5. Study of Earthwork and Foundation Design

In this section, treatment of soft ground and examination of strata as formations for carrying bridge foundation loads are investigated based on the analysis of borehole logs, geological longitudinal profiles and laboratory soil tests.

5.1 Soft Ground Treatment

5.1.1 General

Areas of soft ground (Ac-deposit) are extensively distributed along the railway area extending up to 4~13 meters below ground level. In order to construct high embankments for bridges, improvement of the soft ground is required.

Analysis for improvement of soft ground is carried out as follows:

- Select design soil parameters and Stratigraphy.
- Determine design embankment profile and material.
- Select representative analysis section.
- Decide soft ground design method.
- Decide analysis method.
- Carry out analysis.

5.1.2 Design soil Parameters and Stratigraphy

These are discussed in section 2, 3 and 4 of this report and the parameters and Stratigraphy used for analysis of the soft ground.

(1) Embankment Profile and Material

Embankment profile and fill parameters are as follows:

1) Embankment profile: width of Railway: 10.50m

slope gradient: embankment height less than 6m 1: 1.5

embankment height over 6m 1: 1.75

2) Embankment height and extension

High embankments in this project area are shown as below

Km 0+750～1+100 Embankment height is 10.0 m and 5.0 m

Km 2+150～2+200 Embankment height is 5.0 m

Km 17+900～18+000 Embankment height is 3.5 m

Km 22+800～23+100 Embankment height is 5.7 m

3) Design soil parameters for embankment fill

- Wet Density.........................$\gamma t = 1.70$ t / m^3
- Cohesion.............................. $C = 2.2$ tf / m^2
- Angle of Internal Friction...........$\phi = 10$ (degree)
- Rate of Filling…...........................5 cm / day

(2) Representative Sections for Analysis

Sections for analysis will be made as below:

Km 0+750～1+100 Representative km 1+050 Embankment height is 10.0 m and 5.0m

Km 2+150～2+200 Representative km 2+150 Embankment height is 5.0 m

Km 17+900～18+000 Representative km 17+900 Embankment height is 3.5 m

Km 22+800～23+100 Representative km 23+100 Embankment height is 5.7m

5.1.3 Soft Ground Design Method

(1) Design Method

Soft ground design methods for high approach road embankments to bridges can be summarized as follows:

① EPS method: Reduction of embankment weight

② Soft ground treatment method: Increase strength of soft ground

③ Piled slab method: Embankment is supported by RC piles

Methods ① and ③ are very expensive, therefore method ② is adopted. There are many possible options included in method ②

The method adopted depends upon various factors such as the nature of the soil (bearing capacity and depth of individual strata), availability of soils, embankment height, and the construction period and cost.

These methods can be classified according to their main purpose, which may be either to prevent embankment slope failure, to accelerate settlement, or both.

Eight methods are summarized in table 5.1.1 and 5.1.2.

Table 5.1.1 Soft Ground Treatment Method

	Method	Description
	Ground surface treatment	- Use of sand, sheet, mat, etc. - Functions as upper discharge layer for consolidation - Prevents upward flowing ground water entering the embankment - Ensures access for construction plant - Cakar Ayam System - EPS method
	Replacement of soft ground	- Protects against slope failure and reduces settlement - Replacement depth is limited
	Berm (additionalembankment)	- Increases resistance to slip circle failure - May be used for environmental reasons.
	Slow speed embankment construction	- To increase shear forces over a long period
	Surcharge	- To accelerate settlement prior to completion of the embankment and structure.
	Vertical drain	- To accelerate consolidation and strength increase - Sand drain, PVD drain (Card board drain) etc
	Compaction pile	- To increase strength and stability - Use of compacted sand and crushed stone
	Chemical soil stabilization	- To increase bearing strength and stability - Use of lime pile and cement grout, mortar injection

Table 5.1.2 Countermeasure for Soft Ground Treatment

ITEM	METHOD			
	SAND DRAIN	PBD	SAND COMPACTION	PRE-CAST RC PILE

Diameter (mm)	400	65	700	400×400
Increase in Strength Sub Soil (kg/cm^2)	C=0.3⇒1.0	C=0.3⇒0.5	C=0.3⇒3.0	—
Characteristic	This method is most popular	Construction Speed is Fast	Range of application is wide	No Settlement
Depth for practical application	30m	15m	35m	30m
Minimum Spacing	1.2m	0.9m	1.2m	1.0m
Construction Capacity	300m/day	2,500m/day	150m/day	120m/day
Ratio of Cost	1.0	0.2	2.4	11.0
Other	Many Satisfactory Result	Low depth for practical application		

