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THE STUDY ON
MANAGEMENT OF GROUNDWATER AND
LAND SUBSIDENCE
IN
THE BANGKOK METROPOLITAN AREA AND
ITS VICINITY

KOKUSAI KOGYO CO., LTD.

TOKYO, JAPAN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

DEPARTMENT OF MINERAL RESOURCES
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AND
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MINISTRY OF INTERIOR
THE KINGDOM OF THAILAND

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

FINAL REPORT
SUPPORTING REPORT

MARCH 1995

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1.1 CORE BORINGS

Core borings were conducted to investigate subsurface hydrogeologic conditions as well as to collect core samples for core analyses and soil tests. Three (3) sites were selected to perform core borings and to construct observation wells, to wit:

Site-A: Rom Klao Village of NHA, Lat Krabang
Site-B: AIT Campus, Pathum Thani
Site-C: Ron Riang Wat Klong Kru, Samut Sakhon

The locations of these sites are shown in Figure 1.1.1.

Three (3) types of boreholes were drilled at each site to collect better core samples from different layers. Using rotary drilling method, deep core borings were carried out to collect continuous core samples in HQ and/or NQ sizes below 100 m-depth. Shallow core borings were performed to take undisturbed samples up to a depth of 100 m. Prior to shallow core borings, another borehole was drilled to carry out the standard penetration tests at every meter interval from 0-m to 50-m depths to find out the occurrence of clayey layers.

The maximum depths of core borings are as follows:

Site-A: 600m
Site-B: 300m
Site-C: 325m

Undisturbed samples were taken by thin wall sampler, while disturbed samples were collected by SPT sampler. Core samples except the disturbed and undisturbed samples were kept in split PVC pipes, wrapped with plastic sheet to prevent change in soil moisture, and placed in wooden boxes. All core samples were transported to AIT for lithologic description, photographs, and selection of samples for soil tests and core analyses.

1.1.1 Site-A (Lat Krabang)

Core boring was performed up to the 600-m depth at Site-A. The HQT wire line core barrel was used up to 538-m depth, and then the NQT wire line core barrel continued up to the 600-m depth. Core recovery was 99.0% from 0-m to 100-m depths and 87.2% from 100-m to 600-m depths.

Detailed lithologic descriptions of each layer are given in "LITHOLOGIC LOG OF SITE-A" in the APPENDICES. Figure 1.1.2 shows the lithologic log up to 50-m depth together with the results of the standard penetration test. The descriptions are summarized below.

0.00m to 17.20m

This portion consists of very soft clay. Color is dark greenish gray. N values of the standard penetration test range from 0 to 2. This very soft clay can be categorized as an alluvial formation.

17.20m to 30.45m

Very dense fine to medium sand is dominant. Upper part from 17.20m to 20.30m consists of very fine silty sand and sandy silt. Color of sand layers is brown to yellowish gray. The N values range from 15 to 46.

30.45m to 37.40m

This layer is composed of brownish clay. The clay is stiff to very stiff. The N values range from 34 to 53.

37.40 to 57.80m

This portion is composed mainly of fine to medium sand. Pebbles are contained in the layer from 39.00m to 48.00m. Lower part of this portion is intercalated with thin clay layers.

57.80m to 69.85m

Very stiff silt and clay are dominant. The silt layer from 63.12m to 68.23m is sandy and overlain by a fine sand bed.

69.85m to 76.94m

This portion consists of fine silty sand and fine sand beds.

76.94m to 104.00m

This portion is composed of alternating beds of clay and silt. Color of the upper part is brown to yellowish brown, but the lower part shows reddish brown mottled with gray. Calcareous nodules are contained in the lower portion.

104.00m to 109.00m

Fine to medium sand is predominant in this portion. Upper sand bed contains silt and trace of carbonized materials. A thin clay bed from 106.41m to 106.70m contains pebbles (0.2 to 0.5cm in diameter).

109.00m to 127.00m

This portion is mainly composed of silt and clay beds. The clay is characterized by its reddish color. Calcareous nodules like gravel and carbonized materials are irregularly contained. Some parts of silt and clay beds are moderately consolidated.

127.00m to 148.90m

This portion is composed mainly of medium to coarse sand beds and contains intercalated thin fine sand beds. Granule and pebble are contained. The shape of gravel is angular to subangular. Medium to coarse sand beds are mostly loose.

148.90m to 168.30m

Upper part of this portion is composed of clay beds, and lower part is composed of sandy silt and silt beds. In contrast to the brownish color of the silt beds, the clay bed from 156.90m to 160.50m has a reddish brown color. The silt bed from 164.00m to 168.30m contains a lot of carbonized materials.

168.30m to 178.28m

This portion consists of sand beds which show a normal graded bedding. The lower part is composed of medium sand, and the upper part consists of very fine sand. Silt is contained in most beds.

178.28m to 183.25m

Silt with very fine sand is predominant in this portion. Color is brown mottled with gray. The core is partly well consolidated. A thin loose sand bed is intercalated in the lower part.

183.25m to 218.60m

This portion is composed mainly of fine to medium sand with silt and contains intercalated thin silt beds. The sand grain is poorly sorted. Sand beds containing medium sand tend to be loose.

218.60m to 229.80m

This portion is composed of sand beds with different grain size. Silt content is less than that of the above layer. The sand grain in each bed is well sorted. Sand beds containing medium sand tend to be loose.

229.80m to 240.00m

Alternating silt and sand beds compose this portion. Silt is laminated in the middle part.

240.00m to 246.42m

This portion shows one sedimentary cycle from medium sand to very fine sand with silt in ascending order.

246.42m to 252.30m

This portion consists of silt with brown to reddish brown mottled with gray color. Well consolidated calcareous nodules are contained.

252.30m to 259.00m

Lower part is composed of coarse sand to granule, whereas the upper part is composed of fine to very fine sand. Lamination can be seen in very fine sand beds in the upper part.

259.00m to 270.85m

This portion is composed mainly of very fine sand with silt. Medium to coarse sand beds are interbedded. Very fine sand beds in the lower part show reverse grading.

270.85m to 288.60m

This portion consists of silt with interbeds of thin fine to medium sand.

288.60m to 311.00m

This portion is composed of fine to coarse sand with silt and granule. In contrast to the brownish color in the above formations, this portion has greenish gray color. Sand grain size is poorly sorted.

311.00m to 325.73m

Silt beds are predominant in this portion. Loose fine sand beds are intercalated in the upper part. Silt and clay beds in the lower part are reddish brown.

325.73m to 332.54m

This portion consists of loose fine sand. A bedding plane at the bottom dips 20°.

332.54m to 338.30m

This portion consists of moderate to well consolidated silt. The middle part contains consolidated calcareous nodules.

338.30m to 345.20m

Alternating beds of fine sand with silt and very fine sand with silt compose this portion. Sand in the lower part looks like arkose sand.

345.20m to 350.60m

This portion is composed mainly of reddish brown silt.

350.60m to 361.40m

Fine to very fine sand with silt is predominant in this portion. Color is greenish gray to bluish gray. Lower part consists of well sorted fine sand beds and contains plant fossils.

361.40m to 378.35m

This portion is composed mainly of silt and clay. Fine to very fine sand beds are intercalated in the upper middle part. Clay is partly well consolidated and contains calcareous nodules. Sand and silt beds are loose.

378.35m to 389.70m

This portion consists of loose fine to very fine sand with intercalated thin silt beds. The silt bed from 381.80m to 382.50m contains well consolidated calcareous nodules. A plant fossil of wooden fragment was discovered from 384.80-m to 384.90-m depths.

389.70m to 399.00m

Silt and clay beds compose this portion. Thin loose very fine sand beds are intercalated. Color of the upper part is dark gray to dark greenish gray; the lower part has dark brownish gray to reddish brown color and is partly well consolidated.

399.00m to 408.45m

This portion is composed of fine to very fine sand with a thin medium to coarse sand bed.

408.45m to 427.00m

Alternating beds of silt and clay compose this portion. The clay is sticky. The silt is partly well consolidated and contains calcareous nodules.

427.00m to 440.00m

This portion is composed mainly of loose fine to very fine sand. A medium to coarse sand bed occurs from 437.00-m to 437.75-m depths.

440.00m to 457.38m

This portion consists of well layered silt and clay beds and thin intercalated sand beds with trace of granules.

457.38m to 474.00m

This portion is composed of alternating beds of silty sand and sandy silt. Sand beds in the lower part is poorly sorted and contain granules. Silt beds also contain granules.

474.00m to 482.28m

This portion is composed of light gray silt beds with sand.

482.28m to 496.80m

This portion is composed mainly of sandy silt with granules. Grain size is poorly sorted.

496.80m to 510.00m

Silt and clay beds with interbedded silty fine sand compose this portion. Clay is partly well consolidated.

510.00m to 529.65m

This portion is composed of poor sorted silty sand with intercalated thin silt beds. Sand beds contain granules.

529.65m to 550.80m

This portion consists of well consolidated silt with sand.

550.80m to 577.50m

Fine to very fine sand with silt is predominant in this portion. Moderate to well consolidated thin clay and silt beds as well as thin medium sand to granule beds are intercalated. A well sorted very coarse sand bed occurs from 556.00-m to 557.45-m depths.

577.50m to 600.00m

Alternating beds of fine sand with silt and sandy silt compose this portion. The fine sand with silt beds are loose, whereas sandy silt beds are moderate to well consolidated.

1.1.2 Site-B (AIT)

Core boring was performed up to the 300-m depth at Site-B. The HQT wire line core barrel was used up to 283.1-m depth, and then the NQT wire line core barrel continued up to the 300-m depth. Core recovery was 98.8% from 0-m to 100-m depths and 82.2% from 100-m to 300-m depths.

Detailed lithologic descriptions of each layer are given in the "LITHOLOGIC LOG OF SITE-B" in the APPENDICES. Figure 1.1.3 shows the lithologic log up to 50-m depth together with the results of the standard penetration test. The descriptions are summarized below.

0.00m to 15.80m

This portion consists of a very soft clay bed, a thin clayey sand bed, and a sandy clay bed in descending order. The very soft upper clay bed from 0m to 9.20m has dark greenish gray color and zero N-value. The sandy clay bed from 10.00m to 15.80m has brown color and its N values range from 12 to 17.

15.80m to 23.20m

Fine to fine silty sands comprise this portion. A thin silt bed is intercalated. N values range from 20 to 66.

23.20m to 28.80m

This portion consists of sandy silt. Sandy silt is stiff, and its N values range from 9 to 30.

28.80m to 38.60m

Medium sand comprises this portion. N values range from 16 to 71.

38.60m to 44.50m

Gravelly sand composes this portion. Sand is poorly sorted and contains granules and pebbles. N values range from 23 to 42.

44.50m to 49.00m

This portion consists of fine sand. N values range from 36 to 43.

49.00m to 67.40m

This portion is composed mainly of clay. The lower part from 66.00m to 67.40m consists of gravelly clay, and that part from 58.00m to 66.00m is silty clay.

67.40m to 73.55m

This portion consists of very fine silty sand.

73.55m to 86.95m

Clay comprises this portion. The lower part from 85.05m to 86.95m consists of gravelly clay.

86.95m to 95.40m

Fine silty sand with thin intercalated silt bed composes this portion.

95.40m to 102.30m

This portion is composed of gravelly clay. Pebble is calcareous and subangular in shape.

102.30m to 106.00m

This portion consists of fine sand. The upper part contains silt, and the lower part has trace of granules.

106.00m to 109.50m

This portion is composed of moderately consolidated silt and contains calcareous nodules.

109.50m to 114.00m

Gravel with clay and fine to medium sand beds compose this portion.

114.00m to 126.25m

This portion is composed of coarse sand, fine to very fine sand, silt, and clay in ascending order. Thin clay and gravel beds are intercalated in the middle part.

126.25m to 134.10m

Reddish brown silt and clay beds in ascending order compose this portion. The lower silt is well layered. The upper clay contains trace of gravel and carbonized fragments.

134.10m to 165.55m

This portion is mainly composed of fine to very fine sand with intercalated silt beds. The lower part from 155.00m to 165.55m consists of well layered alternating beds of fine sand and clay.

165.55m to 183.13m

This portion is composed of silt and clay beds with intercalated fine sand. Clay has reddish brown color and contains calcareous nodules. Sand bed in the lower part contains trace of granules.

183.13m to 193.40m

This portion is mainly composed of medium to coarse sand with silt. The lower part from 191.75m to 193.40m consists of very coarse sand and granule. The bottom of this layer could be unconformity.

193.40m to 260.00m

This portion is composed of thick silt and clay beds. The color is yellowish brown to reddish brown mottled with gray. Calcareous nodules are contained in both silt and clay beds. Parts of clay are fractured.

260.00m to 276.00m

Alternating beds of medium to coarse sand and silty fine sand compose this portion. The medium to coarse sand beds occasionally contain granule and pebble.

276.00m to 292.14m

This portion is composed mainly of silt and clay and contains calcareous nodules. The clay bed from 285.75m to 288.25m has reddish brown color and is fractured.

292.14m to 295.65m

This portion is composed mainly of laminated fine silty sand.

295.65m to 300m

This portion is composed mainly of sandy silt. The upper part contains calcareous nodules.

1.1.3 Site-C (Samut Sakhon)

Core boring was performed up to the 325-m depth at Site-C. The HQT wire line core barrel was used up to 325-m depth. Core recovery was 95.7% from 0-m to 100-m depths and 86.8% from 100-m to 325-m depths.

Detailed lithologic descriptions of each layer are given in the "LITHOLOGIC LOG OF SITE-C" in the APPENDICES. Figure 1.1.4 shows the lithologic log up to 50-m depth together with the results of the standard penetration test. The descriptions are summarized below.

0.00m to 29.45m

This portion consists of a very soft clay bed, a stiff clay bed, a silty clay bed, and stiff clay bed in descending order. The very soft upper clay is 14.5m thick and its N values range from 0 to 2. This bed contains shell fragments and organic materials. Underlying clay bed from 14.50m to 19.45m is stiff and its N values range from 5 to 14. The silty clay bed from 19.45m to 23.50m is very stiff and its N values range from 27 to 39. The N values of the stiff clay bed from 23.50m to 29.45m range from 19 to 33.

29.45m to 34.00m

This portion consists of fine silty sand and silty medium sand.

34.00m to 71.70m

Clay is predominant in this portion. The upper part from 34.00m to 43.45m is composed of silt and sandy clay. The lower part from 67.50m to 71.70m is composed of sandy silt.

71.70m to 80.10m

This portion consists of loose fine sand to medium sand.

80.10m to 102.55m

This portion consists of yellowish to reddish brown clay.

102.55m to 106.43m

This portion is composed of loose very fine sand with clay.

106.43m to 121.90m

Silt is predominant in this portion. Calcareous nodules are irregularly contained.

121.90m to 132.00m

Alternating beds of fine sand with silt and silt comprise this portion.

132.00m to 142.35m

This portion consists of fine to medium sand and contains granules.

142.35m to 159.15m

Silt and clay comprise this portion. The clay bed from 142.35m to 147.20m has slickenside at the crack surface. The silt bed from 147.20m to 159.15m contains calcareous nodules and is partly well consolidated.

159.15m to 162.70m

This portion consists of gravel and fine to coarse sand with silt.

162.70m to 176.00m

This portion is composed mainly of silt. The middle part from 165.33m to 170.00m consists of sandy silt. The silt contains calcareous nodules and is partly well consolidated.

176.00m to 178.57m

This portion is composed of fine to coarse sand with silt.

178.57m to 187.60m

Silt is predominant in this portion. Silt is partly well consolidated like limestone.

187.60m to 202.00m

This portion consists mainly of clay. The clay has partly reddish brown color and has slickenside.

202.00m to 204.00m

This portion consists of fine to coarse sand in the lower part and very fine sand with silt in the upper part.

204.00m to 207.80m

Silt comprises this portion. Its color is yellowish brown mottled with gray.

207.80m to 213.35m

This portion is composed of fine to very fine sand.

213.35m to 227.58m

This portion is composed of silt and clay with intercalated very fine sand beds. The silt and clay contain calcareous nodules.

227.58m to 230.95m

This portion is composed mainly of loose silty fine sand.

230.95m to 244.05m

Silt and clay compose this portion. The silt bed from 231.25m to 232.45m contains granules.

244.05m to 250.12m

This portion is composed mainly of fine to coarse sand with silt. A 1.89-m thick silt bed is intercalated.

250.12m to 257.10m

The lower part consists of silt with fine sand and the upper part consists of clay. Both silt and clay beds are partly well consolidated.

257.10m to 263.10m

This portion consists mainly of loose very fine sand with silt. The lower part from 262.85m to 263.10m consists of cemented gravel like conglomerate.

263.10m to 271.15m

Silt comprises this portion. The silt is partly well consolidated.

271.15m to 281.00m

This portion is composed of fine to coarse sand with silt. The sand contains trace of granule.

281.00m to 291.60m

This portion is composed mainly of silt. The silt is moderately to well consolidated.

291.60m to 297.00m

Loose fine sand comprises this portion.

297.00m to 309.00m

The lower part consists of clay, whereas the upper part consists of silt and very fine silty sand.

309.00m to 323.55m

This portion is composed of fine to very fine sand with intercalated thin silt beds and thin medium to coarse sand beds.

323.55m to 325.00m

This portion consists of well consolidated silt.

1.1.4 Analyses of Core Samples

Core samples collected from Site-A, Site-B, and Site-C were analyzed for the following items:

- ^{14}C dating
- Microfossils (Diatom and Foraminifera)
- Salt content

Table 1.1.1 shows the number of samples collected for core analyses.

Table 1.1.1 NUMBER OF SAMPLES FOR CORE ANALYSES

Site	^{14}C	Diatom	Foraminifera	Salt Content
Site-A	5	39	38	10
Site-B	4	21	21	10
Site-C	1	19	19	10
Total	10	79	78	30

Numbers and depths of samples are given in Tables 1.1.2 to 1.1.4. All samples were sent to Japan for laboratory analyses.

(1) ^{14}C Dating

The radiocarbon dating (^{14}C dating) was used to determine the absolute age of the samples by measuring the proportion of the isotope ^{14}C in the carbon they contain. The method is suitable for determining ages up to a maximum of about 50,000 years.

Preparation of Samples

Wood fragments, shell fragments, and organic sediments are suitable samples for ^{14}C dating analysis. If the sample is to be taken from organic sediments, it should be at least 500g. The samples are prepared using the following procedure: heat the sample in 1% to 5% of NaOH solution to dissolve humic acid and acidify to obtain a deposit; burn the deposited material in oxygen gas and absorb the released CO_2 gas using ammonium; make carbide from the retrieved ammonium carbonate and then mix with water; and finally, send the acetylene to the isotope-proportion counter.

Method of Analysis

Count the current surges which are caused by the radiocarbon for about 20 hours; obtain the number of counts per hour for statistical examinations during the 20 hours; obtain the average number of counts and compute the absolute age and accuracy of measurements.

Results of ^{14}C dating is shown as follows:

LOCATION NO.	DEPTH in Meter	LITHOLOGY	Age
Minburi A-1	1.00-1.45	Clay,dark gray	1,110±100
Minburi A-2	8.00-8.45	Clay,dark greenish gray	4,850±140
Minburi A-3	11.00-11.45	Clay ,dark gray	7,170±550
Minburi A-4	17.00-17.45	Clay ,dark gray	8,620±340
Minburi A-5	385	Silt, black, peaty	>37,840
AIT B-1	3.00-3.45	Clay, dark greenish	5,730±470
AIT B-2	4.00-4.45	Clay, dark greenish	8,040±380
AIT B-3	7.00-7.45	Clay,dark greenish	8,400±140
AIT B-4	9.00-9.45	Clay,dark greenish	7,550±140
AIT B-5	11.00-11.45	Shell fossil	3,510±200

*Age in Year since 1950.

(2) Diatom Analysis

Diatom analysis can estimate the sedimentary environment and can be used for stratigraphic correlation.

Preparation of Samples

Clayey or silty sediments are suitable samples for the diatom analysis. Steps in the preparation of samples are: grind the collected sample and then put several grams of ground sample into a test tube; add several cubic centimeters of 15% oxygenated water and then leave it for 24 hours; add pure water and stir; after the sand particles have settled down, take a sample of the turbid water and put it on a slide glass to make a preparate.

Method of Analysis

Inspect the preparate and finally identify the diatoms by a microscope using 600 times magnification. About 200 diatoms should be identified. If the diatom content is small or nil in a preparate, it should be noted in the results of the analysis.

Results of Analysis

Most samples did not contain diatom fossils. At Site-A, five (5) out of 39 samples contained diatom fossils; at Site-B, only one (1) out of 21 samples contained diatom fossils; and at Site-C, only two (2) out of 19 samples contained diatom fossils.

The samples containing diatom fossils were as follows:

Site	Sample No.	Depths
Site-A	D-A1	4.00- 4.45m
	D-A2	10.00-10.45m
	D-A3	16.00-16.45m
	D-A4	18.00-18.45m
	D-A5	20.00-20.45m
Site-B	D-B1	2.00- 2.45m
Site-C	D-C1	8.00- 8.45m
	D-C2	14.00-14.45m

The diatoms found in the above samples are listed in Table 1.1.5. The results of diatom analysis for each sample are discussed below.

D-A1 (Depths: 4.00m-4.45m)

The diatom content of the sample is normal. *Cyclotella stylorum* and *Thalassionema nitzschioides* which are embayment planktonic diatoms share 30% and 20% of the total number of counted diatoms, respectively. Also *Coscinodiscus spp.*, a marine planktonic diatom, has a percentage of 25%. Thus, 75% of the total are marine planktonic diatoms. Though a few diatoms show marine dry beach environment and fresh water environment, the sedimentary environment is estimated as an embayment condition.

D-A2 (Depths: 10.00m-10.45m)

The diatom content of the sample is normal. The diatom composition is similar to that of the D-A1 sample, containing many embayment planktonic diatoms such as *Cyclotella stylorum*, *Thalassionema nitzschioides*, *Coscinodiscus spp.*, etc. Diatom composition has more embayment conditions than D-A1 because it has more *Cyclotella stylorum* and *Thalassionema nitzschioides.*

D-A3 (Depths: 16.00m-16.45m)

The diatom content of the sample is normal. *Cyclotella stylorum*, *Thalassionema nitzschioides*, and *Coscinodiscus spp.* are dominant in the sample, but its paleoenvironment seems to be more of the open sea as compared with D-A1 due to its lesser content of *Cyclotella stylorum* and *Thalassionema nitzschioides.*

D-A4 (Depths: 18.00m-18.45m)

The diatom content of the sample is small. The diatom composition is similar to that of the D-A3 sample.

D-A5 (Depths: 20.00m-20.45m)

The diatom content is very small so that the detailed paleoenvironment cannot be estimated.

D-B1 (Depths: 2.00m-2.45m)

The sample contains many diatoms. *Coscinodiscus spp.* shares 70% of the total number of counted diatoms. The result indicates an open sea environment.

D-C1 (Depths: 8.00m-8.45m)

The diatom content is small. *Cyclotella stylorum* and *Thalassionema nitzschioides* are predominant; and *Coscinodiscus spp.* is also found in the sample. The result indicates an embayment environment.

D-C2 (Depths: 14.00m-14.45m)

The diatom content is very small. Fresh fluvial diatoms such as *Distoma vulgare*, *Navicula cf. yuraensis*, and *Rhoicosphenia abbreviata* are found in the sample. Marine planktonic diatom, such as *Paralia sulcata*, is also found. These diatoms may be allochthonous so that the paleoenvironment cannot be estimated.

(3) Foraminifera Analysis

Clayey or silty sediments are suitable samples for the foraminifera analysis. Foraminifera analysis can also estimate the sedimentary environment and can be used for stratigraphic correlation.

Preparation of Samples

Samples are prepared as follows: Grain the collected sample and then put 100 grams of sample into an evaporation pan; add water and then boil for more than 30 minutes so as to separate fossils from sediments; wash the sample and sieve using 200-mesh, 100-mesh, and 32-mesh sizes. The materials remaining in the sieves are used for the analysis. If the sample is consolidated, sodium sulfate or naphtha is added to separate fossils from sediments.

Method of Analysis

Select 200 foraminiferas from the sample prepared in the 32- mesh sieve; and finally identify the foraminifera using a binocular microscope. If the foraminifera content is small or nil in a sample, it should be noted in the result of the analysis.

Results of Analysis

After thorough examinations, it was found out that only a few samples, representing the uppermost parts at Site-A and Site-C, contained foraminifera. No foraminifera fossil was detected at Site-B. The fossil contents of the samples are discussed below.

Here, the characters after the species names indicate the species relative abundance:

ea - extremely abundant	:	>50
a - abundant	:	26-50
c - common	:	11-25
f - frequent	:	6-10
r - rare	:	3-5
er - extremely rare	:	1-2

F-A1 (Depths: 16.00m-16.45m)

The sample contains foraminifera, echinoid spines, and molluscan shell fragments. Foraminiferal species contained in this sample are:

- *Asterorotalia trispinosa* (Thalmann) ---------------- c
- *Asterorotalia subtrispinosa* (Ishizaki) --------------- f
- *Asterorotalia multispinosa* (Nakamura) ------------ er
- *Pararotalis sp* --- c

F-A2 (Depths: 18.00m-18.45m)

The sample contains foraminifera and a few shell fragments. Foraminiferal specie contained in this sample is:

- *Ammonia beccarii* (Linne)

F-A3 (Depths: 20.00m-20.45m)

The sample contains foraminifera, shell fragments (common to abundant), echinoid spines, and echinodermal fragments. Foraminiferal assemblage of this sample consists of:

- *Ammonia beccarii* (Linne) --------------------------- r
- *Pseudorotalia schroeteriana* (Parker & Jones) ----- r

F-C1 (Depths: 8.00m-8.45m)

The sample's main fossil contents are foraminifera, molluscs, and ostracoda. Echinoid spines and echinodermal fragments are also present. Glauconite is found as faecal pellets.

The foraminiferal assemblage is composed of benthonic forms only:

- *Ammonia sp* -- a
- *Ammonia beccarii* (Linne) ----------------------------ea
- *Asterorotalia milletti* (Billman, Hottinger, and Oesterle) -- r
- *Brizalina sp* -- er
- *Cavarotalia annectens* (Parker & Jones) ------------ c
- *Elphidium advenum* (Cushman) ---------------------- f
- *Elphidium crispum* (Linne) ---------------------------- r
- *Elphidium koeboeense* (Le Roy) ---------------------- f
- *Glandulina laevigata* (d'Orbigny) -------------------- er
- *Hanzawaia sp* -- er
- *Lagena semistriate* (Williamson) --------------------- er
- *Pararotalia sp* -- c
- *Pseuorotalia schroeteriana* (Parker & Jones) ------- c
- *Quinqueloculina sp* ------------------------------------ r
- *Spiroloculina terquemiana* (Fornasini) --------------- c
- *Textularia foliacea* (Heron-Allen & Earland) -------- f

Partly fragmented molluscs occur abundantly and consist of bivalve and gastropod. Bivalve is composed of *Alvenieus cf. ojimanus* (Yokoyama), *Veremorpa sp*, and *Criptomya sp*, whereas gastropo consists of *Ringicula sp, Retusa cf. minima* (Yokoyama) and *Acteoclna sp*.

