CASE HISTORIES FROM SOUTH EAST QUEENSLAND MAIN ROAD'S EXPERIENCE

Soft Soils and Ground Improvement

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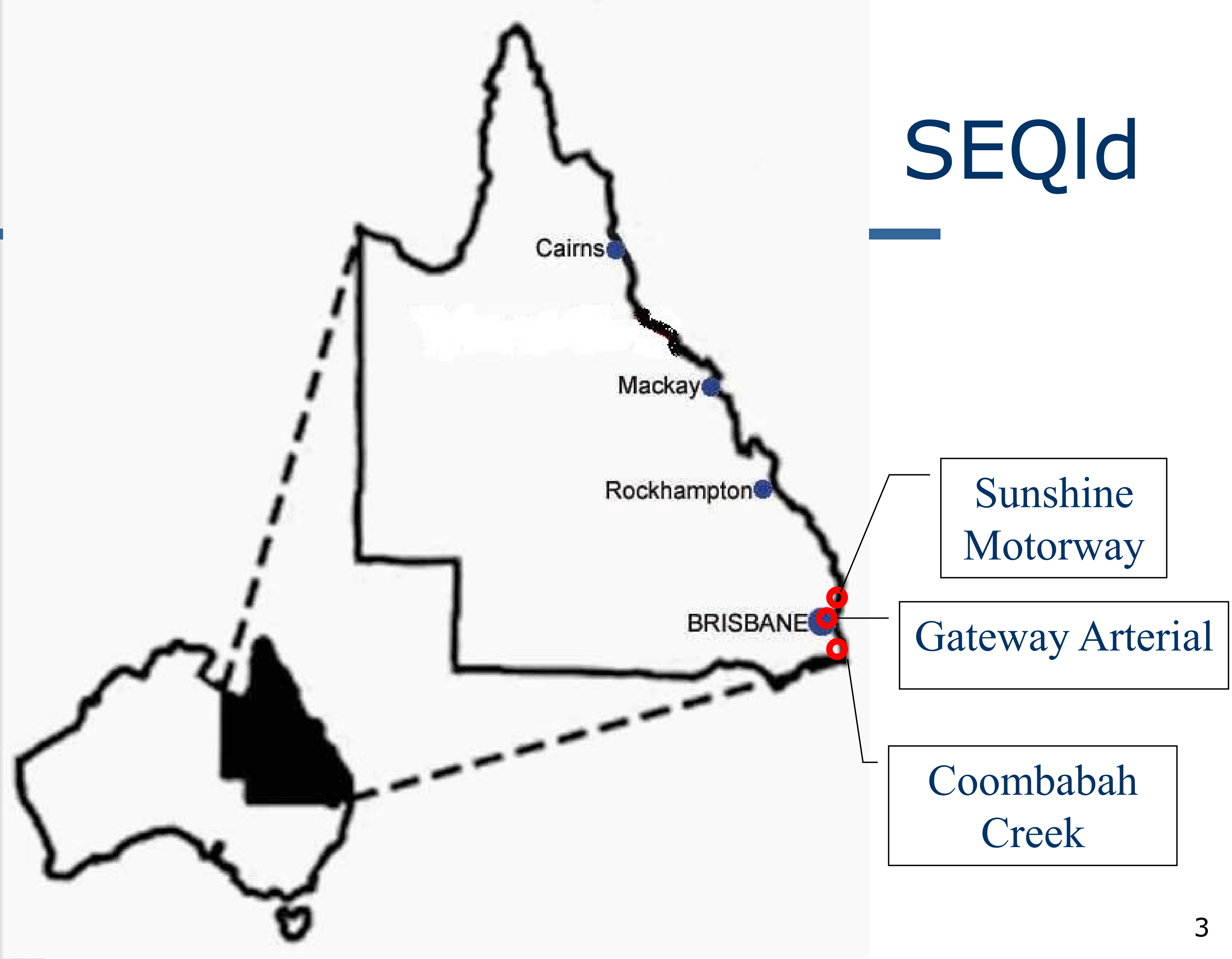
Queensland Government
Department of **Main Roads**

Geotechnical Branch

Overview

- Soft Clays in South East QLD
- Design and construction challenges
- Observational approach
- Case studies:
  - Sunshine Motorway
  - Coombabah Creek
  - Gateway Arterial
    - East-West Arterial
    - Toombul Road
    - Bald Hill Creek