(2) Institution of Soil Criteria

General characteristics of the Soft Ground are as in the followings:

1) Definitions of Soft Ground

General criteria of soft ground are as in table 5.1.3

Table 5.1.3 General Characteristics of Soft Ground

Soils	Peat or Clayey Soil		Sandy Soil
Stratum Thickness	Less than 10 m	More than 10 m	-----
SPT Blowcount	Less than 4	Less than 6	Less than 10
Unconfined Compressive Strength: qu (kgf/cm^2)	Less than 0.6	Less than 1	-----
Cone Resistance Dutch Cone Test: qc (kgf/cm^2)	Less than 8	Less than 12	Less than 40

2) Classification by thickness of soft ground

The soft ground in the Project area can be classified in terms of its thickness as follows:

- Very Shallow	:	soft ground depth	:	D < 2.5 m
- Shallow	:	soft ground depth	:	2.5 m < D < 5.0 m
- Deep	:	soft ground depth	:	D > 5.0 m

5.1.4 Selection of Treatment Method

For the selection of treatment methods the following criteria are used:

- Stable and permanent foundations necessary.
- Priority is given to a slow construction rate due to the substantial available time period, and the high cost of remedial works in the event of embankment failure.
- Sufficient program time to be allocated for settlement to occur.
- Replacement of soft ground to be limited to 2.5 m for economic reasons but to 5.0m for technical reasons
- Special attention to be paid to prevent heave of the surrounding ground

A number of alternatives have been considered, including vertical sand drains and drainage blanket as set out below.

5.1.5 Method of Analysis

The embankment is analyzed for stability and for settlement. Improvement is calculated by reference to the case of no treatment. Formulae for analysis are as follows:

(1) Ultimate settlement

$$Sc = \frac{eo - e1}{1 + eo} H$$

Where

Sc: Ultimate settlement (cm)

eo: Initial voids ratio

e1: Voids ratio after consolidation

H: Thickness of soil layer to be consolidated (cm)

(2) Consolidation Time

- No Treatment Case

$$t = \frac{d^2 \times T}{Cv}$$

Where

t: Consolidation time (days)

D: Drainage path length (cm)

Cv: Consolidation coefficient (cm^2/day)

T: Time factor

- Sand Drain Case

$$t = \frac{De^2 \times T}{Cv}$$

Where

De: Effective drain radius (m) in square arrangement of sand pile, =1.13Dc

Dc: Centre to centre spacing of sand pile (m)

T: Time factor (obtained by n= Dc/Dw)

Dw: Diameter of sand pile (m)

(3) Stability

$$Fs = \frac{\Sigma\{Cl + \tan\phi(W\cos\theta - ul - KW\sin\theta\ )\}}{\Sigma(W\sin\theta - KW\cos\theta\ )}$$

Where

C: Cohesion

ϕ: Angle of internal friction

l: Length of base of slice (embankment and existing ground layers)

W: Weight of soil slice

θ: Angle of base of slice to horizontal

u: Pore water pressure

k: Seismic coefficient

(4) Analysis Condition

- The stress distribution in the soil beneath the embankment is obtained from Figure 5-1-1 and 5-1-2. The intensity of the distributed embankment load is calculated at points in Figure 5-1-1.

- The grid size for the sand piles was determined on the basis that 30 days after completion of the embankment the degree of settlement remaining will be less than 10 cm

- Condition for sand pile.

Diameter of pile: Dw = 40 cm

Centre to centre spacing of piles: 1.2 < Dc < 3.0 meters

- Sliding check of existing ground treated by sand pile is carried out for two cases, immediately upon completion of the embankment and at a time thirty days after completion.

(5) Target for Settlement and Stability

- 30 days after completion of the embankment remaining settlement is not to exceed 10cm.

- Factor of safety against slip circle failure

a) Upon completion of the embankment: Fs > 1.10

b) 30 days after completion of the embankment: Fs > 1.20

c) when traffic open: Fs > 1.25

(6) Degree of Consolidation

Graphs of degree of consolidation and time factors are shown in Figure 5.1.3.

