JKR LECTURE

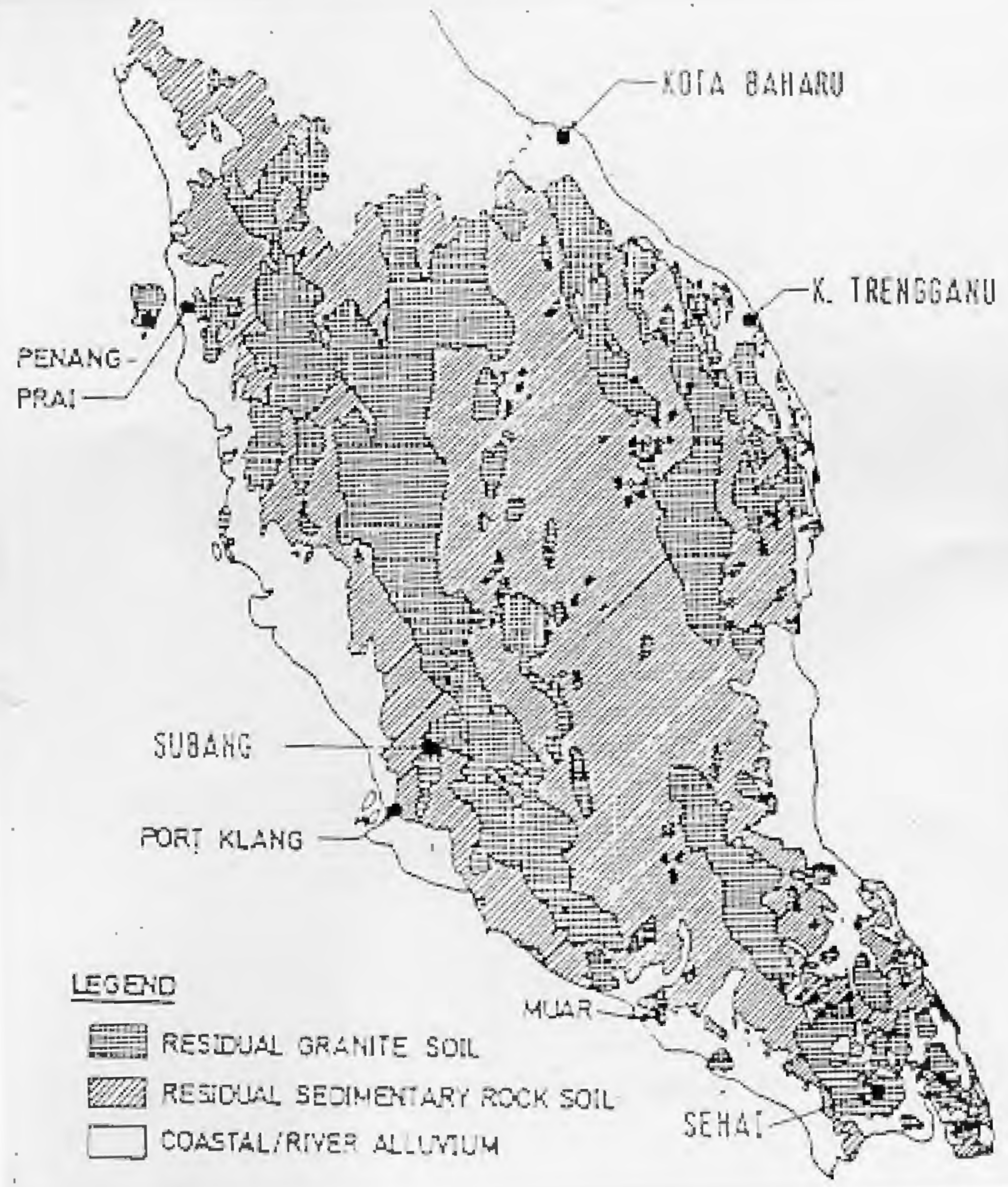
Design and construction of roads on soft clay

Dr C T Toh, Ir Chee Sai Kim

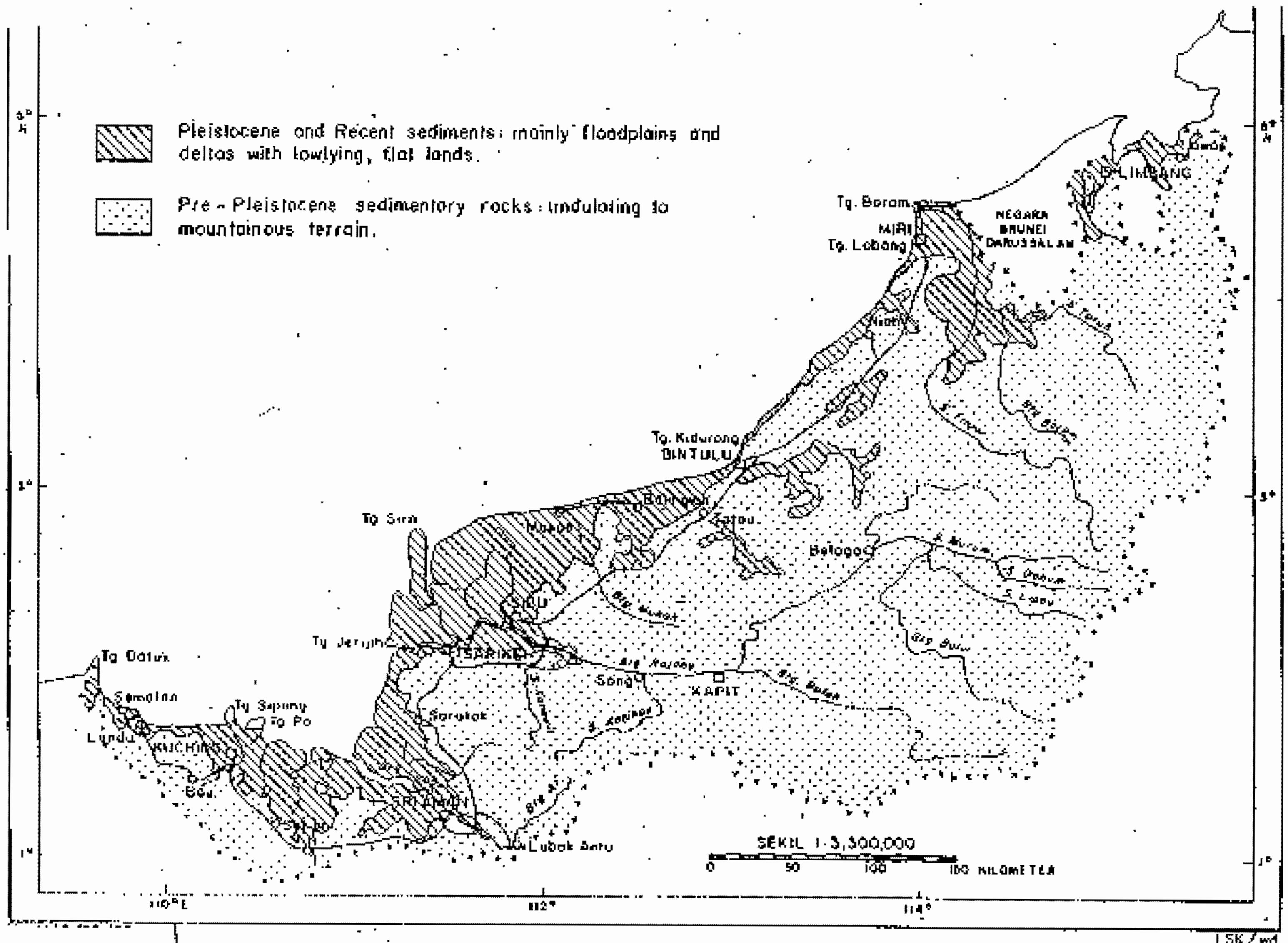
DR C T TOH CONSULATANT

DISTRIBUTION OF SOFT CLAY

- LOW LYING AREAS ON THE WEST COAST AND EAST COAST OF PENINSULAR MALAYSIA.
- COASTAL AND ALLUVIAL PLAINS OF SABAH AND SARAWAK.



KOTA BAHARU
K. TRENGGANU
PENANG-
PRAI
SUBANG
PORT KLANG
MUAR
SEHAI
LEGEND
RESIDUAL GRANITE SOIL
RESIDUAL SEDIMENTARY ROCK SOIL
COASTAL/RIVER ALLUVIUM



Geographic and geologic setting of some major urban centres in Sarawak

SOFT CLAY TOPICS

(i) Stability

(ii) Settlement

(iii) Actual behavior of embankments

(iv) Embankment stabilization and settlement mitigation

SOFT CLAY STABILITY TOPICS

- Mechanism of instability and the development of the mechanism
- Methods of stability analysis
- Relevant parameters and factors affecting stability
- Soil investigation to obtain relevant parameters
- Design factors of safety
- Lateral movements

SOFT CLAY SETTLEMENT TOPICS

- Consolidation
- Relevant soil investigation
- Methods of analysis

SOFT CLAY. EMBANKMENT BEHAVIOR

- Pore pressure behavior
- Pre-consolidation pressure
- Lateral movements
- Undrained and drained volume change
- Settlement due to lateral movements
- Gain in strength

SOFT CLAY TREATMENT TOPICS

Purpose of treatment :

- Mitigate long term settlement
- Enhance the stability of the embankment
- Reduce lateral movements

METHODS

- Stability berms
- Stage construction with gain in strength
- Preload / surcharge
- Vertical drains
- Stone columns
- Pile embankments

SOFT CLAY STABILITY MECHANISMS

- Slope failure mostly circular extending into the soft clay.
- However if thin soft clay present failure can be planar.

Soft clay. stability

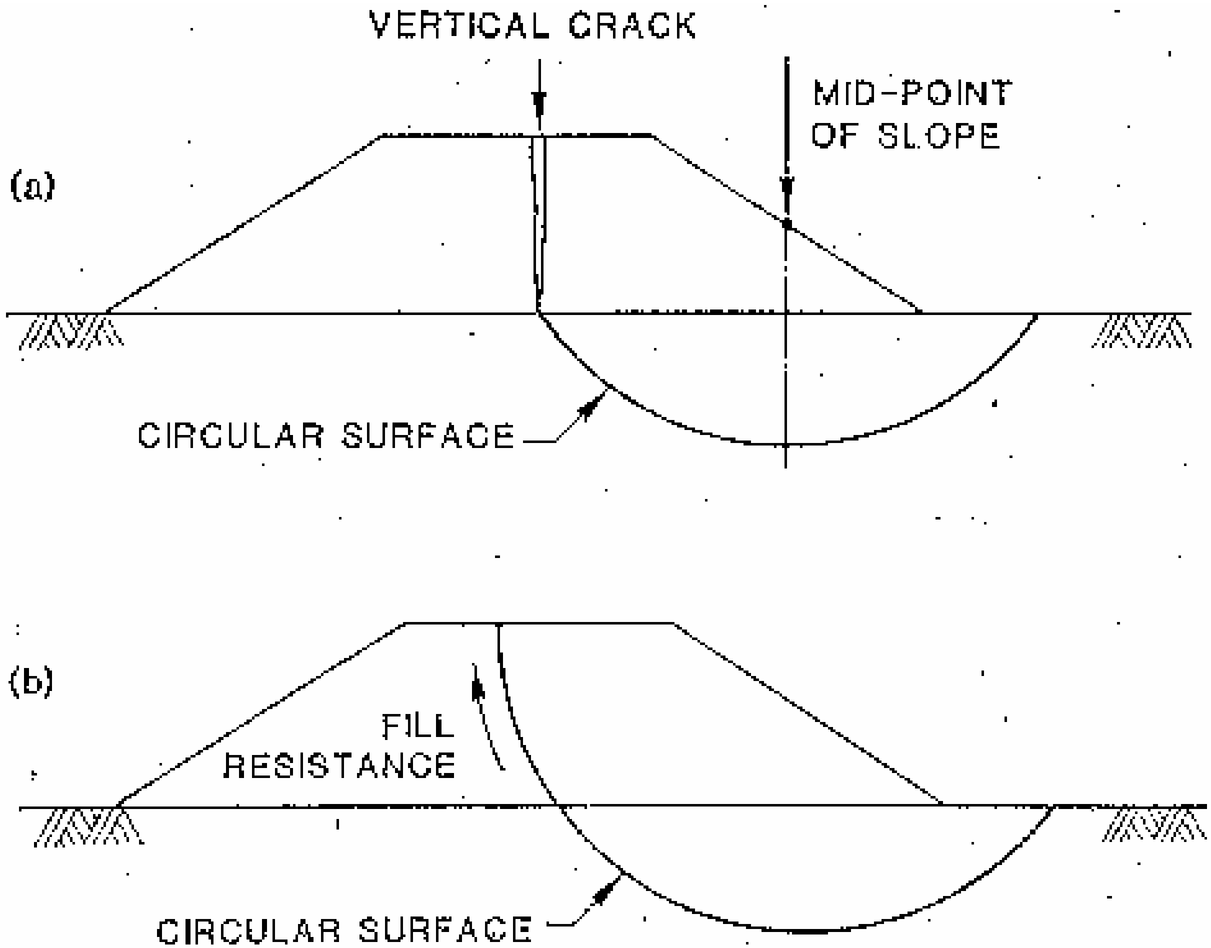


Figure 4 The two basic modes of embankment failure : (a) tension crack through fill - no shearing resistance; (b) full mobilization of fill shearing resistance

Soft clay stability

METHODS OF STABILITY ANALYSIS

Soft clay stability. Critical conditions

- Embankment instability mostly occur within a short period (days or a few weeks) after completion of embankment construction when pore pressures highest
- Short term conditions critical
- Use total stress analysis. No need to know pore pressure distribution. Use un-drained shear strength.
- Can also use effective stress analysis but this will require knowledge of pore pressures

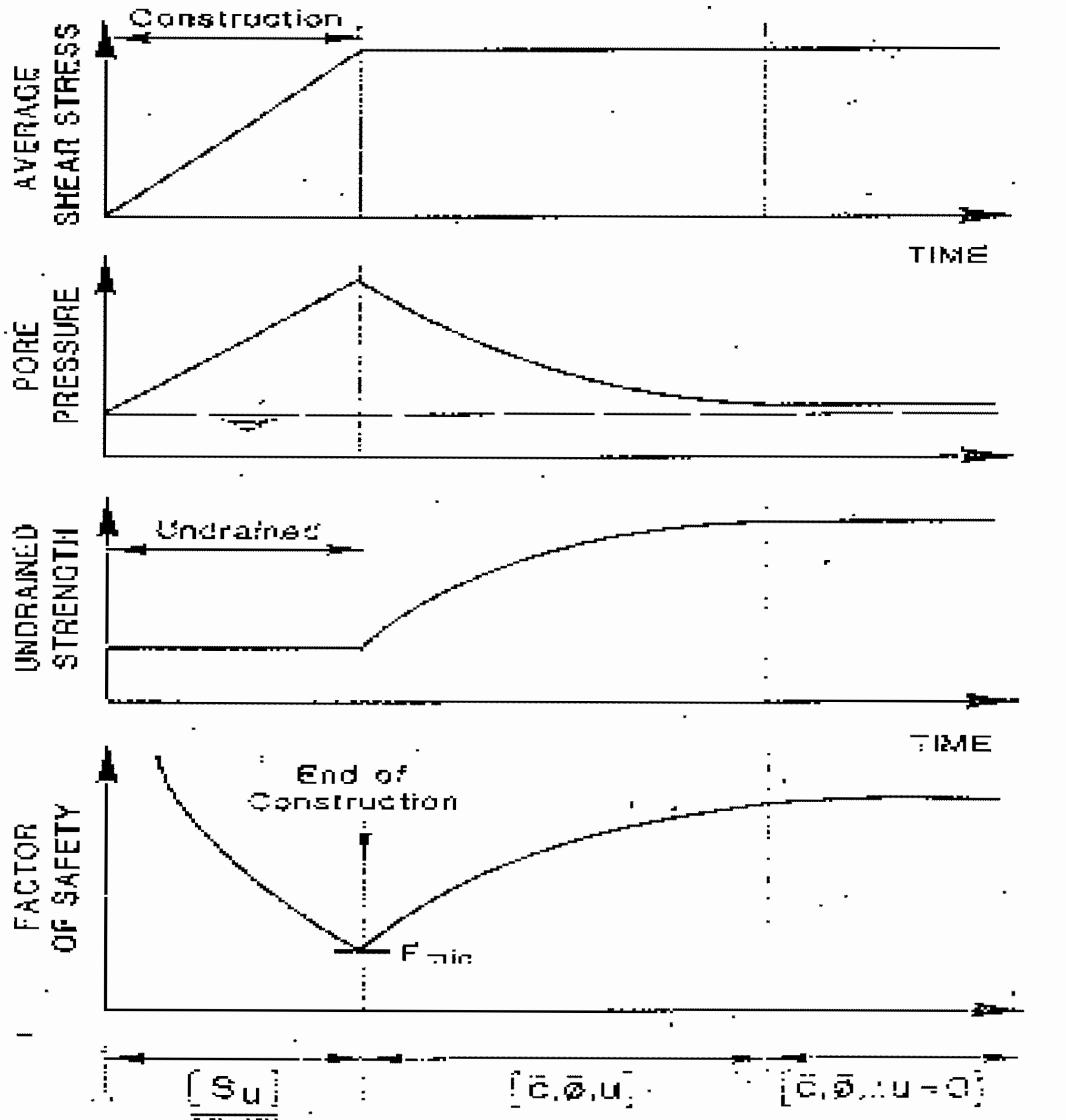


Figure 3 Changes in safety factor under an embankment built rapidly on soft clay (Bishop & Bjerrum, 1960)

PARAMETERS

TOTAL STRESS ANALYSIS:

- Un-drained shear strength of the soft clay. Best to use the vane shear strength.
  Cu or Suv
- No need to consider pore pressures. Total implies all effects encompassed in the un-drained shear strength.
- Shear strength of the embankment fill material. Usually c and phi

PARAMETERS

EFFECTIVE STRESS ANALYSIS

- C' AND PHI' OF SOFT CLAY
- C' AND PHI' OF EMBANKMENT
- PORE PRESSURES THROUGHOUT SOFT CLAY AT FULL EMBANKMENT HEIGHT – This is difficult and will need a coupled effective stress finite element with consolidation to estimate.

METHODS OF LIMIT EQUILIBRIUM ANALYSIS

- Swedish (Fellenius)
- Bishop (Rigorous)
- Bishop (Simplified)
- Janbu (Rigorous)
- Janbu (Simplified)
- Spencer
- Morgenstern – Price
- Sarma
- Gwedgem

NOTES ON CIRCULAR SLIPS

- Swedish – least accurate, can be un-conservative, errors can be up to 60 %
- Bishop (simplified) – Most popular, similar answers to Bishop (rigorous)
- Bishop(simplified) – Usually error less than 5 %. Often less than 2 % compared to Bishop (rigorous)
- Bishop(simplified) gives similar answers compared to Spencer, Morgenstern – Price and Janbu
- If in doubt check using Morgenstern – Price, Spencer, Janbu

Comparisons on circular slips by Whitman & Bailey (1967)

CASE	Accurate F of S	Bishop (simplified)	Fellenius
A	1.58 TO 1.62	1.61	1.49
B	1.24 TO 1.26	1.33	1.09
C	0.73 TO 0.78	0.72 TO 0.82	0.66
D	2.01 TO 2.03	2.00	1.14

COMPARISONS OF METHODS OF STABILITY ANALYSIS BY FREDLUND AND KRAHN

Method / case	1	2	3	4	5	6
Bishop (simplified)	2.08	1.38	1.77	1.12	1.83	1.25
Spencer	2.07	1.37	1.76	1.12	1.83	1.25
Morgenstern - Price	2.08	1.38	1.77	1.12	1.83	1.25
Janbu	2.04	1.45	1.74	1.19	1.83	1.34

Choosing the correct method of analysis

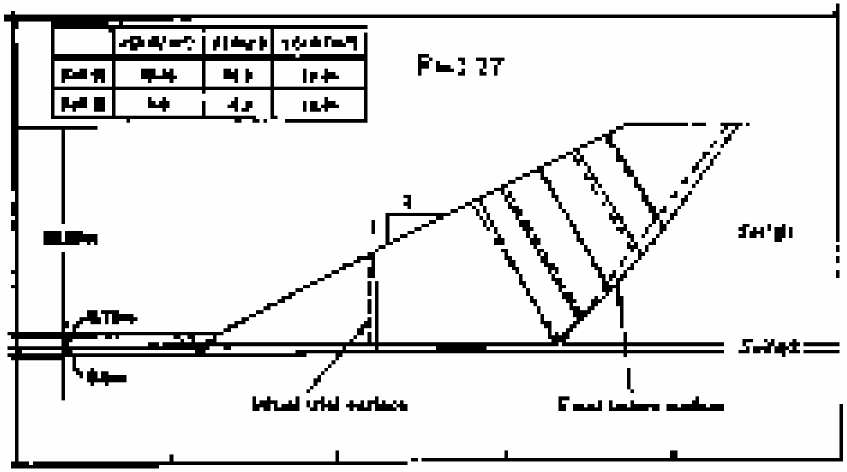


Fig. 23(a): Slope with weak layer - 8 wedges

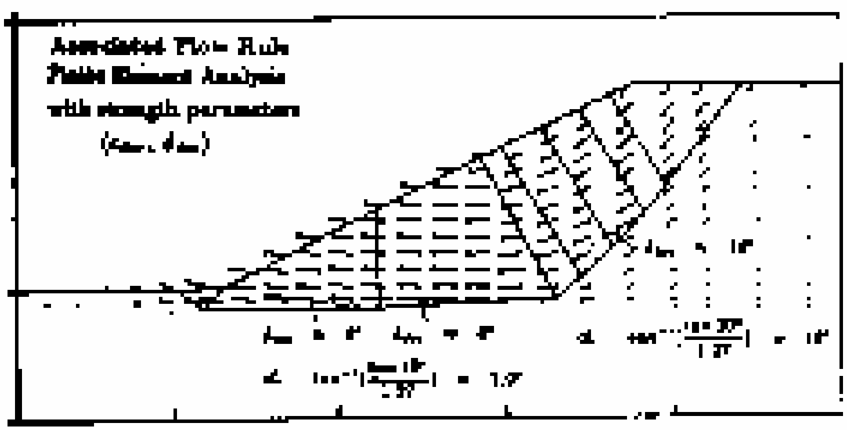


Fig. 23(b): Comparison with F.E. predictions

Donald (1995) carried out different types of stability analysis on bi – linear mechanism.

True solution. Upper bound solution. Factor of Safety = 1.25

Donald (1995)

Method of analysis	Factor of safety
Bishop simplified	1.50
Janbu simplified	1.45
Janbu rigorous	1.43
Morgenstern - Price	1.38
Spencer	1.29
Sarma	1.28
GWEDGEM	1.27
EMU	1.27
UPPER BOUND	1.25

Soft clay total stress parameters

VANE

- Most common method of strength indexing
- Approximate empirical tool for strength measurement, need to relate the vane shear strength to the actual shear strength by back analysis of failed embankments
- Bjerrum, Larsson and Ladd correction factors

Soft clay. Stability. vane

Commonly adopted vane:

- Height / Diameter ratio = 130/65 or 110 / 55
- Gear driven
- Area ratio < 12 %
- Vanes in boreholes – Acker, Geonor, Farnell. Acker vane should not be used.
- Vanes jacked into the ground (without borehole). Geonor vane.

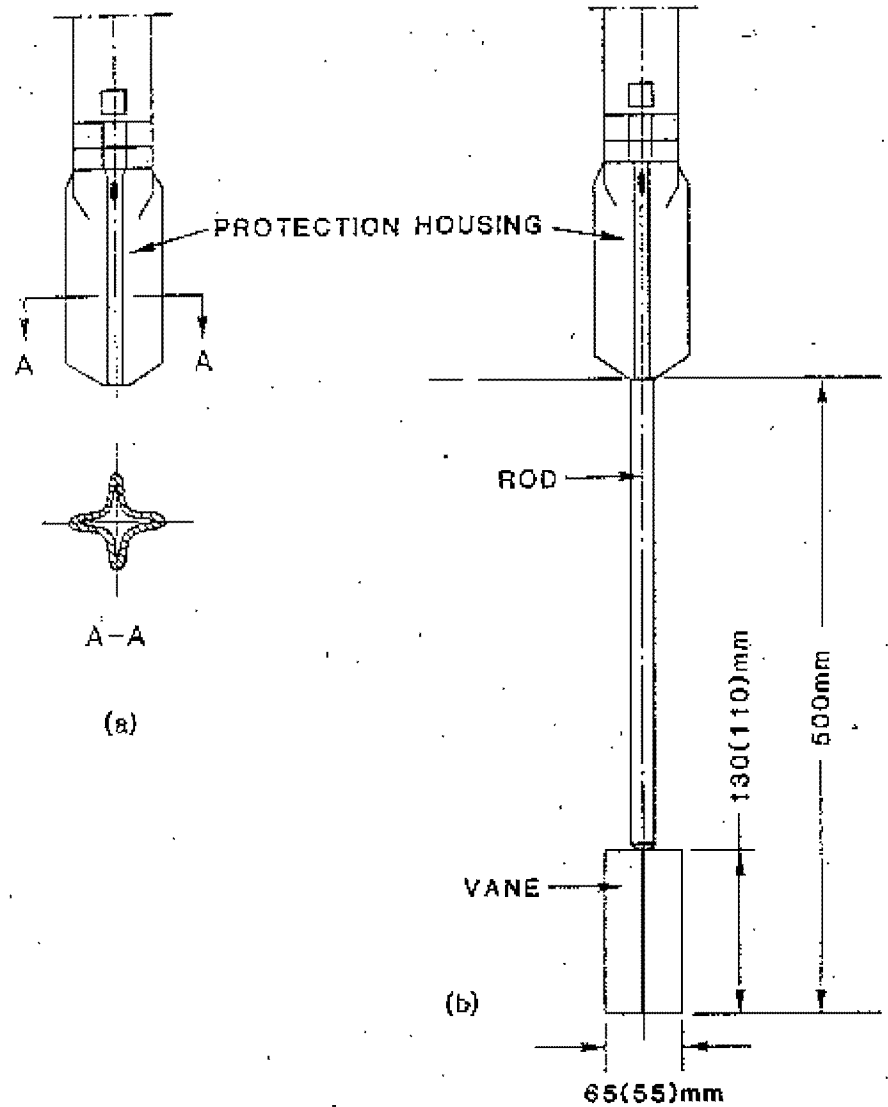


Figure 5 The vane borer for soft clays : (a) during penetration, (b) during shear

Soft clay. Stability. vane

Test procedure

- Penetrate vane beneath borehole depth – 3 diameter (BS) or 5 diameter (Chandler) or 500 mm (Norwegian)
- Rate of rotation – 6 to 12 degree / min
- Time to failure – 5 min (BS) ; 1 to 3 min (Norwegian)
- If carried out inside borehole, can be disturbed and lower shear strengths. Preferable independent of borehole

Soft clay. Stability. vane

- In 1973, Bjerrum showed that embankments on soft clay failed when using vanes to design even if F of S > 1.0 theoretically.
- Bjerrum attributed this to:

(i) vane shear tests carried out at high strain rate overestimates field undisturbed strength

(ii) Vane unable to measure the effects of anisotropy – different strengths in horizontal and vertical directions

Soft clay, stability. Vane

Wroth (1974) quoting the work of Donald et al (1977) and Menzies & Merrifield(1980) concluded:

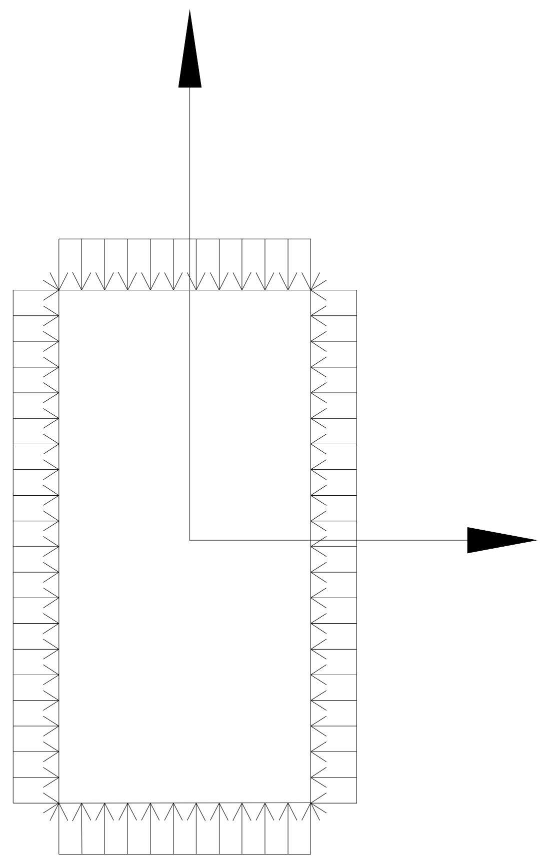
Shear stress distribution around the vane is different from that assumed when computing the vane shear strength from the measured torque.