F-C2 (Depths: 14.00m-14.45m)

The sample contains foraminifera, molluscs, ostracoda, echinoid spines, and echinodermal fragments. It also contains glauconite (faecal pellets). Like in F-C1, foraminifera, molluscs and ostracoda are dominant.

Its foraminiferal assemblage consists of the following taxa, which are all of benthonic forms:

- *Ammonia beccarii* (Linne) ------------------------------ a
- *Ammonia cf. tepida* (Cushman) ------------------------ a
- *Asterorotalia milletti* (Billman, Hottinger, and Oesterle) -- r
- *Asterorotalia trispinosa* (Thalmann) ------------------ a
- *Bigenerina sp* -- er
- *Brizalina sp* -- er
- *Cavarotalia annectens* (Parker & Jones) ------------- f
- *Elphidium advenum* (Cushman) ---------------------- a
- *Elphidium crispum* (Linne) ---------------------------- r

- *Elphidium koebeense* (Le Roy) ------------------------ a
- *Elorilus sp* -- er
- *Hanzawaia sp* -- er
- *Lagena sp* -- er
- *Pararotalia sp* -- c
- *Pseudorotalia schroeteriana* (Parker & Jones) ------ f
- *Quinqueloculina sp* ----------------------------------- r
- *Spiroloculina terquemiana* (Fornasini) --------------- c
- *Textularia foliacea* (Heron-Allen & Earland) -------- f
- *Triloculina tricarinata* (d'Orbigny) ------------------ er

The molluscan fossil contains bivalves and a gastropod: *Alvenius sp*, *Veremorpa sp* and *Moerella sp* (all bivalves) and *Solidula sp* (a gastropod).

Nannofossil contents of this sample were also examined. While *Gephyrocapsa oceanica* is abundant, *Gephyrocapsa caribbeanica* (Boudreaux and Hay), *Pseudoemiliania lacunosa* (Kamptner) and *Emilianis huxley* (Lohman) are all absent in the sample.

F-C3 (Depths: 16.00m-16.45m)

The sample contains a few foraminifera, echinoid spines, and abraded fragments of molluscan shells. It has also glauconitic faecal pellets. The foraminiferal species are:

- *Asterorotalia trispinosa* (Thalmann) ----------------- r
- *Ammonia beccarii* (Linne) --------------------------- er
- *Pararotalia sp* -- er

F-C4 (Depths: 25.60m-25.70m)

This sample, a yellowish gray fine grained quartz sand, contains a single specimen of *Spiroloculina terquemiana* (Fornasini) and rare molluscan shell fragments.

All samples that contained fossils came from the uppermost part of the borehole section. Hence, it is reasonable to assume that they are of the same age.

Planktonic foraminifera, which is a very good and widely used tool in age determination, was completely absent in the samples. Although the degree of reliability is not so high, age determination from the foraminiferal point of view was therefore based only on the occurrence of benthonic forms. However, the occurrence of nannofossil species at Site-C (depths: 14.00m-14.45m) provided a good dating tool, hence a more conclusive result was made.

Billman et al. (1980) recorded the stratigraphic range of *Asterorotalia milletti* in the Indopacific region as Pleistocene (N.22-N.23, Blow, 1969). The occurrence of the nannofossil specie Gephyrocapsa oceanica in abundance and the absence of species *Pseudoemiliania lacunosa*, *Emiliania huxley* and *Gephytocapsa caribbeanica* (in F-C2 sample) suggested an age of Pleistocene of Billman et al. (1980), Zone CN 14b of Okada and Burky (1980) or Zone NN 20 of Martini (1971) to the sample. It meant that the uppermost sections at Site-A and Site-C were stratigraphically higher than the Brunhes/Matsuyama paleomagnetic epoch boundary or younger than 0.73Ma. These nannofossil zones could be correlated partly with Zone N 23 in terms of planktonic foraminiferal biostratigraphy. Finally, the age should be refined using ^{14}C dating.

Environments of Deposition

Samples from the three (3) boreholes which were barren of foraminifera were interpreted as continental deposits (river or fluvial deposits). There are at least two (2) distinct extreme types of roundness, i.e., angular and rounded, shown by the sand grain composition of the sediments. Euhedral bipyramidal quartz grains were also found in many samples. These observations suggest that the sediments are continental deposits (fluvial) having at least two (2) different sources of materials; one is located relatively much farther from the site than the other. Also, the carbonate material that was often found in the sediments might represent caliche.

The depositional environments of samples containing foraminifera and other fossils are discussed as follows: These samples have one thing in common; planktonic foraminiferal species are totally lacking. This suggests that the environments in which they were deposited were poorly connected with the open sea, which resulted also in a poor circulation of water among them. It is concluded therefore that the samples might have been deposited in a marginal sea environment.

The depositional environments of the foraminifera-bearing samples are described in detail in the following discussions:

Site-A

The deepest sample containing foraminifera in this site came from the depth of 20.45m where rare specimens of *Ammonia beccarii* and *Pseudorotalia schroeteriana* were found and accompanied by some shell fragments, echinoid spines, etc. This association indicates a shallow marine environment, probably very near the shore. This condition persisted up to the time of the deposition of the sample from 18.45-m depth, which contains *rare A. beccarii* and a few shell fragments.

The maximum marine condition in this area was achieved during the deposition of sample F-A1 (depths: 16.00m-16.45m) which contained quite a number of specimens of *A. trispinosa*, *A. subtrispinosa*, and *Pararotalia sp*. Also, this sample contained echinoid spines and molluscan shell fragments. This paleontological association might probably indicate a shallow bay environment.

Site-C

The deepest sample containing foraminifera came from the depth of 25.6m where only a single specimen of *Spiroloculina* and molluscan shell fragments were found. This suggests that the sample was deposited probably in a littoral environment.

Sample from 16.45-m depth contained more foraminifera and echinoid spines and some shell fragments. The depositional environment was more or less the same (littoral) but probably a slight deepening had taken place.

Further deepening of the sea was interpreted based on the paleontological evidence of the sample from depths of 14.00m-14.45m. This sample was characterized by dominant association of *Ammonia beccarii*, *Asterorotalia trispinosa*, and *Elphidium advenum*. Other important species occurring in this sample were *Spiroloculina terquemiana*, *Quinqueloculina sp*, *Textularia foliacea*, and *Pseudorotalia schroeteriana*. Molluscs and ostracoda were abundant. The sample also contained echinoid spines and abundant nannofossil specie *Gephyrocapsa oceanica*.

Ammonia beccarii and *Elphidium* are both euryhaline (tolerant to a wide range of salinity) and shallow water species. The association of the two were common in the marginal seas (bay, lagoon, etc.) and shallow shelf seas. The occurrence of *A. trispinosa*, *P. schroeteriana*, *Quinqueloculina sp*, and *T. foliacea* suggests that the salinity was very close to a normal marine condition. This was supported by the occurrence of the marine molluscan species. *Gephyrocapsa oceanica* is very abundant in the marginal sea and inland sea environments (Okada, 1984 in: Perch-Nielsen, 1985).

Based on the lithological and paleontological data, it is concluded that the depositional environment of the sample from depths of 14.00m-14.45m was the outer part of the bay where the salinity was close to a normal marine condition. The depth was probably around 40m and the bottom was muddy.

Paleontologically, the sample from 8.00-m to 8.45-m depths resembled the sample from depths of 14.00m to 14.45m. However, *A. beccarii* was very dominant and extremely abundant. At the same time, *Elphidium* was much less dominant than in the sample from 8.00-m to 8.45-m depths. This indicates a regression of the sea although the depositional environment of the sample is a bay still.

(4) Salt Content Analysis

Salt contents in the samples helped in analyzing the occurrence of saline water and the mechanism of saline water intrusion as well as the sedimentary environment.

Preparation of Samples

Clayey or silty sediments are suitable samples for the salt content analysis. Samples are prepared using the following procedure: Break the sample into granule-size pieces and then dry them under a temperature of 110°C for 48 hours; grain the sample into the size finer than the 32-mesh; take 10 grams of the sample and put it into a 140-cc test bottle; add 120cc of pure water, stir it for 3 minutes and leave it for one hour; and finally analyze the turbid water.

Method of Analysis

Measure the chloride concentration and electric conductivity of the turbid water; keep the water samples for five days without evaporation; and finally measure again the chloride content and electric conductivity. Unless there is a significant difference, the latter measured values are adopted. The chloride concentration in mg/l is converted into chloride content in g/kg. Also, the measured value of electric conductivity is corrected for temperature of 25°C.

Results of Analysis

Figures 1.1.5 to 1.1.7 show that the three (3) sites have high salt content in the shallow portion up to a depth of about 50m and low in the deeper portions. It is also shown that the changes in the electric conductivity are similar to those in the chloride content.

At Site-A, chloride content is 1.71g/kg at 31.0-m depth and 1.28g/kg at 59.8-m depth. The chloride contents from 89.0-m to 200.1-m depths range correspondingly from 0.14g/kg to 0.37g/kg, while the electric conductivities vary respectively from 115mS/cm to 141mS/cm. The samples from 240.0-m to 550.4-m depths have chloride contents of 0.10g/kg or lesser and electric conductivities ranging from 47.2mS/cm to 57.8mS/cm.

At Site-B, the sample from 27.0-m depth has the highest salt content: chloride content is 2.18g/kg and electric conductivity is 1,980mS/cm. The chloride contents from 149.5-m to 265.4-m depths are 0.10g/kg or lesser. On the other hand, the electric conductivities decrease from 300mS/cm at 50.1-m depth to 28.5mS/cm at 149.5-m depth. But they are relatively higher at deeper layers, ranging from 107mS/cm at 180.3-m depth to 147mS/cm at 208.4-m depth.

At Site-C, the sample from 17.0-m depth has the highest chloride content at 3.51g/kg and the highest electric conductivity at 1,190mS/cm. Between 17.0-m depth and 69.9-m depth, salt content decreases; from 89.0-m to 314.9-m depths, chloride content is less than 0.10g/kg.

As shown by the results discussed above, the shallow portions at the three (3) sites, up to around 50-m depth, are affected by salinity. The occurrence of high salt content in the shallow portions may be explained considering the results of microfossil analyses and hydrogeological investigations. Also, the soil content analysis showed that no fossil water occurred in the deeper portions.

1.1.5 Soil Tests

Laboratory soil tests of core samples were conducted to determine their physical and mechanical properties. On the basis of soil mechanics theory, test results were utilized to compute the amount of compaction of the aquifer system in the Study Area. Also, the results were used to estimate hydrogeological parameters of the aquifer system.

The following laboratory tests were performed in this Study:

Physical Property Test

Water content
Specific gravity
Grain size
Atterberg limits
Unit weight

Mechanical Property Test

Unconfined Compression
Consolidation (standard)
Consolidation (high stress)

(1) Soil Samples

Soil samples were obtained from core borings at Site-A, Site-B and Site-C. Table 1.1.6 shows the types of soil tests and the numbers of soil samples. As mentioned in section 4.3, three (3) types of boreholes were drilled at each site to collect better core samples from different layers. After confirming the occurrence of soft clay up to a depth of 50m by using the standard penetration test (SPT), undisturbed soft clay samples were collected using thin wall sampler. Undisturbed stiff clay samples up to a depth of 100m were collected from shallow core borings by using the Denison type sampler. Disturbed samples which consisted mainly of sandy soils were collected from the SPT sampler and shallow core borings.

The samples below 100-m depth were collected from deep core borings using the rotary wire-line drilling method. The double core tube and triple core tube were used to collect continuous core samples in HQ and/or NQ sizes. Though the were not completely undisturbed, the clayey sample was treated as an undisturbed sample because of its consolidated nature. The sandy soil samples were totally disturbed so that limited physical property tests were carried out.

In Table 1.1.7, samples collected are tabulated by site, by depth and by type of soil tests.

(2) Methods of Soil Tests

Physical Property Test

The physical property tests were carried out using procedures in accordance with the ASTM standards, and the soils were classified in accordance with the Unified Soil Classification System (USCS). The following ASTM standard test methods were employed to determine the physical properties of the soil samples:

Water Content: D2216-90 Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soils and Rocks

Specific Gravity: D854-91 Standard Test Method for Specific Gravity of Soils

Grain Size: D422-63 Standard Test Method for Particle-Size Analysis of Soils

Atterberg Limits: D4318-84 Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Unit Weight: D2216-90 Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soils and Rocks

Mechanical Property Test

To determine the mechanical properties of the soil samples, the following were conducted:

Unconfined Compression Test

Unconfined compression triaxial tests with diameter of 36mm were conducted on the undisturbed and core samples to determine the shear strength characteristics. The soil samples were trimmed to cylindrical shape by using wire saw or sharp knife depending on the stiffness of the soil. Then, the sample was placed in a compression machine and sheared at a rate of 1% per minute. The initial and final water contents were measured in the test.

Consolidation Test

One-dimensional consolidation tests were performed on soil samples to determine the consolidation characteristics as well as to establish the stress history of the ground. The results provided the relationships between compression and load and between compression and time for a given load.

Two (2) types of odometer tests were conducted, namely standard consolidation test and high stress consolidation test. In the standard consolidation test, a test specimen of 63-mm diameter was consolidated one-dimensionally to a maximum vertical stress of about 16kg/cm² with a load increment ratio (LIR) of one (1) and with increment duration of 24 hours in most sample tests. The samples were loaded to 8 kg/cm², unloaded to 2kg/cm², and reloaded to the maximum stress of 16kg/cm² before they were unloaded to 0.5kg/cm².

In the high stress consolidation test, a 45-mm sample was loaded to a maximum vertical stress of 60kg./cm² with a load increment ratio of 0.5. The tests were performed on samples taken from greater depths, i.e., between depths of 30m and 600m. In most of the high stress consolidation tests, the samples were loaded to 25.6kg/cm², unloaded to 5kg/cm², and reloaded to the maximum stress of 60kg/cm² before they were unloaded to 1kg/cm², with a total of 19 increments per test.

(3) Results of Soil Tests

The results of the soil tests are given below. The soils are classified according to the following hydrogeological classification:.

Symbol	Hydrogeological classification
SF	Bangkok Clay (soft clay)
ST	Bangkok Clay (stiff clay)
BK	Bangkok Aquifer
PD	Phra Pradaeng Aquifer
NL	Nakhon Luang Aquifer
NB	Nonthaburi Aquifer
SK	Sam Khok Aquifer
PT	Phayathai Aquifer
TB	Thonburi Aquifer
PN	Pak Nam Aquifer

The above hydrogeological symbols are used to describe the results of the soil tests.

Water Content Test

The water content test results for the three (3) sites are presented in Figures 1.1.8 to 1.1.10. Generally, the natural water content decreases with depth; this implies that the unit weight increases with depth. The water content of the soil is possible to measure when the soil exhibits some cohesion; i.e., it should contain some fine particles. For sandy soil or cohesionless soil, it is very difficult to obtain its natural water content or unit weight.

At Site-A, the water content ranges from 115% to 123% in SF's upper portion; it decreases to 62% in SF's lower portion. From ST to PN, most soils' water content ranges from 10% to 30%.

At Site-B, SF's water content ranges from 45% to 87%. From BK to SK, most soils' water content vary from 10% to 30%.

At Site-C, SF's water content ranges from 43% to 90%, whereas that of ST ranges from 19% to 36%. From BK to SK, the water content varies from 10% to 25%.

Specific Gravity Test

Figures 1.1.11 to 1.1.13 show the specific gravity test results for the three (3) sites. Generally, the specific gravity can provide some information on the mineralogy of the materials. For example, if the organic content is high, the specific gravity would be low.

At Site-A, the results show a very small variation in specific gravity with respect to depth, ranging from 2.6 to 2.75.

At Site-B, the specific gravity of most soils tested ranges from 2.6 to 2.75. NB's thick clayey formation at depths of 193m to 260m has a specific gravity of about 2.7.

At Site-C, the variation of specific gravity with depth is small, mostly ranging from 2.6 to 2.7.

Grain Size Analysis

Figures 1.1.14 to 1.1.16 present the results of the grain size analysis for the three (3) sites. The hydrometer analysis was carried out for clayey soils, and the sieve analysis was done for sandy soils. In sandy soil, the grain size distribution gives some indication of the permeability of the soil material.

At Site-A, SF consists of more than 60% clay and 20% to 30% silt. The clayey soils of PT, TB, and PN contain 30% to 70% sand. The sandy soils of NL and NB are composed mainly of medium sand and fine sand. The clay+silt content is less than 20%. The sandy soils of TB and PN are poorly sorted, which contain 20% to 60% clay+silt, 20% to 40% fine sand, and 10% to 30% medium sand.

At Site-B, SF consists of about 80% to 90% clay. The clayey soils of NL consist of 50% to 80% clay and 20% to 40% silt. The clayey soils in NB's upper portion 70% to 80% clay, whereas the clayey soils in NB's lower portion contain 10% to 40% sand and a small amount of gravel.

At Site-C, SF consists 50% to 65% silt and 30% to 50% clay. The clayey soils of BK, PD, NL, and NB contain about 60% clay. In most sandy soil samples, fine sand and clay+silt are predominant.

Atterberg Limits Test

Figures 1.1.17 to 1.1.19 show the results of the Atterberg limits test for the three (3) sites. The liquid limit, plastic limit, and plasticity index are important parameters in classifying the soil for engineering purposes and in correlating the properties of the soil.

At Site-A, SF's upper portion has more than 100% liquid limit; the liquid limit decreases to about 50% in SF and BK. From PD to PN, the liquid limits gradually decreases from 60% to 40%, except in PD's upper portion where the liquid limits range from 80% to 85%. The variation of the plastic limits is similar to that of the liquid limits.

At Site-B, SF's liquid limits range from 51% to 103%. Though some soils from PD, NL, and NB have liquid limits of 70% to 80%, the liquid limits generally tend to decrease with depth. The variation of plastic limits is smaller than that of liquid limits, ranging from 20% to 40% in SF and from 10% to 30% in BK to SK.

At Site-C, the liquid limits range from 59% to 95% in SF and from 38% to 78% in ST. PD's clayey soils have 45% to 70% liquid limits. The liquid limits of the aquifers below PD gradually decreases with depth.

Unit Weight Test

Figures 1.1.8 to 1.1.10 present the total unit weights and dry unit weights of the soil samples from the three (3) sites.

At the three (3) sites, SF's both total unit weight and dry unit weight increase with depth. From PD to PN, there is a small variation in total unit weight, ranging from $20KN/m^3$ to $22KN/m^3$.

Unconfined Compression Test

Figures 1.1.20 to 1.1.22 give the results of the unconfined compression test for the three (3) sites. The accuracy of the unconfined compression test depends greatly on the degree of sample disturbance which can be caused by either poor sampling, storing or trimming. If the sample disturbance is due to poor sampling, a lower unconfined compressive strength will result. On the other hand, if the sample is not stored properly, for instance due to poor waxing, the dried sample will give a higher value.

At Site-A, SF's and ST's unconfined compressive strengths range from 18kPa to 36kPa. Except for NL, NB and PN, some samples from aquifers below PD have more than 500kPa unconfined compressive strength. Samples from NL, NB,and PN have unconfined compressive strengths lower than 200kPa.

At Site-B, SF's unconfined compressive strength ranges from 25kPa to 39kPa. Unconfined compressive strengths of samples from PD vary widely from 7kPa to 630kPa. Most samples from NL and from NB's and SK's upper part have 200kPa to 600kPa.

At Site-C, SF's unconfined compressive strength ranges from 10kPa to 42kPa. In BK and PD, the unconfined compressive strength ranges from 10kPa to 250kPa. The unconfined compressive strengths from NL's lower portion to SK tend to increase with depths.

Consolidation Test

The preconsolidation pressures obtained from the standard consolidation test are shown in Figure 1.1.23.

SF's preconsolidation pressure ranges from 50kN/m^2 to 190 kN/m^2. This pressure tends to increase with depths. Most samples are plotted on the right side of the line of average effective stress with a maximum deviation of 80kN/m^2. At Site-A and Site-C, preconsolidation pressures of the SF's lower portion are almost the same as the average effective stress. In conclusion, the three sites' SF is a normally consolidated clay.

The preconsolidation pressure could not be obtained from the high stress consolidation test because the deep core samples are stiff and the test is less reliable.

If the clayey soil sample is very stiff, the e-log(p) plots will show a smooth line, and the preconsolidation pressure cannot be determined. Sample disturbance has significant effect on the result of the consolidation test. The sample taken by coring from a deeper portion may be disturbed by the coring procedure itself or by storing or by trimming. Though sample disturbance is difficult to quantify, it greatly influenced the consolidation curve.

Curves of void ratio versus consolidation pressure, coefficient of consolidation versus consolidation pressure and coefficient of volume compressibility versus consolidation pressure are shown in Figures 1.1.24, 1.1.25, and 1.1.26, respectively.

(4) Data Interpretation and Evaluation of Test Results

Figures 1.1.27, 1.1.28 and 1.1.29 summarize the results of the soil tests for depths of up to 50m at Site-A, Site-B, and Site-C, respectively.

As shown in these figures, Bangkok Clay (SP) is characterized by a high natural water content, a high liquid limit, a low total unit weight, and a low N-value. These SP's soil mechanics properties show that Bangkok Clay could significantly contribute to the occurrence of land subsidence.

Figure 1.1.30 shows the relationship between natural water content and liquid limit for the three (3) sites. SF and ST are distributed along $Wn=1.2(W_L)$, whereas BK to PN are plotted between $Wn=0.5W_L$ and $Wn=0.25W_L$.

Results of the Atterberg limits tests on clayey soils were plotted on the plasticity chart as shown in Figure 4.3.31. Most of the data were plotted just above PI=0.73(LL-20) (or "A"-line), indicating that the materials are either CL (low plasticity clay) or CH (high plasticity clay). Most of the clayey soils from SF fall below "A"-line, so that the materials are classified as MH (elastic silt).

Sample disturbance will affect the results of the mechanical property tests. Sample disturbance is very difficult to quantify, especially those due to poor sampling. One of the most common ways of evaluating the degree of sample disturbance is to check its degree of saturation. The soil samples below the groundwater table should be fully saturated, i.e., Sr=100%. If the sample dries up due to poor waxing or storing, the degree of saturation would be less than 100%.

Figure 1.1.32 shows the relationship between total unit weight and natural water content. The degree of saturation of most samples is between 80% to 100%. Samples taken from shallow depths by the thin wall sampler have a degree of saturation close to 100%. Some samples collected from deep coring however show a poor degree of saturation.

Table 1.1.2 SAMPLE LIST FOR CORE ANALYSES AT SITE - A

Depth (m)		Sample No.			
From	To	C-14	Diatom	Foraminifera	Salt Content
1.00	1.45	C-A1			
4.00	4.45		D-A1		
8.00	8.45	C-A2			
10.00	10.45		D-A2		
11.00	11.45	C-A3			
16.00	16.45		D-A3	F-A1	
17.00	17.45	C-A4			
18.00	18.45		D-A4	F-A2	
20.00	20.45		D-A5	F-A3	
31.00	31.45		D-A6	F-A4	S-A1
37.00	37.45		D-A7	F-A5	
59.80	60.00		D-A8	F-A6	S-A2
69.40	69.60		D-A9	F-A7	
80.00	80.10		D-A10	F-A8	
89.00	89.10		D-A11	F-A9	S-A3
89.90	90.00		D-A12		
100.10	100.20		D-A13		
101.10	101.20			F-A10	
118.10	118.20		D-A14		S-A4
118.40	118.40			F-A11	
130.40	130.50			F-A12	
140.50	140.50			F-A13	
150.00	150.10		D-A15	F-A14	
159.90	160.00		D-A16	F-A15	S-A5
180.00	180.20		D-A17	F-A16	
200.10	200.20		D-A18	F-A17	S-A6
208.50	208.50		D-A19		
210.00	210.10			F-A18	
219.80	220.00		D-A20	F-A19	
230.00	230.10		D-A21	F-A20	
240.00	240.10		D-A22	F-A21	S-A7
261.80	261.90		D-A23	F-A22	
280.00	280.10		D-A24	F-A23	
296.70	296.80		D-A25	F-A24	S-A8
320.00	320.20		D-A26	F-A25	
336.30	336.30		D-A27		
337.40	337.50			F-A26	
359.00	359.00			F-A27	
365.50	365.50		D-A28		
366.40	366.40			F-A28	
384.90	385.00	C-A5	D-A29		
389.90	390.00		D-A30	F-A29	
415.20	415.30		D-A31	F-A30	
434.50	434.60		D-A32	F-A31	
461.50	461.60		D-A33	F-A32	S-A9
481.40	481.60		D-A34	F-A33	
501.20	501.20		D-A35	F-A34	
518.20	518.30		D-A36	F-A35	
550.40	550.50		D-A37	F-A36	S-A10
579.80	579.90		D-A38	F-A37	
594.50	594.70		D-A39	F-A38	

Table 1.1.3 SAMPLE LIST FOR CORE ANALYSES AT SITE - B

Depth (m)		Sample No.			
From	To	C-14	Diatom	Foraminifera	Salt Content
2.00	2.45	C-B1	D-B1	F-B1	
3.00	3.45	C-B2			
4.00	4.45	C-B3			
7.00	7.45	C-B4			
9.00	9.45		D-B2	F-B2	
11.00	11.45		D-B3	F-B3	S-B1
14.00	14.45		D-B4	F-B4	
27.00	27.45		D-B5	F-B5	S-B2
50.10	50.20		D-B6	F-B6	S-B3
67.40	67.50		D-B7	F-B7	S-B4
79.80	79.90		D-B8	F-B8	
99.80	99.90		D-B9	F-B9	
108.80	108.90		D-B10	F-B10	S-B5
116.20	116.20		D-B11		
118.20	118.20			F-B11	
130.10	130.30		D-B12	F-B12	
139.70	139.70		D-B13		
140.10	140.10			F-B13	
149.50	149.60		D-B14	F-B14	S-B6
165.50	165.50			F-B15	
180.30	180.60		D-B15	F-B16	S-B7
196.30	196.40		D-B16	F-B17	
208.40	208.50		D-B17	F-B18	S-B8
241.30	241.40		D-B18	F-B19	S-B9
254.50	254.50		D-B19		
265.40	265.60		D-B20	F-B20	S-B10
296.60	296.60		D-B21		
299.80	299.80			F-B21	

