy Layer	19-20%	41-87%	20-24%	22-(58)
	Residual Clayey Layer	14-27%	58-64%	22-36%	28-37
	Residual Sandy Layer	23%	63%	31%	32
Gurney Drive & Offshore Area	Upper Clayey Layer, C_u	76-110%	89-129%	31-52%	58-88
	Middle Clayey Layer, C_m	22-78%	42-130%	23-51%	20-88
	Lower Clayey Layer, C_l	48%	74%	23%	51
	Upper Sandy Layer, S_u	10-41% (64)	33-51% (83)	14-24% (30)	19-30 (57)
	Lower Sandy Layer, S_l	15-20%	-	-	-
	Residual Clayey Layer	30%	55%	34%	21%

Note: ( ) = Abnormal Value.

b) Specific Gravity, Unit Weight and Void Ratio

Specific gravity and unit weight at natural water content vs. depth are shown in Figs. 1.18 and 1.19, Engineering Properties of Soil vs. Depth. The specific gravity (Gs) for any layer is generally in the range of 2.57 to 2.66. The unit weight and natural void ratio of soil at natural water content are shown in Table 1.11.

Table 1.11 UNIT WEIGHT AND NATURAL VOID RATIO

Area	Layer	Unit Weight	Natural Void Ratio
Hilly Area	Clayey Layer	rt = 1.82t/m^3	0.79
	Sandy Layer	2.00t/m^3	0.56
	Residual Clayey Layer	2.00t/m^3	0.50
Gurney Drive & Offshore Area	Upper Clayey Layer, Cu	1.52 - 1.64t/m^3 (Ave. = 1.57t/m^3)	1.96 - 2.089 - (2.747) (Ave. = 2.02)
	Middle Clayey Layer, Cm	1.53 - 1.60t/m^3 (Ave. = 1.56t/m^3)	1.93 - 2.08 (Ave. = 2.01)
	Upper Sandy Layer, Su.	(1.66) - 1.74 - 2.14t/m^3 (Ave. = 1.94t/m^3)	0.38 - 1.13 - (1.60) (Ave. = 0.65)

c) Grain Size Analysis

Grain size distribution curves of soil are shown in Fig. 1.20, Grading Texture vs Depth.

Grain size distribution for each layer is shown in Table 1.12.

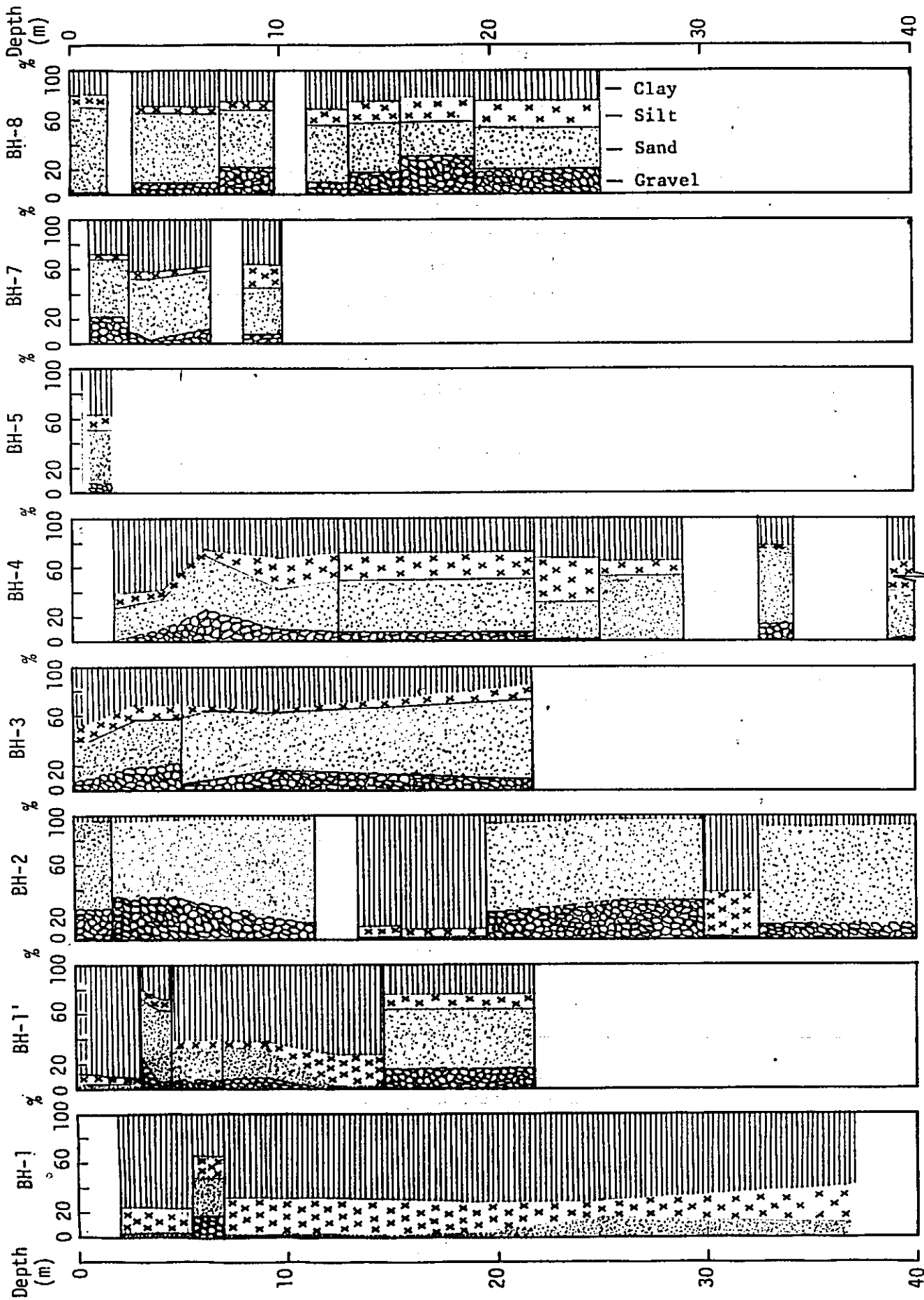


FIG. 1.20 GRADING TEXTURE VS. DEPTH

Table 1.12 GRAIN SIZE DISTRIBUTION

Area	Layer	Clay & Colloid(%)	Silt(%)	Sand(%)	Gravel(%)
Hilly Area	Clayey Layer	25-26	7-26	31-47	7-21
	Sandy Layer	20-31	5-15	45-69	1-9
	Residual Clayey Layer	22-41	3-22	28-49	3-30
	Residual Sandy Layer	37	12	43	8
Gurney Drive & Offshore Area	Upper Clayey Layer, C_u	68-92	3-31	1-4	0-1
	Middle Clayey Layer, C_m	28-72-(92)	6-39	2-42-(53)	0-9
	Lower Clayey Layer, C_l	58	30	12	0
	Upper Sandy Layer, S_u	21-60	2-31	23-84	3-35
	Lower Sandy Layer, S_l	19-36	2-10-(36)	29-46-(80)	3-16
	Residual Clayey Layer	27	31	40	2

(2) Unconfined and Triaxial Compression Tests

Unconfined and triaxial compression tests were performed on undisturbed samples. Triaxial compression tests were carried out under unconsolidated undrained (U-U) condition.

Results of the tests are summarized in Tables 1.3 to 1.9 and are plotted in Fig. 1.21, Results of Unconfined and Triaxial Compression Tests.

Cohesion and angle of internal friction of each layer is tabulated in the following table.

Table 1.13 COHESION OF LAYERS

Area	Layer	Unconfined Compression Test, C = qu/2 (t/m^2)	Triaxial Compression Test	
			C (t/m^2)	ϕ (°)
Hilly Area	Clayey Layer	5.25	-	-
	Sandy Layer	4.85	2.2	8.5
	Residual Clayey Layer	4.25	3.6	10
Gurney Drive & Offshore Area	Upper Clayey Layer, C_u	(0.27) - 1.9 - 2.9	0.4 - 1.5	0
	Middle Clayey Layer, C_m	(1.0) - 3.2 - 3.85	(1.4) - 3.2 - 4.5	0
	Upper Sandy Layer, S_u	(0.72) - 1.0 - 1.5 - (5.5)	1.2 - 1.8 1.5	0 ...24

Cohesion vs depth for any layer is roughly given in the following formula: $C = 0.25 \cdot Z$ (t/m^2)

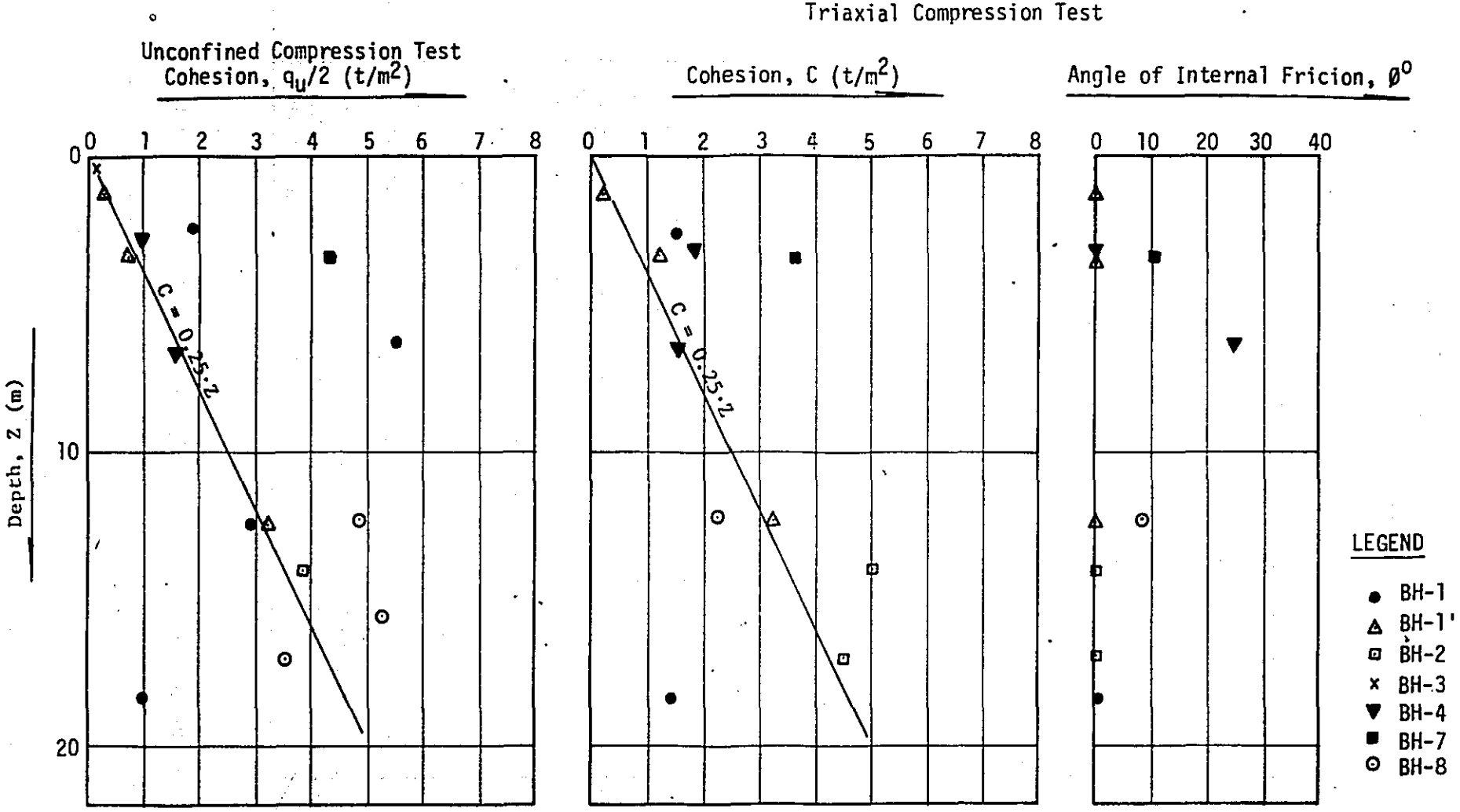


FIG. 1.21 RESULTS OF UNCONFINED AND TRIAXIAL COMPRESSION TESTS

(3) Consolidation Tests

The test results are illustrated in Tables 1.3 to 1.9, Summary of Test .