Soft clay. Stability. vane

Donald et al 91973) and Tavenas & Leroueil (1980) concluded:

(i) On the complexity in analyzing the vane
(ii) At best an approximate tool for indexing strength

Soft Clay. Assumed shear stress across Vane to relate Torque to Suv



STANDARD ASSUMPTION OF STRESS
DISTRIBUTION ACROSS THE VANE

ANALYSIS OF VANE TO GET SUV

- Measure torque
- Torque = (Suv x top area of vane x moment arm) + (Suv x side perimeter area of vane x moment arm).
- Assume Suv same throughout
- Torque gives Suv

ANALYSIS OF VANE TO GET SUV

Torque =

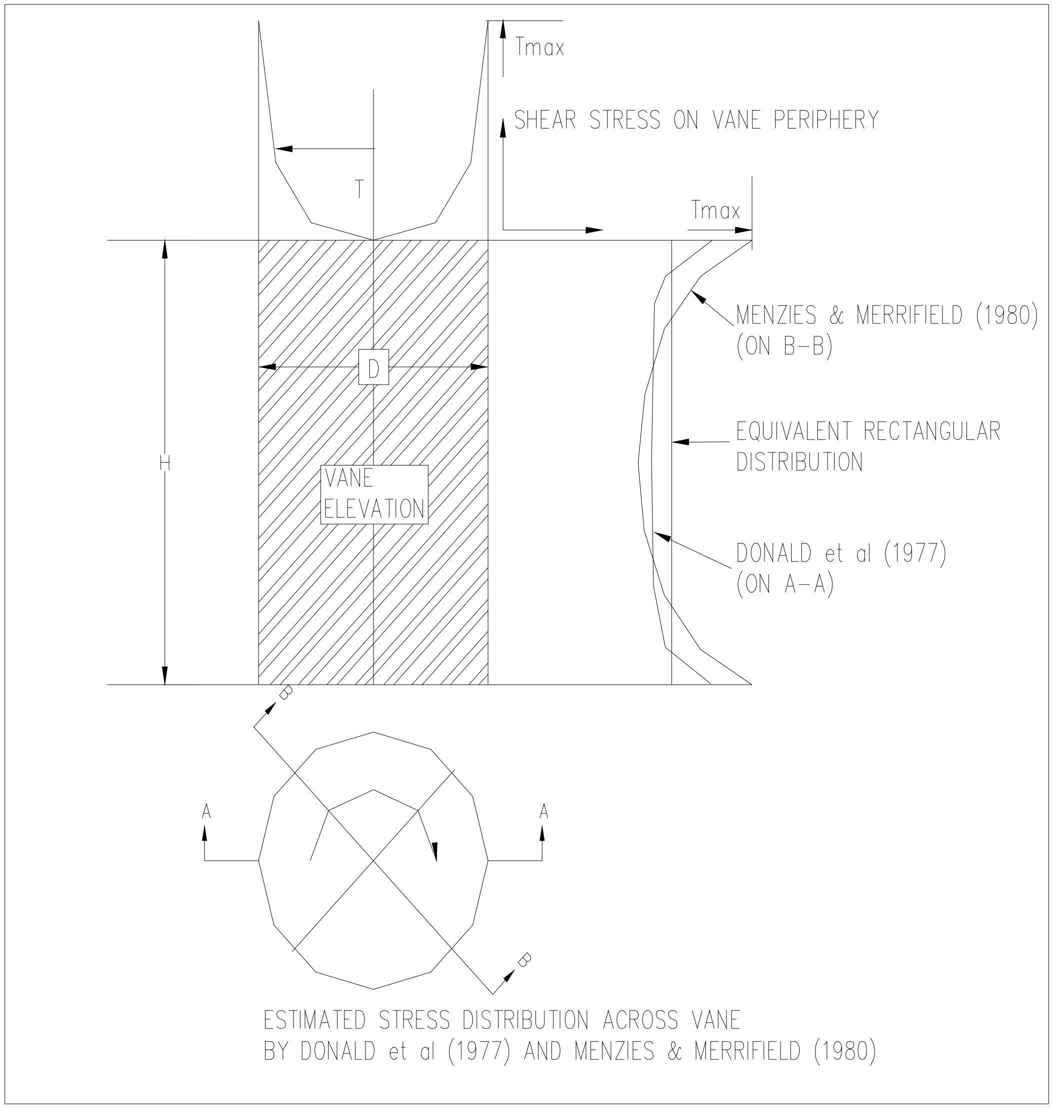
Suv x 3.14 x d^2 / 4 x d /4 +

Suv x 3.14 x d x l x d/2

Measure torque and calculate Suv

Basic problem is asumption that Suv constant across the top and side of vane

Vane. Actual shear stress from Donald et al and Menzies



Error in basic assumption

- Analysis of Suv distribution across diameter and height of vane implies that basic assumption to relate Torque to Suv is not correct

- Therefore there is need to correct vane shear strengths

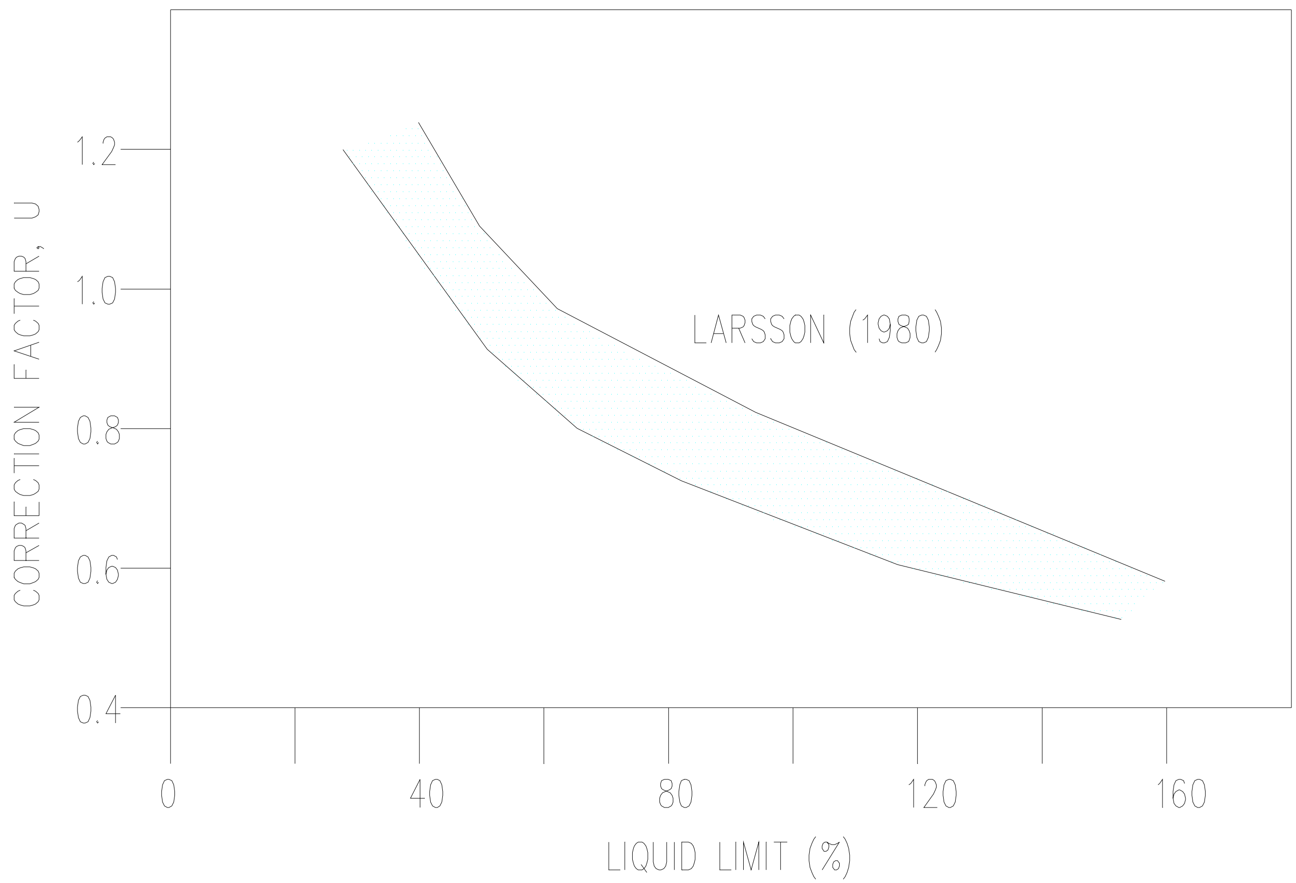
Soft clay. Stability. vane

Methods of indexing vane:

- Bjerrum correction factor dependent on plasticity index
- Larsson correction factor dependent on liquid limits

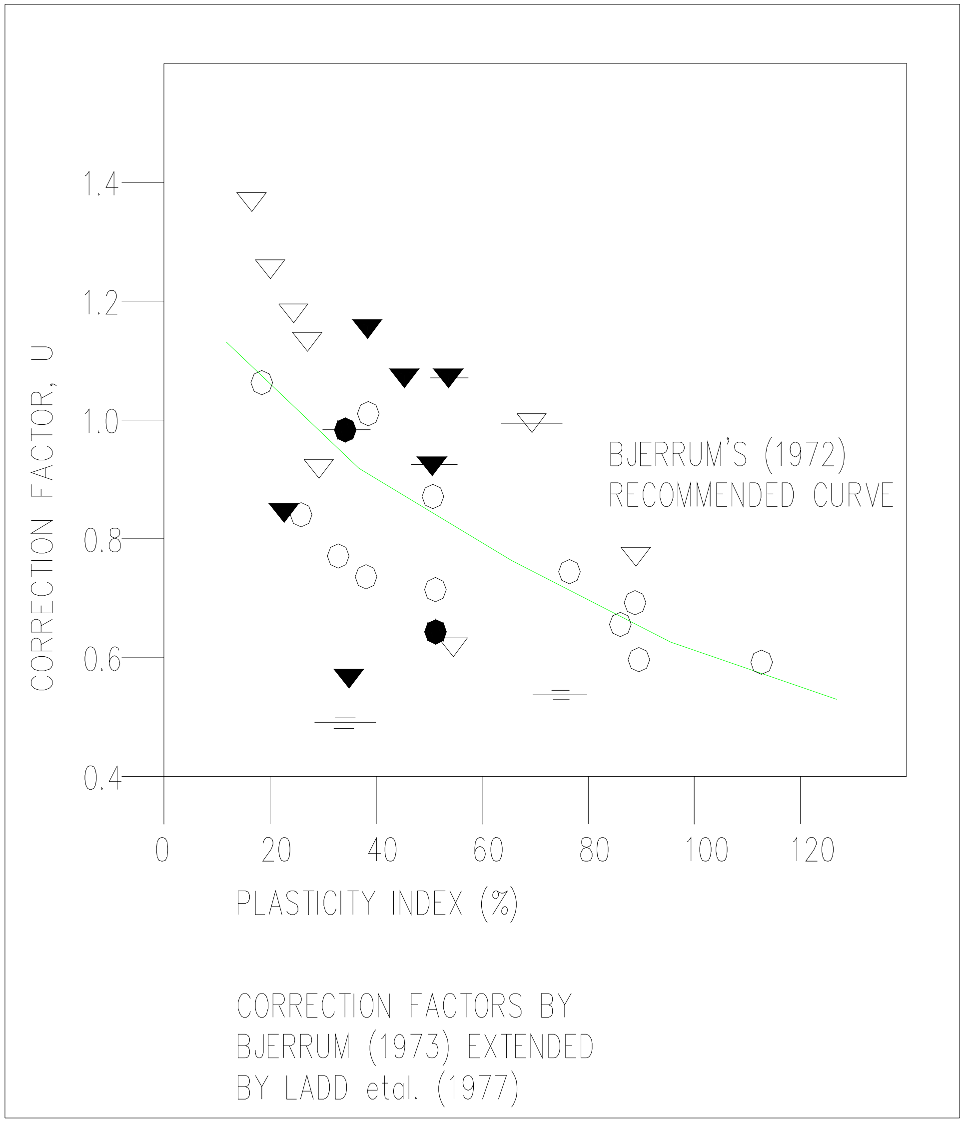
Undrained shear strength = correction factor x Vane shear strength

Soft Clay. Vane Correction



CORRECTION FACTORS BY LARSSON (1980)

Soft Clay. Vane Correction

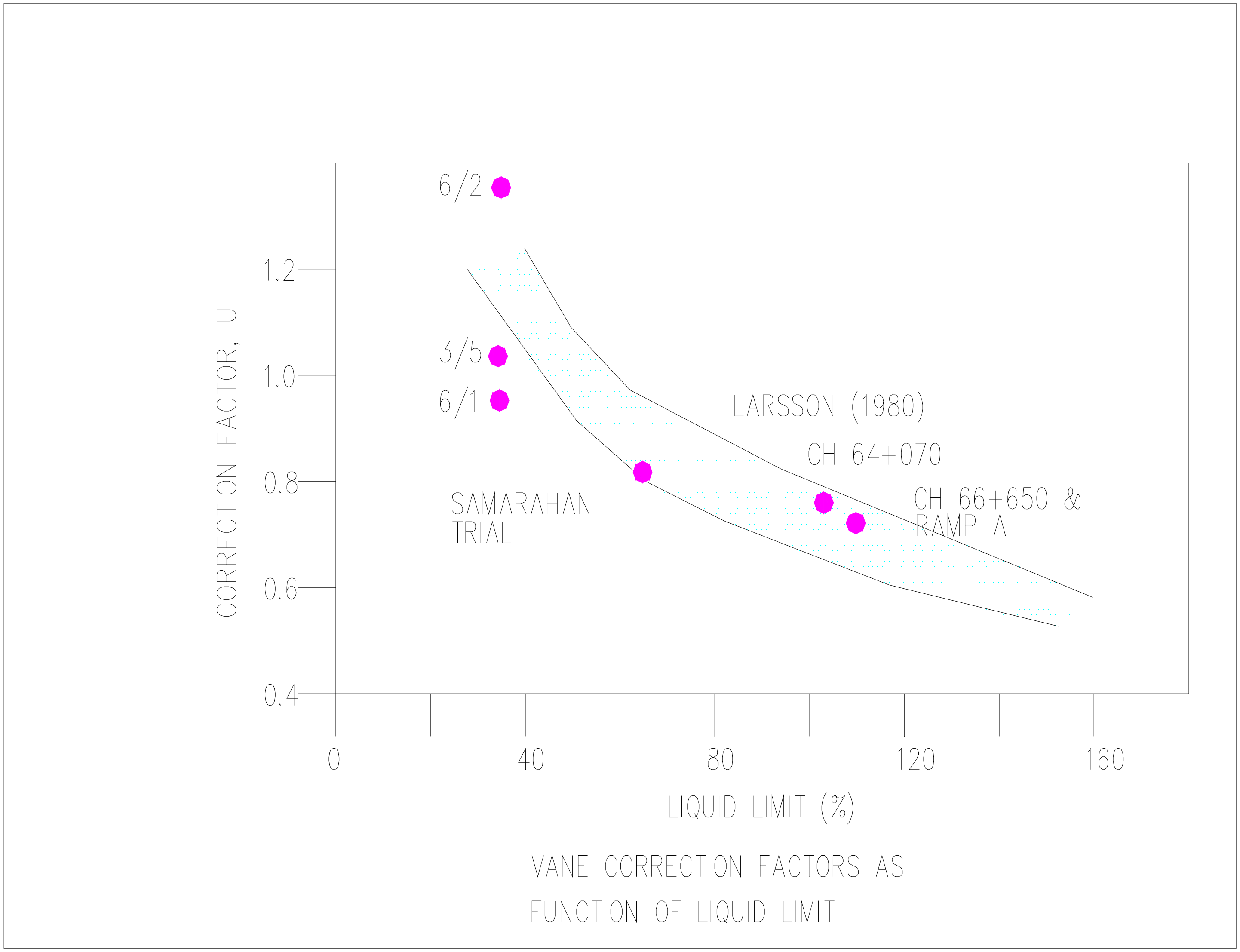


Soft clay. Stability. Local correction factors

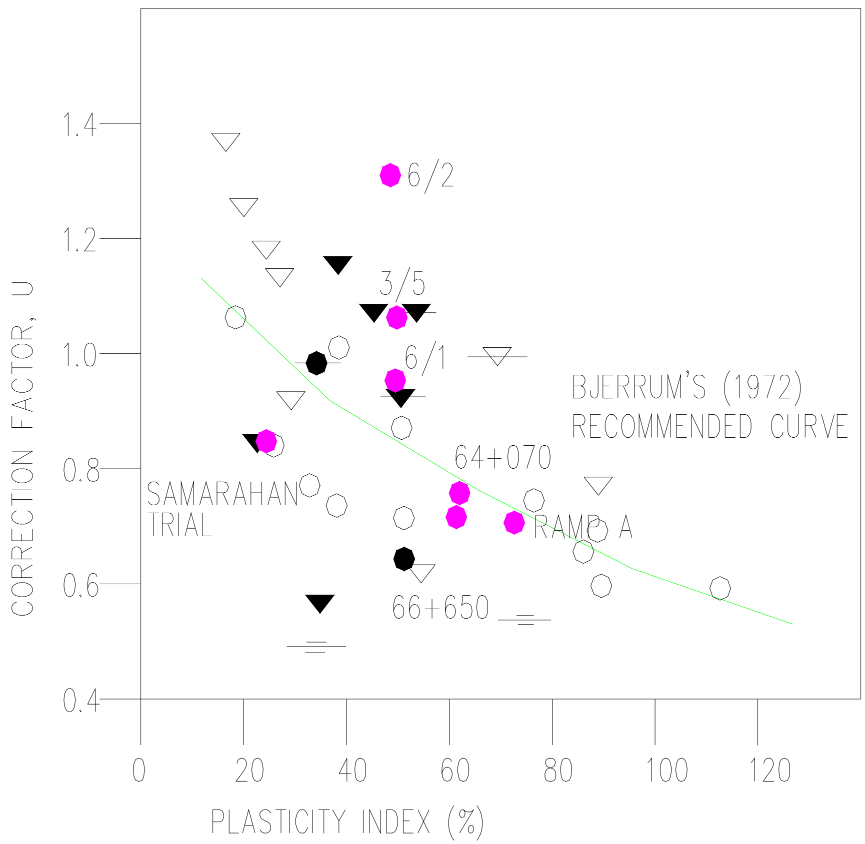
Chee Sai Kim has analyzed a number of embankment failures in soft clay and compared against the properties of the soft clay.

The correction factors are plotted against the set of international data. The trends are similar.

Vane Correction. Malaysian Data



Vane Correction. Malaysian data



VANE CORRECTION FACTORS AS FUNCTION OF PLASTICITY INDEX

Soft clay. Stability. Factors of safety

JKR. Immediate at end of construction without considering effects of gain in strength = 1.2

Should try to obtain 1.4 to 1.5 if gain in strength not considered.

If stage construction with gain in strength required, at each stage the F. of S. with gain in strength at each stage should be 1.2

Soft Clay. Stability. vane

Scatter in vane shear strength expected at any location:

- Natural variability of the soil e.g. sand lenses, organic matter, etc
- Deviation from standard method of testing
- Variations in degree of disturbance due to rotation of the vane during insertion

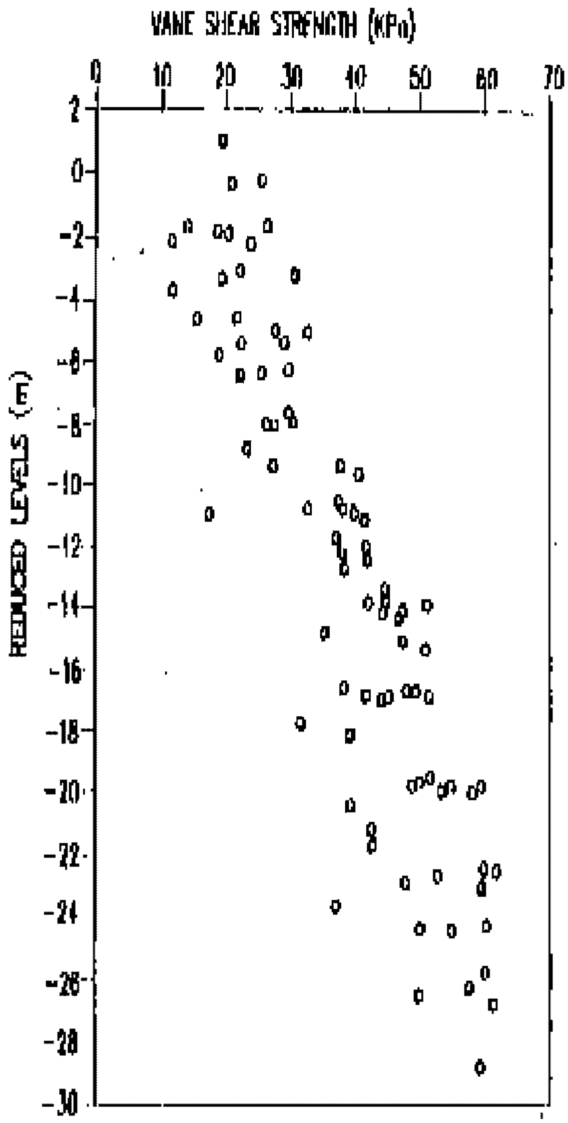


FIG. 5a - VANE SHEAR STRENGTH FROM VANES BENEATH BOREHOLES

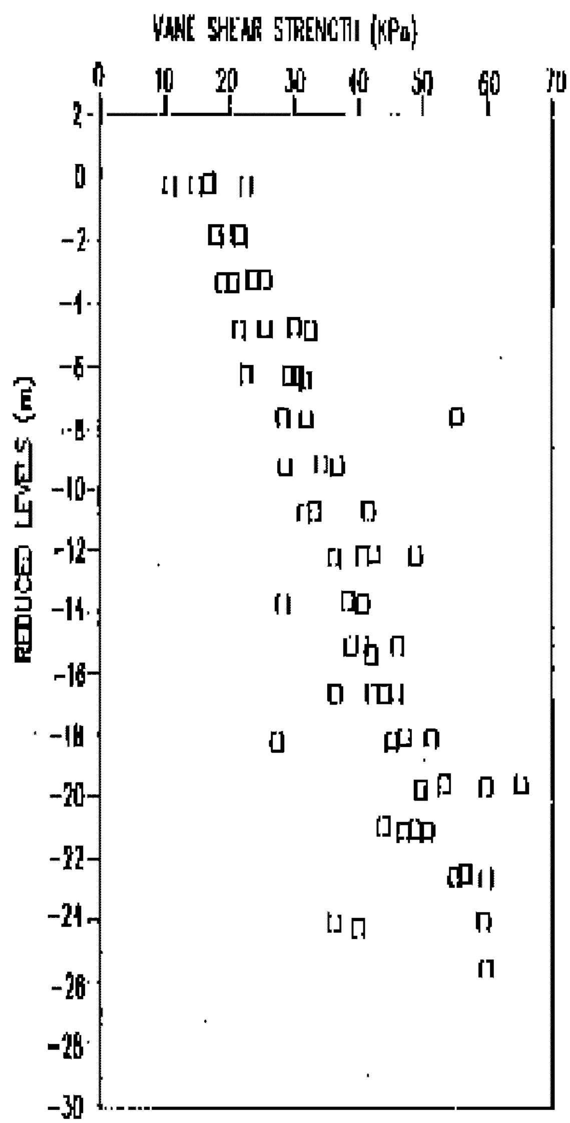


FIG. 5b - VANE SHEAR STRENGTHS FROM PENETRATION VANES

Soft clay. Stability. vane

Scatter would imply that any site there must be sufficient number of vane tests to ensure that the complete range of the scatter is actually captured.

Designer must then decide whether to use lower bound, median or some other values.

Computation of median values should not include exceptionally high values which may be due to tests in sand layer, shells, roots, etc

Soft clay. Stability. Choice of strength

- Generally vane correction factors should be applied to median values
- Lesser or no correction factors if lower bound vane shear strengths are adopted.
- Usually applying correction factor to median would result in near lower bound conditions.
- Also designer need to make judgment about degree of disturbance if vane tests in boreholes

Soft clay. Stability. Strength

- Vane shear strengths from vanes in boreholes generally lower compared to jack – in vanes because of borehole disturbance.
- There is a natural scatter in the vane shear strength results due to natural heterogeinity.

Soft clay. settlement

Basic parameters for analysis:

- Depth and thickness of the different layers;
- Drainage boundaries – sand layers
- Over consolidation ratio OCR
- Cc / (1 +eo) – compressibility index after pc
- Cr / (1 + eo) – compressibilty index before pc
- Cv - coefficient consolidation after pc
- Cvr - coefficient consolidation before pc

Soft clay. Settlement

Typical values:

OCR – 1 to 1.5

$C_r /(1 + e_o) = 0.02$ to 0.03

$C_c /(1 + e_o) = 0.2$ to 0.3

$C_v = 2$ sq m per year

$C_{vr} = 5$ to 10 sq m per year

Soft clay. Settlement

Soil investigation method

- Boreholes
- Undisturbed samples – use stationary thin wall piston sampler for minimal disturbance
- Laboratory oedometer tests. Should modify BS standard for load increments. Use small (10 kPa) pressure increments until pass pc.

Soft clay settlement

TERZAGHI classical theory

$Sf = Cc / (1 + e_0) \times H \times Log (1 + \Delta p / p_0')$

$T = Cv\ t / H^2$

U (degree of consolidatio) related to T

For U = 0.9 (90 % consolidation)

T = 0.848

Soft clay settlement

Problem is Terzaghi theory is for a point in the soil layer.

In calculating U and time, often simplify by using H as the drainage distance.