Table 1.1.4 SAMPLE LIST FOR CORE ANALYSES AT SITE - C

Depth (m)		Sample No.			
From	To	C-14	Diatom	Foraminifera	Salt Content
8.00	8.45		D-C1	F-C1	
11.00	11.45	C-C1			
14.00	14.45		D-C2	F-C2	
16.00	16.45		D-C3	F-C3	
17.00	17.45				S-C1
25.60	25.70		D-C4	F-C4	
34.00	34.00		D-C5		
40.40	40.50		D-C6	F-C5	S-C2
51.00	51.20		D-C7	F-C6	
69.40	69.50			F-C7	
69.90	70.00		D-C8		S-C3
80.10	80.30		D-C9	F-C8	
89.00	89.10			F-C9	S-C4
100.60	100.60			F-C10	
101.50	101.60		D-C10		S-C5
121.10	121.50		D-C11	F-C11	
143.50	143.50		D-C12	F-C12	S-C6
164.20	164.30		D-C13	F-C13	
180.10	180.20		D-C14	F-C14	S-C7
200.50	200.50		D-C15		
202.50	202.50			F-C15	
220.40	220.50		D-C16	F-C16	S-C8
240.10	240.30		D-C17	F-C17	
281.00	281.20		D-C18	F-C18	S-C9
314.70	314.90		D-C19	F-C19	S-C10

Table 1.1.5 RESULT OF DIATOM ANALYSIS

Fossil name	Ecotype	DA-1	DA-2	DA-3	DA-4	DA-5	DB-1	DC-1	DC-2
Actinocyclus ehrenbergii	B,P	5	1	18	1		2	3	
Actinocyclus spp	B				1	1	2		
Actinoptycus annulatus	M,P						2		
Actinoptycus undulatus	M,P	3						2	
Cocconeis placentula	F,A								1
Coscinodiscus spp.	M,P	50	22	92	43	15	145	28	1
Cyclotella stylorum	M,P	62	92	14	6	8	3	84	1
Cymatotheca sp.	M,P			4					
Cymatotheca meissflogii	M,P	19	1	11	2		19	1	
Diatoma vulgare	F,Fl								8
Diploneis bombus	B			2					
Diploneis smithii	M,D	3							
Gomphonema spp.	F,Fl								2
Grammatophora macilenta	B,D				2				
Gyrosigma spp.	F	2							
Navicula cf.yuraensis	F,Fl								3
Navicula clementis	F to B			1					
Navicula mutica	F	1							
Nitzschia cocconeiformis	M,D	2	1	1	1				
Nitzschia granulata	M,D	1							
Paralia sulcata	M,P	2	2	5			1	13	3
Pleurosigma normanii	M,P						3	1	
Pleurosigma sp.	M,P	1							
Rhoicosphenia abbreviata	F,Fl								3
Surirella fluminensis	B,A			1					
Thalassionema nitzschioides	M,P	44	78	37	10	6	16	68	
Tryblioptychus cocconeiformis	M,P	5	3	14			6		
Unknown							1		
Total counted		200	200	200	66	30	200	200	22

M: marine, B: brackish, F: fresh

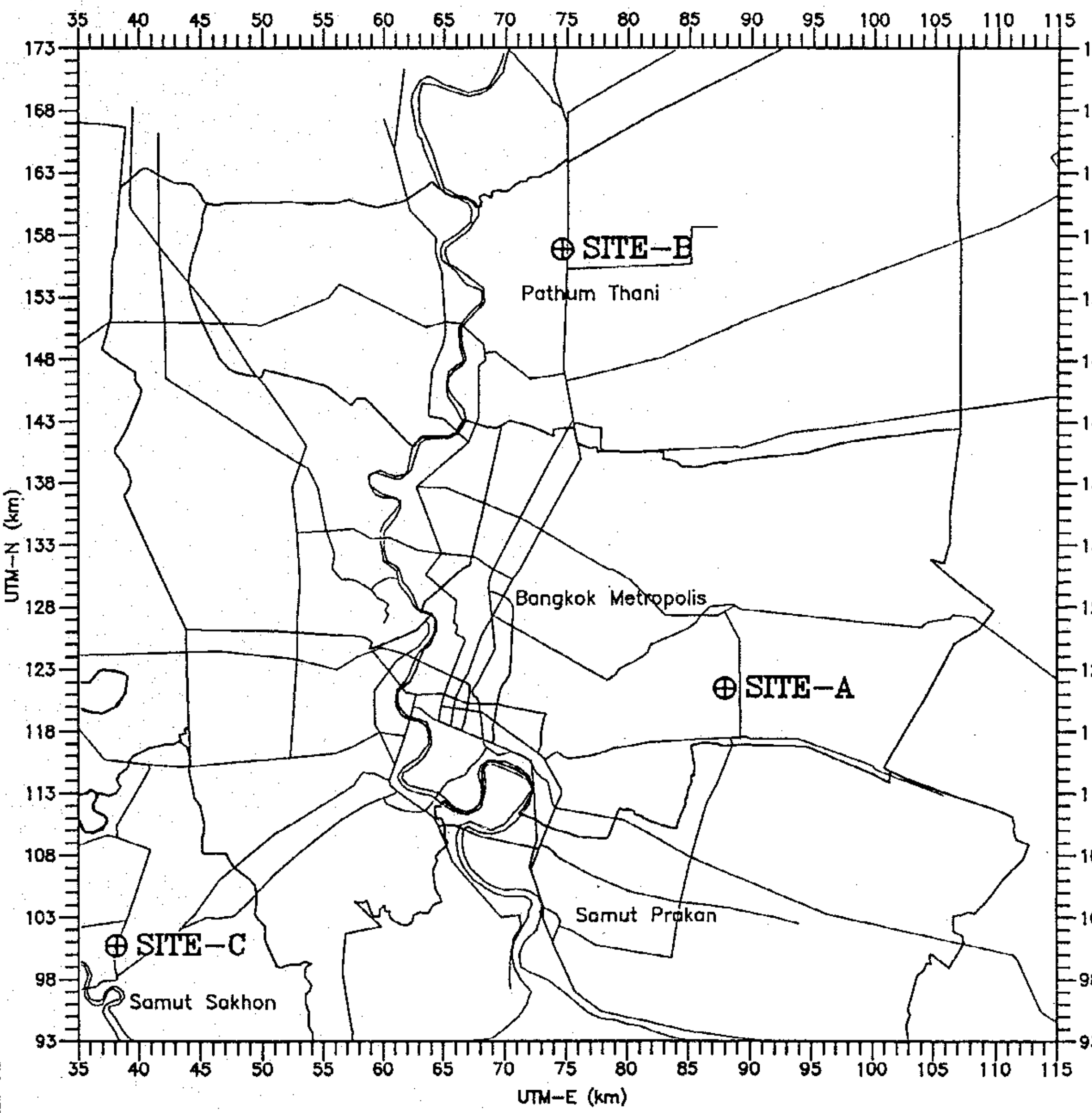
P: planktonic, A: adhering, Fl: fluival, D: dry beach

Table 1.1.6 QUANTITY OF LABORATORY SOIL TEST

TYPE OF TEST		SHALLOW CORE BORING (DEPTH<=100m)		DEEP CORE BORING (DEPTH>100m)		TOTAL
		UNDISTURBED (nos.)	DISTURBED (nos.)	CLAYEY SOIL (nos.)	SANDY SOIL (nos.)	(nos.)
PHYSICAL PROPERTIES	WATER CONTENT	64	56	115	83	318
	SPECIFIC GRAVITY	64	57	66	122	309
	GRAIN SIZE	64	77	41	263	445
	ATTERBERG LIMITS	61	-	70	-	131
	UNIT WEIGHT	64	-	116	-	180
MECHANICAL PROPERTIES	UNCONFINED COMPRESSION	64	-	65	-	129
	CONSOLIDATION (STANDARD)	22	-	-	-	22
	CONSOLIDATION (HIGH STRESS)	27	-	36	-	63

Table 1.1.7 NUMBER OF SOIL SAMPLES COLLECTED FROM THE SITES

Site	Depth (m)	PHYSICAL PROPERTY TEST								MECHANICAL PROPERTY TEST		
		Water Content		Specific Gravity		Grain Size		Atterberg Limits	Unit Weight	Unconfined Compression	Consolidation (Standard)	Consolidation (High Stress)
		Clay (nos.)	Sand (nos.)	Clay (nos.)	Sand (nos.)	Clay (nos.)	Sand (nos.)	(nos.)	(nos.)	(nos.)	(nos.)	(nos.)
A	0-100	21	27	19	31	18	33	17	21	19	8	9
	100-300	12	11	9	38	9	93	10	12	12	-	8
	300-600	27	17	24	15	23	45	16	28	19	-	10
Subtotal		60	55	52	84	50	171	43	61	50	8	27
B	0-100	31	17	20	15	7	29	21	31	24	5	9
	100-300	39	28	23	29	21	84	33	39	26	-	9
Subtotal		70	45	43	44	28	113	54	70	50	5	18
C	0-100	28	11	19	11	18	15	23	28	21	9	9
	100-300	21	23	16	35	9	35	11	21	8	-	9
	300-325	-	5	-	5	-	6	-	-	-	-	-
Subtotal		49	39	35	51	27	56	34	49	29	9	18
Grand Total		179	139	130	179	105	340	131	180	129	22	63



	UTM GRID	LONGITUDE	LATITUDE	LOCATION
SITE-A:	879215	100°44'17"	13°45'26"	ROM KLAO VILLAGE, NHA, LAT KRABANG
SITE-B:	746568	100°37'02"	14°04'41"	AIT CAMPUS, PATHUM THANI
SITE-C:	381007	100°16'35"	13°34'23"	RON RIAN WAT KLONG KRU, SAMUT SAKHON

Figure 1.1.1 **LOCATION MAP OF DRILLING SITES**

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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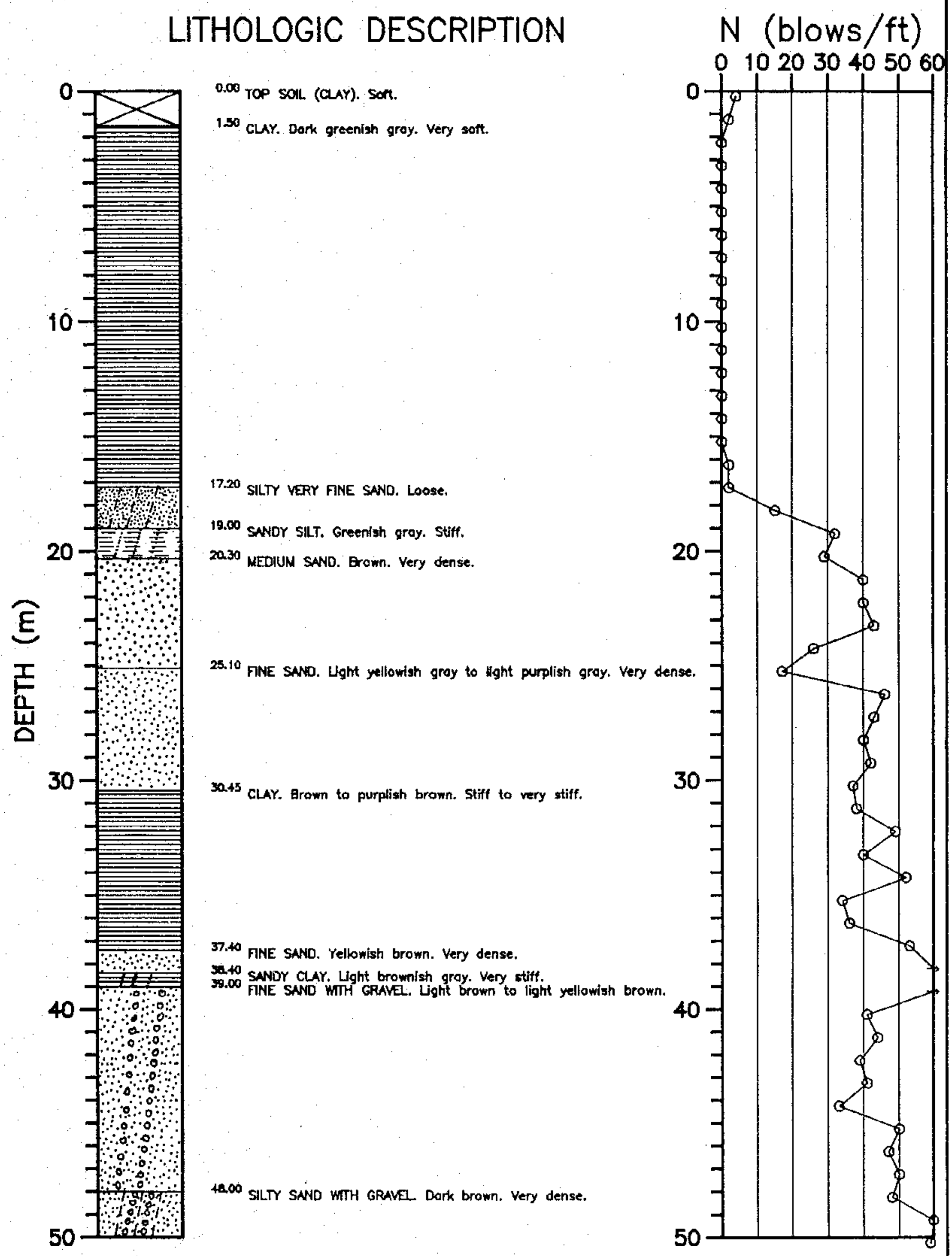

Figure 1.1.2	RESULTS OF STANDARD PENETRATION TEST AT SITE - A
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

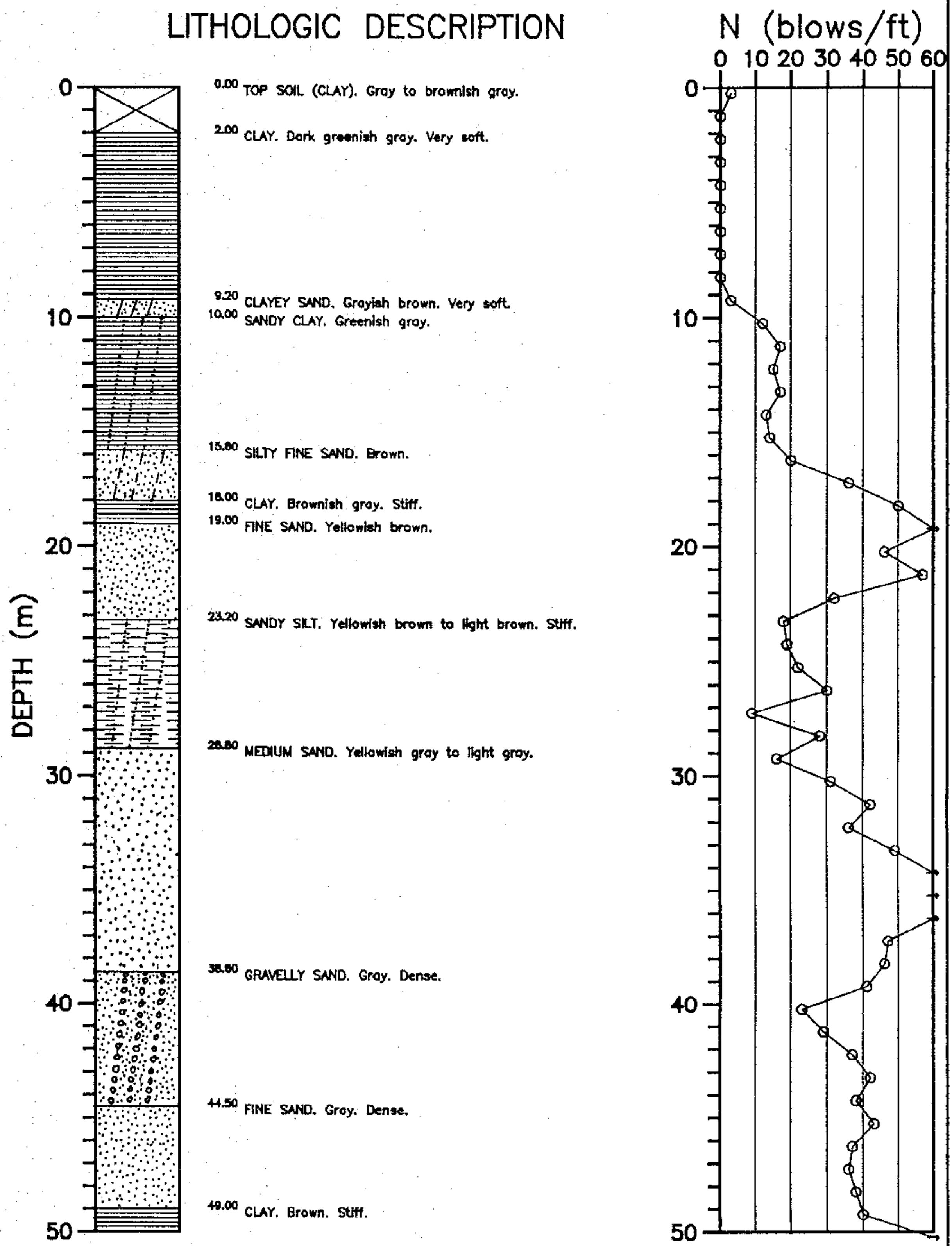

Figure 1.1.3	RESULTS OF STANDARD PENETRATION TEST AT SITE - B
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

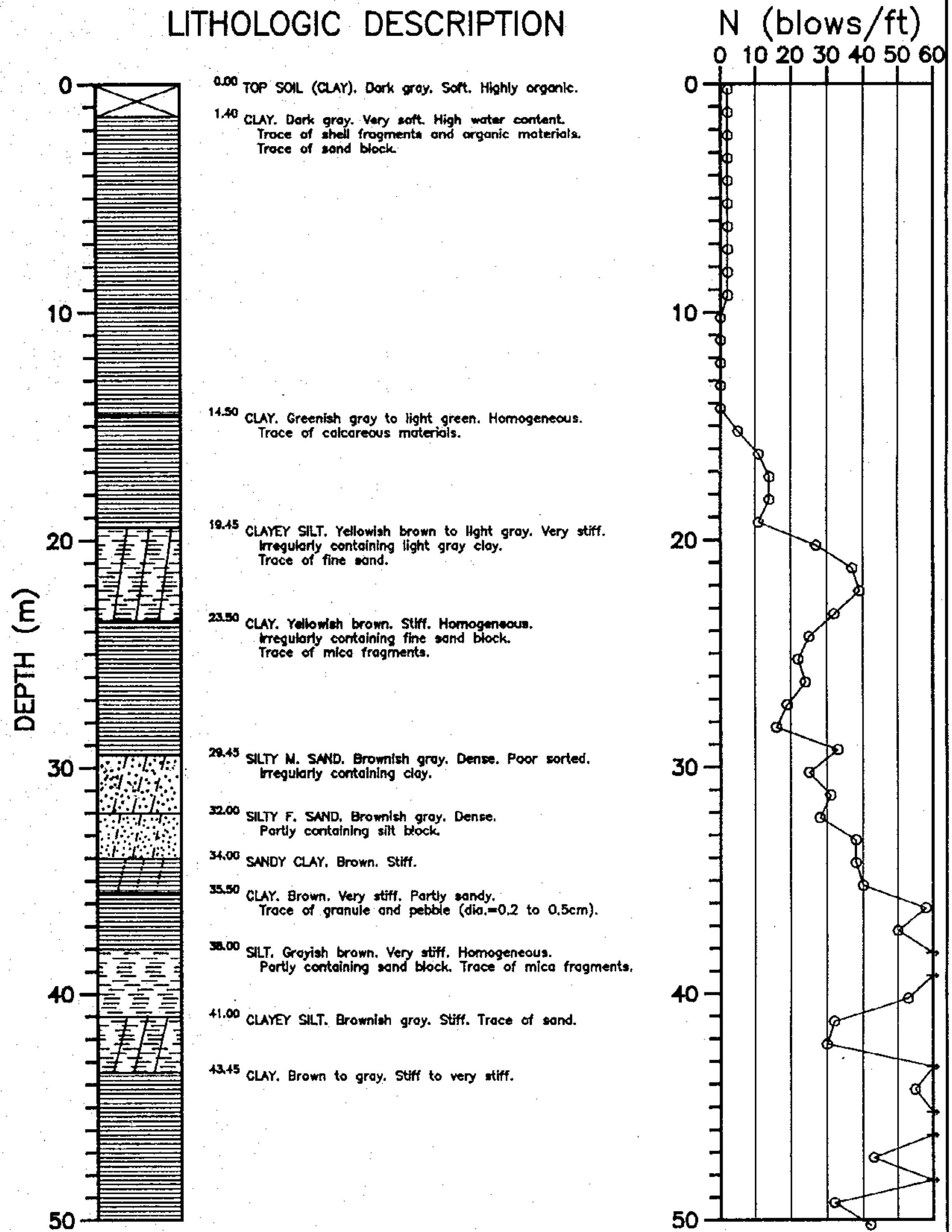

Figure 1.1.4	RESULTS OF STANDARD PENETRATION TEST AT SITE - C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

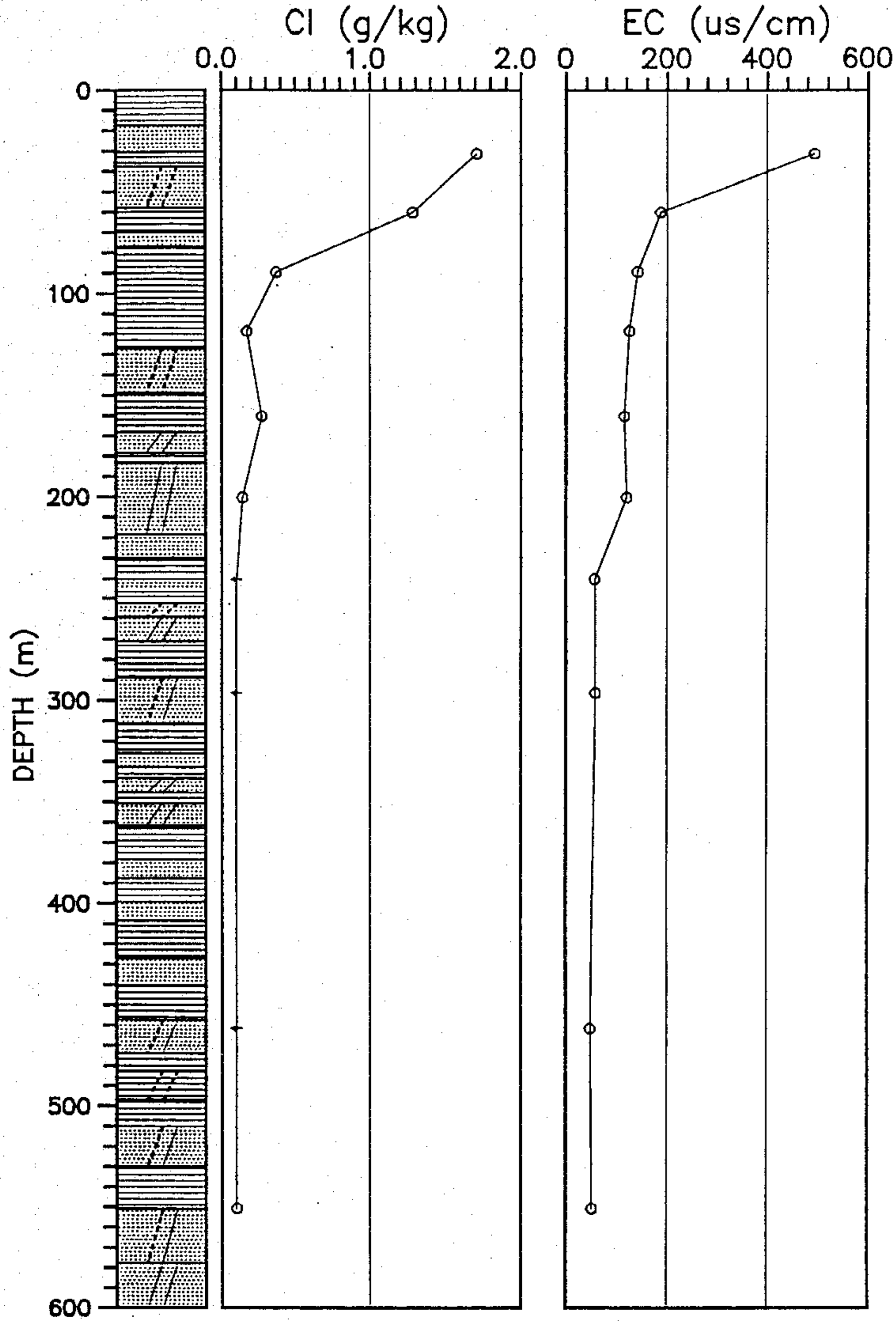

Figure 1.1.5	SALT CONTENT ANALYSIS AT SITE - A

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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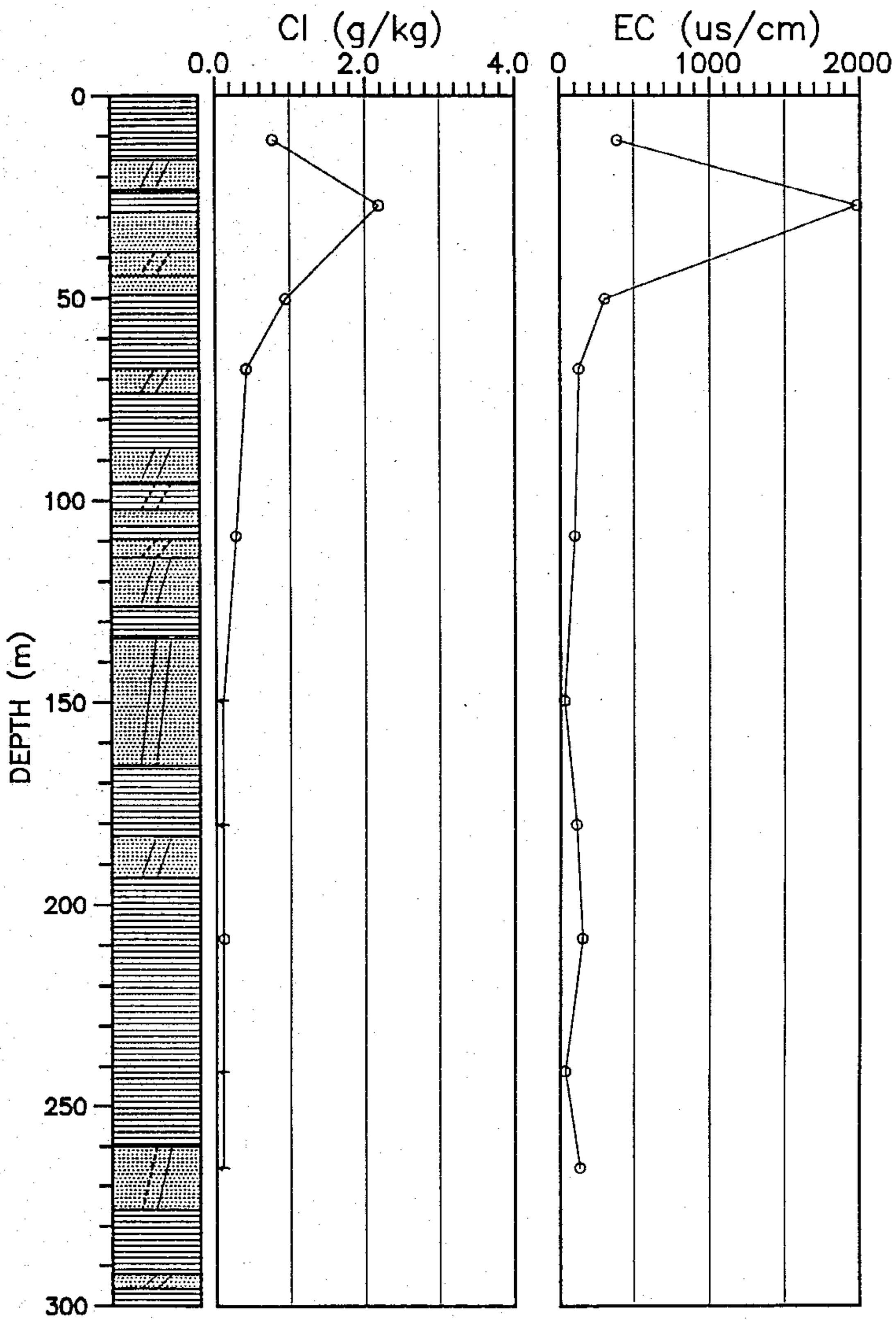