Preconsolidation pressure and compression index versus depth is plotted in Fig. 1.22 and according to the figure, almost all layers are over-consolidated.

All e-log p curves obtained are plotted in Figs. 1.23 to 1.24.

The compression index, C_c, the coefficient of consolidation, C_v, the coefficient of volume compression, mv, and the coefficient of permeability, k, are shown for each layer in Table 1.14.

Table 1.14 INDEX AND COEFFICIENTS OBTAINED FROM CONSOLIDATION TESTS

Area	Layer	C_c	C_v	mv	k
Hilly Area	Clayey Layer	0.30	$7 \times 10^{-1} cm^2/min$	$5 \times 10^{-2} cm^2/kg$	$2.3 \times 10^{-5} cm/min$
	Sandy Layer	0.21	3×10^{-1}	2.4×10^{-2}	7.1×10^{-6}
	Residual Clayey Layer	0.14	4.2×10^{-1}	1.6×10^{-2}	6.4×10^{-6}
Gurney Drive & Offshore Area	Upper Clayey Layer, C_u	0.81-1.75	1.25×10^{-2} - 2×10^{-1}	2.1×10^{-2} - 1.7×10^{-1}	$(2 \sim 6) \times 10^{-6}$
	Middle Clayey Layer, C_m	1.29-1.35	1.6×10^{-2} - 1.1×10^{0}	$(1.1 \sim 7.3) \times 10^{-2}$	1.2×10^{-6} - 1.2×10^{-5}
	Upper Sandy Layer, S_u	0.08-0.16 -(0.41)	8.3×10^{-2} - 1.9×10^{-1}	$(2.6 \sim 3.0) \times 10^{-2}$	$(2.7 \sim 5) \times 10^{-6}$

Note : C_v, mv and k are given at a pressure of 10 t/m^2.