SEQld



Sunshine Motorway

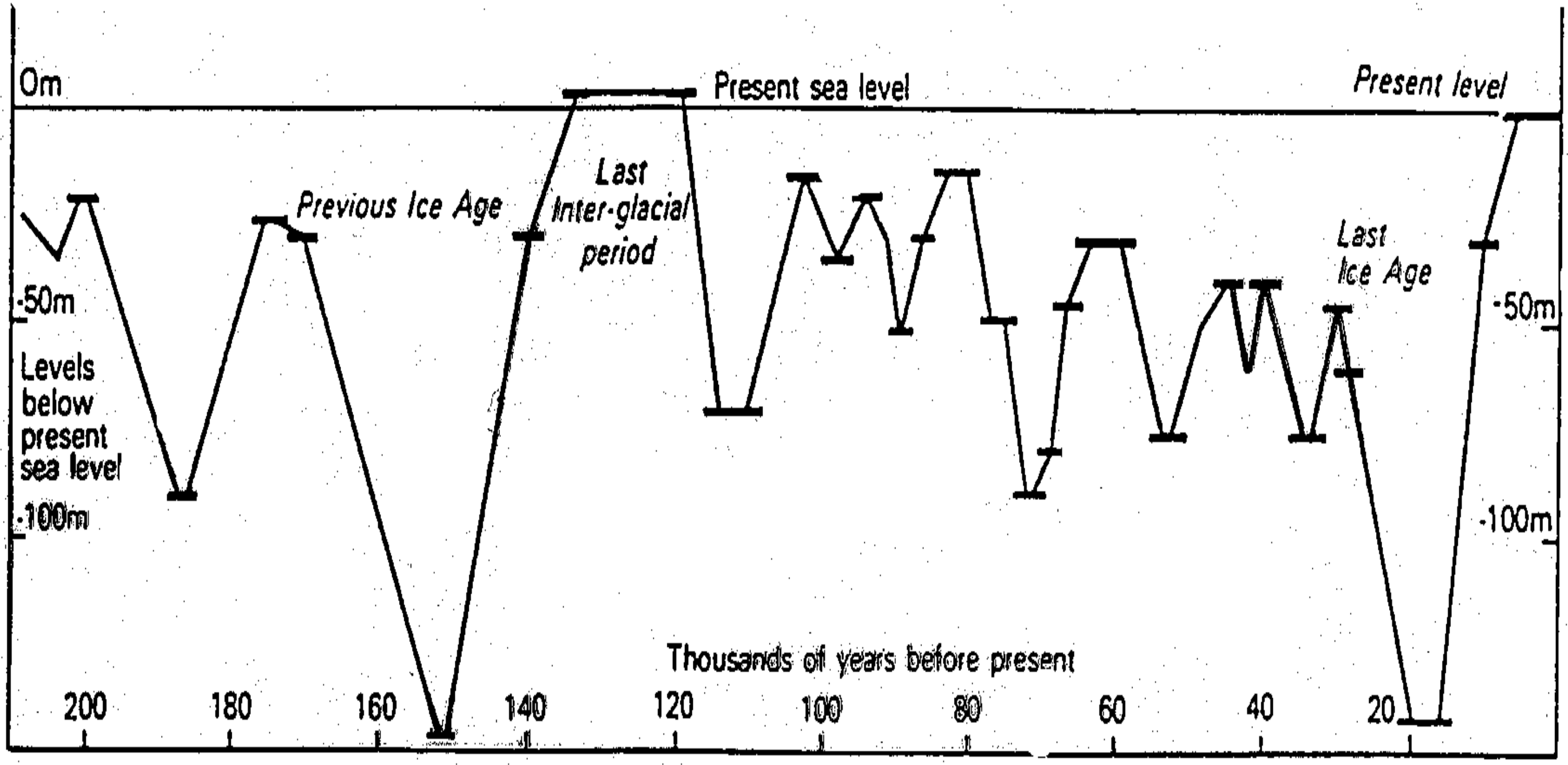
Gateway Arterial

Coombabah Creek

Regional Geology, SEQld

- Very complex
- Coastal processes
  - Sea level fluctuations
  - Shoreline topography
- Coastline Changes
- Deposition of marine and fluvial (river) sediments