This is not correct and leads to incorrect answers

Proper analysis of Terzaghi equation requires finite difference or finite element numerical methods

Soft clay settlement

Short Comings Associated with the Conventional Method

- Submergence and Buoyancy Effect
- Large Strain Effect
- Non-Uniform Strain Effect
- Layered System
- Intermediate drainage due to sand layers
- Variations of C_c , C_v with $\bar{p}$
- Time Dependent Loading

Soft clay settlement

Conventional hand calculations using charts not accurate

Not possible to calculate time effects for layered soils using hand calculations and charts

Require finite difference (1 dimensional) or finite element (2 dimensional) methods

Soft clay settlement

Design criteria:

Peninsular MHA JKR – Post construction settlement less than 10 % of total consolidation settlement

Sarawak JKR – Post construction settlement of 200 mm over first 3 post construction years or over first 5 post construction years

CONSEQUENCE OF 90% CRITERIA

- In almost all cases regardless of height of embankment and soft clay thickness > 3 m, will need vertical drains
- Not a good criteria
- Criteria should be based on the time before first pavement overlay – maybe about 7 years

Soft Clay. Embankment behavior
pore pressures

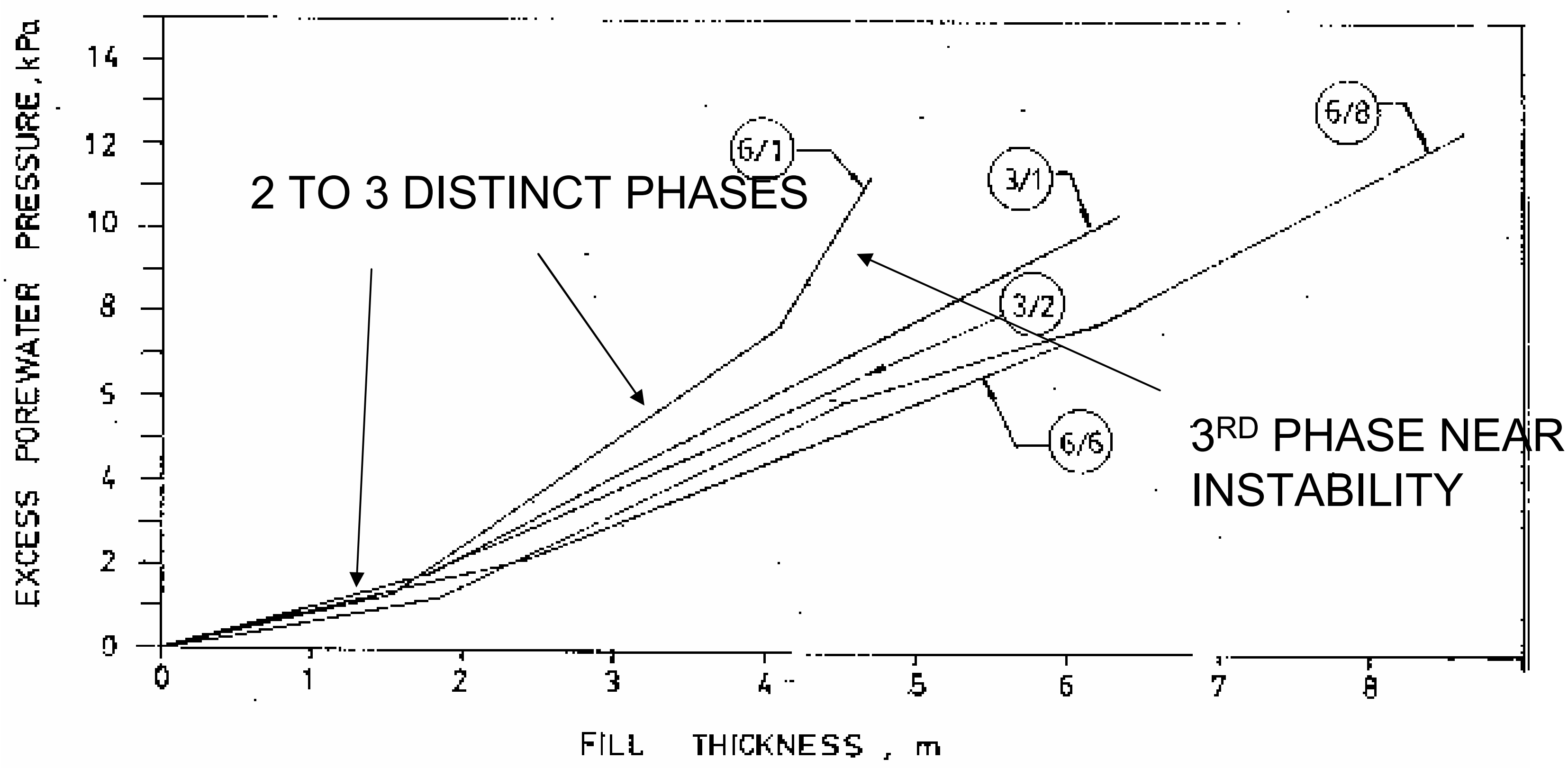
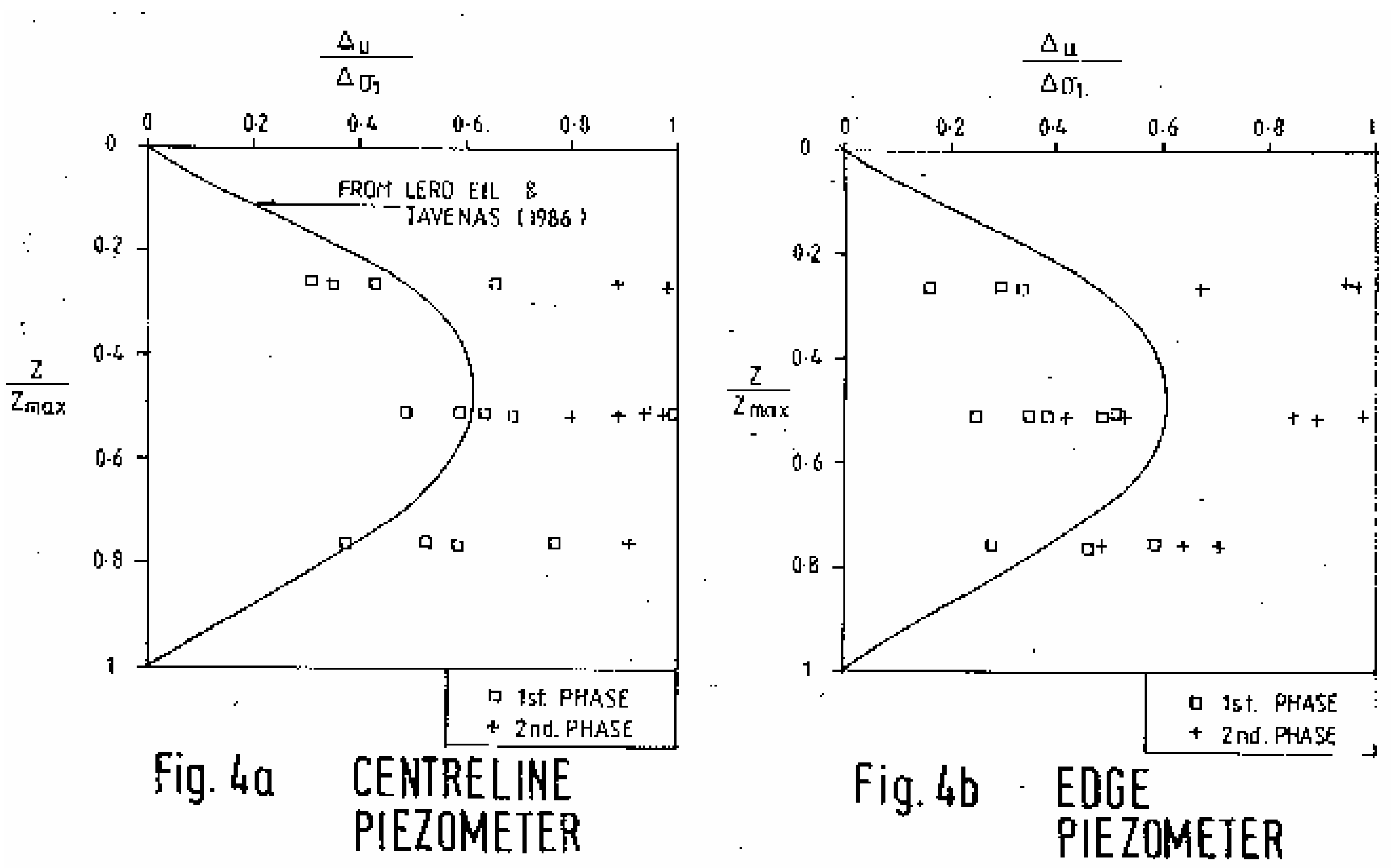


Fig. 3 EXCESS POREWATER PRESSURE RESPONSE

Soft clay. Embankment behavior pore pressures



Soft clay. Embankment behavior

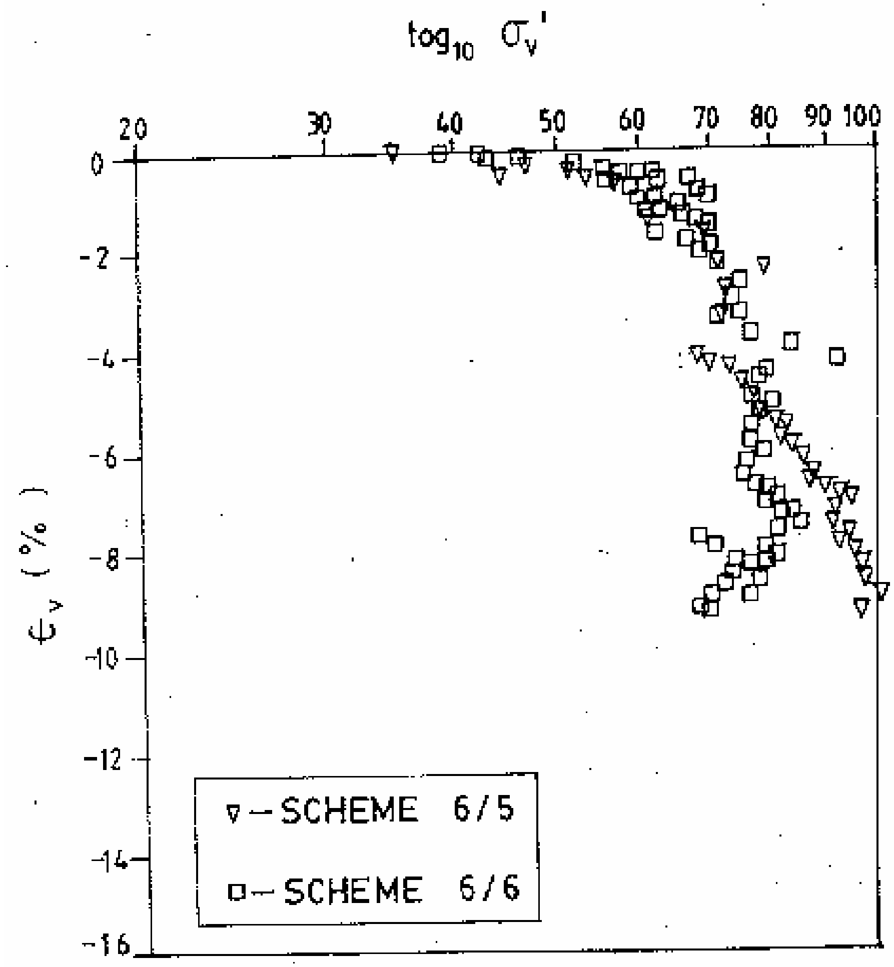


Fig. 6a FIELD ϵ_v - $\log_{10}$ σ_v'
(PIEZOMETER P4)

Soft clay. Embankment behavior

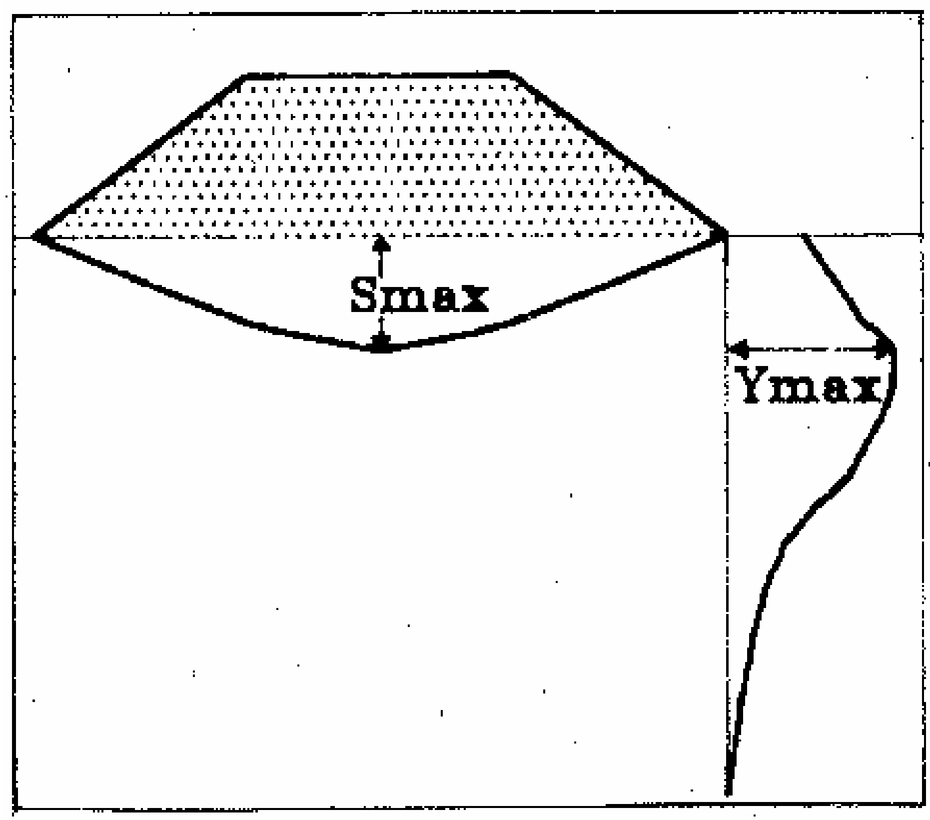


Fig. 28   Definitions of Smax & Ymax

Embankment behavior

Settlement that is measured is due to two components:

- Consolidation settlement
- Lateral movements causing embankment to settle

Soft clay. Embankment behavior

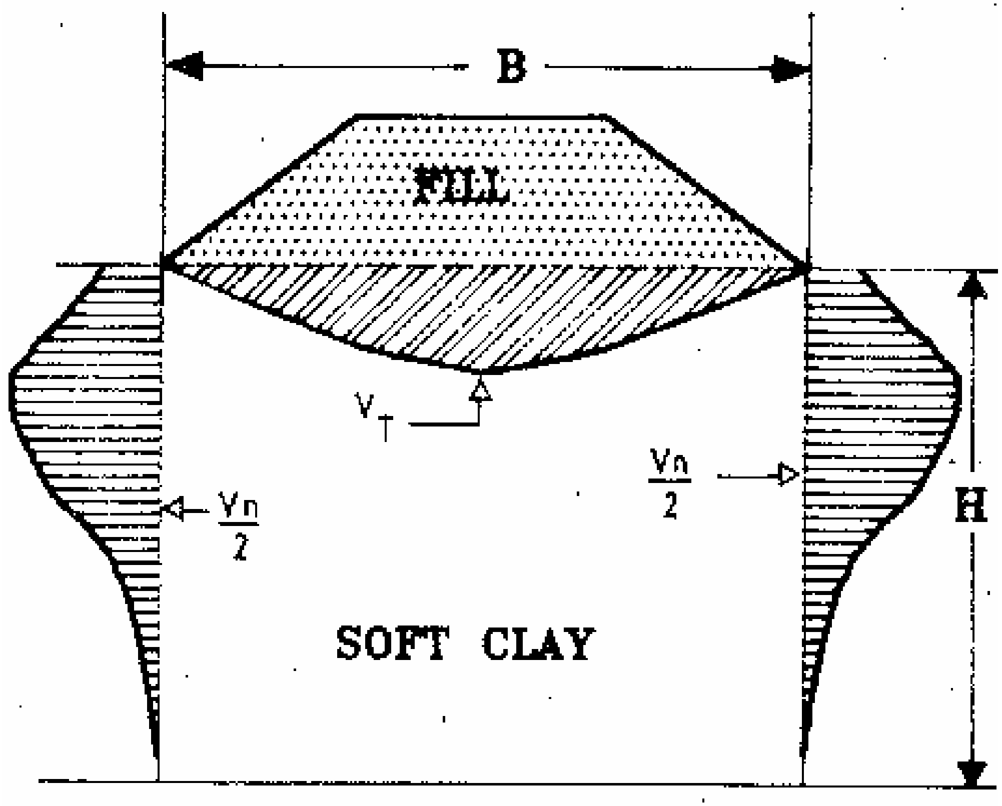


Fig. 29 Volumes Definitions

Soft clay. Embankment behavior

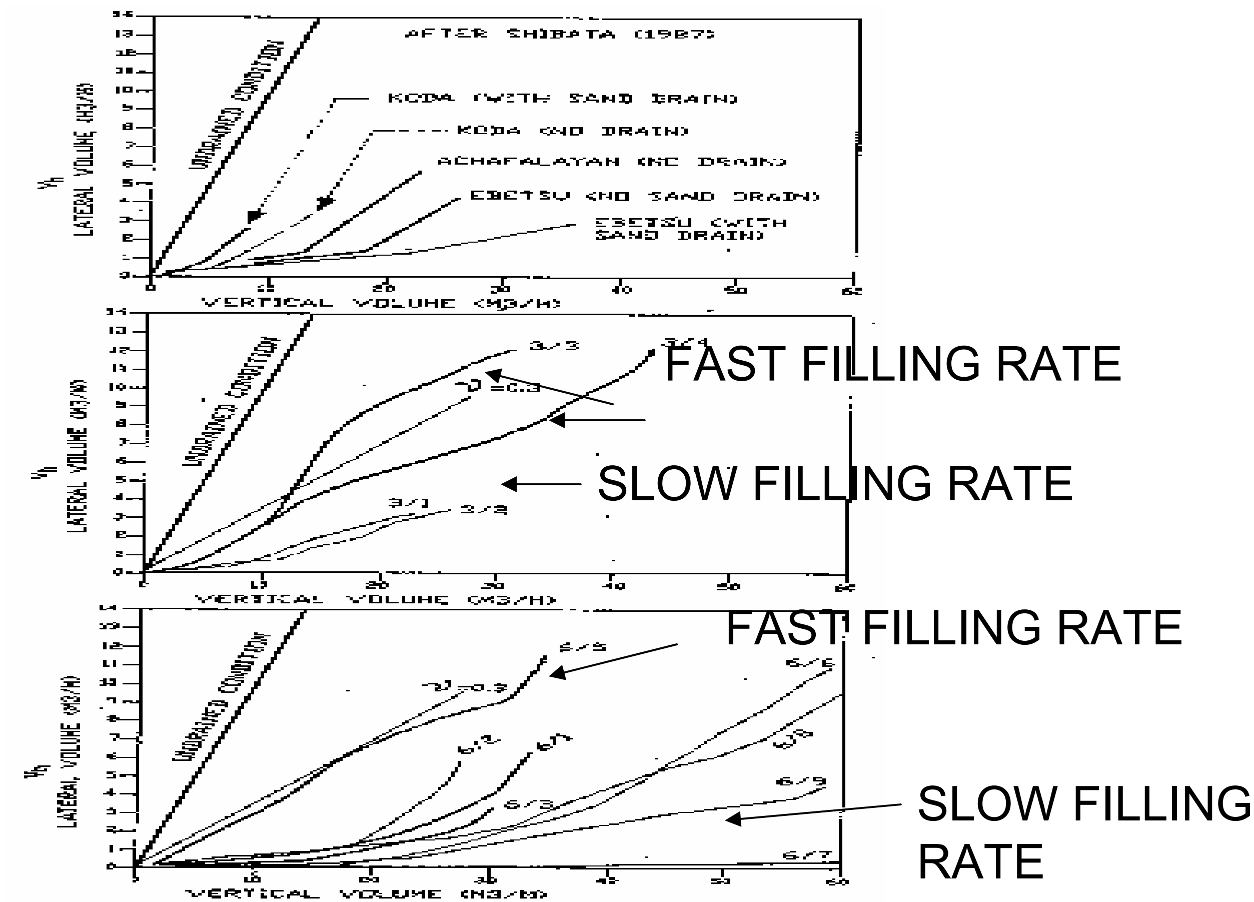


Fig. 10. LATERAL – VERTICAL VOL.

Soft clay. Embankment behavior

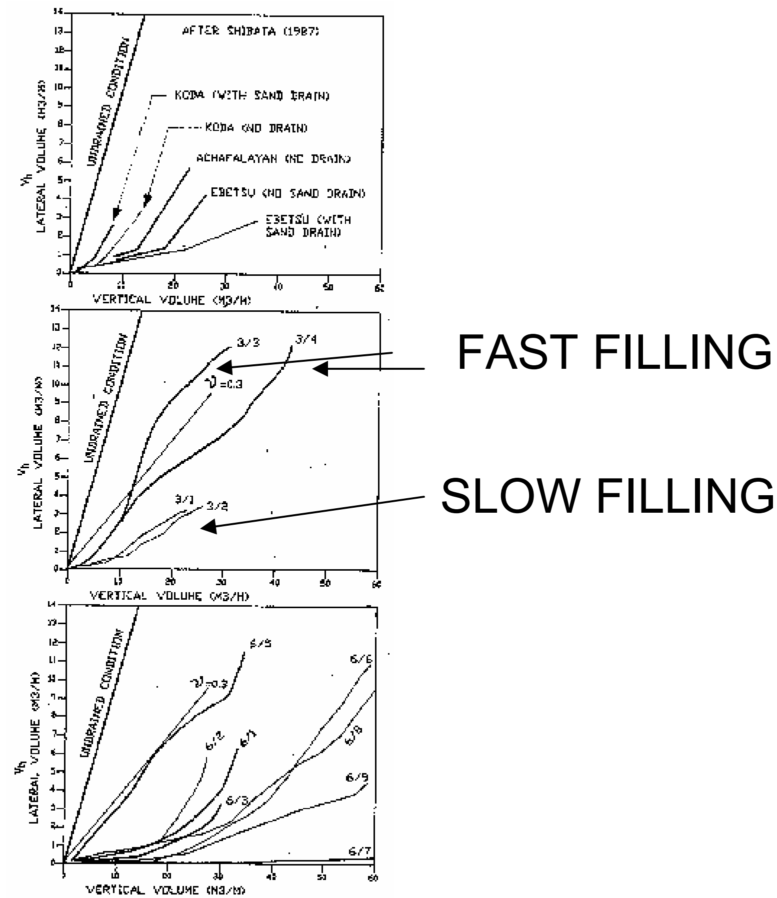


Fig. 10. LATERAL - VERTICAL VOL.

EMBANKMENT FILLING RATE

- SLOW FILLING RATE RESULTS IN LARGER CONSOLIDATION AND LESS LATERAL MOVEMENT
- FASTER FILLING RESULTS IN HIGHER PORE PRESSURES, HIGHER LATERAL MOVEMENTS AND LOW DEGREE OF CONSOLIDATION

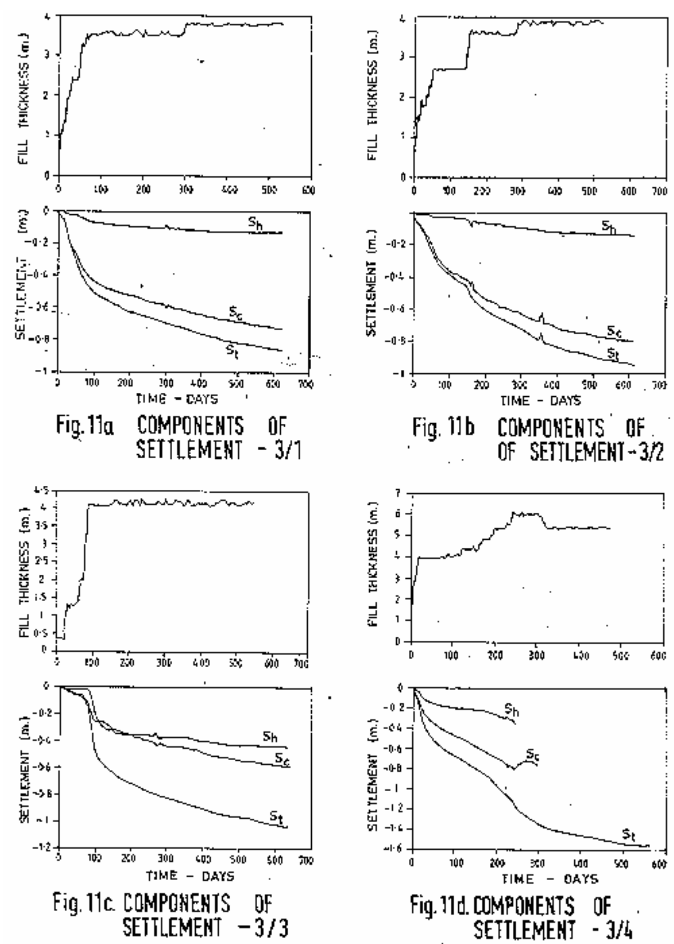
EMBANKMENT FILLING RATE

- FAST RATE OF FILLING CAN LEAD TO TENSION CRACKS
- PREFER TO KEEP FILLING RATE TO LESS THAN 500 MM (TWO LAYERS A WEEK) IF NO STONE COLUMNS