Figure 1.1.6	SALT CONTENT ANALYSIS AT SITE - B

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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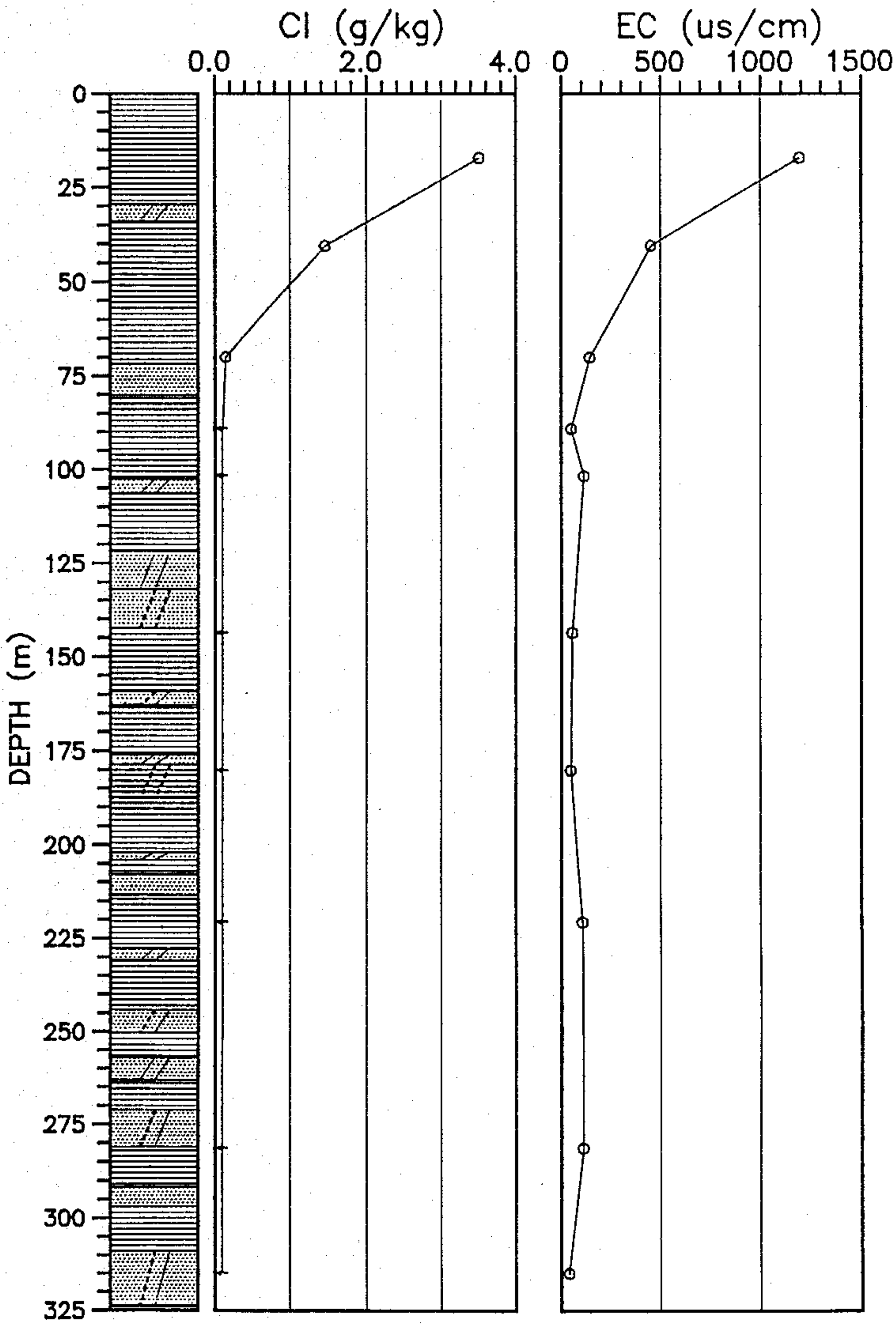

Figure 1.1.7	SALT CONTENT ANALYSIS AT SITE - C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

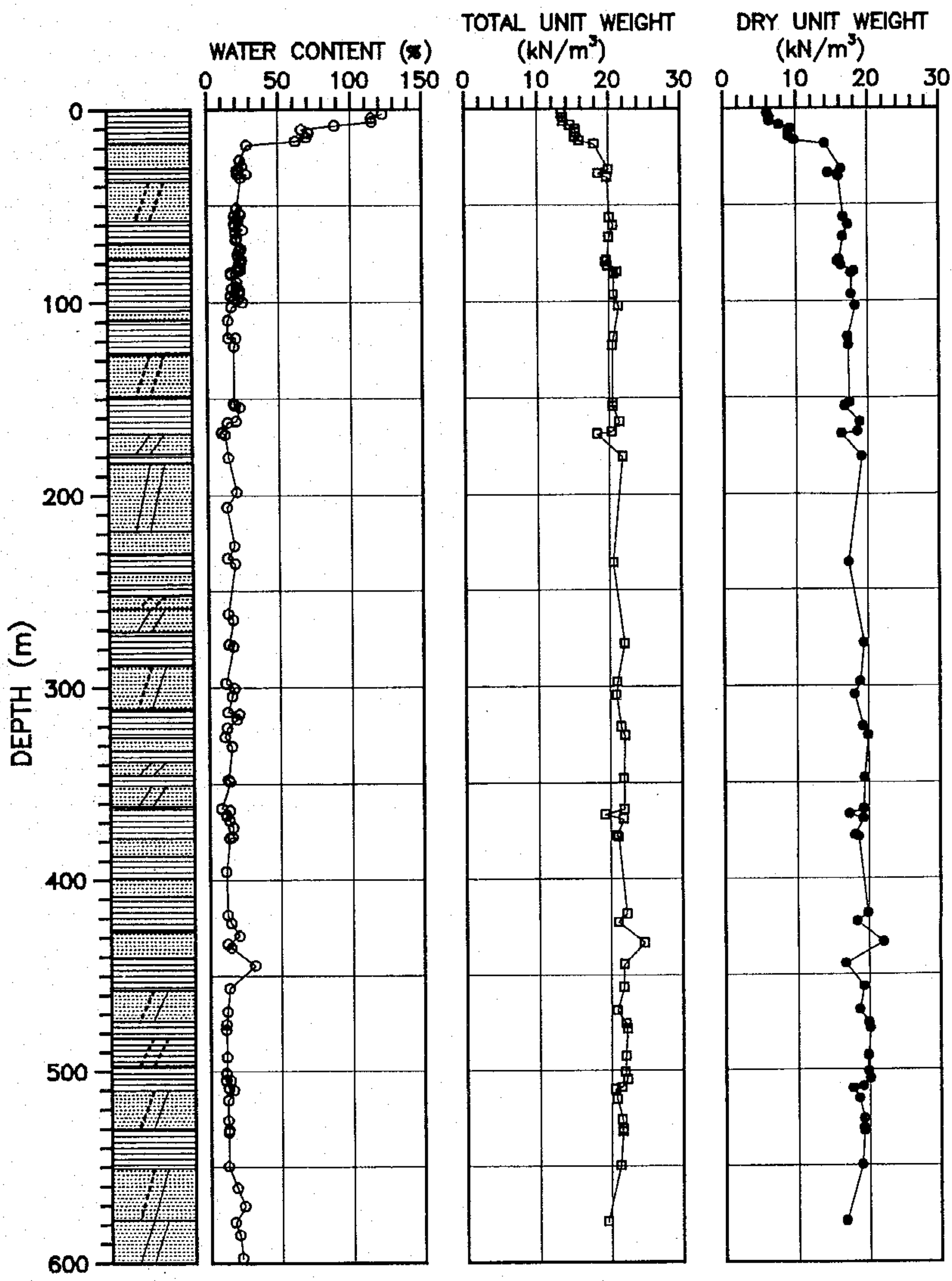

Figure 1.1.8	WATER CONTENT TEST AT SITE - A

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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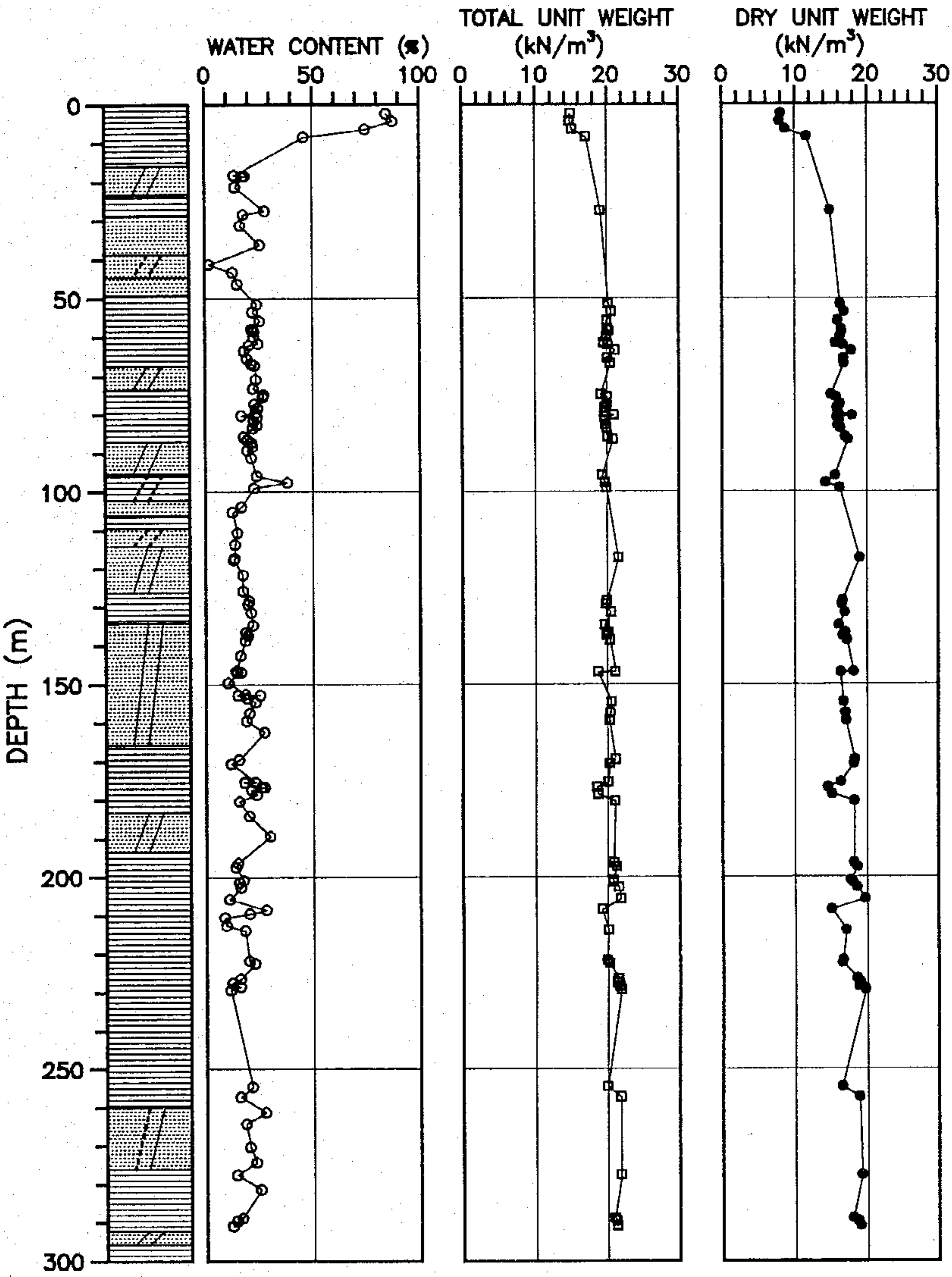

Figure 1.1.9	WATER CONTENT TEST AT SITE - B
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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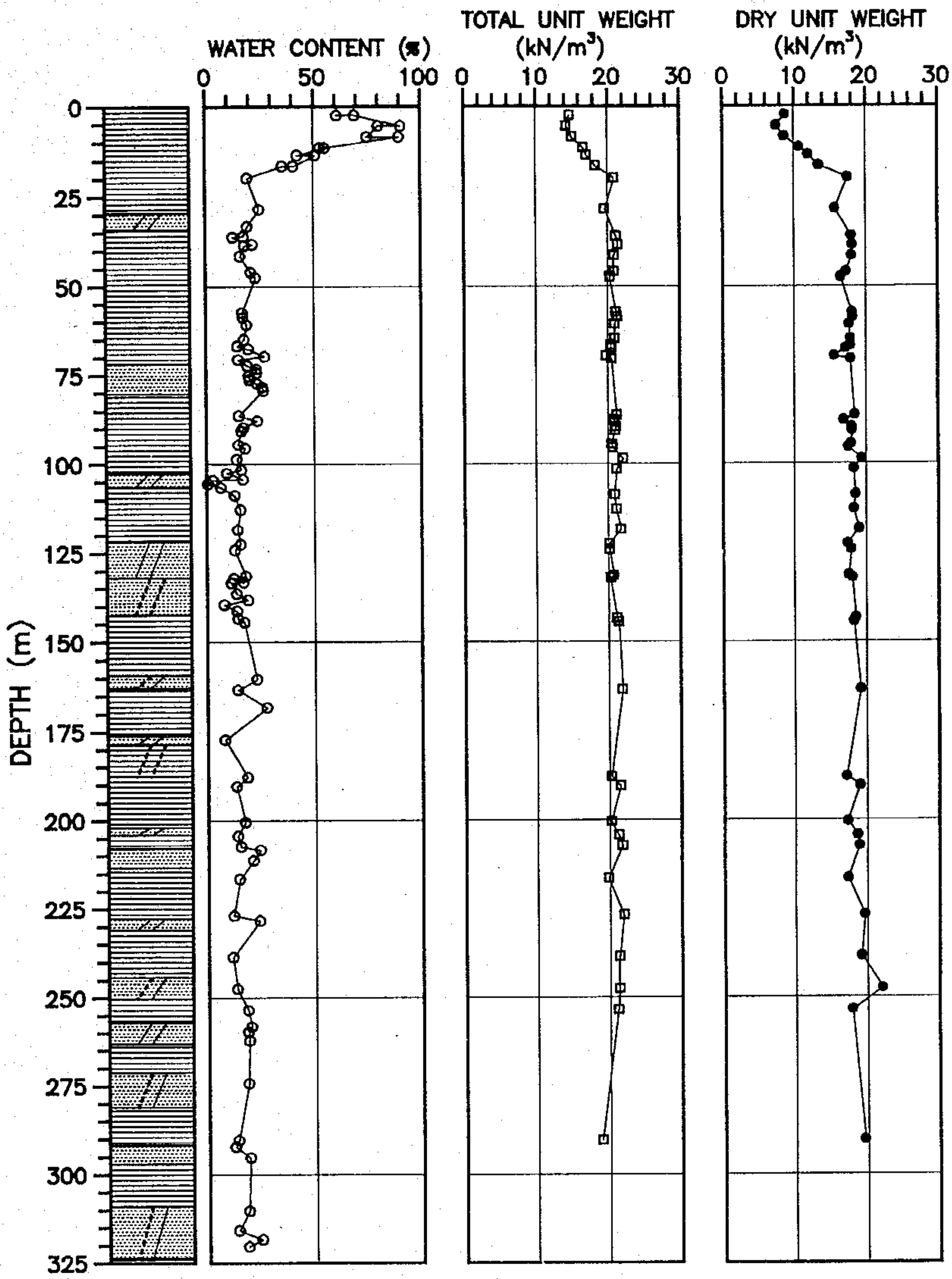

Figure 1.1.10	WATER CONTENT TEST AT SITE - C

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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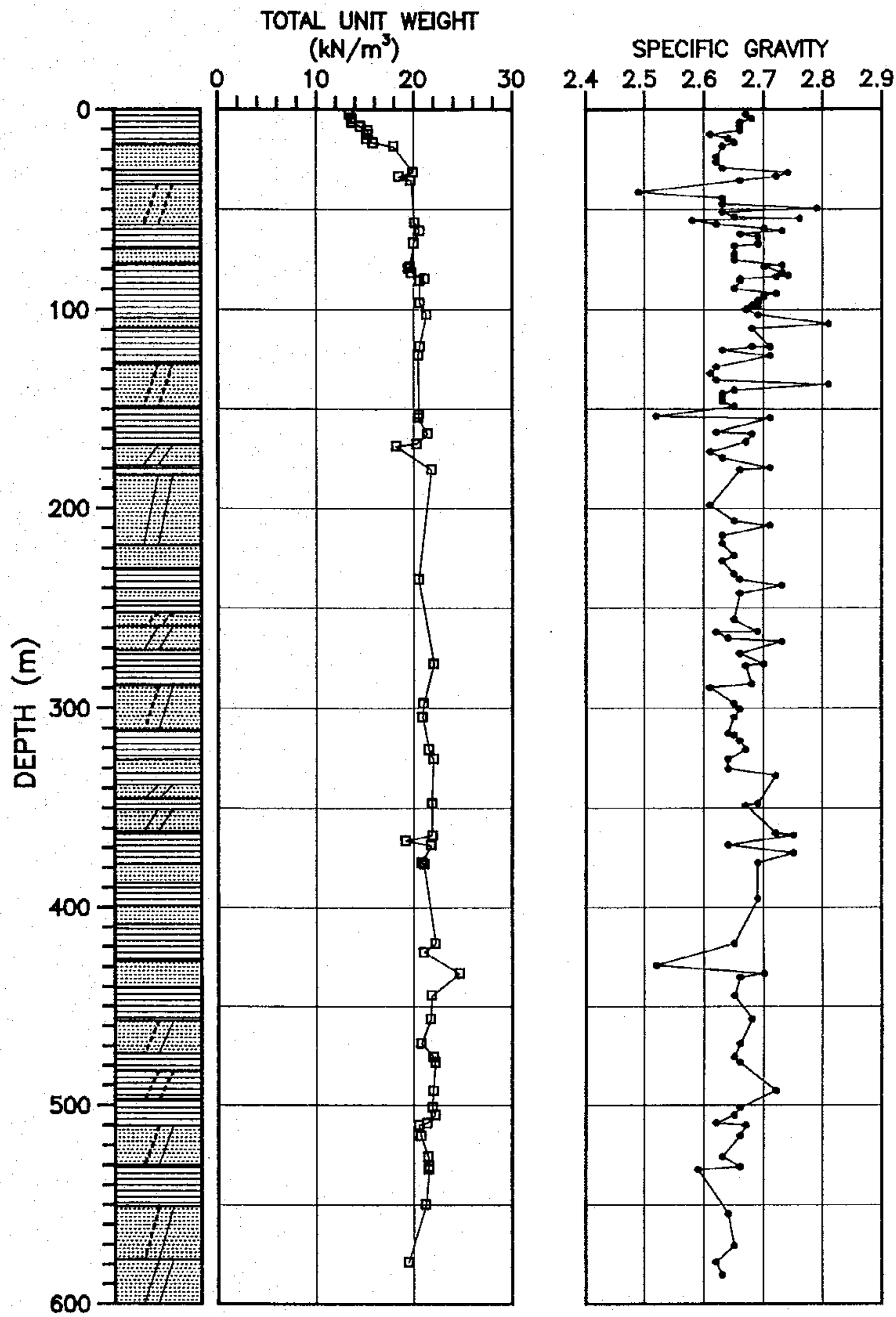

Figure 1.1.11	SPECIFIC GRAVITY TEST AT SITE - A

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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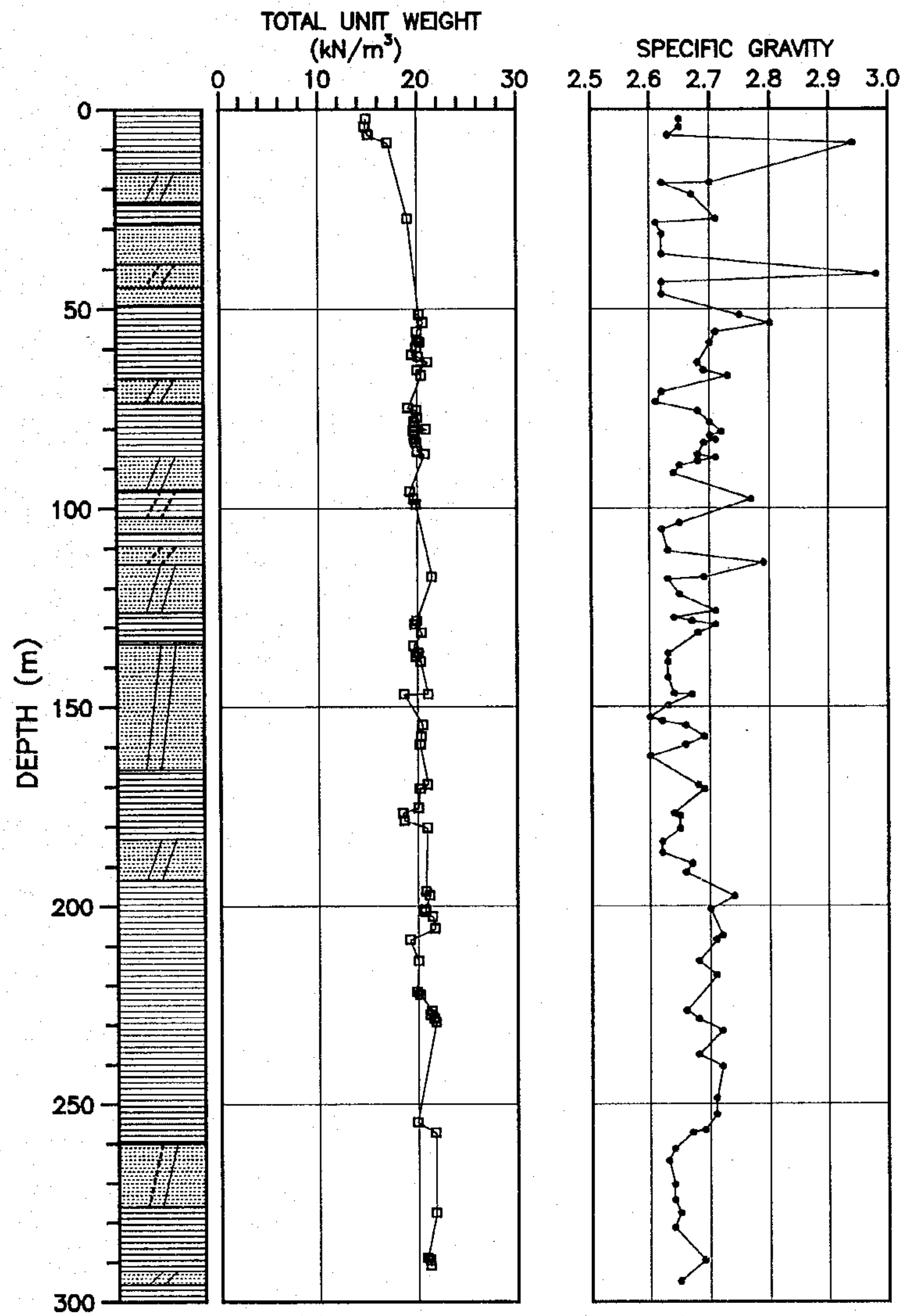

Figure 1.1.12	SPECIFIC GRAVITY TEST AT SITE - B

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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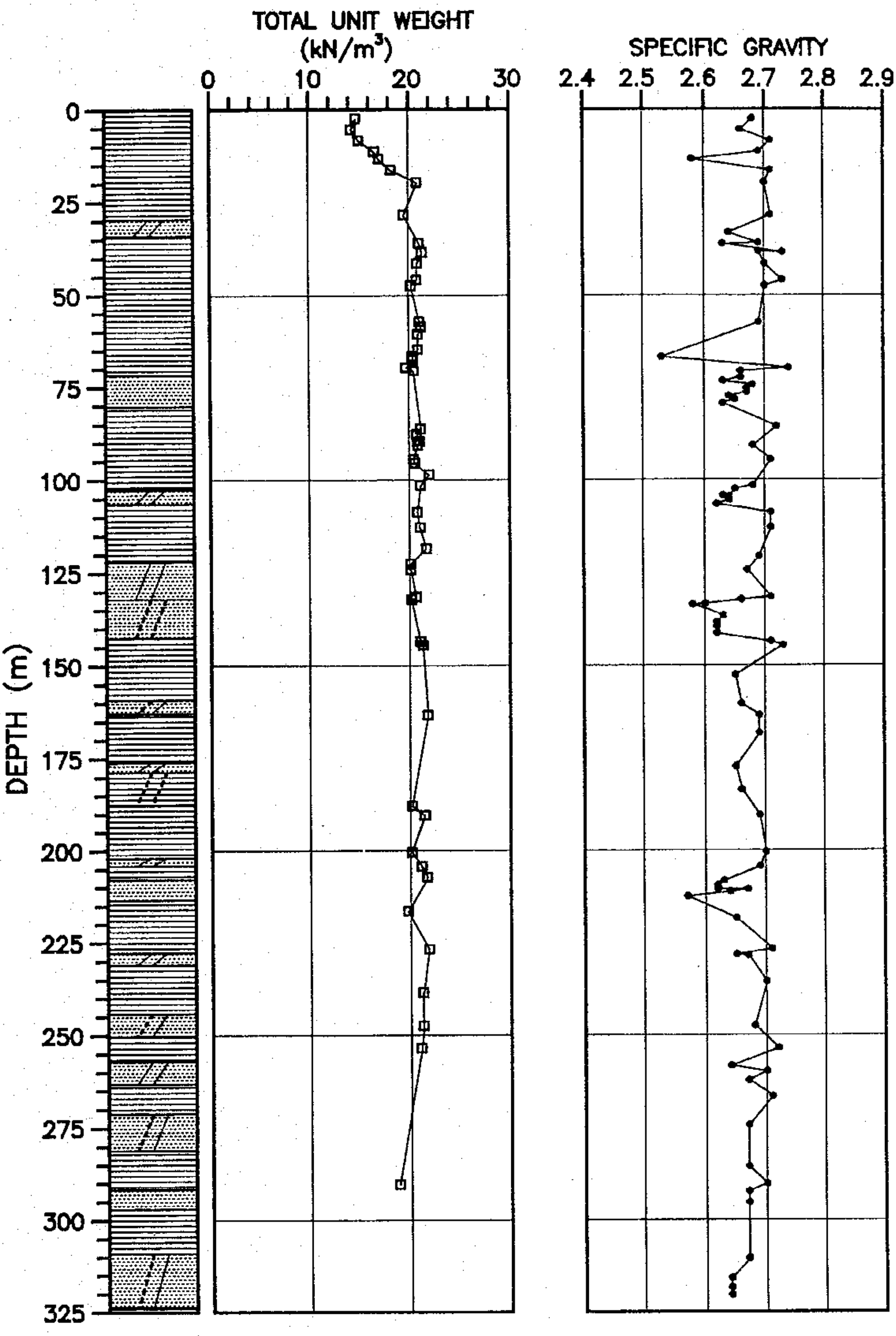