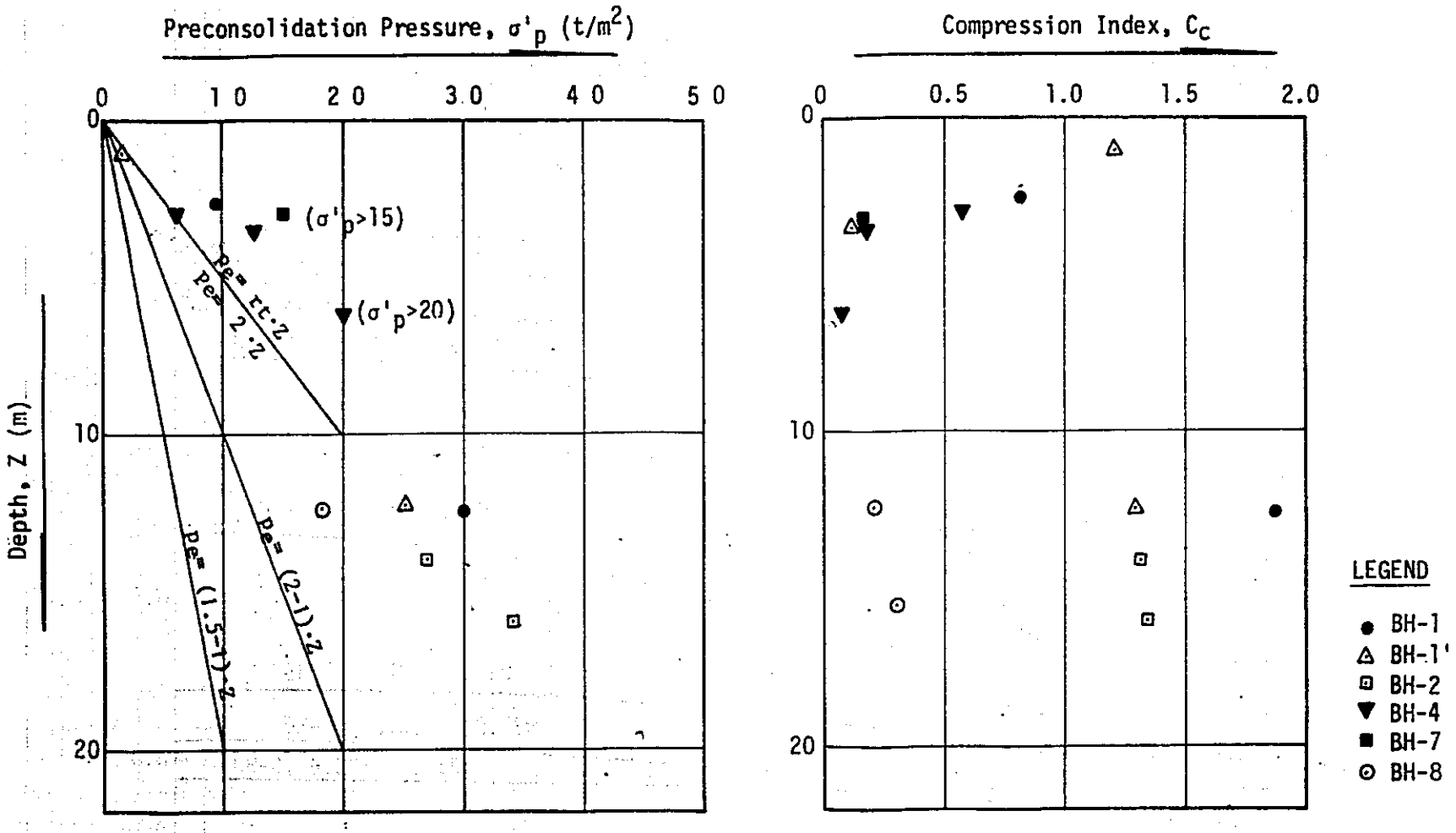


FIG. 1.22 PRECONSOLIDATION PRESSURE AND COMPRESSION INDEX VS. DEPTH

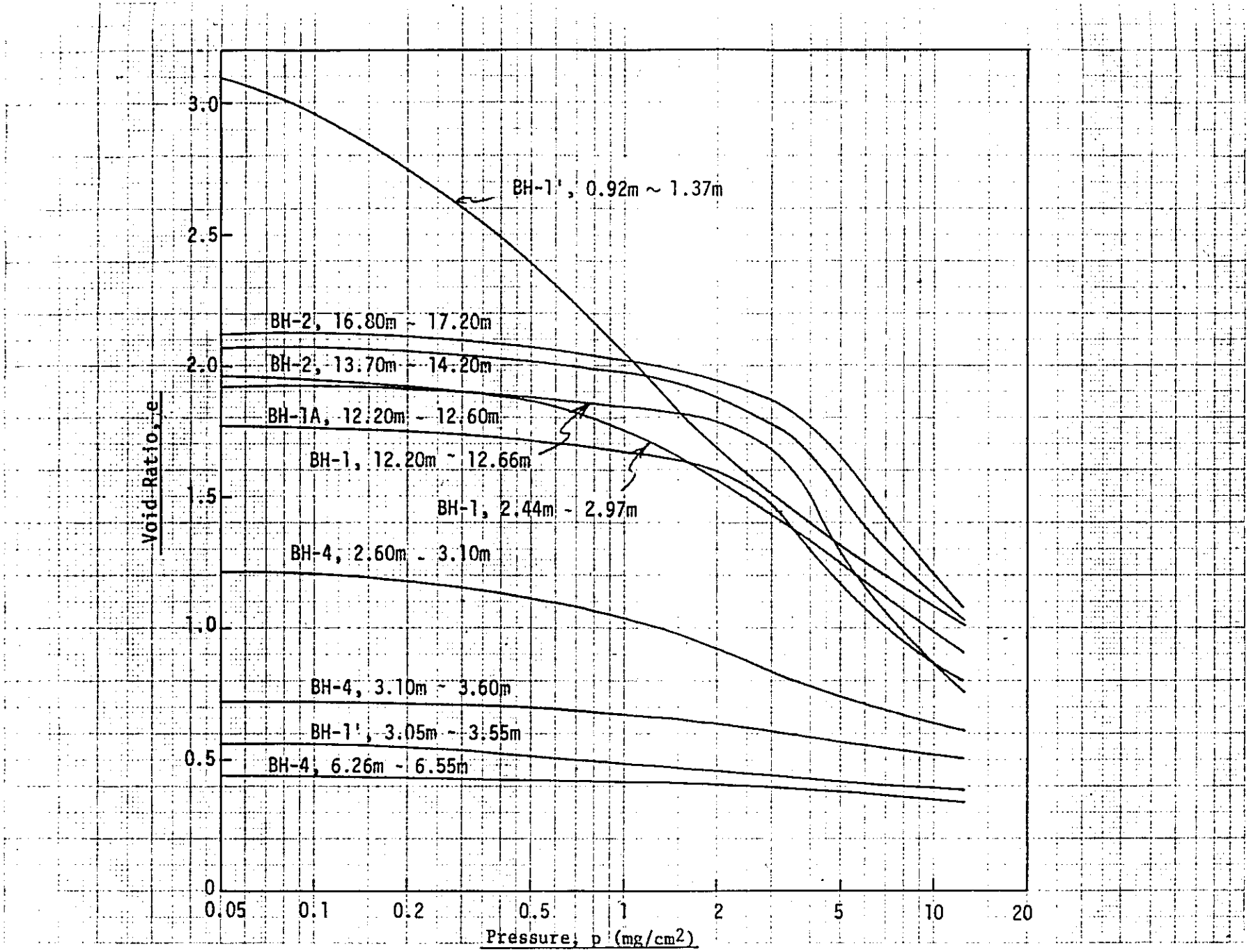


Fig. 1.23 VOID RATIO vs. PRESSURE

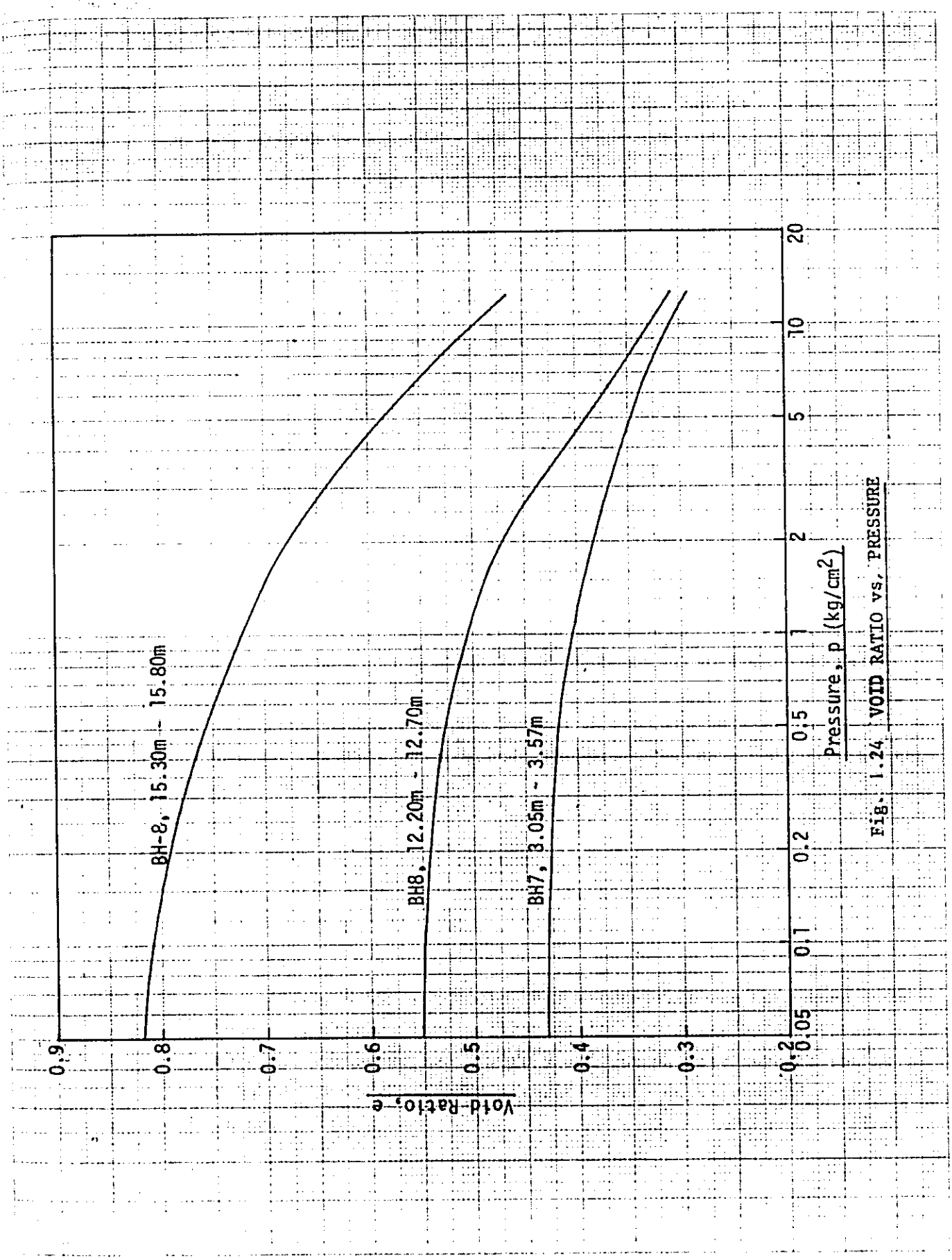


Fig. 1.24 VOID RATIO vs. PRESSURE

1.2.2 Subsurface Ground Conditions along the Alternative Road Alignments

1) Geological Outline

The proposed road alignments are laid out on the hilly topography to the south and west of George Town.

Geologically, the area consists of a mass of granite, talus and alluvium. A swampy area of alluvium is found around the mouth of Sungei Pinang.

a. Granite

Granite bodies are extensively distributed throughout the country and commonly form topographic heights. The basic formation of Penang Island is a single mass of granite isolated from the Peninsular. The granite of Penang Island seems to be intruded during the Jurrassic period, radiometrically between 165 million to 208 million years ago. The granite mass has been highly weathered by the tropical climate in this region, the surface portion of which have changed into residual soil. The depth of weathered granite is great and a thickness in excess of 10m is not uncommon. In areas of massive granite, weathering have produced rounded core boulders of granite which are "floating" in a thick layer of residual soil derived from heavily weathered granite. In drilling at field investigation, such core boulders pose a further difficulty in ascertaining whether drilling has reached the bedrock or have only reached the core boulder.

b. Talus

Talus which is a collection of fallen disintegrated materials transported from weathered granite mass has formed a slope at the foot of steep hills and mountains.

c. Alluvium

About 20,000 years ago, sea water level was more than 100m below the present level. Then as the level gradually started to rise erosion worked severely and cut valleys through the area. Simultaneously the eroded materials were deposited under the water.

About 6,000 years ago, the invasion of sea ceased at about 5m above the present sea level and the present town area became calm shallow sea where sedimentation continued. About 2,000 years ago, by a regression to the present sea level the area became coastal plain and the Sungei Pinang river started to flow around the present route with a much wider flood area and the present swampy area was also formed.

2) Subsurface Ground Conditions along the Alternative Road Alignments

Ground conditions along the Alternative Road Alignments based on the results of geological reconnaissance, exploratory drillings and laboratory soil tests are summarised below.

(1) Subsurface Ground Conditions according to Field Works

Geological stratifications are shown in Figs. 1.2 to 1.3, Geological Profile, Fig. 1.4, Geological Cross-Section and Figs. 1.5 to 1.8, Typical Geological Cross-Section. The stratification in the figures are explained from Station to Station.

A. Stratification along Alternative Road Alignment A

a. From Station -5 to Station 6

Subsurface ground in the area may consist mainly of a clayey layer derived from weathered granite.

b. From Station 6 to Station 12

Subsurface ground in the area consists of a sandy layer (mainly Clayey Sand) and a clayey layer (Sandy Clay).
N value-blow counts by Standard Penetration Test for sandy layer varies from 6 to 23 and N value for clayey layer is in the range of 16 to 20 (very stiff).

c. From Station 12 to Station 31

Subsurface ground in the area may consist of intact granite and residual sandy soil of granite with a thickness of 0.3m to 15m. The weathered depth may be thicker around Station 24 to Station 27 than in the other areas; the depth may reach a maximum of 15m from ground level.

Debris consists mainly of boulders with a diameter of 1m to 5m at Station 20 to Station 22. Boulders with a diameter of 5m to 10m can be seen in the debris at Station 27 to Station 30.

Diameters of boulders along the area are generally 2m to 20m and approximately 150 of these boulders may be required to be removed or blasted to make them stable at construction time. The average size of the boulders are 4m in diameter. Joints of granite in the area do not have the same direction of strikes, however, the main strikes are north-south with main dips of 80° to 83°SE.

d. From Station 31 to Station 52

Ground in this area may consist mainly of intact granite and residual clayey soil of granite. At BH-7, residual soil is encountered from ground level to 10m below ground level and the N-value of the soil varies from 3 to 17. Two boulders were found at the depths of 11m and 17m and their vertical thicknesses were 1.55m and 1.20m respectively. Intact granite was found at a depth of approximately 20m and the rock core length obtained by diamond bid was 15mm to 40mm which is short. The joints of granite around Station 34 strikes N 35° E and dips 50°SE. The number of boulders that have to be treated to make them stable at construction time is approximately 100 in the area, and the average size of the boulders is approximately 3m.

e. From Station 52 to Station 72

The ground may be composed of sandy and clayey layers and residual clayey layer of granite. Generally, the ground will be well consolidated. No significant problems of earthwork for embankment is expected.

f.. From Station 72 to Station 102

The ground may consist mainly of intact granite and residual sandy layer. The thickness of residual sandy layer may be 5m to 10m at Station 72 to Station 78. The thickness of residual sandy layer at Station 78 to Station 88 will be 3m to 7m and the thickness at Station 88 to Station 96 may be 0.5m to 3.0m which is comparatively thinner.

N-value (SPT) of the sandy layer varies from 14 to more than 50.