Soft clay. Embankment behavior

SLOW FILLING
HIGH DEGREE
OF CONSOLIDATION
LOW SH HIGH SC

FAST FILLING
LOW DEGREE
CONSOLIDATION
HIGH SH
LOWER SC



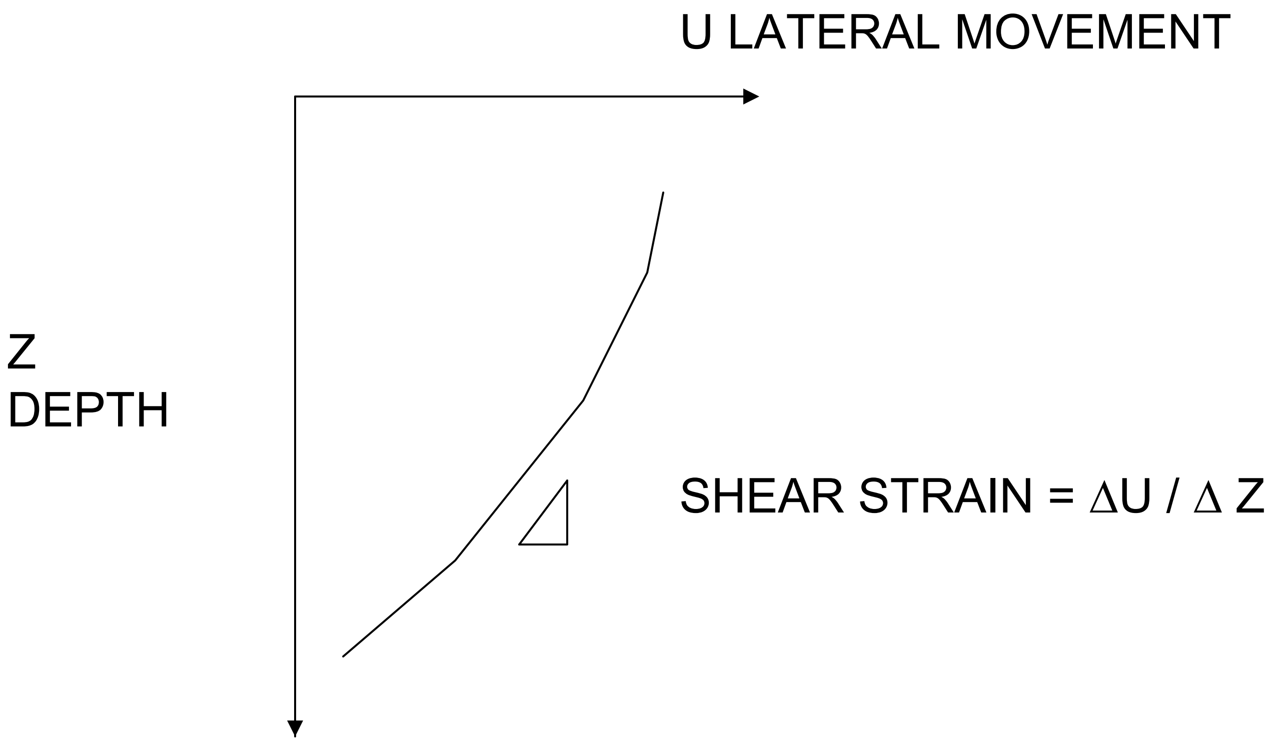
SH = LATERAL COMPONENT

ST = TOTAL SETTLEMENT

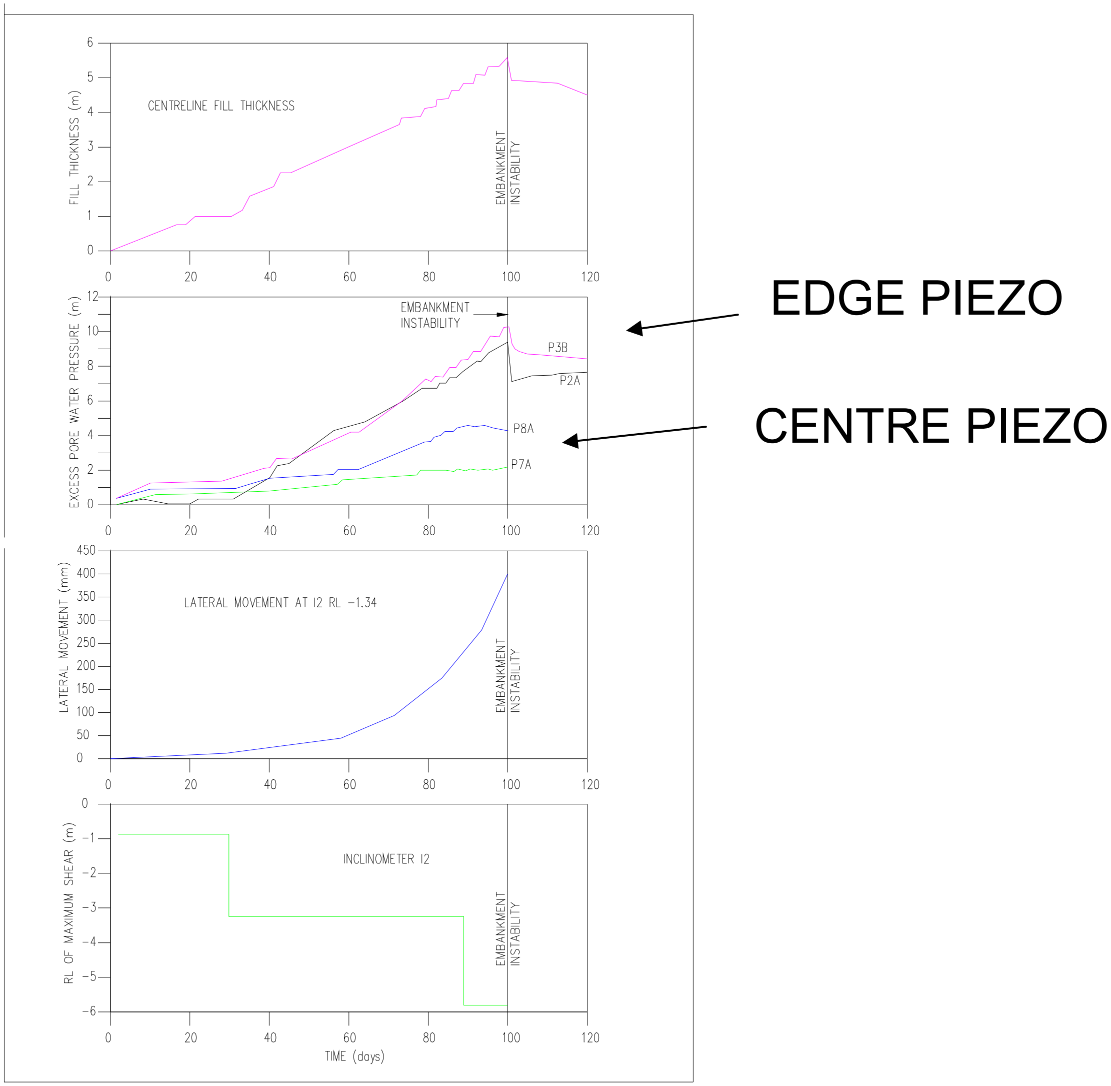
SC = CONSOLIDATION COMPONENT

SC = ST - SH

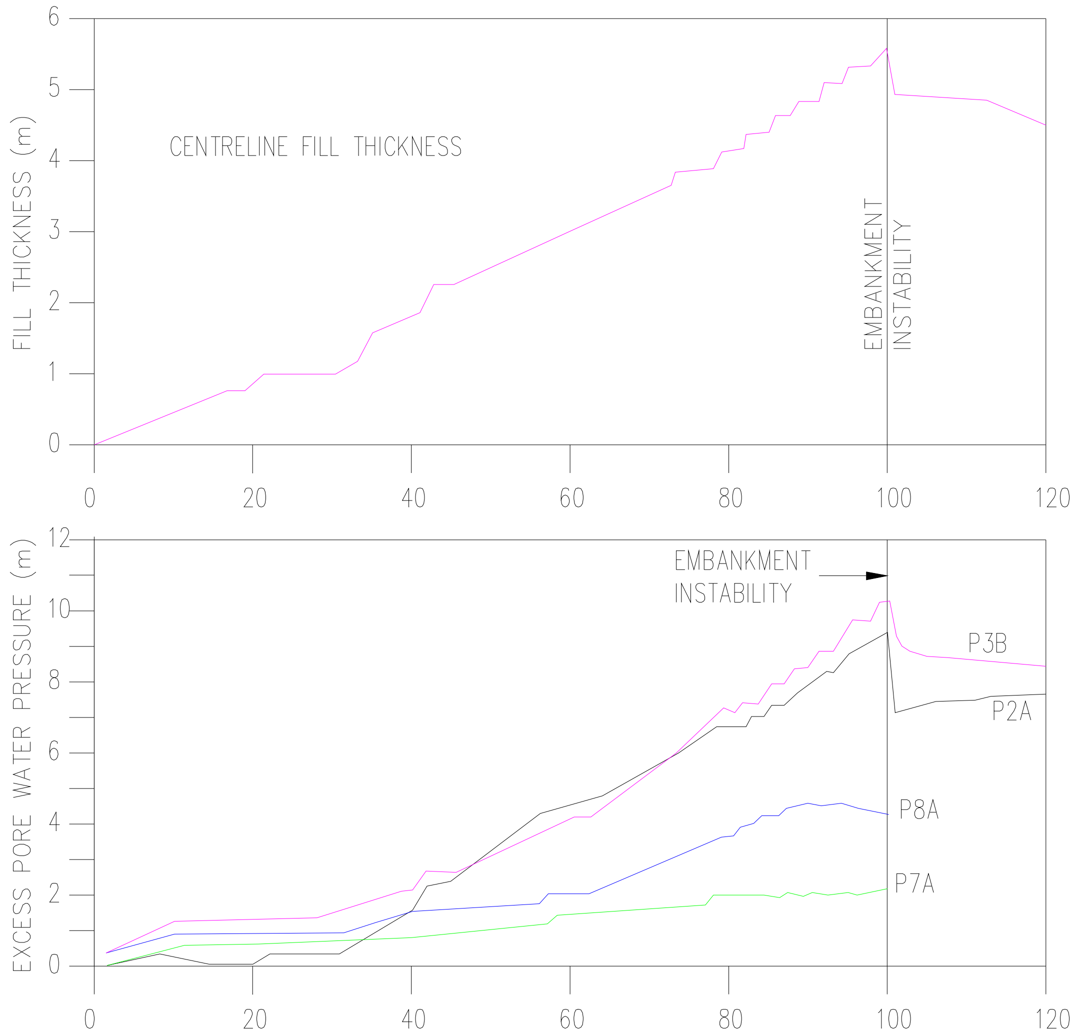
INCLINOMETER



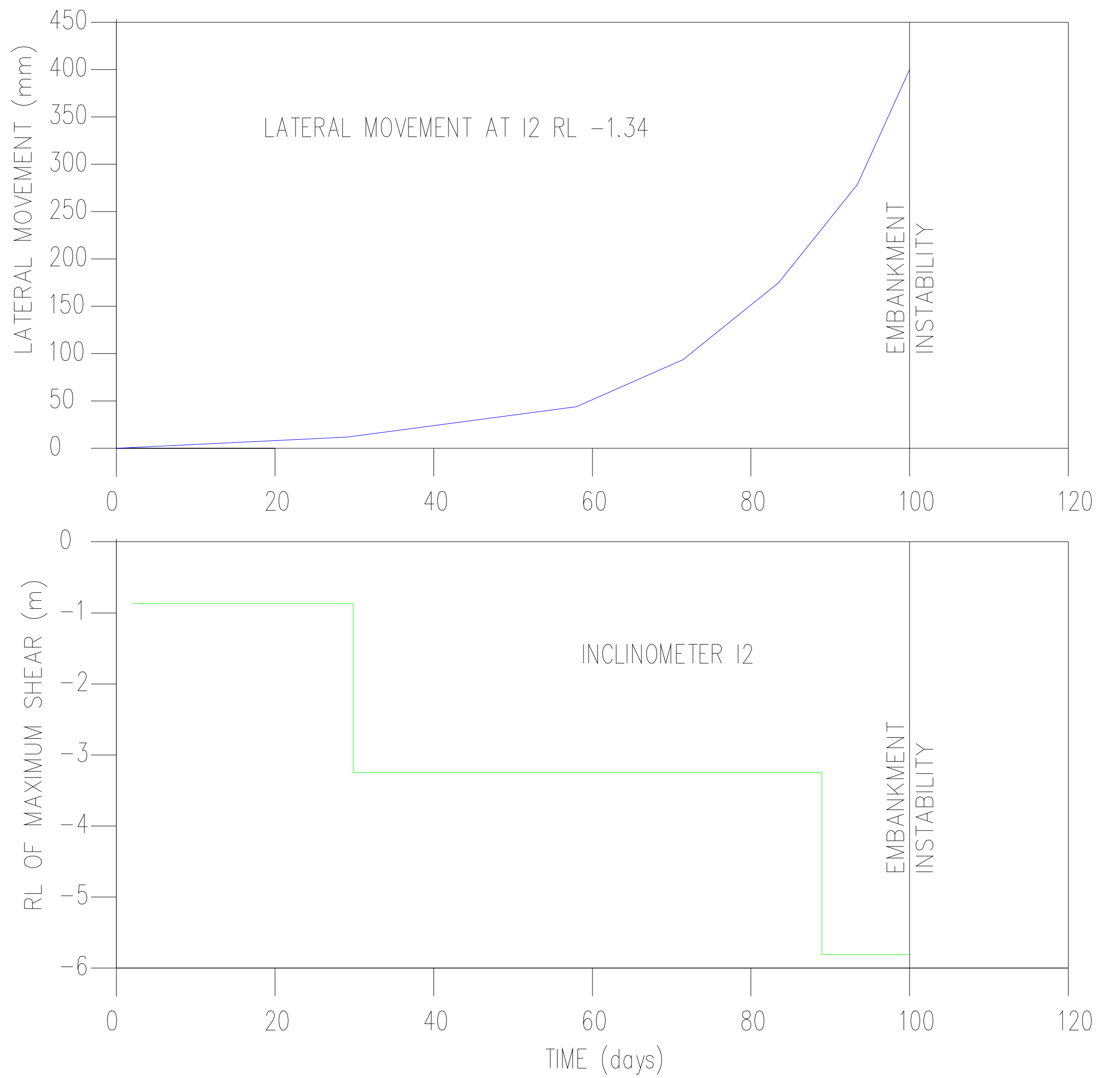
Soft clay. Embankment behavior up to failure



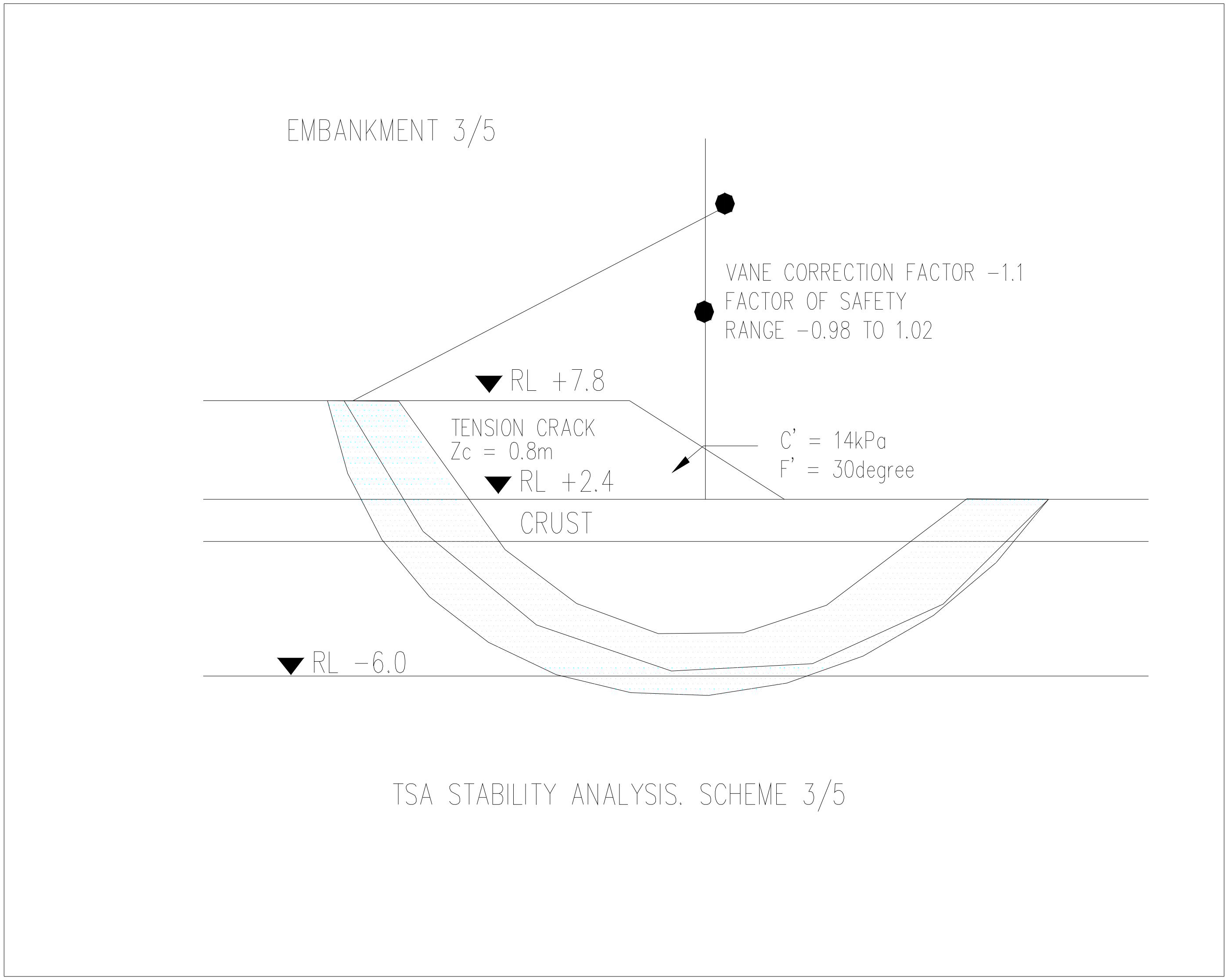
Soft clay. Embankment behavior up to failure



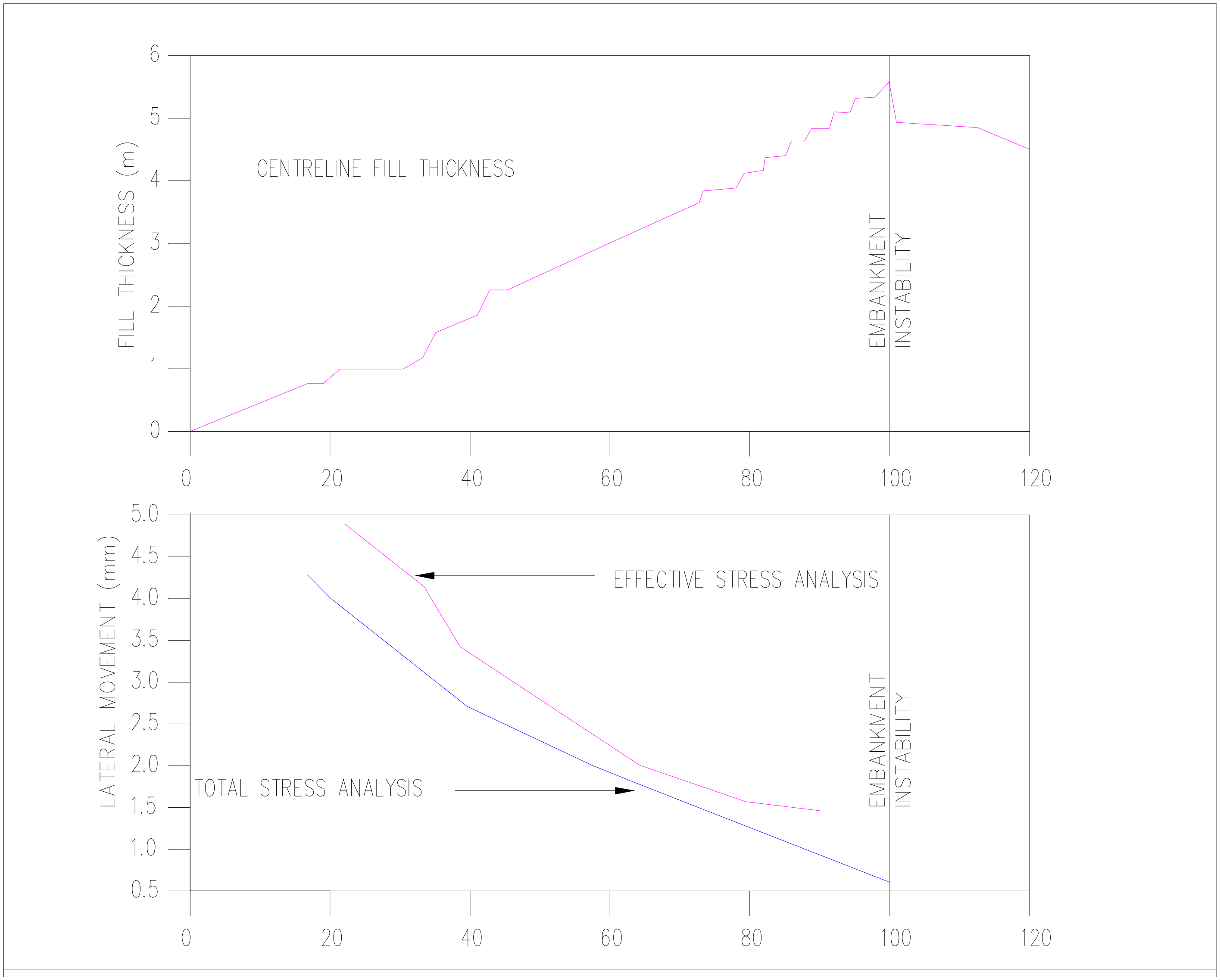
Soft clay. Embankment behavior up to failure



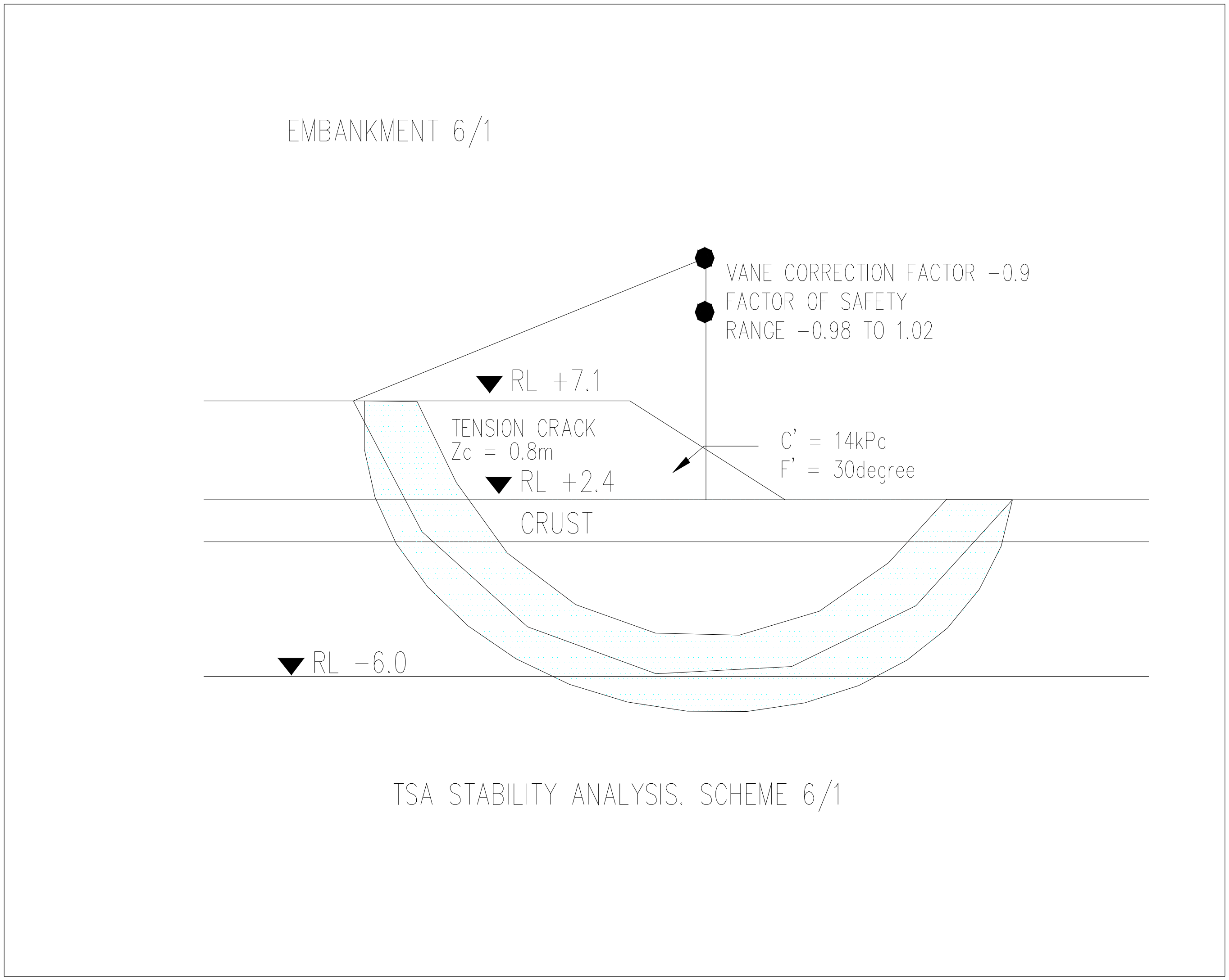
Soft clay. Stability back analysis



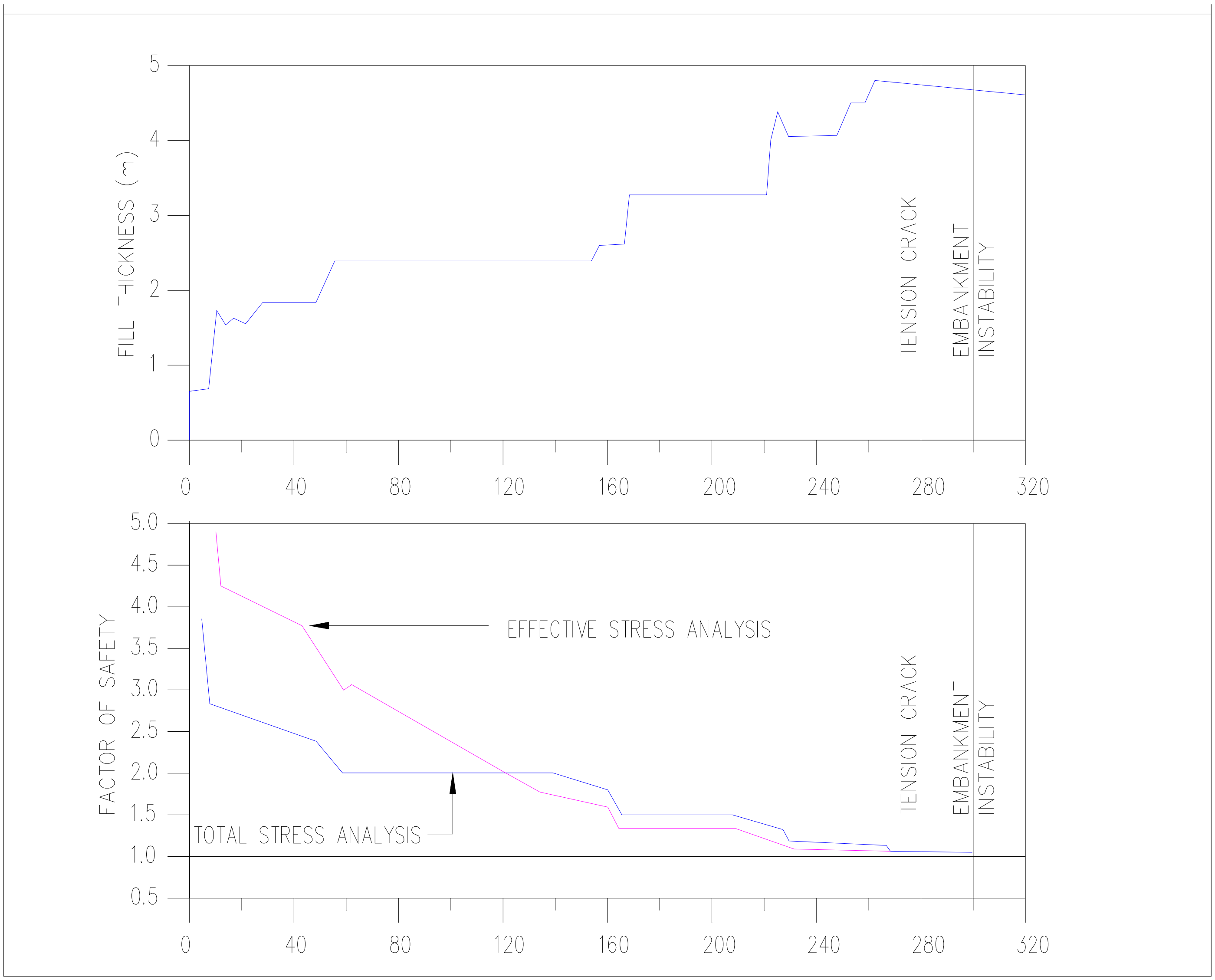
Soft clay. Embankment behavior up to failure



Soft Clay. Stability. Backanalysis



Soft clay. Stability back analysis



GAIN IN STRENGTH

- Yes if there is consolidation;

- Lesser if there has been larger lateral movements (Sh high) and lower degree of consolidation (Sc low)

Soft clay. Embankment behavior
GAIN IN STRENGTH

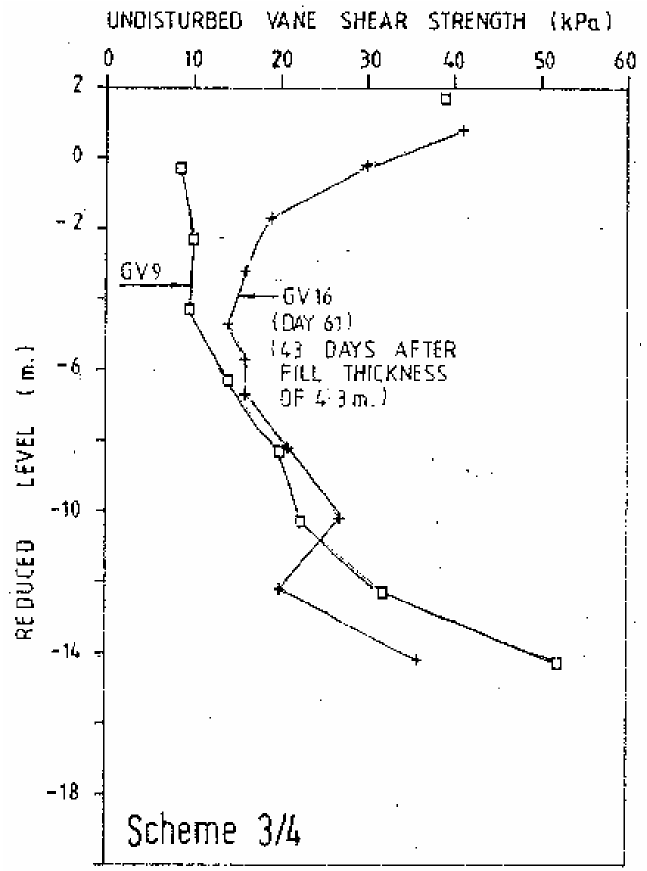


Fig. 7b GAIN IN STRENGTH

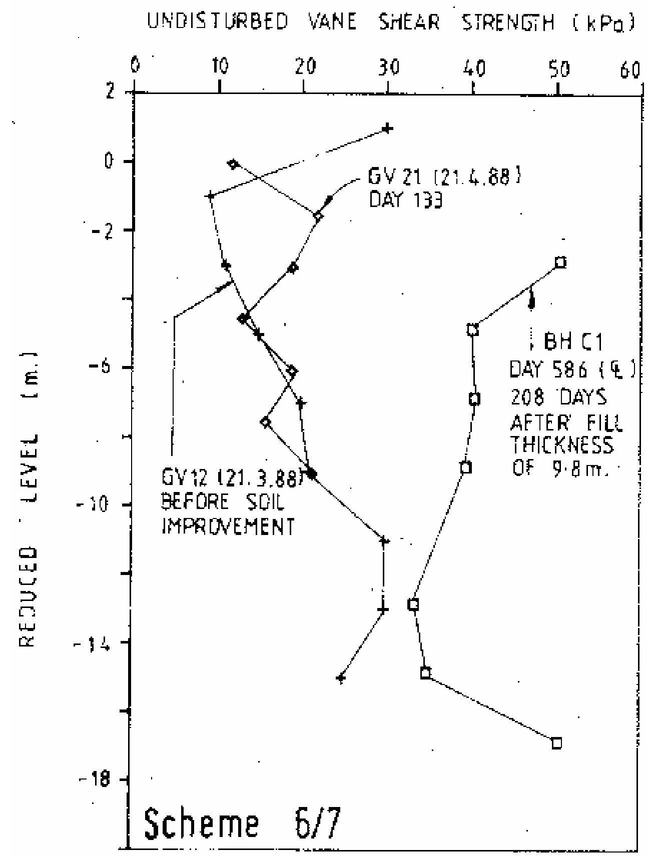


Fig. 7c GAIN IN STRENGTH

Soft clay. Embankment behavior
GAIN IN STRENGTH

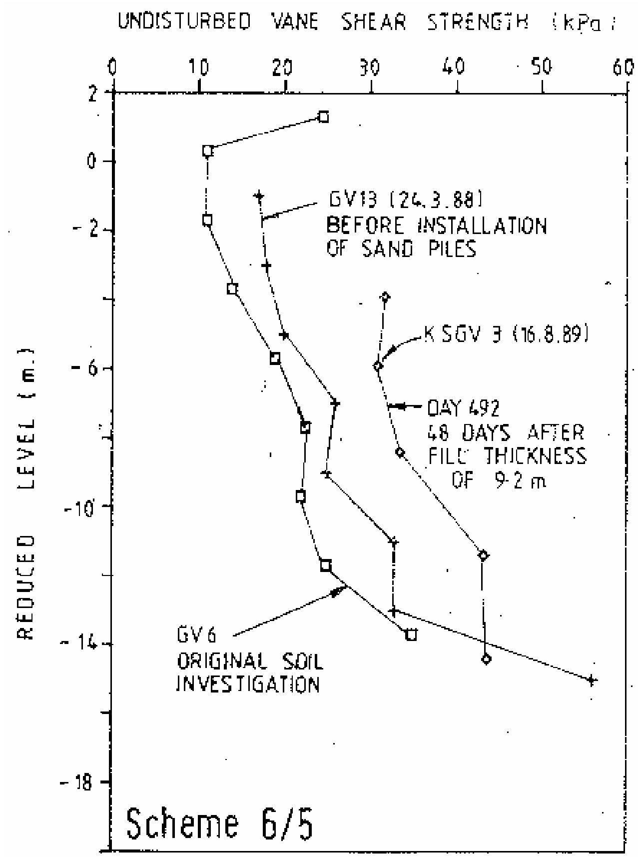


Fig. 7d GAIN IN STRENGTH

COMMON METHODS OF SOFT CLAY TREATMENT

- Surcharge without prefabricated vertical drains
- Surcharge with prefabricated vertical drains
- Stone columns
- Pile embankments

SURCHARGE WITHOUT PVD

- Just build embankment to a height higher than the final height and allow the embankment to settle until an acceptable post construction settlement.