Sea Level Fluctuations

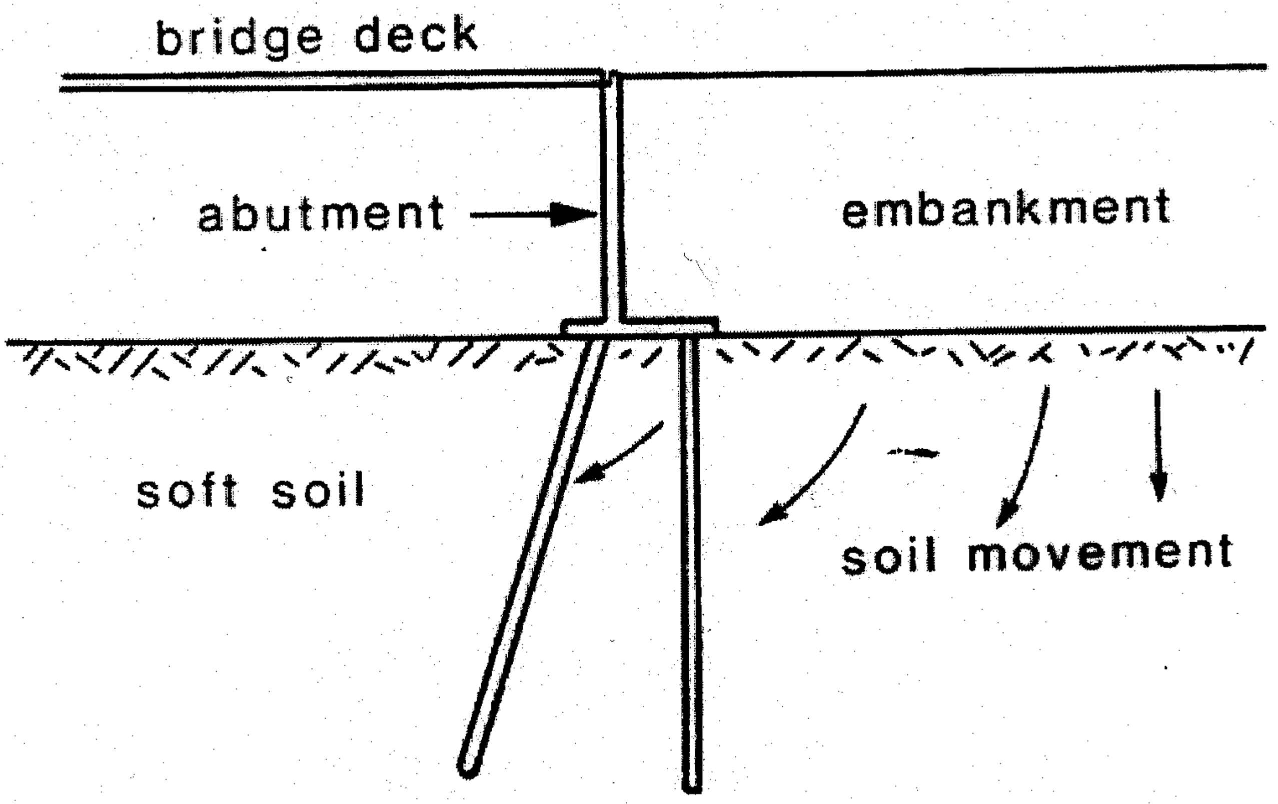


Soft Clays: Geotechnical Risks

- Design Issues
  - Stability (failure)
  - Settlement (functional impairment)
  - Interaction with other structures
    - Bridges/culverts
    - Retaining walls
- Construction Issues
  - Access difficulties (plant and vehicle movement)
- Contractual Issues
  - Delays due to prolonged settlement

Embankment Stability

Lateral Thrust



Piles subjected to lateral thrust from soil

Piles in consolidating soil

Lateral Thrust

Design & Construction Challenges

- Swampy ground
  - no hard crust
  - Construction problems
- Thick deposits of clay
  - Up to 20m
- Low strength (10 kPa or lower)