Figure 1.1.13	SPECIFIC GRAVITY TEST AT SITE - C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

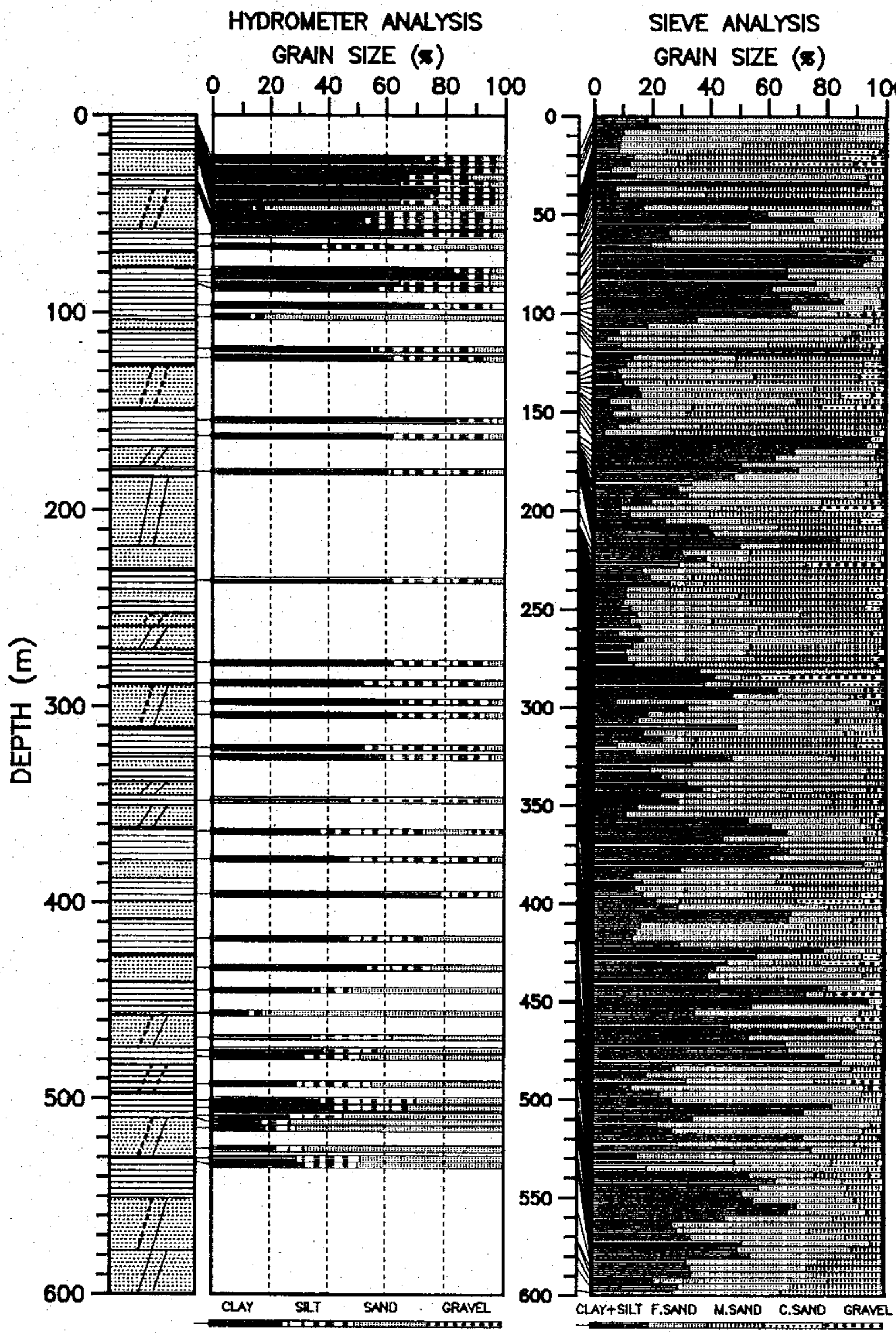

Figure 1.1.14	GRAIN SIZE ANALYSIS AT SITE - A
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

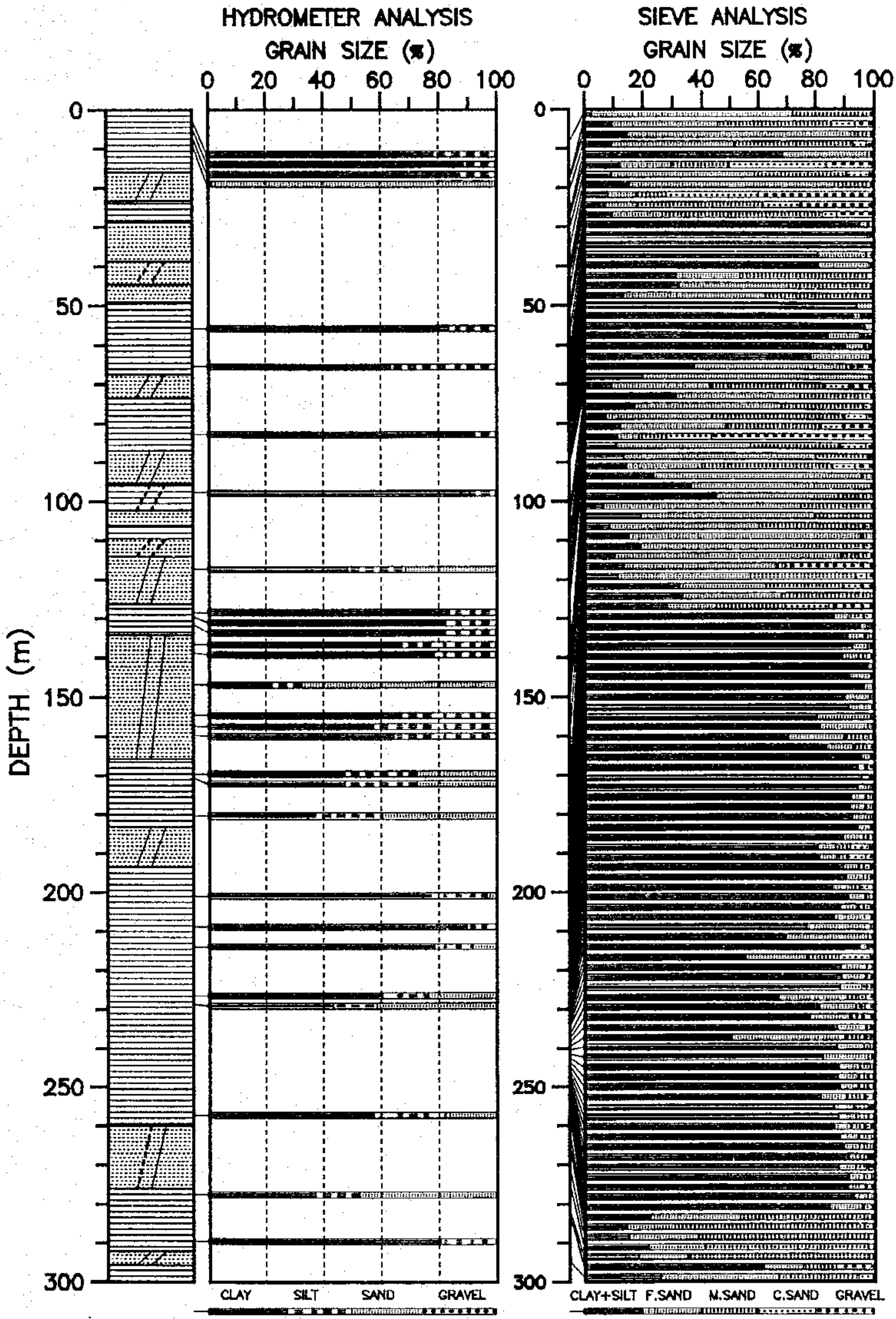

Figure 1.1.15	GRAIN SIZE ANALYSIS AT SITE - B

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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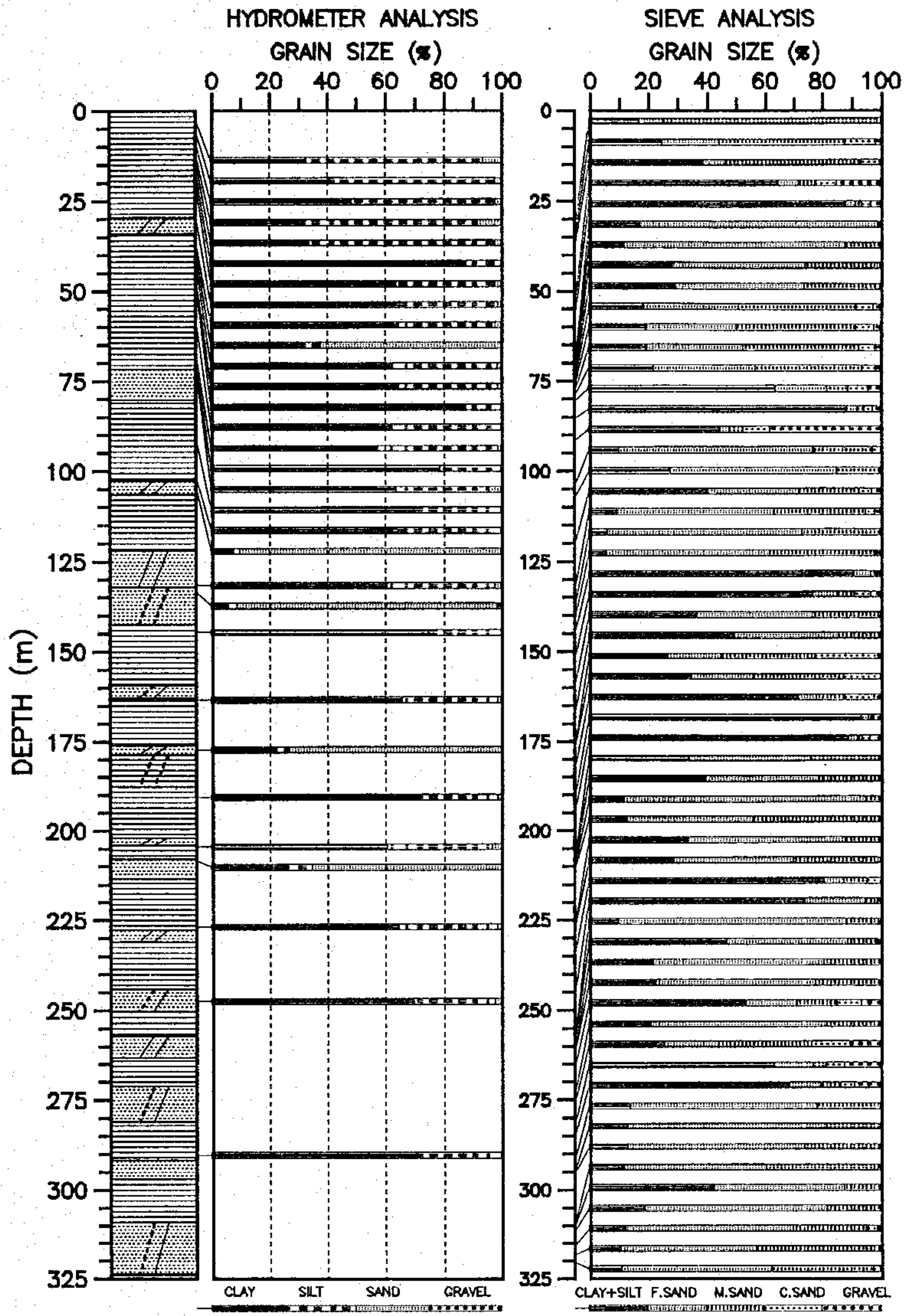

Figure 1.1.16	GRAIN SIZE ANALYSIS AT SITE - C

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD.

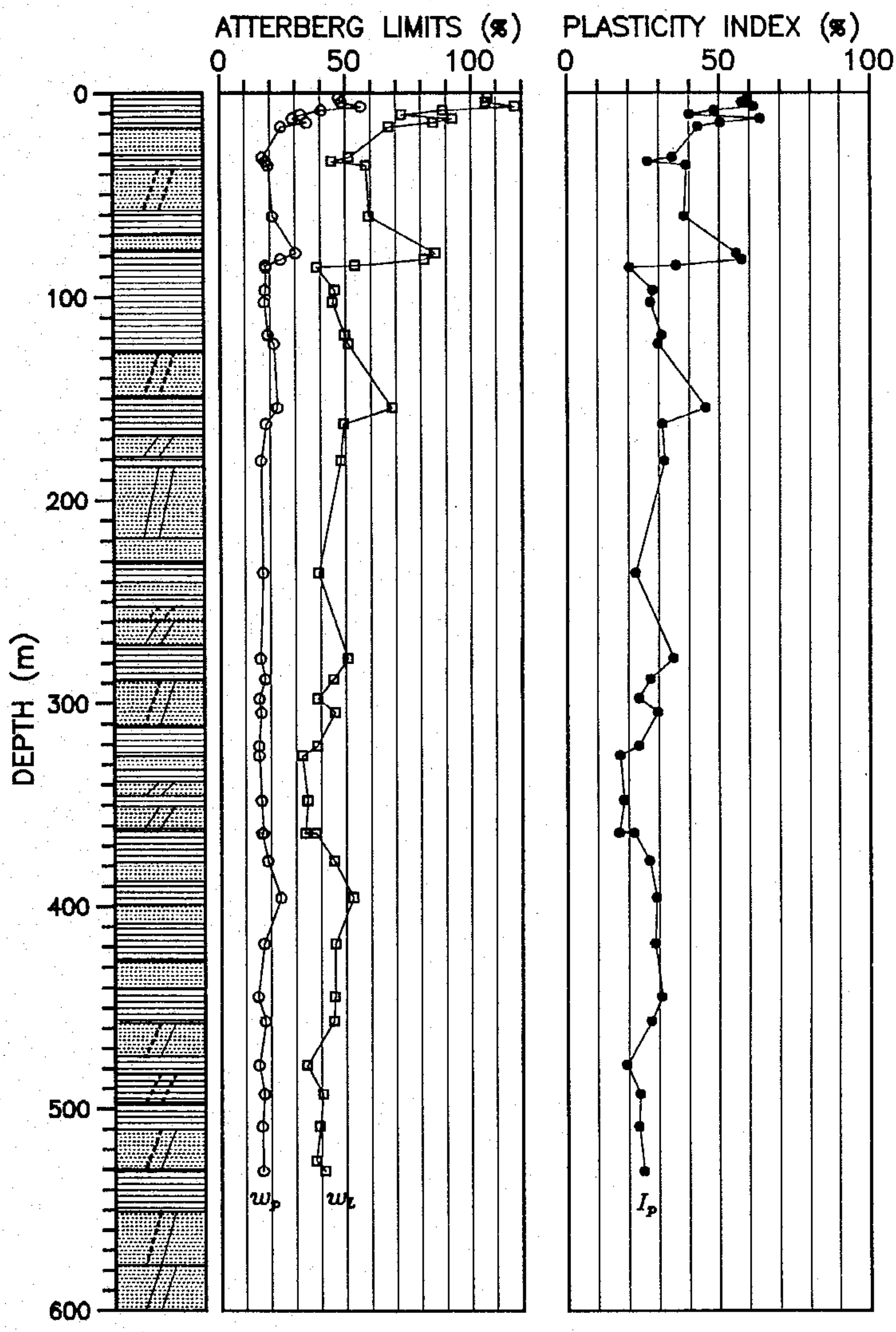

Figure 1.1.17	ATTERBERG LIMITS TEST AT SITE - A

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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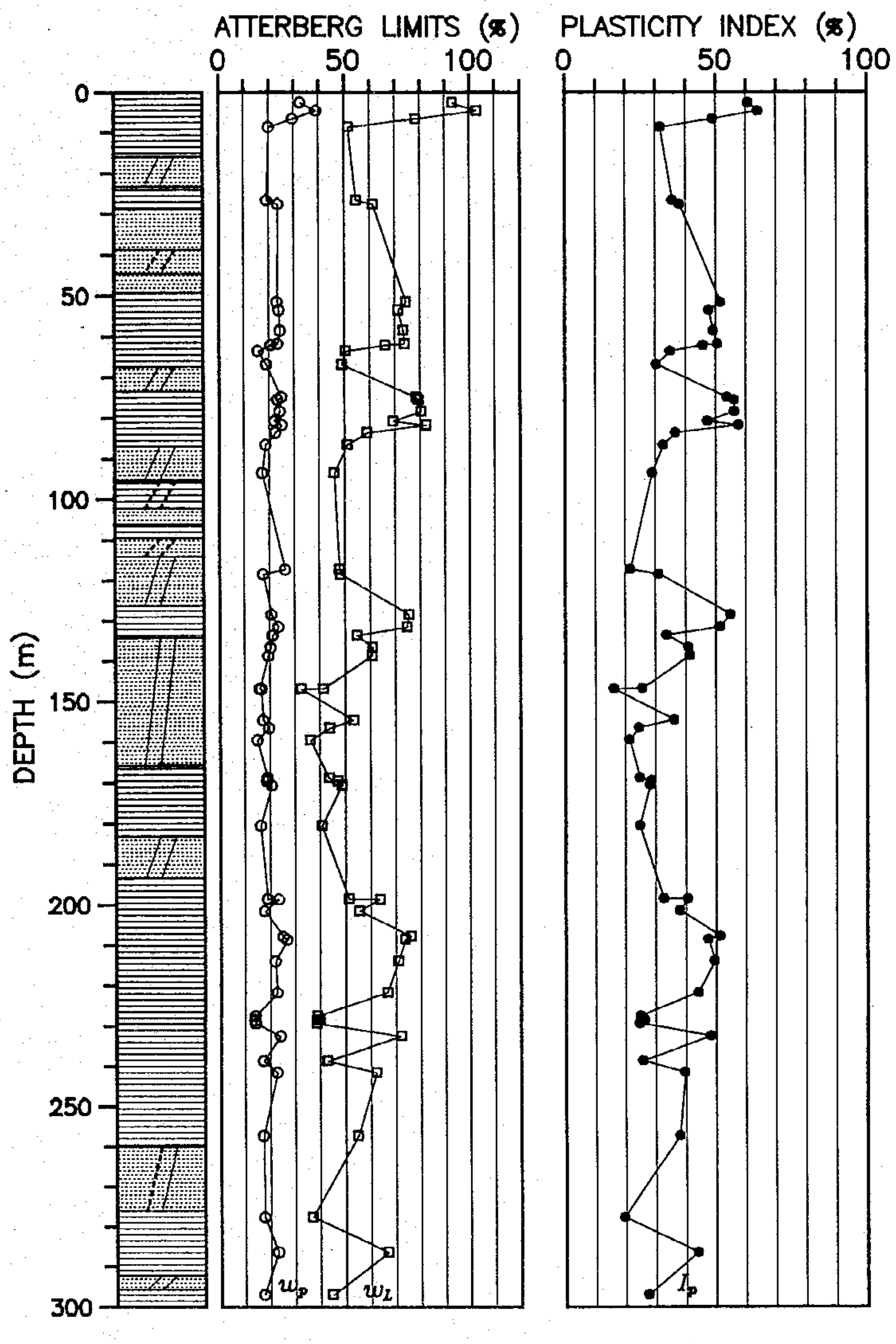

Figure 1.1.18	ATTERBERG LIMITS TEST AT SITE - B
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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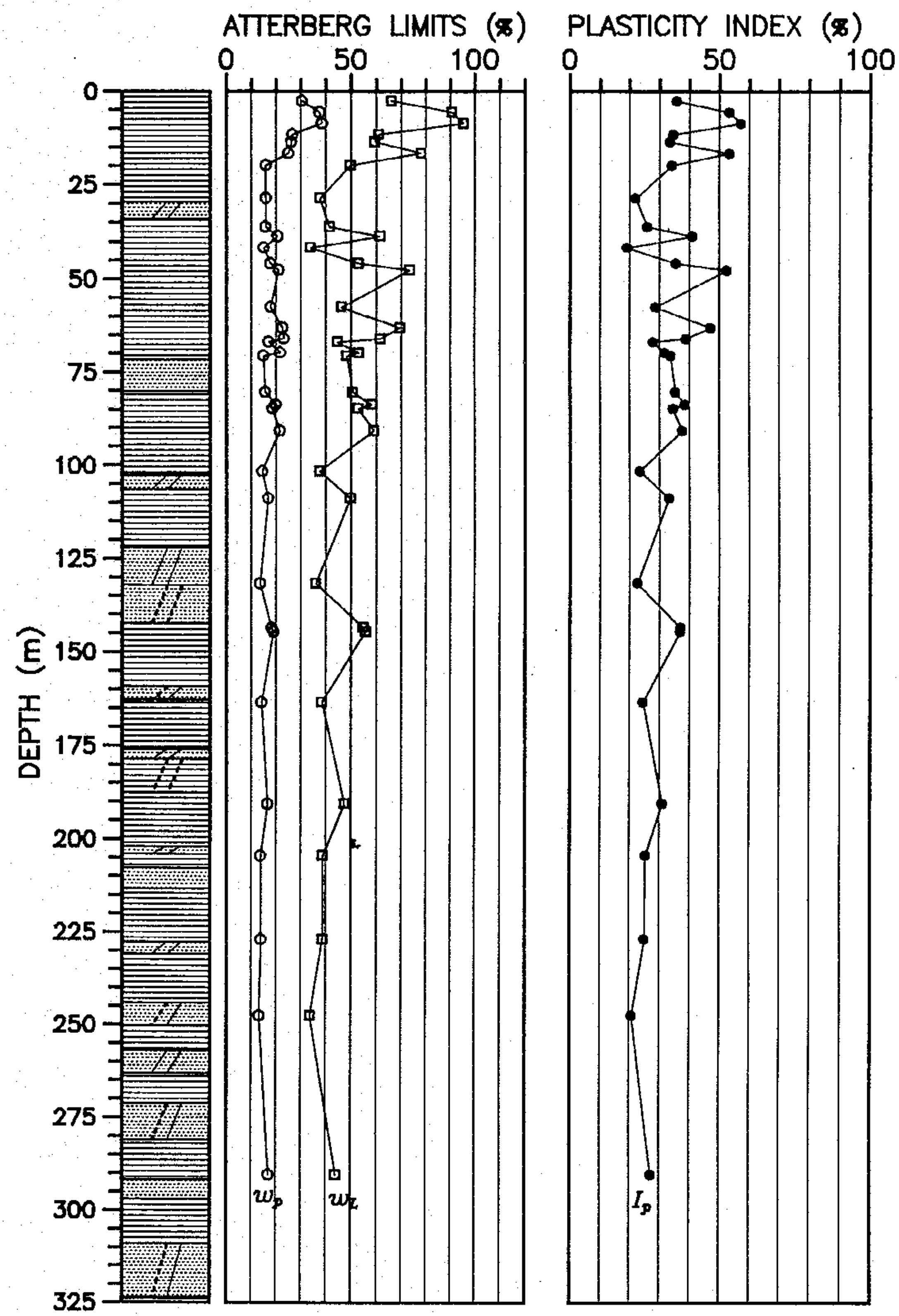

Figure 1.1.19	ATTERBERG LIMITS TEST AT SITE - C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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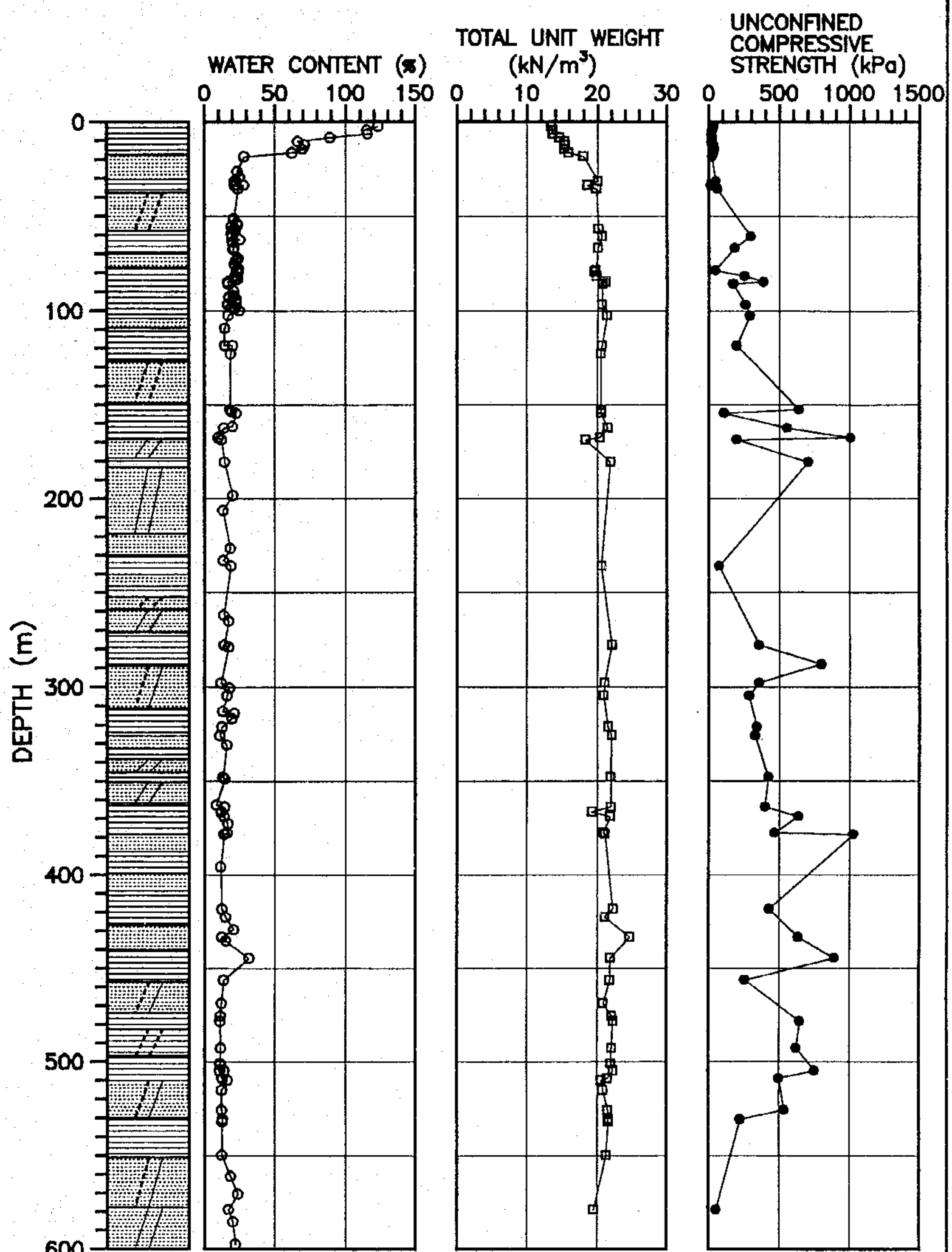