- Consolidation settlement analysis as discussed earlier

SURCHARGE WITH PVD

- Use prefabricated vertical drains to accelerate consolidation settlement and reduce surcharge time.

HANSBO EQUATION FOR PVD

$t = (D_e^2 / 8C_h) \times \mu \times z\,(1/(1 - U_h))$

$\mu = \ln(n/s) - 0.75 + (k_c / k_c')\ln(s) + nz(2 - z)k_c/q_v$

D_e = equivalent drain diameter = 0.05

S = smear zone ratio = D_s / D_e = 4

n = drain spacing ratio = D_w / D_e

D_w = 1.128 x spacing of drain

HANSBO EQUATION FOR PVD

k_c = permeability of soil

k_c' = permeability of disturbed zone

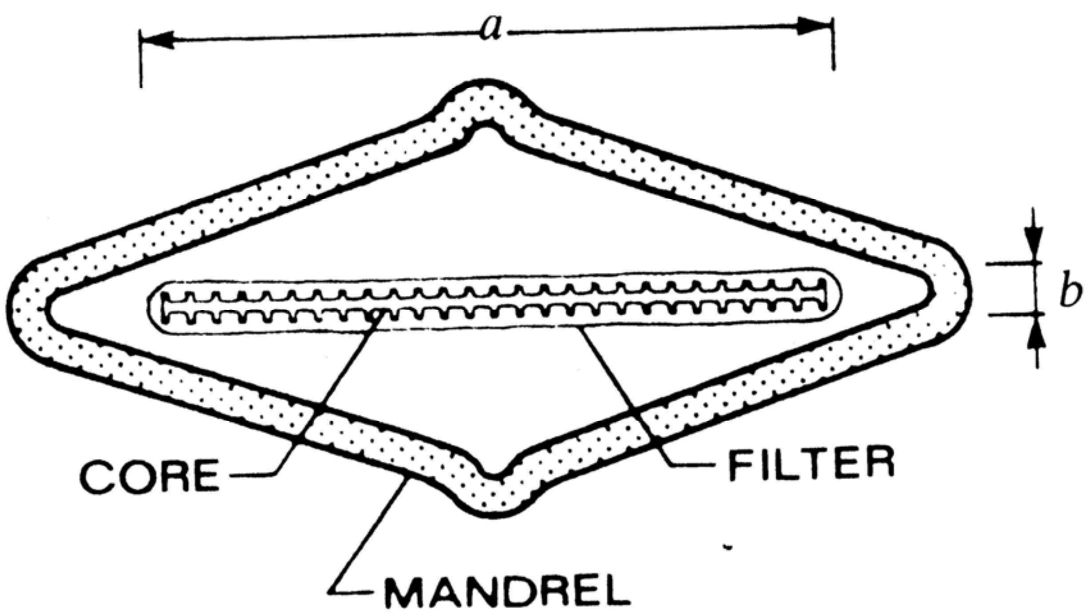
$k_c / k_c' = 3$

z = depth from open end

q_v = discharge capacity of drain

Hansbo's equation takes into account smear effects and limited discharge capacity of the drain

Cross section mandrel with pvd



$$d_w = [2(a + b)]/\pi$$

Installation of pvd with mandrel

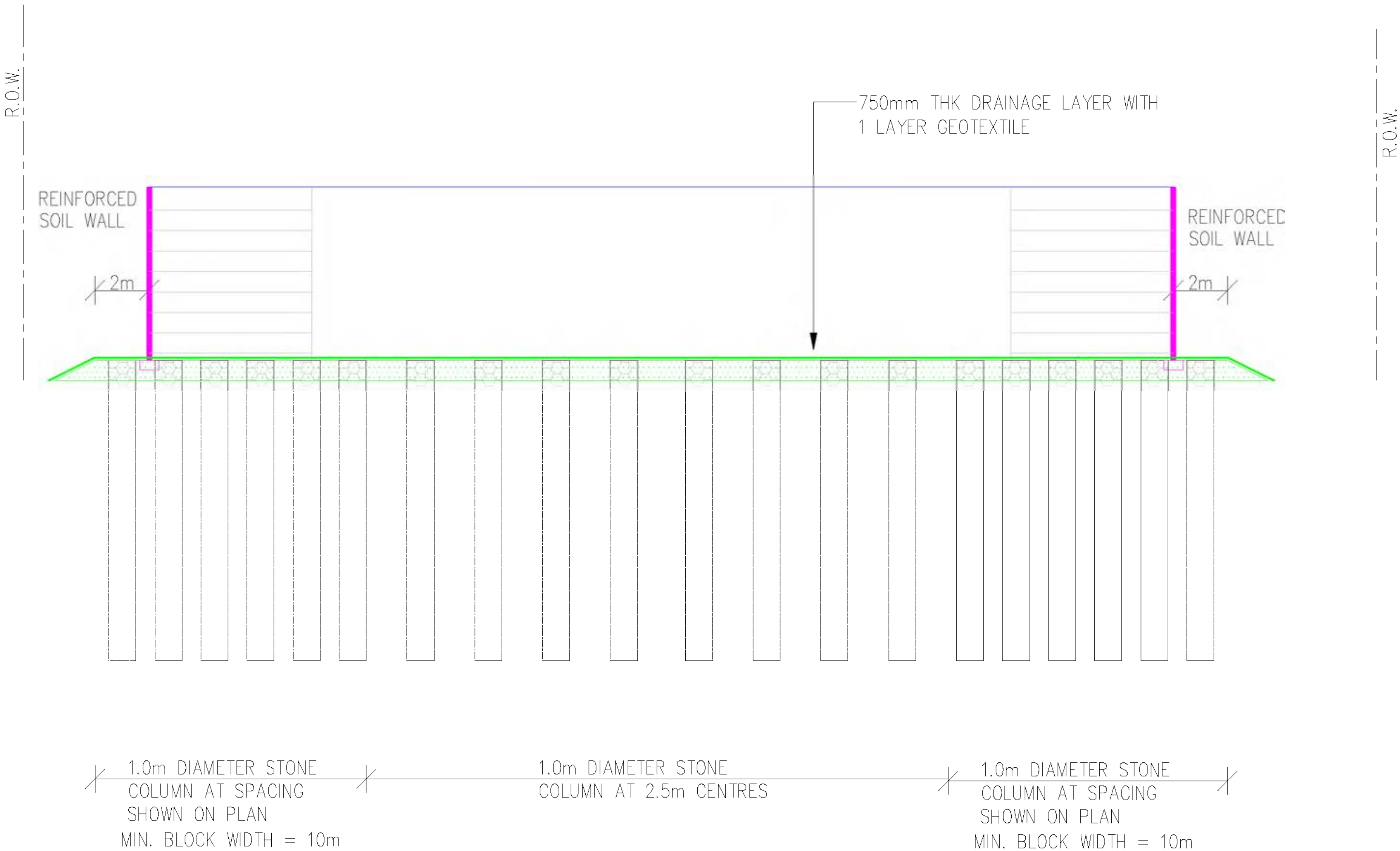
Installation of pvd

Completed pvd installation

STONE COLUMNS

STONE COLUMNS

- Adopted to stabilize the soft clays and loose sands to support the highway embankments and retaining walls.
- To ensure that adequate factor of safety against stability
- To minimize post construction settlement



STONE COLUMN TREATMENT

STONE COLUMNS

- Developed by KELLER in 1957
- Method of constructing columns of compacted stones through weak cohesive soils by use of deep vibrators

STONE COLUMNS

- Improvement in stiffness of the sub soil serves to decrease settlement
- Rapid consolidation of the sub soil – acts as very large vertical drains
- Improvement in the shear strength of the sub soil thereby improvement bearing capacity and overall stability of embankments
- Capacity depends on confining pressure due to embankment weight and therefore can carry high loads
- Densification of loose silts to mitigate potential for liquefaction due to vibratory loads

STONE COLUMNS

- Usually 800 mm to 1000 mm diameter
- Usual stone column spacing between 1.5 m and 2.5 m centers
- Depth usually between 6 m and 20 m

CONSTRUCTION OF STONE COLUMNS

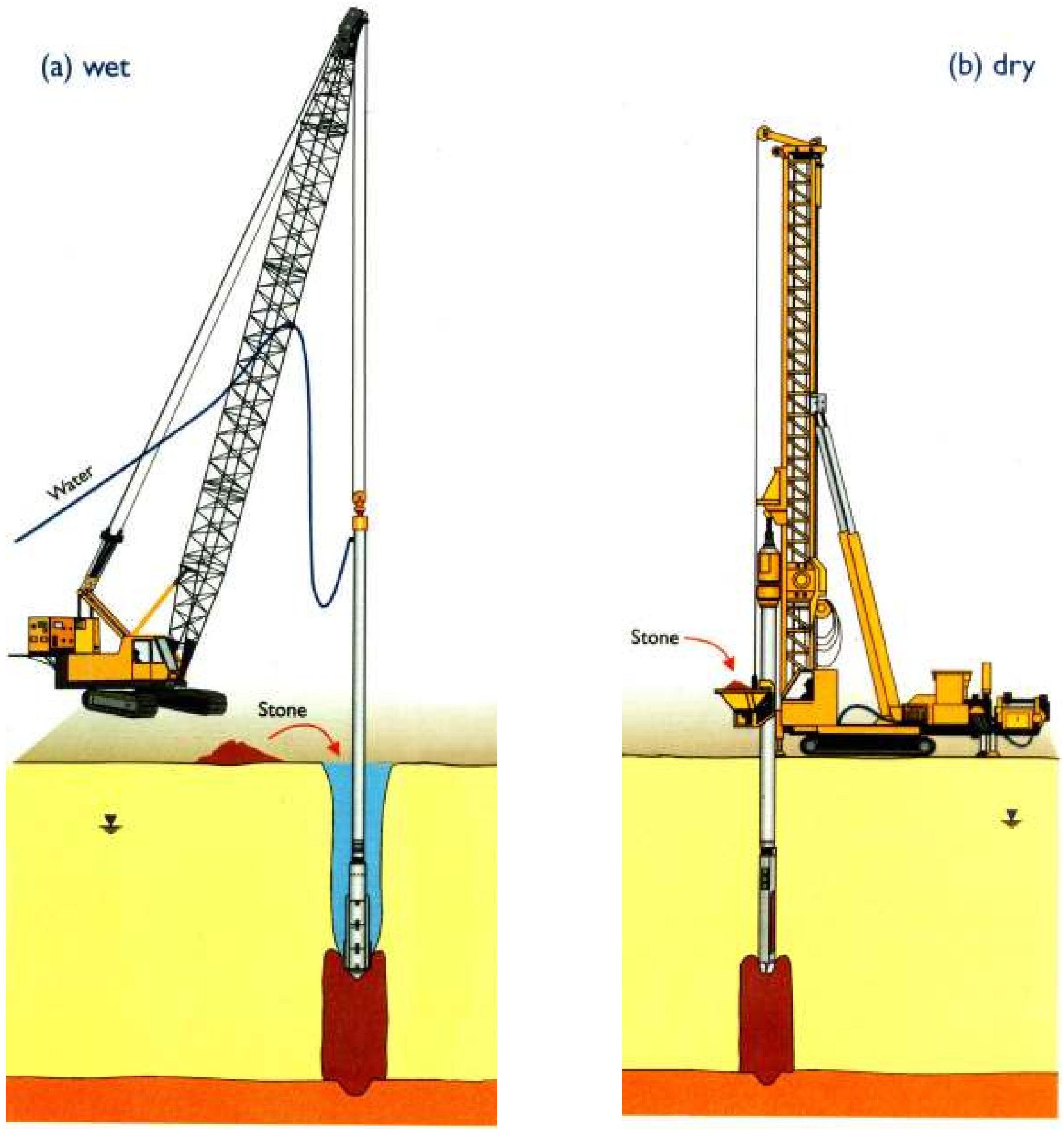
- Vibrator to penetrate to design depth
- Penetration by jacking – in (dry method) or by flushing – in with water (wet method),
- Fill the resulting cavity with clean, hard, inert stones.
- Necessary for the stone fill to be introduced and compacted in stages.
- Each charge of stones to be thoroughly compacted.

WET and DRY METHODS

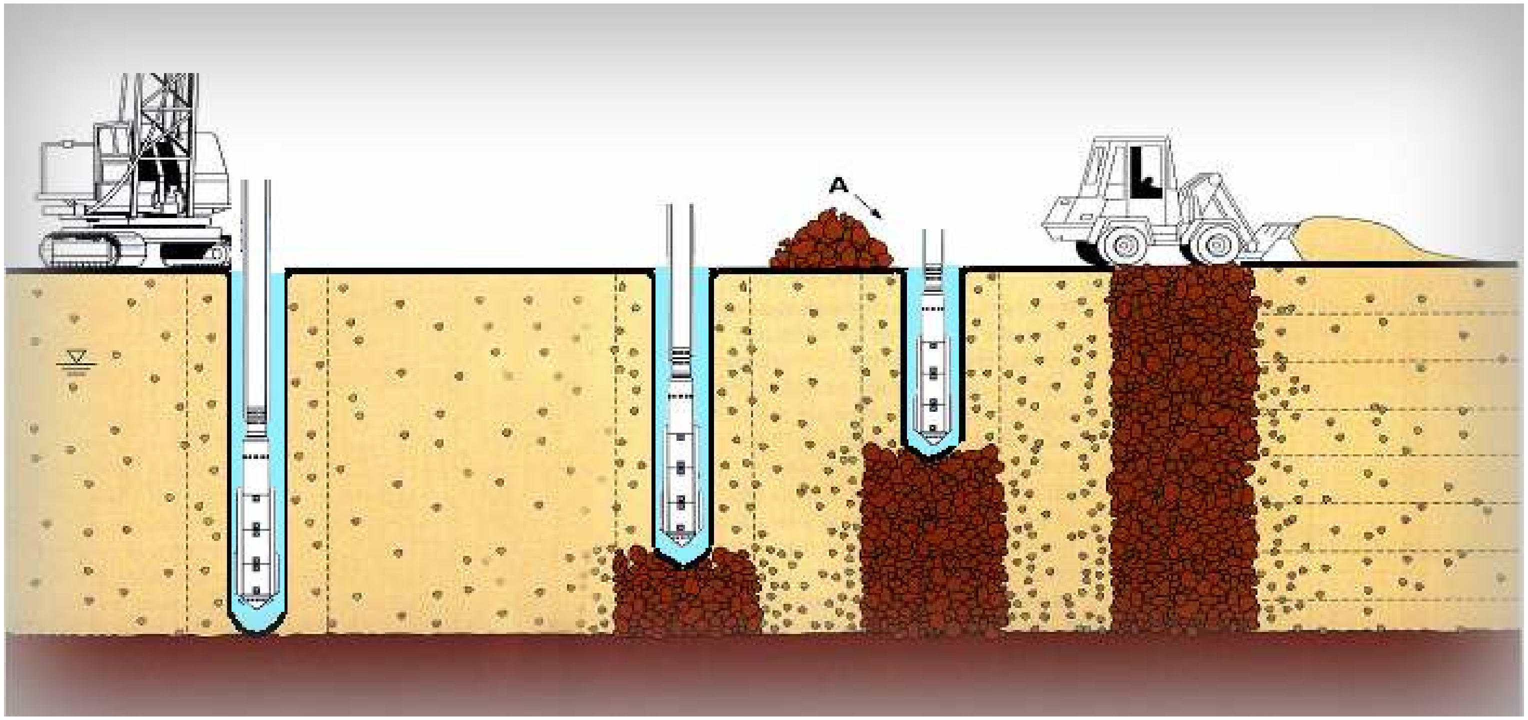
Two methods of forming stone columns:

- WET method where water is used to flush out soils and stones fed into the hole – VIBRO REPLACEMENT
- DRY method where mandrel is jacked into the ground and stones fed through mandrel – VIBRO- DISPLACEMENT

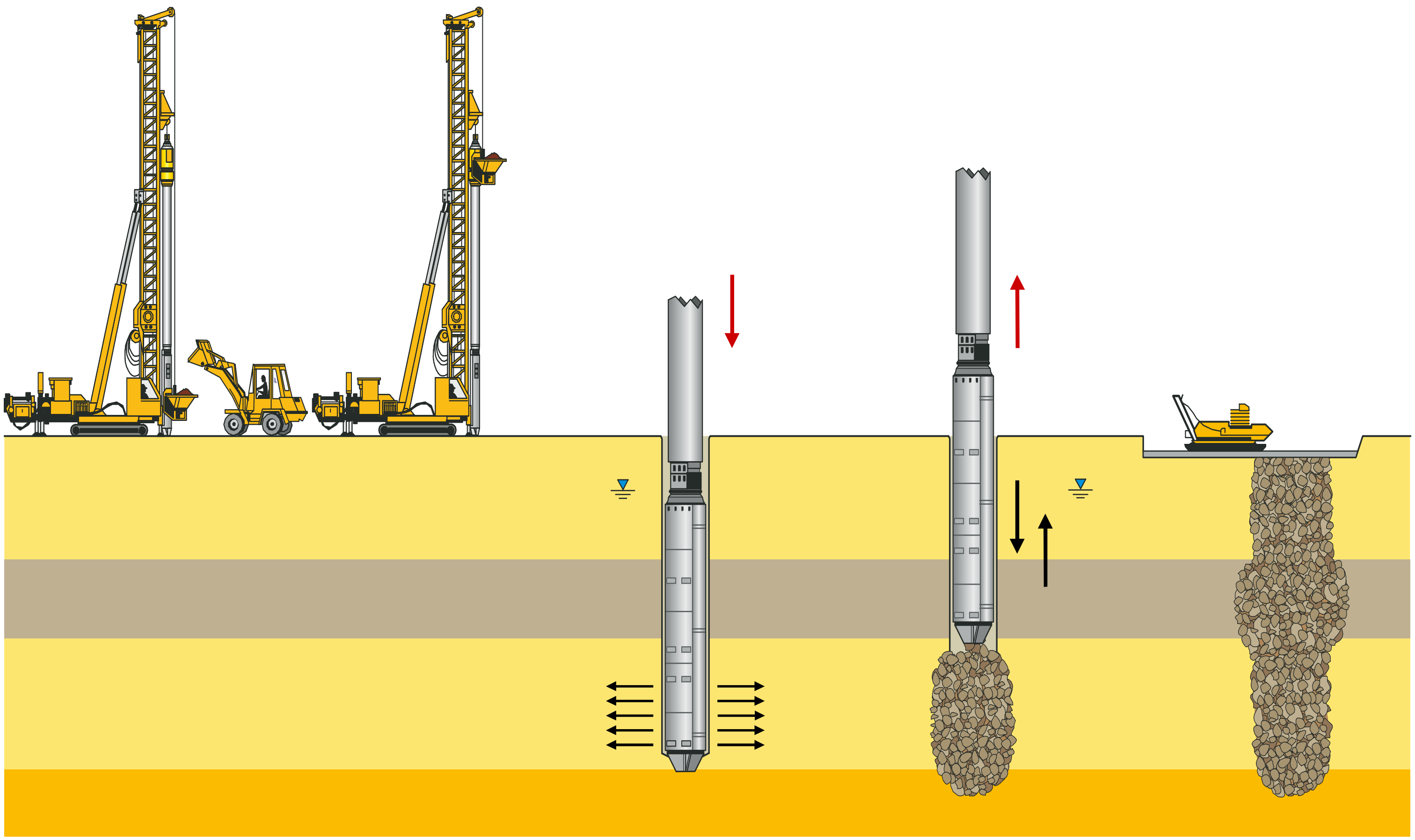
Stone Column Installation Method



Column Installation - Wet



Column Installation - Dry



Differences between dry and wet method

DRY METHOD

- Vibro displacement method
- Soil is displaced due to penetration of the vibrator – mandrel
- Ground heave of 500 to 1000 mm will occur
- Displacement can cause lateral movement affecting nearby structures and infrastructures
- No need for silt traps and sedimentation ponds to limit suspended solids for discharge to streams
- Ideal for urban conditions
- Require customized equipment

Differences between dry and wet methods

WET METHOD

- Vibro – replacement method
- Soft soils replaced – washed out by the velocity and constant flow of water
- Water stabilized the bore hole and stones fed in
- Sand cannot be used as sand will be washed out. Therefore cannot form sand columns
- Soil flushed out in liquid sate will have to be directed to sedimentation ponds – sometimes more than one to ensure compliance with DOE's suspended solids requirements

Dry method and wet methods

Placing stones into hopper – dry method

Placing stones into hopper – dry method

Compacting to form stone columns

Wet method equipment

Forming stone columns wet method

Compacting stones wet method

1.0 m diameter stone column

Load testing stone columns

Soft Clay Embankment Treatment

Case History 1: Bandar Semariang

Case History 2: Pulau Indah railway

Case History 2: Gurun Reinforced Soil wall

Case History 3: Putrajaya Core Island

Case History 4; Johore Causeway

Case History 5; Light weight Tatau

Soft Clay. Case History 1.

Bandar Semariang

- Low lying area at RL 2.0m
- 13 to 24 m soft clay
- None to 4 layers of sand between soft clay layers
- Surcharge to limit post construction settlement less than 200 mm
- Low cost housing on flexible raft without piles

Soft Clay. Bandar Semariang

Soft clay properties

- NMC about 60 % top 8m
- NMC decreases with depth until 30 % at 20m
- PI = 40 % constant with depth
- LL = 70 to 80 % over top 10m. 60 to 65 % at greater depths
- Cc / (1 + eo) = 0.2 to 0.3
- Cr / (1 + eo) = 0.03 to 0.06
- Cv = 2 sq m / year mostly
- Cvr varies from 5 to 30 sq m per year

Bandar Semariang. Soft Clay

Condition	Depth	OCR
1	0 to 2m 2 to 8m > 8m	8 4 3
2	0 to 2m > 2m	8 2
3	0 to 2m > 2m	8 1.2
4	0 to 2m 2 to 8m	8 1.2

Bandar Semariang. Soft clay

Condition 1 will have least settlement

Condition 4 will have highest settlement

Soft Clay. Bandar Semariang

Surcharge procedure.

- Fill from RL 2.3 m (OGL) to RL 3.55 m rapidly
- Consolidate over 60 days
- Raise surcharge to RL 4.8 m
- Consolidate for 6 months
- Remove fill to RL 3.4 m
- Apply building loads of 10 kPa

Soft Clay. Bandar Semariang

Theoretical finite difference analysis.

- Soft clay thickness : 15 to 26 m
- Cvr = 5 to 30 sq m per year
- OCR Condition1
- Settlement at end of surcharge = 180 to 290 mm
- Post construction settlement = 70 to 120 mm
- Clay thickness will influence settlement only after 1 ½ years
- Heave immediately after removal surcharge. After 30 days settlement resumes

Soft clay. Bandar Semariang

Analysis also carried out for low OCR conditions and sand layers.

CASE 1. OCR = 8 at top 2m. OCR = 2 for depths > 2m. Cv = 1 sq m / yr. Cvr = 10 sq m / yr

CASE 2. OCR = 8 at top 2m. OCR = 1.6 for depths > 2m. Cv = 1 sq m / yr. Cvr = 10 sq m / yr

Soft clay. Bandar Semariang

Case	Settlement at end of surcharge (mm)	Post construction settlement at 20 years (mm)
1	365	15
2	405	35

Soft Clay. Bandar Semariang

Sand lenses cause settlement to occur quicker. Therefore settlement during surcharge higher. Long term settlement lower.

Soft clay. Bandar Semariang

Settlement measurements

Set 1. Similar to Condition1. High OCR. Cvr = 5 and 15 sq m per year

Set II. Similar to Condition1. High OCR. Cvr = 30 sq m per year

Set III. Similar to multiple sand lenses condition.

Soft Clay. Bandar Semariang

Surcharge area by area.

Successfully implemented.

Buildings constructed.