(Source: Standard of Japan Highway Corporation)

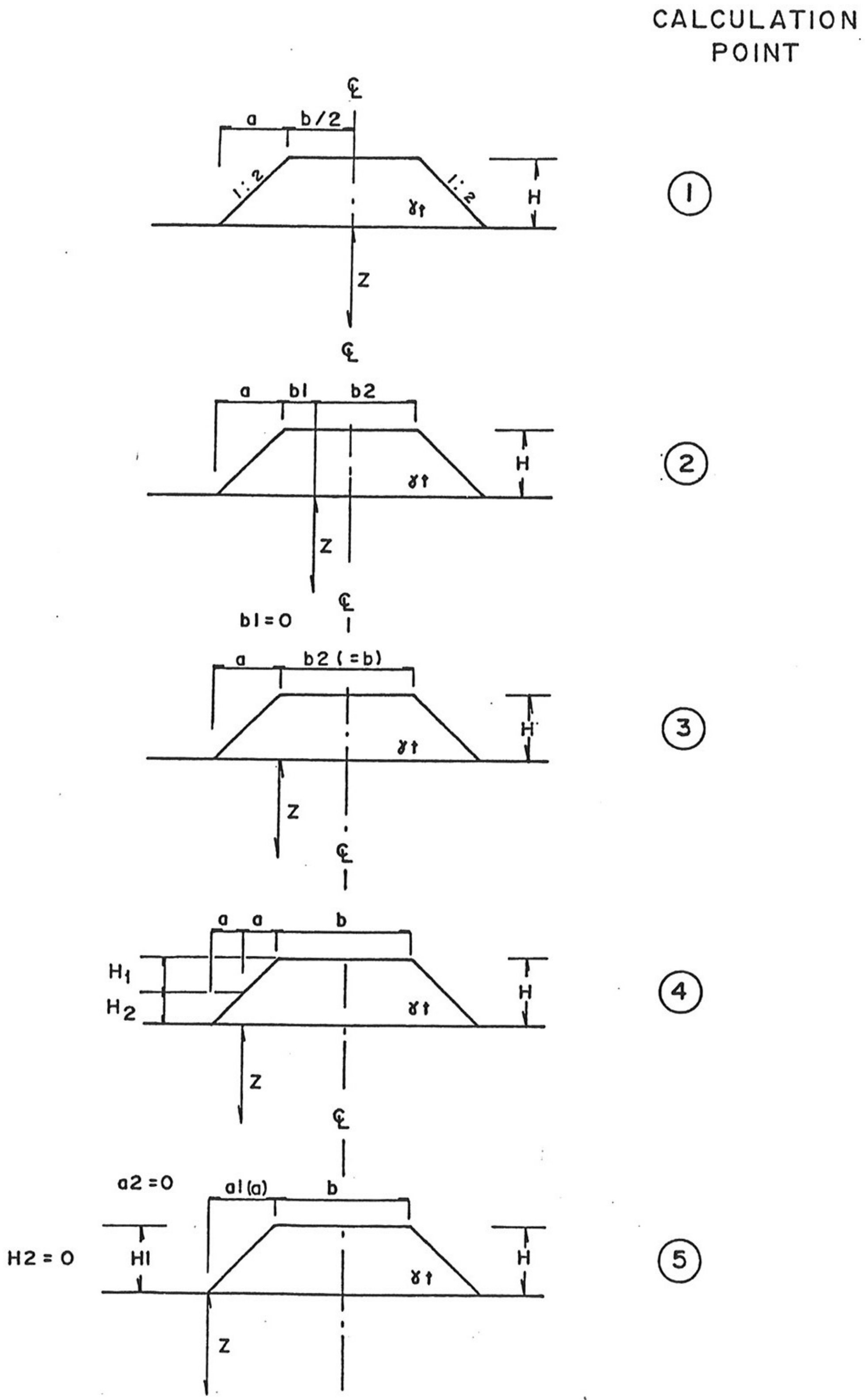

Figure 5-1-1

THE DETAILED DESIGN STUDY OF RAILWAY ELECTRIFICATION AND DOUBLE-DOUBULE TRACKING OF THE JAVA MAIN LINE PROJECT

