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Flood Action Plan

North West Regional Study (FAP-2)

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VOLUME 7

GAIBANDHA IMPROVEMENT PROJECT

TOPOGRAPHIC SURVEY AND GEOTECHNICAL INVESTIGATION

October 1992

PART I

TOPOGRAPHIC SURVEY FOR THE GAIBANDHA IMPROVEMENT PROJECT

PART I

TOPOGRAPHIC SURVEY ON THE GAIBANDHA IMPROVEMENT PROJECT

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CHAPTER 1

INTRODUCTION

The topographical survey works for the Gaibandha improvenet project (GIP) were carried out between February and June 1992 to produce the topographic survey data required for the feasibility study as well as to install the permanent ground control points usable in the successive detailed design and construction stages of GIP. The substancial field works were conducted by the local surveyors under the supervision of the senior surveyors of the FAP 2 study team. The distance measurement between the ground control points was performed with a distance meter brought from Japan, since it was hardly available in this country. On the other hand, the river cross sectional survey performed comprises the Karatoya-katakali and Bangali rivers other than those located in and surrounding the GIP in order to look at the impact on water levels in those downstream reaches through the hydraulic modelling analysis with accuracy, which might take place by the improvement of the present flooding situation in the GIP area after provision of the proposed FCD components.

In principle, the survey stndards in Japan were applied in supervising the levelling and traversing. The main topographic survey works carried out are summarised as follows;

Work Item	Quantity
- Installation of new ground control points in the GIP area, including ground control point survey to determine their elevations and coordinates through levelling and traverse survey	30 (points)
- River cross sectional survey on the Teesta, Ghagot-Manas (inc. Alai), Karatoya-Katakali and Bangali rivers including installation of permanent base points on both banks for each section, including levelling and traverse survey	69 (sections)
- Embankment survey for existing/proposed major flood embankments, roads and railway (Teesta right embankment (TRE), Ghagot left embankment, Sonail embankment, Brahmaputra right embankment (BRE), embankment for Gaibandha town protection and existing railway, and Jihinia -Bamondanga road)	200 (sections)
- Plane table survey at existing FCD structure sites as well as those planned for GIP in the interim regional study	35 (sites)
- Ground survey for producing new 1 to 20,000 scaled topographic maps covering the GIP area by means of modifying existing 1 to 15,346 scaled maps through levelling and traverse survey	640 (km2)

Location of the topographic survey performed for GIP is shown in Figure 1.1

Prior to the commencement of the survey works, the following data and information related to the topographic survey were obtained from the Survey of Bangladesh (hereinafter referred to as SOB) through the FPCO office;

- topographic maps (national base maps) at a scale of 1/15,840 & 1/50,000 covering the GIP area,

- 1/50,000 scaled aerial photographies which were shooted in 1990 by Finnmap and photographies enlarged from 1/50,000 to 1/20,000 in a scale. Figure 1.2 shows the flight course at the time of shooting and photo number,

- data of existing bench marks and control points in and around the GIP area with their elevations and coordinates, respectively.

Through the topographic survey, a total of 116 sheets of drawing, which are of A1 or larger size, are produced. All of these are traced and numbered with index map. One set of reproducible sheets of sepia base and three sets of ammonia copies of those survey products are scheduled to be submitted to FPCO before completion of the FAP 2 study.

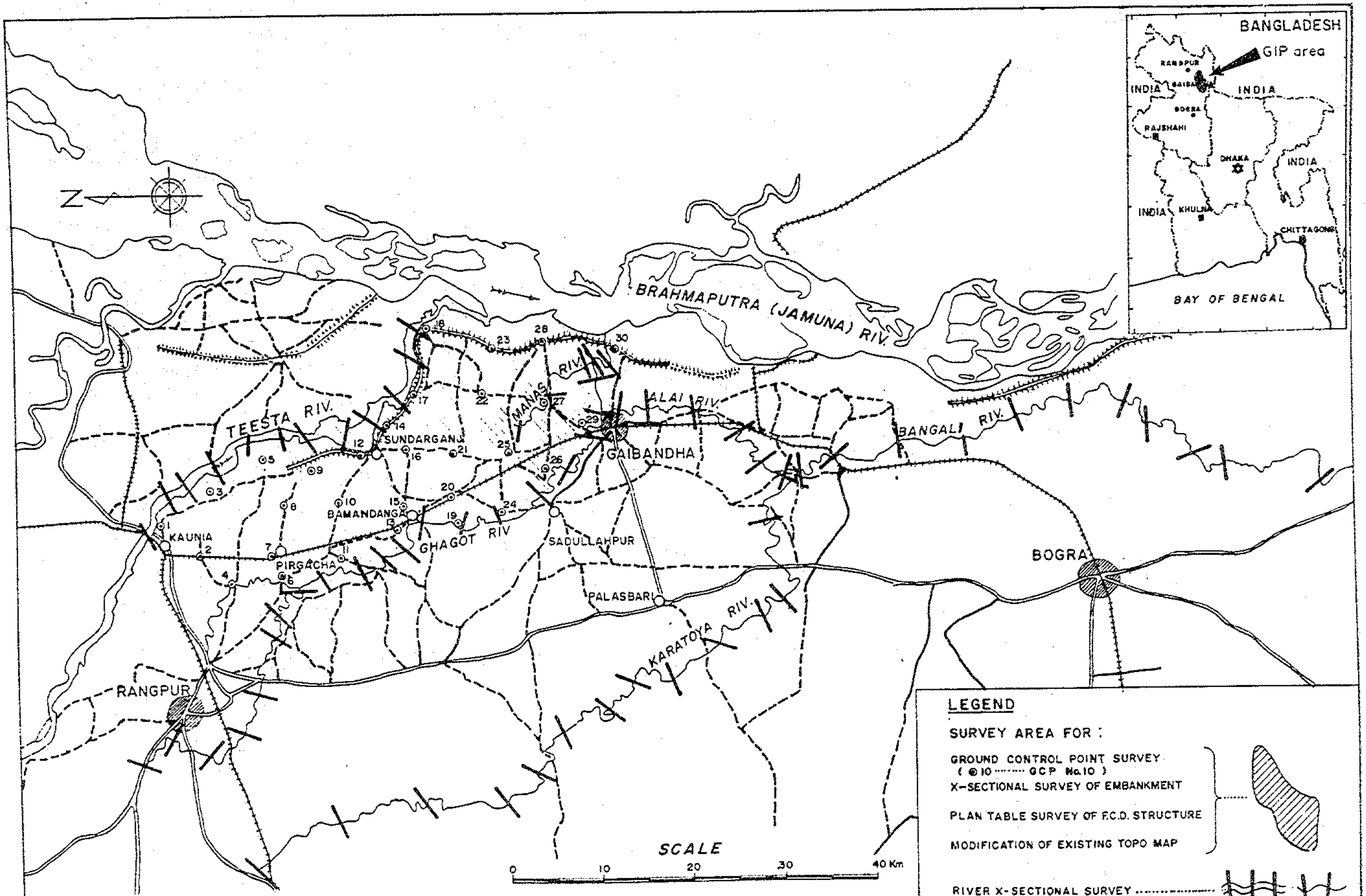

Figure 1.1 LOCATION OF SURVEY AREA

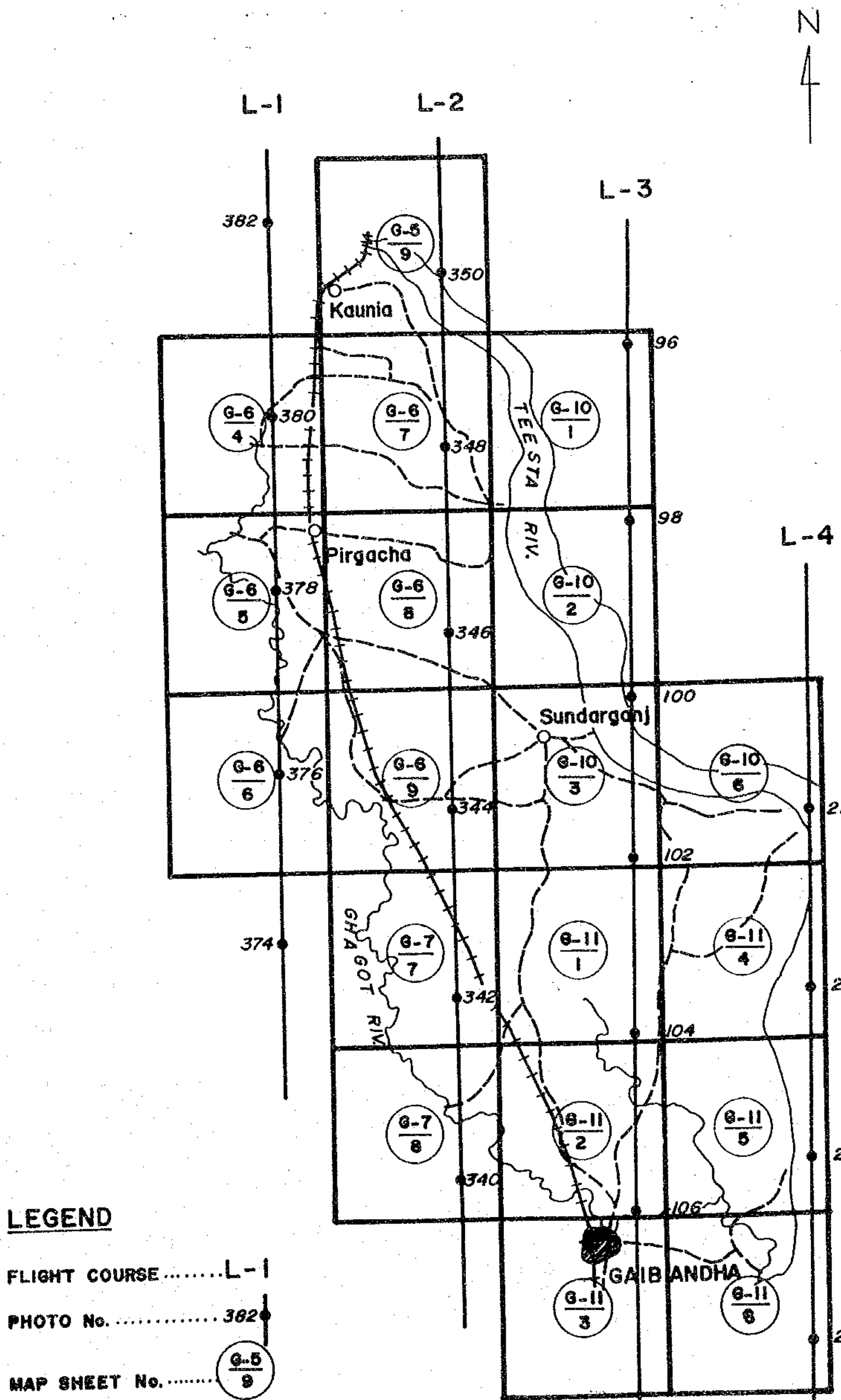

Figure 1.2 FLYING COURSE AND INDEX OF 1:20,000 SCALED TOPOGRAPHIC MAPS PRODUCED

CHAPTER 2

TOPOGRAPHIC SURVEY WORKS CARRIED OUT

2.1 Ground Control Point Survey

The objective of the ground control survey is to establish new permanent ground control points (GCP) with coordinates and elevation, which will be used in the successive detailed design and construction stages of the Gaibandha Improvement Project. These ground control points are built with concrete pillar to be durable for the use in those stages as explained in the following subclause. Therefore, the topographic survey works in the detailed design stage as well as setting out of the FCD components in the construction stage will be able to be carried out based on the elevation and coordination systems set up in the present topographic survey for the GIP area.

In measuring coordinates of the ground control points through levelling and traverse survey, the temporary conrol points and bench marks which were made of wooden pegs were placed in between the neighbouring ground control points for the other works such as cross sectional survey, plane table survey and etc.

All the elevation data obtained through the present topographical survey are expressed on the PWD's datum basis, except where the use of the SOB's datum system is noted, since the PWD's one has been exclusively used in the regional planning study of FAP 2. The SOB's elevation datum is set to be lower than the PWD's one by 0.4599 m (1.509 feet). To convert the PWD's datum into the SOB's one, therefore, 0.4599 m has to be substracted from those expressed on the PWD's datum basis in this report.

(1) Installation of ground control points

A total of 30 ground control points made of reinforced concrete pillars were installed so that they evenly distribute all over the GIP area. The Locations of the ground control points are shown in Figure 1.1.

(2) Traverse survey

Before the start of the field works, it was identified through the data and information collected from SOB clarified that there are ground contol points with coordinates in and around the GOP area. Two existing ground control points, No.2 and No.29, are identified at the field immediately on commencement of the field work. To check the accuracy of coordinates of those control points, the distace measurement and levelling were done with the theodlite and EDM mentioned hereinafter. Thereafter the distance between these two existing ground control points was calculated using the UTM mehtod to rectify a curve length of the earth (In Japan as well as in case of the development projects financed by Japan, the UTM's method is adopted in principle). As a result of the check survey, it was found out that there is a considerable diferrence between the distace measured through the present survey and that calculated from the given coordinates of these two points. It was reported that coordinates of these existing control points were determined using the other mehtod than the UTM method. Thus, it appeared that the significant difference took place due to the adoption of the differrent methods in rectifying the measured distance. Accordingly, it is determined that the local coordianates system to be set up in the present ground control survey was adopted as that for GIP,

since it is so often used for the practical reason without occurrnce of any technical problems in the construction stage and it can be easily linked with the Control Points which are being installed under JICA to cover the whole of Bangladesh when becomes necessary. The coordinates of the ground control points were determined in accordance with the following procedure;

i) The existing two ground control points, GCP No. 2 & No. 29, were plotted on the existing 1 to 15,840 scaled topographic maps in accordace with the original coordinates.

ii) The longitude and latitude of those points were read on the map, and then those value were converted into the UTM coordinates system.

iii) The coordinates of those points were adjusted to meet the results of the traverse survey.

iv) For all other ground control points, their coordinates were determined besed on the traverse survey whose routes were all linked with GCP No. 2 & No. 29.

The looped traverse lines were set to link all the new ground control points. Horizontal angles were measured through a pair of observation consisting of two times reading with theodolites. Distance was measured with EDM through one set of observation consisting of two reading for one section between neighbouring two control points. The following instruments were used for the traverse survey;

- Angle measurement : Wild T2
- Distance measurement : Auto Ranger, Topcon Gupy

The network of the traverse routes established for the traverse survey of the ground control points as well as the accuracy of the traverse survey for every route are shown in Figure 2.1. As a result, the accuracy of the traverse survey could satisfy the requirement shown below;

- Closure of bearing : $10\sqrt{n}$
- Closure rate of traverse line concerning coordinates : 1/8,000

where, n : number of observed angles

(3) Levelling

After installation of the new ground control points, the direct levelling was carried out to determine those elevations using auto levels. The levelling was done along the aforesaid looped traverse routes linking all the ground control points. Prior to the levelling for the traverse survey, the elevation data on the existing bench marks located comparatively adjacent to the GIP area were collected from SOB to determine the basic bench mark which was to be linked with all the new ground control points installed in the GIP area. The elevations of those bench marks were notified as follows;

Place of SOB's Bench Mark	Elevation (m, PWD)
Rangpur DC off	31.9897
Nichintapur	30.7409
Mithapukur	28.5558
Uzirpur	24.5394
Dhaperhat	24.4056
Palasbari	22.7643
Tajpur	21.1556
Gobindagonj	20.9199
Nawdatara	19.9955
Ashekpur	18.1542

As shown in Figure 2.2, the above existing bench marks are installed along the Rangpur-Bogra highway. Levelling was done to check the relative accuracy of those elevation data so that the existing bench mark at Palasbari was selected as the basic bench mark taking into consideration its location as well as the relatively high accuracy. Thus, the elevation system for the GIP area was set up based on the datum of bench mark at Palasbari.

The levelling for the traverse survey was carried out along the routes shown in Figure 2.2, which also shows the accuracy of the levelling. Concerning every route, the levelling was able to satisfy the following requirement for the traverse survey;

- Closure of looped route : 2 cm x $\sqrt{s}$
- Closure to other bench marks : 4 cm ± 2cm x $\sqrt{s}$

where, s : distance of levelling route in km

The coordinates and elevations of the ground control points installed newly in the Gaibandha area, which were worked out through the above topographic survey works, are shown in Table 2.1.

2.2 River Cross Sectional Survey

(1) Installation of base points

The river cross sectional survey was performed on the rivers flowing inside and surrounding the GIP area, which comprise the Teesta, Ghagot-Manas-Alai, Karatoya-Katakali and Bangali. Primarily, the river cross sectional survey aimed to provide the basic data required for the hydraulic modelling analysis for GIP, but those data are very useful in verifying the river morphological change of the these rivers, especially the Teesta. Thus, the river morphological change will be able to be monitored in the detailed design stage. The same concrete pillars as those for the aforesaid ground control survey were manufactured to be installed on both river banks for each of the river cross sectional survey lines. These concrete pillars will be used as the base points in the successive study stage.

(2) Levelling to link the base points and ground control points

In order to determine the vertical datum of cross sectional survey, those base points were connected by direct levelling with the ground control points newly established, which are mentioned in the forgoing Section 2.1.

(3) Determination of coordinates of the base points

In order to determine the coordinates of the base points, the following two survey methods were adopted taking into account the distance from the GIP area although the coordinates are not essential data for the present study;

- For river cross sections located inside or very near to the GIP area (The Teesta and Ghagot-manas-Alai)

  The coordinates of the base points were obtained by means of the open traverse survey, which were linked with the ground control points newly established in the GIP area.

- For river cross sections located far from the GIP area (the Karatoya-katakali and bangali)

  The longitude and latitude of the base points were measured using the GPS instruments (IPS-360).

(4) Cross sectional survey

In compliance with the requirement for the hydraulic modelling analysis, the width of the river cross sectional survey was extended over 500 m from the river channel edge in both the right and left bank sides except the Teesta river. The river cross sectional survey was done by means of the direct/trigonometric levelling method as well as the distance measurement starting from the base points.

(5) Preparation of drawing for the river cross sections and longitudinal profile

After computation/collation of the surveyed data, the survey results were input in the 3.5" computer floppy disks to draw the river cross sections and longitudinal profiles along the river course automatically using the computer system. The longitudinal profile was prepared by measuring the river length on the 1 to 20,000 aero photographic. Besides, the elevation datum of existing water level gages on the rivers are shown in the longitudinal profiles.

The coordinates and elevations of the base points, worked out through the aforesaid survey procedures, are summarized in Table 2.2.

2.3 Plane Table Survey at FCD Structure Sites

Large scale topographic maps for existing FCD structure sites and those proposed in the Interim Regional study stage for GIP were prepared through the plane table survey. Prior to the plane table survey, levelling and traverse survey were done to link the structure sites with the newly installed ground control points. In addition, the typical profiles of the existing FCD structures were surveyed

through measurement of the major dimensions. Based on the survey results, the topographic maps were produced and finally traced on polyester base sheets by inking after editing. The specifications for drawing are the following;

(i) map scale	:	1/500 or 1/1,000
(ii) control interval	:	0.5 m

Each location of surveyed existing/proposed FCD structure sites is shown in Figure 2.3

2.4 Cross Sectional Survey of Existing/Proposed Major flood embankments/roads/railway

The cross sections along centre lines of existing/proposed flood embankments, major roads and railway were surveyed at about 1 km intervals and for a width of 50 m at each location of the cross sections. The longitudinal profile was prepared based on the cross sectional survey results with incorporation of location/size of the existing FCD structures on the existing embankments. The cross sections and longitudinal profiles were drawn on polyester base sheets by inking.

2.5 Production of 1 to 20,000 Scaled Topographic Maps

Although the existing topographic maps at a scale of 1 to 15,840 cover the whole GIP area, they were produced in 1960's and after then a lot of flood embankments, elevated home steads and infrastructures such as public roads which would have an influence on the FCD planning had been built in the GIP area. Besides, the ground elevations in the existing topographic maps were expressed in a unit of inch so that they were quite inconvenient for the use of the present study. For these reasons, it was intended to newly produce the 1 to 20,000 scaled topographic maps through modification of the existing maps, which also show the present land use in the GIP area. All the survey results done for other survey items, which are explained in the foregoing Sections, are incorporated in producing the new topographic maps. The main topographic survey works performed for the purpose comprise the following;

- Additional traverse survey along;
    - traverse lines to be established along the major existing embankments and roads in and around the Gaibandha area.
    - traverse lines to be established along both northern and southern directions at about 1 km interval covering the whole Gaibandha area to supplement the above traverse survey,
- Field identification and plane table survey for spot areas for classification of land use.
- Spot height survey covering the GIP area.
- Modification of contour lines and making up present land use.

The procedures adopted to produce the new topographic maps are shown in Figure 2.4 and an index map thereof is presented in Figure 1.1.

Table 2.1 COORDINATES AND ELEVATION OF GROUND CONTROL POINT NEWLY INSTALLED

Station No.	Coordinates(m) X	Coordinates(m) Y	Distance (m)	Bearing (°-'-")	Elevation (m)
GCP - 1S	2852746.137	744976.271			30.807
			5784.402	212-05-21	
GCP - 2S	2847845.459	741903.379			30.130
			6541.414	102-51-54	
GCP - 3S	2846388.997	748280.590			30.622
			8932.746	256-33-04	
GCP - 4	2844311.428	739592.802			30.417
			12249.458	102-56-56	
GCP - 5S	2841566.533	751530.757			28.870
			12326.827	260-49-31	
GCP - 6	2839601.091	739361.628			29.603
			2678.538	63-16-57	
GCP - 7S	2840805.342	741754.188			28.242
			5718.410	104-34-11	
GCP - 8S	2839366.823	747288.705			27.207
			6006.500	133-13-44	
GCP - 9S	2835252.885	751665.182			26.063
			4591.790	249-46-39	
GCP - 10S	2833665.650	747356.444			26.690
			5755.202	265-10-42	
GCP - 11S	2833181.899	741621.609			28.307
			11824.139	101-39-10	
GCP - 12S	2830793.662	753202.049			25.794
			9108.176	245-05-46	
GCP - 13	2826958.244	744940.788			26.950
			11591.224	85-38-04	
GCP - 14	2827840.580	756498.381			26.502
			9557.859	261-02-33	
GCP - 15S	2826352.413	747057.087			25.366
			6746.170	91-00-11	
GCP - 16S	2826234.307	753802.223			24.772
			5873.741	99-25-17	
GCP - 17S	2825272.809	759596.734			24.809
			6428.627	100-40-57	
GCP - 18S	2824081.168	765913.951			23.937
			20430.470	259-57-37	
GCP - 19S	2820519.462	745796.338			24.180
			2841.236	79-22-13	
GCP - 20S	2821043.559	748588.818			24.845
			4446.932	102-35-39	
GCP - 21S	2820073.930	752928.752			23.741
			7332.240	108-44-38	
GCP - 22S	2817717.809	759872.126			23.518
			4937.120	108-32-43	
GCP - 23S	2816147.543	764552.876			25.907
			17846.978	268-57-22	
GCP - 24S	2815822.375	746708.860			25.324
			6630.963	102-39-16	
GCP - 25S	2814369.717	753178.748			23.324
			4293.682	211-10-27	
GCP - 26S	2810696.051	750956.163			24.856
			7898.686	90-24-39	
GCP - 27S	2810639.426	758854.646			22.451
			5962.388	85-57-00	
GCP - 28S	2811060.538	764802.144			25.295
			9714.920	233-49-11	
GCP - 29S	2805325.541	756960.621			21.717
			7772.897	114-11-48	
GCP - 30S	2802139.676	764050.627			23.420

Notes: 1. The elevations are based on the PWD datum.
2. Coordinates are set up by the local coordinates system for GIP.

Table 2.2 COORDINATES AND ELEVATION OF BASE POINT NEWLY INSTALLED IN RIVER CROSS SECTIONAL SURVEY (1/3)

(1) River Name : Teesta

No.	Bank side	Coordinates (m) X	Coordinates (m) Y	Elevation	Distance between base point on both banks
T-0.0	L-side	(25-32-33)	(89-39-53)	23.779	
	R-side	2,823,227.286	766,071.311	25.187	4494.1
T-4.0	L-side	(25-33-15)	(89-37-59)	25.523	
	R-side	2,824,649.984	762,246.465	27.413	4670.3
T-8.5	L-side	(25-34-13)	(89-35-44)	27.011	
	R-side	2,826,316.859	757,700.700	25.869	5024.7
T-12.0	L-side	(25-35-10)	(89-33-58)	24.889	
	R-side	2,828,832.764	755,466.766	26.586	3838.6
T-15.5	L-side	(25-36-06)	(89-33-10)	25.388	
	R-side	2,831,581.550	753,239.858	26.279	4316.2
T-20.0	L-side	(25-39-04)	(89-33-27)	28.355	
	R-side	2,831,284.361	751,091.402	27.281	5641.0
T-24.0	L-side	(25-39-50)	(89-33-00)	28.629	
	R-side	2,839,449.042	751,354.898	26.436	4774.2
T-28.0	L-side	(25-40-40)	(89-32-19)	28.448	
	R-side	2,843,896.065	750,073.050	30.126	5857
T-32.0	L-side	(25-43-10)	(89-31-46)	28.866	
	R-side	2,814,919.534	749,074.283	30.021	5111
T-36.0	L-side	(25-45-29)	(89-30-40)	29.717	
	R-side	2,847,428.909	748,010.648	30.198	5380.8
T-40.0	L-side	(25-46-46)	(89-29-20)	29.565	
	R-side	2,850,392.998	746,160.779	30.846	4585
T-44.0	L-side	(25-47-44)	(89-26-33)	30.659	
	R-side	2,854,298.678	744,425.782	30.547	770

(2) River Name : Ghagot

No.	Bank side	Coordinates (m) X	Coordinates (m) Y	Elevation	Distance between base point on both banks
GH-1	L-side	2,804,525.661	757,970.090	20.949	
	R-side	2,804,425.241	757,993.000	20.817	103
GH-2	L-side	2,806,337.658	755,480.593	21.719	
	R-side	2,806,271.620	755,494.565	21.776	67.5
GH-3	L-side	2,808,354.117	751,525.382	24.727	
	R-side	2,808,443.548	751,482.920	22.587	99.0
GH-4	L-side	2,811,302.383	749,011.911	22.837	
	R-side	2,811,214.553	748,994.703	21.962	89.5
GH-5	L-side	2,815,626.741	745,893.074	24.162	
	R-side	2,815,602.938	745,831.516	23.221	66.0
GH-6	L-side	2,820,135.461	744,826.846	23.152	
	R-side	2,820,130.500	744,732.977	24.550	94.0
GH-7	L-side	2,824,370.454	745,498.106	25.869	
	R-side	2,824,344.753	745,437.553	25.510	65.8
GH-8	L-side	2,826,264.771	742,676.756	25.230	
	R-side	2,826,250.518	742,637.674	27.040	44.6
GH-9	L-side	2,828,626.088	742,423.566	25.801	
	R-side	2,828,588.947	742,369.615	25.896	65.5
GH-10	L-side	2,830,827.912	739,784.934	26.812	
	R-side	2,830,867.868	739,740.576	26.312	59.7
GH-11	L-side	2,834,900.037	740,507.681	27.830	
	R-side	2,834,902.331	740,434.117	27.043	73.6
GH-12	L-side	2,837,534.565	738,426.927	28.112	
	R-side	2,837,462.811	738,452.659	27.716	76.2
GH-13	L-side	2,839,834.198	735,480.590	27.804	
	R-side	2,839,751.676	735,437.080	28.254	93.3

Notes 1. Coodinates are obtained by traverse survey.
2. Coordinates (X/Y) of base points on the left bank side of the Teesta to represent Latitude and Longitude respectively which were observed by portable GPS instrument
3. Elevation is based on the PWD datum.

Table 2.2 COORDINATES AND ELEVATION OF BASE POINT NEWLY INSTALLED IN RIVER CROSS SECTIONAL SURVEY (2/3)

No.	Bank side	Latitude(N)	Longitude(L)	Elevation	Distance between base point on both banks
GH-14	L-side	25-40-07.2	89-18-25.7	29.711	
	R-side	25-40-06.6	89-18-23.3	28.581	70.3
GH-15	L-side	25-40-44.1	89-15-54.6	29.058	
	R-side	25-40-40.9	89-15-54.8	29.628	93.0
GH-16	L-side	25-41-42.7	89-13-22.2	33.980	
	R-side	25-41-41.5	89-13-20.5	34.450	64.7
GH-17	L-side	25-43-50.8	89-11-58.1	31.638	
	R-side	25-43-51.5	89-11-55.8	31.099	68.6
GH-18	L-side	25-45-57.9	89-12-46.2	32.162	
	R-side	25-45-59.1	89-12-43.6	32.332	81.2
GH-19	L-side	25-47-56.0	89-11-21.7	32.844	
	R-side	25-47-55.1	89-11-20.5	33.974	43.6

(3) River Name : Alai

No.	Bank side	Latitude(N)	Longitude(L)	Elevation	Distance between base point on both banks
A-1	L-side	25-09-12.3	89-29-37.4	19.618	
	R-side	25-09-14.5	89-29-35.2	17.930	91.09
A-2	L-side	25-11-08.8	89-30-12.4	17.934	
	R-side	25-11-08.8	89-30-08.9	18.334	62.0
A-3	L-side	25-11-54.1	89-32-17.6	20.851	
	R-side	25-11-55.2	89-32-15.7	20.647	65.5
A-4	L-side	25-14-31.4	89-33-36.3	21.559	
	R-side	25-14-35.8	89-33-40.4	18.689	105
A-5	L-side	25-17-39.4	89-33-37.6	21.720	
	R-side	25-17-39.1	89-33-35.9	21.468	51.2
A-6	L-side	2,803,273.442	758,309.990	23.515	
	R-side	2,803,289.339	758,219.374	20.532	92

(4) River Name : Ghagot/Manas

No.	Bank side	Coordinates (m)		Elevation	Distance between base point on both banks
		X	Y		
GM-1	L-side	2,803,899.050	763,062.915	18.961	
	R-side	2,803,834.744	763,057.912	21.227	64.5
GM-2	L-side	2,805,589.614	763,245.564	21.580	
	R-side	2,805,426.426	763,224.828	20.640	164.5
GM-3	L-side	2,805,350.929	761,850.063	22.026	
	R-side	2,805,064.600	761,912.231	22.989	293.0
GM-4	L-side	2,804,690.138	758,806.011	23.238	
	R-side	2,804,568.437	758,829.778	23.734	124.0
M-1	L-side	2,803,964.218	762,887.985	21.668	
	R-side	2,805,952.822	762,817.703	19.958	71.2
M-2	L-side	2,810,428.560	759,982.449	20.606	
	R-side	2,810,359.182	759,971.590	21.512	70.3
M-3	L-side	2,813,983.340	756,353.495	20.879	
	R-side	2,813,995.664	756,324.504	20.808	31.5

Notes 1. Latitude (N) and Longitude (L) are observed by Portable GPS instruments.
2. Elevation is based on the PWD datum.