Soft Clay. Bandar Semariang. Cv

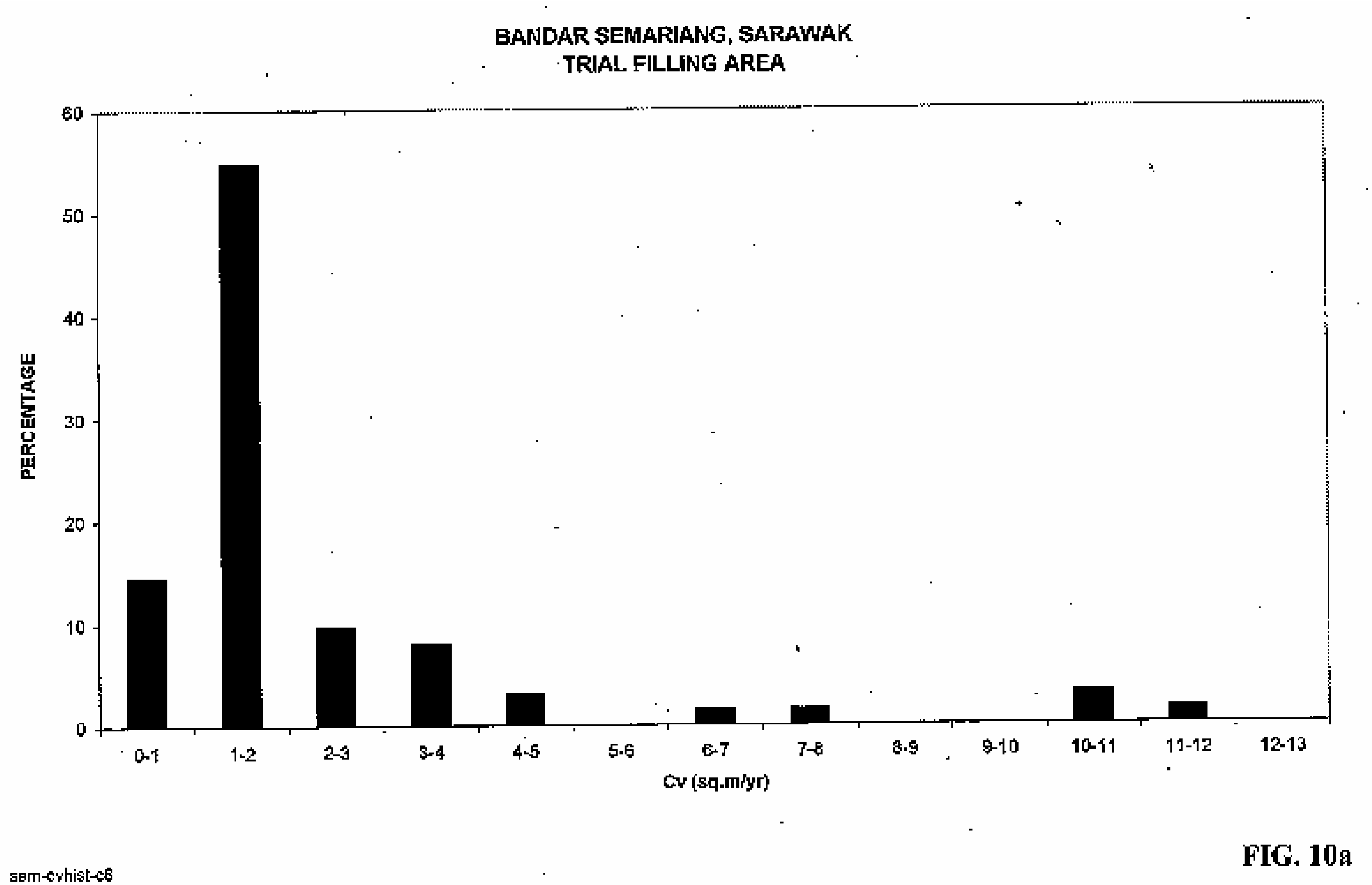


FIG. 10a

Soft clay. Bandar Semariang. Cvr

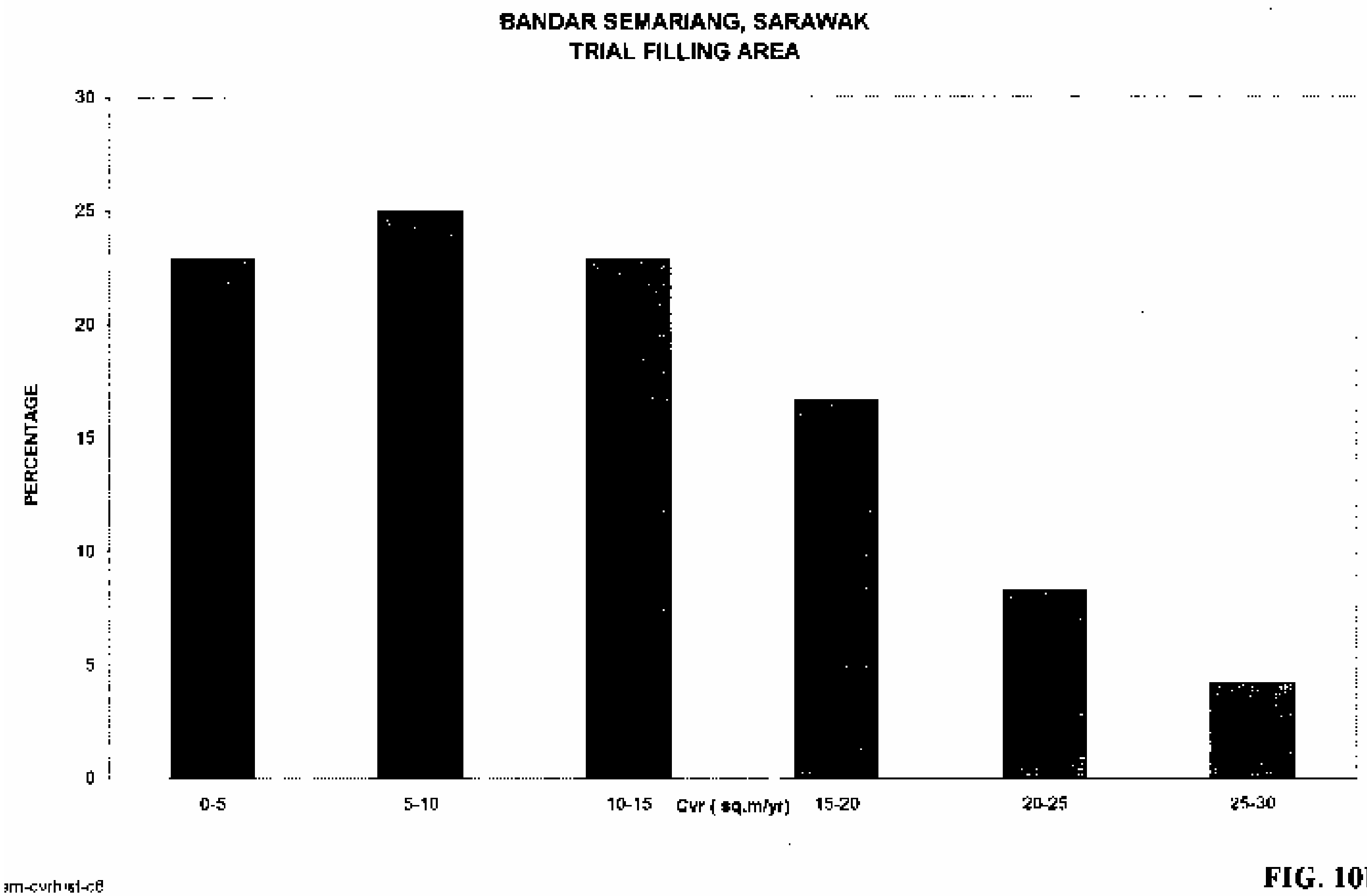


FIG. 10b

Soft Clay. Bandar Semariang. Vane shear strength

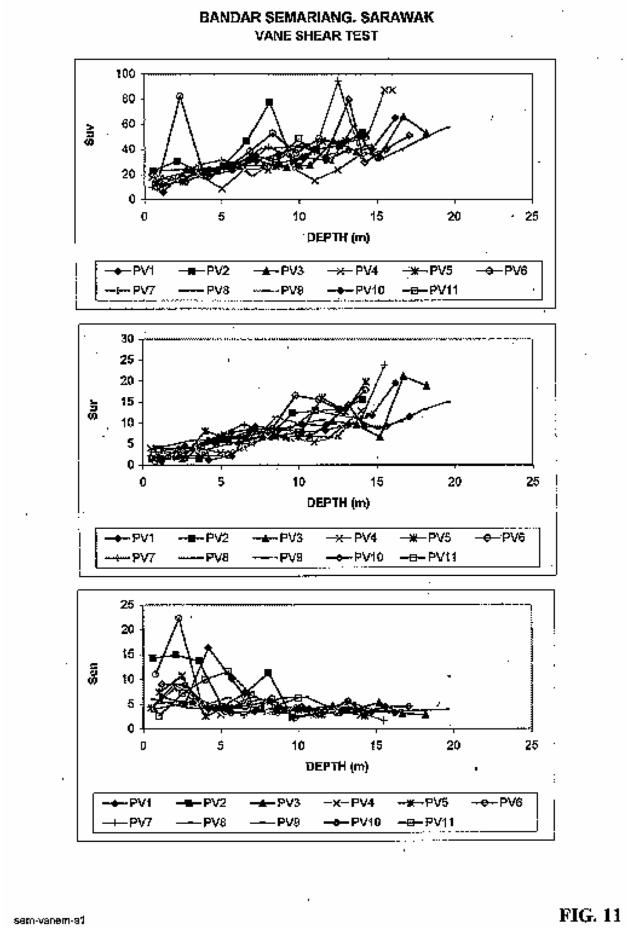


FIG. 11

Soft clay. Bandar Semariang. Settlement analysis

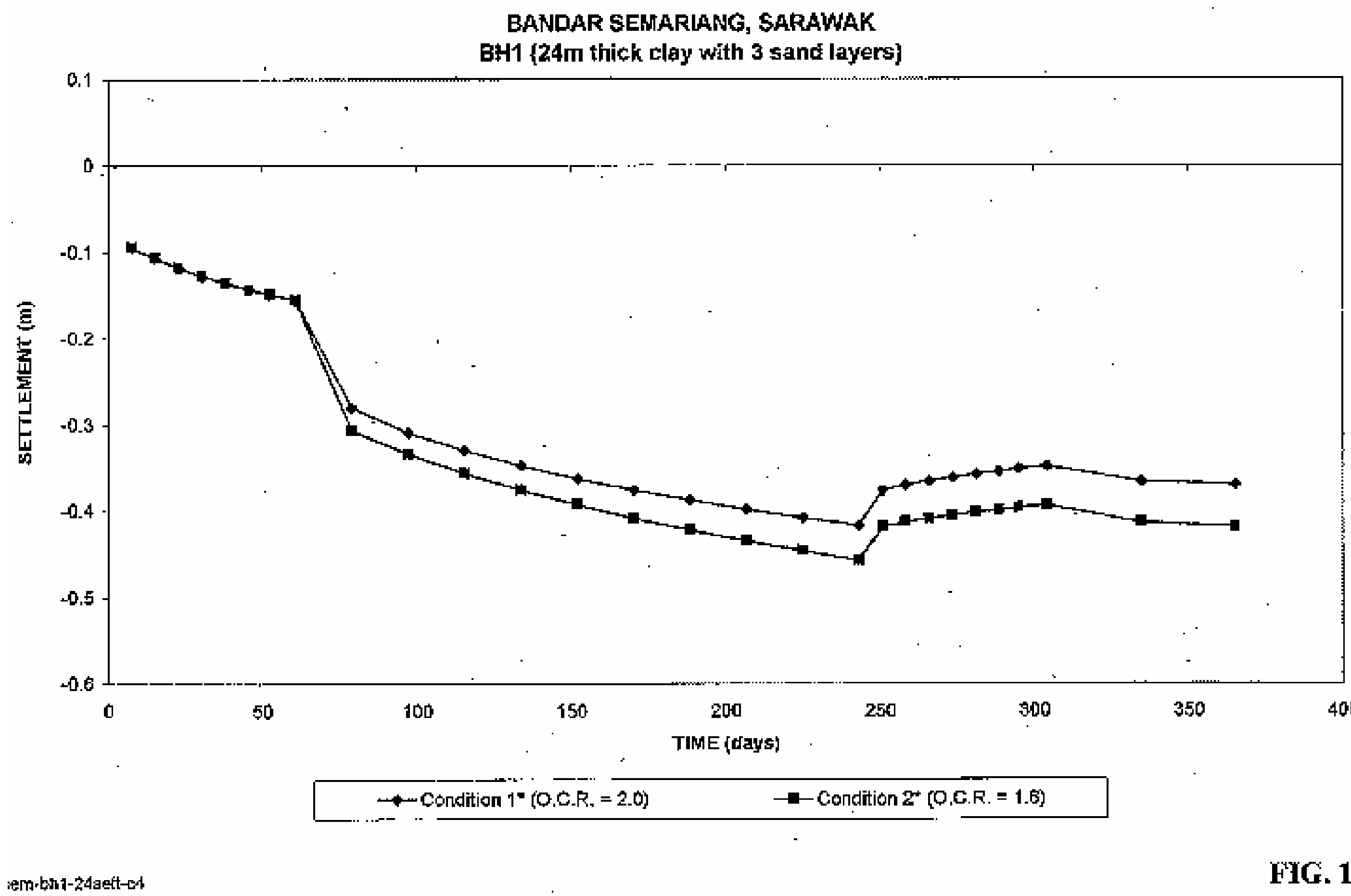


FIG. 16a

Soft Clay. Bandar Semariang. Settlement analysis

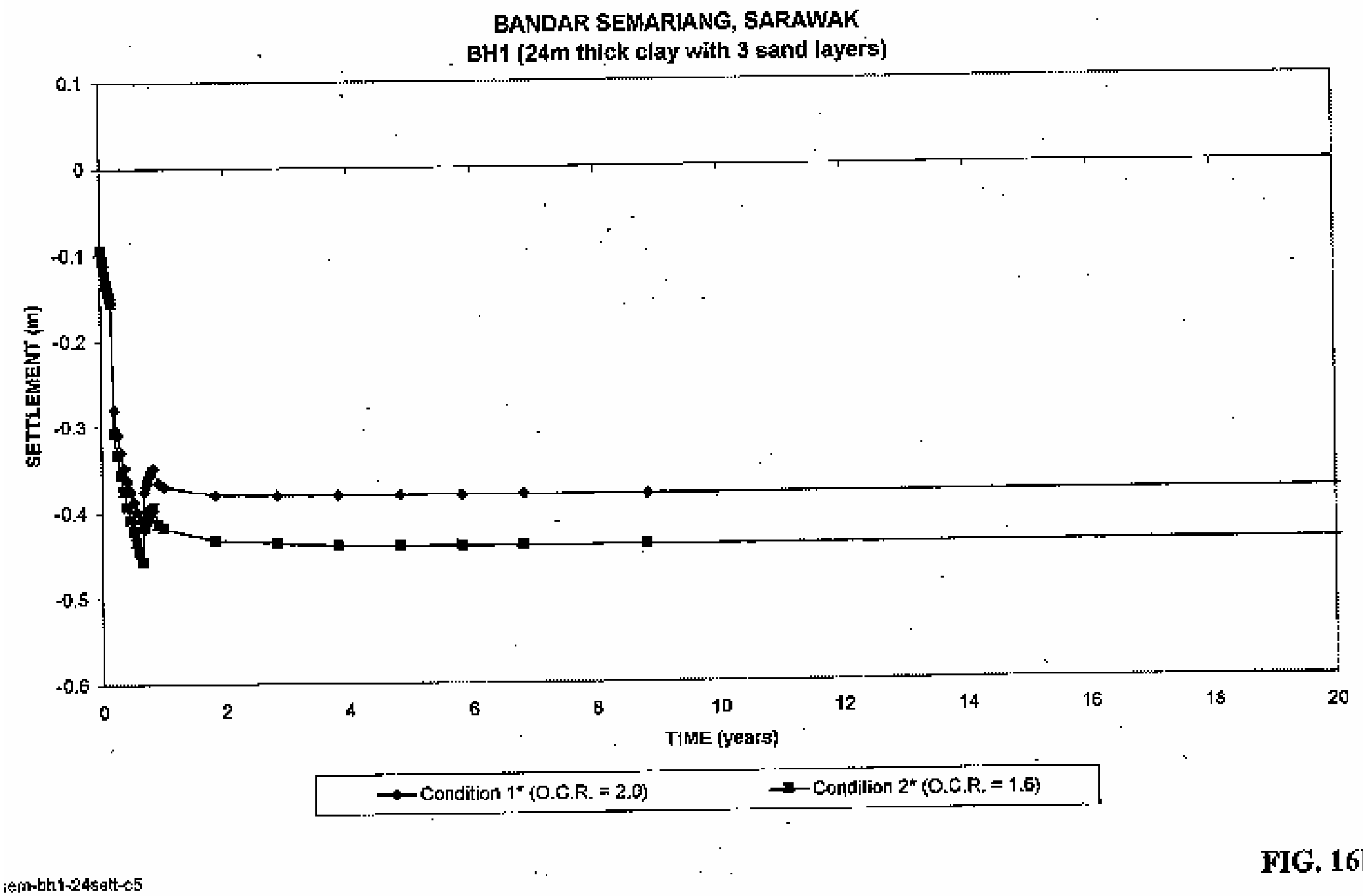


FIG. 16b

Soft clay. Bandar Semariang. Measured settlement

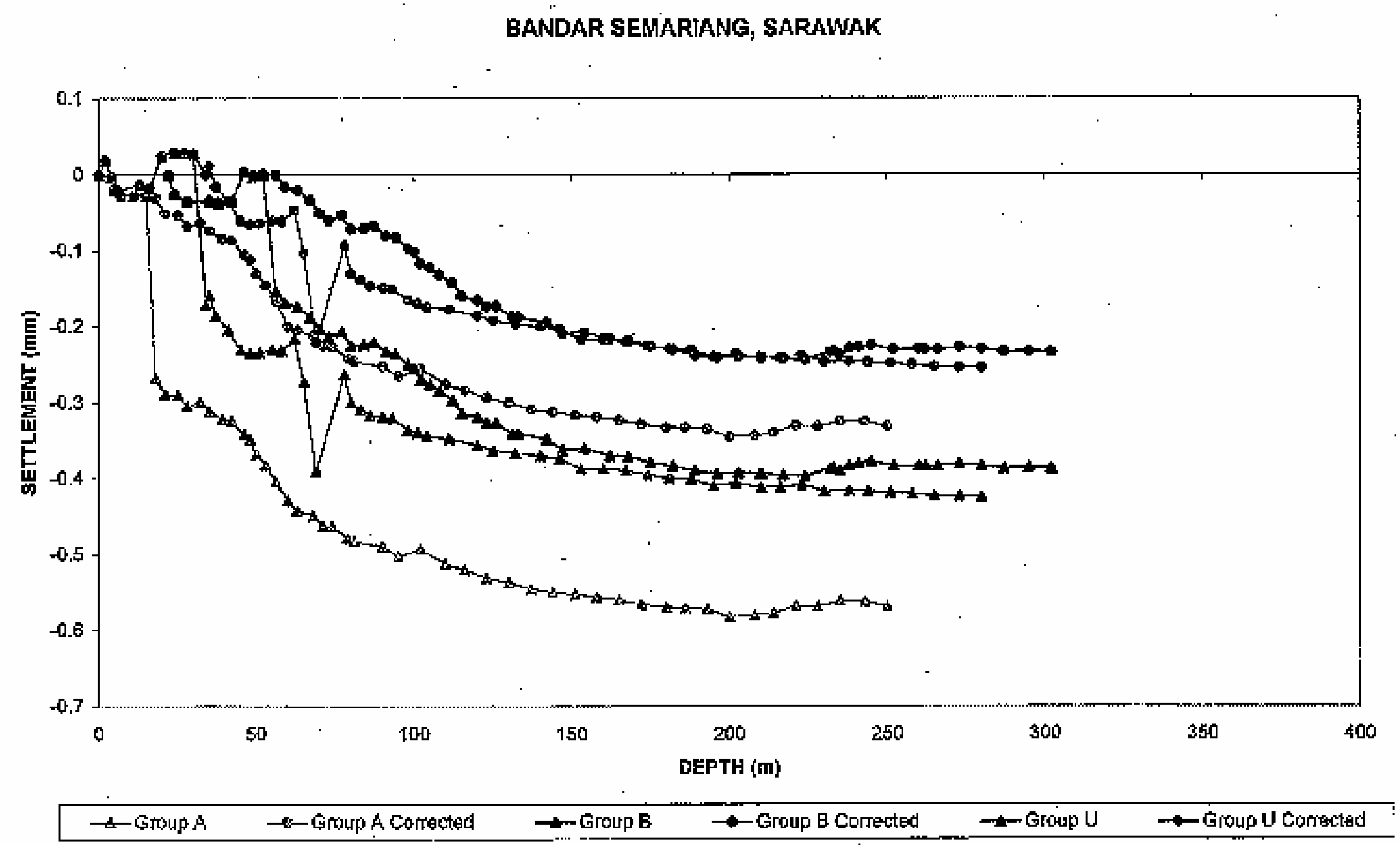
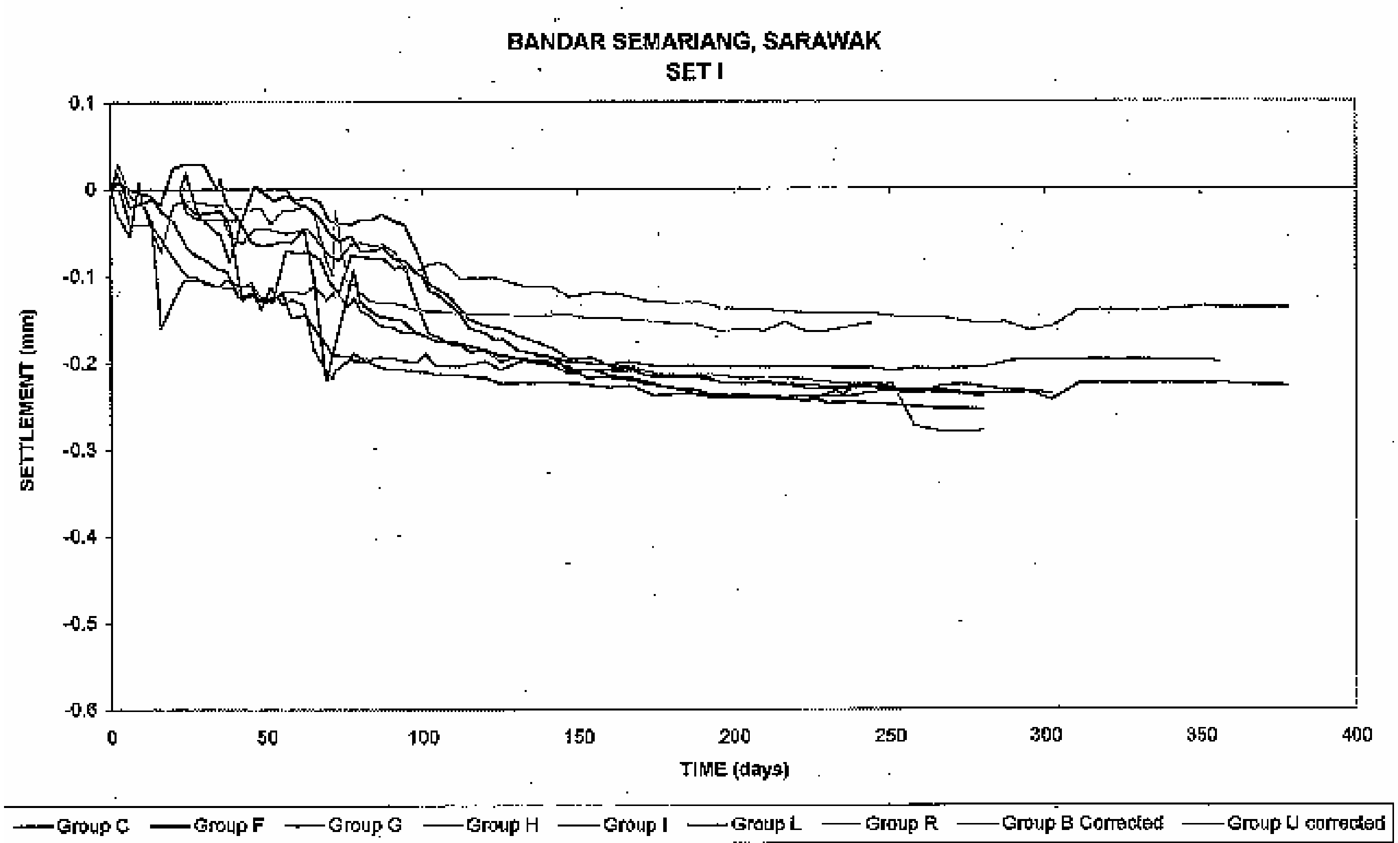


FIG. 17

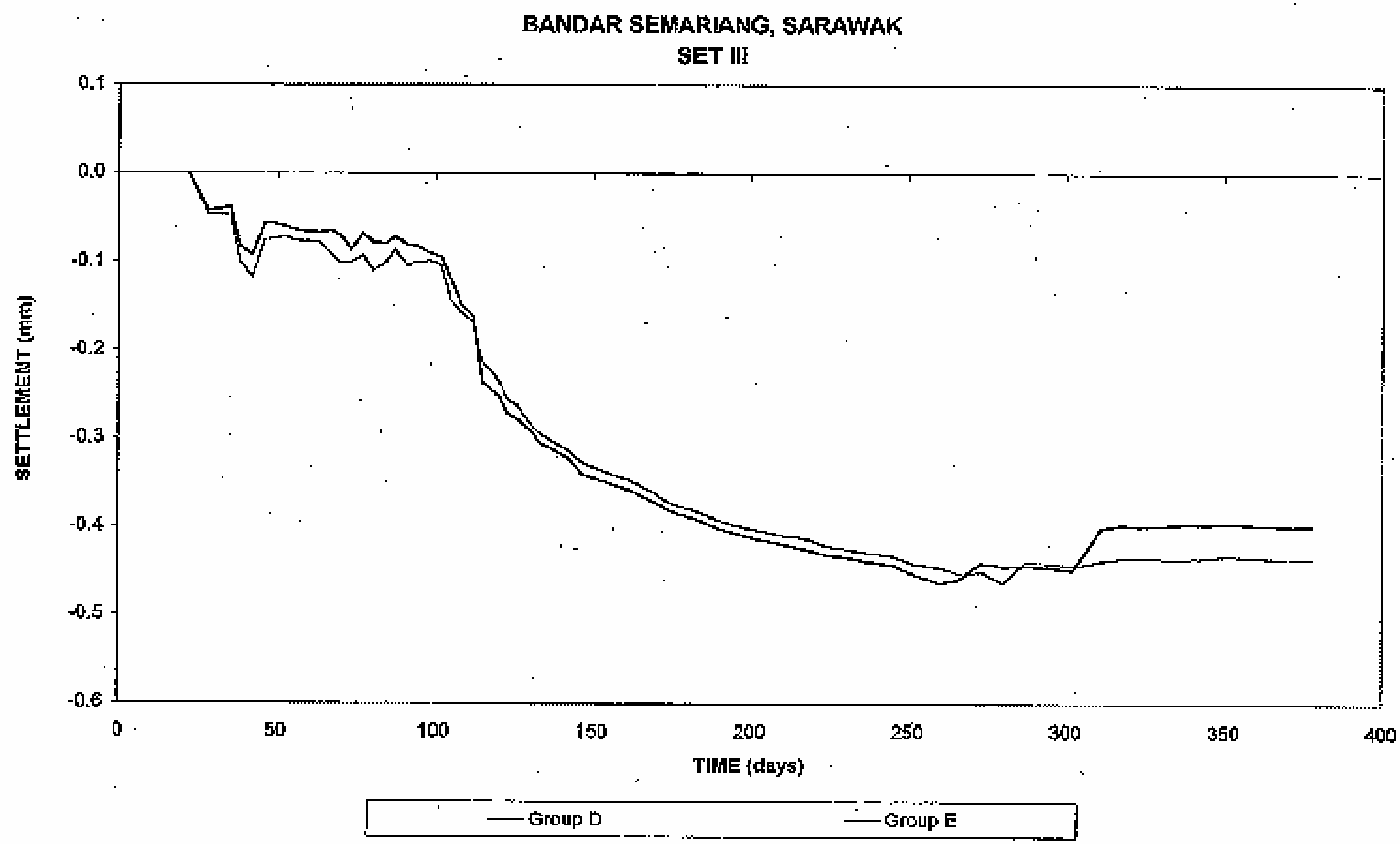
Soft Clay. Bandar Semariang. Measured settlement



m-measett-c1

FIG. 18a

Soft Clay. Bandar Semariang. Measured settlement



sem-measett-c3

FIG. 18c

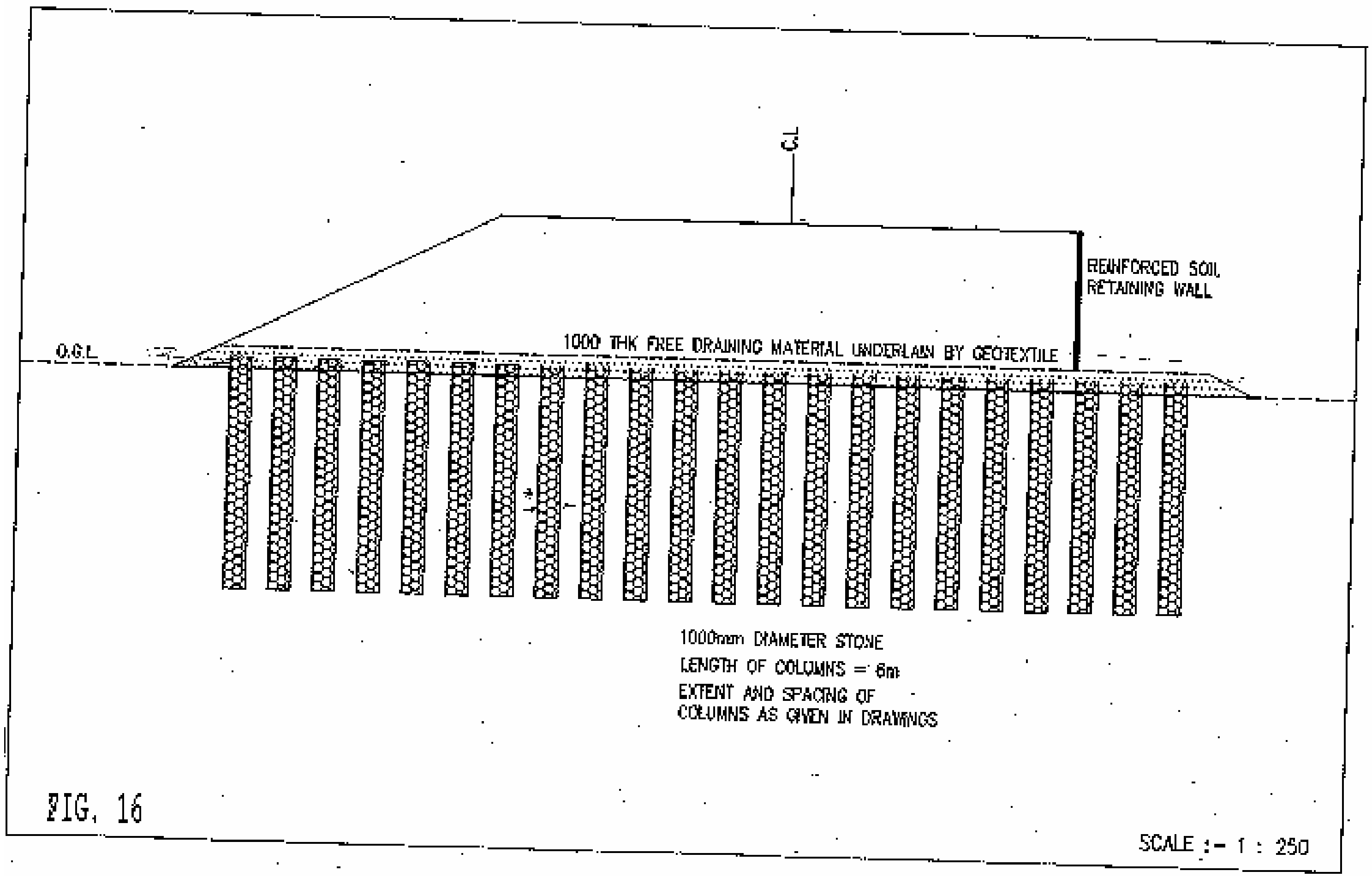
Soft Clay. Gurun Railway Wall

- Double sided Reinforced Soil wall with railway track.
- 6 m soft clay.
- Vane shear strength = 10 to 30 kpa
- OCR = 3.0
- $C_c / (1 + e_o)$ = 0.1 to 0.3
- C_v = 4 to 7 sq m /yr
- NMC = 40 %
- PI = 20 %