Figure 1.1.20	UNCONFINED COMPRESSION TEST AT SITE - A

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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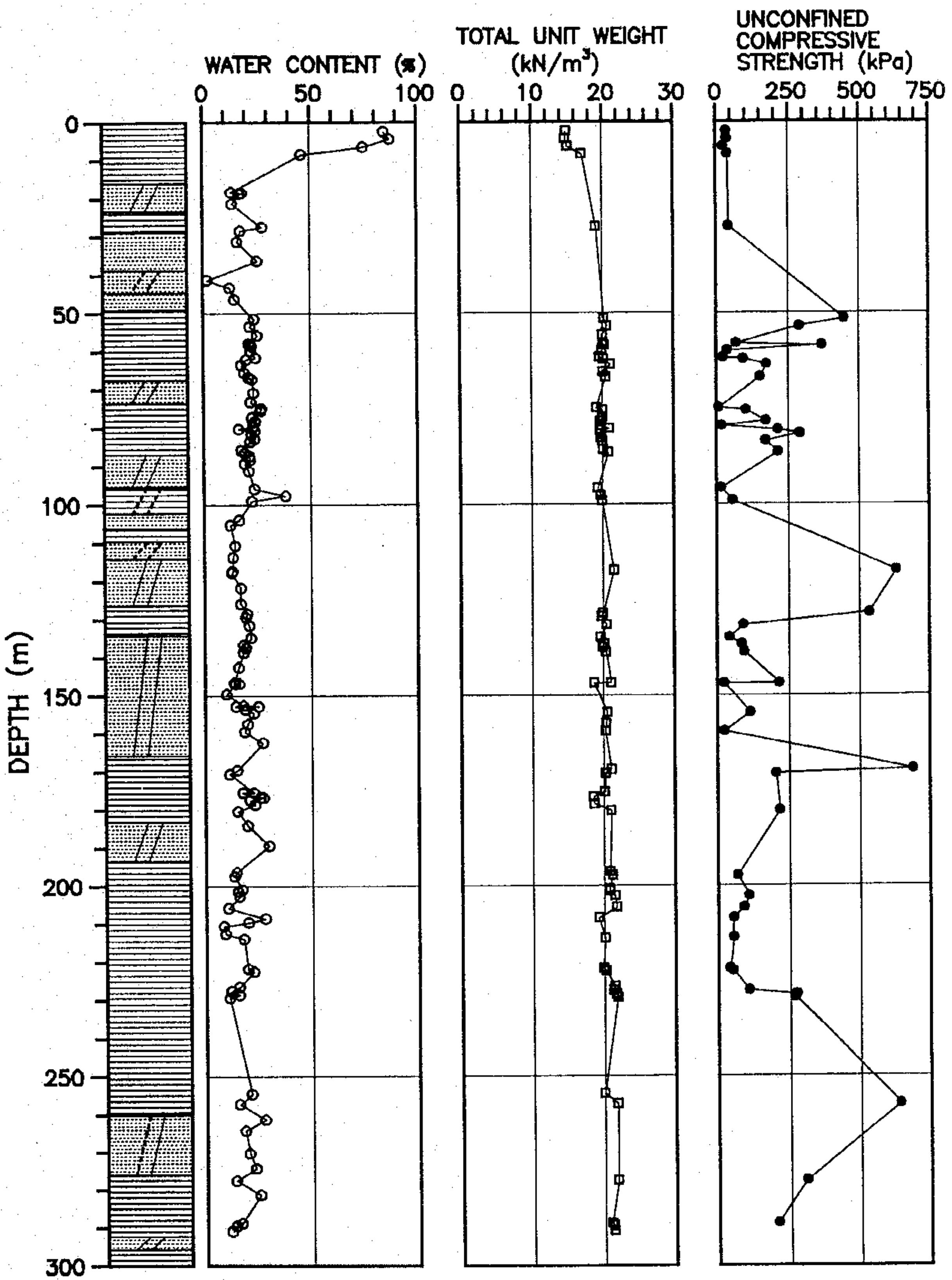

Figure 1.1.21	UNCONFINED COMPRESSION TEST AT SITE - B
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

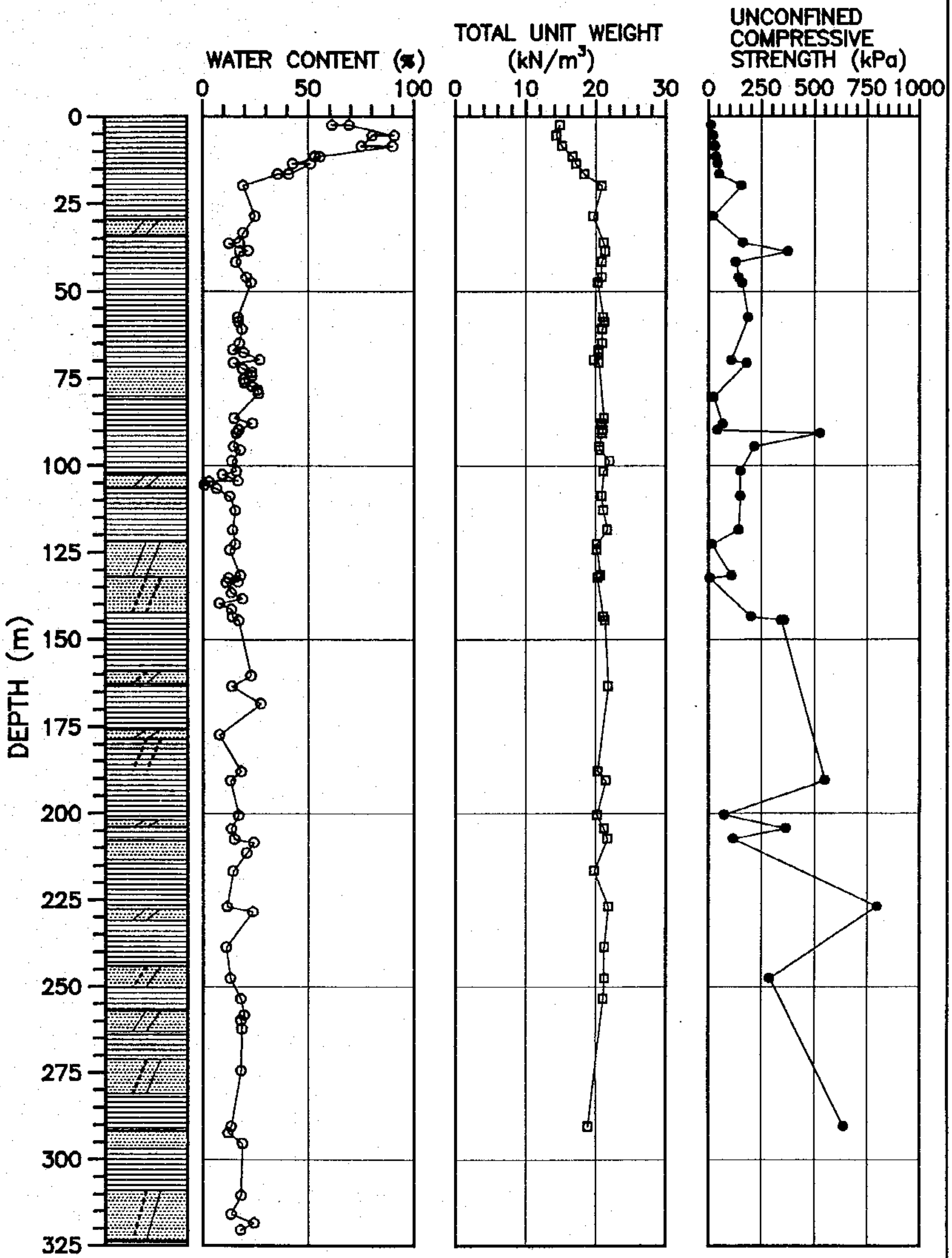

Figure 1.1.22	UNCONFINED COMPRESSION TEST AT SITE - C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

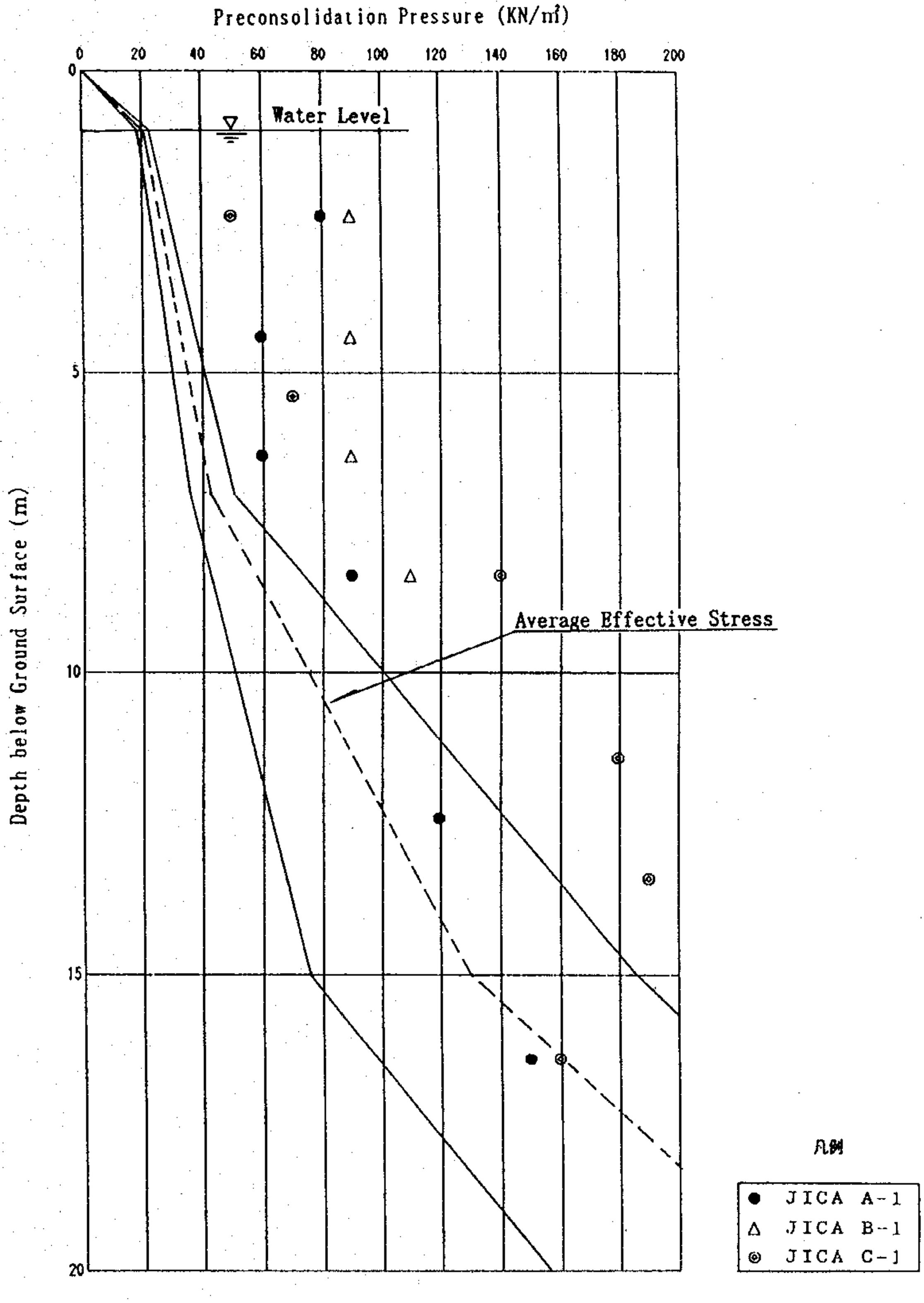

Figure 1.1.23	PRECONSOLIDATION PRESSURE versus DEPTH PLOT AT SITES - A, B, C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

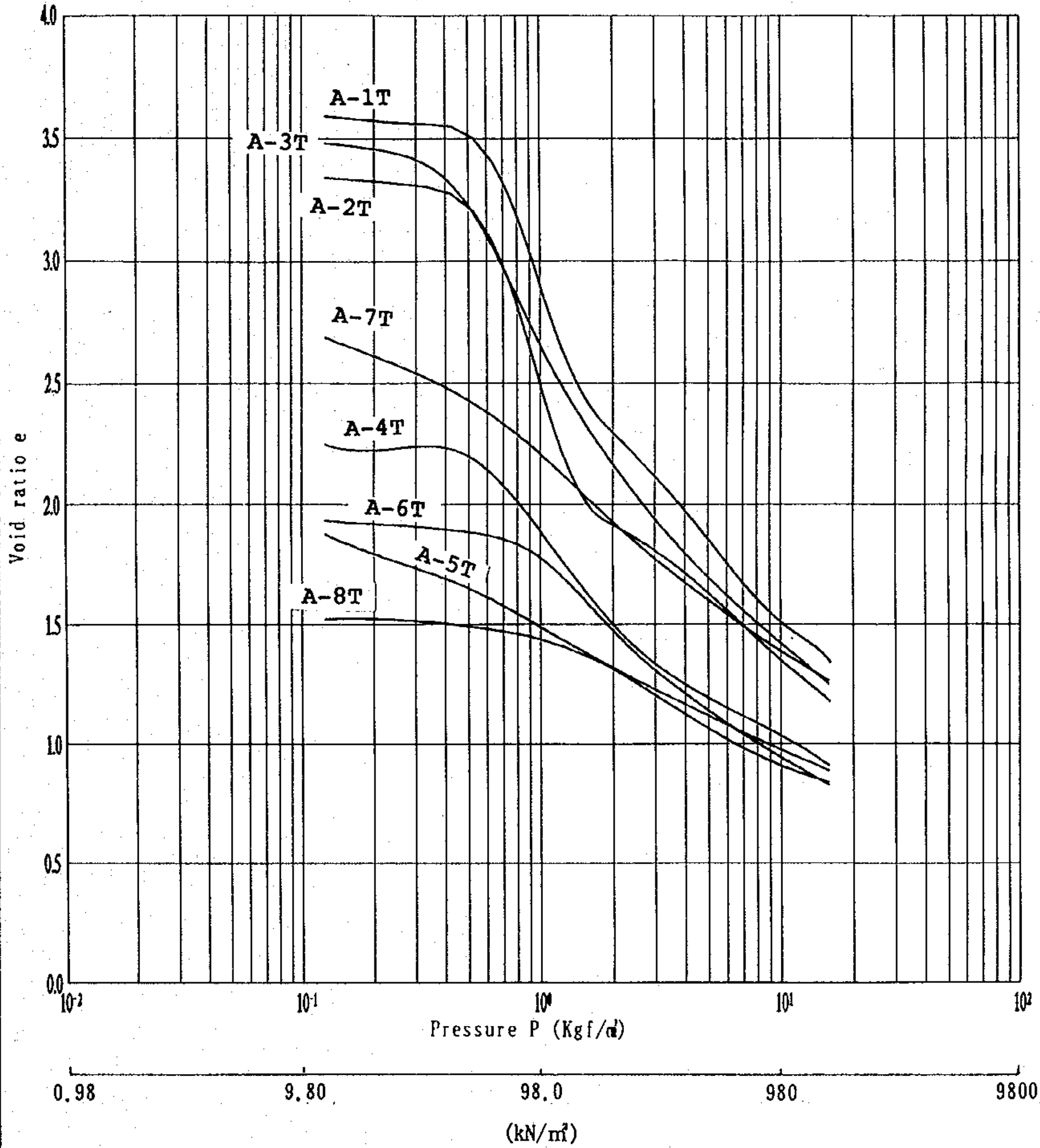

Figure 1.1.24 (1)	e~log P CURVE AT SITE - A (Sf)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

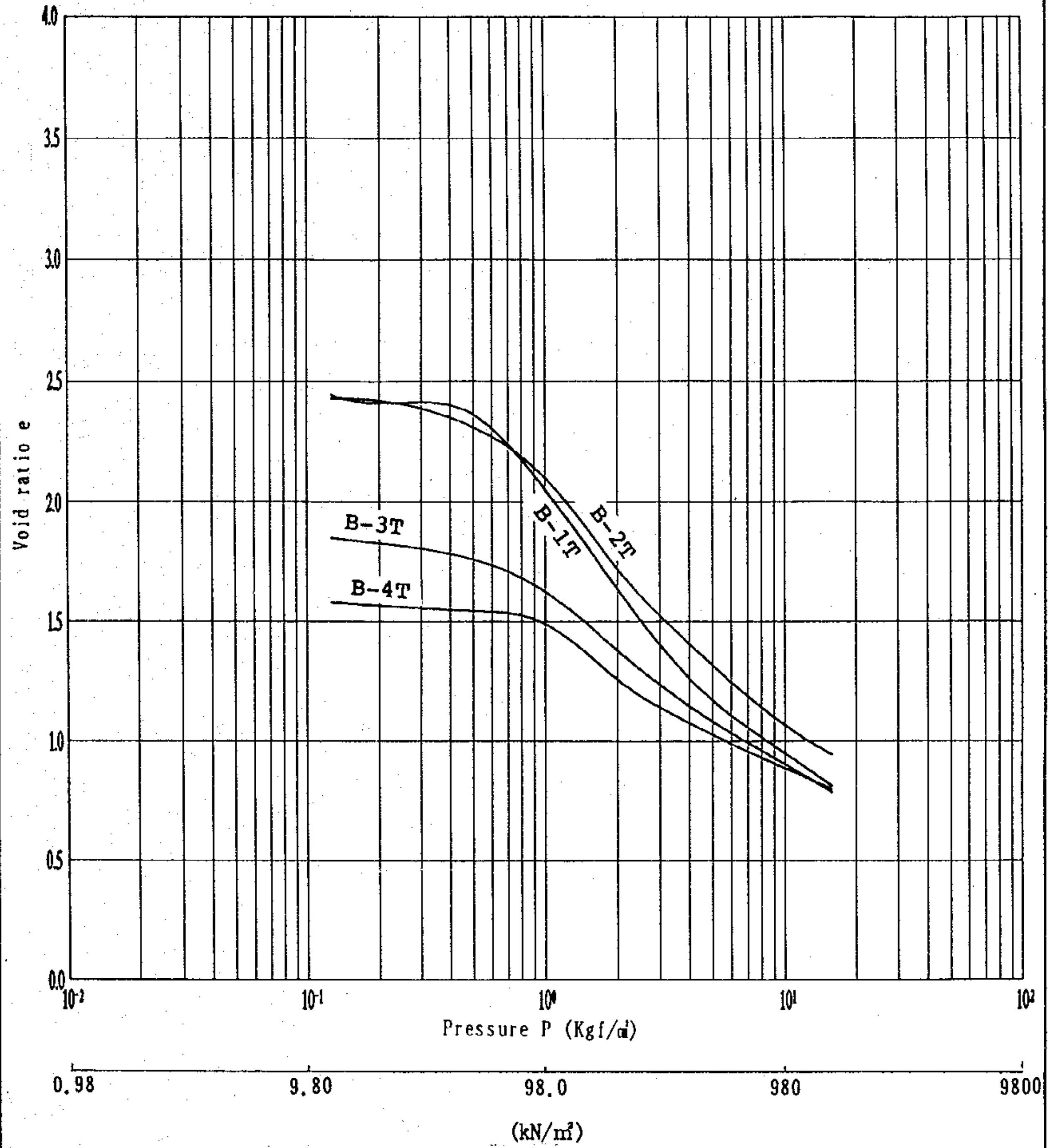

Figure 1.1.24 (2)	e~log P CURVE AT SITE - B (Sf)

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD.

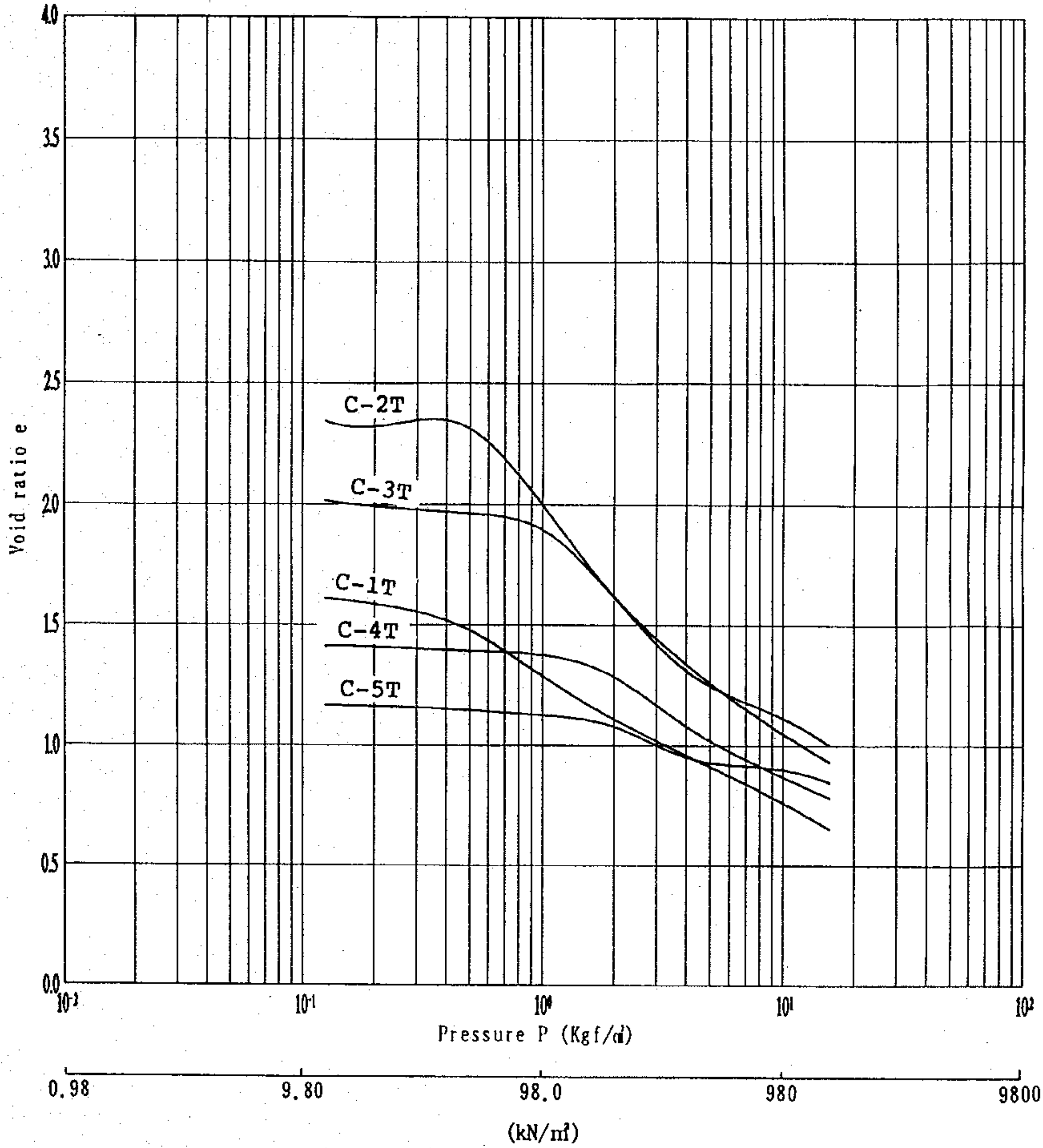

Figure 1.1.24 (3)	e~log P CURVE AT SITE - C (Sf)

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD.