Table 2.2 COORDINATES AND ELEVATION OF BASE POINT NEWLY INSTALLED IN RIVER CROSS SECTIONAL SURVEY (3/3)

(5) River Name : Karatoya

No.	Bank side	Latitude(N)	Longitude(L)	Elevation	Distance between base point on both banks
KK-1	L-side	25-09-06.7	89-29-07.0	17.808	
	R-side	25-09-00.4	89-29-07.1	19.128	173.7
KK-2	L-side	25-10-53.4	89-26-29.4	19.384	
	R-side	25-10-46.2	89-26-24.1	19.754	221.2
KK-3	L-side	25-09-22.4	89-21-29.7	20.652	
	R-side	25-09-19.3	89-21-35.9	22.332	195
KK-4	L-side	25-10-52.1	89-20-03.1	21.657	
	R-side	25-10-49.2	89-19-59.2	23.707	134.5
KK-5	L-side	25-13-44.5	89-18-52.0	22.428	
	R-side	25-13-44.4	89-18-52.0	22.028	200.0
KK-6	L-side	25-16-35.5	89-16-22.0	22.846	
	R-side	25-16-37.3	89-16-08.9	22.516	336.4
KK-7	L-side	25-18-40.5	89-16-22.0	23.896	
	R-side	25-18-37.7	89-16-17.9	23.310	133.4
KK-8	L-side	25-20-16.7	89-14-26.4	24.544	
	R-side	25-20-15.8	89-14-08.4	23.244	513.5
KK-9	L-side	25-22-56.4	89-13-03.1	24.622	
	R-side	25-22-47.8	89-13-01.2	25.002	263.2
KK-10	L-side	25-24-05.9	89-10-21.8	25.447	
	R-side	25-23-59.2	89-10-20.9	23.887	208.8
KK-11	L-side	25-27-19.8	89-08-40.9	26.322	
	R-side	25-27-26.0	89-08-35.1	25.222	246.4
KK-12	L-side	25-31-18.9	89-08-50.6	28.758	
	R-side	25-31-17.5	89-08-38.4	28.268	300.5
KK-13	L-side	25-36-07.0	89-07-25.3	30.188	
	R-side	25-36-03.2	89-07-17.6	30.378	242.3
KK-14	L-side	25-40-40.2	89-03-50.4	33.529	
	R-side	25-40-34.2	89-03-52.8	33.829	223.8

(7) River Name : BANGALI

No.	Bank side	Latitude(N)	Longitude(L)	Elevation	Distance between base point on both banks
B-1	L-side	25-08-41.4	89-29-21.4	18.681	
	R-side	25-08-45.2	89-29-17.6	19.371	157
B-2	L-side	25-06-41.1	89-30-24.9	23.536	
	R-side	25-06-38.2	89-30-17.6	23.293	156.3
B-3	L-side	25-02-42.2	89-31-41.4	17.780	
	R-side	25-02-46.1	89-31-39.0	16.320	137.2
B-4	L-side	24-59-16.1	89-31-57.9	17.060	
	R-side	24-59-12.0	89-31-54.3	17.470	165.5
B-5	L-side	24-55-39.8	89-33-17.8	16.703	
	R-side	24-55-42.4	89-33-11.2	16.883	194.5
B-6	L-side	24-52-30.0	89-33-59.1	16.260	
	R-side	24-52-42.4	89-33-11.2	15.430	176.5
B-7	L-side	24-49-30.1	89-33-41.6	14.730	
	R-side	24-49-32.5	89-33-35.2	15.944	205.1
B-8	L-side	24-48-00.3	89-32-11.6	15.497	
	R-side	24-48-04.5	89-32-06.5	16.947	191
B-9	L-side	24-45-39.6	89-30-21.8	15.699	
	R-side	24-45-44.8	89-30-24.4	13.979	161.5
B-10	L-side	24-43-18.5	89-29-51.2	15.333	
	R-side	24-43-19.8	89-29-46.6	12.244	141.5
B-11	L-side	24-37-38.9	89-28-13.4	14.062	
	R-side	24-37-45.2	89-28-09.4	10.483	185.2

Notes 1. Latitude (N) and Longitude (L) are observed by Portable GPS instruments.
2. Elevation is based on the PWD datum.

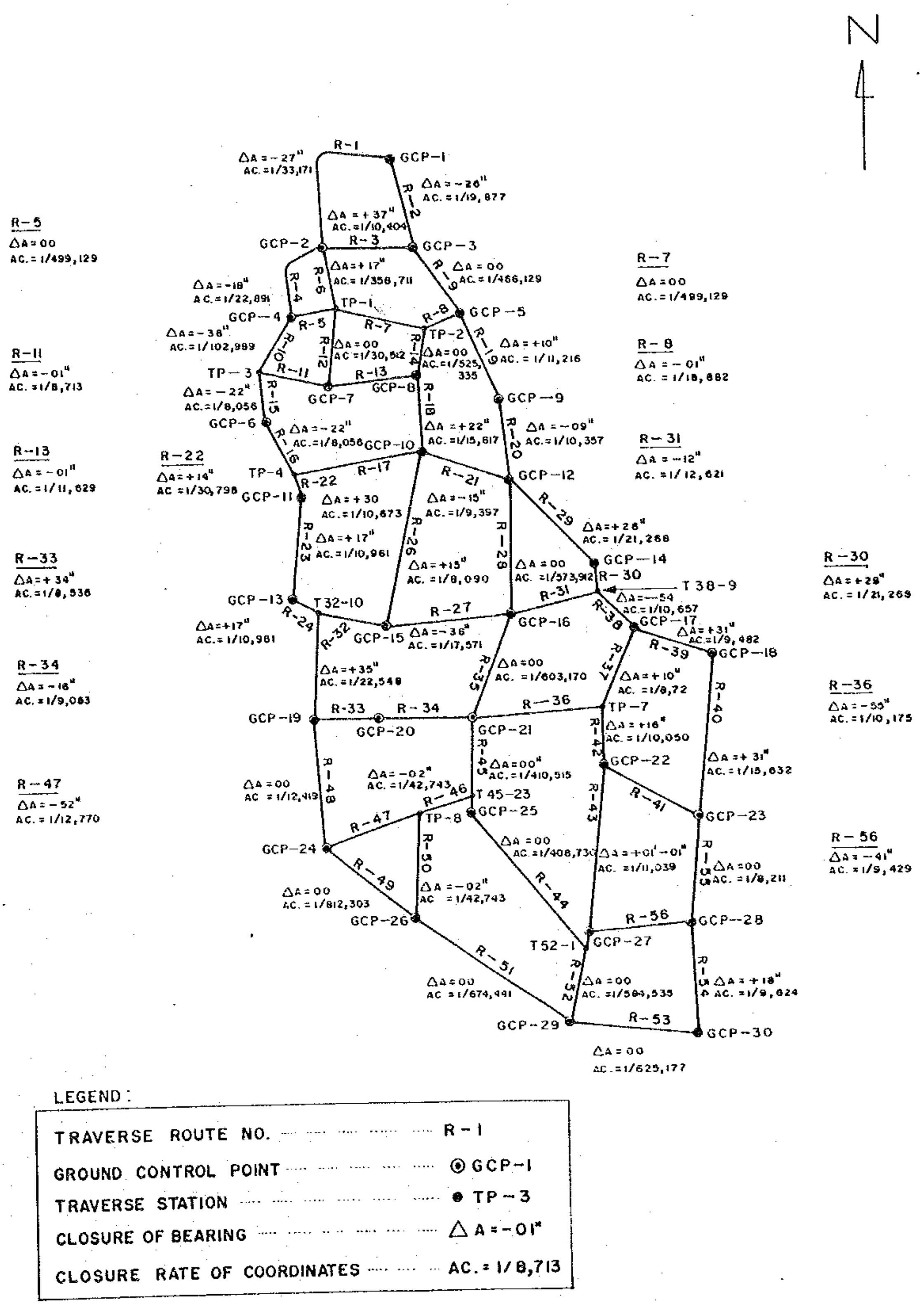

Figure 2.1 TRAVERSING NETWORK FOR GROUND CONTROL POINT SURVEY

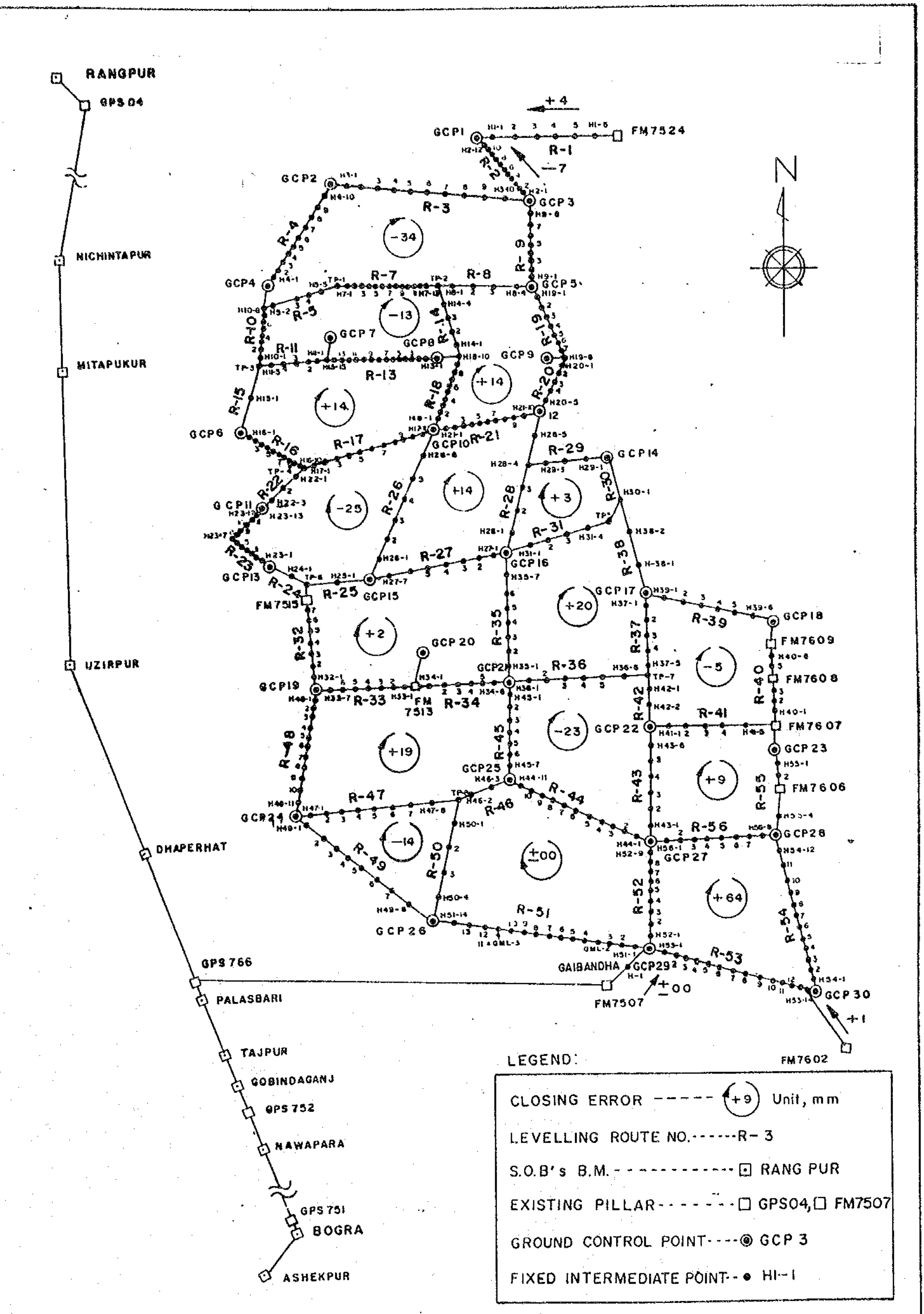

Figure 2.2 LEVELLING NETWORK AND ACCURACY CONTROL

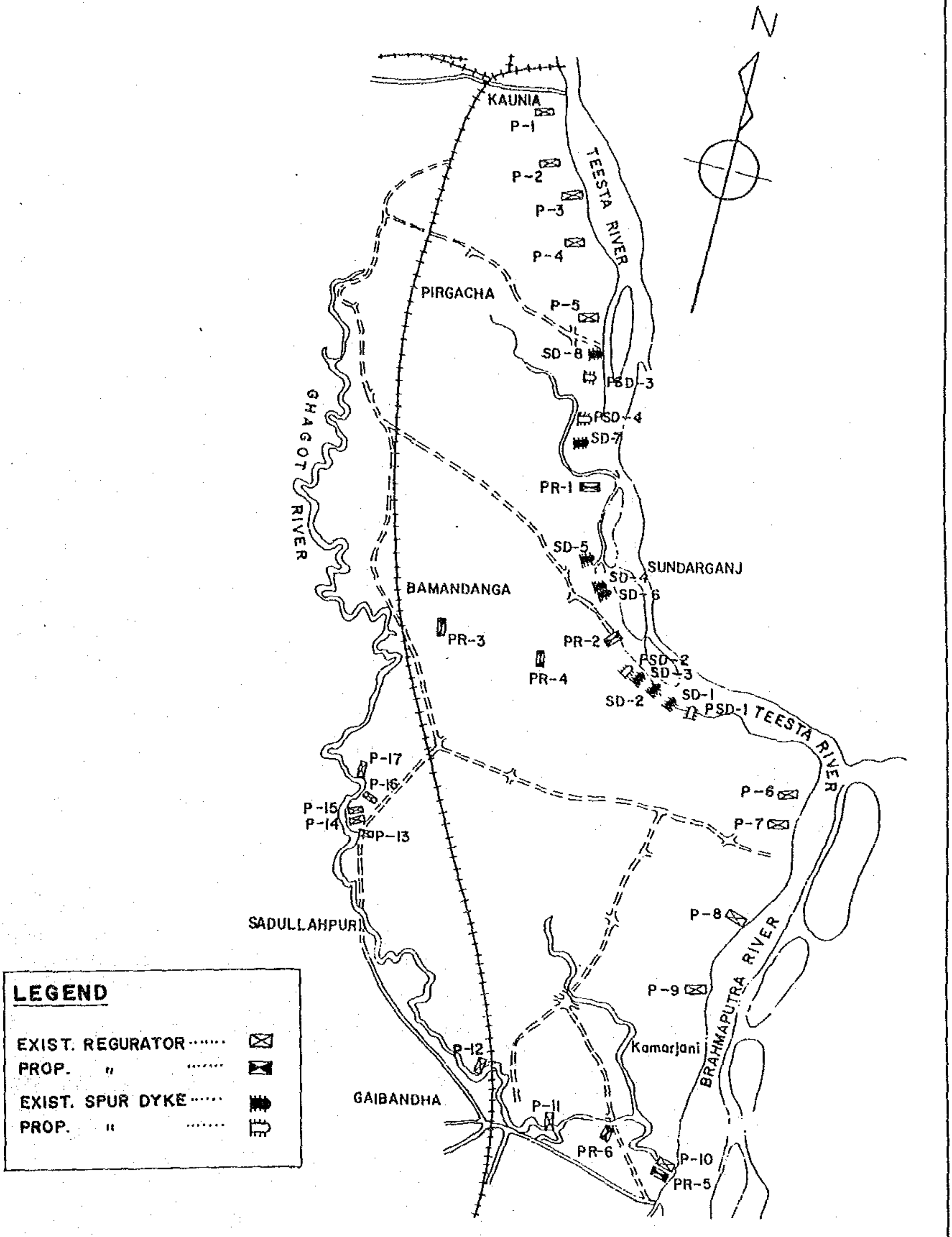

Figure 2.3 LOCATION OF PLANE TABLE SURVEY

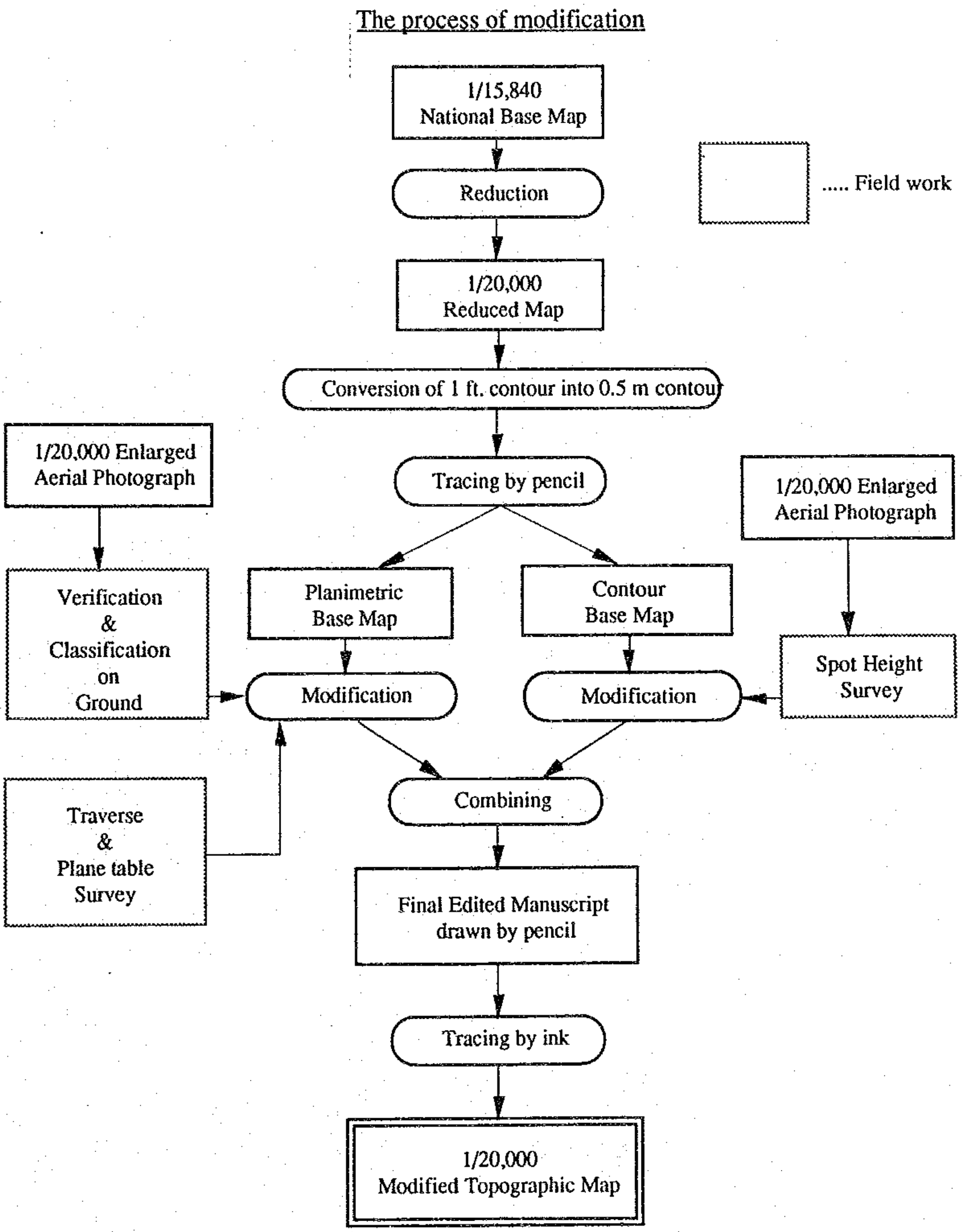

Figure 2.4 WORK FLOW FOR PRODUCING 1 TO 20,000 SCALED TOPOGRAPHIC MAPS

PART II
GEOTECHNICAL INVESTIGATION FOR THE GAIBANDHA IMPROVEMENT PROJECT

PART II

GEOTECHNICAL INVESTIGATION ON THE GAIBANDHA IMPROVEMENT PROJECT

CONTENTS

ATTACHMENTS : GEOTECHNICAL DATA ON GIP

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Acronyms & Abbreviations

FAP	Flood Action Plan
GIP	Gaibandha Improvement Project
NW	North West
FCD	Flood Control and Drainage
ASTM	American Society for Testing and Materials
BS	British Standard
USBR	United States Bureau of Reclamation
GLE	Ghagot Left Embankment
BRE	Brahmaputra Right Embankment
TRE	Teesta Right Embankment
SPT	Standard Penetration Test
CD	consolidated drained
Ec	standard proctor energy
F_C	fine particles content
F_L	liquefaction resistant factor
F_S	safety factor
G_S	specific gravity
LL	liquid limit
PI	plasticity index
M	magnitude of earthquake
M_L	Ritcher scale
M_S	surface wave scale
S_f	total settlement
c	cohesion
cu	unconfined shear strength
cv	coefficient of consolidation
e	void ratio
kh	seismic coefficient
mb	body wave scale
qd	ultimate bearing capacity
qu	unconfined compressive strength
γ_{sat}	saturated density
γ_t	wet density
ϕ	internal friction angle
σ_v	overburden pressure

CHAPTER 1

INTRODUCTION

At the initial stage of the FAP 2 interim regional study continued throughout 1991, it was identified that a lot of existing flood embankments in the NW region had been deteriorated much or less. It was envisaged that in general the deterioration resulted from inappropriate construction method of embankment with the insufficient geotechnical investigation, especially for the compaction works as well as insufficient operation and maintenance after construction thereof. Since it is considered essential to clarify the subsurface conditions and engineering properties of embankment material in the GIP area, we proposed in the FAP 2 Inception Report to carry out the geotechnical investigation works for the priority project to be selected through the Interim Regional Study in order to make a study of the feasibility level. Thus, the geotechnical investigation works for the Gaibandha Improvement project, selected as the priority project, has been commenced in early 1992, which constitutes the essential part of the engineering study thereon.

The geotechnical investigations for the GIP area, which comprise field investigations and laboratory tests were carried out for the period of February to August 1992. The geotechnical investigations aimed mainly at confirming and clarifying the subsurface conditions at the major structure sites planned for the GIP such as regulators and flood embankments as well as assessing the availability of embankment materials for flood embankments and clarifying the seismic condition in the GIP area.

Except for this chapter, the Part-II of this Volume comprises 3 Chapters, namely; General Geology, Geotechnics and Seismicity. The Chapter 2 "General Geology" provides the general data and information related to the geomorphology and stratigraphy of Bangladesh and the NW region as well as the GIP area, which are mainly worked out by the related agencies to date. The Chapter 3 "Geotechnics" Summarizes the results of the geotechnical investigation such as core borings, auger borings, test pitting and laboratory tests conducted during the investigation period. The Chapter 4 "Seismicity" describes the seismic and liquefaction analyses which are made based on the historical earthquake data in and around Bangladesh.

CHAPTER 2

GENERAL GEOLOGY

2.1 Physical Framework

2.1.1 Landform

Bangladesh is of an alluvial and deltaic plain laid down by the sediments transported by three of the world's large rivers, the Ganges, the Meghna and Brahmaputra. The hilly region on the north east, east and southeastern margins of the country accounts for only 15% of the area. Within the plains, there are few slightly elevated tracts, sometimes referred to as terrace areas, and several depressions. About half of the country lies within an elevation of less than 12.5 m. The Chittagong Hill Tracts region forms the highest parts of the country that comprise a series of north-south trending alternate anticlinal ridges and synclinal valleys varying from 70 to 1,000 m in elevation. Besides, the hill ranges sweep northwards through Tripura and dip north to northeast below the Sylhet plains. While, The alluvial plain gradually slopes southeastwards falling from an elevation of 90 m at Banglaband (north of Tetulia) in the northwest corner of the country and extends for about 400 km up to coastal plain having an elevation of 1.5 m in a line south of Khulna-Barisal-Lakhmipur.

In Bangladesh, the relatively elevated tracts of land form terraces within the alluvium. Significant of them are the Lalmai hills of Comilla in the southeast region, Madhupur Tract at the central region and Barind Tracts in the NW region of the country. The Barind Tracts of the NW region are characterized by two level of terraces: one is the level Barind of the Bogra, Dinajpur and Rangpur districts and the other is the high Barind north of Rajshahi which in total occupies an area of 9,320 km^2. The level Barind is marginally higher by 1 to 5 m than the adjacent floodplain and forms a distinct and relatively flood free zone. The high Barind like the Madhupur Tracts is tilted, but to a greater extent its western part forms a north to south ridge of 40 m in elevation, which is 25 m above the adjacent flood plain.

Among the depressions, the Sylhet basin in the northeast region is the largest which is a subsiding one. One of the other notable basins is the Chalan Beel and its adjoining low lying areas in the NW region which is being generally silted up.

On the other hand, there is considerable local variation in the relief, although the overall relief is fairly uniform. Local differences in relief could exceed 3 to 5 m between old levees and abandoned meander channels on the floodplain. The local relief can adversely affect the efficiency of water development projects, particularly those for irrigation and drainage. Villages are normally on the raised platform or the highest land to avoid inundation of their homesteads.

2.1.2 Geomorphology

Three major geomorphological zones are recognized in Bangladesh, namely; hill areas, terrace areas and floodplain as summarized in the following table:

Geomorphological Zone	Physiographic Units	Areas included
Hill areas	Unit 19	Chittagong hill tracts, parts of Chittagong, Noakhali, Comilla, Sylhet, Mymensingh districts
Terrace areas	Units 17 to 19	Madhupur Tract in Dhaka, Tangail and Mymensingh districts, and Barind Tract in Rajshahi and Bogra districts
Flood plain area	Units 1 to 16	Piedmont plains, meander flood plain and estuary flood plain

Piedmont plains include gently sloping areas of colluvial and alluvial sediments coming from the nearby hills. Piedmont plains occur throughout most of Dinajpur district and part of Rangpur district at the foot of the Himalayas, and also adjacent to the northern and eastern hills. The Himalayan plain is composed mainly of sand and minor pebbles and cobbles. The drainage pattern is braided with broad, smooth, but irregular-shaped ridges crossed by numerous branching and reconnecting, broad and shallow channels. The piedmont plains at the foot of the northern and eastern hills are from a few meters to several kilometres wide. The deposits are coarsely textured near the hills and streams but become more sandy with increasing distance from the origin.

Meander floodplain includes the greater parts of the Teesta, Brahmaputra, Ganges, Surma, and the middle basin of the Meghna river. These rivers, when flood takes place, deposit material up to such a height that the river eventually breaks out into adjoining lower land; subsequently laying down new deposits and always following a meandering course, constantly eroding the outside banks of bends and depositing new sediments on the inside banks. The resulting landscape is curved ridges, saucer-shaped basins, and abandoned channels. Generally, the sandy or silty sediments occur in the ridges and the finer materials occur in the basins.

2.1.3 Physiography of the GIP area

Within the three major geomorphological zones especially in the floodplain area, as many as twenty physiographic units have been identified with fairly uniform physical characteristics as shown in Figure 2.1. The GIP area falls within the physiographic unit no. 2, the Teesta Floodplain.

The Teesta floodplain is composed of the younger part of the Teesta alluvial fan and floodplain , comprising a variety of landscapes which were created as the Teesta river formed and abandoned successive channels across the area. At various times in the past, the Teesta has occupied the channels now followed by the Mahananda, Purnarbhaba, Atrai, Little Jamuna, Karatoya and Ghagot since two hundred years ago.

The unit mainly comprises young alluvial land within and adjoining the Teesta river and other smaller rivers crossing the unit. The surface deposits are predominantly grey and stratified silts with some sands. They occupy a low, generally smooth, but locally irregular relief of ridges and depressions, and partly infilled channels. Seasonal flooding is generally shallow, but all the rivers are subject to flash floods during which inundation is deeper for a few days and when crops may be drowned, buried by new alluvium or damaged by rapidly flowing currents. The Teesta alluvium is rich in weatherable minerals, especially mica. An important feature is the instability of the alluvial formations, both in outline and in relief. Shifting river channels erode large areas of river banks and islands (chars) during the monsoon season and create large areas of alluvium as new land within the channels or on top of older deposits.

2.2 Geology

Bangladesh is a major part of the Bengal basin which is considered as a part of the Shindhu-Ganga depression, generally known as the Himalayan Foredeep or Indogangetic Trough. The Himalayan Foredeep is a subsiding region in front of the mountain belt, stretches across the Indian subcontinent to Pakistan in the west. The rivers that originate from the Himalayas, entering the subsiding foredeep, are diverted along it either to the southwest as the Indus system or to the east as the Ganges-Brahmaputra river system. However, according to the plate tectonics theory, the Bengal Basin forms a rifted, passive and marginal basin of the Indian plate that is gradually closing due to plate destruction in the zone beneath the Indo-Burma ranges in the western Burma (Mayanmar).

The Bengal basin located at the head of the Bay of Bengal covers an extensive area that includes Bangladesh and parts of the adjacent Indian states, namely; West Bengal, Tripura and Assam. It comprises a flat surface created by the recently formed delta and alluvial plains of the Ganges, the Brahmaputra and Meghna rivers, with a total area of 60,000 km^2. This huge subaerial delta grades offshore into the world's largest submarine fan complex, the Bengal Fan, that extends over 3000 km south to the 10^o south latitude. The Bengal basin is essentially a Cretaceous-Eocene depositional centre within major delta building episodes (progradational) during the recent Oligocene age.

The exposed bed rocks comprise soft to poorly consolidated sandstone, siltstone, shale and limestone varying from Plio-Pleistocene to Palaeocene in age. The oldest sediments exposed in Bangladesh are the Tura sandstones of Palaeocene to Eocene age which are situated in the Takerghat area of Sylhet. The northeastern part of the Sylhet district in the area of Jaintapur and Tamabil exposes a sequence of sedimentary rocks of about 8,300 m varying from Oligocene to Plio-Pleistocene in age. The Miocene through Plio-Pleistocene rocks are best exposed in the Chittagong folded belt. Mesozoic and Palaeozoic sediments and Pre-cambrian basement rocks are not exposed anywhere in the country but are encountered in drill holes in the NW region.

However, about 85% of the country is a plain land covered with unconsolidated Holocene sediments. The rest of the country is underlain by the early to late Tertiary rocks in the north east region and Neogene sedimentary rocks in the eastern folded belts.

A generalized geological sequence of rocks in Bangladesh is given in Table 2.1, while the geological map of the NW region is shown in Figure 2.2. The oldest rock exposed in the country is the Tura Formation at Takerghat while the oldest rock found in the boreholes is the precambrian basement rock, which range from 130 meters at Madhyapara in Dinajpur district to more than 13,000 meters in thickness in south near the Bay of Bengal.

The unconsolidated sediments comprise coastal, deltaic, paludal, alluvial, and alluvial fan deposits of Holocene age. The older alluvium consists of Madhupur, Barind and Lalmai residual deposits of Holocene-Pleistocene age. In general, the deposits range from coarse sand and gravel in the alluvial fan areas to silty clay and clay in the mangrove swamps in Sundarban. Different rivers carry different kinds of sediments depending upon source materials which have great bearing in the nature of deposits. The Brahmaputra river sand is coarse to fine grained which contains mostly quartz, feldspar, mica and a little amount of heavy minerals.

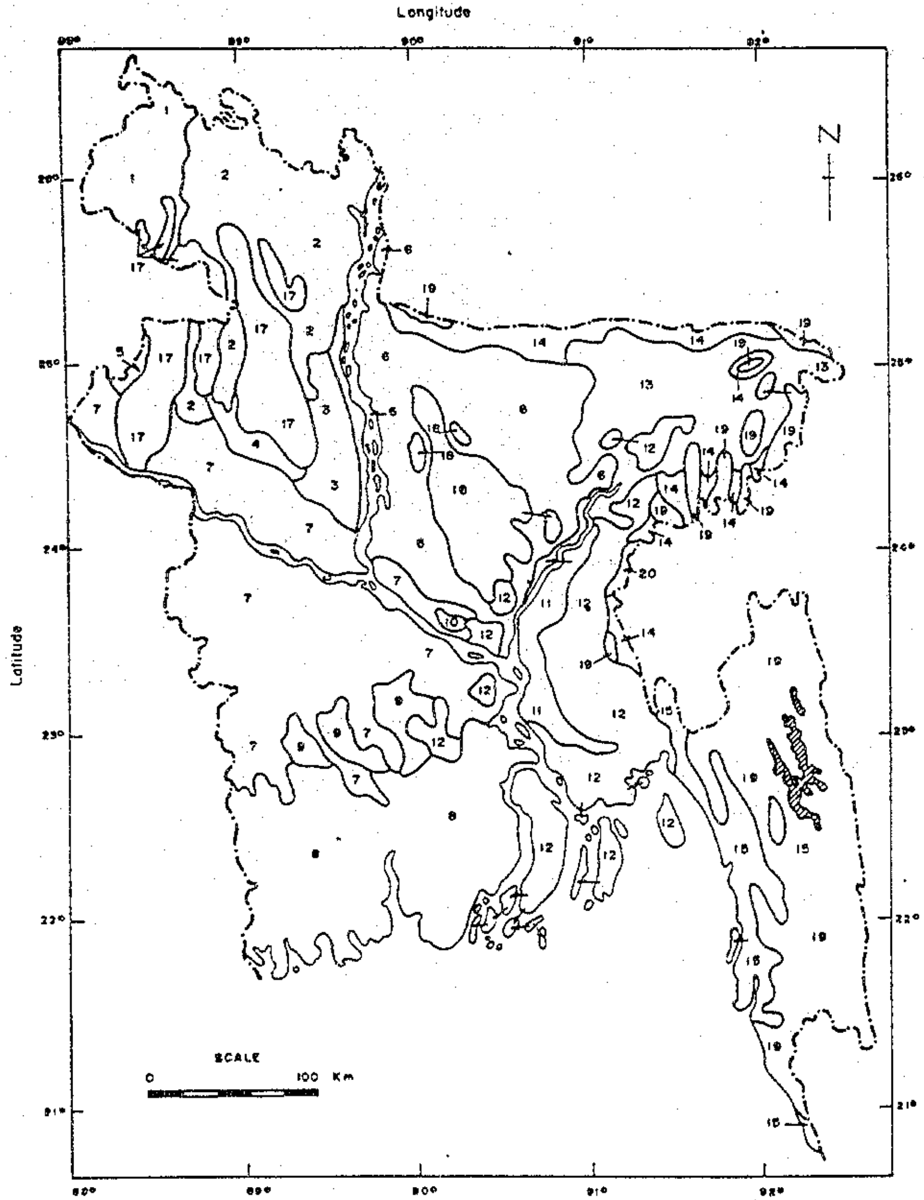
The GIP area geologically falls within the alluvial fan deposits and represented by map unit "afy - Young Gravelly Sand" as shown in Figure 2.2. The eastern part of the fan is active, flooded annually by the Teesta river and its distributaries. On the other hand, sand depositing in the GIP area is generally finer and contains more silt as discussed in the succeeding Chapter 3.