Design & Construction Challenges cont

- Very sensitive to disturbance during ground improvement
  - wick drain or stone column installation
- Leads to strength reduction

$$\frac{disturbed}{undisturbed}\,strength = \frac{1}{10}\,to\,\frac{1}{15}$$

- High compressibility
  - Up to 25% of soft clay thickness

Design & Construction Challenges cont

- Consolidation time > 10 years
- High secondary settlement/creep
  - 2% strain per log cycle of time
- Fast tracking leads to low Factors of Safety (FOS ≈ 1.3 or lower)
- Challenges with control of stability during construction
  - ‘Brittle’ soils, little warning prior to failure

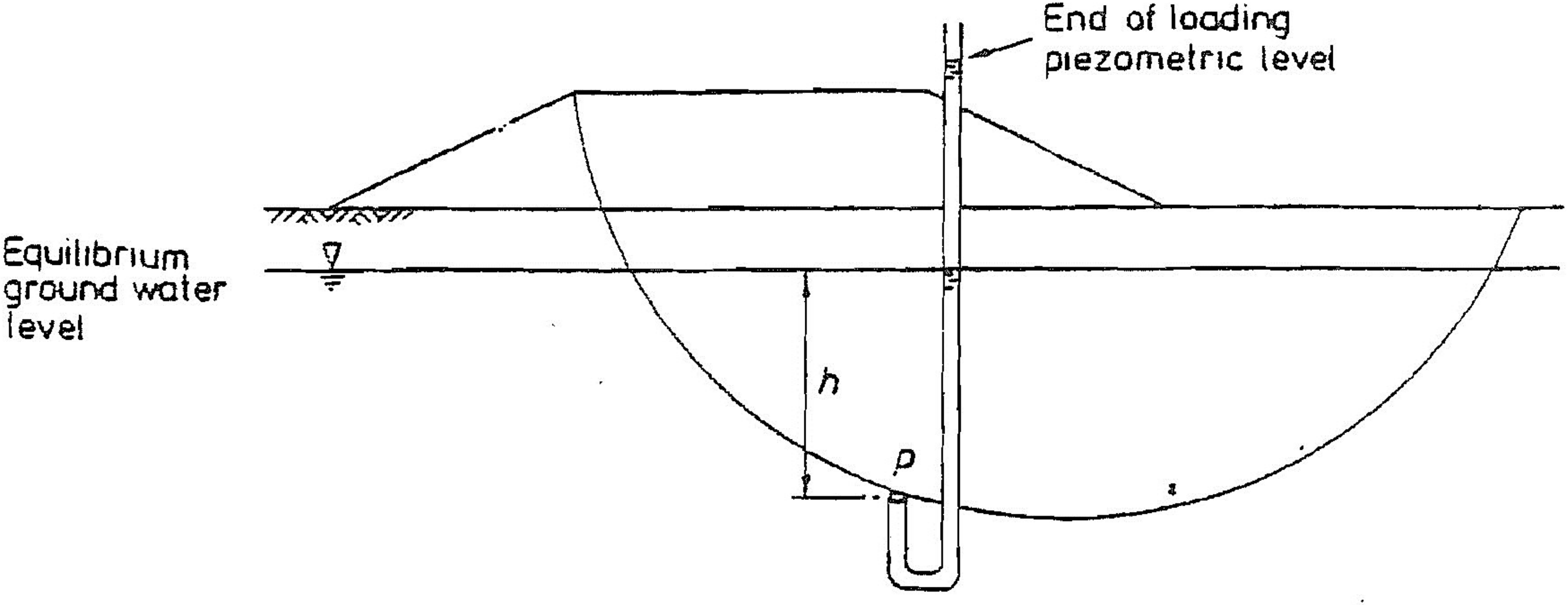
Observational Approach

- Performance monitoring for
  - Construction control of stability
  - Monitor consolidation progress
    - When piling can start
  - Refine predictions for in-service behaviour (maintenance management)
  - Better understanding of in-situ behaviour
  - Assessment of fill quantities