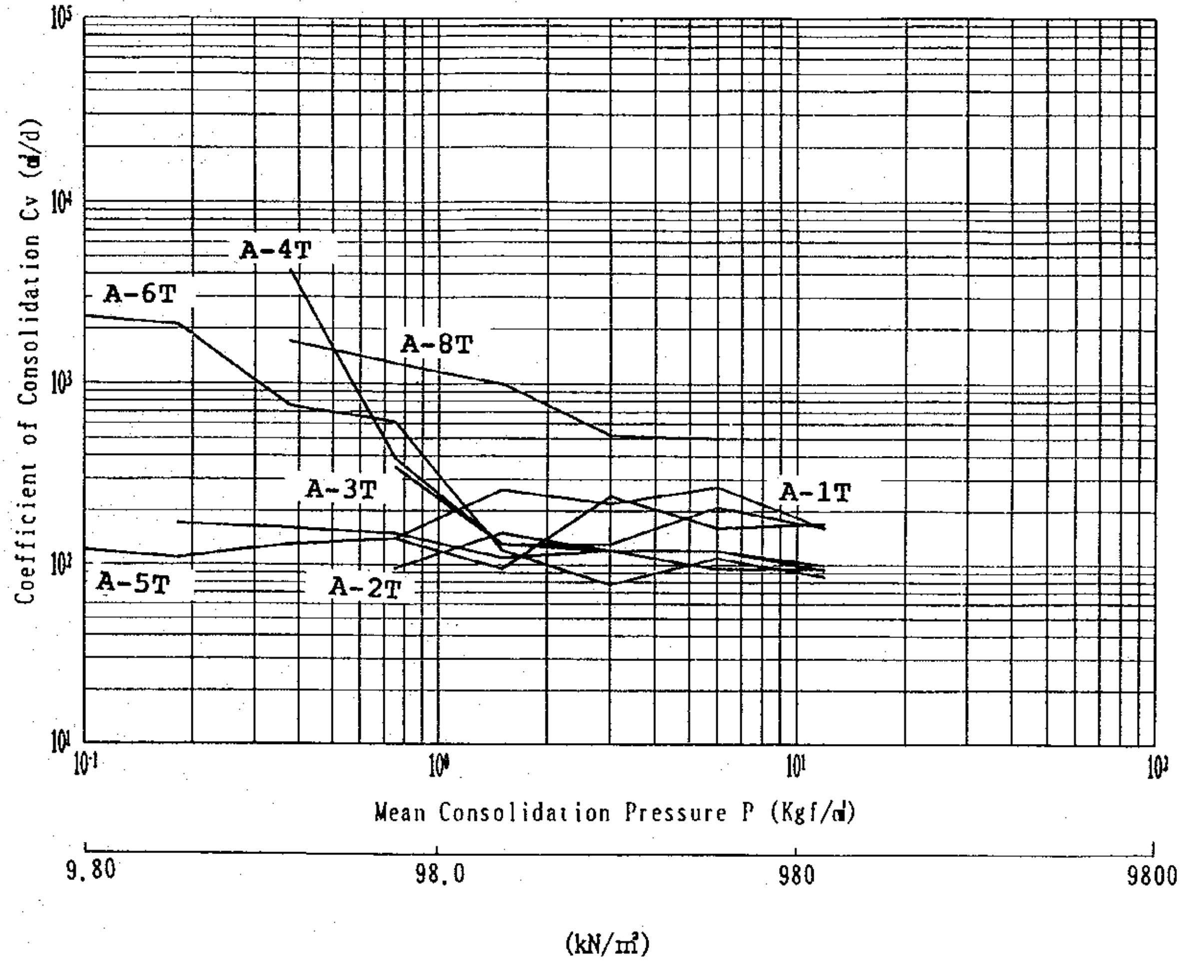

Figure 1.1.25 (1)	COEFFICIENT OF CONSOLIDATION, Cv versus PRESSURE CURVES AT SITE - A (Sf)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

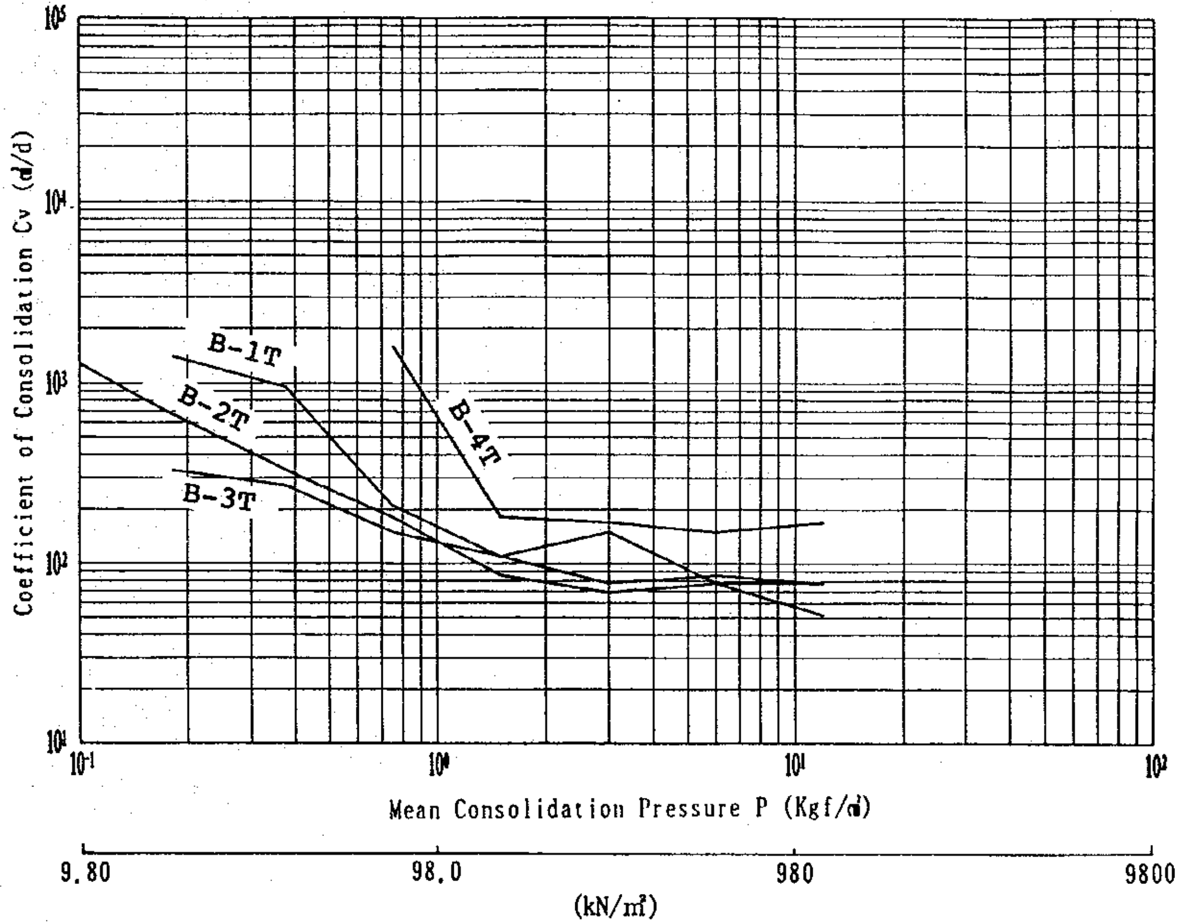

Figure 1.1.25 (2)	COEFFICIENT OF CONSOLIDATION, Cv versus PRESSURE CURVES AT SITE - B (Sf)
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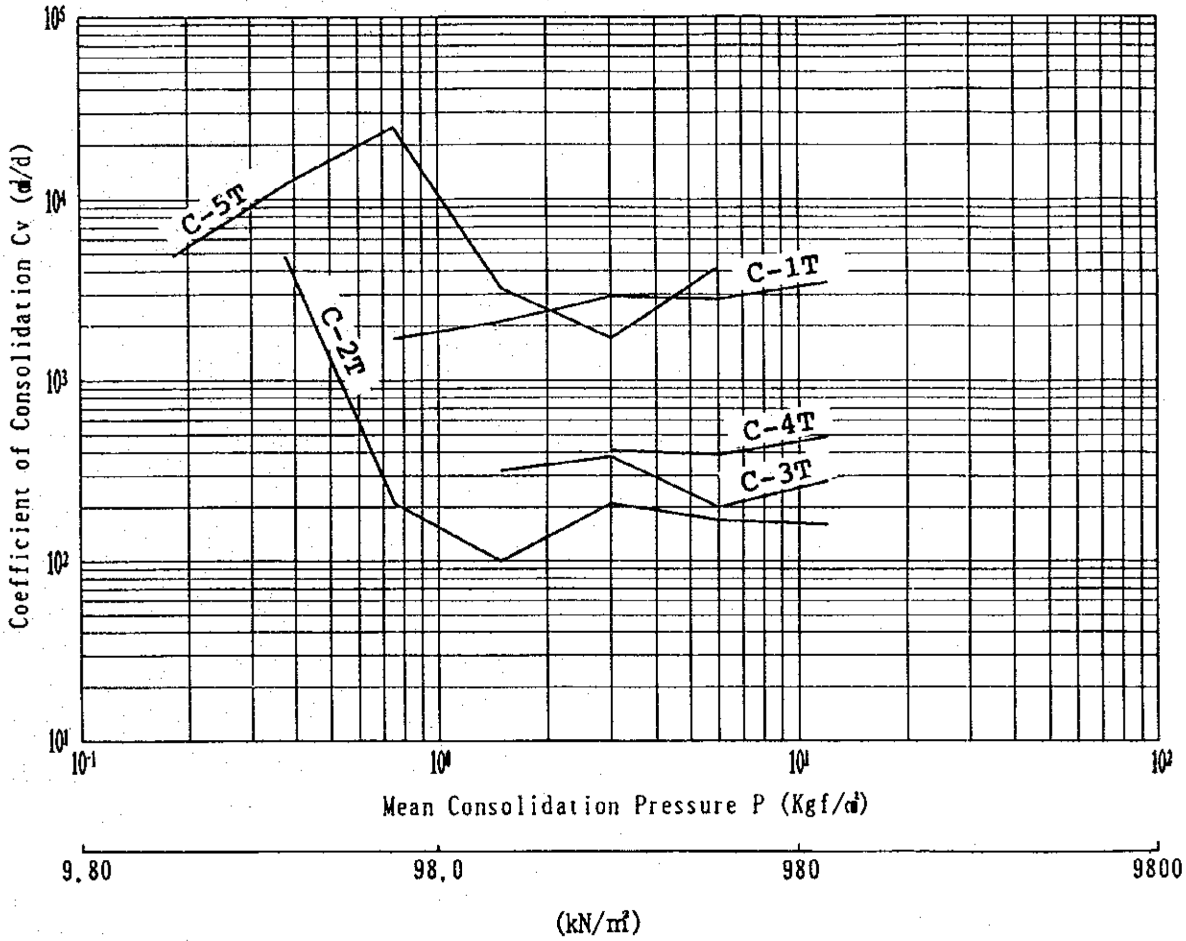

Figure 1.1.25 (3)	COEFFICIENT OF CONSOLIDATION, Cv versus PRESSURE CURVES AT SITE - C (Sf)
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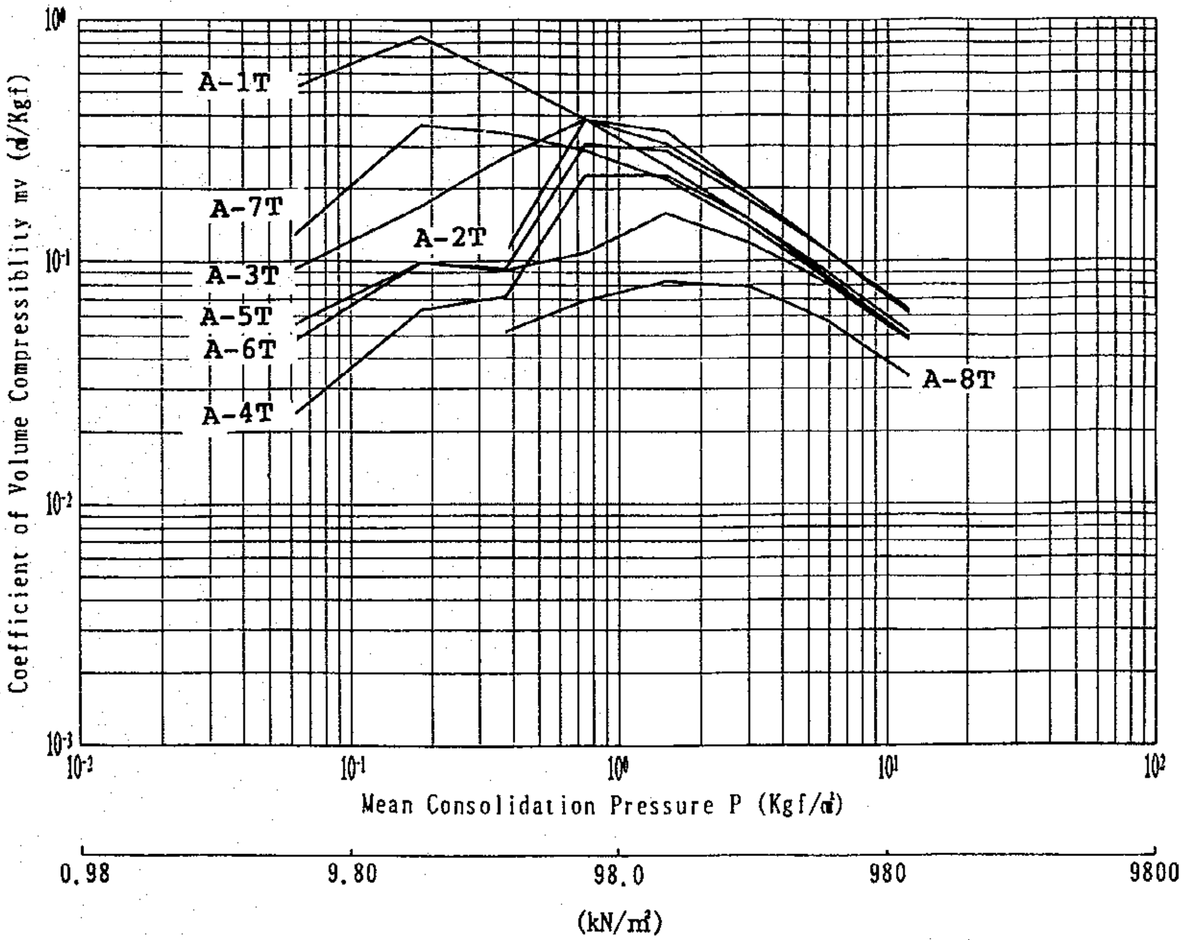

Figure 1.1.26 (1)	COEFFICIENT OF VOLUME COMPRESSIBILITY, mv versus PRESSURE CURVES AT SITE - A (Sf)

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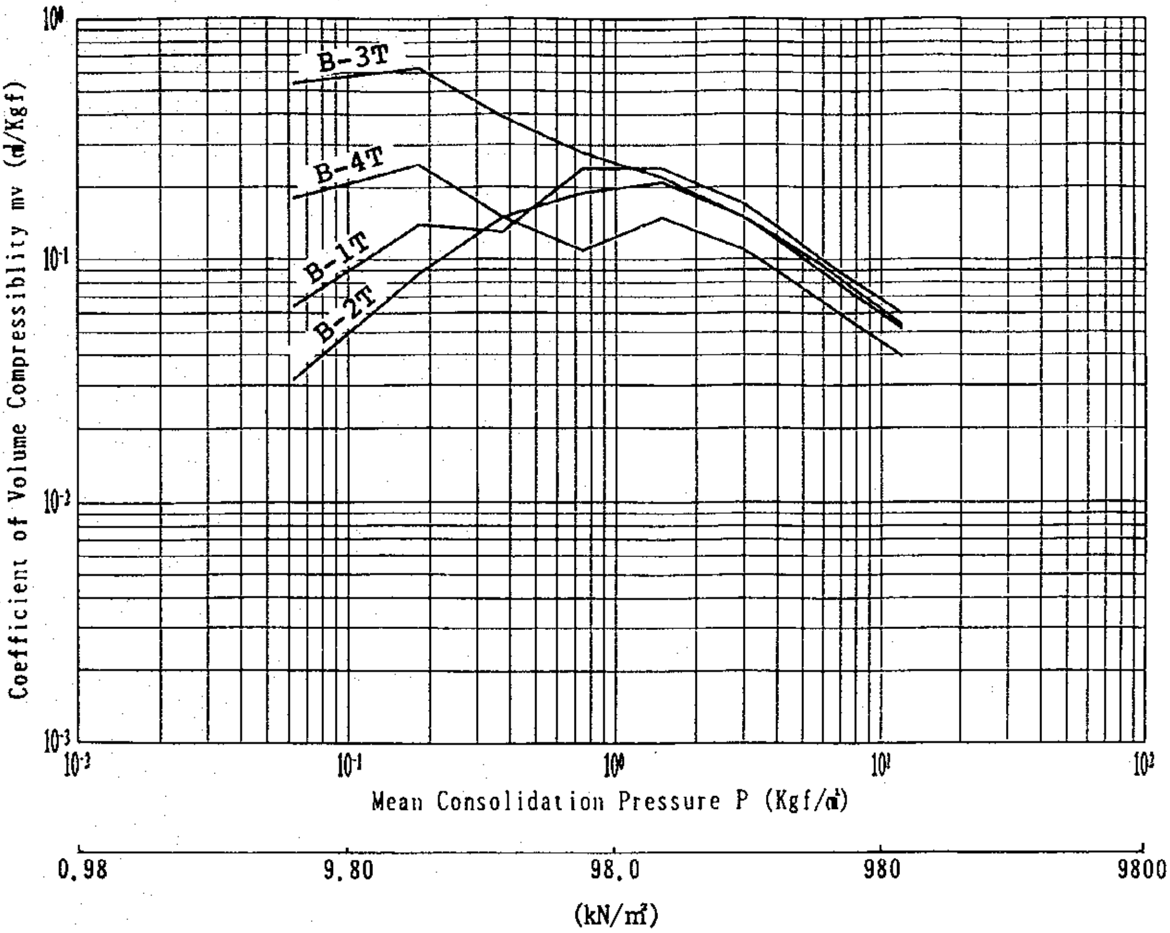

Figure 1.1.26 (2)	COEFFICIENT OF VOLUME COMPRESSIBILITY, mv versus PRESSURE CURVES AT SITE - B (Sf)
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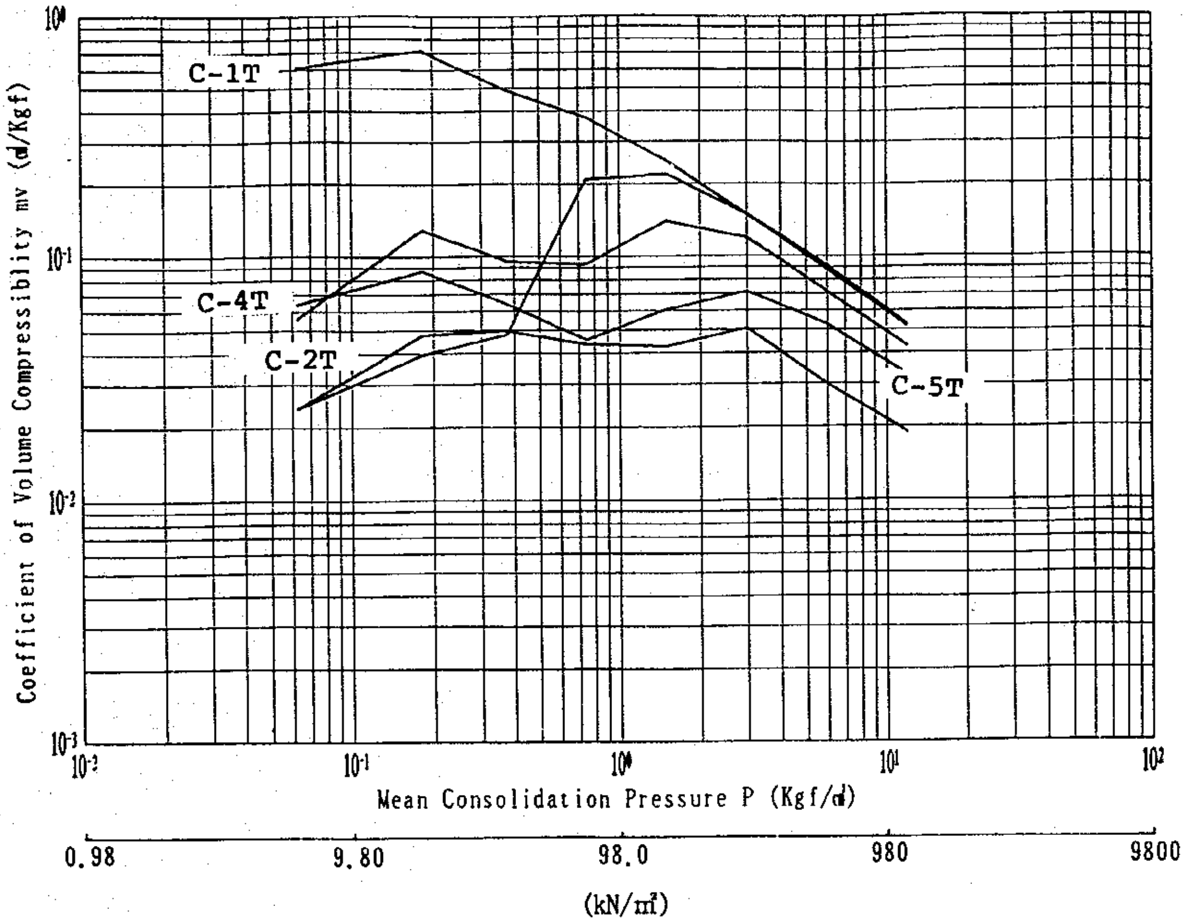

Figure 1.1.26 (3)	COEFFICIENT OF VOLUME COMPRESSIBILITY, mv versus PRESSURE CURVES AT SITE - C (Sf)

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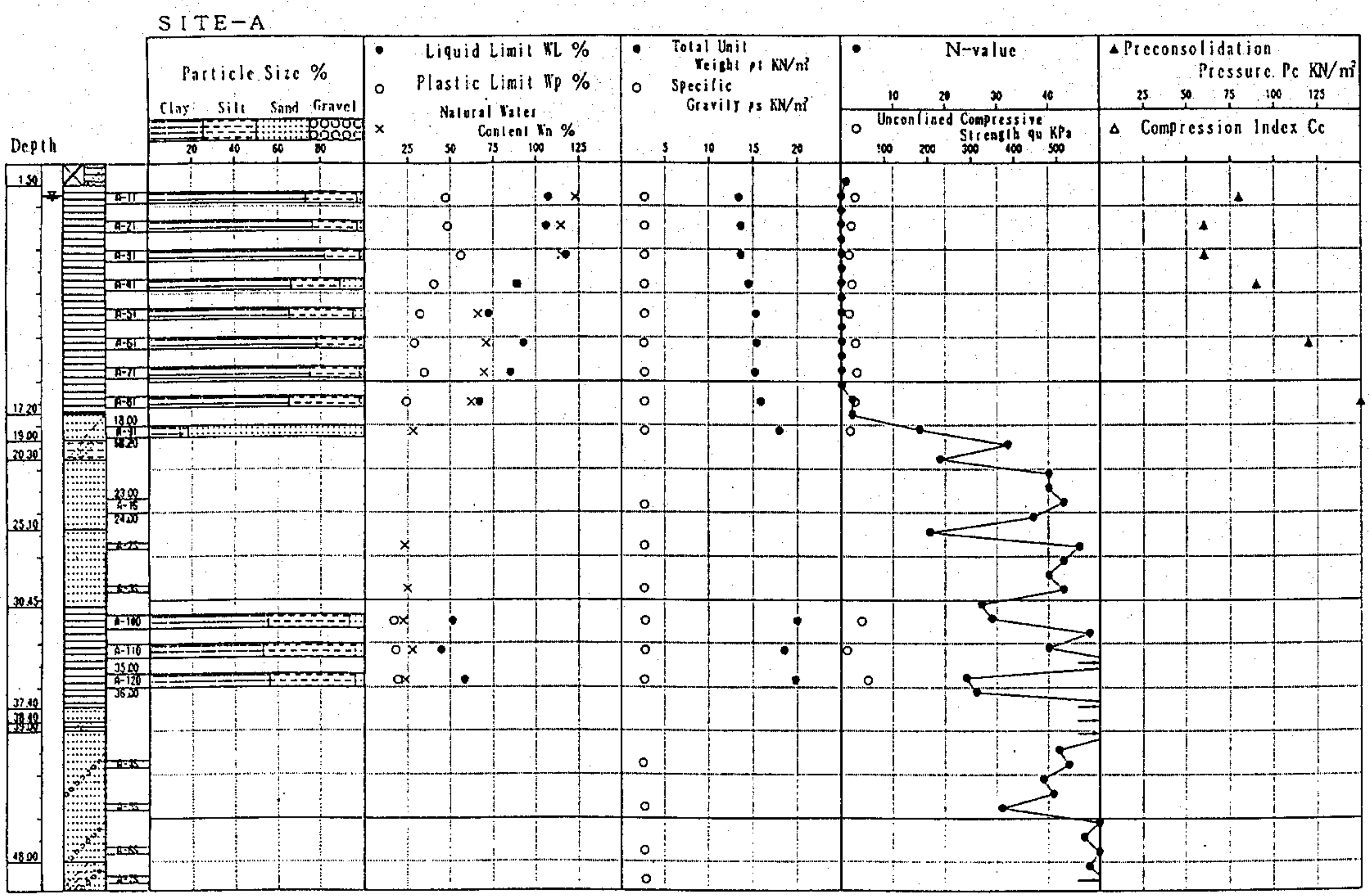

Figure 1.1.27	SUMMARY OF SOIL TESTS AT SITE - A (DEPTH = 0 m to 50 m)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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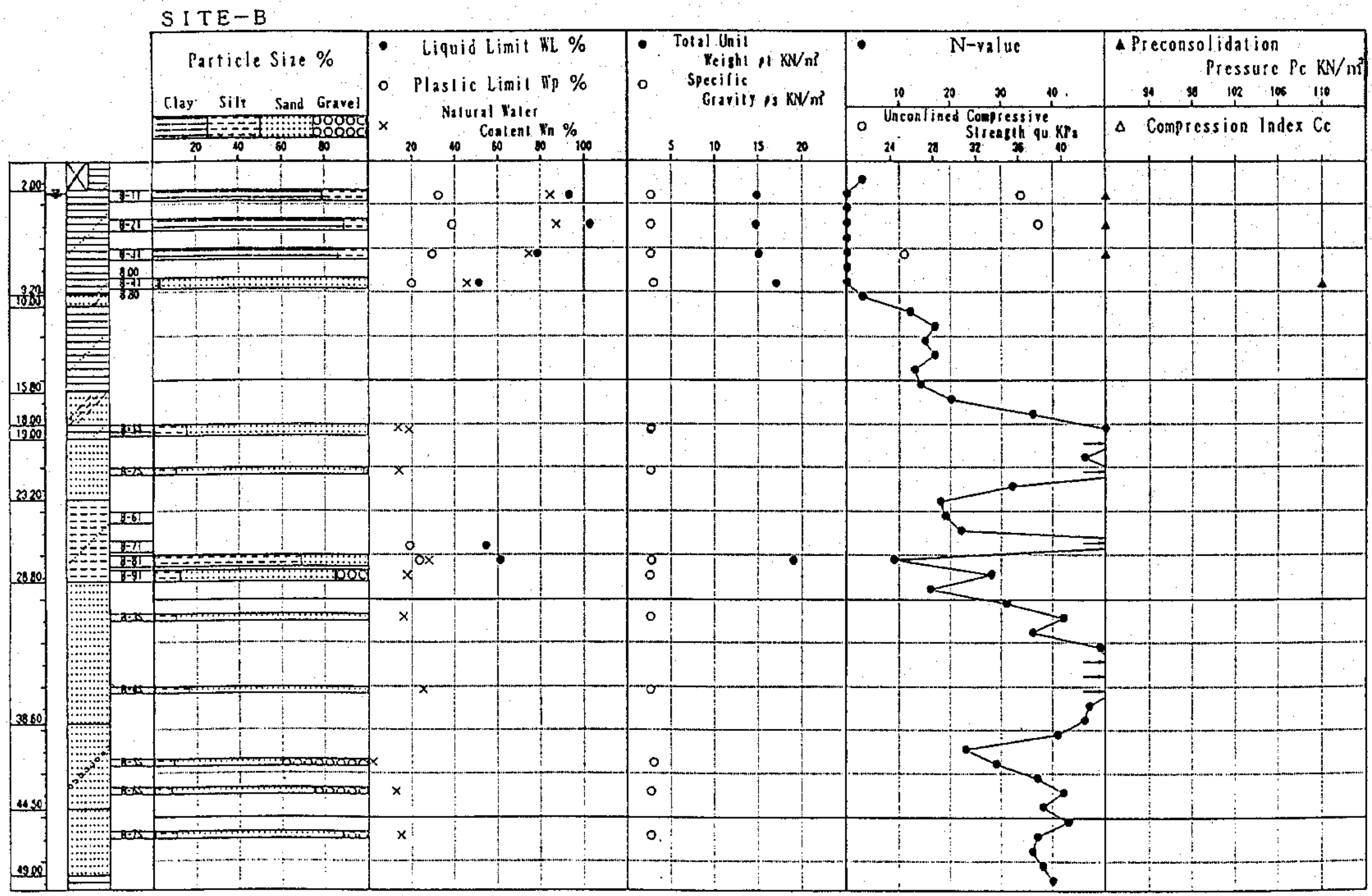