The rock cores obtained by diamond bid at BH-5 and BH-6 are generally 200mm to 1000mm long and the rocks are in firm contact with each other. The rock at a depth of around 15.3m at BH-5 has many joints and the core length was 20mm to 50mm which is short. However, no clay was observed at the joints at any depth at the bore-holes of BH-5 and BH-6.

The joints of intact rock in the area have irregular strikes and dips. Boulders of size 2m to 20m can be observed and the number of boulders to be removed or blasted to avoid them falling at construction time are in the range of 100 to 120 and the average size is 5m in diameter in the area. Outcrops of intact granite were seen at previous quarry sites along the alignment at Station 88 to Station 95, and the outcrops are cut with the vertical height of 10m to 25m. The interval of joints of outcrops are generally 0.3m to 1.5m and the rocks are in firm contact with each other at the joints.

g. From Station 102 to Station 120

The ground in the area may compose mainly of sandy layer and residual clayey layer derived from weathered granite. The soils may be well consolidated.

h. From Station 120 to Station 165

Subsurface ground in the area consists of several types of soil.

The soil stratification is shown in Fig. 1.2, Geological Profile and Fig. 1.4, Geological Cross-Section. In the figures, the stratification can be explained from upper to lower layers as follows:

Cu layer : Upper Clayey Layer
Soft to medium marine clay with decomposed organic matter, shell fragments and some sand and gravel.
N-value blow counts : 4 to 8.

Cm Layer : Middle Clayey Layer
Stiff to very stiff silty clay with shell fragments and fine sand.
N-value : 9 to 28.
Colour : Light grey - Dark grey - Grey

Cl Layer : Lower Clayey Layer
Hard silty clay with traces of sand
N-value : 30 to 34
Colour : Light grey

Su Layer	:	Upper Sandy Layer Loose to medium sand to clayey sand with shell fragments. N-value : 5 to 20 Colour : Bluish to whitish grey
Sl Layer	:	Lower Sandy Layer Medium to dense clayey or silty sand N-value : 15 to more than 50 Colour : Grey - reddish light grey
Residual Clayey Layer	:	Hard clay silt from weathered granite N-value : 31 to more than 50 Colour : Reddish brown

B. Stratification along Alternative Road Alignment B

a. From Station 94' to Station 105'

The subsurface ground may be composed mainly of intact rock and residual sandy layer. The thickness of the residual sandy layer may be in the range of 1.0m to 5.0m. There is debris with huge boulders (ϕ 2m to 6m) around Station 101'. According to the outcrop of granite at Youth Park, the interval of joints is 0.2m to 2.0m. Joints are generally firm in contact with each other and are not weathered. However, open joints can also be seen at a few spots.

The number of huge boulders to be removed or blasted will be approximately 60 and the average size is about 5m in diameter.

b. From Station 105' to Station 132'

Subsurface ground may consist of intact rock, residual sandy layer and sandy layer. Generally, these sandy layers may be well consolidated. From field observation, there does not seem to be any need to remove any boulders during construction time.

3) Summary of Subsurface Ground Conditions

The physical and mechanical properties of soil along the alternative road alignments were described under Laboratory Soil Tests earlier and are summarized in Tables 1.3 to 1.9.

Subsurface ground conditions are summarized in Table 1.15.

Table 1.15 SUMMARY OF SUBSURFACE GROUND CONDITIONS

	Layer	Standard Penetration Test SPT	Specific Gravity Gs	Natural Water Content wn	Atterberg Limits: Liquid Limit	Atterberg Limits: Plastic Limit	Atterberg Limits: Plasticity Index	Grading Analysis: Gravel G	Grading Analysis: Sand S	Grading Analysis: Silt M	Grading Analysis: Clay C	Unit Weight γt	Cohesion & Angle of Internal Friction*: c	Cohesion & Angle of Internal Friction*: φ	Consolidation Properties: Cc	Consolidation Properties: Cv	Consolidation Properties: mv	Consolidation Properties: k
Hilly Area	Clayey Layer	16-20	2.616 - 2.620	19-25 %	60%	37%	23	7-21 %	31-47 %	7-26 %	25-26 %	1.82t/m^3	5.25t/m^2	-	0.30	7 x 10^{-1}cm^2/min	5 x 10^{-2}cm^2/kg	2.3 x 10^{-5}cm/min
	Sandy Layer	6-23	2.588 - 2.605	19-20%	41-87	20-24	22-(58)	1-9	45-69	5-15	20-31	2.00	4.85 2.2	85°	0.21	3 x 10^{-1}	2.4 x 10^{-2}	7.1 x 10^{-6}
	Residual Clayey Layer	3-17	2.588 - 2.032	14-27	58-64	22-36	28-37	3-30	28-49	3-22	22-41	2.00	4.25 3.6	10	0.14	4.2 x 10^{-1}	1.6 x 10^{-2}	6.4 x 10^{-6}
	Residual Sandy Layer	14->50	2.579	23	63	31	32	8	43	12	37	2.00	-	-	-	-	-	-
Offshore and Gurney Drive Area	Upper Clayey Layer, Cu	4-8	2.568 - 2.671	76-110	89-129	31-52	58-88	0-1	1-4	3-31	68-92	1.57	(0.27) 1 1.9 2.9	0	0.81 - 1.75	1.25 x10^{-2} - 2 x10^{-1}	2.1 x 10^{-2} -1.7x 10^{-1}	(2-6) x 10^{-6}
	Middle Clayey Layer, Cm	9-28	2.584 - 2.664	22-78	42-130	23-51	20-88	0-9	2-42 -(53)	6-39	28-92	1.56	3.2 1 4.5	0	1.29 -1.35	1.6 x 10^{-2} -1.1x10^{0}	(1.1-7.3)x 10^{-2}	1.2 x 10^{-6} -1.2 x 10^{-5}
	Lower Clayey Layer, Cl	30-38	2.642	48	74	23	51	0	12	30	58	1.60	-	-	-	-	-	-
	Upper Sandy Layer, Su	5-20	2.567 - 2.641	10-41 -(64)	33-51 -(83)	14-24 -(30)	19-30 -(57)	3-35	23-84	2-31	21-60	1.94	1.0 1 1.8 1.5	24	0.08 -0.16 -(0.41)	8.3 x 10^{-2} -1.9x 10^{-1}	(2.6-3.0)x 10^{-2}	(2.7-5) x 10^{-6}
	Lower Sandy Layer, Sl	13->50	2.593 - 2.614	15-20	-	-	-	3-16	29-80	2-10 -(36)	19-36	2.00	-	-	-	-	-	-
	Residual Clayey Layer	31->50	2.622	30	55	34	21	2	40	31	27	2.00	-	-	-	-	-	-

(Notes) Cc : Compression Index Mv : Coef. of Volume Compressibility ( ) : Abnormal Value * : Triaxial Comp. Test (U-U)
Cv : Coef. of Consolidation k : Coef. of Permeability —— : Assumed Value
Cv, mv and k are given at a pressure of 10 t/m^2

1.2.3 Investigation for Construction Materials

Construction of the road requires concrete materials, earth, and also some dumping area for waste soil.