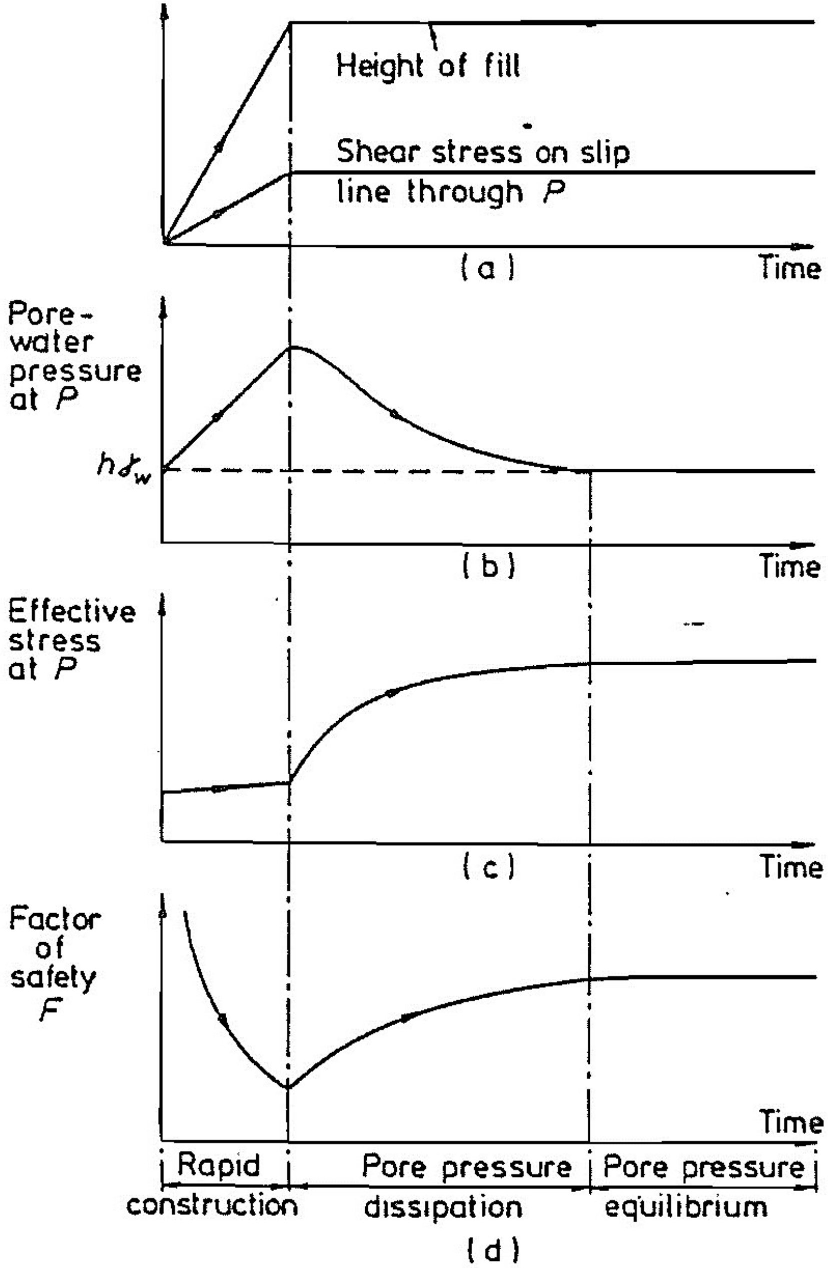
Three indications of impending failure

1. Increasing rate of settlement
2. Increasing pore pressure under constant load
3. Some lateral spreading

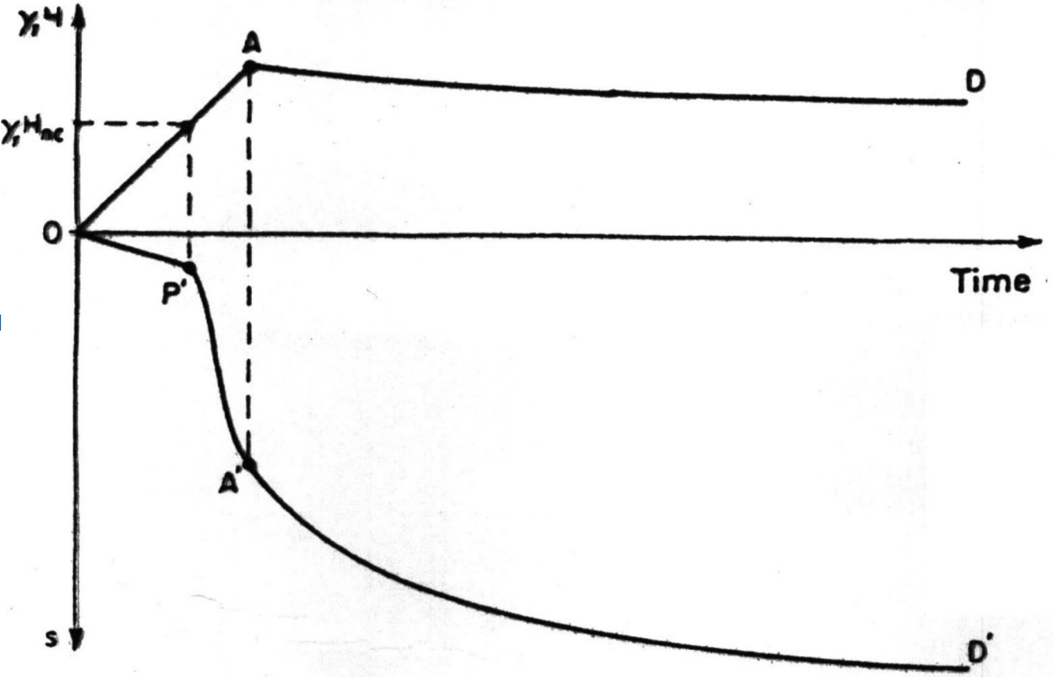
- "… increasing pore pressure was probably the best warning of all"
- From Crawford et al (1995) "Embankment failures at Vernon, British