Figure 1.1.28	SUMMARY OF SOIL TESTS AT SITE - B (DEPTH = 0 m to 50 m)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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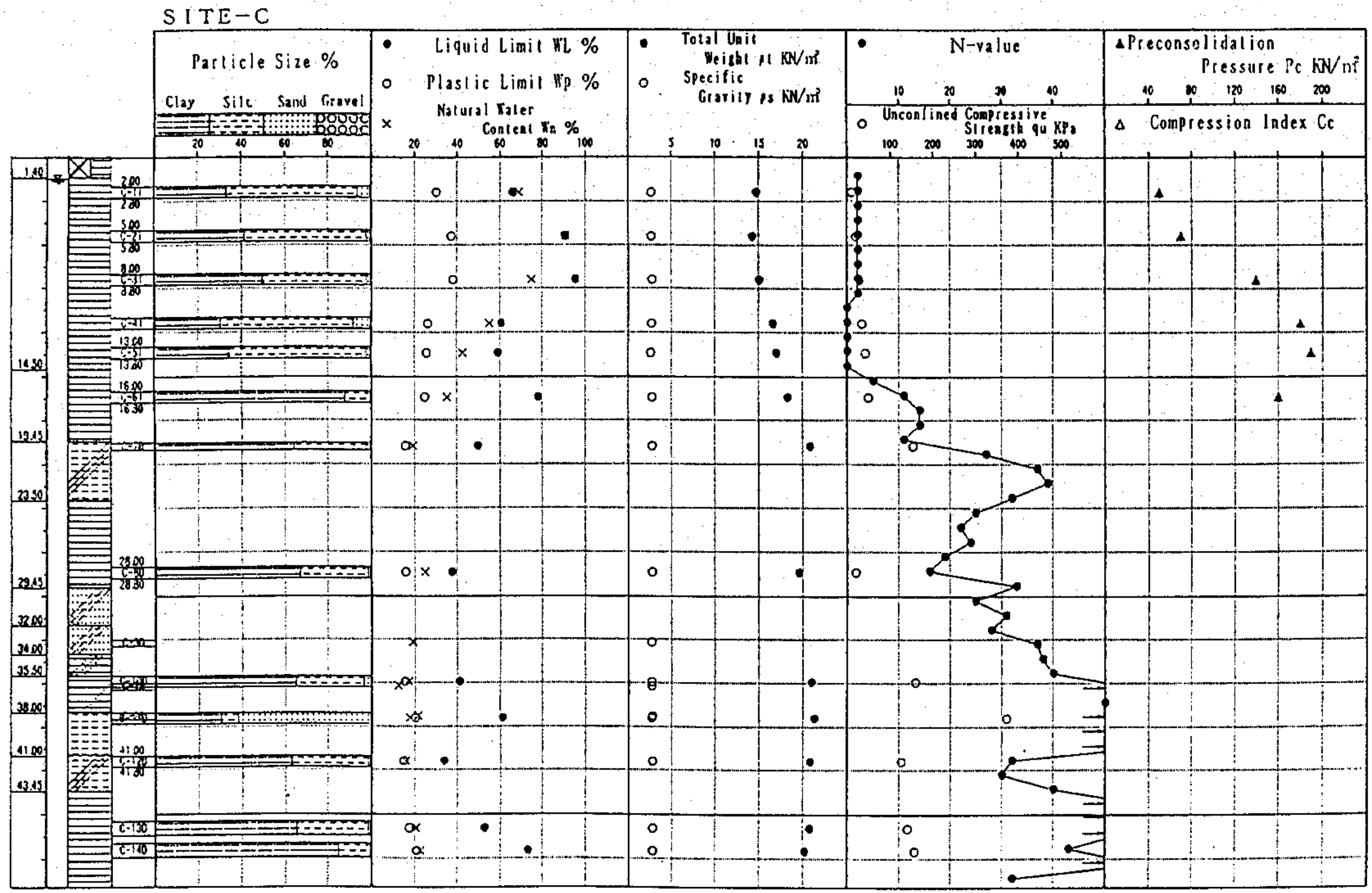

Figure 1.1.29	SUMMARY OF SOIL TESTS AT SITE - C (DEPTH = 0 m to 50 m)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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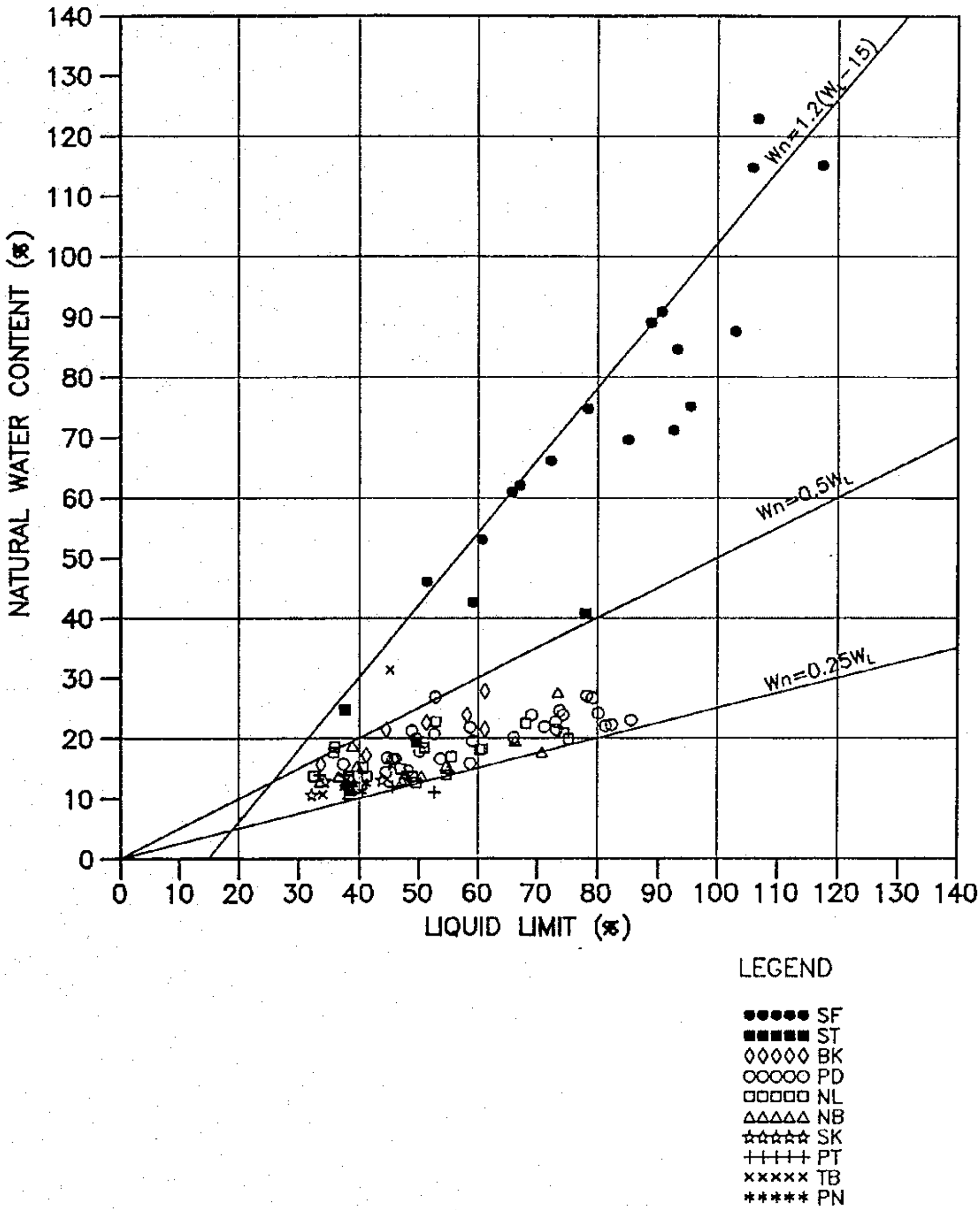

Figure 1.1.30	RELATION BETWEEN NATURAL WATER CONTENT AND LIQUID LIMIT (SITES - A, B, C)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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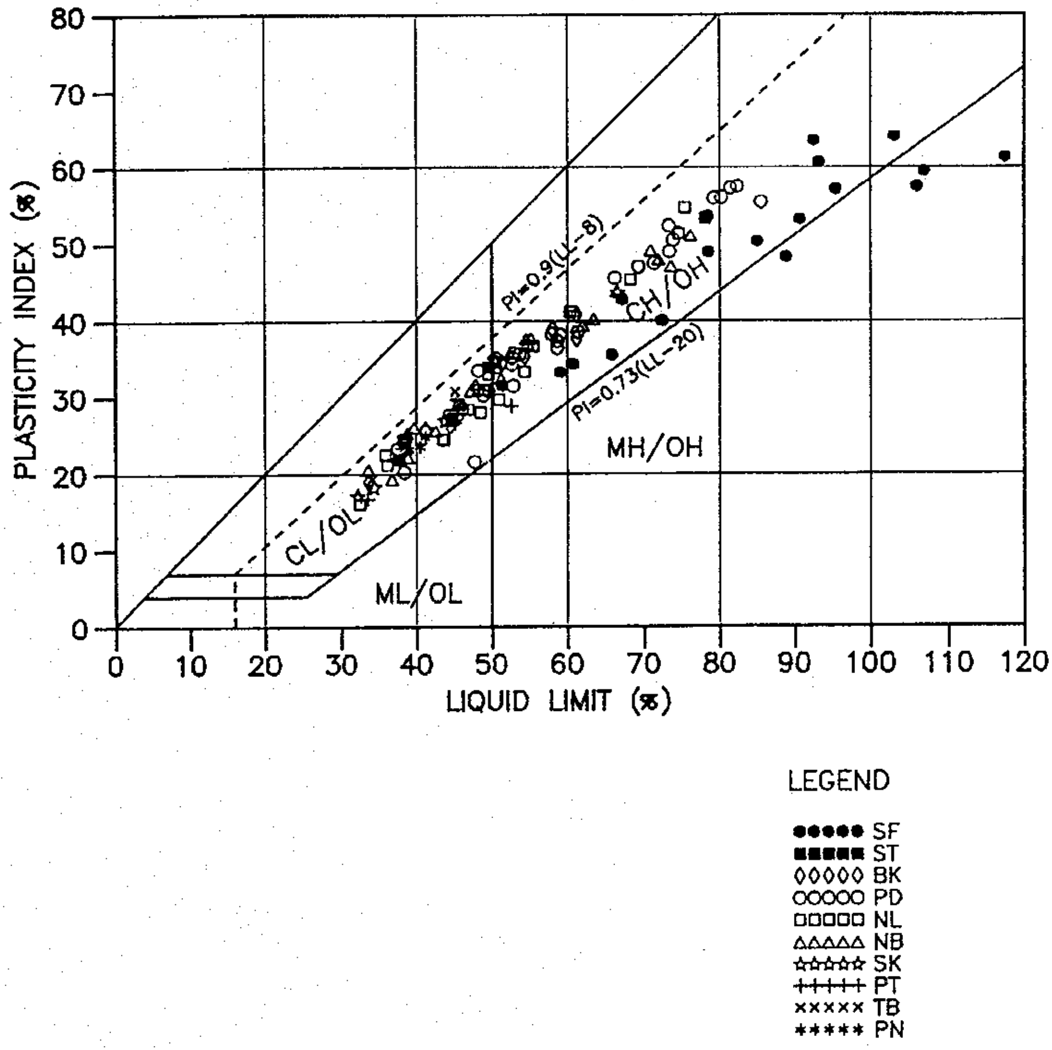

Figure 1.1.31	PLASTICITY CHART (SITES - A, B, C)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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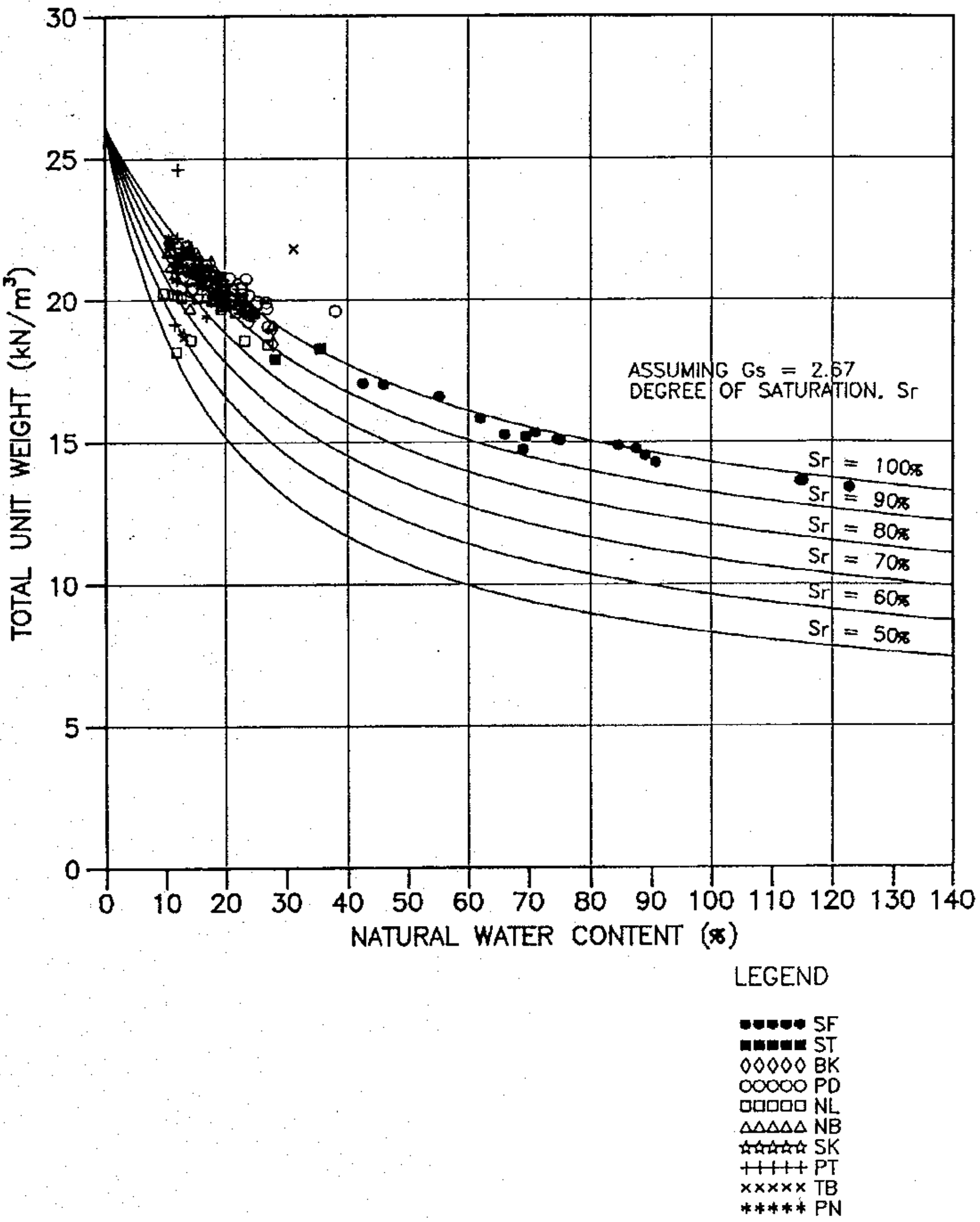

Figure 1.1.32	RELATION BETWEEN TOTAL UNIT WEIGHT AND NATURAL WATER CONTENT (SITES - A, B, C)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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1.2 WELL DRILLING AND PUMPING TESTS

1.2.1 Hydrogeological Descriptions

(1) Geophysical Loggings

Geophysical loggings were performed at the deepest monitoring well in each site. Resistivity logging (12" and 48"), spontaneous potential (SP) logging, and natural gamma (s) logging were carried out immediately after drilling the well. The screen position was later determined based on the results of core observations and these geophysical loggings.

The resistivity logging usually provided information useful in identifying aquifers. High resistivity values were obtained from gravel and sand layers with fresh water, which could be classified as aquifers. On the other hand, clay and silt layers had low resistivity. If the groundwater is saline, it will affect the resistivity.

The SP-logging is usually done together with the resistivity logging. Spontaneous potentials were naturally occurring electrical potentials that result from chemical and physical changes due to contacts between different types of geologic materials. If the sand formations contain saline water, only the SP-logging could indicate the presence of a permeable layer because the resistivity is low.

The natural gamma logging measures the naturally occurring radiation coming from the materials encountered in the borehole. The record of gamma radiation is used as a qualitative guide for stratigraphic and permeability correlations. Clay usually contains higher concentration of radioactive isotopes than sand and gravel.

Figures 1.2.1 to 1.2.3 present the results of the geophysical loggings for the three (3) sites.

(2) Hydrogeological Classification

Hydrogeological classification at the three sites is made based on the results of core observations, standard penetration tests (SPT), and geophysical loggings. To determine the aquifer names based on the hydrogeological classification in DMR (1992), the lithologic logs and geophysical logs were compwered with those of the DMR monitoring wells located near the sites.

<u>**Site-A (refer to Figure 1.2.1)**</u>

Sixteen (16) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. Geophysical logging results were generally in good agreement with the facies. The geophysical logs indicated changes of geologic materials at depths of 20m, 60m, 150m, 300m, 400m, and 500m, where these boundaries could be unconformities.

The resistivity log provided useful information about facies changes from depths of 60m to 400m, but low resistivity values were measured in the shallow portion up to a depth of 60m; this is due to the occurrence of saline water. The resistivity values were also low below 400-m depth due to the occurrence of dense mud water.

The SP-logs which were in good agreement with the resistivity logs identified the aquifers.

The natural gamma log showed a clear boundary of gamma ray patterns at 300-m depth. Above this boundary, a relatively low but stable gamma ray was detected; below this boundary, the log indicates higher levels of radioactivity. This high gamma ray which was detected at a depth of 385m was due to the occurrence of carbonized wooden fragments.

As demonstrated in Figure 1.2.1, the detailed correlation of the lithologic log with the geophysical logs shows that the facies units could be divided into small aquifer units. The formations from the ground surface to the depth of 600m were hydrogeologically categorized into the aquifer units in DMR (1992). For this purpose, several hydrogeological profiles were made and the continuities of geologic formation were examined. The top clay usually referred as the Bangkok Clay was divided into soft clay and stiff clay. The hydrogeological classification at Site-A is summarized as follows:

Hydrogeological Classification	Depth
Bangkok Clay (soft clay)	1.50m to 17.20m
Bangkok Clay (stiff clay)	17.20m to 20.30m
Bangkok Aquifer	20.30m to 57.80m
Phra Pradaeng Aquifer	57.80m to 121.50m
Nakhon Luang Aquifer	121.50m to 178.28m
Nonthaburi Aquifer	178.28m to 280.80m
Sam Khok Aquifer	280.80m to 361.40m
Phayathai Aquifer	361.40m to 440.00m
Thonburi Aquifer	440.00m to 482.00m
Pak Nam Aquifer	482.00m to 600.00m+

It is also possible to subdivide Nakhon Luang and Nonthaburi aquifers into upper and lower portions based on the sedimentary cycle.

Site-B (refer to Figure 1.2.2)

Eleven (11) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. Geophysical logging results were generally in good agreement with the facies.

The resistivity log provided useful information about facies changes from depths of 87m to 209m, but low resistivity values were measured in the shallow portion up to a depth of 87m due to the occurrence of saline water. The resistivity values were also low between depths of 209m and 260m due to occurrence of clay and silt.

The SP-logs which were in good agreement with the resistivity logs identified the aquifers even in the portion where the saline water occurred.

High gamma ray was detected up to a depth of 209m at clayey formations. From depths of 209m to 260m, the natural gamma log showed a relatively low gamma ray. This pattern could be seen usually at sandy formations. However, said layer consisted of partly lateritic clay and silt with calcwereous nodules and botryoidal oxidized iron. Also, geophysical logging results showed that it was composed of loose fine materials and had a high conductance. It was presumed that the sediments were under high temperature and in a dry environment. The formations from 163m to 170m had the same sediments. At about 123-m depth, thin intercalated clay beds emitted high gamma ray intensity.

As shown in Figure 1.2..2, the detailed correlation of the lithologic log with the geophysical logs shows that the facies units could be divided into 13 aquifer units. The formations from the ground surface to the depth of 300m were hydrogeologically categorized into the aquifer units in DMR (1992). For this purpose, several hydrogeological profiles were made and the continuities of geologic formations were examined. The top clay usually referred to as the Bangkok Clay was divided into soft clay and stiff clay. The hydrogeological classification at Site-B could be summarized as follows:

Hydrogeological Classification	Depth
Bangkok Clay (soft clay)	2.00m to 9.20m
Bangkok Clay (stiff clay)	9.20m to 15.80m
Bangkok Aquifer	15.80m to 49.00m
Phra Pradaeng Aquifer	49.00m to 126.25m
Nakhon Luang Aquifer	126.25m to 193.40m
Nonthaburi Aquifer	193.40m to 281.13m
Sam Khok Aquifer	281.13m to 300.00M+

It is possible to subdivide Phra Pradaeng and Nakhon Luang aquifers into upper and lower portions based on the sedimentary cycle.

Site-C (refer to Figure 1.2.3)

Thirteen (13) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. Geophysical logging results were generally in good agreement with the facies.

The resistivity log provided useful information about facies changes from depths of 60m to 325m, but low resistivity values were measured above the 60-m depth due to the occurrence of saline water.

The SP-logs which were in good agreement with the resistivity logs could identify clearly both sandy and clayey formations even in the portion where the saline water occurred.

The natural gamma log also indicated clayey formations. The Bangkok Clay occurring at shallow depths was characterized by a low gamma ray intensity.

As shown in Figure 1.2.3, the detailed correlation of the lithologic log with the geophysical logs shows that the facies units could be divided into 29 aquifer units. The formations from the ground surface to the depth of 325m were hydrogeologically categorized into the aquifer units in DMR (1992). For this purpose, several hydrogeological profiles were made and the continuities of geologic formations were examined. The top clay usually referred to as the Bangkok Clay was divided into soft clay and stiff clay. The hydrogeological classification at Site-C is summarized as follows:

Hydrogeological Classification	Depth
Bangkok Clay (soft clay)	1.40m to 14.50m
Bangkok Clay (stiff clay)	14.50m to 19.45m
Bangkok Aquifer	19.45m to 43.45m
Phra Pradaeng Aquifer	43.45m to 108.00m
Nakhon Luang Aquifer	108.00m to 170.00m
Nonthaburi Aquifer	170.00m to 281.00m
Sam Khok Aquifer	281.00m to 325.00m+

1.2.2 Analysis of Pumping Test Data

Pumping test is performed in each observation well at Site-A, Site-B, and Site-C. Three (3) types of pumping test were carried out:

1. Step-drawdown test (3 hours by 6 steps)
2. Continuous pumping test (48 hours)
3. Recovery test (8 hours)

(1) Methods of Pumping Test Analysis

(a) Step-drawdown Test

The step-drawdown test is used for the evaluation of well loss and for planning a suitable pumping rate for the continuous pumping test. In each step, drawdown is measured as follows:

- 0 to 30 minutes : every 5 minutes
- 30 to 180 minutes: every 10 minutes

For each step, the specific capacity is ascertained by dividing the pumping rate by the drawdown measured at the end of the step. Normally the specific capacity decreases with increasing pumping rate due to increasing well loss at higher pumping rates.

According to Jacob (1946), the total drawdown could be expressed by the following equation

$$sw = BQ + CQ^2$$

where

sw = total drawdown (m)
Q = pumping rate (m^3/day)
B = aquifer loss coefficient (day/m^2)
C = well loss coefficient (day^2/m^5).

By plotting sw/Q versus Q and fitting a straight line through the points, the well loss coefficient C is given by the slope of this line and the aquifer loss coefficient B is given by the intercept at Q=0.

Well efficiency is defined as the ratio of aquifer loss to measured drawdown. A well efficiency of each step and an average well efficiency could be computed from the results of step-drawdown test.

(b) Continuous Pumping Test

The continuous pumping test is used for the evaluation of aquifer parameters such as transmissivity and storage coefficient. The suitable pumping rate determined from the step-drawdown test should be maintained throughout the pumping period. Drawdown is measured in the pumped well at the following time-steps:

0 to 10 minutes	:	every 1 minute
10 to 25 minutes	:	every 3 minutes
25 to 60 minutes	:	every 5 minutes
60 to 120 minutes	:	every 10 minutes
120 to 180 minutes	:	every 15 minutes
180 to 300 minutes	:	every 30 minutes
300 to 2,880 minutes	:	every 60 minutes

If the well loss in one well is significouldt, the measured drawdown should be corrected, otherwise the calculated transmissivity might be smaller than the actual transmissivity. If the average well efficiency is smaller than 90%, the measured drawdown is therefore corrected, and aquifer parameters were calculated using both measured and corrected draw-downs.

Two methods were employed for correcting measured drawdown, namely, Correction 1 and Correction 2. Correction 1 uses a well efficiency at the pumping rate. If the well efficiency at the pumping rate is Ew and the measured drawdown is sw, the corrected drawdown s_1 is computed as

$$s_1 = Ew \times sw / 100$$

Correction 2 uses a well efficiency at each measured drawdown. If well efficiencies were plotted versus measured drawdowns, the plotting points were fitted normally by a logarithmic line. This means that under a constant pumping rate, the well efficiency decreases with increasing measured drawdown. This result suggests that the well loss depends on the entrance velocity of flow (into a well) and not on the quantity of pumping. Therefore, Correction 2 computes corrected drawdown from measured drawdown using logarithmic regression equation.

Theis type-curve matching method and Cooper-Jacob method were employed to obtain aquifer parameters from continuous pumping tests.

Theis Type-Curve Matching Method

Type-curve matching techniques were often used to determine aquifer parameters from pumping test data. It is usually accomplished by manually matching field data to available type-curves. This is a time consuming procedure and requires close scrutiny to obtain the best match.

In this study, a type-curve matching program (TECAUTO) is used. The program could match drawdown data automatically to the best type-curve in a least-squwere sense to determine the aquifer parameters. Families of type-curves were parametrically generated until a best fit to the time-drawdown data is obtained. The program finally computes transmissivity, storage coefficient, computed drawdowns, and standard deviation of drawdowns.

Cooper-Jacob Method

This is a semilogarithmic approximation which is good for small values of well function's argument u (i.e., for small r and/or large t). If drawdown observations were made in a single well for various times, a plot of drawdown versus the logarithm of time yields a straight line.

The method of solution employed in this study was the least-squwere regression analysis and the fitting of a straight line through reliable test data in a semilogarithmic diagram. Transmissivity and storage coefficient were calculated from the straight line.