Details for such materials are given in this section.

1) Fine Aggregate

Fine aggregates are available from several sand borrow pits in Penang Island. The sand is washed sand of heavily weathered granite.

The sources are indicated as sand borrow pits from S-1 to S-8 in Fig. 1.25, Location of Materials.

The name of the company, address and present production capacity of each site is shown in Table 1.16.

Fine aggregates are produced by the method of crushing granite and this is only done at one site (TEIK QUARRY SDN).

Some laboratory tests were performed on the collected samples and the results are indicated in Table 1.19. Grain-size distribution curves are shown in Figs. 1.26 to 1.29.

a. Specific Gravity

True and apparent specific gravity tests were performed and the results are given below.

True specific gravity (Gs) : 2.602 to 2.618
Apparent specific gravity (Gsa) : 2.263 to 2.416
(Saturated surface dry condition)

Both values of Gs and Gsa are less than the values obtained for normal fine aggregates. Gsa values obtained for normal fine aggregates are generally 2.50 to 2.70.

b. Water Absorption of Fine Aggregates

Water absorption of fine aggregates was from 2.15% to 10.4%, which is very high.

c. Fineness Modulus

Fineness Modulus was from 3.55 to 4.21.

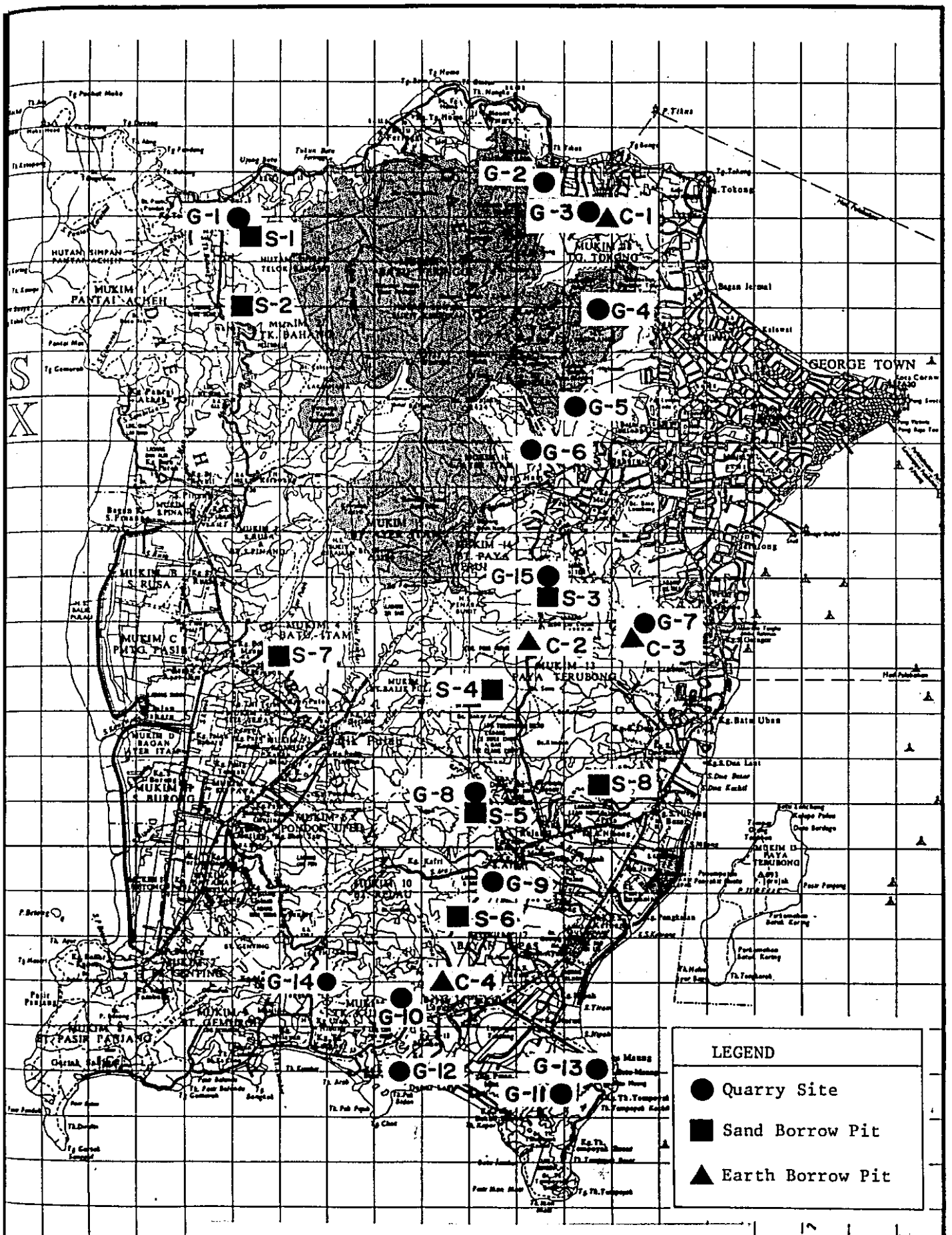


FIG. 1.25 LOCATION OF MATERIALS
(Coarse and Fine Aggregates and Embankment Material)

Table 1.16 SOURCE OF FINE AGGREGATE (SAND)

SOURCE NO.	SOURCE OF BORROWED SAND	ADDRESS OF OFFICE	PRESENT APPROX. PRODUCTION CAPACITY
S-1	LIM KHENG KIM	82-H, Free School Road.	100 to 300 tons/day.
S-2	FAR EAST DEVELOPMENT CO.	700, Mk.2, Jln. Sungei, Telok Bahang*.	100 to 300
S-3	LAU GEOK SWEE CO. LTD.	324, Mk. 17, Batu Ferringhi.	100 to 300
S-4	RELAU ESTATE	-	100 to 300
S-5	LIM KHENG KIM	82-H, Free School Road.	100 to 300
S-6	POSSIBLE SOURCE (SEPULOH KONGSI)	-	-
S-7	NIMBUS SDN. BHD. (LIM TENG HOE)	156, Mk. 4, Ayer Puteh, Balik Pulau.	500
S-8	TEOH CHEE KEONG	156, Beach Street	100 to 200

Note: * means site location

Table 1.17 SOURCE OF SUBGRADE MATERIAL

SOURCE NO.	NAME OF LOCATION
C-1	Mukim 18, Tanjong Tokong.
C-2	Paya Terubong Estate.
C-3	Mukim 13, Paya Terubong
C-4	Bukit Lada Mati

Table 1.18 SOURCE OF COARSE AGGREGATE

SOURCE NO.	NAME OF QUARRY SITE	ADDRESS OF OFFICE	PRESENT APPROX. PRODUCTION CAPACITY
G-1	LIM KHENG KIM	82-H, Free School Roads	500 to 1000 tons/day
G-2	CHEE SENG STONE	1, Jln. Maxwell, Penang.	500 to 1000
G-3	TEIK QUARRY SENDIRIAN	77, Leboh Bridge, Penang.	500 to 1000
G-4	WATERFALL QUARRY	(PDC) Batu Gantong	Not in operation
G-5	TEIK GRANITE QUARRY	77, Leboh Bridge, Penang.	Occasional operation (500)
G-6	SOON GIM QUARRY	790, Mk. 16, Ayer Itam, Penang.	500
G-7	CHOONG LIM LIM SDN. BHD.	82-H, Free School Road.	500
G-8	LIM KHENG KIM	- do -	500
G-9	LIM KHENG KIM & ISMAIL BIN HASHIM	- do -	500
G-10	LIM KHENG KIM	82-H, Free School Road	500
G-11	POSSIBLE SOURCE (LOH POH HENG)	- -	- -
G-12	POSSIBLE SOURCE	* Bukit Payong	-
G-13	POSSIBLE SOURCE	* Batu Maung	-
G-14	POSSIBLE SOURCE	* Telok Kumbar	-
G-15	TAT SENG QUARRY	20W, Jln. Paya Terubong, Penang.	-

Notes: * means site location

Each manufacturer generally produces the following sizes of aggregates.

a. Diameter 3" & 4" (CRUSHER RUN)

b. " 1½"

c. " 3/4"

d. " 3/8"

e. Quarry Dust (is sometimes used as fine aggregate)

Table 1.19 SUMMARY OF MATERIAL TEST

Project: Urban Transport Study in Penang Standard: JIS

Aggregate		Fine Aggregate								
Sample No.		1	2	3	4	5	6	7		
Source No.		S-1	S-1	S-2	S-8	G-3	S-7	S-7		
Water Absorption, %		2.15	6.61	8.45	7.92	9.53	7.75	10.4		
Specific Gravity	Apparent	2.340	2.341	2.349	2.416	2.263	2.404	2.354		
	True	2.607	2.609	2.602	2.616	2.609	2.618	2.608		
Grain size analysis	Gravel ,%	40	52	50	40	54	52	38		
	Sand ,%	60	48	50	60	46	48	62		
	Silt ,%	-	-	-	-	-	-	-	Seive only	
	Clay&colloid ,%	-	-	-	-	-	-	-		
	Max.diameter,mm	5.0	5.0	10.0	5.0	5.0	20	20		
	F.M.	3.55	3.72	4.09	3.66	3.99	4.21	3.92		
Description of Aggregate		Lim Kheng Kim White Sand	Lim Kheng Kim Brown Sand	Far East Dev.	Teoh Chee Kong	Teik Quarry Crushed Sand	Nimbus Sdn. White Sand	Nimbus Sdn. Brown Sand		

Aggregate		Coarse Aggregate								
Sample No.		1	2	3						
Source No.		G-3	G-15	G-7						
Water Absorption, %		0.4	0.7	0.6						
Specific Gravity	Apparent	2.625	2.613	2.619						
	True	2.670	2.660	2.632						
Los Angeles Abrasion Value ,%		29	36	40						
Description of Aggregate		Teik Quarry	Tai Seng	Choong Lim Lim						
Fineness Modulus		6.79	6.92	7.08						