Columbia"; Canadian Geotechnical Journal, 32: 271 - 284



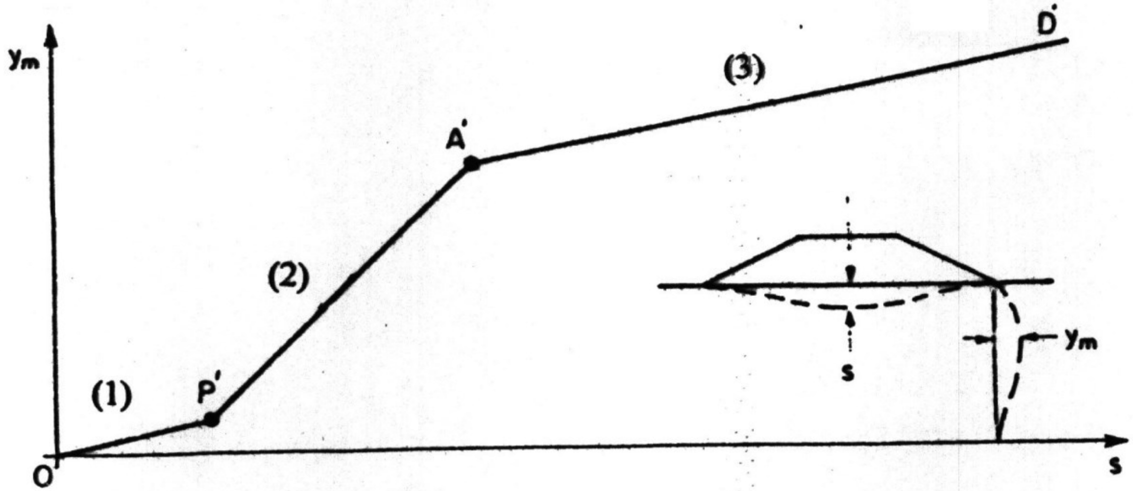
Pore pressure generated on a potential slip surface by embankment loading



Variation with time of the shear stress, local pore pressure, local effective stress, and factor of safety for a saturated clay foundation beneath an embankment (after Bishop and Bjerrum)