Figure 2.3 shows the representative stratigraphic sections from the Himalayan Foredeep across the Bengal Basin through the NW region. while, the surface and subsurface stratigraphy shows the only geological formation that crop out are of Cenozoic age. The stratigraphy includes, in addition to the continuation of the surface geological formation, the Precambrian, the Permian Gondwana sediments, the upper Jurassic volcanic rocks and a thin mantle of Cretaceous sedimentary rocks originating mainly from the deposition of the denuded volcanic.

TABLE 2.1 GENERALIZED GEOLOGICAL SUCCESSION OF BANGLADESH

AGE	FORMATION	LITHOLOGY
HOLOCENE	ALLUVIUM (Unconsolidated Sediments) (Coastal/Deltaic/Paludal/Alluvial/ Fan Deposits)	Sand, Silt and Clay.
	UNCONFORMITY	
HOLOCENE TO PLEISTOCENE	OLDER ALLUVIUM (Unconsolidated Sediments) (Madhupur/Barind Clay)	Brick red, yellowish brown, mottled clay, sandy clay, silty clay.
	UNCOMFORMITY	
	ST. MARTIN LIMESTONE	Coquina, soft and friable.
	UNCONFORMITY	
PLESTOCENE	DIHING	Yellow, yellowish grey, poorly consolidated, massive sandstone and clayey sandstone with pebbles.
	UNCONFORMITY	
	GIRUJAN	Grey, greenish grey, silty shale and claystone.
MIO-PLIOCENE	TIPAM	Light yellow, yellowish grey, grey fine to medium sandstone (upper part) siltstone and shale (middle part), fine sandstone (lower part)
	LOCALUNCONFORMITY	
MIO-PLIOCEN	BOKA BIL	Greenish and bluish grey shale, siltstone and sandstone.
MIOCENE	BHUBAN	Grey, bluish grey fine to medium sandstone in the upper part; siltstone and claystone in the lower part.
	UNCONFORMITY	
OLIGOCENE	BARAIL	Brown, yellowish brown, pink and grey sandstone, siltstone and shale.
	UNCONFORMITY	
LATE EOCENE	KOPILI	Grey, greenish grey, black, silty claystone, shale and bands of sandstone, thin bands of fossilli ferous limestone in the lower part.
MID-EOCENE	SYLHET LIMESTONE	Grey, grayish brown fossilli-ferous limestone with dark grey claystone.
EARLY EOCENE TO PALEOCENE	TURA	Grey, brown, limestone white fine to coarse sandstone with shale.
	UNCONFORMITY	
	SIBGANJ** (Trap Wash)	Yellow, brown, coarse sandstone, volcanic material, white clay.
	UNCONFORMITY	
MID-CRETACEOUS TO LATE JURASSIC	RAJMAHAL TRAP**	Amigdoidal basalt, agglomerate and serpentinised shale.
	UNCONFORMITY	
PERMIAN	PAHARPUR** (Raniganj Group) KUCHMA** (Barakar Group)	Feldspathic sandstone, shale and coal beds, sandstone and grit with subordinate shale interbedded with coal beds.
	UNCONFORMITY	
PRECAMBRIAN	BASEMENT COMPLEX	Gneiss, schist, granodiorits, quartz diorite.

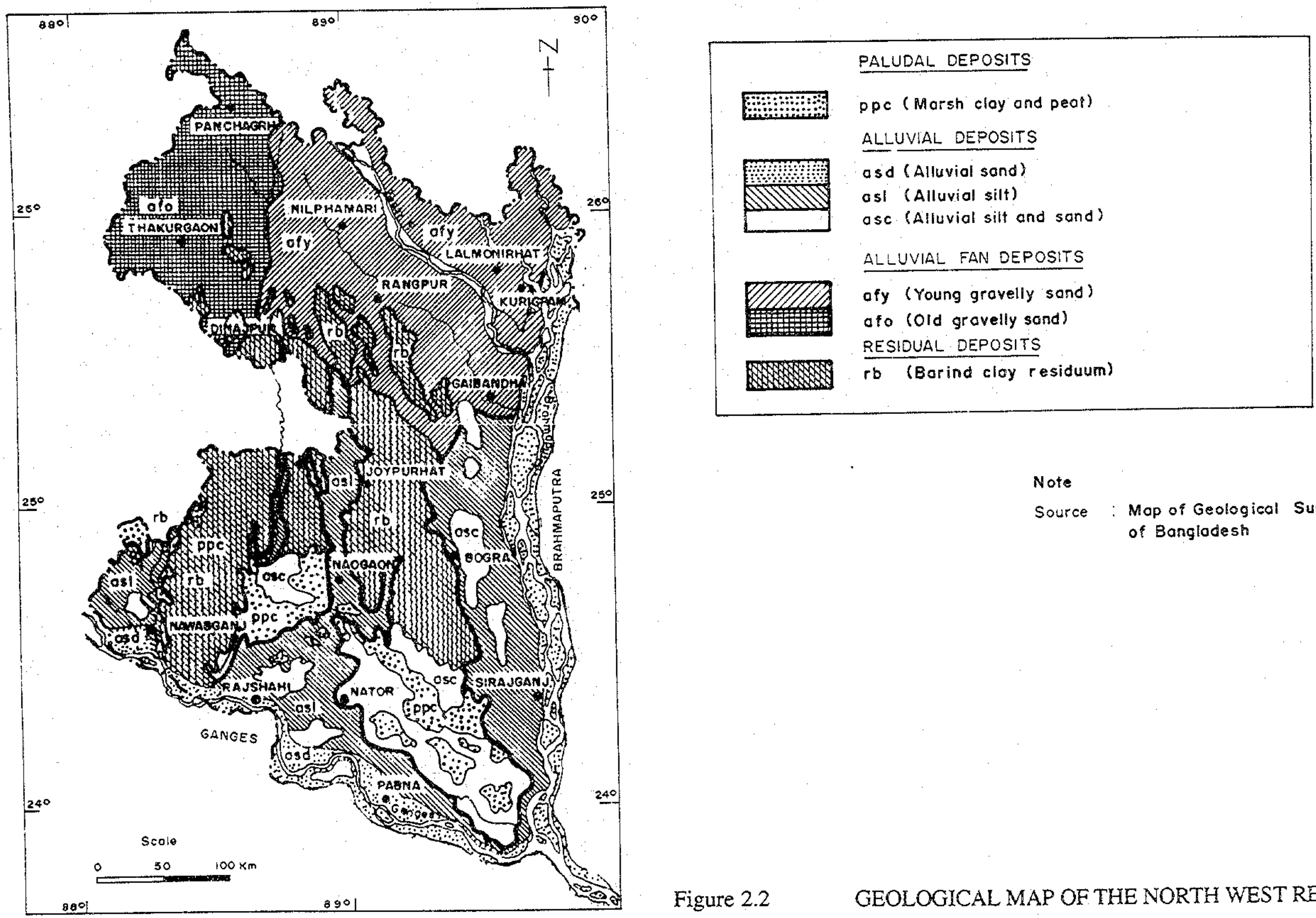
** Not exposed.



LEGEND

Unit no.	Physiography
1	Old Himalayan Piedmont Plain
2	Teesta Floodplain
3	Karatoya-Bangali Floodplain
4	Lower Atrai Basin
5	Lower Punarbhaba Floodplain
6	Brahmaputra Floodplain
7	Ganges River Floodplain
8	Ganges Tidal Floodplain
9	Gopalganj-Khulna Bils
10	Arial Bil
11	Meghna River Floodplain
12	Meghna Estuarine Floodplain
13	Surma-Kusiyara Floodplain
14	Northern and Eastern Piedmont Plains
15	Chittagong Coastal Plain
16	St Martin's Coral Island
17	Barind Tract
18	Madhupur Tract
19	Northern and Eastern Hills
20	Akhaura Terrace

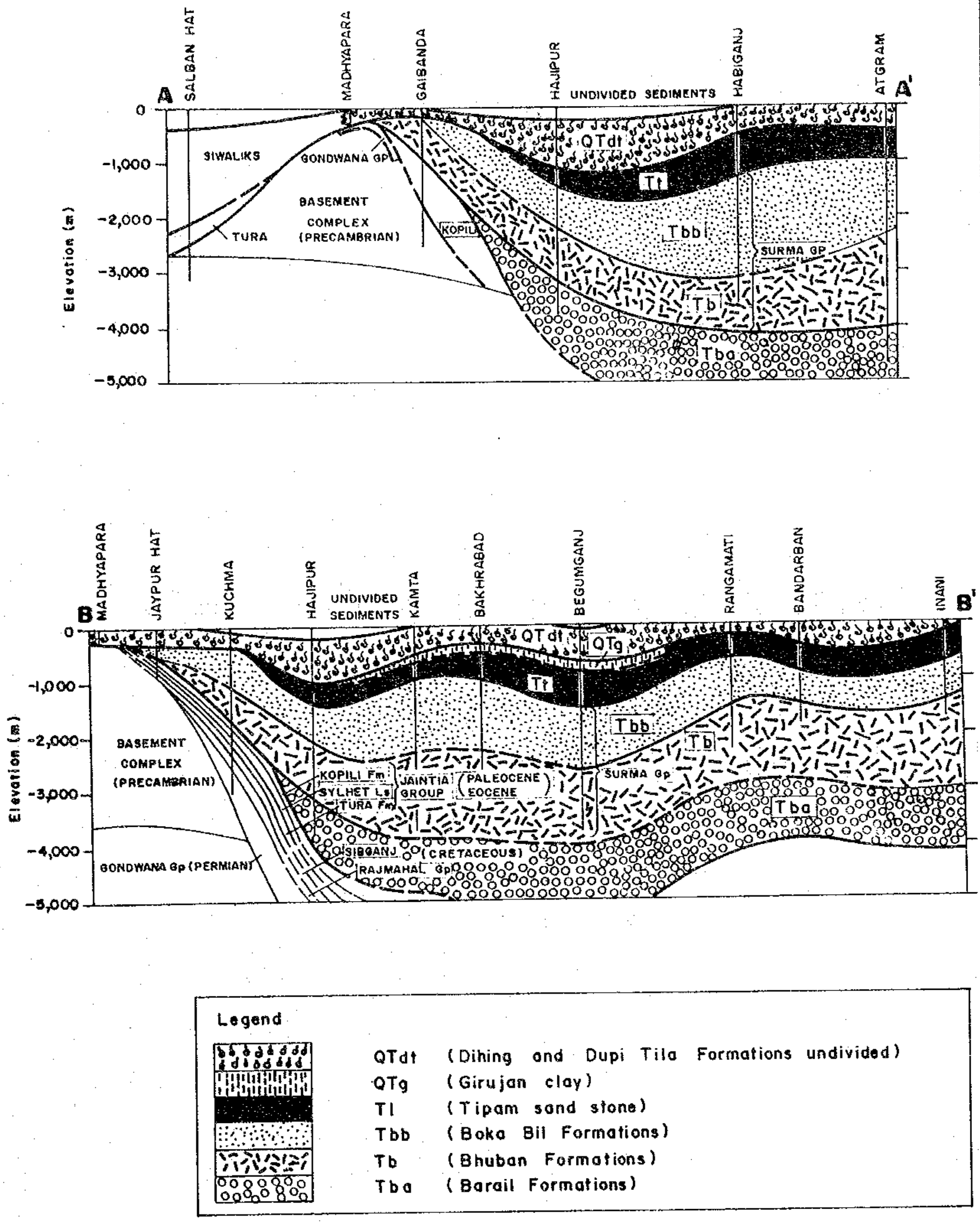
Figure 2.1 PHYSIOGRAPHIC UNITS OF BANGLADESH



Note

Source : Map of Geological Survey of Bangladesh

Figure 2.2 GEOLOGICAL MAP OF THE NORTH WEST REGION



Note : The geological formations are explained in Table 2.1.

Figure 2.3 REPRESENTATIVE STRATIGRAPHIC SECTION FROM THE HIMALAYAN FOREDEEP ACROSS THE BENGAL BASIN

CHAPTER 3

GEOTECHNICS

3.1 General

The geotechnical investigations for GIP consisting of field investigations and laboratory tests were carried out to clarify the subsurface conditions of the proposed FCD sites as well as the availability of the embankment materials to be used for construction of the flood embankments. The basic design values of the subsurface soils for preliminary design of flood embankments, and seismic and liquefaction analyses which are described in the succeeding Chapters 4 and Chapter 5 of the volume 6 respectively are determined based on the geotechnical investigation results.

The field investigations works for the GIP area including core boring, auger boring, test pitting as well as sampling of soil materials therefrom for the laboratory tests area were carried out in the dry season of 1992. Thereafter, the laboratory tests were conducted in laboratories of Dhaka for the period from April to July 1992.

3.2 Geotechnical Condition at Planned Regulator Site

3.2.1 Investigation works performed

In the FAP 2 Interim Report, it was proposed to build six new regulators in the GIP area, namely; 2 on the TRE, 1 on BRE, 1 at the confluence of the Manas and Ghagot and 2 on the embankment for dividing the GIP area into major two compartments, in order to improve the flooding condition therein. In order to clarify the subsurface conditions at these locations, the following geotechnical investigation works were performed;

(1) The field reconnaissance to confirm the overall geotechnical conditions at existing regulators sites in the GIP area.

(2) Core boring of 20 m deep at each of the regulator sites, which includes the standard penetration test (SPT) at interval of 1.5 m and observation of groundwater table in each of the boreholes.

(3) Laboratory tests on soil materials sampled from the boreholes, which comprise tests on specific gravity, grain size analysis, Atterberg limits and moisture content in accordance with the standardized testing methods such as ASTM (American Society for Testing and Materials), BS (British Standard) and Earth Manual of USBR.

3.2.3 Investigation results

Location of the boreholes dug for the purpose are is shown in Figure 3.1 and explained below;

Borehole No.	Location
B3	intersection point of the Burail river and the TRE in Tambulpur
B4	intersection point of the Halhalia river and the TRE in Tarapur
B6	existing Manas regulator
B6'	right bank of the Ghagot about 5 km downstream of the town Gaibandha
B12	about 1.5 km distant from Bamondanga on existing Jhinia-Bamondanga road in Bamondanga
B13	about 7.5 km distant from Bamondanga on existing Jhinia-Bamondanga road in Gopalchiri

Logs of those boring and grading curves of soil materials sampled therefrom are compiled in Attachment-1 to this Part I. The subsurface condition at these locations are assessed as follows based on the geotechnical investigation results;

Item	Borehole Nos. (Location)					
	B3 (Tambulpur)	B4 (Tarapur)	B6 (Manas)	B6' (Gaibandha)	B12 (Bamandanga)	B13 (Gopalchiri)
- Upper Soil layer						
Thickness (m)	2	5.1	14.0	3.8	1.9	5.1
Soil texture	Sandy Silt	Silt with sand, clay and sandy silt	Silt with sand and sandy silt	Silty Soil	Silty Soil	Silty soil
N value (Stiffness)	3 (soft)	5-6 (firm)	5-13 (firm to stiff)	7-12 (firm to stiff)	2 (very soft)	4-7 (firm)
Soil classificiation <1	ML	ML	ML	ML	CL and ML	ML
Fire particles content ratio (%)	78	53-79	77 to 90	58	90-99	57-91
- Lower Soil layer <2						
Thickness (m)	Over 18	Over 14.9	Over 6	Over 12	Over 18.1	Over 14.9
Soil texture	Silty sand and fine sand with silt	Silty sand and fine sand with silt	Fine sand with silt	Silty sand, sand and fine sand	Fine sand with silt and sand	Fine sand with silt and silty sand
N value (Stiffress)	14-30 (Medium dense)	10-26 (Medium dense)	31-48 (Dense)	16-41 (medium dense to dense)	5-25 (Loose to medium dense)	18-38 (Medium dense to dense)
Soil classificiation<1	SP-SM or SM	SP-SM or SM	SP or SP-SM	SM,SP and SP-SM	SM,SP-SM and SM	SP-SM and SM
Fine particles content ratio (%)	8-15	3-15	3-8	1-33	1-28	12-17
Ground table<3	0.54	1.89	3.55	0.58	0.87	0.92

Note: 1. <1; classified in accordance with the unified soil classification

2. <2; depth of borehore is 20m at every location, but the lower soil layer is considered to have a considerable depth.

3. <3; depth from ground surface thereat to the groundtable.

As a result of the geotechnical investigation, it is clarified that strata of the subsurface in the GIP area is composed mainly of two ones as a whole, namely; the upper silty soil layer and lower sandy soil layer overlaid by the silty layer. The upper soil layer is classified to be ML in accordance with the unified soil classification. In general, thickness of the silty soil layer from the ground surface is as thin as 1.5 to 5.1 m and its N values are generally larger than 4, except for the soft layers detected

in the boreholes No.1 (Tambulpur) and No.12 (Bamondanga) with which the ground surface is covered up to about 2 m depth from the ground surface. From the core boring dug, however, it appears that there exist areas covered by such soft layer of silty soil with N value of less than 4 place by place. In principle, it is recommended that the regulator with a height of about 5 m be founded on the sandy soil layer with N value of 10 to avoid the differential settlement of the foundation concrete. In case the depth of the soft layer is very thin as encountered in the borehole sites at Tambulpur and Bamondanga, on the other hand, the alternative method of the foundation treatment is that the soft layer is to be replaced by sandy soil materials after stripping it and then compacted sufficiently with appropriate mechanical equipment under the adequate moisture content. The similar construction method has also been practiced in building the existing regulators in the GIP area, as far as their construction drawings are concerned. While, it is recommended to provide concrete piles beneath the foundation concrete to support the structure taking account of the safer design, in case the concrete structures with a height of more than 5 m are provided at places where the depth to the firm sand soil layer is rather deep and the foundation may be eroded by the flood flow.

The core boring clarifies that the lower sandy soil layer which is predominantly composed of fine sands has a considerable thickness over the GIP area. The sandy soils are classified into SM, SP-SM and SP in accordance with the unified soil classification. N values of the sandy soil layers mostly exceed 10 except minor loosed parts and gradually increase with depth from the ground surface. Although it is informed through the site reconnaissance that the existing regulators are constructed without driving of piles in the foundation, it is judged from the characteristics of the sandy soils that it is desirable to provide piles of about 5 m as the friction type, if pile foundation be selected as the foundation treatment method.

3.3 Geotechnical Condition at Planned Embankment Site and Engineering Property of Embankment Material

3.3.1 Investigated area

For the purpose of the geotechnical investigation on flood embankments, the flood embankments proposed to be constructed in the FAP 2 Interim Report which include those to be heightened and resectioned are divided in the following four embankment sections;

Section No.	Embankment Planned in the GIP Area
Section-1 :	TRE from Kaunia to the confluence of the Teesta and the Brahmaputra
Section-2 :	Southern flood embankment along the Ghagot
Section-3 :	Northern flood embankment along the Ghagot
Section-4 :	Dike for compartmentalization of the GIP area

Location of those four Sections are depicted in Figure 3.1. To clarify the subsurface conditions of the foundations at the areas along the existing and proposed flood embankments as well as to assess the availability of embankment materials in the adjacent areas in terms of their quality, the following geotechnical investigation works have been performed;

(1) Field reconnaissance to confirm the geotechnical conditions of foundations of existing and proposed flood embankments as well as to select suitable borrow areas from which embankment materials are to be obtained in the construction stage.

(2) Core boring along the aforesaid four Sections, which includes the SPT at intervals of 1.0 or 1.5 m and observation of groundwater table.

(3) Auger boring to assess the availability of embankment materials to be used for new construction of flood embankments and/or strengthening and resectionning of existing ones, which also includes observation of groundwater table.

(4) Test pitting to a depth of about 2 m at the selected borrow areas.

(5) In-situ tests; i.e. in-situ permeability tests and in-situ density tests, in order to confirm the in-situ conditions of subsurface soil at embankments.

(6) Sampling of disturbed soil samples from the boreholes and holes of the auger boring at interval of 1.0 m depth and from the test pits at depths of 1 m and 1.75 or 2 m, and sampling of undisturbed samples (cohesive soil materials) from the boreholes using shelby tube sampler of 7 cm diameter.

(7) The laboratory tests on specific gravity, grain size analysis, Atterberg limit, moisture content, standard compaction, permeability, consolidation, unconfined compressive strength, triaxial shear and direct shear tests for the disturbed and undisturbed soil materials in accordance with the standardized testing methods such as ASTM (American Society for Testing and Materials), BS (British Standard) and Earth Manual of USBR.

The laboratory test results are on the soil samples collected from boreholes are compiled in Attachment-2 to this Part-II.

3.3.3 Field reconnaissance

Prior to the start of the field investigation works, the site reconnaissance was performed to confirm the present conditions of subsurface soil at the existing and proposed flood embankments as well as to select the borrow areas embankment materials and examine suitable construction method of flood embankment.

(1) Present condition of foundation of existing flood embankments

As a result of the visual observation, it appears that the existing flood embankments such as TRE and BRE are founded on the sandy and silty soils of non-plasticity and that the foundations of the flood embankments was comparatively stable at the time of the site reconnaissance, since there took place no significant damages in the foundation such as slope failures, heaving in toe of slope of the embankments, deformation of embankments due to settlement of the foundations and seepage failures including piping through the foundations. On the other hand, it was observed that the embankment materials used for existing flood embankments were not obtained only from the river side thereof, but also from the country side. Although the area adjacent to toe of the country side slope is excavated to obtain the embankment materials, thus, it is recommended to provide the borrow area in the river side to avoid the damage of embankment body due to seepage and slope failures.

It was found that there were a lot of cracks in the Teesta right embankment (TRE) where the side slopes are very steep. At these locations, it seems that the TRE is likely to take place the slope failure sooner or later. Besides, the bank erosion of the TRE is quite serious problem as compared with other existing flood embankments in the GIP area. The bank protection and/or river training

works along the eroded portions of TRE are required to be provided, if it is intended to maintain the present river bank line along the Teesta river.

(2) Shape of existing flood embankments

TRE and BRE have an embankment height of 2 to 4 m above the surrounding ground height and their side slopes are mostly 1:2 to 1:3 as a whole, although there are places where the slopes are steeper than 1:2. Concerning these embankments, no berms are provided on their side slopes and their crest widths are in a range of 3 to 5 m. Most of the side slopes are covered by grasses. Although these embankments have also been utilized as traffic road, uneven surface of crest caused by the man-made activities and natural phenomenons hampers the smooth traffic. At present, a lot of landless people reside on the crest and slopes by levelling there. The present deterioration is caused mainly by the poor quality and adoption of the embankment construction method, especially in the compaction of embankment, as well as the man-made activities done by the landless people under the social circumstance that they have increased due to the extensive bank erosion along the TRE and BRE. Except for the public-cut of BRE near the Manas regulator, major breaches of flood embankments in the GIP area took place in a section of the TRE between Tambulpur and Tarapur. It has to be noted that the embankment materials obtainable from those areas are partly of poorly graded sand containing lesser fine particles soil. Thus, it appears that a part of the breached portion is responsible for use of unfavourable embankment materials.

(3) Borrow area for flood embankments

According to the design manual of the Third Flood Control and Drainage Project, it is recommended that the borrow areas be located in the river side of flood embankment and that a distance between toe of the embankment slope and edge of the borrow area be taken at 3 to 6 m with an average excavation depth of 2 m therein. With respect to the existing embankments in the GIP area, the borrow areas are provided in the both sides of flood embankments, located close to embankment body as aforesaid. In principle, the borrow areas need to be developed in the river side in order not to cause the seepage failures. In most of the borrow areas utilized for construction of TRE, the excavation depths exceed 2 m that is an allowable maximum depth according to the aforesaid design manual. Such overexcavated borrow areas which usually are left without backfilling after completion of construction, especially in the country side, may come to the cause of seepage failures during and after monsoon season. Hence, the maximum excavation depth in the borrow areas needs be limited to 2 m with excavation slopes of about 1 : 2 to 1 : 3, which are nearly equal to those of embankment side slopes.

(4) Construction method of flood embankments

Most of construction works of flood embankments such as excavation, transportation of embankment materials, spreading/compaction works had been carried out by manpower without mechanical equipment. Besides, it appears that the required quality control including moisture control of embankment materials, in-situ density tests at embankment sites and compaction of embanked materials as well as construction control such as accurate setting out of design cross section had not been carried out, as long as the considerable deterioration of the existing flood embankments shows.

3.3.4 Engineering properties of subsurface soil along the planned embankments

The geotechnical conditions for the embankment foundation are assessed for each of the four embankment Sections (Section-1 to Section-4) shown in Figure 3.1 based on the results of the core boring exploration and test pitting as well as the laboratory tests.

(1) Stratigraphy

Figure 3.1 shows location of boreholes explored along the four Sections and their boring logs are compiled in Attachment-1 to this Part II. On the basis of those boring logs, a soil profile is worked out for each of the Section-1 to Section-4 as shown in Figures 3.2 to 3.5, respectively. Those core boring also clarifies that the stratigraphic conditions along the four Sections show the similar tendency one another, say, in general the strata of the GIP area is composed of the upper silty soil layer and the lower sandy soil layer, although there are vague zones which make the clear distinction difficult, especially in the area along the Ghagot where the strata seems to be strongly affected by meandering of the river to date. On the other hand, groundwater tables are observed to be 2 to 3 m, 1 to 2 m, 2.5 to 3 m and less than 1 m from their ground surfaces in the Section-1 to Section-4, respectively.

(2) Physical properties

The results of the laboratory and in-situ tests conducted for soil materials, which were collected from areas along the Section-1 to Section-4, are listed in Tables 3.1 to 3.4, respectively. The grading curves of subsurface soil along the four Sections, which are analyzed with sieves and hydrometer, are depicted in Figures 3.6 to 3.9, respectively. The physical properties derived through the tests are summarized below;

Item	Embankment Section			
	Section-1	Section-2	Section-3	Section-4
-Silty soil layer				
Specific gravity	2.67 (2.66-2.67)	2.67 (2.66-2.67)	2.67 (2.66-2.67)	2.67 (2.66-2.68)
-Fine particles content ratio(%)	75 (47-92)	88 (47-92)	72 (44-91)	76 (44-91)
-Natural moisture Content ratio(%)	24.9 (16.0-39.0)	29.8 (25.1-33.6)	24.4 (12.5-32.8)	32.9 (24.3-46.4)
Classification of soil*	ML	ML	ML	ML
Sandy Soil Layer				
-Specific gravity	2.66 (2.65 to 2.67)	2.66 (2.65 to 2.66)	2.66 (2.65 to 2.66)	2.66 (2.65 to 2.66)
-Fine particles content ratio(%)	12**	18 (1-39)	21**	13 (1-28)
-Natural moisture content ratio(%)	24.5 (5.2-35)	21.1 (8.1-30.3)	26.5 (23.3-29.9)	22.2 (18.5-28.9)
-Classification of soil*	SM, SP-SM, SP	SM,SP-SM,SP	SM,SP-SM, SP	SM,SP-SM, SP

Notes:
1. concerning each item, value in upper column shows the average one, while that in the lower parentheses indicates a range of the tested values.
2 *; classified by the united soil classification.
3**; interbedded by silty soil place by place as shown in Figure 3.2 and 3.3.

As seen above, the physical properties of subsurface soil along the four Sections are very similar. In the upper silty soil layer, the specific gravity is derived to be 2.67 on average of the whole samples tested and the average fine content ratios in the four Sections range between 72 and 88% as a whole. The average mean particle size is 0.030 to 0.050 mm on average. All the soil materials are classified into ML in accordance with the united soil classification and their consistency are almost non-plastic. While, the average natural moisture content ratios in the four Sections exhibit a comparatively large variation because of the different groundwater table.

In the sandy soil layers, the specific gravity comes to 2.66 on the average of the whole soil samples tested and the average fine particles content ratios in the four Sections range from 12 to 21 % on average. The average particle sizes range from 0.14 to 0.16 mm. While, the soil materials are mainly classified into SM, SP-SM and SP. The average natural moisture contents in the four Sections are very similar, which range from 22.2 to 26.5 %.

(3) N value

The N values measured in the boreholes at interval of 1 m are shown in their logs, which are compiled in Attachment-1 to this Part II. The following summarizes N values of each soil layer measured through the standard penetration test (SPT) by the Section and average internal friction angle of the sandy soil layer which is estimated applying the relationship between N value and internal friction angle, developed by Dunham (1954).

Item	Embankment Section			
	Section-1	*Section-2*	*Section-3*	*Section-4*
N value				
- Silty soil layer	8.4 (2-21)	7.4 (4-16)	6.1 (2-13)	7.6 (2.19)
- Sandy soil layer	17.4 (4-38)	18.2 (4-35)	17.3 (5-26)	17.6 (5-26.5)
Estimated average engineering properties				
- Unconfined compressive strength of *silty soil layer* (tf/m^2)	10.5	9.3	7.6	9.5
- Internal friction angle of sandy soil (degree)	29-34	30-35	29-34	30-35

The N value of the upper silty and lower sandy soil are derived to be between 2 and 21 and between 4 and 38, respectively. Except for the lower values in the soft silty soil, the N value in the upper silty layer comes to between 6.1 and 8.4 as a whole, while that in the lower sandy soil layer increase with depth from the ground surface.

(4) In-situ density

The in-situ density tests were performed in the test pits dug along the existing and proposed embankments, whose locations are shown in Figure 3.1. The test results are tabulated in Table 3.5 and summarized below by the Section.

Item	*Embankment Section*			
	Section-1	*Section-2*	*Section-3*	*Section-4*
- Test pit No. (Depth of Sampling)	T1, T2 (1.00 & 1.75m)	T3 (1.00 & 2.00m)	T4, T5 (1.00 & 1.75m)	T6, T7 (1.00, 1.75, 2.00m)
- Soil texture of sample	Sandy silt or silty sand	Sandy silt or silty sand	T4: Fine sand T5: Sandy silt or silt sand	Sandy silt or silt except for T6 at a depth of 1m
- Natural moisture Content ratio(%)	35.1 (23.1-42.7)	19.4 (9.1-30.3)	24.8 (13.1-33.0)	30.4 (18.3-30.6)
- Wet density (tf/m³)	1.63 (1.56-1.69)	1.49 (1.39-1.58)	1.69 (1.40-1.84)	1.58 (1.35-1.72)
- Dry density (tf/m³)	1.21 (1.10-1.35)	1.24 (1.19-1.29)	1.35 (1.24-1.43)	1.21 (1.14-1.30)

Notes: 1. As for the moisture conent ratio and wet/dry densities, the value in upper column shows the average one, while that in the lower parentheses indicates a range of the tested values.
2. Location of the test pits is shown in Figure 3.1.