FIG. 1.26

GRAIN SIZE DISTRIBUTION

Project URBAN TRANSPORT STUDY IN PENANG Job. No. 251

Location of Project PENANG Boring No. FINE AGGREGATE

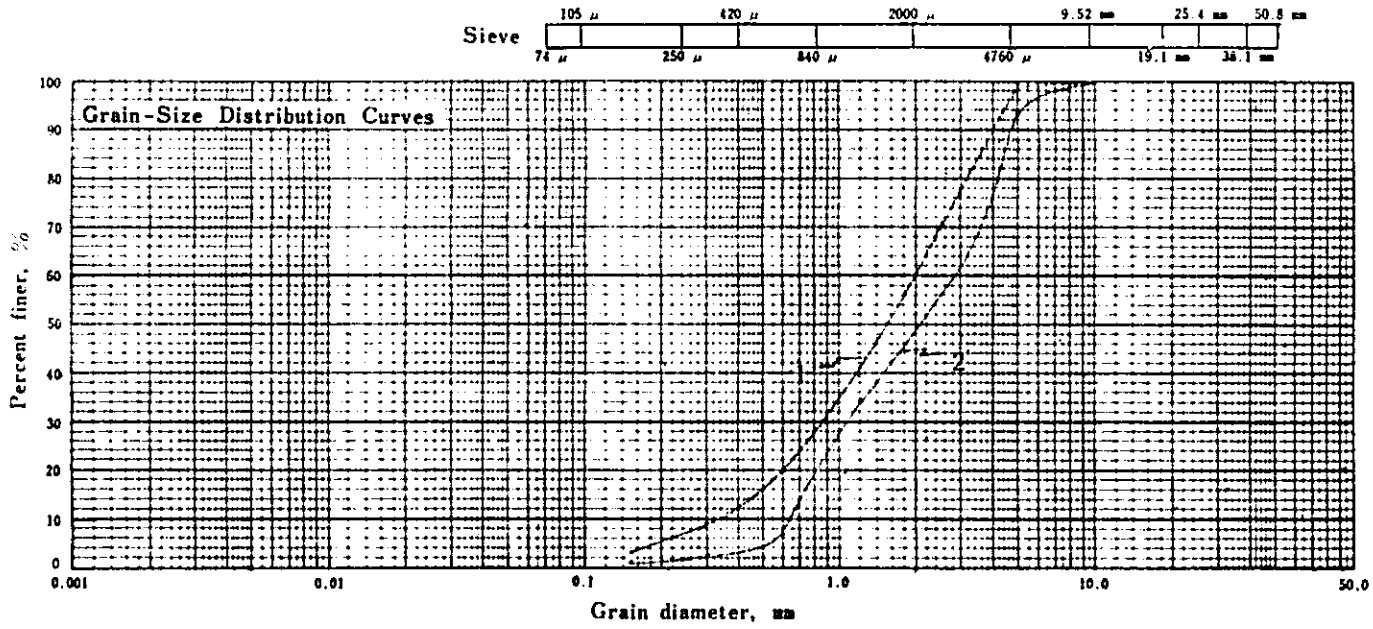
Tested by. TAN Date of Testing

Sample No., Depth. : No. 1 (m ~ m) Specific Gravity, Gs=

Sieve	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing										100	99.63	70.95
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	41.40	19.90	9.35	3.47								

Sample No., Depth. : No. 2 (m ~ m) Specific Gravity, Gs=

Sieve	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing										100	93.55	68.79
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	34.35	6.85	2.45	1.73								



Colloid	Clay	Silt	Sand	Gravel
0.001	0.005	0.074	2.0	

Sample No., Depth	No. 1 m ~ m	No. 2 m ~ m
F.M.	3.55	3.72
Max. dia. (mm)	5.0	5.0

FIG. 1.27

GRAIN SIZE DISTRIBUTION

Project URBAN TRANSPORT STUDY IN PENANG Job. No. 251

Location of Project PENANG Boring No. FINE AGGREGATE

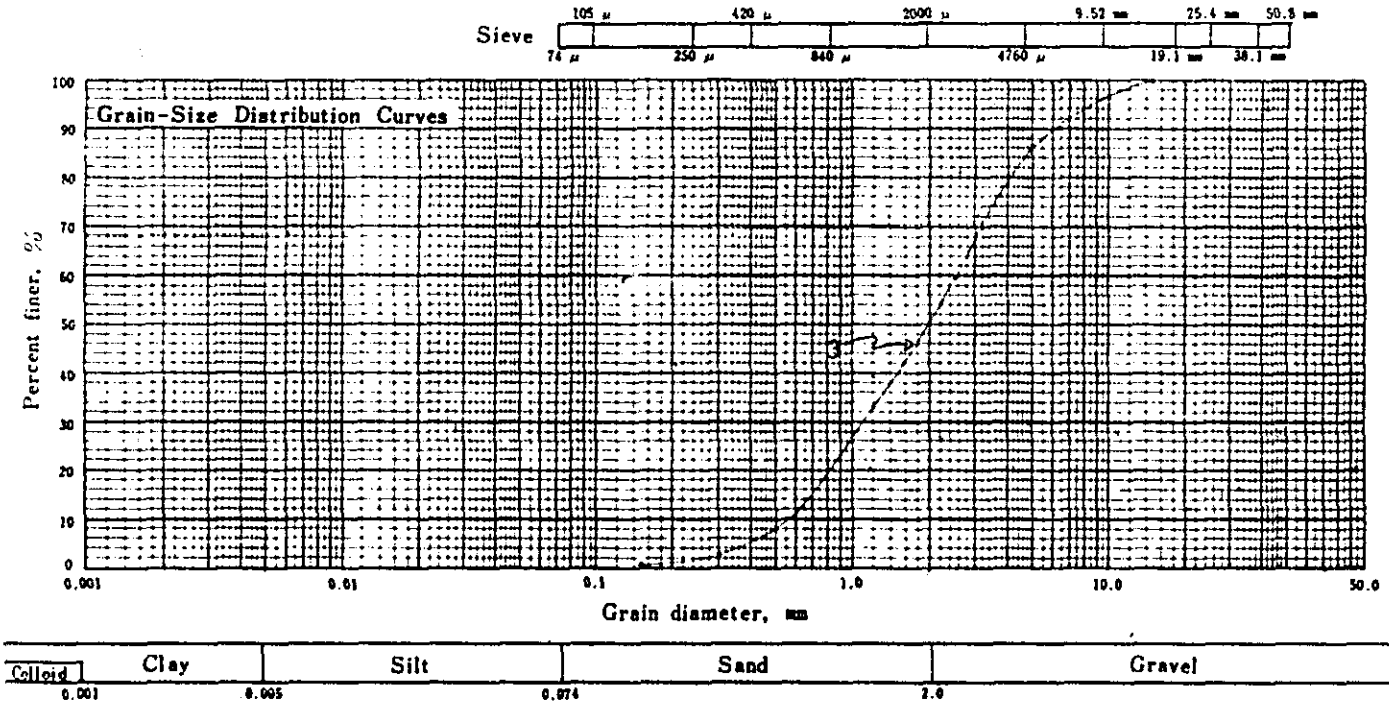
Tested by. TAN Date of Testing

Sample No., Depth. : No. 3 (m ~ m) Specific Gravity, Gs=

	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
Sieve	% Passing									100	96.57	86.70	59.70
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	33.30	11.45	2.63	0.70								

Sample No., Depth. : No. (m ~ m) Specific Gravity, Gs=

	Diam. mm	50.8	38.1	25.4	19.1	9.52	4.76	2.00	0.84	0.42	0.25	0.105	0.074
Sieve.	% Passing												
Hydro.	Diam. mm												
	% Passing												



Sample No., Depth	No. 3 m ~ m	No. m ~ m
F.M.	4.09	
Max. dia. (mm)	10.0	

FIG. 1.28

GRAIN SIZE DISTRIBUTION

Project URBAN TRANSPORT STUDY IN PENANG Job. No. 251

Location of Project PENANG Boring No. FINE AGGREGATE

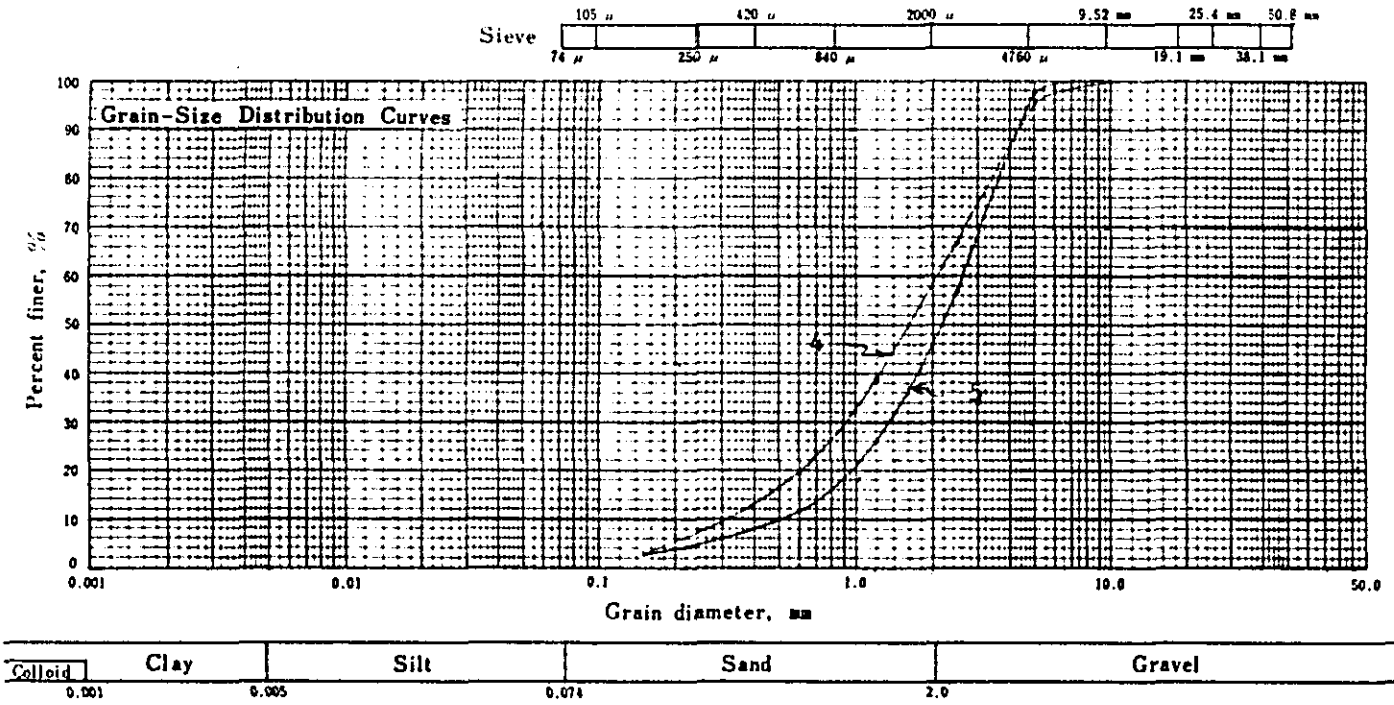
Tested by. TAN Date of Testing

Sample No., Depth. : No. 4 (m ~ m) Specific Gravity, Gs=

Sieve	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing										100	95.77	67.10
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	38.60	19.75	9.35	9.85								

Sample No., Depth. : No. 5 (m ~ m) Specific Gravity, Gs=

Sieve	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing										100	97.35	57.16
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	25.85	11.52	6.25	2.73								