Typical variation in embankment load and settlement with time

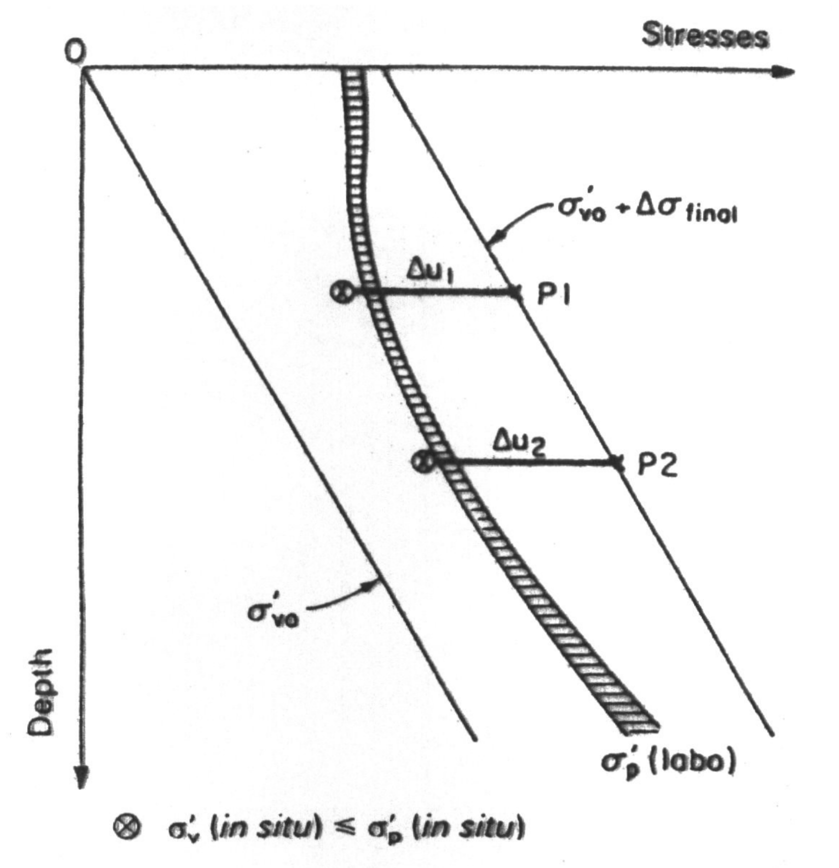


(1) $\Delta y_m = (0.18 \pm 0.09)\,\Delta s$

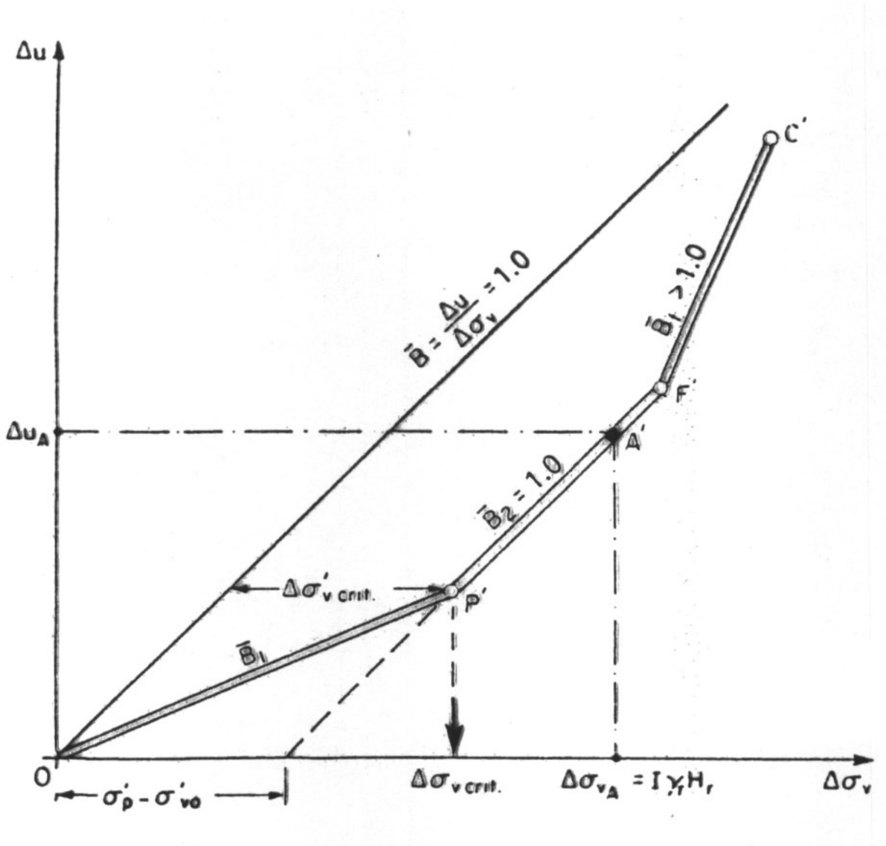
(2) $\Delta y_m = (0.91 \pm 0.2)\,\Delta s$