Soft Clay. Gurun Railway

Stabilized with stone columns

Gurun Embankment

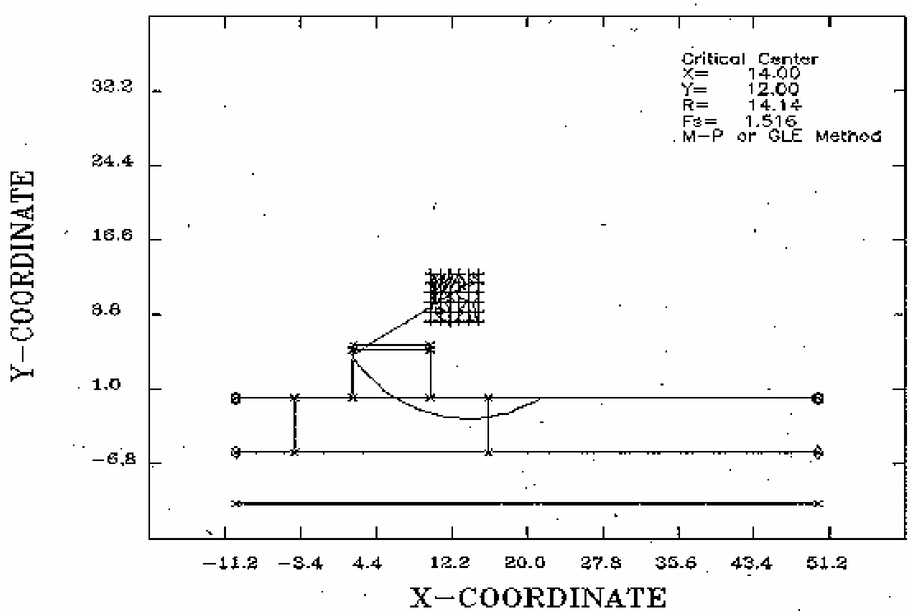


Gurun Embankment

GURUN RAIL TRACK – 5.0m RE WALL EMBANKMENT

1 27.12.95

WITH STONE COLUMNS AT 1.50m CENTRES

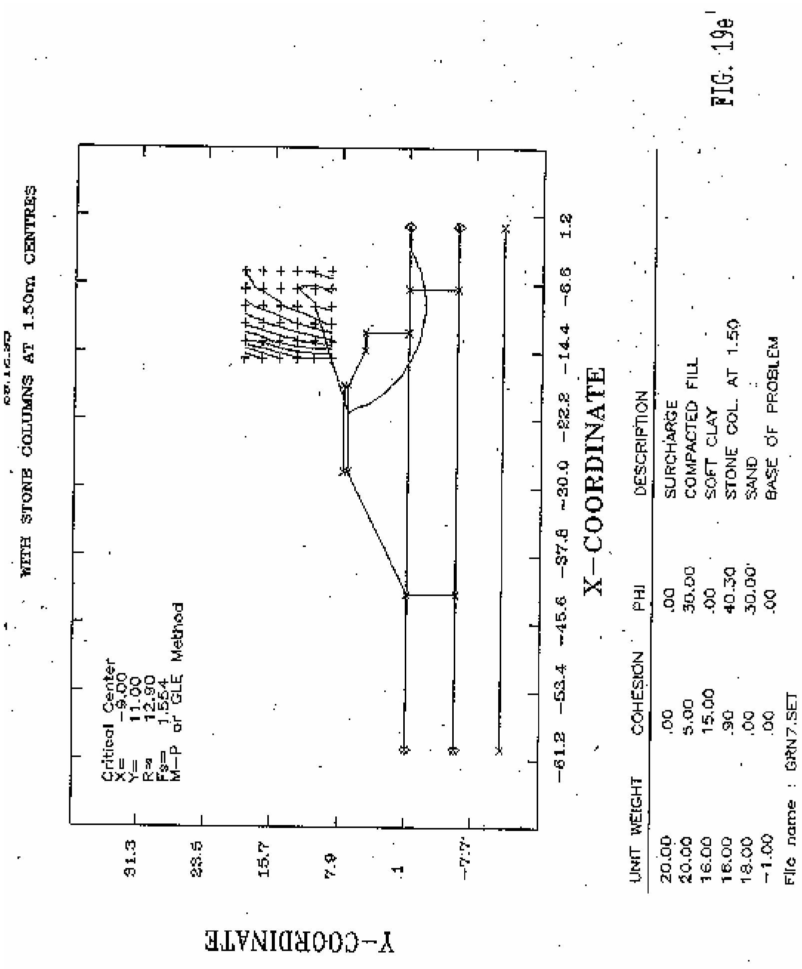


UNIT WEIGHT	COHESION	PHI	DESCRIPTION
20.00	.00	.00	SURCHARGE
20.00	5.00	30.00	COMPACTED FILL
16.00	15.00	.00	SOFT CLAY
16.00	.90	40.30	STONE COL. AT 1.50
18.00	.00	30.00	SAND
–1.00	.00	.00	BASE OF PROBLEM

File name : GRN4.SET

FIG. 19d

Gurun Embankment



Gurun. Railway embankment

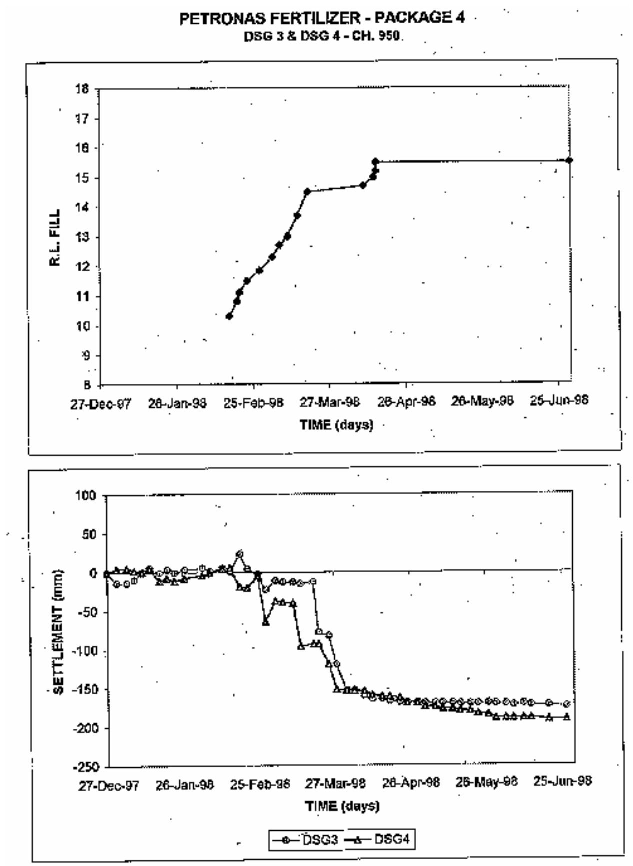


FIG. 2b

Gurun railway Embankment

Gurun railway embankment

Gurun Railway Embankment

Gurun Railway Embankment

Gurun railway Embankment

SOFT CLAY CASE HISTORY

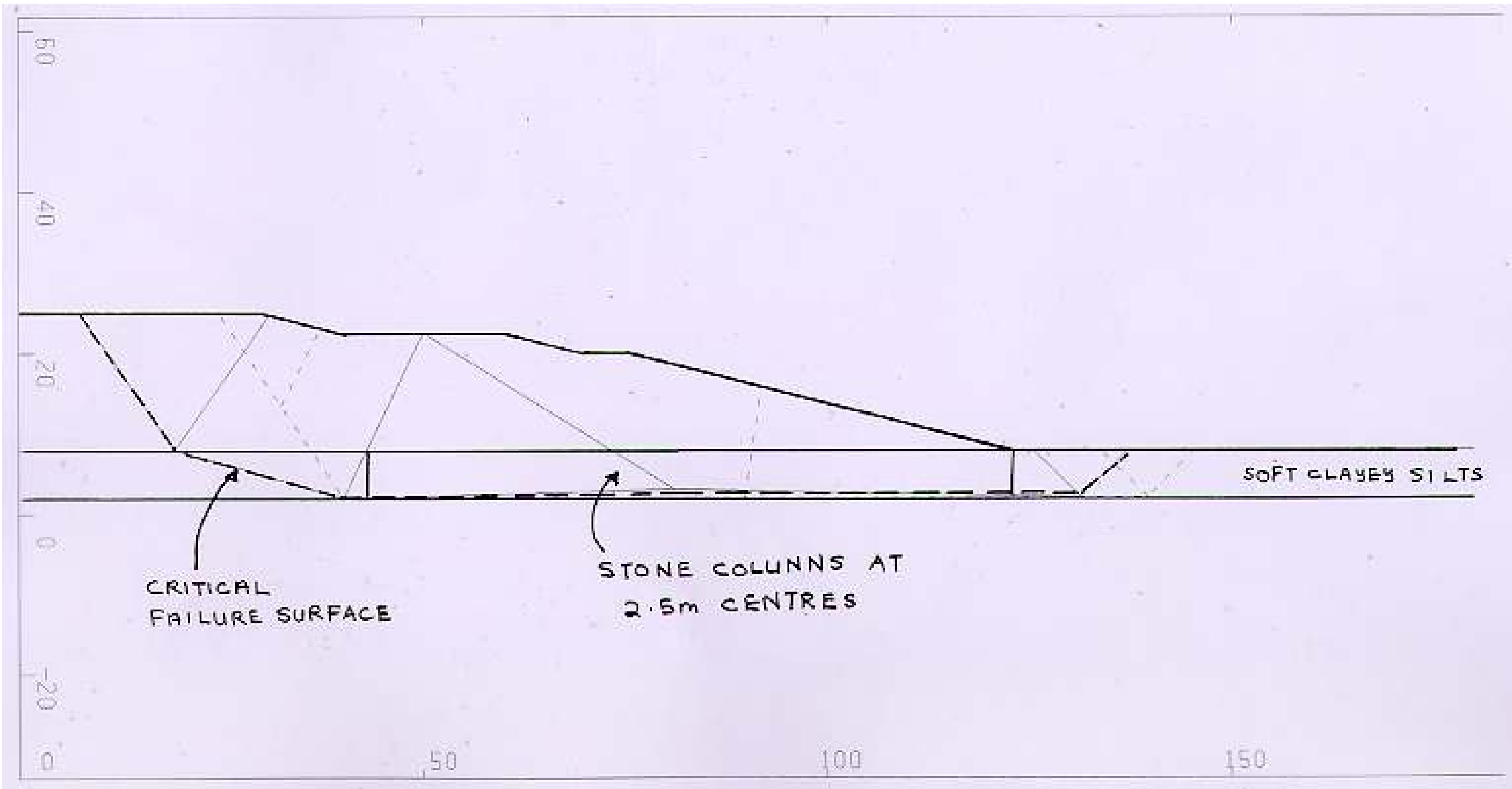
PUTRA JAYA CORE ISLAND.

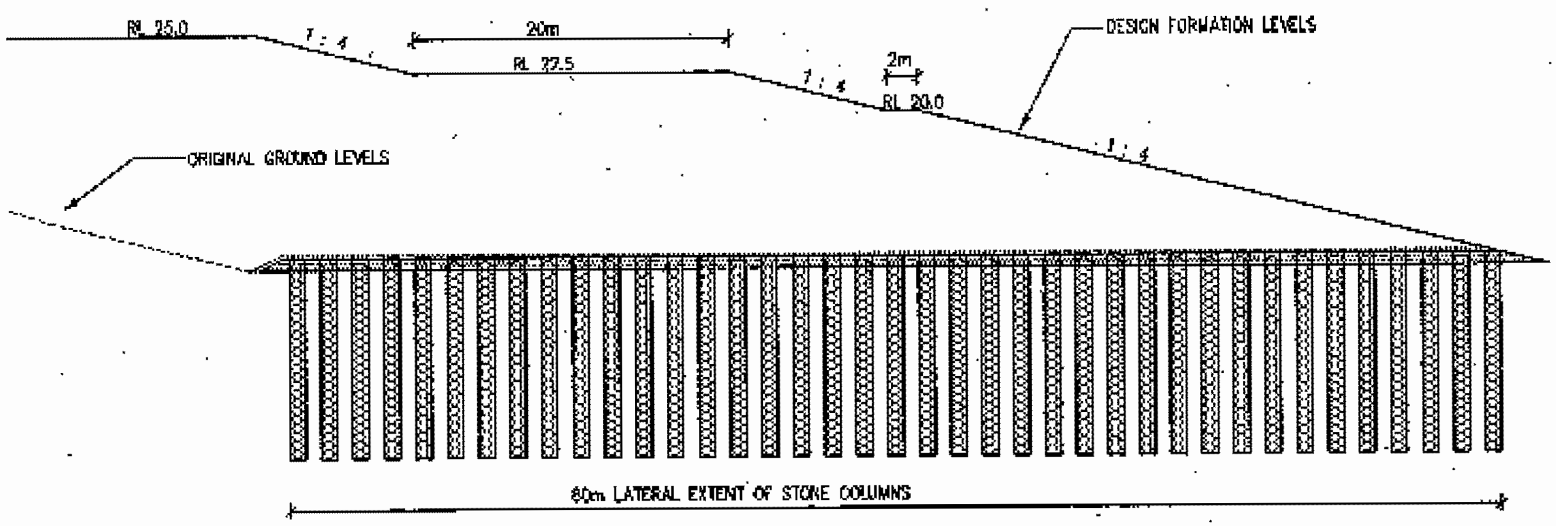
17 m high embankment on soft clay

Soft clay average 4 to 9 m deep

Embankments to form the banks of the Putra jaya lake

Putrajaya Core Island.Stability analysis





EMBANKMENT ON STONE COLUMNS AT BOULEVARD; PUTRAJAYA

SCALE :- 1 : 400

Soft Clay. Putra jaya Core Island

Putra Jaya Core island

Putra jaya Core Island. Stone columns

Putra jaya Core Island. Stone column load test

Putra jaya Stone column. Wet method

Putra jaya. Stone column. Wet method

Putra jaya Stone column. Dry method

Putra jaya. Stone column. Dry method

Putra jaya. Stone column

Putra jaya. Stone column. Dry method

Putra jaya. Approach embankment on stone column

Putra jaya Core Island

SOFT CLAY CASE HISTORY

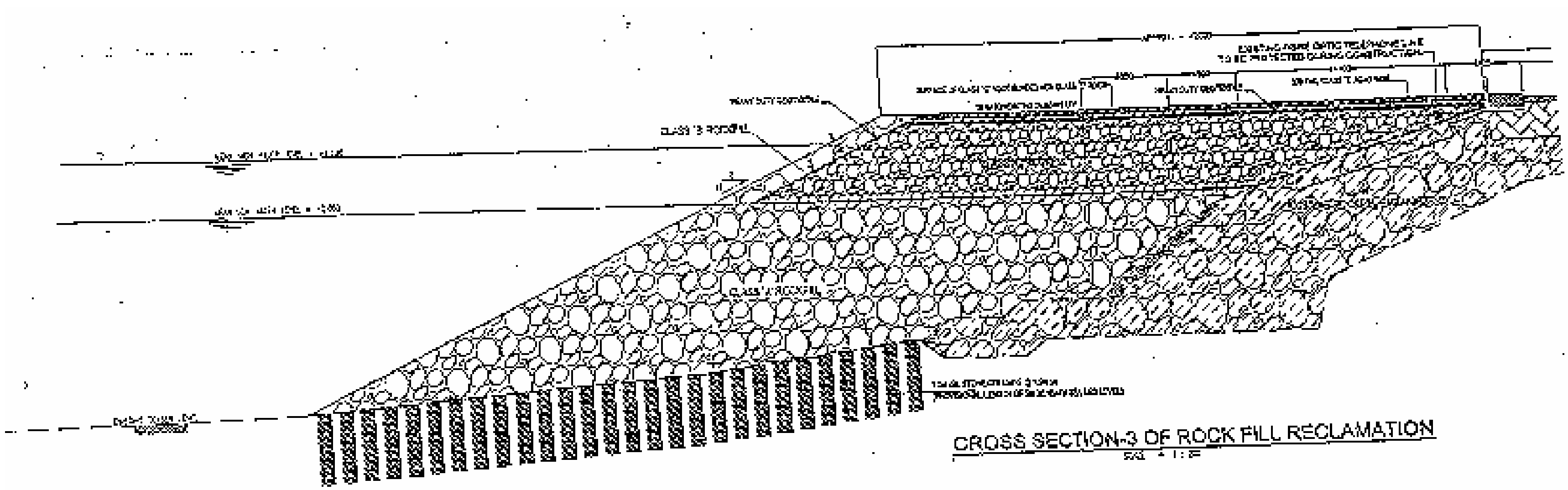
WIDENING JOHOR CAUSEWAY

Thin soft clay < 5 m

Stabilized with stone columns

Installed under water

Johore. Causeway widening. Stone columns



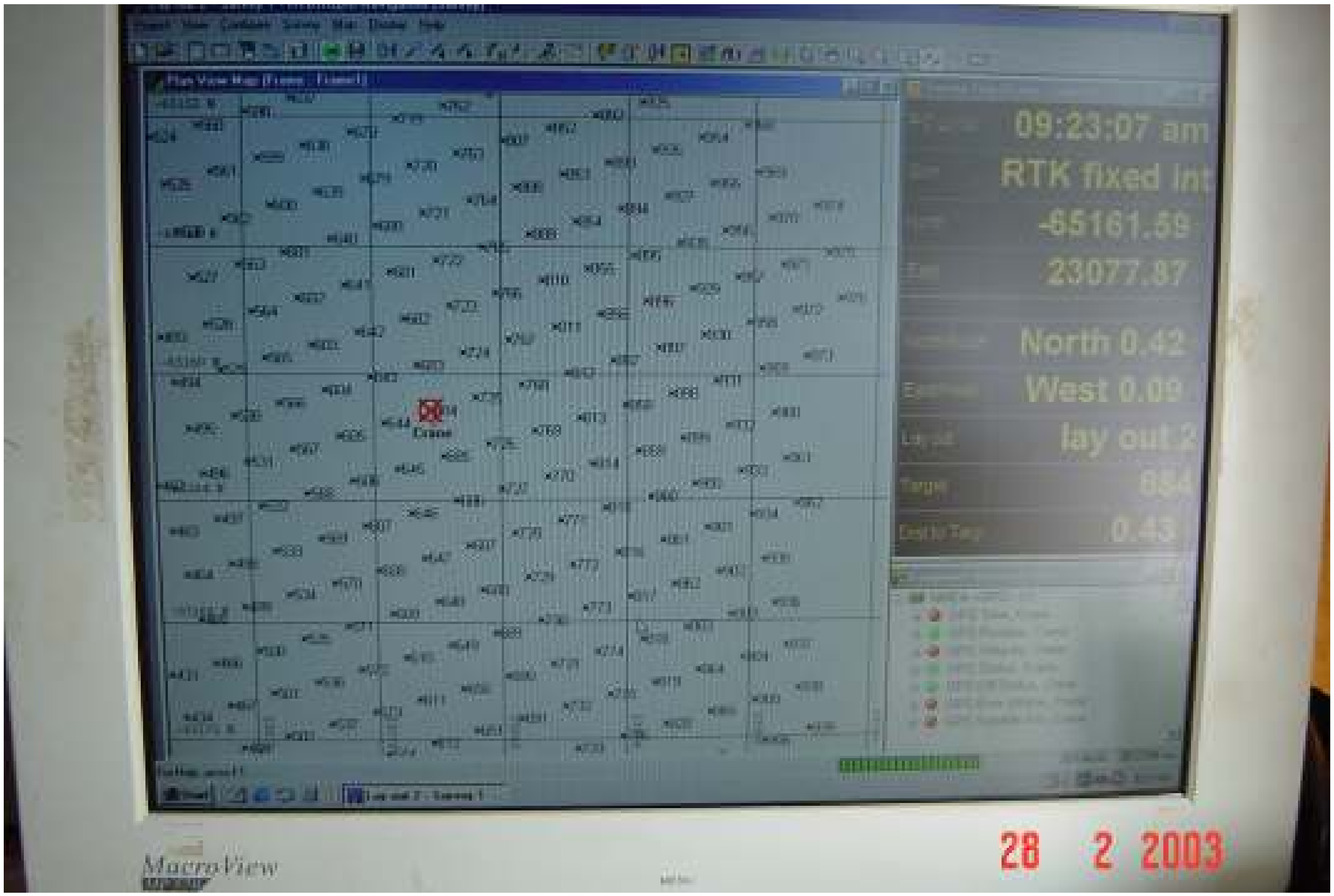
JOHORE CAUSEWAY Crane hung method stone columns

Johore Causeway. Crane hung method stone columns

Johore Causeway. Crane hung method stone columns

Johore Causeway. Crane hung method stone column

Johore causeway. GPS positioning stone column



SOFT CLAY CASE HISTORY

PULAU INDAH RAILWAY

RAILWAY EMBANKMENT MOSTLY 2.5 M TO 3.0 M HEIGHT

PRELOAD FOR 2 YEARS

SOFT CLAY EXTENDS TO > 25 M

SOFT CLAY. PULAU INDAH RAIL

Type B1 – Embankment height up to 2.0 m. Preload without vertical drains

Type B2 – Embankment height 2 to 3 m. 10 m long prefabricated vertical drains to gain strength for stability

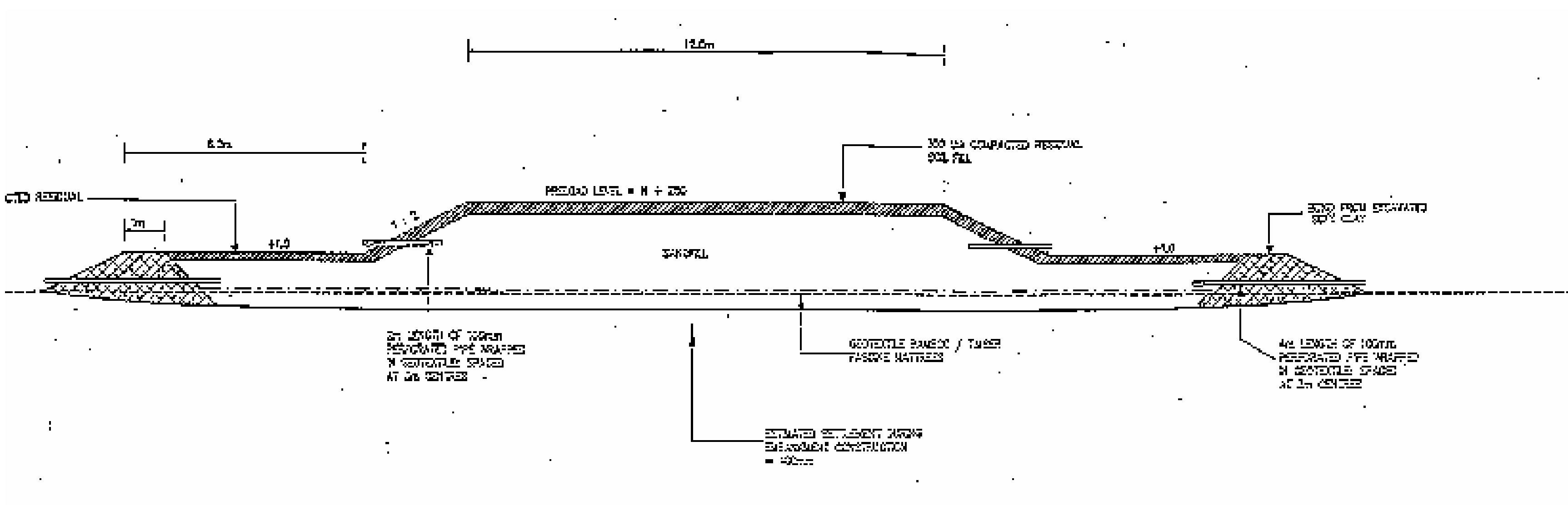
Transition Pile Embankment with 175 x 175 piles at 500 cntres

SOFT CLAY. PULAU INDAH

Soft clay properties

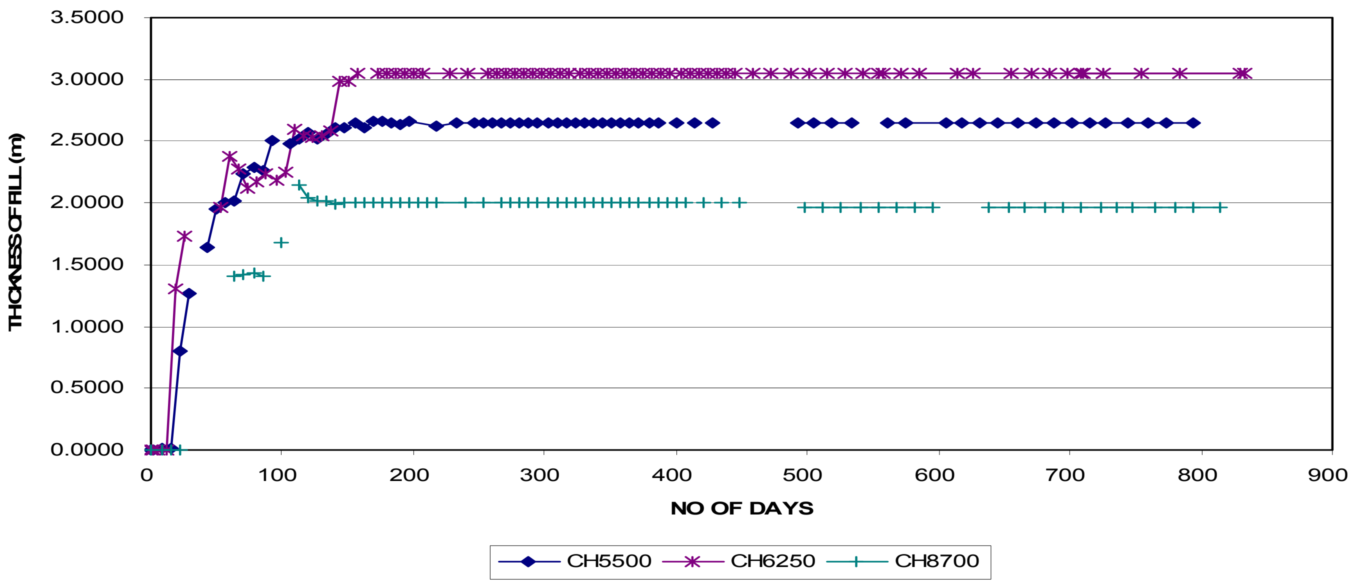
- Natural moisture content – 50 to 150 %
- Liquid Limit - 60 to 120 %
- Plastic Limit - 30 to 50 %
- Plasticity Index - 30 to 80 %
- Su 10 kPa at top increasing with depth to 40 kPa at 20 m
- Sensitivity - 2 to 5
- OCR - 1.0
- Cc/(1 + eo) - 0.3 to 0.5
- Cv 0.7 sq m / year

Pulau Indah. Type B1

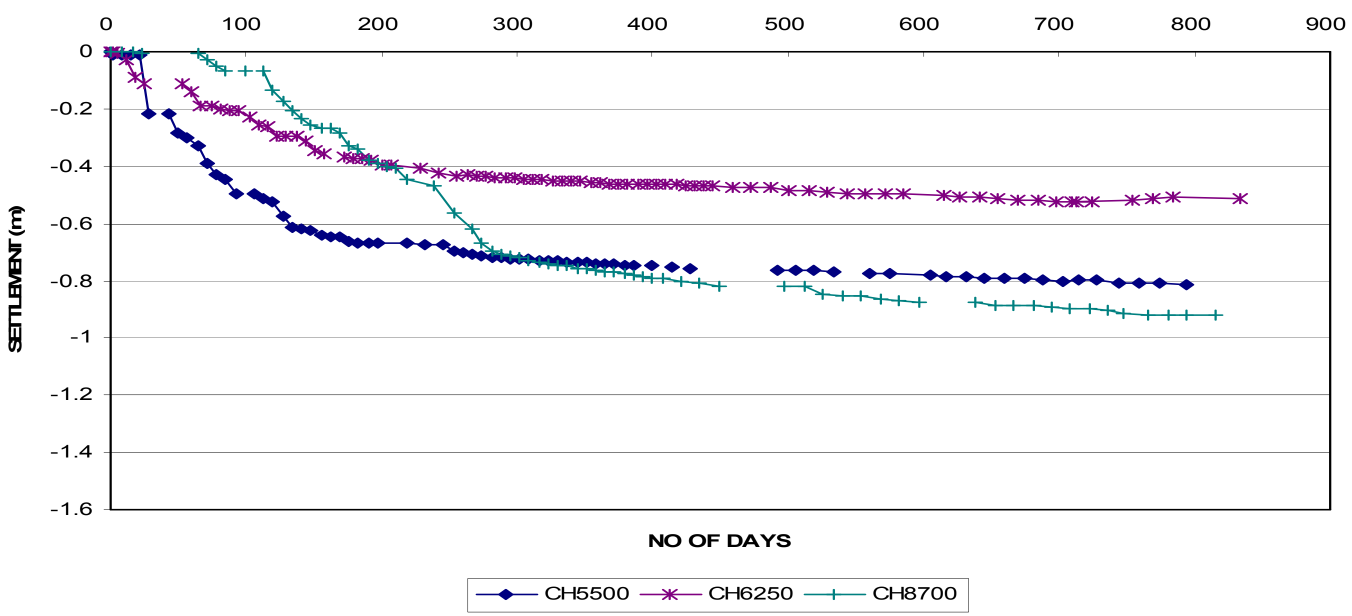


TYPE B1 – 1m < H < 2m

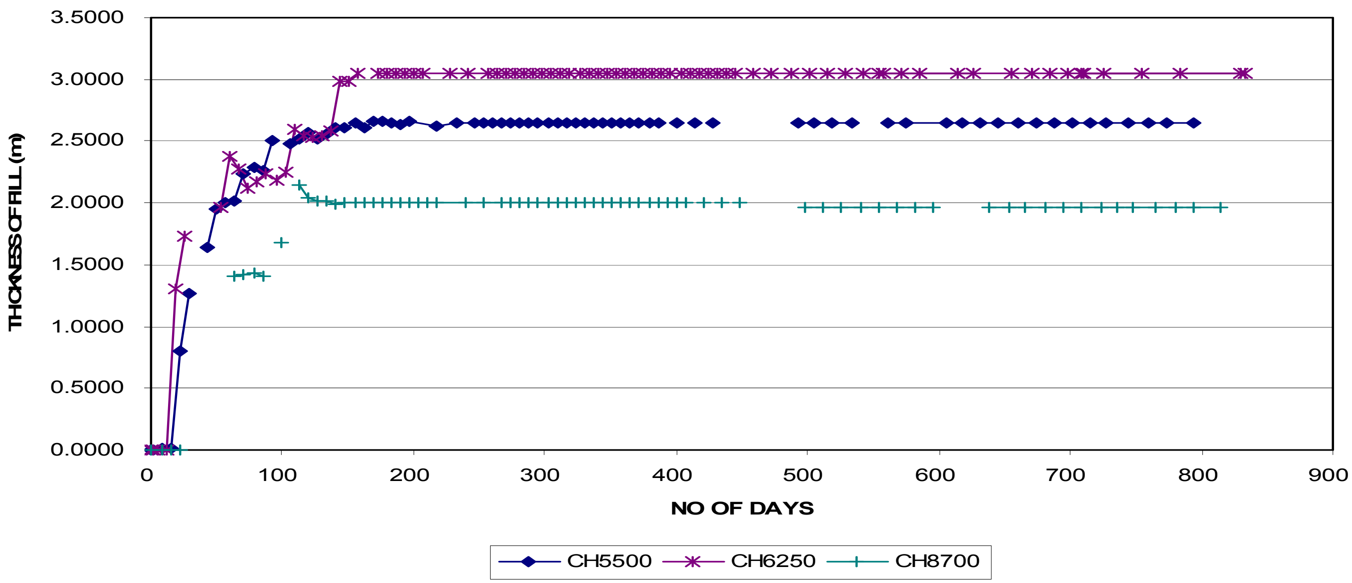
SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B1 TYPE TREATMENT)