Sample No., Depth	No. 4 m ~ m	No. 5 m ~ m
F.M.	3.66	3.99
Max. dia. (mm)	5.0	5.0

FIG. 1.29
GRAIN SIZE DISTRIBUTION

Project URBAN TRANSPORT STUDY IN PENANG Job. No. 251

Location of Project PENANG Boring No. FINE AGGREGATE

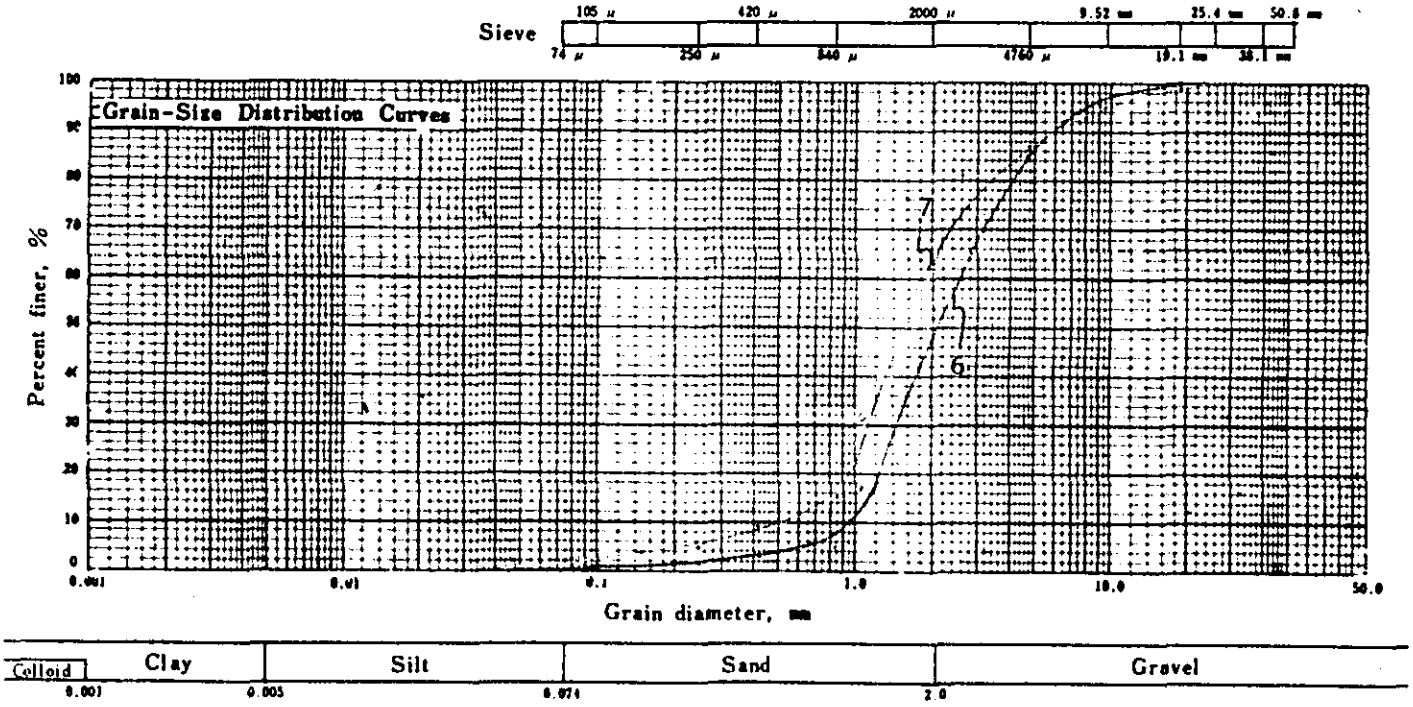
Tested by. TAN Date of Testing

Sample No., Depth. : No. 6 (— m ~ — m) Specific Gravity, Gs=

Sieve	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing								99.5	99	97.5	86.4	69.0
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	18.0	4.8	2.3	1.0								

Sample No., Depth. : No. 7 (— m ~ — m) Specific Gravity, Gs=

Sieve	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing								99	98	95	87.3	72
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	34.6	11.7	6.3	3.7								



Sample No., Depth	No. 6 m ~ m	No. 7 m ~ m
F.M.	4.21	3.92
Max. dia. (mm)	20.0	20.0

2) Coarse Aggregate

Crushed aggregates of granite are used as coarse aggregates for construction works in Penang Island.

The location of quarry sites presently in operation, abandoned quarry sites and some possible future quarry sites are shown in Fig. 1.25.

The present rate of production at each site is approximately 500 tons per day while the maximum rate is 1000 tons per day at some sites.

Some laboratory tests were performed on the crushed coarse aggregates and the results are illustrated in Table 1.19, Summary of Material Test.

Grain-size distribution curves of the tested aggregates are shown in Fig. 1.30.

a. Specific Gravity

True specific gravity (Gs) is in the range of 2.632 to 2.670 and apparent specific gravity (Gsa) varies from 2.613 to 2.625. Both values of Gs and Gsa are in the range of values obtained for normal coarse aggregates.

b. Water Absorption of Coarse Aggregates

Water absorption of coarse aggregates is in the range of 0.4 to 0.7 and showed the value for normal aggregates.

c. Los Angeles Abrasion Test

Los Angeles Abrasion values (after 500 rotations) are from 29 to 40 and showed the values obtained for normal crushed aggregates.

d. Fineness Modulus

Fineness modulus is in the range of 6.78 to 7.08.

FIG. 1.30

GRAIN SIZE DISTRIBUTION

Project URBAN TRANSPORT STUDY IN PENANG Job. No. 251

Location of Project PENANG Boring No. COARSE AGGREGATE

Tested by. TAN Date of Testing

Sample No., Depth. : No. 1 (G-3) (m ~ m) Specific Gravity, Gs=

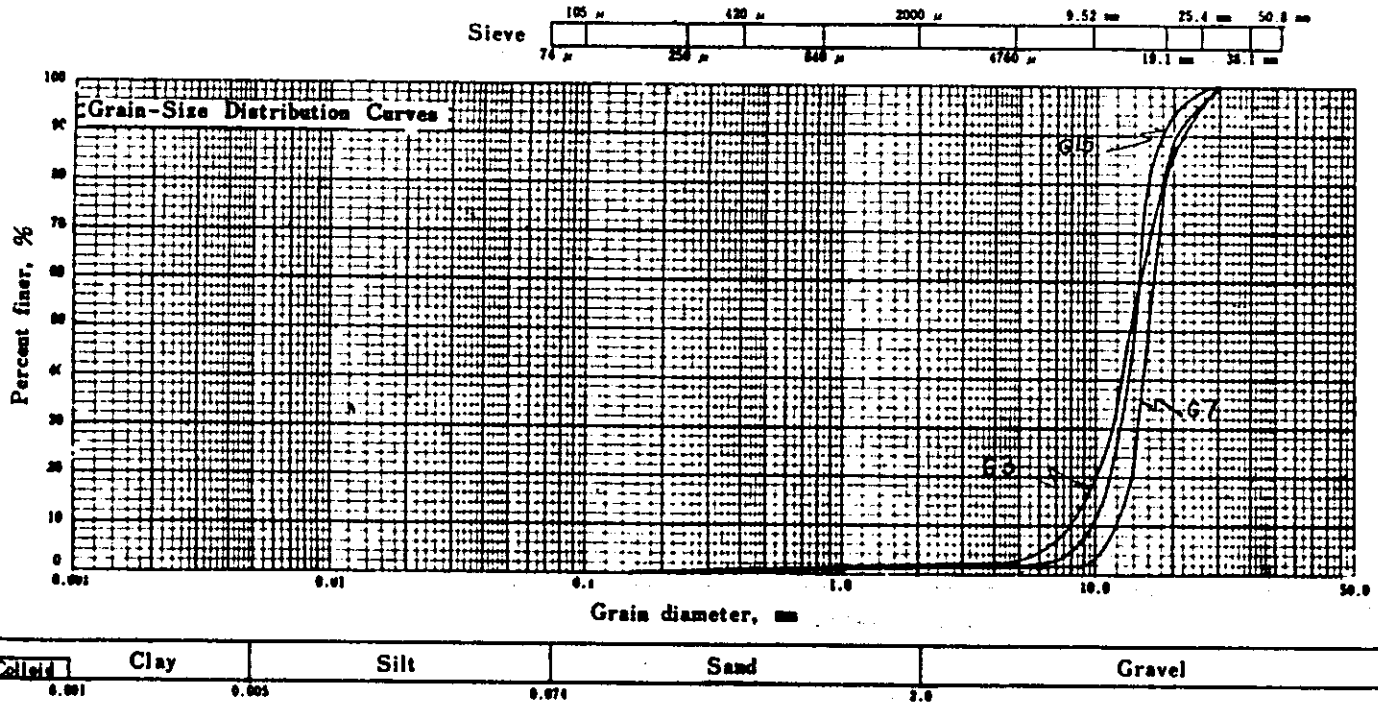
Sieve												
	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing						100	95.7	88.75	62.75	22.00	3.75	2.25
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	2.0	1.0	0.75	0.25								

Sample No., Depth. : No. 2 (G-15) (m ~ m) Specific Gravity, Gs=

Sieve												
	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing						100	98.3	95.75	70.25	8.25	1.0	0.9
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	0.85	0.75	0.65	0.3								

Sample No., Depth. : No. 3 (G-7) (m ~ m) Specific Gravity, Gs=

Sieve												
	Diam. mm	100	80	60	50	40	30	25	20	15	10	5	2.5
	% Passing						100	95	85.75	36.75	2.5	1.0	0.9
	Diam. mm	1.2	0.6	0.3	0.15								
	% Passing	0.75	0.6	0.35	0.15								



Colloid	Clay	Silt	Sand	Gravel
0.001	0.005	0.074	2.0	

Sample No., Source No.	No. 1 / No. G-3	No. 2 / No. G-15	No. 3 / No. G-7
F.M.	6.79	6.92	7.08
Max. dia. (mm)	30.0	30.0	30.0

3) Embankment and Reclamation Materials

(1) Embankment Material on Land

Earth materials are available in abundance from the foothills.

The soils are residual sandy and clayey materials or talus deposit derived from heavily weathered granite, and are composed mainly of clayey sand with gravel and silty sand with gravel.

The location of possible sources of the materials is shown in Fig. 1.25 and in Table 1.17.

Laboratory soil tests were conducted for the samples obtained at C-1, C-2 and C-3. The engineering properties are given in Table 1.20, Summary of Material Test, and are discussed below.

a. Natural Water Content and Atterberg Limits

Natural water content (wn) is in the range of 15% to 20%.

Atterberg limits (LL, PL and PI) are given below:

LL = 39% to 69%

PL = 27% to 38%

PI = 12.7 to 31

b. Specific Gravity

Specific gravity is in the range of 2.57 to 2.61.

c. Grain Size Analysis

17% to 23% gravel

34% to 55% sand

12% to 26% silt

11% to 24% clay

d. Compaction Test

Compaction tests on three samples (C-1, C-2 and C-3) performed according to Standard AASHTO (T-99) and Modified AASHTO (T-180).

Max. Dry Density	Optimum Moisture Content (%)	Standard
1.81 to 1.88t/m^3	13.2 - 15.0	Standard AASHTO
1.88 to 1.95t/m^3	9.8 - 13.4	Modified AASHTO

The difference in maximum dry density between Standard and Modified AASHTO is approximately 4% to 6%.

Table 1.20 SUMMARY OF MATERIAL TEST

Project: Urban Transport Study in Penang Standard: JIS

Borehole No.										
Sample No.		C-1	C-2	C-3	BH-3					
Sample depth		0.5 m	0,5 m	0.5 m	5.5 m 8.0 m	m	m	m	m	m
Condition of sample		Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed	Disturbed Undisturbed
Natural water content, %		16.0	19.1	14.5	19.6					
Specific gravity		2.614	2.614	2.573	2.605					
Wet density, g/cm³		-	-	-	-					
Dry density, g/cm³		-	-	-	-					
Natural void ratio		-	-	-	-					
Degree of saturation , %		-	-	-	-					
Atterberg limits	Liquid limit , %	68.9	43.7	39.4	80.0					
	Plastic limit , %	38.2	30.9	26.7	24.9					
	Plasticity index	30.7	12.8	12.7	55.1					
Grain size analysis	Gravel , %	23	17	22	9					
	Sand , %	34	39	55	52					
	Silt , %	19	26	12	5					
	Clay & colloid , %	24	18	11	34					
	Max. diameter, mm	9.52	9.52	9.52	4.76					
	Diam. at 60%	0.96	0.45	0.86	0.48					
	Diam. at 10%	-	0.001	0.0043	-					
Visual soil description		Clayey Sand	Clayey Sand	Clayey Sand	Clayey Sand					
Unified soil classification										
Compaction Test	Max. Dry Density g/cm3	1.81	1.88	1.83	1.796	Standard AASHTO				
	O.M.C %	14.8	13.2	15.0	16.2					
	Max. Dry Density g/cm3	1.88	1.89	1.95	1.87	Modified AASHTO				
	O.M.C %	12.2	13.4	9.8	14.7					
CBR TEST	CBR % at 95% of Max. Dry Density (Modified AASHO)	6.5	11.0	22.5	11.5					
Consolidation test	Preconsolidation pressure, kg/cm²									
	Compression index									

Remarks:
O.M.C = Optimum Moisture Content

e. California Bearing Ratio (CBR) Test

CBR at 95% of maximum dry density compacted according to Modified AASHTO Standard varies from 6.5% to 22.5%.