Although the densities in the upper soil layers distribute in a wide range, the average wet and dry densities in the four Sections are very similar one another as shown above. As the average values of the whole soil samples tested, the wet and dry densities are derived to be 1.61 and 1.25, respectively.

(5) In-situ permeability

The in-situ permeability tests were carried out in the boreholes employing the open-end pipe method of "Earth manual" by USBR. The test results are shown in Table 3.6 and summarized below by the Section;

Item	Embankment Section			
	Section-1	Section-2	Section-3	Section-4
Location of test				
- Borehole No. (depth from ground surface	B3 (3m) B3' (6m) B4 (3m)	B7 (3m)	B10 (3m) B11 (3m)	B12 (3m) B13 (3m)
Soil texture	B3': Sandy Soil B4: Clayey soil	Clayey soil	Silty soil	Silty or Sandy soil
Co-efficient of permeability:				
• Silty soil	None	None	$7.2x10^{-4}$-$1.1x10^{-3}$	$8.1x10^{-3}$
• Sandy soil	$1.7x10^{-3}$ - $1.2x10^{-2}$	None	None	$2.7x10^{-3}$
• Clayey soil	$2.5x10^{-5}$	$4.9x10^{-4}$	None	None

The coefficient of permeability in the upper silty and lower silty soil layers are observed to be between 2.5 x 10^{-5} cm/sec to 1.1 x 10^{-3} cm/sec and between 1.7 x 10^{-3} and 1.2 x 10^{-2} cm/sec, respectively. The lowest value of 2.5 x 10^{-5} cm/sec is measured in the clayey soil, which interbeds the upper silty layer.

To carry out the shear and consolidation tests with the undistiubed sample, the fine grained soil samples with fine particles content of moe than 90% were collected from boxer of core boring, at least 1 sample for each of the four embankment sections, as shown below:

Item	Embankment Section			
	Section-1	Section-2	Section-3	Section-4
Location of sampling: -Borehole No (depth from ground surface)	B4(2.08-2.54m)	B9 (4.08-4.54m)	B11 (4.08-4.54m)	B12 (0.58-1.04m) B13 (0.54-1.00m)

The direct shear and consolidation tests were carried out for undisturbed soil samples collected from the boreholes from the respective Sections, which contain fine particles of more than 90 %. The laboratory test results on the undisturbed samples are shown in Table 3.7, and their grading curves are shown in Figure 3.10. The Mohr's circles and direct shear test results are shown in Figure 3.11 and 3.12, respectively. The consolidation test results are compiled in Attachment-3 to this part-2, and they are summarized in Figure 3.13.

The physical properties of soil samples selected for the direct shear and consolidation tests are quite similar to those of the silty soil layer. The densities are sufficiently high, but the shear strength

The physical properties of soil samples selected for the direct shear and consolidation tests are quite similar to those of the silty soil layer. The densities are sufficiently high, but the shear strength analyzed is relatively less as compared with those estimated from N values for the silty soil layer. The e - log p curves show low gradients to the right side as a whole, and the coefficient of consolidation (Cv) is as relatively high as 250 to 500 cm2/day. Therefore, the settlement of the subsurface soil layer below the embankment is expected to be rather small and to be completed during construction thereof.

3.3.5 Embankment materials for flood embankments

The borrow areas from which the embankment materials for construction of the flood embankments are to be obtained are planned to be situated in the riverward, taking the required clearance from the toe of the embankment slope that ensure their stability. In addition, the criteria adopted is that the borrow areas are allowed to be excavated to a depth of 2 m from ground surface thereat where the soil texture is mostly of the silty soil all over the area which are the most suitable as the embankment materials among those exploitable therein. The laboratory test results for soil samples taken from the auger boring (A1 to A10) are shown in Tables 3.10 and 3.11.

The availability of the soil materials as well as their engineering properties are assessed based on the results of the geotechnical investigations including boring, auger boring and test pitting, performed along the four Sections, as well as laboratory tests for the soil samples collected therefrom. Firstly, the assessments are made for each of the four Sections of embankments, however, the obtainable soil materials are found to be very similar throughout the entire area investigated in terms of their engineering properties as discussed in the foregoing Sub-section 3.3.4. Therefore, the engineering properties of the embankment materials to be used for construction of embankments are examined to determine the representative ones for the entire area investigated as described below;

(1) *Physical properties*

The specific gravity is 2.666 on average, ranging from 2.650 to 2.678. These values are in very reasonable rage concerning the sort of soils. The content ratio of fine particles is 61 % on average, although the test results show a wide range of 5 to 98 %. The grading curves show that most of the silty materials are of silty sand or sandy silt. The plasticity chart of the soil materials is shown in Figure 3.14. The consistency of the soil materials is almost non-plastic except lesser number of samples with low plasticity so that they are classified into SM or ML in accordance with the unified soil classification. The natural moisture content is 25.2 % on average, ranging from 5.2 to 46.4 %.

(2) *Compaction properties*

For the disturbed soil materials sampled from the test pits, the compaction tests were conducted under the compaction energy of 1 Ec (standard proctor energy) so as to derive the maximum dry density and optimum moisture content of the embankment materials . The compaction test results are listed in Table 3.12. Figure 3.15 shows a compaction curve of those soil materials. The maximum dry density and optimum moisture contents are derived to be 1.56 tf/m^3 and 20.0 % on average, ranging from 1.38 to 1.68 tf/m^3 and from 16.5 to 28.0 %, respectively.

(3) *Permeability*

The permeability tests were carried out for the soil material by means of the conventional falling head method, which were remolded to have the dry density equivalent to 85 % of the maximum one under 1 Ec and the moisture contents of dry and wet sides on the compaction curve worked out above,

taking into consideration that the quality of flood embankments is usually controlled in the construction stage so that the dry density comes to more than 85 % of the maximum dry density. The permeability test results are shown in Table 3.12. The coefficient of permeability ranges from 1.0 x 10^{-5} to 1.0 x 10^{-4} cm/sec in the dry side and from 1.0 x 10^{-5} to 1.4 x 10^{-4} cm/sec in the wet side. Since the coefficient of permeability is mostly less than 1.0 x 10^{-4} cm/sec, it is judged that the soil materials are sufficiently usable as the embankment materials from the permeability point of view.

(4) *Consolidation*

The confined one-dimensional consolidation tests were performed for the disturbed samples, which were compacted to have a density equivalent to 85 and 90 % of the maximum dry density and the natural moisture content. Those specimens were consolidated with six incremental loads of 0 to 8.0 kgf/cm^2 in the stress range. The consolidation test results for the remolded specimen in case of density being 85 and 90 % of the maximum dry density respectively are depicted in Figures 3.16 and 3.17, both of which show the relations between consolidation pressure and void ratio (e-log p curve), between mean consolidation pressure and coefficient of consolidation and between mean consolidation pressure and coefficient of volume change. Figure 3.18 shows those relations for the mean values in case of 85 and 90 % of the maximum dry density.

As seen in Figures 3.16 and 3.17, the e-log p curves of the compacted soil material show the similar tendency that the void ratio is less varied against increase of the consolidation pressure. This means that settlement of embankment body is not significant and that the differential settlement is not likely to occur during and after construction of the flood embankment. Besides, the coefficients of consolidation (c_v), which is an factor showing the speed of consolidation, is as relatively high as 250 to 400 cm^2/day. Hence, it is expected that settlement of the embankment body is completed during construction.

(5) *Shear strength*

Using compacted samples whose soil materials were taken from the test pits, three types of shear tests, namely; unconfined compressive strength, triaxial shear and direct shear tests, were carried out. The specimens for the unconfined compressive strength tests were made to have 85 and 90 % of the maximum dry density under 1 Ec and the natural moisture content. The specimens for triaxial shear and direct shear tests were adjusted to come to 85 % of the maximum dry density under 1 Ec with natural moisture content. Drainage conditions adopted for the triaxial and direct shear tests were the consolidated-drained (CD) condition. The test results are shown in Table 3.12. The Mohr's circles and direct shear test results for the respective specimen are shown in Attachment-4 to this Part II and summarized in Figures 3.19 and 3.20, respectively. The shear velocity during the triaxial shear tests seemed to be slightly too high for the fine particle soils. As a result, concerning the soil materials containing high fine particles content ratio the internal friction angle under the CD condition is derived to be as small as less than 10 degrees. Usually, they are ought to be at least about 20 degrees under the CD condition, and cohesion to be almost zero from the soil engineering point of view. Therefore, the test values of less than 10 degrees are discarded in deciding the design values. While, most of the direct shear test results are in a reasonable range.

3.3.6 Evaluation availability of embankment materials

Usability of the proposed embankment materials are evaluated from the various aspects. In general, embankment materials are required to have the following characteristics:

(a) Compacted materials have sufficient shearing strength,
(b) Compacted materials have imperviousness as much as possible and small compressive deformation,
(c) Handling of soil material in excavation, hauling, spreading and compaction is easy,
(d) Compacted materials is stable against change of the environment such as saturation and drying, and
(e) Material have little organic matter.

Material to satisfy the above are those well graded with coarse and fine particles. Table 3.21 gives the relation between classification of soil and relative evaluation of suitability for flood embankment in consideration of above items, which is commonly used in Japan.

The proposed embankment materials are classified into SP-SM, SM and ML. The grades of SP-SM, SM and ML are 5, 2 and 3, respectively. The materials classified into SM and ML is considered be suitable as embankment materials for flood embankments although some countermeasures may be required for the material which is classified into SP-SM. It is recommended that embankment material is to be constructed mainly with SM and ML and that soil classified as SP-SM is to be used for filter zone of the embankments body.

Table 3.1 SUMMARY OF LABORATORY TEST RESULTS ON SUBSURFACE SOIL ALONG EMBANKMENT SECTION-1 (TEESTA RIGHT EMBANKMENT)

SILTY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		10	2.660	2.673	2.667
	Gravel	(%)	10	0	0	0
Gradation	Sand	(%)	10	8	53	25
	Fine	(%)	10	47	92	75
Mean particle size	D50	(mm)	10	0.024	0.079	0.046
Liquid limit	LL	(%)	1	42	42	42
Plasticity index	PI		1	13	13	13
Natural moisture content		(%)	10	16.0	39.0	24.9

SANDY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		20	2.650	2.668	2.656
	Gravel	(%)	20	0	0	0
Gradation	Sand	(%)	20	18	97	88
	Fine	(%)	20	3	82	12
Mean particle size	D50	(mm)	20	0.042	0.190	0.156
Liquid limit	LL	(%)	0	0	0	0
Plasticity index	PI		0	0	0	0
Natural moisture content		(%)	20	5.2	35.0	24.5

Table 3.2 SUMMARY OF LABORATORY TEST RESULTS ON SUBSURFACE SOIL ALONG EMBANKMENT SECTION-2 (SOURTHEN EMBANKMENT ALONG THE GHAGOT)

SILTY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		7	2.666	2.674	2.670
	Gravel	(%)	7	0	0	0
Gradation	Sand	(%)	7	2	26	12
	Fine	(%)	7	74	98	88
Mean particle size	D50	(mm)	7	0.018	0.054	0.030
Liquid limit	LL	(%)	2	37	38	38
Plasticity index	PI		2	10	11	11
Natural moisture content		(%)	7	25.1	33.6	29.8

SANDY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		16	2.650	2.663	2.657
	Gravel	(%)	16	0	0	0
Gradation	Sand	(%)	16	61	99	82
	Fine	(%)	16	1	39	18
Mean particle size	D50	(mm)	16	0.084	0.200	0.140
Liquid limit	LL	(%)	0	0	0	0
Plasticity index	PI		0	0	0	0
Natural moisture content		(%)	16	8.1	30.3	21.1

Table 3.3 SUMMARY OF LABORATORY TEST RESULTS ON SUBSURFACE SOIL ALONG EMBANKMENT SECTION-3 (NORTHERN EMBANKMENT ALONG THE GHAGOT)

SILTY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		8	2.660	2.673	2.667
	Gravel	(%)	8	0	0	0
Gradation	Sand	(%)	8	9	56	28
	Fine	(%)	8	44	91	72
Mean particle size	D50	(mm)	8	0.023	0.083	0.050
Liquid limit	LL	(%)	1	36	36	36
Plasticity index	PI		1	8	8	8
Natural moisture content		(%)	8	12.5	32.8	24.4

SANDY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		7	2.653	2.665	2.657
	Gravel	(%)	7	0	0	0
Gradation	Sand	(%)	7	18	96	79
	Fine	(%)	7	4	82	21
Mean particle size	D50	(mm)	7	0.047	0.200	0.142
Liquid limit	LL	(%)	0	0	0	0
Plasticity index	PI		0	0	0	0
Natural moisture content		(%)	7	23.3	29.9	26.5

Table 3.4 SUMMARY OF LABORATORY TEST RESULTS ON SUBSURFACE SOIL ALONG EMBANKMENT SECTION-4 (DIKE FOR COMPARTMENTALIZATION)

SILTY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		4	2.663	2.678	2.670
	Gravel	(%)	4	0	0	0
Gradation	Sand	(%)	4	10	43	25
	Fine	(%)	4	57	90	76
Mean particle size	D50	(mm)	4	0.026	0.067	0.046
Liquid limit	LL	(%)	1	49	49	49
Plasticity index	PI		1	19	19	19
Natural moisture content		(%)	4	24.3	46.4	32.9

SANDY SOIL LAYER

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		10	2.650	2.663	2.656
	Gravel	(%)	10	0	0	0
Gradation	Sand	(%)	10	72	99	87
	Fine	(%)	10	1	28	13
Mean particle size	D50	(mm)	10	0.100	0.200	0.157
Liquid limit	LL	(%)	0	0	0	0
Plasticity index	PI		0	0	0	0
Natural moisture content		(%)	10	18.5	28.9	22.2

Table 3.5 RESULTS OF IN-SITU DENSITY TESTS

Test pit No.	Tested depth (GL- m)	Moisture content (%)	Wet density (gf/cm3)	Dry density (gf/cm3)
T1	1.00	42.7	1.58	1.11
		42.4	1.56	1.10
		(42.6)	(1.57)	(1.11)
	1.75	23.1	1.67	1.35
		24.6	1.66	1.33
		(23.9)	(1.67)	(1.34)
T2	1.00	33.8	1.69	1.26
		35.9	1.63	1.20
		(34.9)	(1.66)	(1.23)
	1.75	39.7	1.64	1.17
		38.4	1.59	1.15
		(39.1)	(1.62)	(1.16)
T3	1.00	30.3	1.56	1.19
		28.9	1.58	1.22
		(29.6)	(1.57)	(1.21)
	2.00	9.4	1.41	1.29
		9.1	1.39	1.27
		(9.3)	(1.40)	(1.28)
T4	1.00	13.1	1.41	1.24
		13.3	1.40	1.24
		(13.2)	(1.41)	(1.24)
	2.00	21.1	1.63	1.35
		24.0	1.78	1.43
		(22.6)	(1.71)	(1.39)
T5	1.00	33.0	1.81	1.36
		30.9	1.80	1.38
		(32.0)	(1.81)	(1.37)
	1.75	32.2	1.84	1.39
		30.5	1.83	1.40
		(31.4)	(1.84)	(1.40)
T6	1.00	23.5	1.45	1.17
		18.3	1.35	1.14
		(20.9)	(1.40)	(1.16)
	1.75	32.7	1.72	1.30
		40.6	1.70	1.21
		(36.7)	(1.71)	(1.26)
T7	1.00	38.6	1.63	1.17
		34.5	1.61	1.19
		(36.6)	(1.62)	(1.18)
	2.00	25.9	1.58	1.25
		29.3	1.63	1.26
		(27.6)	(1.61)	(1.26)
Average		(28.6)	(1.61)	(1.25)

Numbers in ( ) are mean values of the test results.

Table 3.6 RESULTS OF IN-SITU PERMEABILITY TESTS

Borehole No.	Tested depth (GL- m)	GWL (GL- m)	Coefficient of permeability (cm/sec.)
B3	3.00	0.54	1.19E-2
B3'	6.00	5.65	1.73E-3
B4	3.00	1.89	2.50E-4
B7	3.00	2.60	4.91E-4
B10	3.00	2.67	7.18E-4
B11	3.00	2.84	1.13E-3
B12	3.00	0.87	2.73E-3
B13	3.00	0.92	8.12E-4

Table 3.7 RESULTS OF LABORATORY TESTS (UNDISTURBED SAMPLES)

			B4	B9	B11	B12	B13
Borehole No.			B4	B9	B11	B12	B13
Sample No.			U1	U1	U1	U1	U1
Depth			2.08 to 2.54	4.08 to 4.54	1.08 to 1.54	0.58 to 1.04	0.54 to 1.00
Specific gravity	Gs		2.672	2.682	2.683	2.673	2.674
Gradation	Gravel	(%)	0	0	0	0	0
	Sand	(%)	3	7	4	1	9
	Fine	(%)	97	93	94	99	91
Mean particle size	D50	(mm)	0.019	0.010	0.010	0.016	0.015
Liquid limit	LL	(%)	43	40	43	46	32
Plasticity index	PI		14	16	17	20	6
Unified soil classification			ML	ML	CL	CL	ML
Natural moisture content		(%)	28.2	29.0	29.9	41.8	29.0
Wet density		(gf/cm3)	1.833	1.819	1.777	1.740	1.840
Dry density		(gf/cm3)	1.430	1.410	1.368	1.227	1.426
Unconfined compressive strength		(kgf/cm2)	0.69	0.75	0.61	0.25	0.74
Triaxial shear (effective stress)							
cohesion	c'	(kgf/cm2)	0.29	0.23	0.18	0.17	0.28
internal friction angle	ϕ	(degrees)	26.7	28.6	20.8	31.4	33.0
Direct shear (CU condition)							
cohesion	cu0	(kgf/cm2)	0.25	0.30	0.21	0.14	0.21
rate of strength increase	cu/p		0.105	0.133	0.132	0.123	0.166

Table 3.8 DESIGN VALUES OF EMBANKMENT MATERIALS FOR NEW CONSTRUCTION OF EMBANKMENT

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		40	2.650	2.678	2.666
	Gravel	(%)	40	0	0	0
Gradation	Sand	(%)	40	2	95	39
	Fine	(%)	40	5	98	61
Mean particle size	D50	(mm)	40	0.018	0.19	0.069
Liquid limit	LL	(%)	9	33	49	39
Plasticity index	PI		9	8	19	11
Natural moisture content		(%)	40	5.2	46.4	25.2

Table 3.9 REPRESENTATIVE ENGINEERING PROPERTIES OF EMBANKMENT MATERIAL USED FOR EXISTING EMBANKMENT MATERIALS

Sample No.			No.	Min.	Max.	Average
Specific gravity	Gs		11	2.600	2.674	2.658
	Gravel	(%)	11	0	0	0
Gradation	Sand	(%)	11	5	90	45
	Fine	(%)	11	10	95	55
Mean particle size	D50	(mm)	11	0.02	0.16	0.075
Liquid limit	LL	(%)	3	36	43	38
Plasticity index	PI		3	9	13	11
Natural moisture content		(%)	11	6.4	41.7	18.7

Table 3.10 RESULTS OF LABORATORY TESTS ON SOIL SAMPLE TAKEN FROM AUGER BORING A1 to A5

Auger Borehole No.			A1	A1	A1	A2	A2	A2	A3	A3	A3	A4	A4	A4	A5	A5	A5
Sample No.			D1	D3	D5	D1	D3	D5	D1	D3	D5	D1	D3	D5	D1	D3	D5
Depth			0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00
Specific gravity	Gs		2.658	2.658	2.657	2.673	2.660	2.657	2.670	2.668	2.664	2.668	2.661	2.659	2.675	2.668	2.674
	Gravel	(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gradation	Sand	(%)	90	62	82	4	48	90	35	31	65	19	49	58	2	25	2
	Fine	(%)	10	38	18	96	52	10	65	69	35	81	51	42	98	75	98
Mean particle size	D50	(mm)	0.13	0.091	0.12	0.021	0.072	0.18	0.059	0.050	0.093	0.037	0.071	0.086	0.023	0.052	0.020
Liquid limit	LL	(%)	NP	NP	NP	35	NP	NP	NP	NP	NP	NP	NP	NP	36	NP	37
Plasticity index	PI		-	-	-	8	-	-	-	-	-	-	-	-	8	-	9
Unified soil classification			SP-SM	SM	SM	ML	ML	SP-SM	ML	ML	SM	ML	ML	SM	ML	ML	ML
Natural moisture content		(%)	26.1	27.4	27.8	25.3	25.3	28.2	32.9	31.9	26.0	30.0	26.6	33.0	28.8	27.5	34.3

Table 3.11 RESULTS OF LABORATORY TESTS ON SOIL SAMPLE TAKEN FROM AUGER BORING A6 to A10

Auger Borehole No.			A6	A6	A6	A7	A7	A7	A8	A8	A8	A9	A9	A9	A10	A10	A10
Sample No.			D1	D3	D5	D1	D3	D5	D1	D3	D5	D1	D3	D5	D1	D3	D5
Depth			0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00	0.50 to 1.00	2.50 to 3.00	4.50 to 5.00
Specific gravity	Gs		2.663	2.668	2.667	2.666	2.672	2.660	2.661	2.666	2.667	2.666	2.660	2.674	2.668	2.672	2.670
	Gravel	(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gradation	Sand	(%)	58	78	37	38	2	50	50	33	40	38	73	2	7	9	12
	Fine	(%)	42	22	63	62	98	50	50	67	60	62	27	98	93	91	88
Mean particle size	D50	(mm)	0.084	0.12	0.054	0.060	0.022	0.074	0.074	0.053	0.061	0.059	0.10	0.022	0.019	0.022	0.033
Liquid limit	LL	(%)	NP	NP	NP	NP	36	NP	NP	NP	NP	NP	NP	NP	NP	35	NP
Plasticity index	PI		-	-	-	-	8	-	-	-	-	-	-	-	-	7	-
Unified soil classification			SM	SM	ML	ML	ML	SM/ML	SM/ML	ML	ML	ML	SM	ML	ML	ML	ML
Natural moisture content		(%)	17.8	16.4	18.3	23.9	34.2	25.0	15.7	24.7	28.2	14.9	16.9	36.2	28.2	23.9	23.7

Table 3.12 RESULTS OF LABORATORY TESTS ON SOIL SAMPLE TAKEN FROM TEST PITS

Test pit No.			T1	T1	T2	T2	T3	T3	T4	T4	T5	T5	T6	T6	T7	T7
Depth			1.00	1.75	1.00	1.75	1.00	2.00	1.00	2.00	1.00	1.75	1.00	1.75	1.00	2.00
Specific gravity	Gs		2.673	2.654	2.672	2.665	2.672	2.662	2.652	2.650	2.671	2.660	2.653	2.669	2.675	2.668
	Gravel	(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gradation	Sand	(%)	10	95	6	16	27	69	93	94	42	76	95	38	4	23
	Fine	(%)	90	5	94	84	73	31	7	6	58	24	5	62	96	77
Mean particle size	D50	(mm)	0.039	0.17	0.019	0.041	0.047	0.097	0.16	0.19	0.066	0.11		0.055	0.018	0.050
Liquid limit	LL	(%)	42	NP	35	NP	33	NP	NP	NP	NP	NP	NP	NP	37	NP
Plasticity index	PI		14	-	9	-	8	-	-	-	-	-	-	-	9	-
Unified soil classification			ML	SP-SM	ML	ML	ML	SM	SP-SM	SP-SM	ML	SM	SP-SM	ML	ML	ML
Natural moisture content		(%)	41.8	22.4	33.1	38.6	29.9	9.4	12.8	20.9	32.6	32.1	23.0	32.0	37.9	26.8
Compaction																
optimum moisture content		(%)	28.0	16.5	25.3	23.3	18.8	19.0	17.5	17.5	17.2	17.5	18.7	17.5	25.0	18.5
max. dry density		(gf/cm3)	1.38	1.51	1.50	1.51	1.68	1.57	1.51	1.52	1.66	1.65	1.62	1.62	1.49	1.59
Permeability																
dry side on compaction curve		(cm/sec.)	1.0E-5			2.1E-5	1.5E-5		1.6E-4		7.2E-5			8.9E-5		1.8E-5
wet side on compaction curve		(cm/sec.)	1.0E-5			2.0E-5	1.4E-5		1.4E-4		7.2E-5			7.1E-5		1.8E-5
Unconfined compressive strength																
85% of max. dry density		(kgf/cm2)	0.22		0.34	0.19	0.22				0.15			0.26	0.39	0.17
90% of max. dry density		(kgf/cm2)	0.29		0.42	0.25	0.35				0.25			0.31	0.50	0.20
Triaxial shear (CD condition)																
cohesion	cd	(kgf/cm2)	0.15		0.16					0.02	0.04		0.02		1.48	
internal friction angle	d	(degrees)	7.6		9.0					29.8	27.8		31.7		8.4	
Direct shear (CD condition)																
cohesion	cd	(kgf/cm2)		0.04		0.07		0.04	0.06	0.03	0.08	0.06	0.04	0.11		0.12
internal friction angle	d	(degrees)		29.8		20.8		28.6	27.9	29.8	25.6	28.7	30.2	25.7		22.4

Table 3.13 EVALUATION ON AVAILABILITY OF EMBANKMENT MATERIAL

Classification of Soils	Kinds of Soils	Grade of Evaluation for Flood Embankments
-	Rocks	-
-	Boulders	-
GW, GP	Gravels	6
GM, GC	Silty/clayey Gravels	1
SW, SP	Sands	5
SM, SC	Silty/clayey Sands	2
ML, CL, OL	Low Plasticity Soils	3
MH, CH, OH	High Plasticity Soils	4
Pt	Organic Soils	7

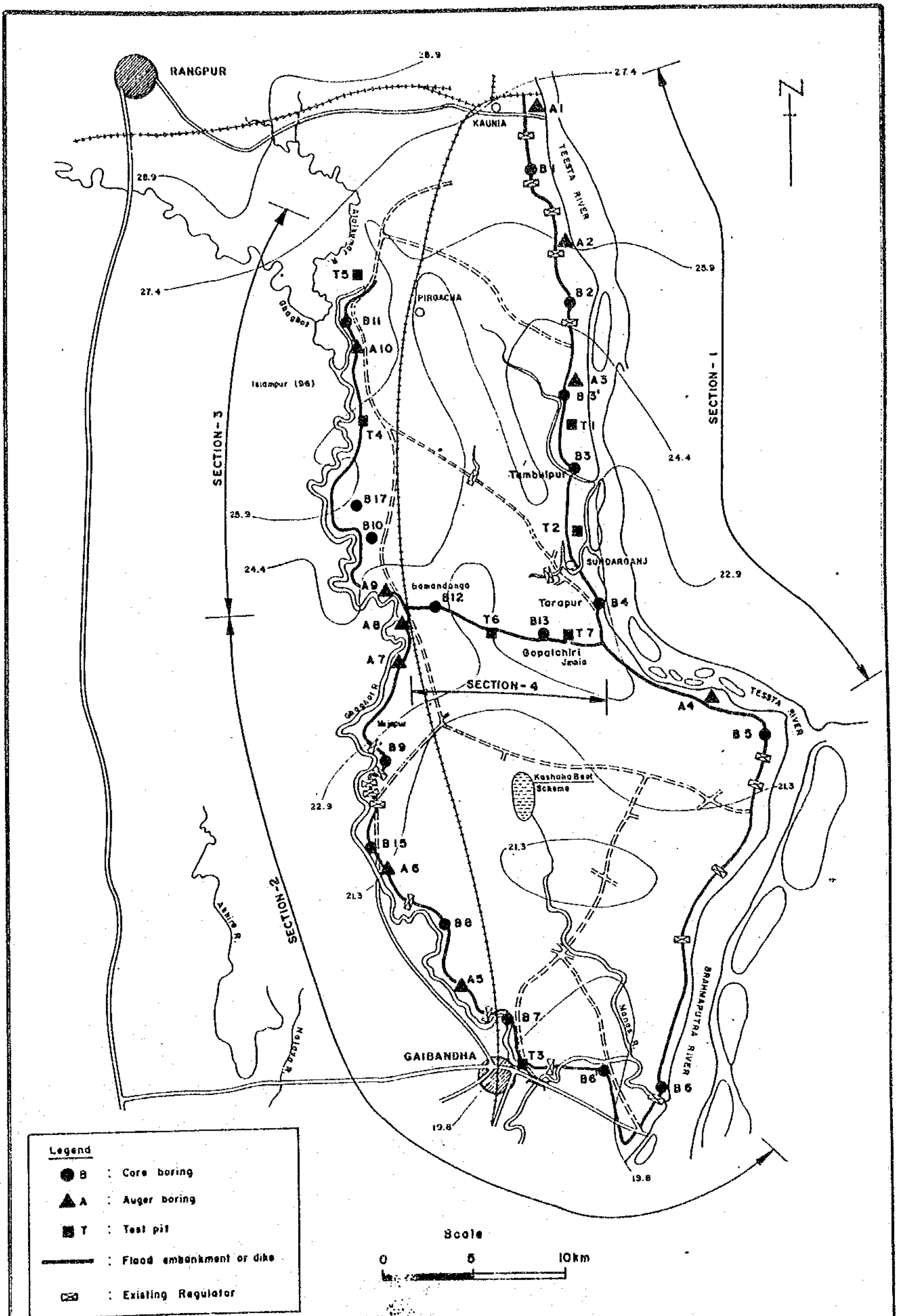


Figure 3.1 LOCATION OF GEOTECHNICAL INVESTIGATION WORKS PERFORMED FOR GIP

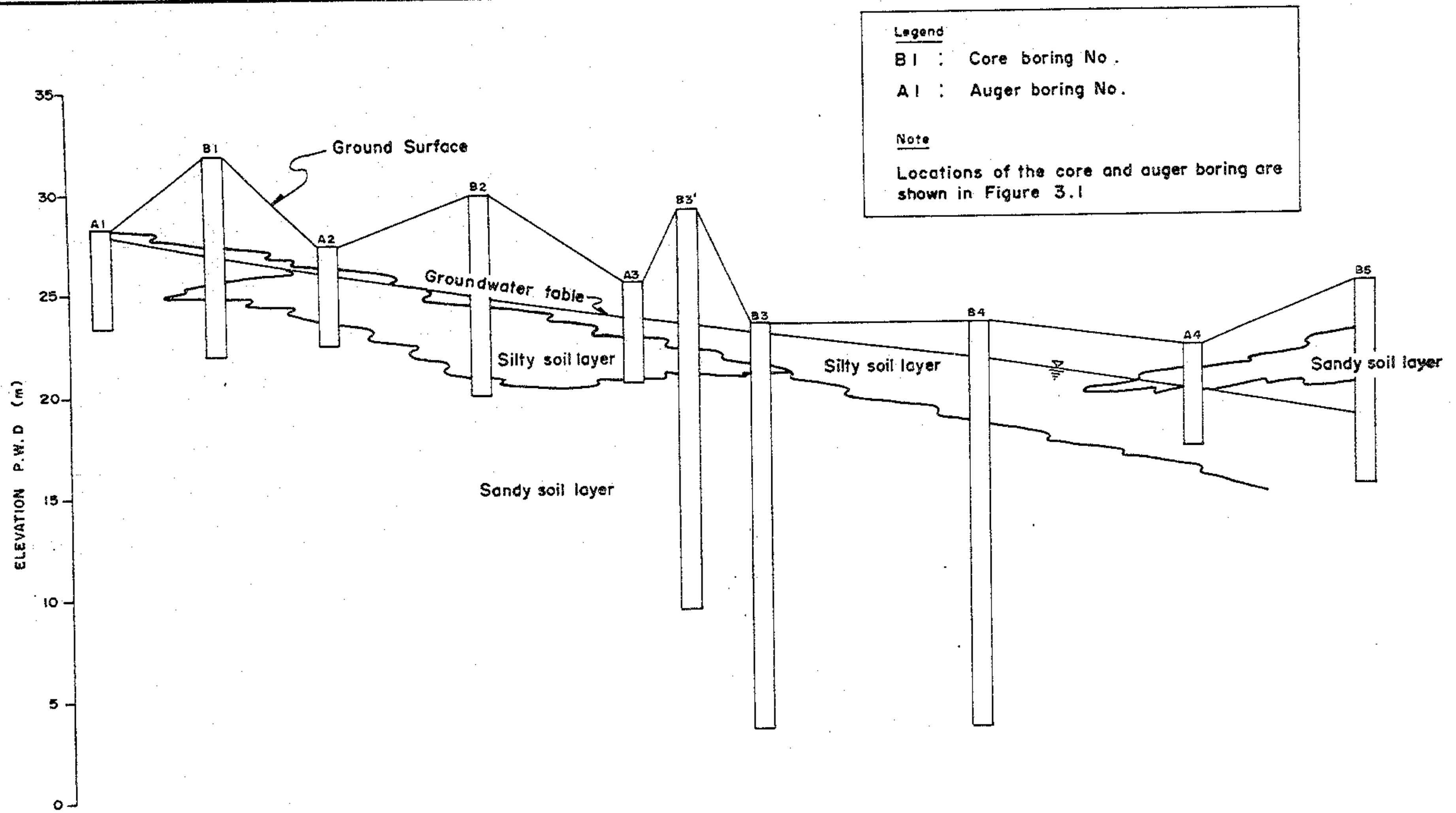


Figure 3.2 SOIL PROFILE ALONG EMBANKMENT SECTION-1
(TEESTA RIGHT EMBANKMENT)