EMBANKMENT LOAD AND CALCULATION POINTS

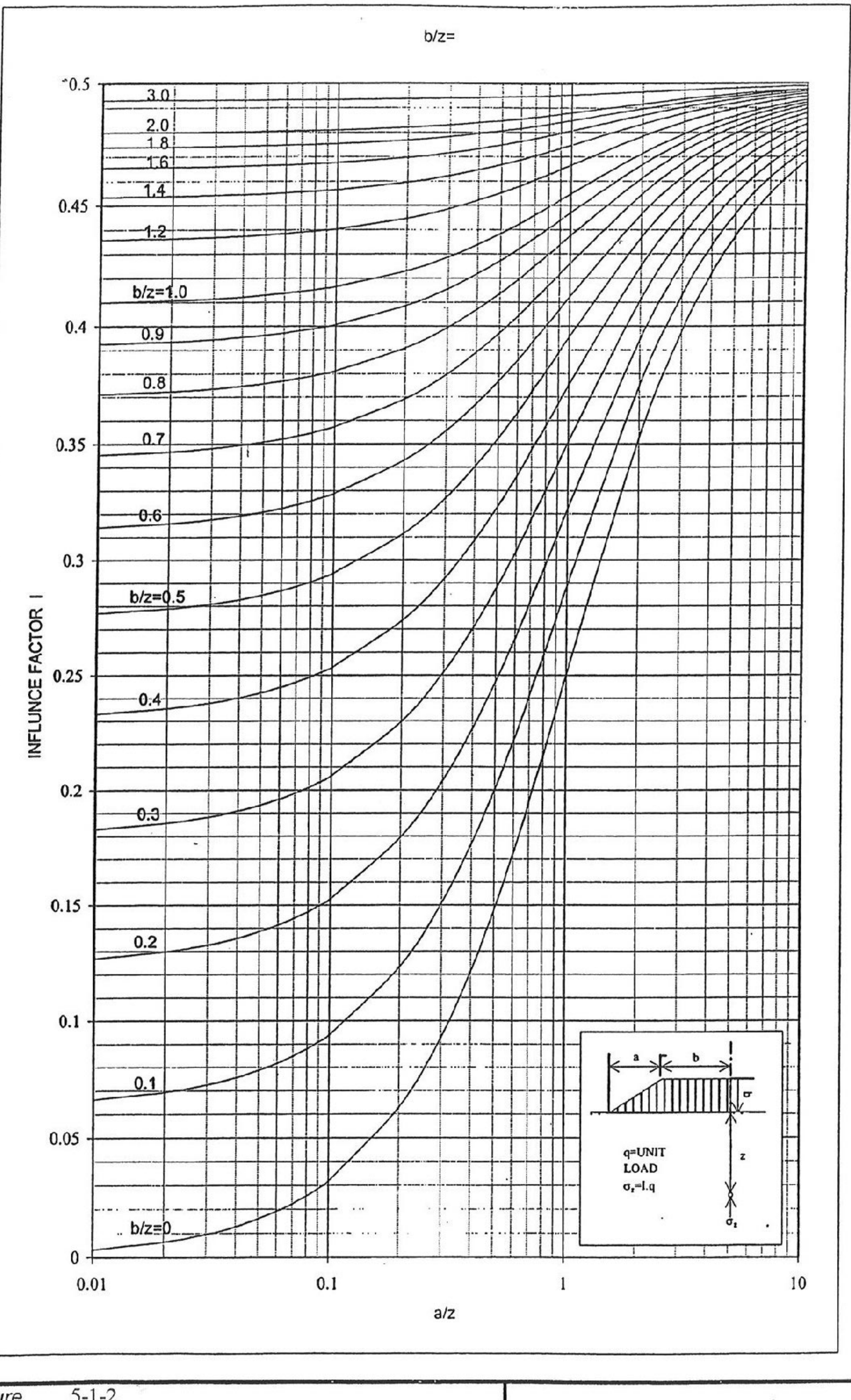

Figure 5-1-2	GRAPH OF INFLUENCE LINE (BY OSTERBERG)
THE DETAILED DESIGN STUDY OF RAILWAY ELECTRIFICATION AND DOUBLE-DOUBULE TRACKING OF THE JAVA MAIN LINE PROJECT	