The results are illustrated in Table 1.20, Summary of Material Test and in Fig. 1.30 to 1.33, CBR Test Result.

According to the results of the laboratory soil test, soils obtained at C-1, C-2 and C-3 can be used as subgrade or basement soil for roads as well as filling material for offshore reclamation.

(2) Reclamation Material from the Sea

In order that reclamation work can be carried out by dredging ship along Gurney Drive, a study of the material from the sea to be used for filling is required.

At BH-1 to BH-4, along Gurney Drive, a sandy layer of about 600m from the seashore is encountered and this layer deepens gradually with distance from the shore and the layer is found at the depth of 14.7m from the seabed at BH-1' underneath a soft to medium clayey layer.

The soil test results for BH-3 and BH-1' are summarized in Tables 1.4 and 1.6, Summary of Soil Test. Stratification and the main results of soil tests at BH-3 are given below.

a. Stratification by Soil Test

0 m - 1.0m Sandy clay with shell fragments
2.0m - 5.2m Clayey sand with gravel, silt and shell fragments
5.2m - 21.7m Clayey (or silty) sand with gravel

b. Grain Size Analysis

At the depth of 0 m to 1.0 m

9% gravel	18% silt
26% sand	47% clay

At the depth of 2.0m to 21.7m

8% to 19% gravel	2% to 11% silt
38% to 55% sand	19% to 36% clay

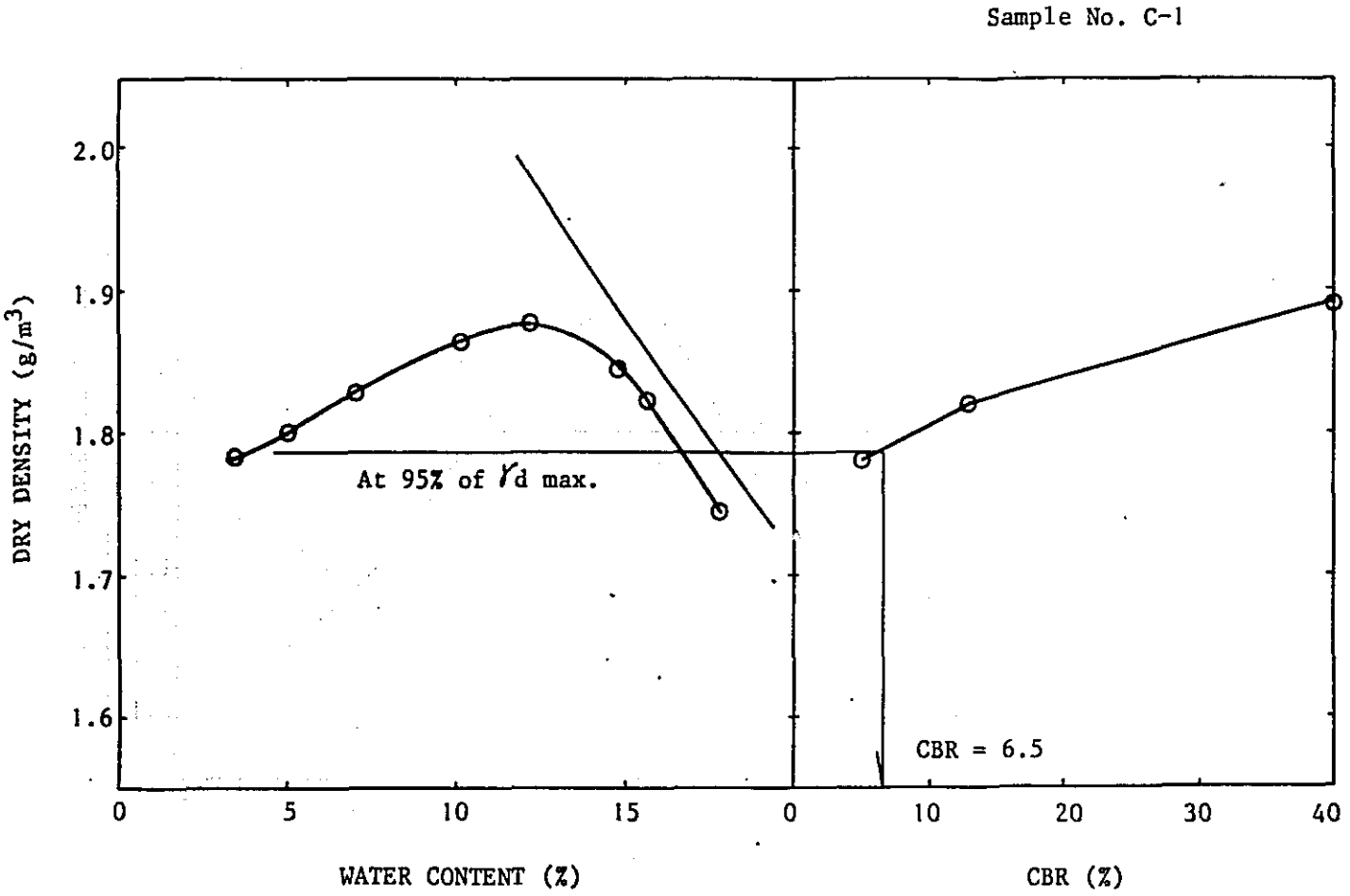


FIG. 1.31 CBR TEST RESULT

Sample No. C-2

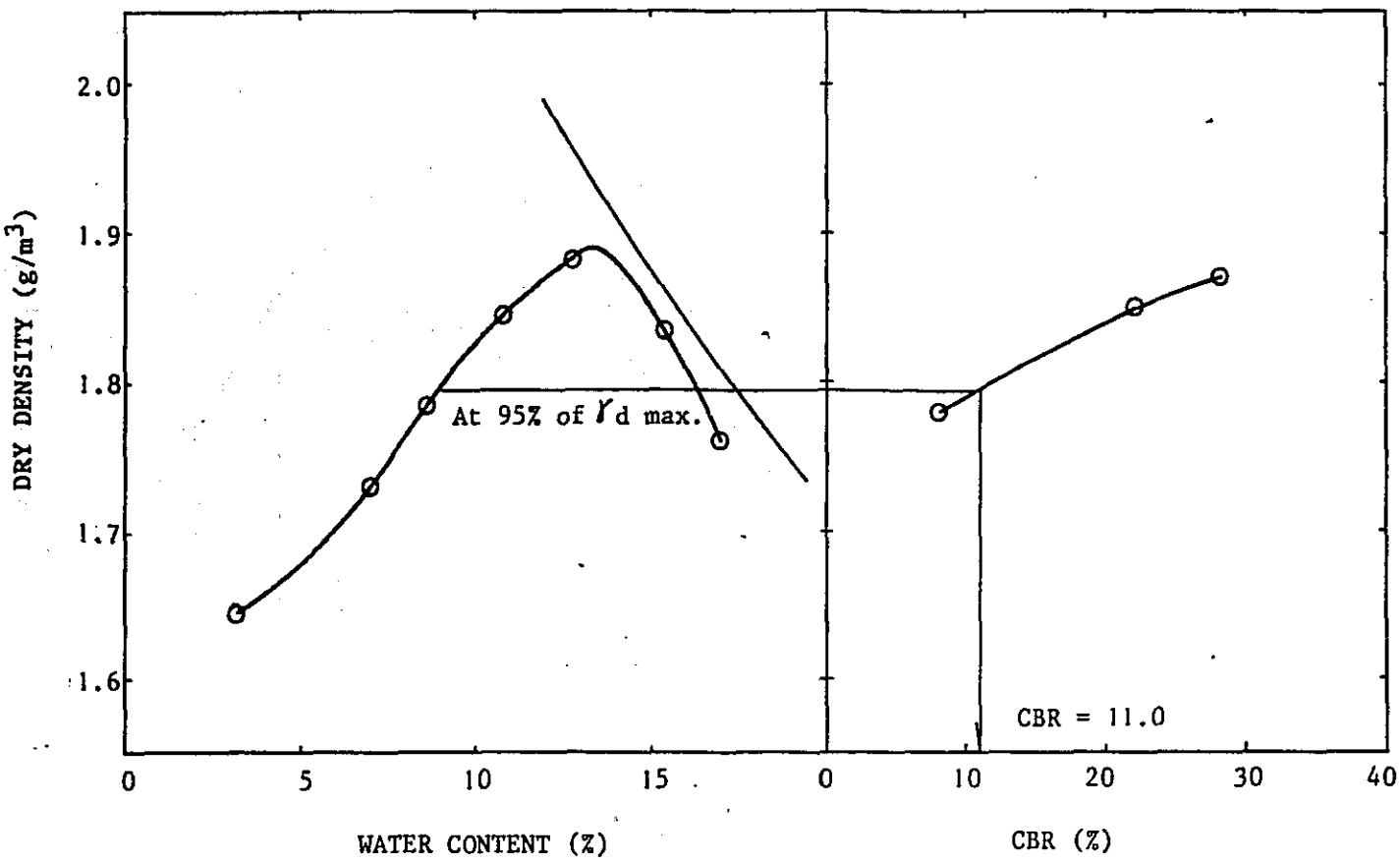


FIG. 1.32 CBR TEST RESULT

Sample No. C-3

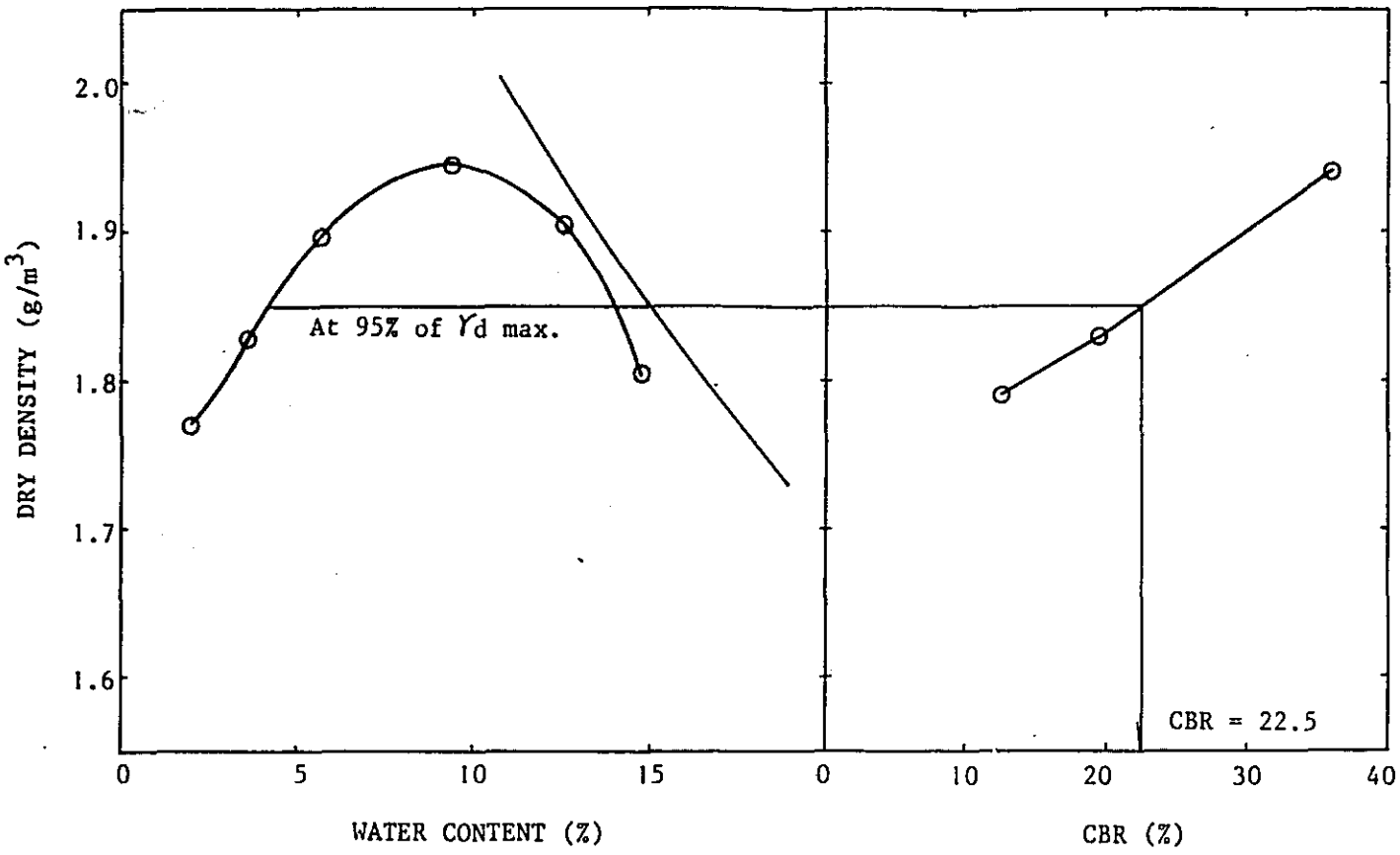


FIG. 1.33 CBR TEST RESULT

c. Compaction and CBR Tests

Compaction tests and CBR tests were performed on the disturbed soil obtained by bailer at the depth of 5.5m to 8.0m at BH-3.

Compaction Test

Max. Dry Density	Optimum Moisture Content	Standard
1.796 t/m^3	16.2%	Standard AASHTO
1.87 t/m^3	14.7%	Modified AASHTO

CBR Test

The CBR at 95% of maximum dry density compacted according to Modified AASHTO Standard was 11.5% which is a rather high value.

Results of laboratory soil tests on disturbed sample obtained from BH-3 are shown in Table 1.20, Summary of Material Test.

CBR results are shown in Fig. 1.34, CBR Test Results. According to the results of soil test, sandy soil from the sea to be used as filling material will be obtained from around BH-3.

4) Dumping Area of Waste Soil

During earth works of road construction, dumping area of waste soil will be required.

The most possible areas in this stage are as follows:-

1. Offshore Area of Tanjong Tokong
2. Offshore Area of Jelutong

Sample No. BH-3 Depth = 5.5 to 8.0m.

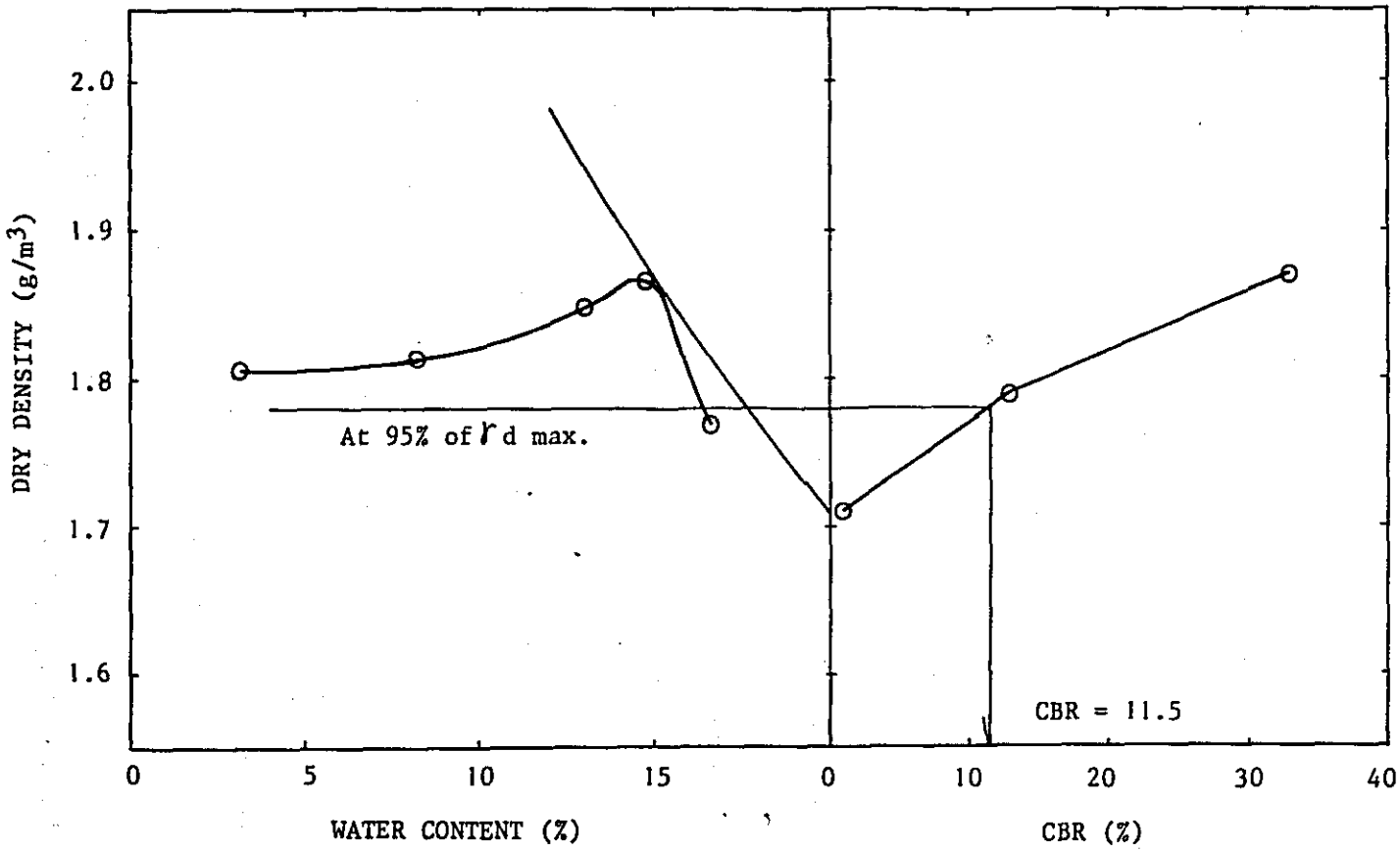


FIG. 1.34 CBR TEST RESULT

1.3 Notes on Construction Work

The proposed road alignments are laid out on hilly topography south and west of George Town. The ground in the hilly area mainly consists of weathered and intact granite, and there are many huge boulders along the alignments. Occasionally, houses and cemeteries are located along the alignments. The road construction will entail problems in (1) cutting the intact granite (2) stabilizing and/or retaining the huge boulders (3) protecting cut slopes of weathered and intact rocks (granite) (4) obtaining sufficient quantities of material suitable for the offshore road embankment and stabilizing the embankment slope after construction.

Regarding the design and construction works, the following points should be noted.

1. As houses and cemeteries are near the road alignments, in order to minimize vibration and damage due to blasting, relatively small amounts of explosive should be employed and nets or other devices should be used to protect houses from flying debris.

2. Suitable steps should be taken to prevent the numerous huge boulders, with diameters of 2m to 20m, from dropping on the proposed roads. The erection of retaining nets or fences and the planting of trees could afford protection.

3. The recommendable slopes for cuts and embankments are:

   a. For Onshore Embankment
      - Slope : 1/1.5 ∽ 1/1.8 (Vertical/Horizontal)
      - Berm interval : 5m to 7m in height
        Berm width : 1.5m

   b. For Cuts
      - Slope : 1/0.5 for intact rock
        0.8/1.0 ∽ 1.0/1.0 for weathered rock and other soils
      - Berm interval : 5m to 7m in height or at the boundary of different layers
        Berm width : 1.0m ∽ 1.5m

   c. For Offshore Embankment
      - Slope : 1/2 (Stone armour slope protection is required)

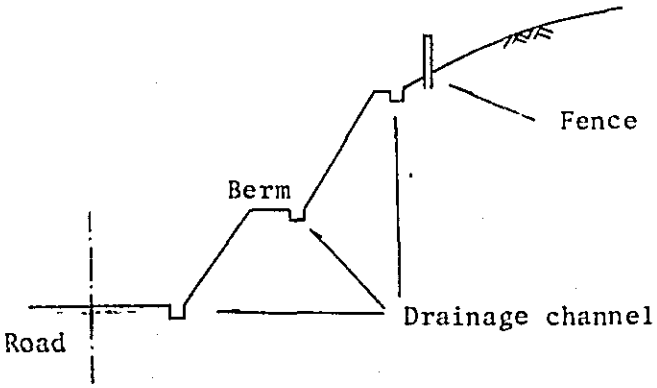
4. Protection of side slopes

4-1. Side slopes must be properly protected against erosion

a. For Onshore Embankment : Planting grass

b. For Cuts : ° Nothing for intact rock or stable weathered rock
° Planting grass for weathered rock and other soils
° Nets if required

4-2. To avoid the erosion of slopes, drainage channels must be provided at the shoulder, the berms, and the base of slopes.



5. Onshore road embankments will be built with fill materials obtained from adjacent cuts or from suitable borrows in the hilly area. Weathered granite (residual clayey or sandy soil) and alluvial clayey or sandy soil can be used as subgrade materials.

6. Offshore road embankments will be built with fill materials from both the borrows in the hilly area and the seabed.

7. Coarse and fine aggregates which are produced locally can be used for concrete and pavement works. Local producers can provide the volume of aggregates required for construction.

8. Foundation

8-1. Direct foundation or caisson foundation will be adequate for major structures because bearing layers are shallow in the hilly area.

The following vertical design bearing capacities are generally recommended:

For intact rock (granite) .... 70 t/m^2

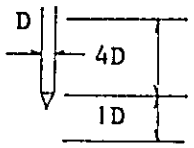
For weathered rock (SPT N-value > 50) .... 50 t/m^2

8-2. If long driven piles are required, the following formula is recommended for deciding the design bearing capacity of each pile.

$$Qa = \frac{1}{3}\left[30 \cdot \bar{N} \cdot Ap + \left(\frac{Ns \cdot Ls}{5} + C \cdot Lc\right)\psi\right] - W$$

Where, Qa = Design bearing capacity per pile

$\bar{N}$ = Mean N-value at tip of pile



N_1 ... Mean N in 4D $\quad \bar{N} = \frac{N_1 + N_2}{2}$

N_2 ... Mean N in 1D

Ap = Sectional Area

Ns = N-value of bearing sandy layer

Ls = Thickness of bearing sandy layer

Lc = Thickness of bearing clayey layer

C = Cohesion of bearing clayey layer

= Circumference of pile

W = Weight of pile

1.4 Notes on Further Investigations

The extent of geotechnical investigation performed to date is sufficient for the feasibility study. For the detailed design, the following additional geotechnical study will be necessary.

a. Borings at the foundation points of each onshore structure and loboratory soil tests of soil samples obtained from the bore holes.

b. A few offshore borings and laboratory soil tests to check the settlement and bearing capacity of the present seabed, and to accurately confirm the stability of the road embankment.

c. Compaction and CBR tests of the soil materials to be used in constructing the road embankment.

d. Trial mixing of concrete using local aggregates to decide the most economical, yet structurally adequate design-strength of concrete.

e. Detailed geological reconnaissance survey to check the stability of hanging boulders in the hilly area.