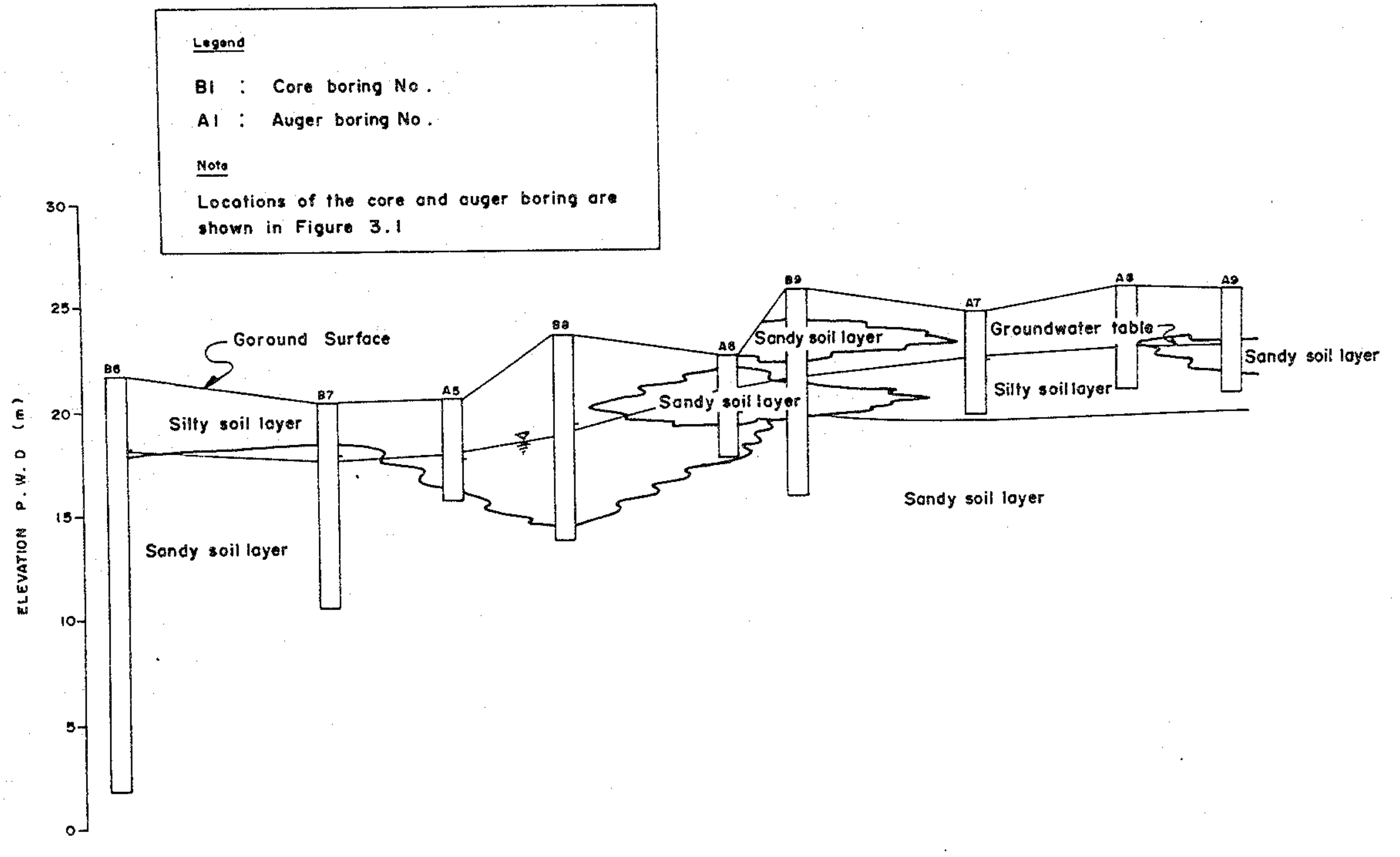


Figure 3.3 SOIL PROFILE ALONG EMBANKMENT SECTION-2
(SOUTHERN EMBANKMENT ALONG THE GHAGOT)

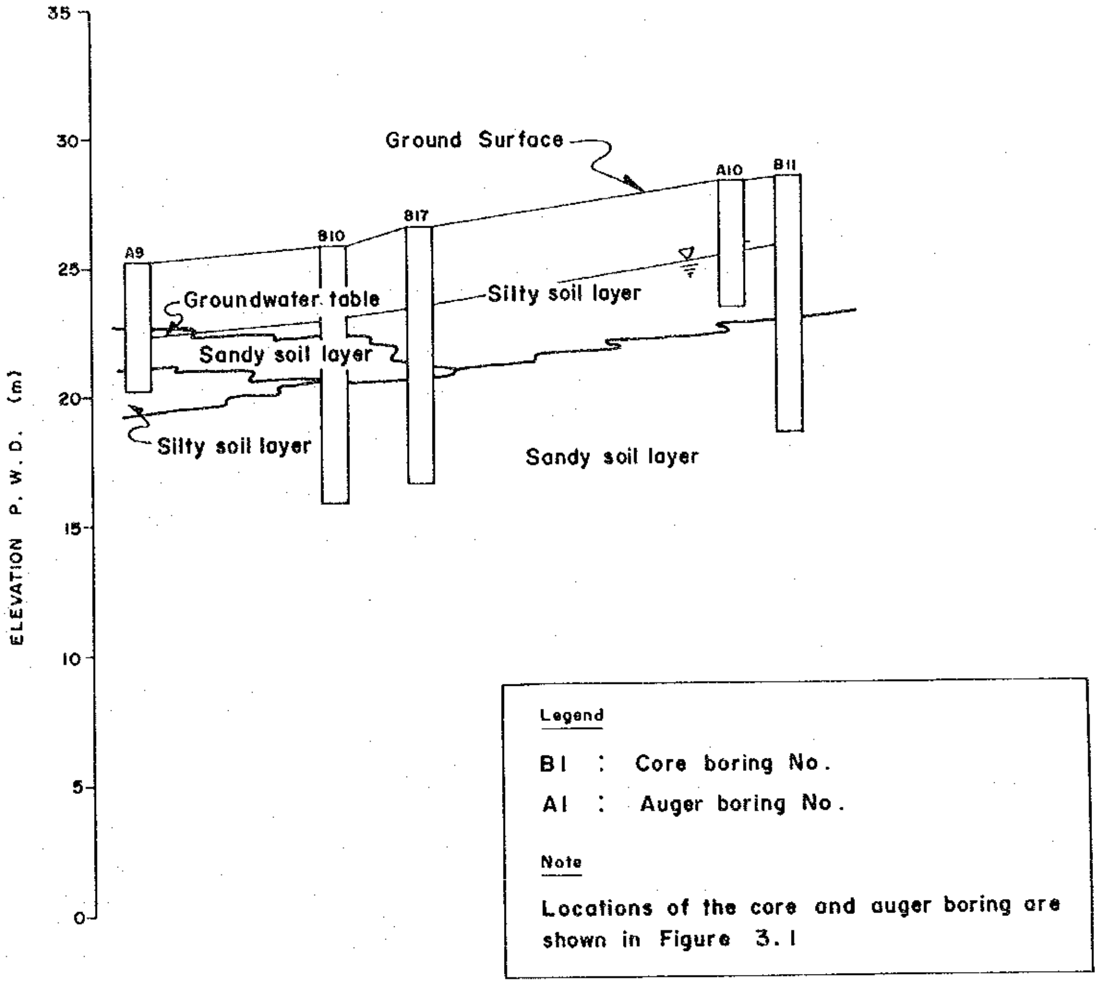


Figure 3.4 SOIL PROFILE ALONG EMBANKMENT SECTION-3 (NORTHERN EMBANKMENT ALONG THE GHAGOT)

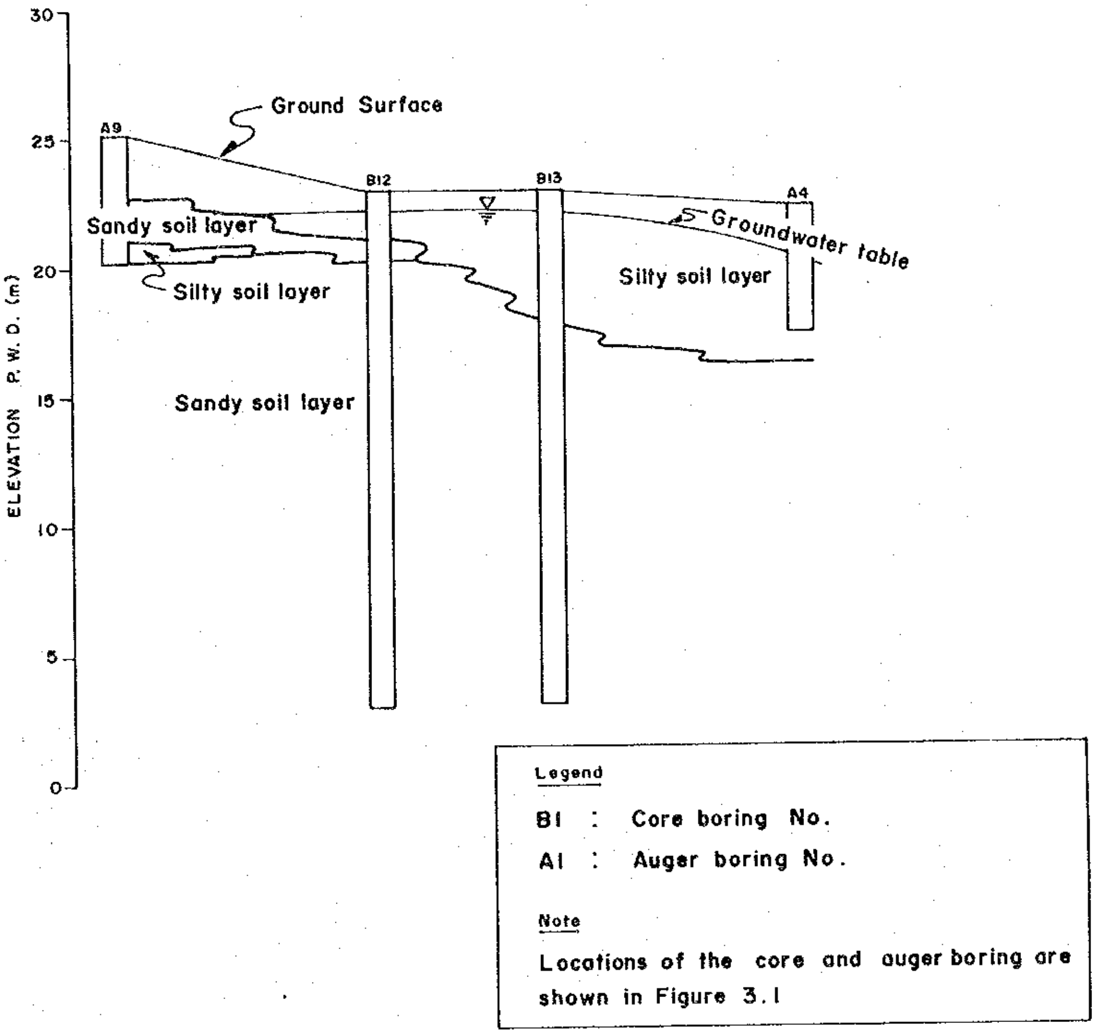


Figure 3.5 SOIL PROFILE ALONG EMBANKMENT SECTION-4 (DIKE FOR COMPARTMENTALIZATION)

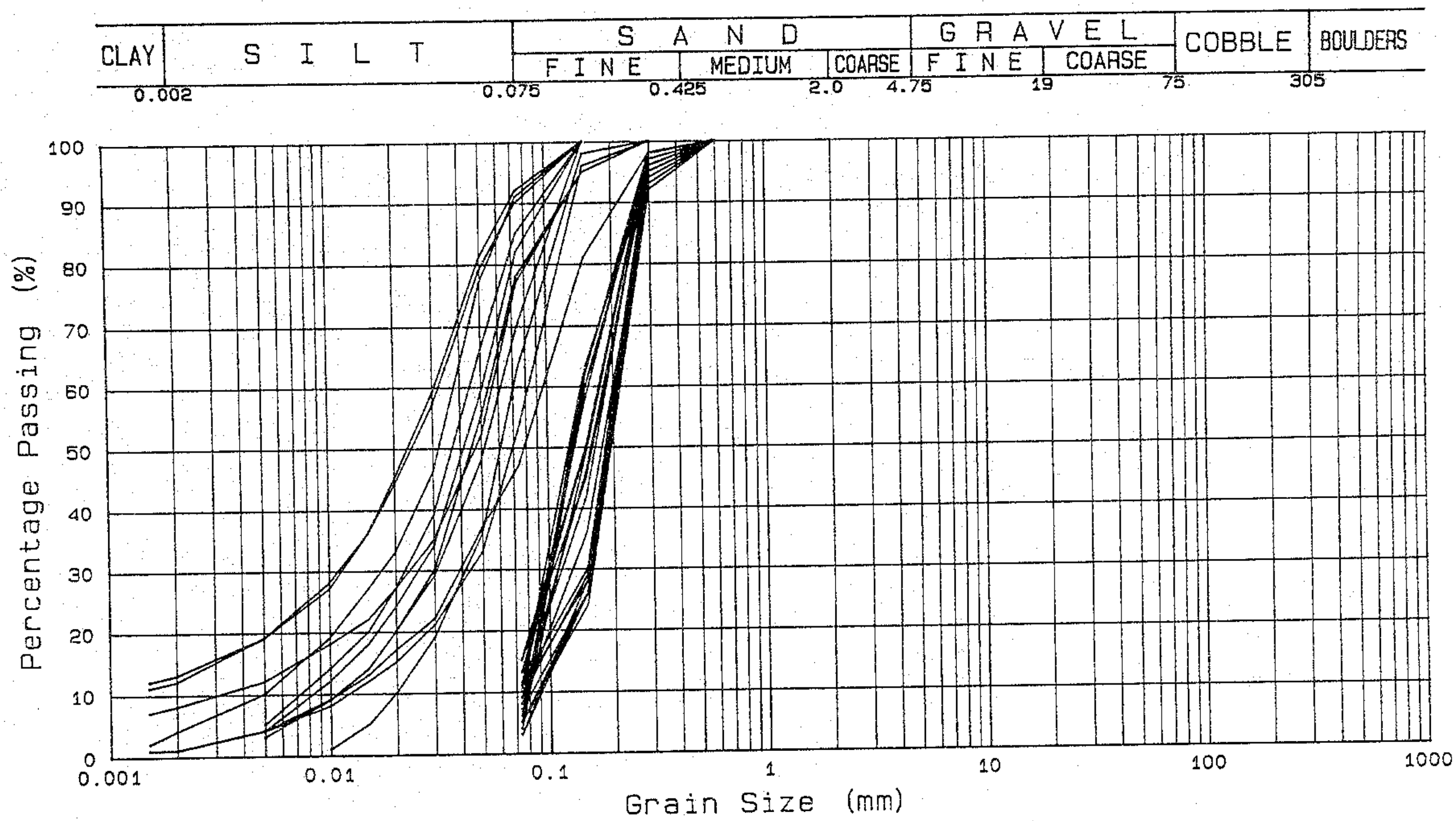


Figure 3.6 GRADING CURVE OF SUBSURFACE SOIL ALONG EMBANKMENT SECTION-1 (TEESTA RIGHT EMBANKMENT)

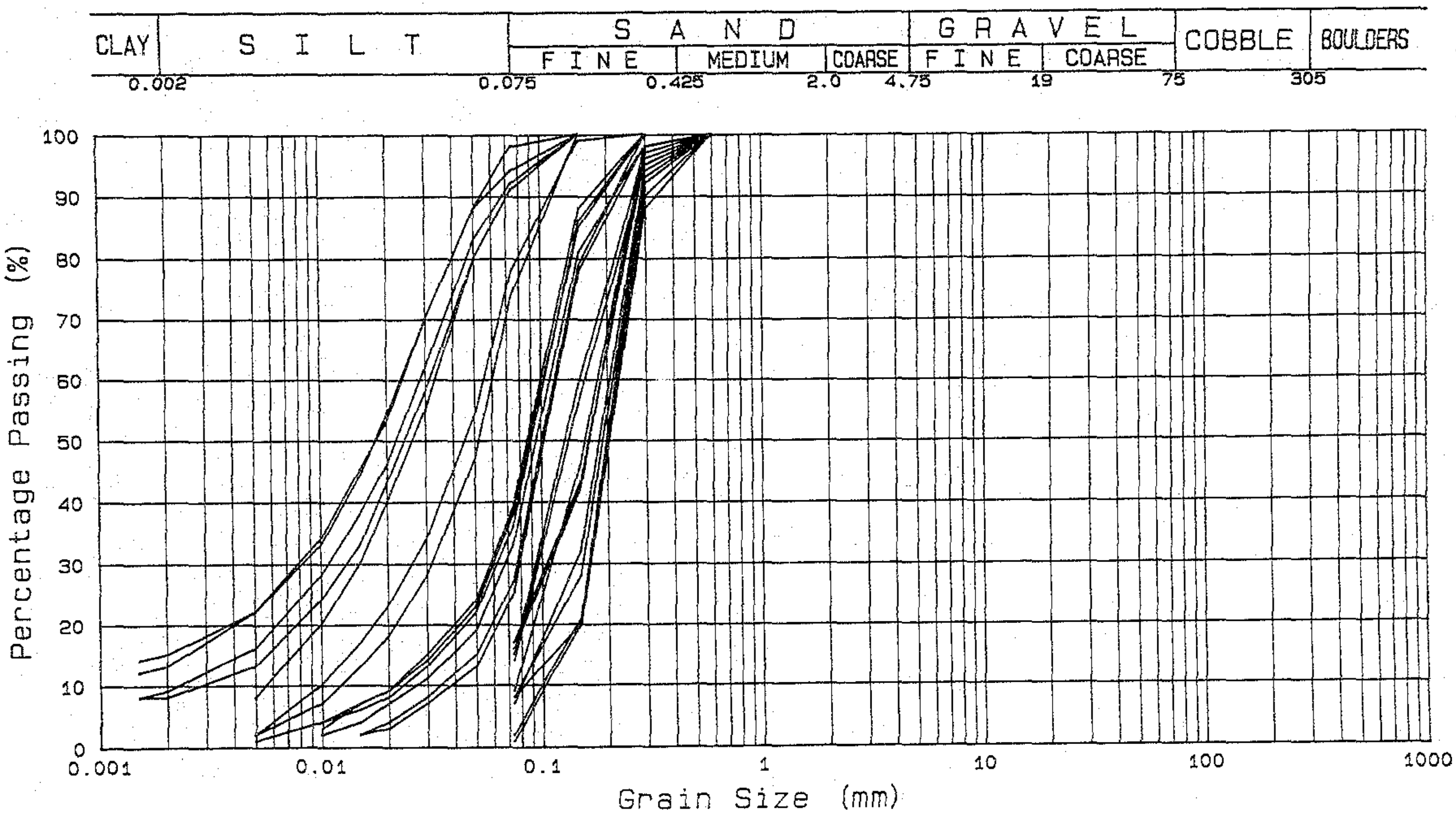


Figure 3.7 GRADING CURVE OF SUBSURFACE SOIL ALONG EMBANKMENT SECTION-2 (SOUTHERN EMBANKMENT ALONG THE GHAGOT)

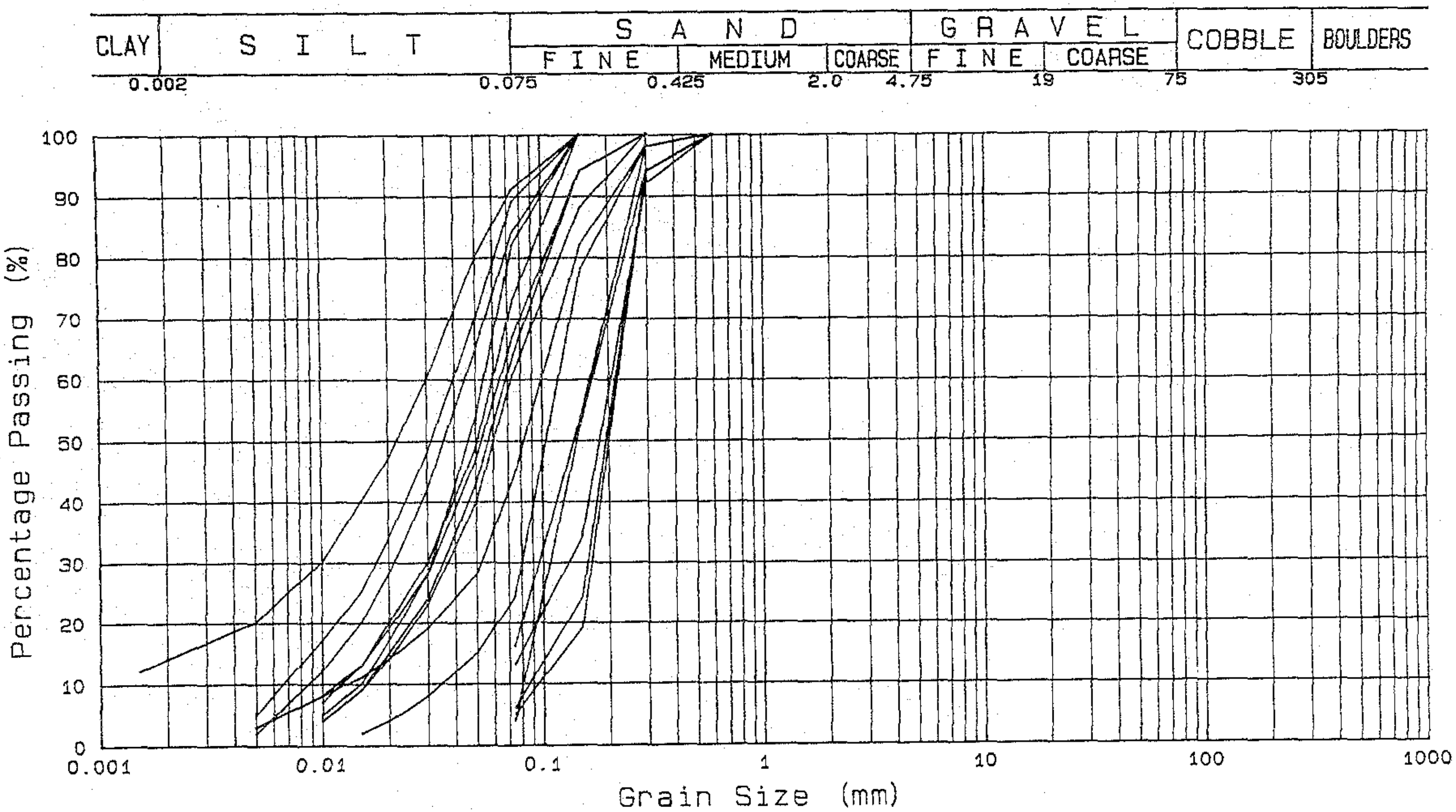


Figure 3.8 GRADING CURVE OF SUBSURFACE SOIL ALONG EMBANKMENT SECTION-3 (NORTHERN EMBANKMENT ALONG THE GHAGOT)

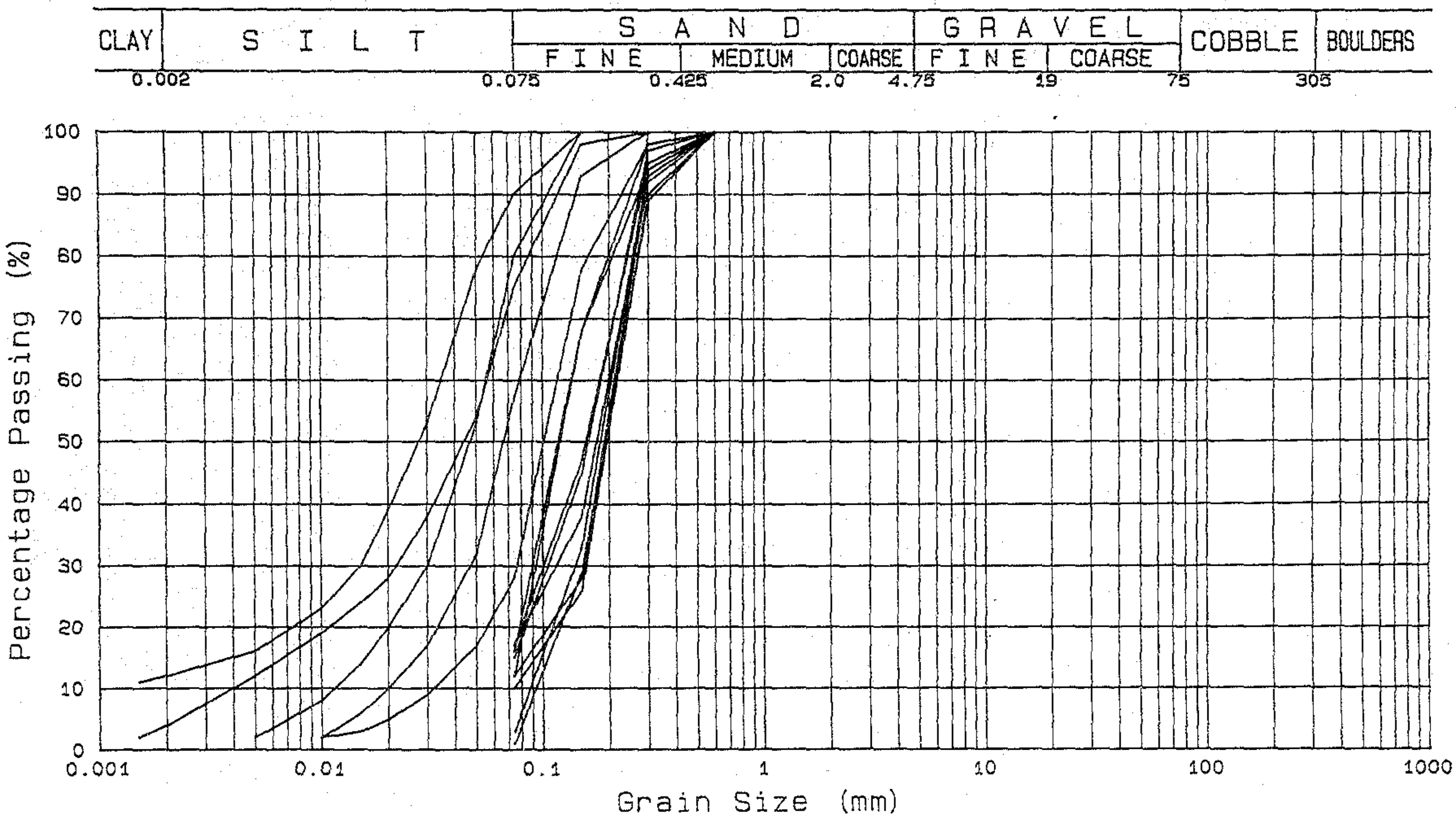


Figure 3.9 GRADING CURVE OF SUBSURFACE SOIL ALONG EMBANKMENT SECTION-4 (DIKE FOR COMPARTMENTALIZATION)