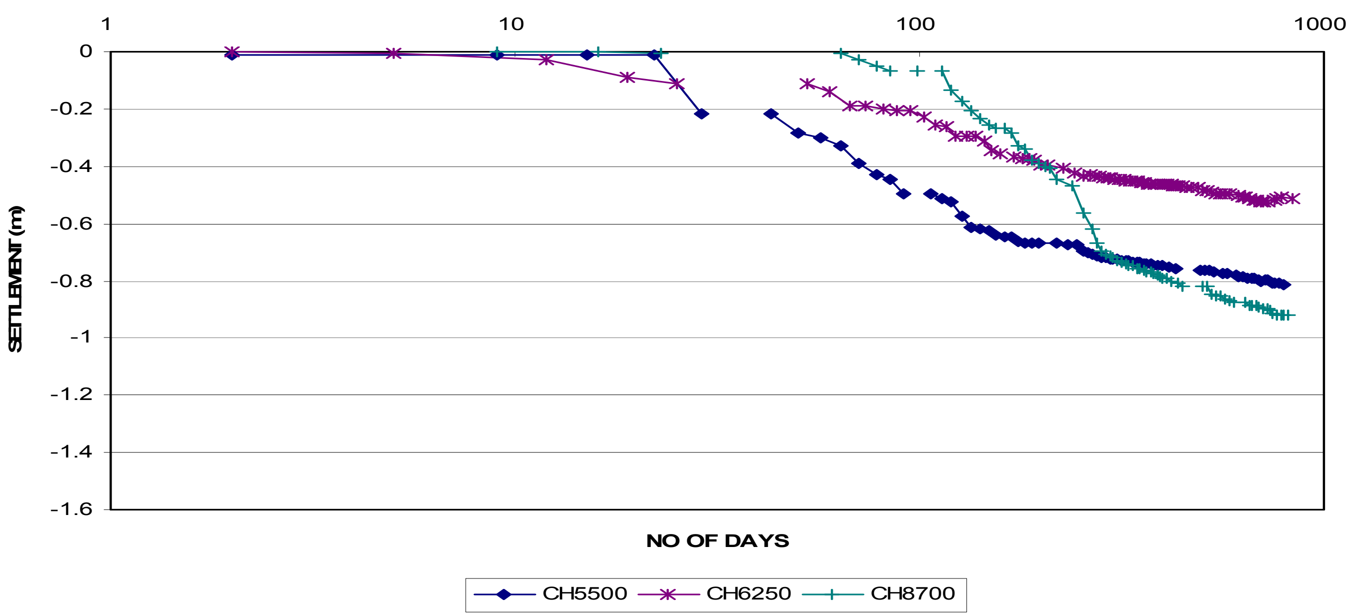
SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B1 TYPE TREATMENT)



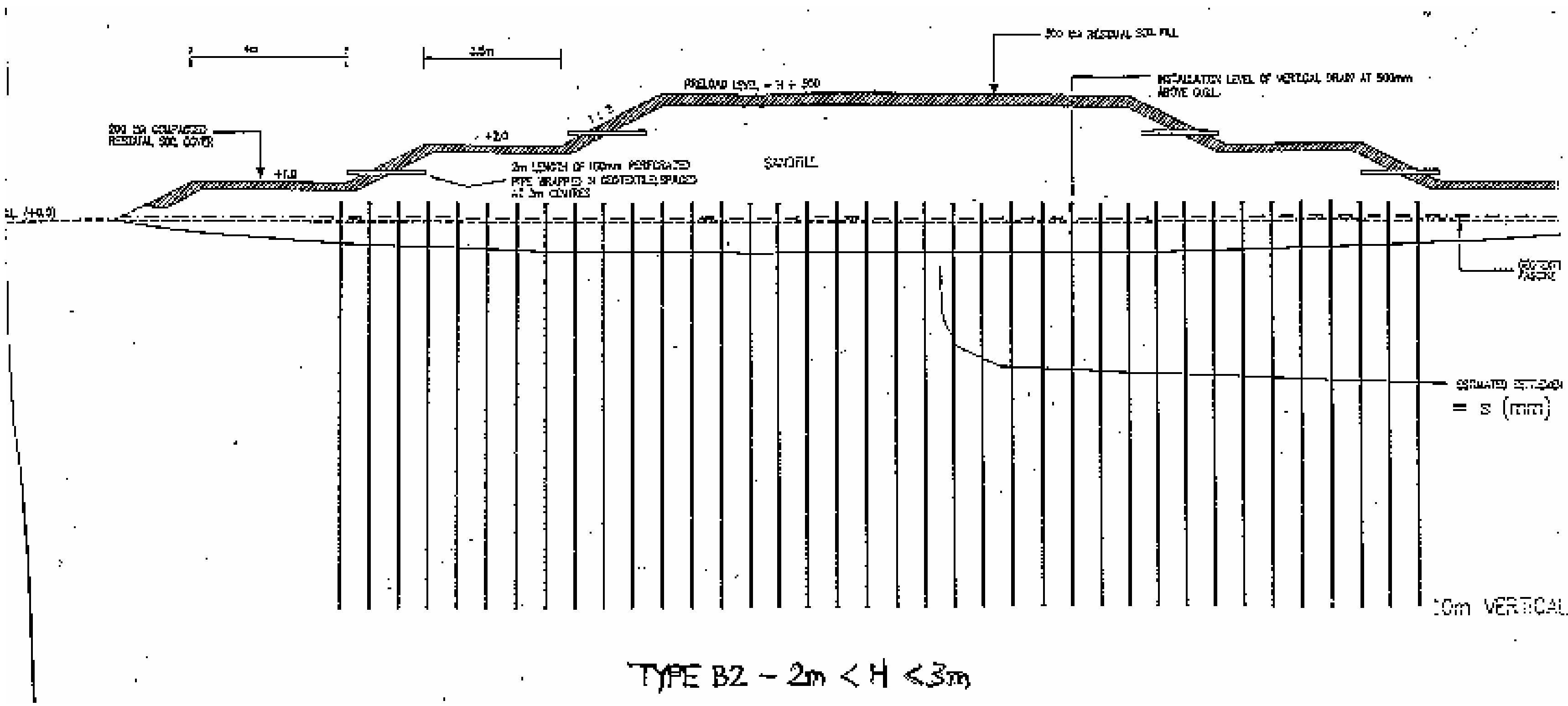
SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B1 TYPE TREATMENT)



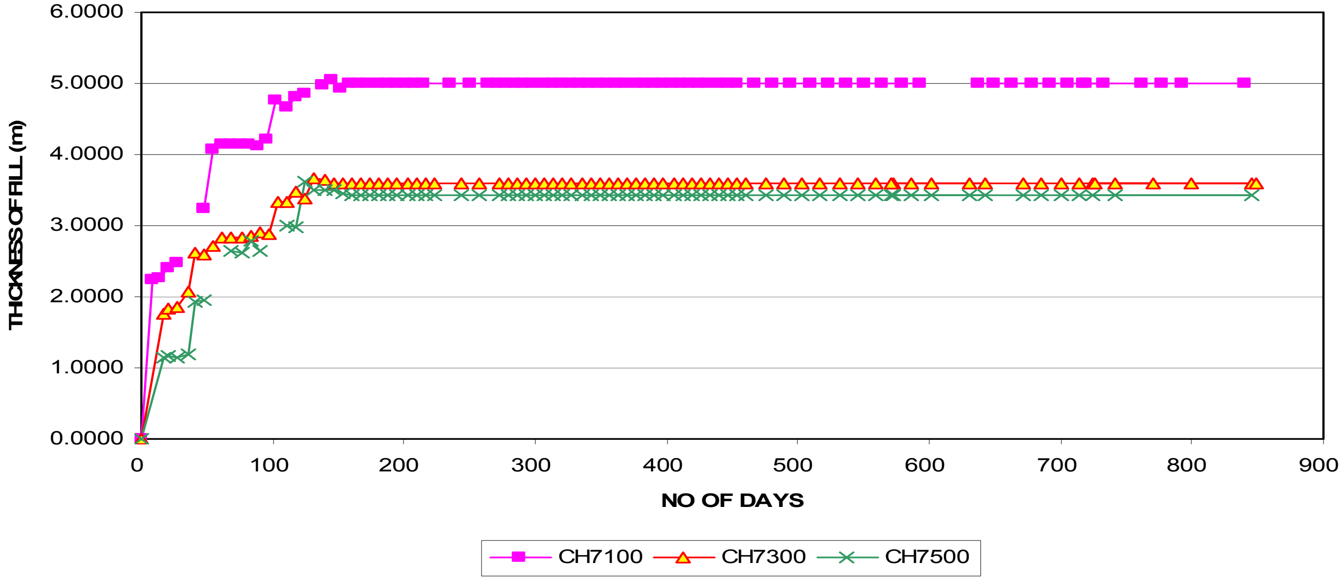
SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B1 TYPE TREATMENT)



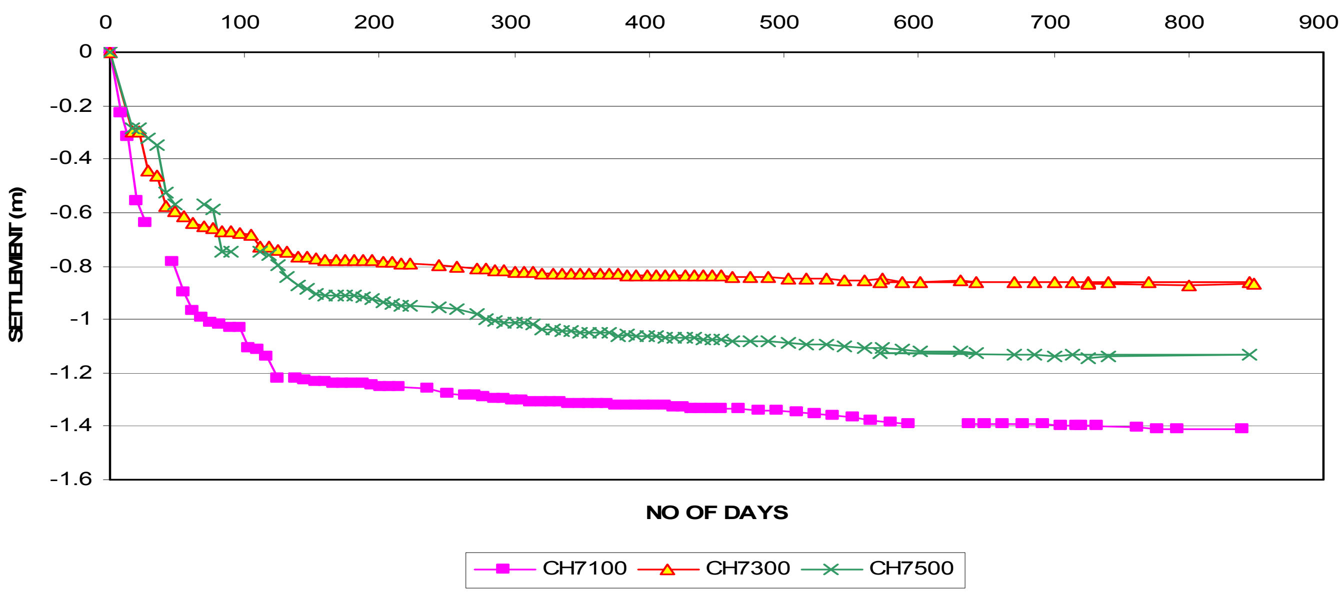
Pulau Indah. Type B2

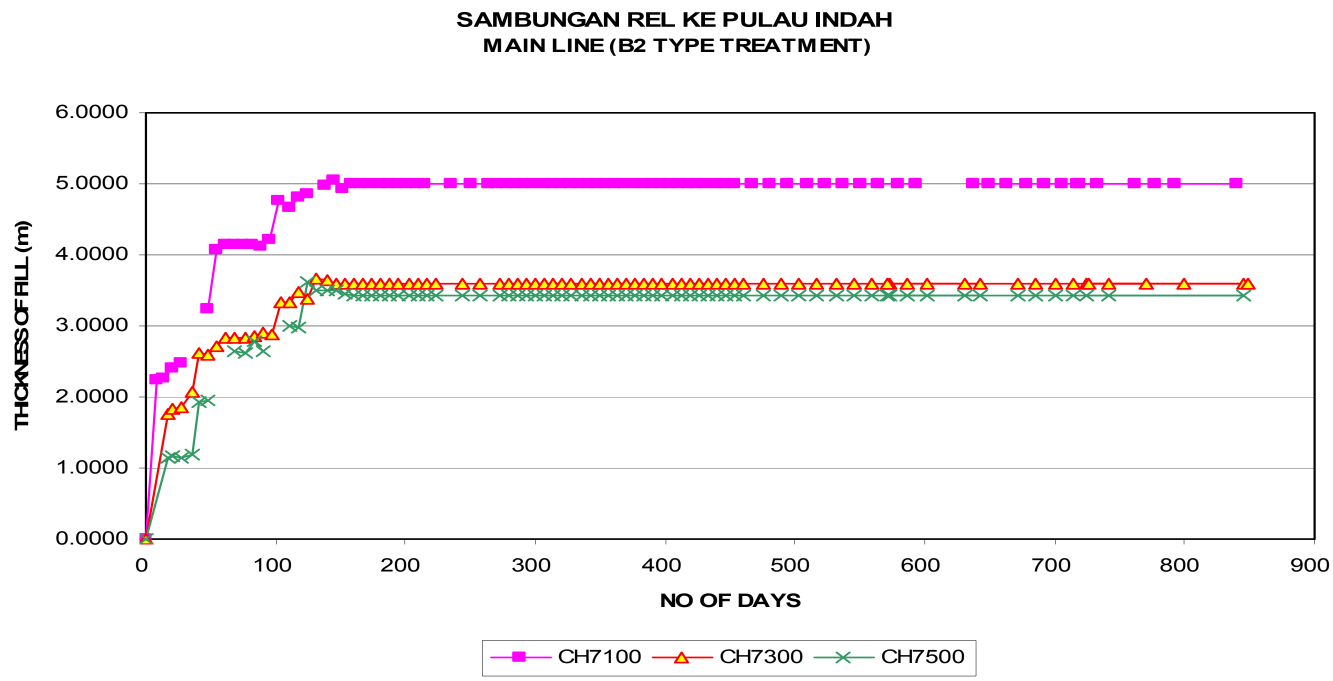


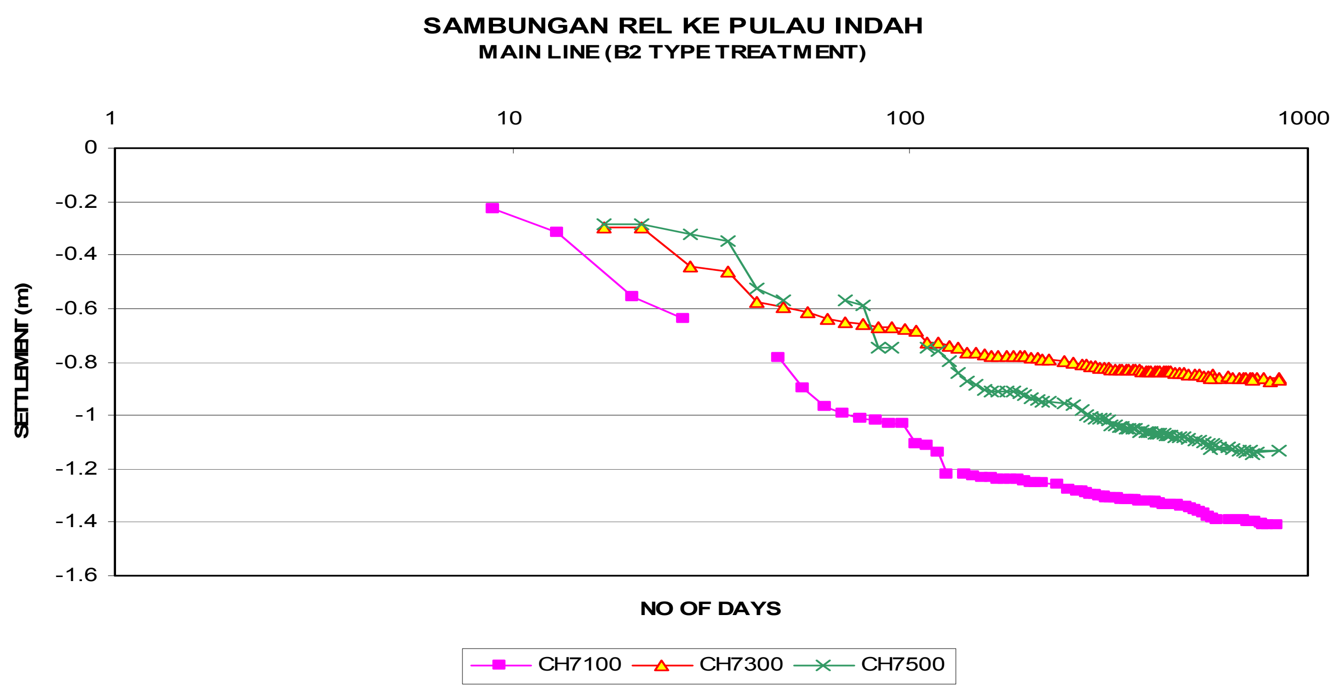
SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B2 TYPE TREATMENT)



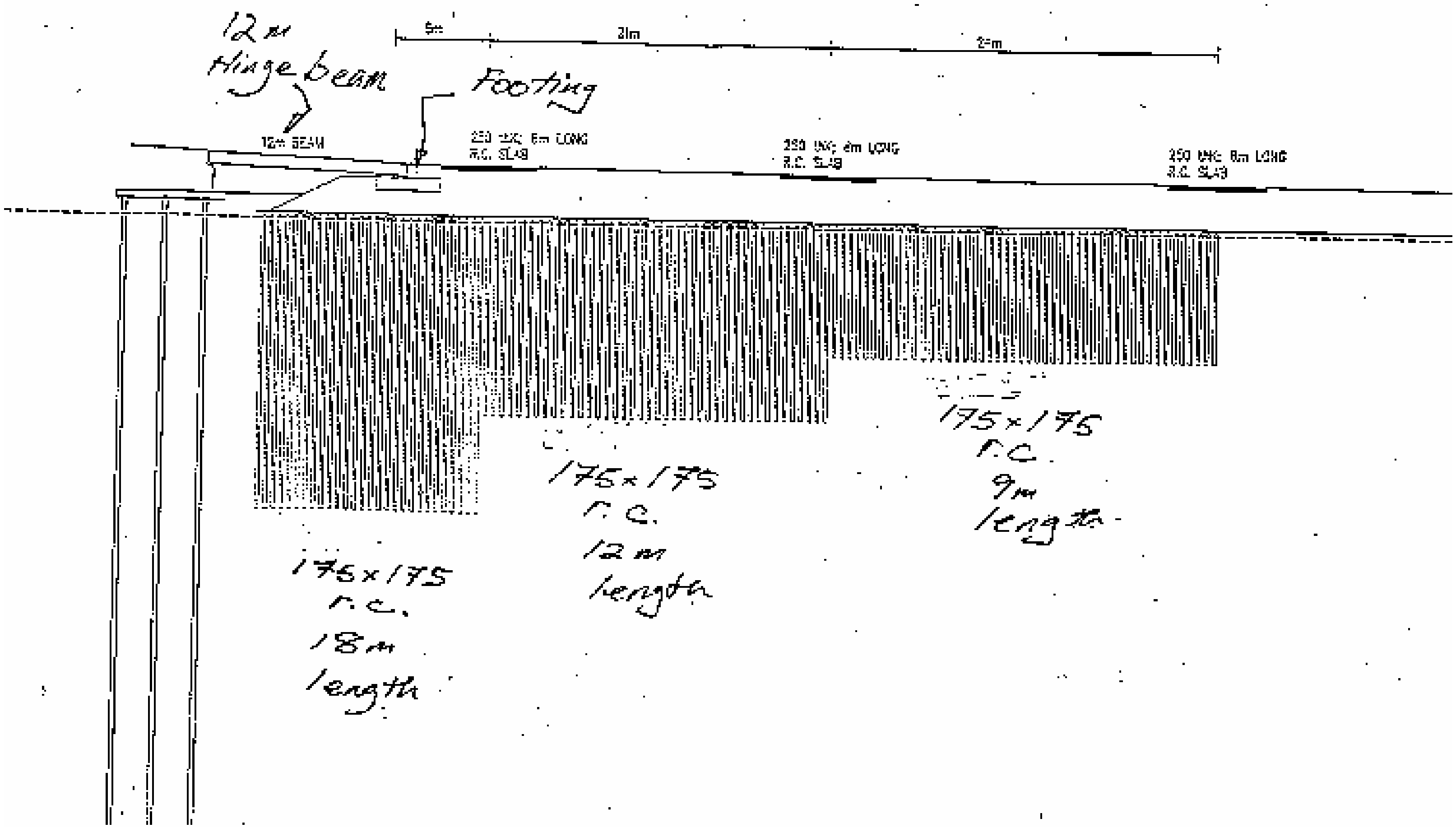
SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B2 TYPE TREATMENT)



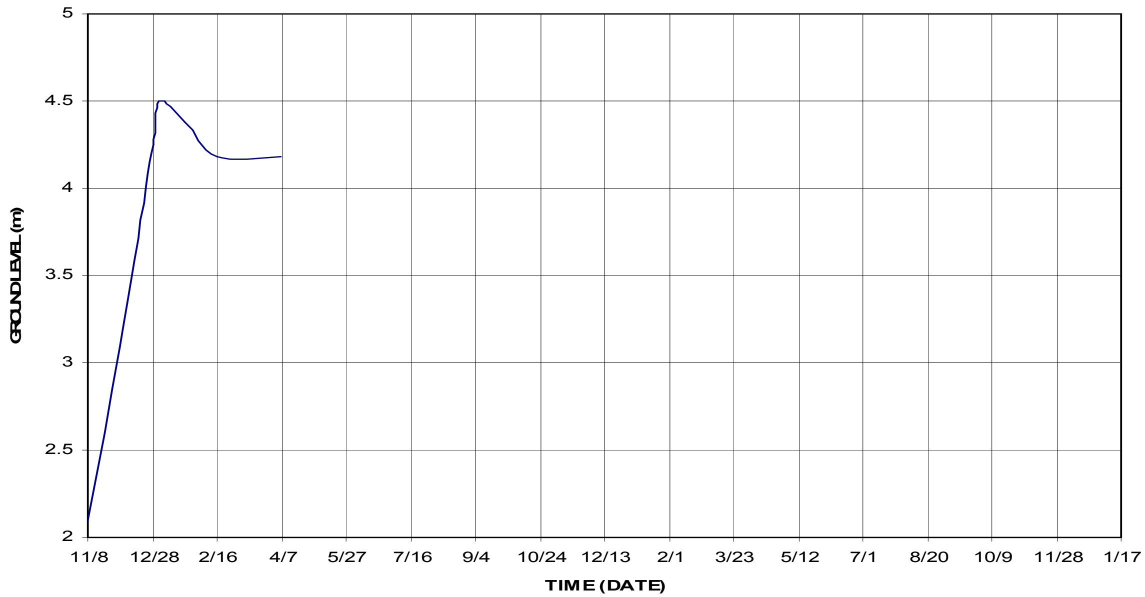

SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B2 TYPE TREATMENT)
THICKNESS OF FILL (m)
6.0000
5.0000
4.0000
3.0000
2.0000
1.0000
0.0000
0
100
200
300
400
500
600
700
800
900
NO OF DAYS
CH7100
CH7300
CH7500

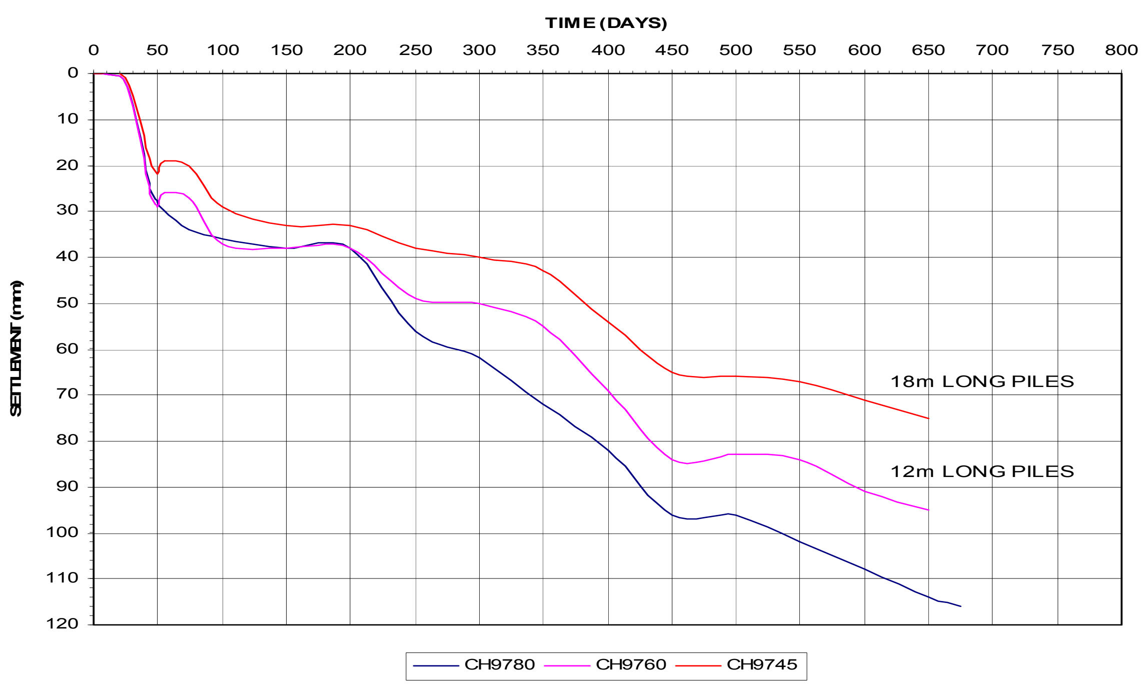

SAMBUNGAN REL KE PULAU INDAH
MAIN LINE (B2 TYPE TREATMENT)
1
10
100
1000
SETTLEMENT (m)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
NO OF DAYS
CH7100
CH7300
CH7500

Pulau Indah. Embankment transition



SAMBUNGAN REL KE PULAU INDAH
TRANSITION PILE EMBANKMENT
(CHANDONG BESAR UPPER)





TATAU EPS LIGHT WEIGHT FILL

TATAU EPS

TATAU EPS

TATAU EPS

TATAU EPS

END OF LECTURE

THANK YOU