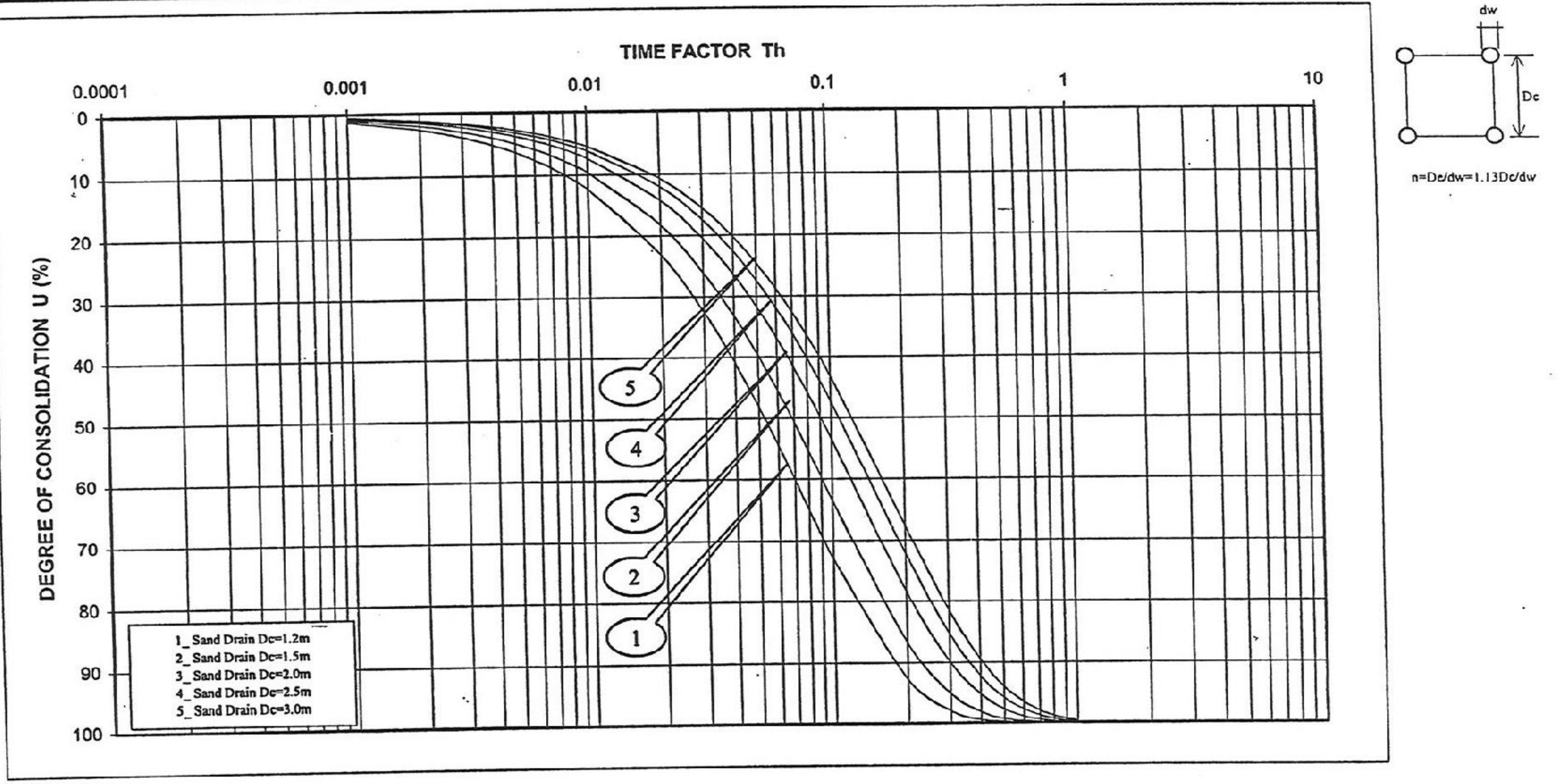

Figure 5-1-3

THE DETAILED DESIGN STUDY OF RAILWAY ELECTRIFICATION AND DOUBLE-DOUBULE TRACKING OF THE JAVA MAIN LINE PROJECT

RELATIVE CHART OF DEGREE OF CONSOLIDATION U(%) AND TIME FACTOR Th FOR VERTICAL DRAIN METHOD