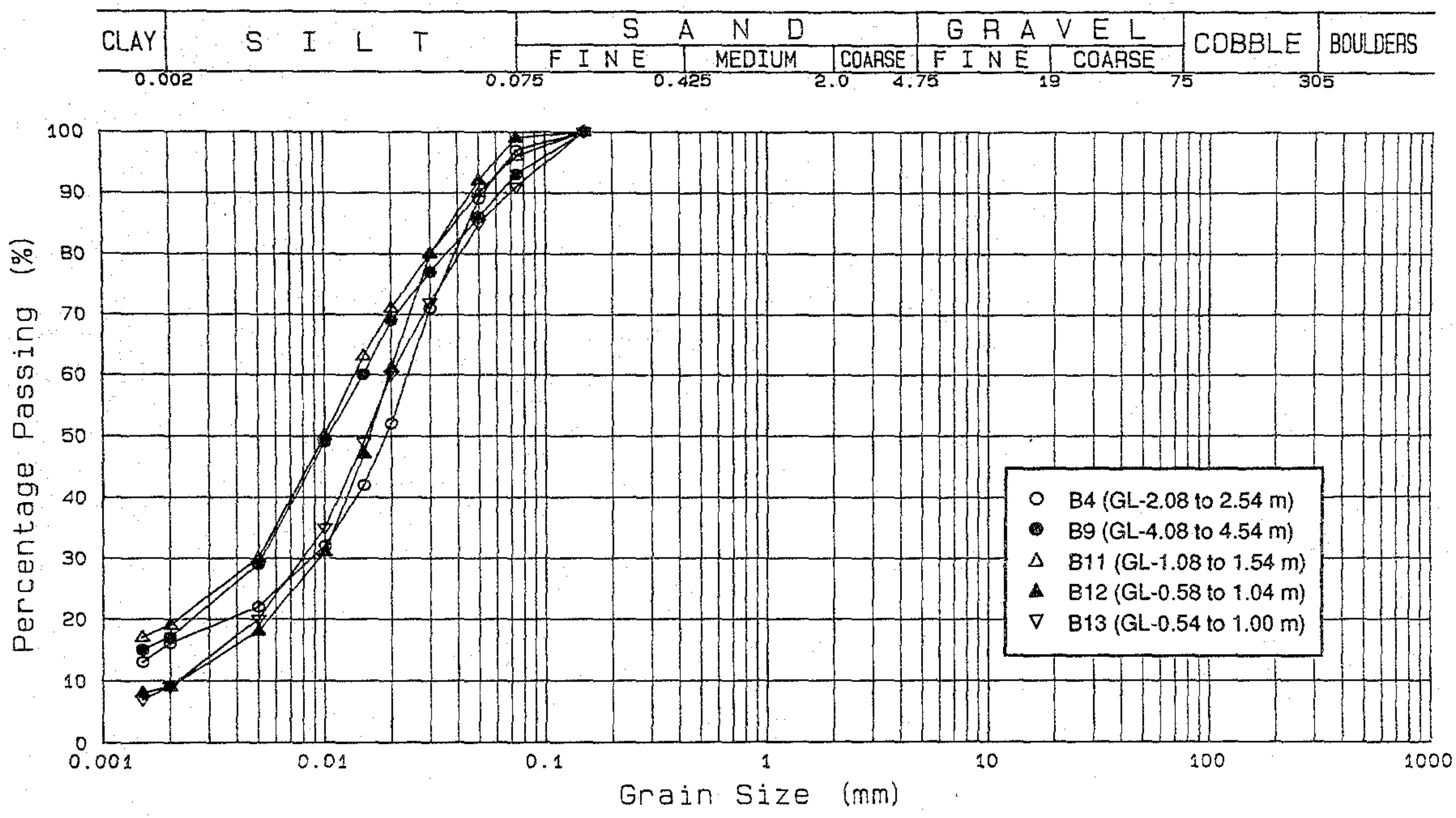


Figure 3.10 GRADING CURVES OF UNDISTURBED SOIL SAMPLES

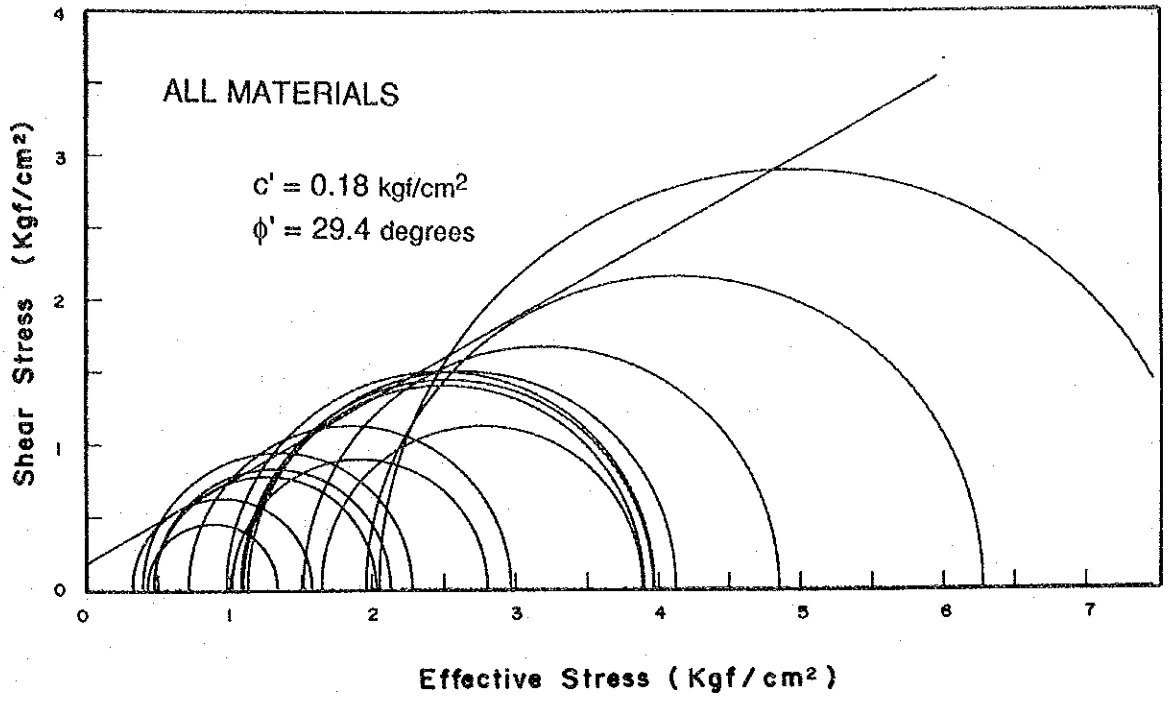


Figure 3.11 MOHR'S CIRCLES OF UNDISTURBED SOIL SAMPLES

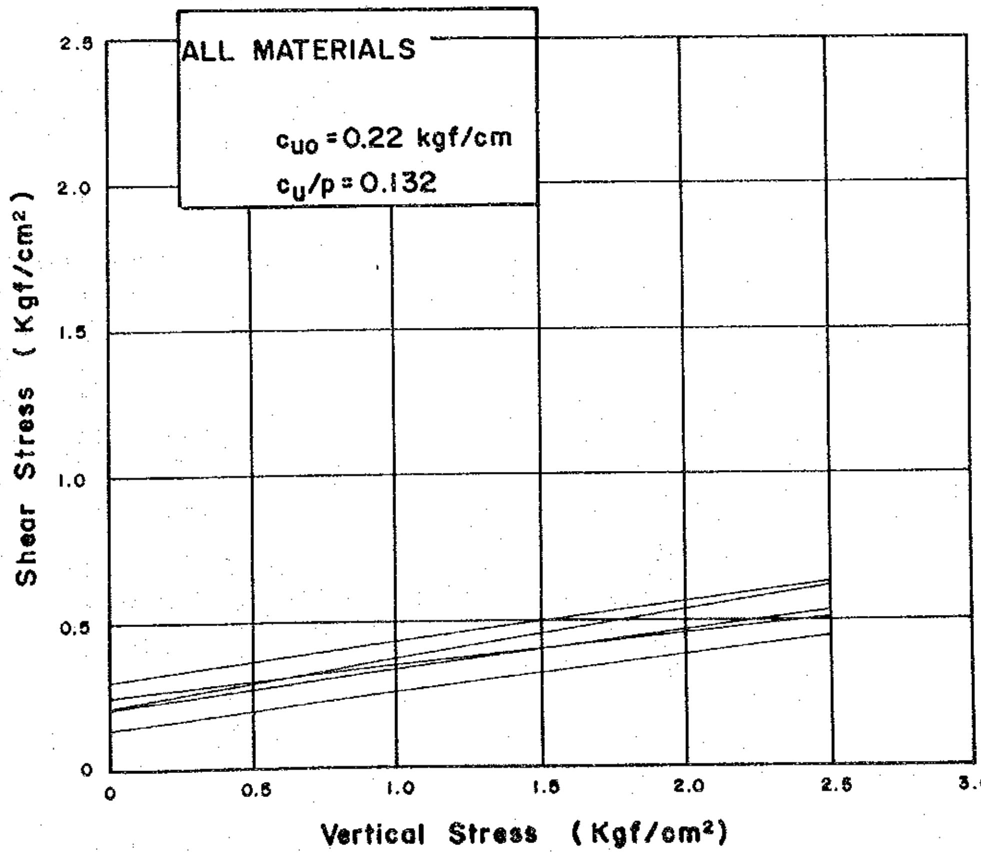


Figure 3.12 DIRECT SHEAR TEST RESULT ON UNDISTURBED SOIL SAMPLES

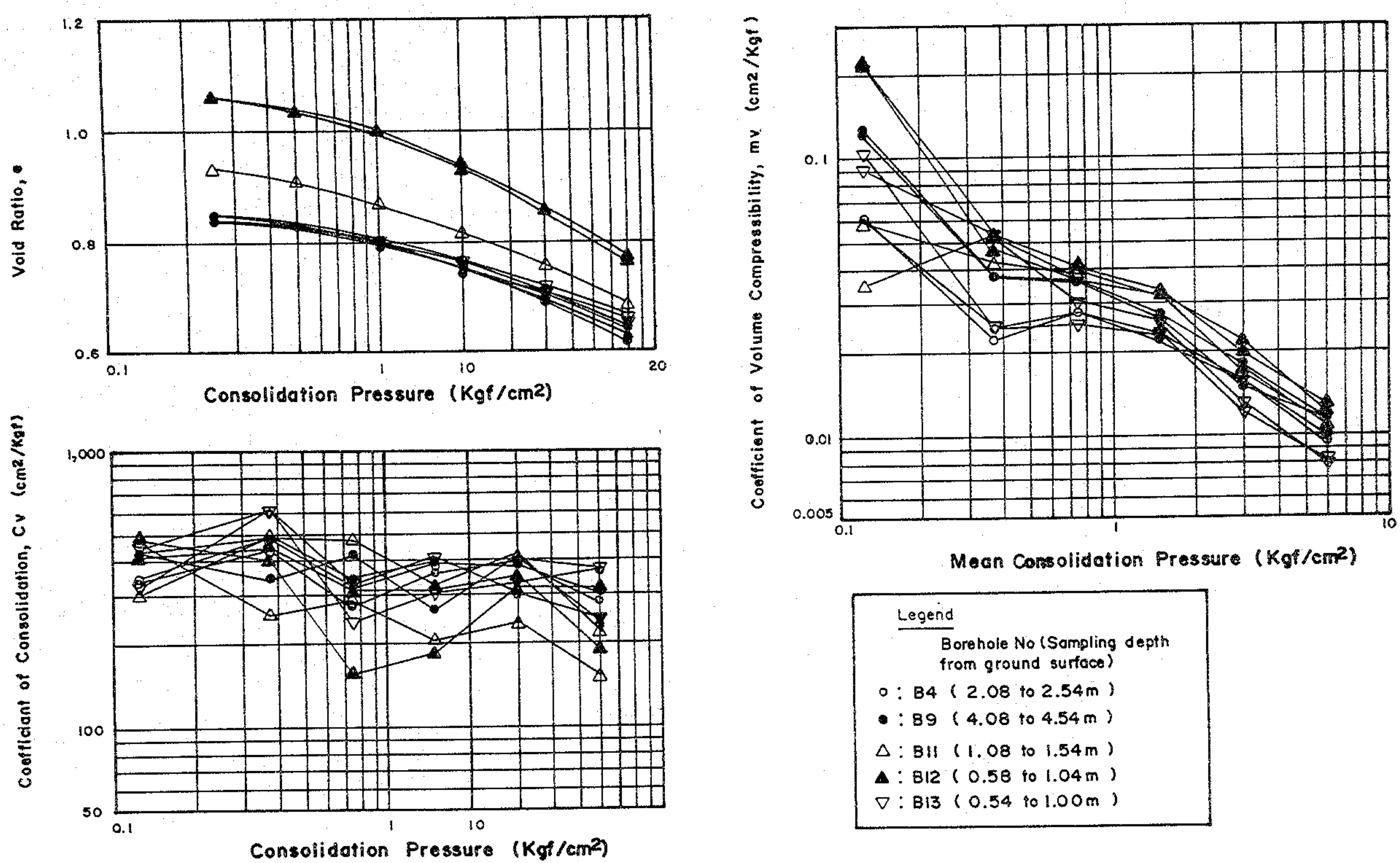


Figure 3.13 CONSOLIDATION TEST RESULT OF UNDISTURBED SOIL SAMPLES

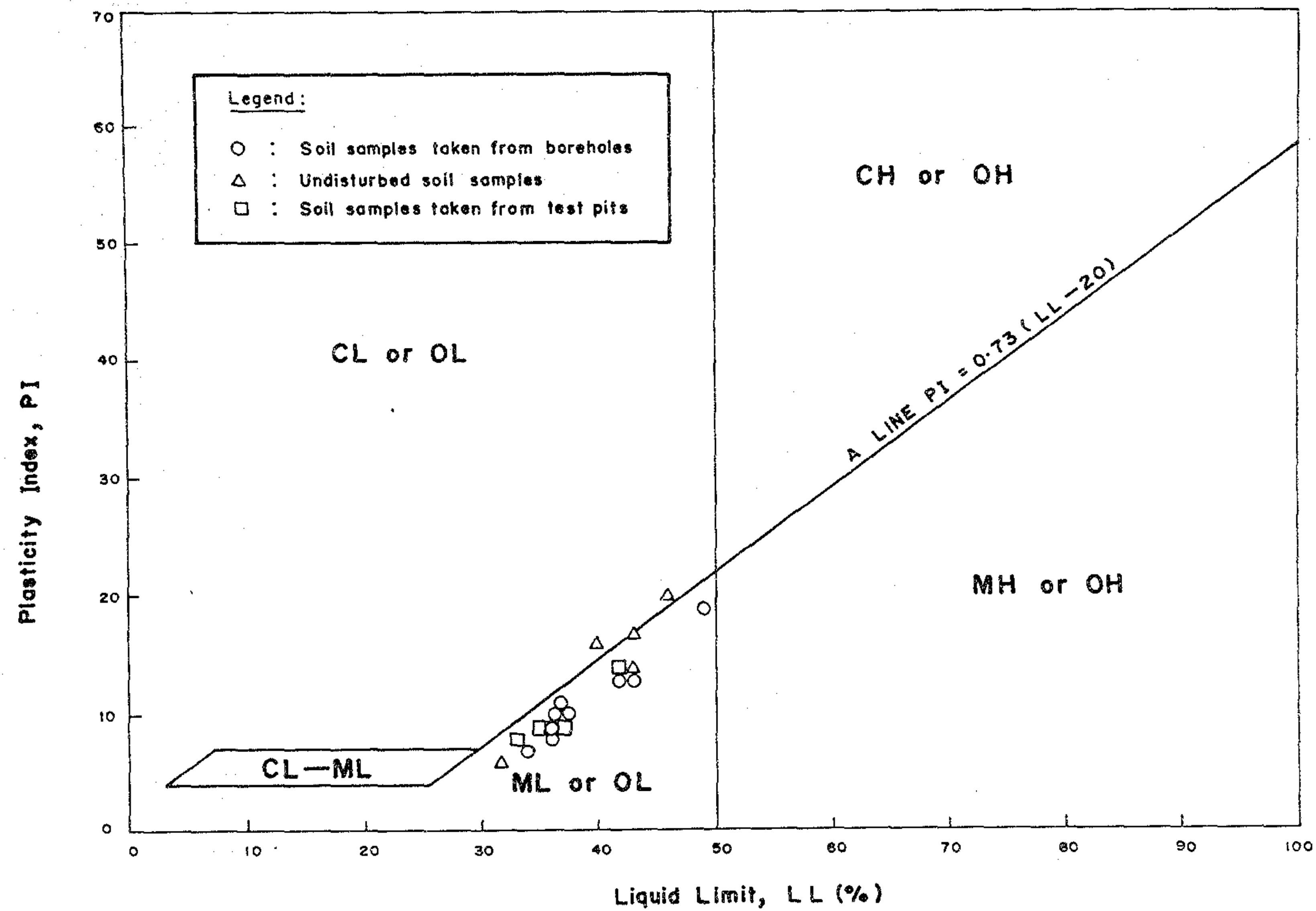


Figure 3.14 PLASTICITY CHART

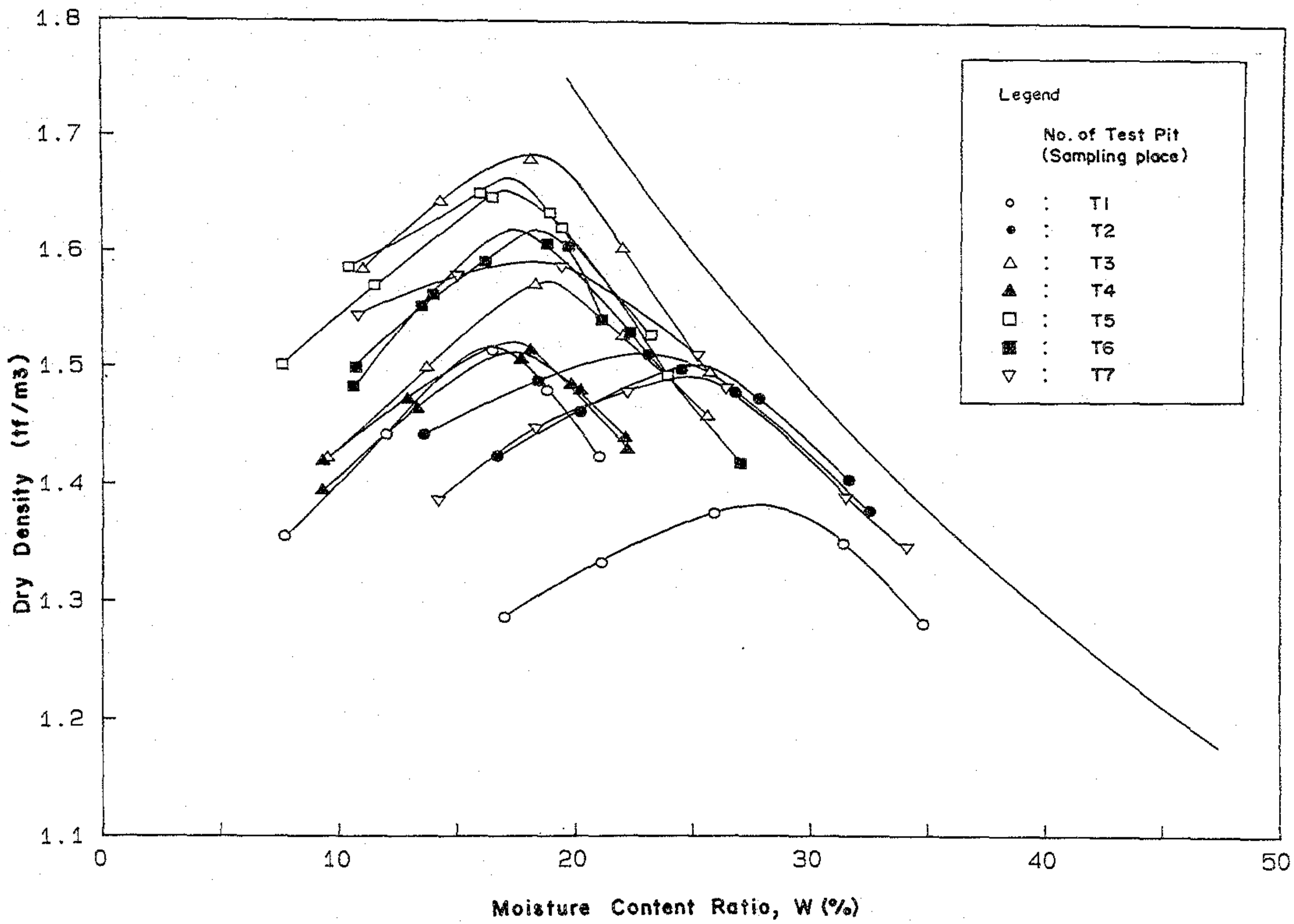


Figure 3.15 COMPACTION CURVE

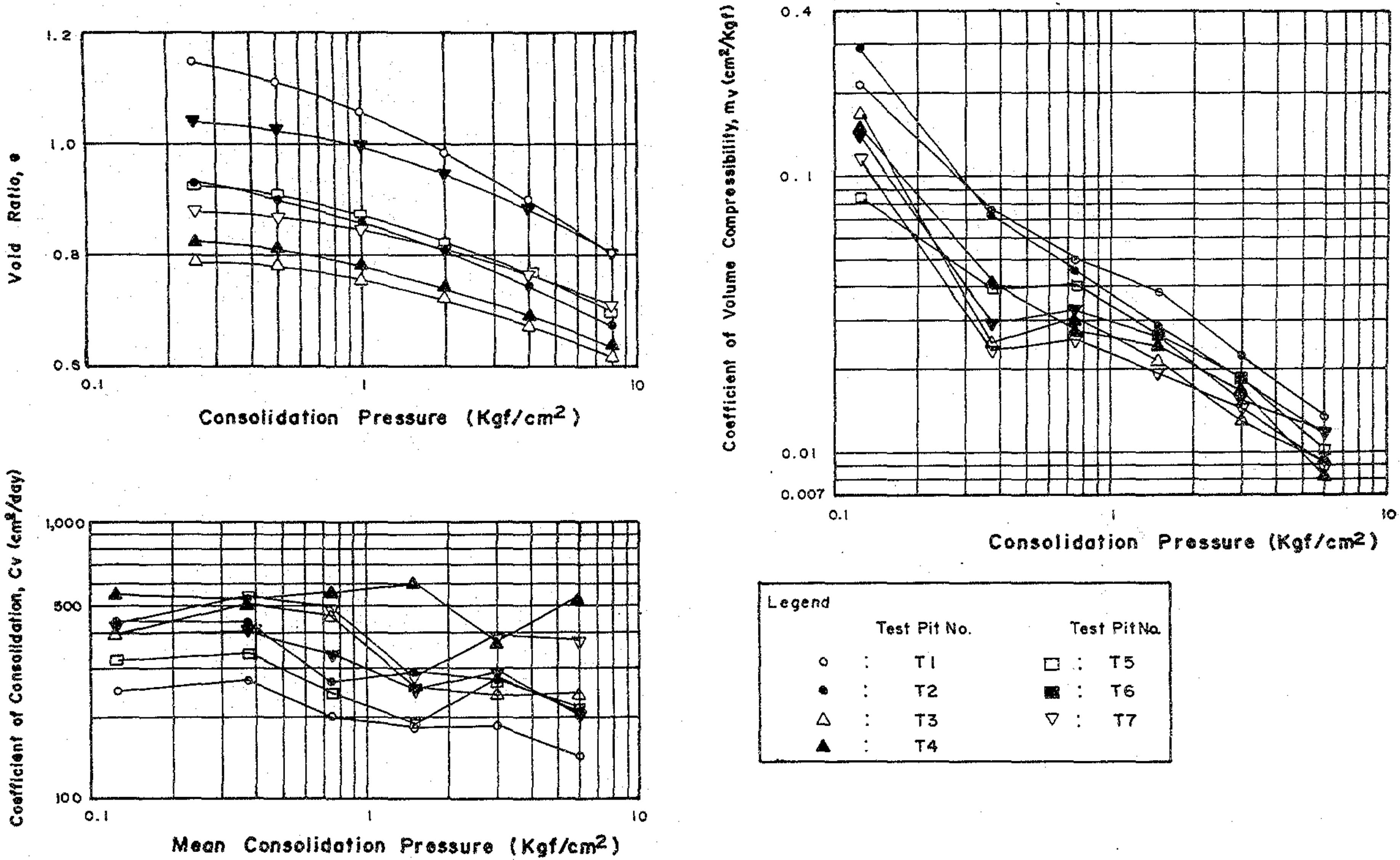


Figure 3.16 CONSOLIDATION TEST RESULT ON REMOLDED SOIL SAMPLES IN CASE OF 85% OF MAXIMUM DRY DENSITY UNDER 1 E_C

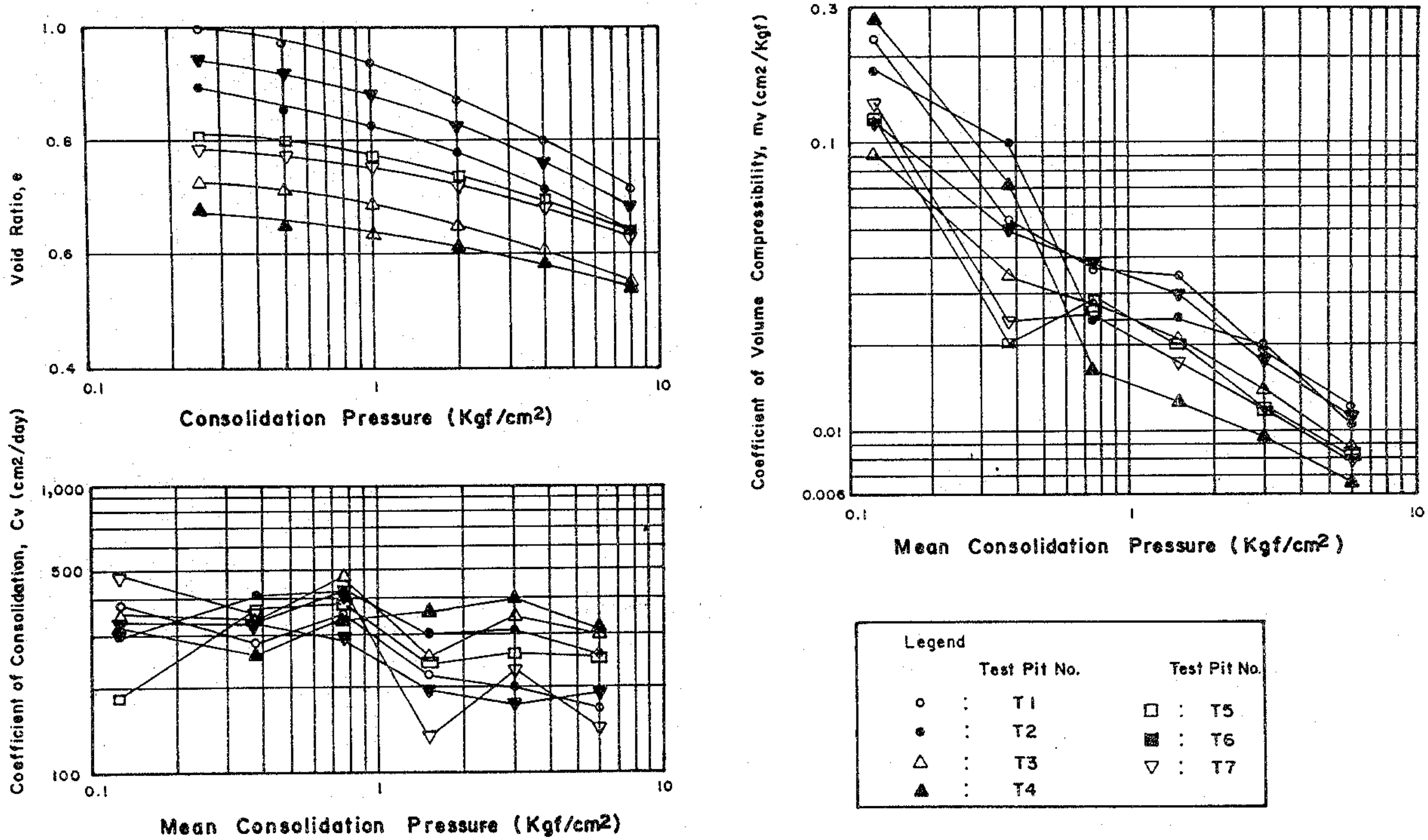


Figure 3.17 CONSOLIDATION TEST RESULT ON REMOLDED SOIL SAMPLES IN CASE OF 90% OF MAXIMUM DRY DENSITY UNDER 1 E_C

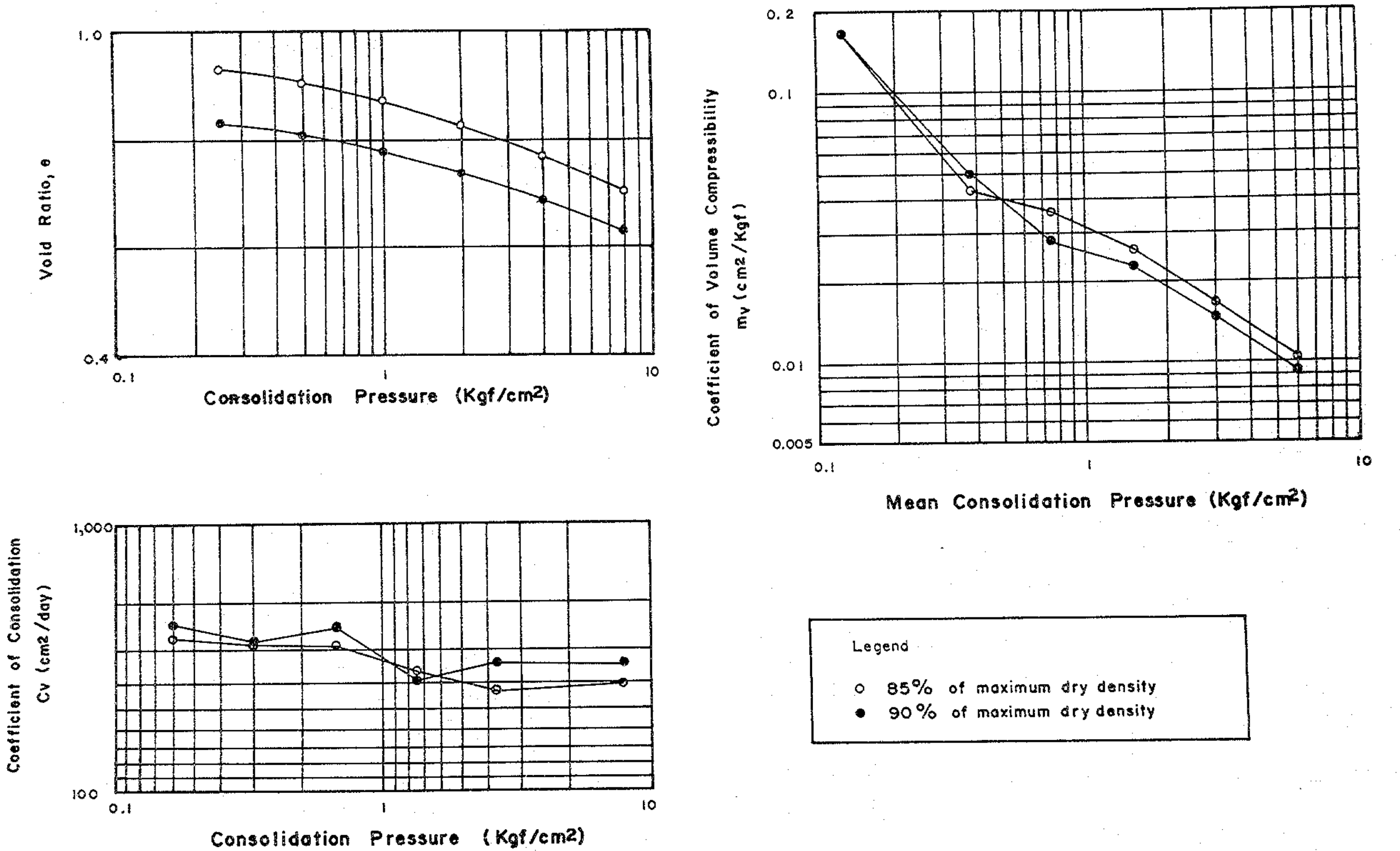


Figure 3.18 RESULTS OF CONSOLIDATION TEST (MEAN VALUES)

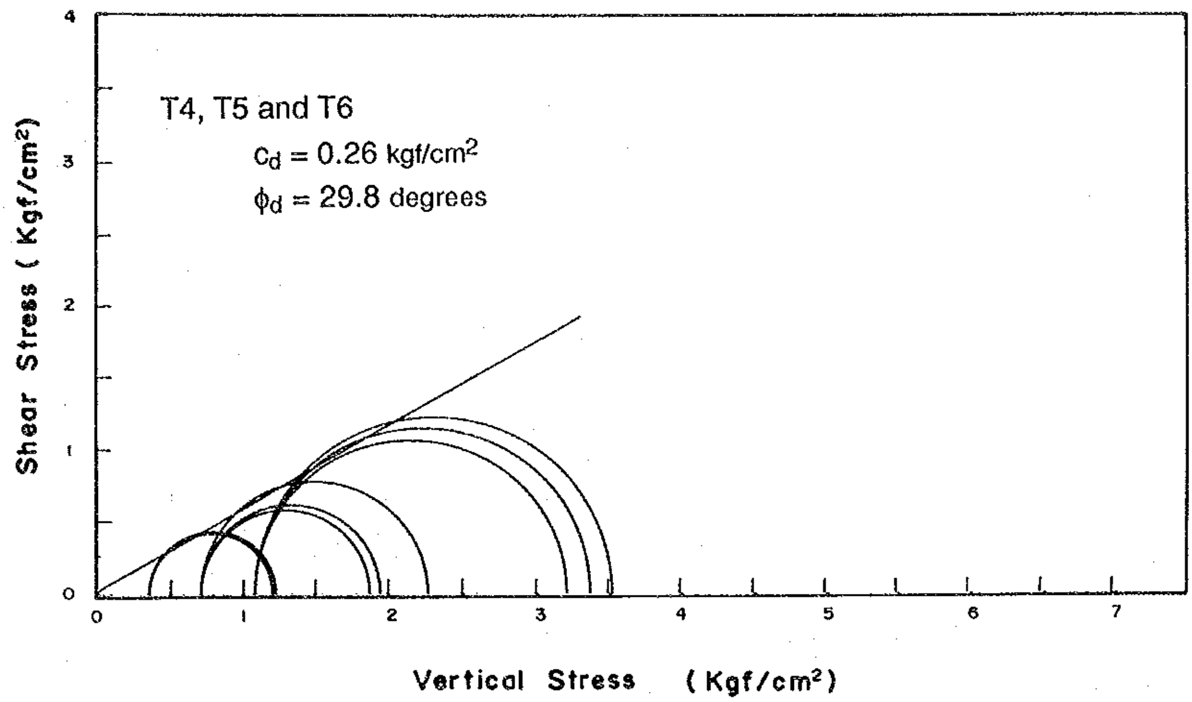


Figure 3.19 MOHR'S CIRCLES OF MATERIALS OF T4, T5 AND T6

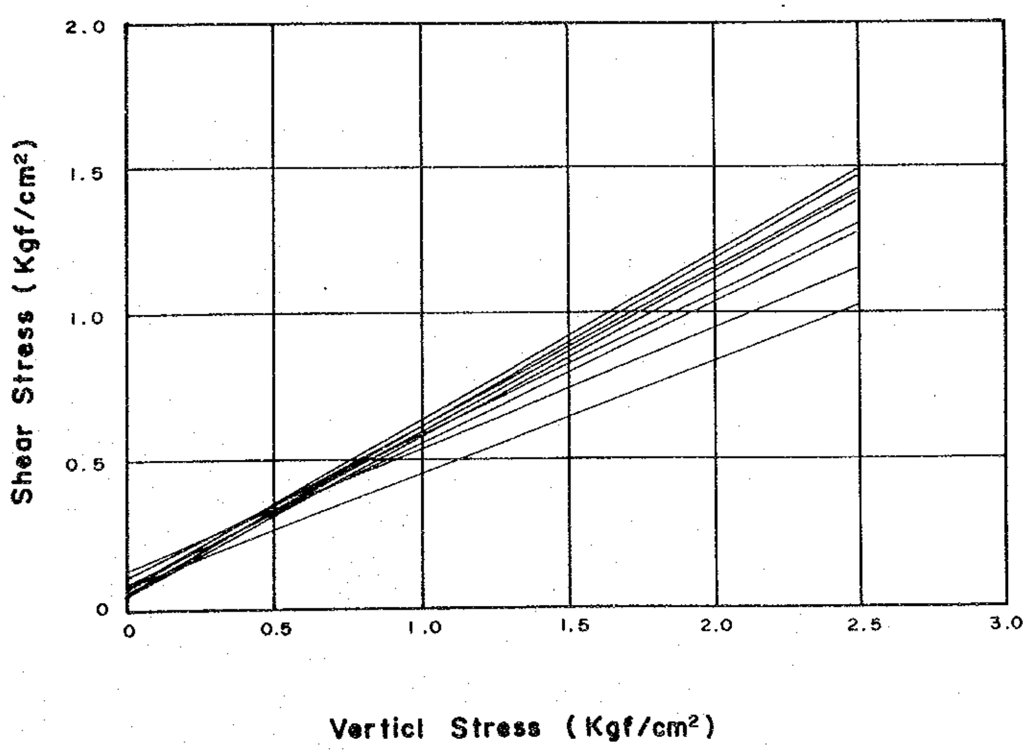


Figure 3.20 DIRECT SHEAR TEST RESULTS (ALL MATERIALS)

CHAPTER 4

SEISMICITY

4.1 General

The subsurface soil of the GIP area is classified mainly into two dominant soil textures, namely;sandy and silty soils, on which the proposed FCD structures are to be founded. From the geotechnical aspect, there is a possibility that those structures suffer from damage when a large scale of earthquake occurs. To clarify the seismic conditions of the GIP area, the following analyses are undertaken;

(1)Statistic analysis based on the historical earthquake data in and around Bangladesh in order to determine the design seismic coefficient for GIP, and

(2) Analysis of Seismic resistance on the soil texture against liquefaction.

4.2 Statistic Analysis on Historical Seismic Data

4.2.1 Historical seismic data in and around Bangladesh

Bangladesh is bounded by the Indian Plate by the Himalayan thrust on the northeast, the Assam syntaxis on the north, and the Indo-Burmese ranges and the Sangaing fault on the east. Main tectonic units in relation to occurrence of earthquake in Bangladesh are the East Himalayan thrust, the Indo Burmese ranges (Arakan Yoma thrust) and the Bengal Basin. The epicentres of the major historical earthquakes concentrate in the Shillong Plateau, Assam valley and Arakan Yoma and Indo-Burmese ranges. The following were collected during the investigation period to obtained historical earthquake data in and around Bangladesh :

(1) The Committee of Experts on Earthquake Hazard Minimization, "Seismic Zoning Map of Bangladesh and Outline of a Code for Earthquake Resistant Design of Structures", Final Report, Geological Survey of Bangladesh, Dhaka, November 1979,

(2) Khandeker Mosharraf Hossain, "Tectonic Significance and Earthquake Occurrences in Bangladesh", 7th Geological Conference, Bangladesh Geological Society, March 1989, and

(3) Meteorological and Geophysical Centre, "Earthquake Records from August 1983 to January 1987".

The above covers the seismic data which took place in and around Bangladesh for the period from 1830 to 1988 are quoted. However, it is found that there is a discrepancy among those sources that some records are not necessarily identical in every data sources above. In the statistical analysis, the earthquake data with a magnitude of more than 5 are used after collation thereof, which are shown in Tables 4.1 to 4.5. The epicentres of those earthquakes are plotted in Figure 4.1. According to the above source (1), Bangladesh suffered from widespread damage by the Shillong earthquake in 1987 over an area within a radius of 200 m from its epicentre and it is said that the main damage was caused by liquefaction. In addition thereto, large scale of earthquakes occurred in 1885 and 1918, which are called the Bengal earthquake and Srimangal one, respectively. Of these, it is said that the former's magnitude is the largest among those in the Bengal basin, causing severe damage in the north of Sirajganj. While, the latter brought about the damage in the relatively limited area although its epicentre was in Bangladesh. These three significant earthquakes are summarized below:

No.	Name of Earthquake	Date of occurrence	source	Magnitude
1	The Bengal earthquake	14th July 1885	Jamuna fault	7.0*
2	The Shillong earthquake	12th June 1897	Shillong Plateau	8.7*
3	The Srimangal earthquake	8th July 1918	Fault near Srimangal	7.6

Note * shows the value evaluated based on the extent of the damages.

4.2.2 Statistic analysis

The statistic analysis was carried out for the purpose of determining the design seismic coefficient for the FCD structures planned for GIP based on the historical earthquake data with a magnitude of more than 5 as well as epicentres being within radius of 400 km from a centre of the GIP area, which took place after 1923, since the data before 1923 has a lot of interruptions. Thus, a total of 91 earthquake events are picked out from the data of Tables 4.1 to 4.5 for the use of the statistic analysis.

The maximum ground acceleration at the centre of the GIP area is calculated to estimate the design seismic coefficient for the GIP. It is related to magnitude of the earthquakes, distance between the epicentres and the project sites, and the ground conditions. Since the attenuation relationship in which the energy of an earthquake decreases with distance is not available in Bangladesh, the maximum ground acceleration at the centre of the GIP area is calculated using the following formula developed by the Public Works Research Institute of Ministry of Construction of Japan. The formula is one of three formulae developed by the ground characteristics of the site. The ground types are classified by stiffness which is represented by the relation between thicknesses of alluvial and diluvial deposits of the ground where structures are founded, as shown in Figure 4.2. On the basis of the geotechnical investigation results, the GIP area is classified into the ground type III on Figure 4.2, since in general thickness of alluvial deposit is more than 24 m.

$$\alpha_{max} = 403.8 \times 10^{0.265M} \times (\Delta + 30)^{-1.218}$$

where,

α_{max}	:	Maximum ground acceleration (gal)
M	:	Magnitude of earthquake
Δ	:	Distance from epicentre (km)

The depth of hypocentres are not taken into consideration in the estimate, since the data on depths of hypocentres are not available or incomplete. Consequently, the results thus estimated would give the safer values against the earthquake to some extent. The estimated maximum ground accelerations for the respective events are shown in Tables 4.1 to 4.5. The results of the statistical analysis are shown in Figure 4.3 and below:

Return Period (year)	Max. Ground Acceleration
20	61 gal (0.062g)
50	88 gal (0.090g)
100	109 gal (0.111g)
200	132 gal (0.135g)
500	164 gal (0.167g)

Note : g means gravity acceleration.

Since the FCD structures proposed for the GIP area can allow deformation to some extent which might be caused in the event of earthquake, it is recommended to adopt 0.11g as the design ground acceleration which corresponds to a return period of 100-year. (For instance, larger return period have to be adopted for the high dam project, it needs to be designed under the quite strict condition.)

4.2.3 Design seismic coefficient

In general, the FCD structures such as flood embankment, drainage regulators, gate and weir are designed by means of the seismic intensity method, in which the earthquake load is calculated by the following equation;

$$Ws = k_h W$$

where,	Ws	:	Design earthquake load
	k_h	:	Seismic intensity (design seismic coefficient)
	W	:	Dead load

The value k_h in the above equation needs to be taken to be less than α_{max}/g, where α_{max} is the peak value of acceleration in the time span and g is acceleration due to gravity. The load Ws is applied to structures statically.

The design seismic coefficient has to be determined in consideration of a ground type where structures are founded as well as significance of the structures which may be damaged by earthquakes. For the ground type, it has been already considered in calculation of the maximum ground acceleration. The design maximum ground acceleration is recommended to adopt 0.11g. In the case, the design maximum ground acceleration divided by the gravity acceleration is the most conservative design seismic coefficient. Therefore, the design seismic coefficient for the GIP area is proposed to be 0.11.

A comprehensive study on the seismicity was carried out by the Committee of Experts on Earthquake Hazard Minimization and the Committee, which published a final report on "Seismic Zoning Map of Bangladesh and Outline of Code for Earthquake Resistant Design of Structures" in November, 1979. According to this zoning map shown in Figure 4.4, Bangladesh was divided into three zones which were Zone-I, II and III. The GIP area is located in Zone-I, the most active seismic zone, where the basic seismic coefficient of 0.08 is indicated.

The design seismic coefficient adopted in the present study (0.11) is larger than 0.08 proposed by the Committee. The seismic coefficient proposed by the Committee approximately corresponds to the return period of 50 year in the present analysis which focuses definitely on the GIP area. It is considered that the design seismic coefficient of 0.11 is in an appropriate range for the GIP area, comprising some allowance for the comprehensive value.

4.3 Liquefaction Analysis

4.3.1 Methodology

The liquefaction analysis was carried out by means of the simple prediction method which utilizes N value derived through the standard penetration test (SPT) and gradation of soil. This method is useful to judge the possibility of liquefaction in soil deposits. It was originally developed by H.B.Seed (1976) et al. The original method has been revised and used by related organizations in Japan to

examine a possibility of the liquefaction. At present, the updated specifications thereof for highway bridges, which have been edited by the Japan Road Association in 1990, is the most advanced one and widely used in Japan. In the method, the liquefaction analysis is made based on the results of the field investigation including the soil gradation tests. The flowchart for the liquefaction analysis is shown in Figure 4.5.

In the method, the liquefaction resistant factor (F_L) is defined by the following equation and it is judged to be liquefiable in case F_L comes to less than 1.0.

$$F_L = R / L$$

where, F_L	:	Liquefaction resistant factor
R	:	Resistance of soil elements to dynamic loads
L	:	Dynamic loads to soil elements induced by earthquake motion

L is expressed by the following equation;

$$L = (1 - 0.015z)\, k_h\, \sigma_v / \sigma'_v$$
$$\sigma_v = \{ {}_t h + {}_{sat} (z - h)\} / 10$$
$$\sigma'_v = \{ {}_t h + ({}_{sat} - 1.0) (z - h)\} / 10$$

where, z	:	Depth from ground surface (m)
k_h	:	Seismic coefficient at ground surface
σ_v	:	Overburden pressure (kgf/cm^2)
σ'_v	:	Effective overburden pressure (kgf/cm^2)
$_t$	:	Wet density of soil (tf/m^3)
$_{sat}$	:	Saturated density of soil (tf/m^3)
h	:	Depth of groundwater table from ground surface (m)

R is expressed by the following equation;

$$R = R1 + R2 + R3$$

where,	$R1 = 0.0882\sqrt{N} / (\sigma'_v + 0.7)$	
N	: N value	
R1 =	0.19	$(0.02\ mm \leq D_{50} \leq 0.05\ mm)$
	$0.225 \log10(0.35 / D_{50})$	$(0.05\ mm < D_{50} \leq 0.6\ mm)$
	-0.05	$(0.6\ mm < D_{50} \leq 2.0\ mm)$
R3 =	0.0	$(0\ \% \leq Fc \leq 40\ \%)$
	0.04 Fc - 0.16	$(40\ \% < Fc \leq 100\ \%)$
Fc	: Fine particles content (%)	

In above equations, R1, R2 and R3 are expressed by the function of N value and effective overburden pressure (σ'_v), mean particle size (D_{50}) and fine particles content (Fc), respectively.

In the analysis, the following field conditions are conceived:

(1) Groundwater table is equal to the surrounding ground level.

(2) D_{50} and Fc are those obtained from the laboratory tests performed in the geotechnical investigations.

(3) For the existing embankment and the uppermost layer, the density values obtained from the laboratory tests (1.61 and 1.78 tf/m^3) are adopted as their wet and saturated densities, respectively. The density values for other layers are derived with reference to those in specifications for highway bridges, edited by the Japan Road Association in 1990, which are shown in Table 4.6.

(4) The design seismic coefficient is adopted to be 0.11, which is derived through the present seismic analysis.

4.3.2 Evaluation on liquefaction potential

The liquefaction analysis was carried out for all the boreholes dug in the course of the geotechnical investigations in order to evaluate liquefaction potential in the GIP area. The analysis results are shown in Tables 4.7 to 4.40. Figures 4.6 and 4.7 give the distribution of the liquefaction resistance factor (F_L), which show that the values are more than 1.0 for the whole boreholes. Therefore, it is concluded that the liquefaction would not occur in the GIP area even in case the GIP area suffer the earthquake with a magnitude equivalent to the design seismic coefficient (Kh=0.11).

Table 4.1 EARTHQUAKE RECORDS OF BANGLADESH FROM 1830 TO 1988 (1/5)

No.	Date			Epicenter		Depth	Magnitude	Distance from site	Max. acceleration
	Year	Month	Day	Latitude	Longitude	(km)		to Epicenter (km)	(gal)
1	1830	12	31	22.0N	91.0E		5.0	419	5
2	1833	8	26	27.5N	86.5E		7.8	370	32
3	1845	8	6	24.8N	91.8E		6.5	243	23
4	1846	10	18	24.0N	90.0E		6.0	177	24
5	1869	1	10	24.3N	92.2E		7.5	302	33
6	1885	7	14	24.0N	90.0E		7.0	177	44
7	1897	6	12	25.8N	91.0E		8.7	152	144
8	1906	8	31	27.0N	97.0E		7.0	765	8
9	1909	2	17	27.0N	87.0E		5.0	298	7
10	1918	7	8	24.3N	91.7E		7.6	258	42
11	1920	8	15	22.2N	93.2E		6.0	522	7
12	1923	6	22	22.7N	94.0E		5.5	547	5
13	1923	8	10	22.6N	93.4E		6.0	506	7
14	1923	9	9	25.3N	91.0E		7.1	152	54
15	1924	1	30	25.0N	93.0E		6.0	354	11
16	1924	2	14	26.0N	96.0E		5.5	650	4
17	1924	9	2	23.0N	95.0E		5.5	616	4
18	1926	5	10	27.0N	96.0E		6.5	668	7
19	1926	8	18	24.5N	94.5E		5.5	511	5
20	1926	10	23	25.0N	93.0E		5.5	354	8
21	1927	3	15	24.5N	95.0E		6.5	560	9
22	1927	5	20	24.5N	94.5E		5.5	511	5
23	1927	7	15	27.0N	96.0E		5.5	668	4
24	1927	8	25	22.0N	90.0E		5.5	394	7
25	1928	7	9	27.0N	96.0E		5.5	668	4
26	1928	8	30	27.0N	96.0E		5.5	668	4
27	1929	10	19	26.7N	96.0E		5.5	661	4
28	1930	7	2	25.8N	90.2E		7.1	76	105
29	1930	7	3	25.8N	90.2E		5.5	76	40
30	1930	7	4	25.8N	90.2E		5.5	76	40
31	1930	7	4	25.8N	90.2E		5.5	76	40
32	1930	7	8	25.8N	90.8E		5.5	133	23
33	1930	7	8	25.8N	90.8E		5.5	133	23
34	1930	7	11	25.0N	93.8E		5.5	432	7
35	1930	7	13	25.8N	90.8E		5.5	133	23
36	1930	9	22	25.3N	93.8E		6.0	429	9
37	1932	3	6	25.5N	92.5E		5.0	299	7
38	1932	3	24	25.8N	90.2E		5.5	76	40
39	1932	3	27	25.5N	92.5E		5.5	299	10
40	1932	11	9	26.5N	92.0E		5.5	271	11
41	1933	3	6	25.7N	90.5E		5.8	101	37
42	1934	6	2	25.1N	94.7E		6.5	520	10
43	1934	1	15	26.6N	86.8E		8.3	294	56
44	1935	3	21	24.4N	89.5E		6.3	125	41
45	1935	4	23	25.1N	94.7E		6.0	520	7
46	1935	5	21	29.0N	89.2E		6.0	386	10
47	1936	6	18	26.6N	90.3E		5.5	143	22
48	1936	6	19	26.4N	90.3E		6.0	125	34
49	1936	9	7	27.5N	87.0E		5.1	331	7
50	1937	3	9	27.0N	92.0E		5.5	298	10

(To be continued)

Table 4.1 EARTHQUAKE RECORDS OF BANGLADESH FROM 1830 TO 1988 (2/5)

No.	Date			Epicenter		Depth	Magnitude	Distance from site	Max. acceleration
	Year	Month	Day	Latitude	Longitude	(km)		to Epicenter (km)	(gal)
51	1937	3	21	25.5N	94.0E		5.5	448	6
52	1937	8	31	25.9N	96.8E		5.5	729	4
53	1937	9	9	24.9N	94.7E		5.5	523	5
54	1938	1	29	27.5N	87.0E		6.0	331	12
55	1938	2	26	28.0N	90.5E		5.5	291	10
56	1938	5	6	24.9N	94.7E		5.5	523	5
57	1938	11	21	29.8N	95.3E		6.0	747	5
58	1939	5	27	24.3N	94.1E		6.8	478	13
59	1939	6	4	28.5N	86.5E		5.5	445	6
60	1940	2	13	27.0N	92.0E		5.5	298	10
61	1940	5	11	24.9N	94.1E		6.0	464	8
62	1940	8	2	28.0N	90.5E		5.5	291	10
63	1941	1	21	27.2N	92.0E		6.3	310	16
64	1941	1	22	27.0N	92.8E		6.3	367	13
65	1941	9	6	27.0N	92.0E		5.5	298	10
66	1942	2	21	24.0N	90.3E		5.9	187	21
67	1943	2	8	27.0N	92.0E		5.5	298	10
68	1943	10	23	26.8N	94.0E		7.2	470	17
69	1944	12	24	24.7N	92.2E		6.0	284	14
70	1945	5	19	25.1N	90.9E		6.0	147	29
71	1946	3	16	26.4N	92.6E		6.0	324	12
72	1947	3	8	24.9N	94.7E		5.5	523	5
73	1947	7	29	28.8N	93.7E		7.8	554	20
74	1947	9	9	25.9N	96.8E		6.0	729	5
75	1947	11	29	27.9N	92.9E		5.5	429	7
76	1948	3	1	26.8N	94.0E		5.5	470	6
77	1949	11	17	25.9N	96.8E			729	0
78	1949	12	10	26.0N	89.0E		6.0	72	56
79	1950	2	26	28.0N	90.5E		6.0	291	14
80	1950	8	15	28.7N	96.6E		8.5	790	20
81	1950	8	15	28.7N	96.6E		5.5	790	3
82	1950	8	15	28.7N	96.6E		6.0	790	4
83	1950	8	15	28.7N	96.6E		6.0	790	4
84	1950	8	15	28.7N	96.6E		6.0	790	4
85	1950	8	15	28.7N	96.6E		6.0	790	4
86	1950	8	15	28.7N	96.6E		6.0	790	4
87	1950	8	15	28.7N	96.6E		6.0	790	4
88	1950	8	15	25.0N	95.8E		8.0	631	20
89	1950	8	15	28.7N	96.6E		5.5	790	3
90	1950	8	15	28.7N	96.6E		6.0	790	4
91	1950	8	16	28.6N	95.7E		7.0	705	9
92	1950	8	16	27.4N	96.4E		6.0	718	5
93	1950	8	16	27.9N	91.9E		5.5	355	8
94	1950	8	16	29.4N	94.7E		6.6	673	8
95	1950	8	16	29.2N	95.1E		6.0	690	5
96	1950	8	16	27.5N	92.5E		6.5	370	14
97	1950	8	16	25.9N	96.8E		6.0	729	5
98	1950	8	16	25.9N	96.8E		6.0	729	5
99	1950	8	16	25.9N	96.8E		6.0	729	5
100	1950	8	17	28.9N	94.5E		5.5	623	4

(To be continued)

Table 4.1 EARTHQUAKE RECORDS OF BANGLADESH FROM 1830 TO 1988 (3/5)

No.	Date			Epicenter		Depth	Magnitude	Distance from site	Max. acceleration
	Year	Month	Day	Latitude	Longitude	(km)		to Epicenter (km)	(gal)
101	1950	8	17	25.9N	96.8E		6.0	729	5
102	1950	8	17	25.9N	96.8E		6.0	729	5
103	1950	8	17	27.9N	91.9E		6.0	355	11
104	1950	8	18	28.7N	96.6E		5.5	790	3
105	1950	8	18	28.7N	96.6E		6.0	790	4
106	1950	8	19	28.7N	96.6E		6.0	790	4
107	1950	8	21	27.5N	97.0E		5.5	779	3
108	1950	8	23	27.2N	96.9E		5.9	760	4
109	1950	8	23	28.8N	96.4E		5.5	777	3
110	1950	8	24	28.3N	96.4E		6.3	753	6
111	1950	8	24	27.5N	96.4E		6.0	721	5
112	1950	8	26	26.8N	95.1E		7.0	575	12
113	1950	8	31	27.5N	96.4E		5.5	721	4
114	1950	8	31	28.2N	95.7E		6.1	685	6
115	1950	9	2	28.7N	96.6E		6.0	790	4
116	1950	9	3	28.7N	94.2E		6.0	585	6
117	1950	9	4	28.7N	96.6E		6.0	790	4
118	1950	9	4	28.7N	96.6E		5.5	790	3
119	1950	9	4	28.7N	96.6E		5.5	790	3
120	1950	9	8	25.9N	96.8E		5.5	729	4
121	1950	9	11	26.8N	95.0E		6.0	566	7
122	1950	9	13	27.8N	95.3E		7.0	630	11
123	1950	9	30	28.7N	94.3E		6.7	593	10
124	1950	10	3	28.0N	96.7E		6.3	768	6
125	1950	10	8	28.9N	96.1E		6.6	756	7
126	1950	10	16	28.3N	95.0E		5.5	628	4
127	1950	10	29	27.8N	94.7E		5.5	576	5
128	1950	10	30	28.0N	96.9E		6.0	787	4
129	1950	11	12	27.7N	94.8E		5.5	580	5
130	1950	11	16	27.5N	96.4E		5.5	721	4
131	1950	11	18	27.7N	94.6E		5.5	562	5
132	1950	12	24	24.4N	91.7E		6.3	252	20
133	1951	1	4	28.6N	94.2E		5.6	579	5
134	1951	2	8	28.2N	94.4E		5.8	571	6
135	1951	2	21	28.9N	94.0E		5.8	584	6
136	1951	3	6	28.8N	95.1E		6.4	665	7
137	1951	3	12	28.2N	94.5E		6.5	579	9
138	1951	4	7	25.8N	90.4E		6.8	95	71
139	1951	4	14	28.2N	94.1E		6.4	546	9
140	1951	7	21	28.7N	96.6E		6.0	790	4
141	1951	9	24	25.9N	96.8E		5.5	729	4
142	1951	10	18	28.8N	93.7E		6.0	554	7
143	1952	1	15	23.8N	94.5E		5.5	534	5
144	1952	4	30	25.5N	94.5E		6.0	498	8
145	1952	5	26	28.5N	94.5E		6.0	597	6
146	1952	8	25	28.0N	94.0E		6.0	525	7
147	1952	11	7	25.5N	94.0E		6.0	448	9
148	1952	11	28	25.0N	95.2E		6.0	571	6
149	1954	2	23	27.8N	91.7E		6.4	334	15
150	1954	3	21	24.2N	95.1E		7.3	577	14

(To be continued)

Table 4.1 EARTHQUAKE RECORDS OF BANGLADESH FROM 1830 TO 1988 (4/5)

No.	Date			Epicenter		Depth	Magnitude	Distance from site	Max. acceleration
	Year	Month	Day	Latitude	Longitude	(km)		to Epicenter (km)	(gal)
151	1955	12	14	22.0N	92.5E		6.5	492	10
152	1956	6	12	24.8N	90.9E		6.0	161	26
153	1956	12	21	26.6N	96.3E		6.0	688	5
154	1957	7	1	24.4N	93.8E		7.3	446	19
155	1957	12	12	24.5N	93.0E		5.5	367	8
156	1958	1	6	25.6N	96.8E		5.8	727	4
157	1958	2	9	24.9N	90.9E		5.0	156	15
158	1958	2	13	27.5N	92.5E		5.5	370	8
159	1958	3	22	23.5N	93.8E		6.5	484	11
160	1958	10	28	25.2N	96.3E		6.0	679	5
161	1958	11	23	28.8N	86.9E		5.5	445	6
162	1959	2	14	28.0N	96.0E		6.0	703	5
163	1959	2	22	28.5N	91.5E		5.7	385	8
164	1959	5	22	25.5N	95.5E		5.0	598	3
165	1959	6	7	24.0N	94.0E		5.4	479	6
166	1959	11	2	28.0N	93.0E		5.0	443	5
167	1960	5	26	27.0N	93.0E		5.0	385	6
168	1960	7	29	26.9N	90.3E		6.5	171	33
169	1960	8	21	26.4N	88.6E		5.5	132	24
170	1961	2	4	24.7N	95.3E		5.4	585	4
171	1961	6	14	24.7N	94.8E		5.8	536	6
172	1961	9	29	28.0N	87.0E		5.5	370	8
173	1961	11	6	26.7N	91.9E		5.5	272	11
174	1961	12	25	27.0N	90.0E		5.5	170	18
175	1962	9	22	26.5N	97.0E		6.3	755	6
176	1962	10	30	26.6N	93.3E		5.5	397	7
177	1963	10	14	25.2N	95.3E		5.3	579	4
178	1964	2	18	27.5N	91.1E		5.5	270	11
179	1964	6	3	25.9N	95.8E		5.5	629	4
180	1964	7	12	24.9N	95.3E		6.7	582	10
181	1964	8	30	27.6N	88.3E		5.2	259	10
182	1964	9	1	27.2N	92.3E		5.7	335	10
183	1964	10	21	28.1N	93.8E		5.9	514	7
184	1964	11	25	26.6N	96.3E		5.4	688	4
185	1964	2	18	25.0N	94.3E		5.4	482	5
186	1965	1	12	27.6N	88.0E		6.1	274	16
187	1965	4	11	26.7N	92.3E		5.1	308	8
188	1965	5	30	26.0N	95.8E		5.8	630	5
189	1965	6	11	24.8N	95.5E		5.3	603	4
190	1965	6	18	25.0N	93.8E		5.9	432	8
191	1965	12	9	27.5N	92.5E		5.3	370	7
192	1965	12	15	22.2N	94.6E		5.3	628	4
193	1966	9	26	27.5N	92.6E		5.6	378	8
194	1966	10	2	25.4N	94.8E		5.2	528	4
195	1966	10	22	23.1N	94.4E		5.3	558	4
196	1967	1	4	23.4N	93.9E		5.4	498	5
197	1967	2	8	23.2N	93.9E		5.1	509	4
198	1967	3	11	28.4N	94.4E		5.3	583	4
199	1967	3	14	28.4N	94.3E		5.9	574	6
200	1967	9	6	24.1N	91.7E		5.0	270	8

(To be continued)

Table 4.1 EARTHQUAKE RECORDS OF BANGLADESH FROM 1830 TO 1988 (5/5)

No.	Date			Epicenter		Depth	Magnitude	Distance from site	Max. acceleration
	Year	Month	Day	Latitude	Longitude	(km)		to Epicenter (km)	(gal)
201	1967	9	15	27.4N	91.8E		5.8	309	12
202	1967	11	14	24.0N	91.5E		5.1	262	9
203	1968	1	23	26.0N	95.5E		5.0	600	3
204	1968	6	12	26.0N	91.1E		5.5	168	18
205	1968	8	18	26.4N	90.6E		5.2	146	18
206	1968	12	27	24.1N	91.6E		5.2	262	10
207	1969	1	25	22.9N	92.3E		5.4	403	7
208	1969	2	26	26.6N	92.4E		5.0	312	7
209	1969	4	28	25.9N	95.3E		5.2	579	4
210	1969	1	1	25.8N	91.8E		5.0	231	10
211	1969	1	30	26.9N	92.6E		5.1	344	7
212	1969	8	29	26.3N	96.1E		5.4	663	4
213	1969	9	30	25.6N	94.7E		5.4	518	5
214	1969	11	5	27.7N	90.2E		5.0	250	9
215	1970	2	19	27.4N	94.0E		5.5	494	6
216	1970	5	9	24.0N	94.1E		5.0	489	4
217	1970	7	25	25.7N	88.5E		5.2	101	25
218	1970	7	29	26.0N	95.4E		6.5	590	8
219	1970	7	29	26.0N	95.3E		5.1	580	4
220	1971	2	2	23.8N	91.8E		5.4	299	9
221	1971	3	31	26.2N	96.6E		5.0	711	3
222	1971	5	31	25.2N	96.5E		5.3	698	3
223	1971	6	26	24.6N	94.7E		5.2	528	4
224	1971	7	17	26.5N	93.2E		5.3	384	7
225	1976	6	23	23.4N	88.8E		5.3	244	11
226	1977	12	23	23.6N	92.4E		5.1	359	6
227	1980	10	30	23.9N	91.3E		5.0	251	9
228	1982	8	31	25.8N	91.5E		5.0	199	11
229	1983	8	30	21.4N	94.8E		5.6	695	4
230	1984	5	6	25.0N	92.4E		6.7	295	21
231	1984	5	21	23.7N	91.5E		5.3	289	9
232	1984	9	22	26.5N	92.2E		5.2	288	9
233	1984	9	30	25.2N	92.0E		5.4	249	11
234	1984	12	30	24.6N	92.9E	23	5.6	352	9
235	1985	1	7	27.2N	92.0E	11	5.6	312	10
236	1985	10	12	27.1N	92.5E	17	5.3	348	7
237	1985	11	3	23.7N	91.6E		5.0	293	7
238	1986	2	2	23.9N	93.0E	39	5.2	393	6
239	1986	2	19	25.1N	91.2E		5.3	173	16
240	1986	9	10	25.4N	92.1E	43	5.2	257	10
241	1987	4	29	22.5N	92.4E		5.3	447	6
242	1988	2	6	24.7N	90.5E		5.8	138	27

Table 4.2 ASSUMED VALUES OF DENSITY, MEAN PARTICLE SIZE AND FINE PARTICLES CONTENT BY SOIL CLASSIFICATION

Soil Classification	Saturated Density g_{sat} tf/m^3	Wet Density g_t tf/m^3	Mean Particle Size D_{50} mm	Fine Particles Content Fc %
Silty clay Sandy clay	1.70	1.50	0.00026	88
Clayey silt Silt Sandy silt	1.75	1.55	0.013	72
Silty sand Fine sand Fine to medium sand	1.95	1.75	0.165	22
Medium sand Medium to coarse sand	2.00	1.80	0.376	13
Coarse sand Gravelley sand	2.10	1.90		

Table 4.3 RESULTS OF LIQUEFACTION ANALYSIS (1/4)

Borehole : B1

GWL = 2.30m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	8	72	0.055	0.1369	0.1369	0.1086	0.2727	0.1808	2.72	3.1735	29.22
2.85	6	85	0.036	0.4682	0.4132	0.1193	0.2048	0.1900	3.24	3.6348	30.46
4.85	4	10	0.160	0.8302	0.5752	0.1472	0.1562	0.0765	0.00	0.2327	1.58
6.85	9	82	0.042	1.2202	0.7652	0.1574	0.2186	0.1900	3.12	3.5286	22.42
8.85	17	7	0.190	1.6102	0.9552	0.1608	0.2827	0.0597	0.00	0.3424	2.13

Borehole : B2

GWL = 2.83m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	4	15	0.140	0.1488	0.1488	0.1086	0.1915	0.0895	0.00	0.2810	2.59
2.85	7	72	0.055	0.4851	0.4831	0.1057	0.2145	0.1808	2.72	3.1154	29.46
4.85	5	47	0.079	0.8411	0.6391	0.1342	0.1704	0.1454	1.72	2.0359	15.17
6.85	2	77	0.044	1.1971	0.7951	0.1486	0.1020	0.1900	2.92	3.2120	21.62
8.85	14	90	0.024	1.5531	0.9511	0.1558	0.2568	0.1900	3.44	3.8868	24.95

Borehole : B3

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
1.35	3	78	0.047	0.2403	0.1053	0.2459	0.1702	0.1900	2.96	3.3202	13.50
4.35	8	11	0.120	0.8143	0.3793	0.2208	0.2401	0.1046	0.00	0.3447	1.56
7.35	16	15	0.160	1.3993	0.6643	0.2062	0.3021	0.0765	0.00	0.3785	1.84
10.35	14	9	0.180	1.9843	0.9493	0.1942	0.2570	0.0650	0.00	0.3220	1.66
13.35	27	10	0.130	2.5693	1.2343	0.1831	0.3295	0.0968	0.00	0.4263	2.33
16.35	25	9	0.160	3.1543	1.5193	0.1724	0.2960	0.0765	0.00	0.3725	2.16
19.85	30	8	0.170	3.8368	1.8518	0.1601	0.3024	0.0706	0.00	0.3730	2.33

Borehole : B3'

GWL = 2.80m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
1.35	4	44	0.082	0.2174	0.2174	0.1078	0.1842	0.1418	1.60	1.9260	17.87
4.35	6	91	0.031	0.7267	0.5717	0.1307	0.1916	0.1900	3.48	3.8616	29.55
7.35	9	13	0.150	1.3058	0.8508	0.1502	0.2125	0.0828	0.00	0.2953	1.97
10.35	27	3	0.180	1.8908	1.1358	0.1547	0.3383	0.0650	0.00	0.4032	2.61
13.35	22	5	0.150	2.4758	1.4207	0.1533	0.2841	0.0828	0.00	0.3669	2.39
16.35	36	4	0.130	3.0608	1.7058	0.1490	0.3412	0.0968	0.00	0.4380	2.94
19.85	38	5	0.190	3.7433	2.0383	0.1419	0.3286	0.0597	0.00	0.3883	2.74

Borehole : B4

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
1.35	6	92	0.024	0.2403	0.1053	0.2459	0.2407	0.1900	3.52	3.9507	16.06
4.35	5	53	0.071	0.7743	0.3393	0.2346	0.1935	0.1559	1.96	2.3093	9.84
7.35	13	15	0.150	1.3466	0.6116	0.2155	0.2777	0.0828	0.00	0.3605	1.67
10.35	23	10	0.180	1.9316	0.8966	0.2002	0.3348	0.0650	0.00	0.3997	2.00
13.35	18	5	0.190	2.5166	1.1816	0.1874	0.2728	0.0597	0.00	0.3325	1.77
16.35	18	6	0.130	3.1016	1.4666	0.1756	0.2542	0.0968	0.00	0.3510	2.00
19.85	26	3	0.170	3.7841	1.7991	0.1625	0.2845	0.0706	0.00	0.3551	2.19

(To be continued)

Table 4.3 RESULTS OF LIQUEFACTION ANALYSIS (2/4)

Borehole : B5

GWL = 2.80m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	6	68	0.054	0.1369	0.1369	0.1086	0.2362	0.1826	2.56	2.9788	27.43
2.85	5	10	0.160	0.4768	0.4718	0.1064	0.1822	0.0765	0.00	0.2587	2.43
4.85	8	11	0.180	0.8668	0.6618	0.1336	0.2138	0.0650	0.00	0.2788	2.09
6.85	10	63	0.059	1.2270	0.8220	0.1473	0.2261	0.1740	2.36	2.7601	18.73
8.85	21	70	0.048	1.5830	0.9780	0.1544	0.3120	0.1900	2.64	3.1420	20.35

Borehole : B6

GWL = 0.65m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
1.35	5	85	0.049	0.2293	0.1593	0.1551	0.2128	0.1900	3.24	3.6428	23.48
4.35	9	77	0.058	0.7633	0.3933	0.1996	0.2531	0.1756	2.92	3.3487	16.78
7.35	6	90	0.034	1.3228	0.6528	0.1983	0.1858	0.1900	3.44	3.8158	19.24
10.35	6	87	0.038	1.8568	0.8868	0.1946	0.1715	0.1900	3.32	3.6815	18.92
13.35	13	87	0.037	2.3908	1.1208	0.1877	0.2357	0.1900	3.32	3.7457	19.96
16.35	40	8	0.130	2.9647	1.3947	0.1765	0.3854	0.0968	0.00	0.4822	2.73
19.85	48	3	0.180	3.6472	1.7272	0.1631	0.3922	0.0650	0.00	0.4572	2.80

Borehole : B6'

GWL = 2.97m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
1.35	7	58	0.065	0.2174	0.2174	0.1078	0.2436	0.1645	2.16	2.5682	23.83
4.35	16	33	0.094	0.7332	0.5952	0.1267	0.3100	0.1285	0.00	0.4385	3.46
7.35	18	17	0.160	1.3182	0.8802	0.1466	0.2977	0.0765	0.00	0.3742	2.55
10.35	27	2	0.190	1.9032	1.1652	0.1518	0.3356	0.0597	0.00	0.3953	2.60
13.35	35	1	0.200	2.4882	1.4502	0.1509	0.3559	0.0547	0.00	0.4105	2.72
16.35	38	9	0.150	3.0732	1.7352	0.1470	0.3484	0.0828	0.00	0.4312	2.93
19.85	38	7	0.180	3.7557	2.0677	0.1403	0.3268	0.0650	0.00	0.3918	2.79

Borehole : B7

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	6	74	0.054	0.1513	0.0663	0.2478	0.2468	0.1826	2.80	3.2294	13.03
2.85	11	36	0.089	0.5175	0.2325	0.2344	0.3029	0.1338	0.00	0.4367	1.86
4.85	8	16	0.160	0.9075	0.4225	0.2191	0.2355	0.0765	0.00	0.3120	1.42
6.85	9	15	0.130	1.2975	0.6125	0.2091	0.2310	0.0968	0.00	0.3277	1.57
8.85	18	8	0.200	1.6875	0.8025	0.2006	0.3053	0.0547	0.00	0.3600	1.79

Borehole : B8

GWL = 3.10m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	2	95	0.020	0.1369	0.1369	0.1086	0.1364	0.1900	3.64	3.9664	36.52
2.85	4	94	0.022	0.4589	0.4589	0.1053	0.1639	0.1900	3.60	3.9539	37.55
4.85	7	78	0.045	0.8106	0.6356	0.1301	0.2019	0.1900	2.96	3.3519	25.77
6.85	4	98	0.018	1.1666	0.7916	0.1455	0.1444		3.76		
8.85	10	92	0.026	1.5226	0.9476	0.1533	0.2173	0.1900	3.52	3.9273	25.62

(To be continued)

Table 4.3 RESULTS OF LIQUEFACTION ANALYSIS (3/4)

Borehole : B9

GWL = 1.70m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	33	48	0.077	0.0465	0.0465	0.1086	0.5864	0.1480	1.76	2.4944	22.97
2.85	16	25	0.100	0.5050	0.3900	0.1364	0.3379	0.1224	0.00	0.4603	3.38
4.85	14	38	0.087	0.8720	0.5570	0.1597	0.2944	0.1360	0.00	0.4304	2.70
6.85	31	14	0.130	1.2391	0.7241	0.1689	0.4115	0.0968	0.00	0.5083	3.01
8.85	18	8	0.180	1.6291	0.9141	0.1700	0.2945	0.0650	0.00	0.3595	2.11

Borehole : B10

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	13	64	0.060	0.1513	0.0663	0.2478	0.3633	0.1723	2.40	2.9356	11.85
2.85	8	73	0.051	0.5073	0.2223	0.2403	0.2598	0.1882	2.76	3.2080	13.35
4.85	8	16	0.140	0.8948	0.7098	0.1286	0.2101	0.0895	0.00	0.2996	2.33
6.85	21	5	0.200	1.2848	0.8998	0.1409	0.3196	0.0547	0.00	0.3742	2.66
8.85	19	6	0.190	1.6748	1.0898	0.1466	0.2874	0.0597	0.00	0.3471	2.37

Borehole : B11

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	5	44	0.083	0.1513	0.0663	0.2478	0.2253	0.1406	1.60	1.9659	7.93
2.85	10	61	0.061	0.5073	0.2223	0.2403	0.2904	0.1707	2.28	2.7411	11.41
4.85	8	67	0.054	0.8762	0.3912	0.2284	0.2388	0.1826	2.52	2.9414	12.88
6.85	27	13	0.180	1.2552	0.5702	0.2173	0.4066	0.0650	0.00	0.4716	2.17
8.85	26	4	0.140	1.6452	0.7602	0.2065	0.3722	0.0895	0.00	0.4617	2.24

Borehole : B12

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
1.35	2	90	0.026	0.2403	0.1053	0.2459	0.1390	0.1900	3.44	3.7690	15.32
4.35	5	28	0.100	0.8160	0.3810	0.2202	0.1897	0.1224	0.00	0.3121	1.42
7.35	20	10	0.190	1.4009	0.6660	0.2059	0.3375	0.0597	0.00	0.3972	1.93
10.35	22	17	0.150	1.9859	0.9510	0.1941	0.3220	0.0828	0.00	0.4048	2.09
13.35	18	1	0.200	2.5710	1.2360	0.1830	0.2689	0.0547	0.00	0.3236	1.77
16.35	19	80	0.047	3.1415	1.5065	0.1731	0.2588	0.1900	3.04	3.4888	20.15
19.85	25	3	0.170	3.8198	1.8348	0.1608	0.2770	0.0706	0.00	0.3476	2.16

Borehole : B13

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
1.35	7	75	0.042	0.2403	0.1053	0.2459	0.2600	0.1900	2.84	3.2900	13.38
4.35	6	57	0.067	0.7743	0.3393	0.2346	0.2119	0.1615	2.12	2.4935	10.63
7.35	22	12	0.180	1.3466	0.6116	0.2155	0.3612	0.0650	0.00	0.4262	1.98
10.35	25	15	0.160	1.9316	0.8966	0.2002	0.3490	0.0765	0.00	0.4255	2.13
13.35	20	16	0.120	2.5166	1.1816	0.1874	0.2876	0.1046	0.00	0.3922	2.09
16.35	38	17	0.170	3.1016	1.4666	0.1756	0.3694	0.0706	0.00	0.4399	2.51
19.85	36	12	0.130	3.7841	1.7991	0.1625	0.3348	0.0968	0.00	0.4315	2.66

(To be continued)

Table 4.3 RESULTS OF LIQUEFACTION ANALYSIS (4/4)

Borehole : B15

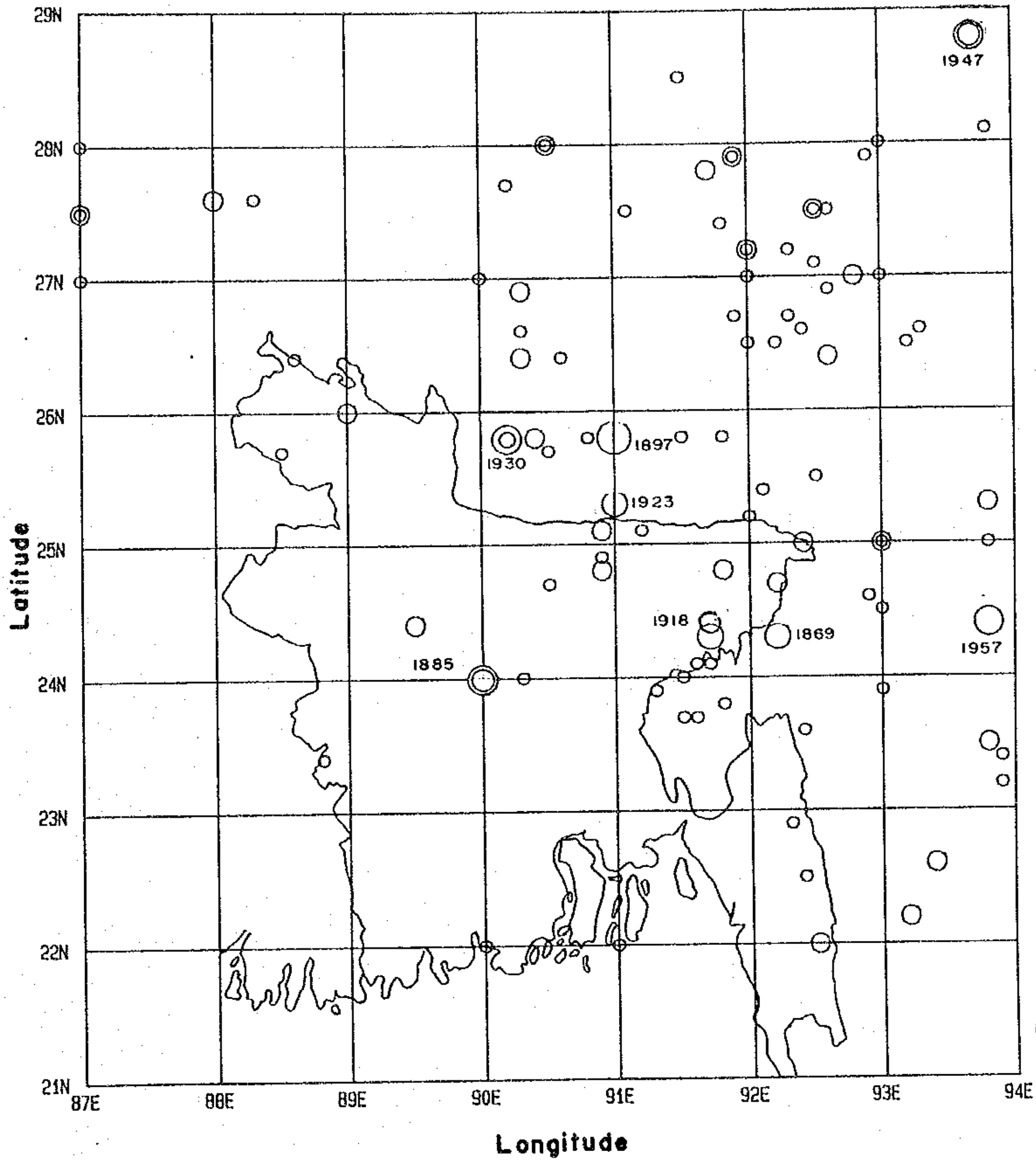
GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	5	91	0.024	0.1513	0.0663	0.2478	0.2253	0.1900	3.48	3.8953	15.72
2.85	6	27	0.100	0.5150	0.2300	0.2358	0.2240	0.1224	0.00	0.3464	1.47
4.85	7	92	0.022	0.8939	0.4089	0.2230	0.2216	0.1900	3.52	3.9316	17.63
6.85	8	94	0.018	1.2499	0.5649	0.2184	0.2218		3.60		
8.85	18	39	0.084	1.6059	0.7209	0.2125	0.3139	0.1395	0.00	0.4534	2.13

Borehole : B17

GWL = 0.00m k = 0.11

Depth (m)	N value	Fc (%)	D50 (mm)	Sigma v (kgf/cm2)	Sigma v' (kgf/cm2)	L	R1	R2	R3	R	Fl
0.85	6	84	0.036	0.1513	0.0663	0.2478	0.2468	0.1900	3.20	3.6368	14.67
2.85	3	91	0.023	0.5073	0.2223	0.2403	0.1591	0.1900	3.48	3.8291	15.93
4.85	2	89	0.032	0.8633	0.3783	0.2328	0.1201	0.1900	3.40	3.7101	15.94
6.85	16	82	0.047	1.2287	0.5437	0.2231	0.3164	0.1900	3.12	3.6264	16.26
8.85	23	24	0.100	1.6187	0.7337	0.2105	0.3533	0.1224	0.00	0.4757	2.26



Legend :

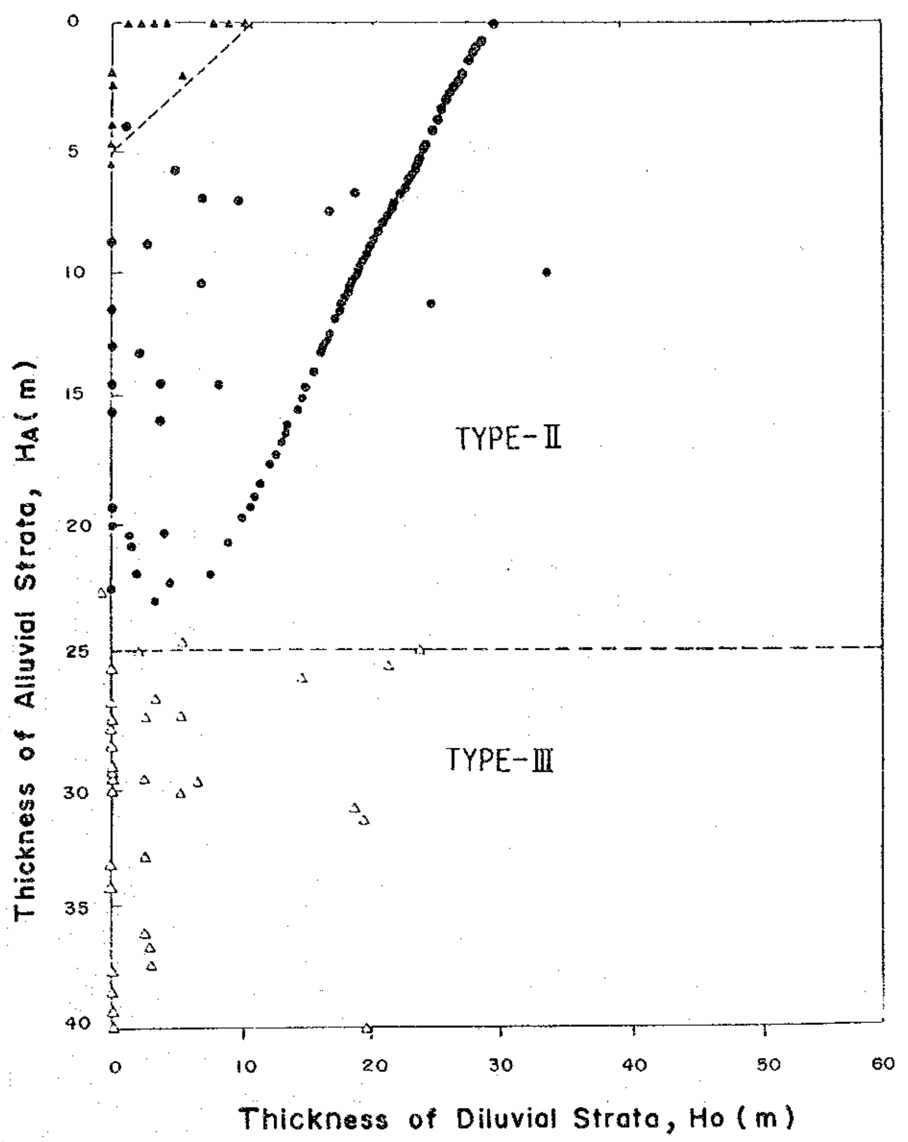
Magnitude

- 5 to 6
- 6 to 7
- 7 to 8
- 8 or more

Note :

The number of a plotmark shows the occurrence year of the earthquake of which magnitude is 7 or more .

Figure.4.1 EPICENTERS OF EARTHQUAKES IN AND AROUND BANGLADESH



Legend:

▲ TYPE-I (Ts <0.25)
● TYPE-II (0.25 ≦ Ts 0.75)
△ TYPE-III (0.75 ≦ Ts)
Ts : Predominant period of response analysis

Source : Specifications for highway bridges edited in 1990 Japan Road Association.

Figure 4.2 CLASSIFICATION OF GROUND TYPE BY USING H_A AND H_D

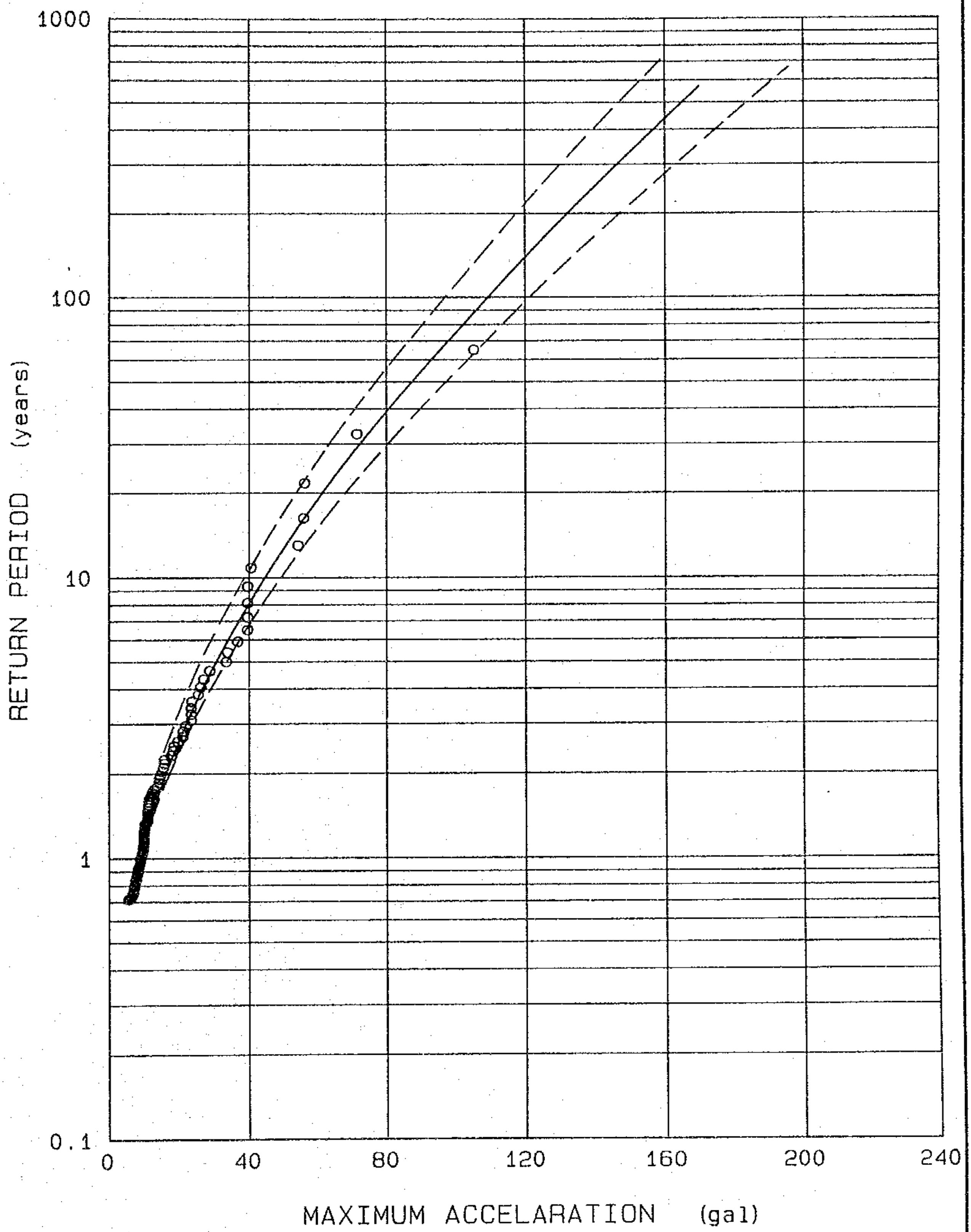


Fig. 4.3 RELATION BETWEEN MAXIMUM GROUND ACCELARATION AND RETURN PERIOD

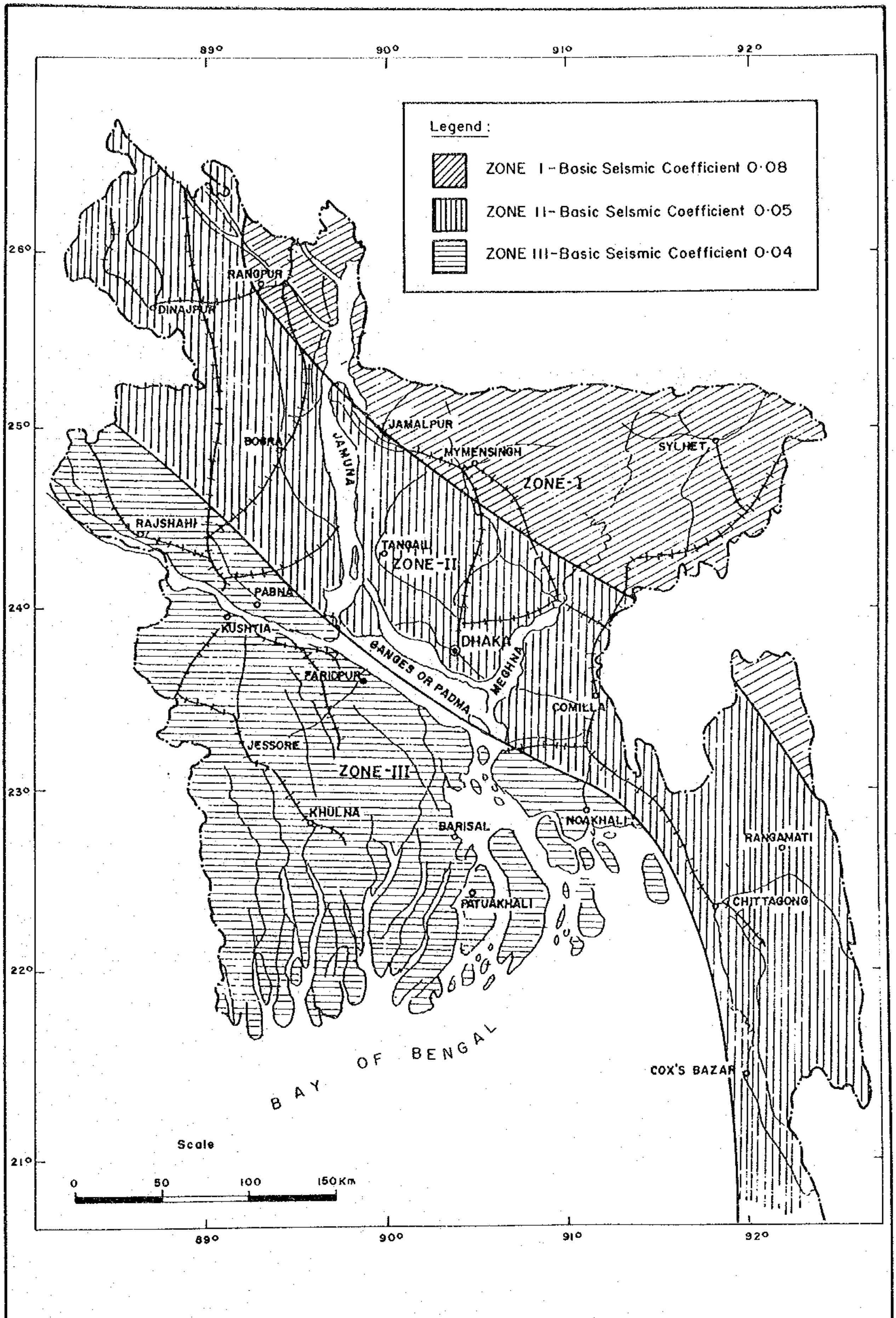


Figure 4.4 SEISMIC ZONING MAP OF BANGLADESH

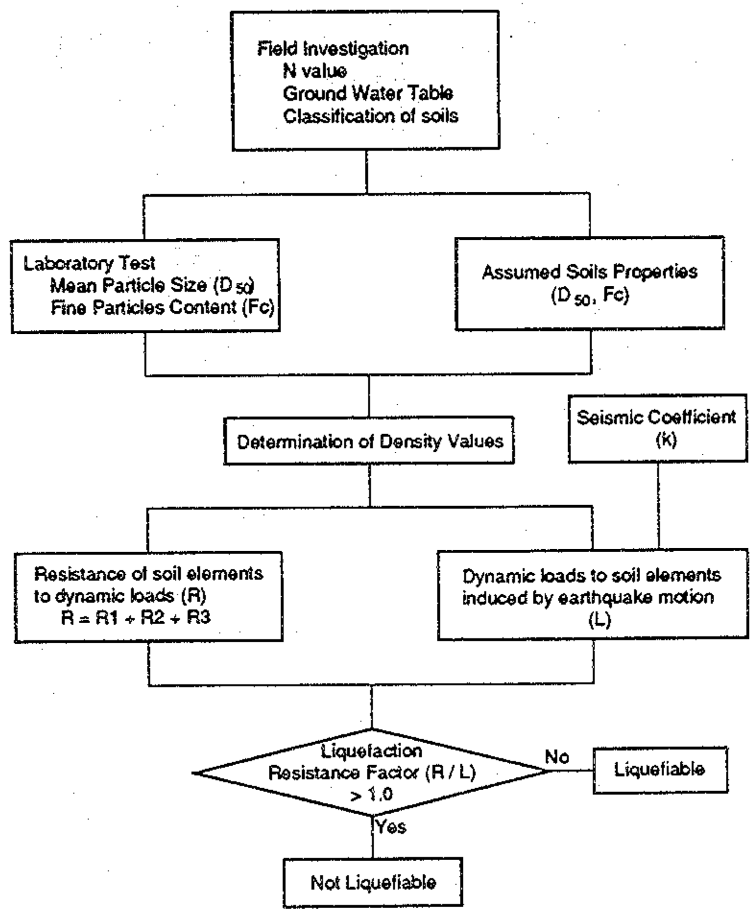


Figure 4.5 FLOW OF LIQUEFACTION ANALYSIS

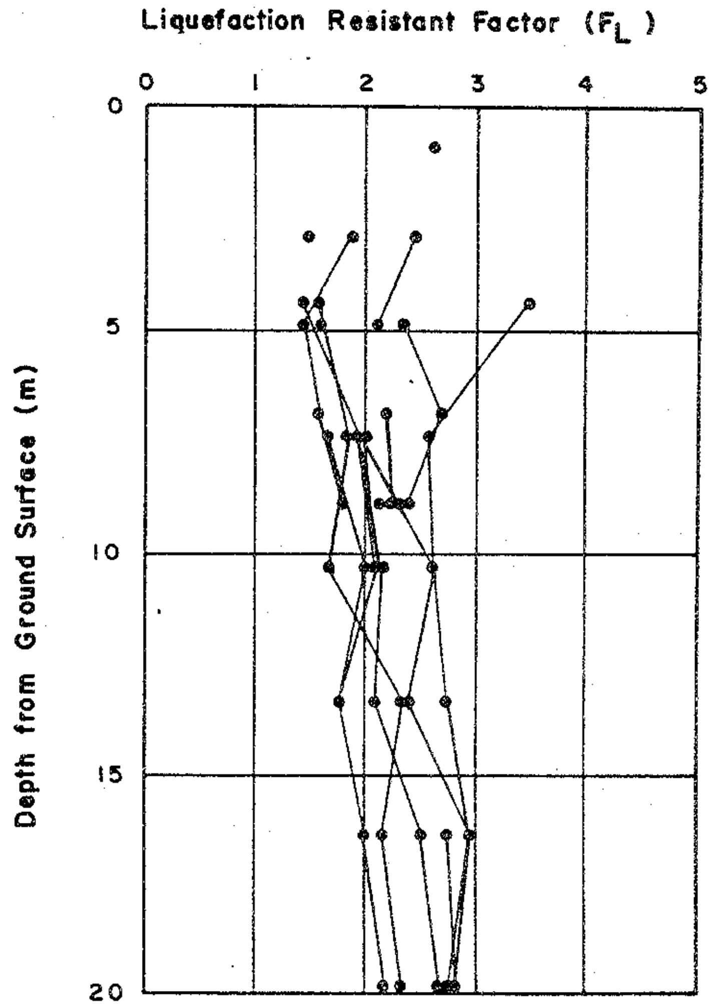


Figure 4.6 RELATION BETWEEN F_L AND DEPTH ON DESIGN SEISMIC COEFFICIENT ($K_h = 0.11$)