(3) $\Delta y_m = (0.16 \pm 0.02)\,\Delta s$

Typical relation between maximum horizontal displacement and settlement under an embankment

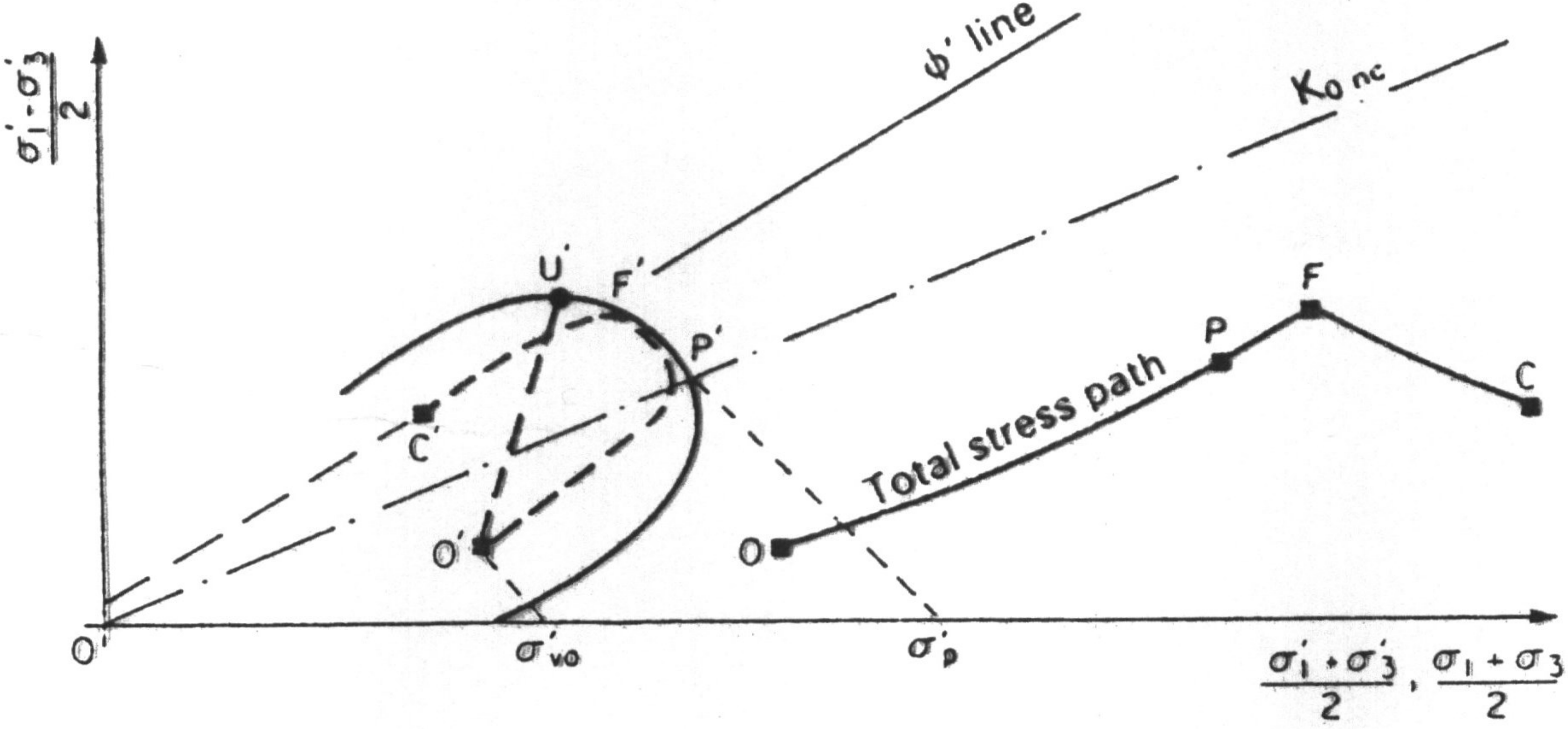


Deduction of pre-consolidation pressures when only pore pressure measured at the end of construction of the embankment are available



Relation between pore pressure and vertical total stress caused by an embankment

Behaviour of clay foundation soils



Typical stress path followed under the centre of an embankment

Case Study: Sunshine Motorway

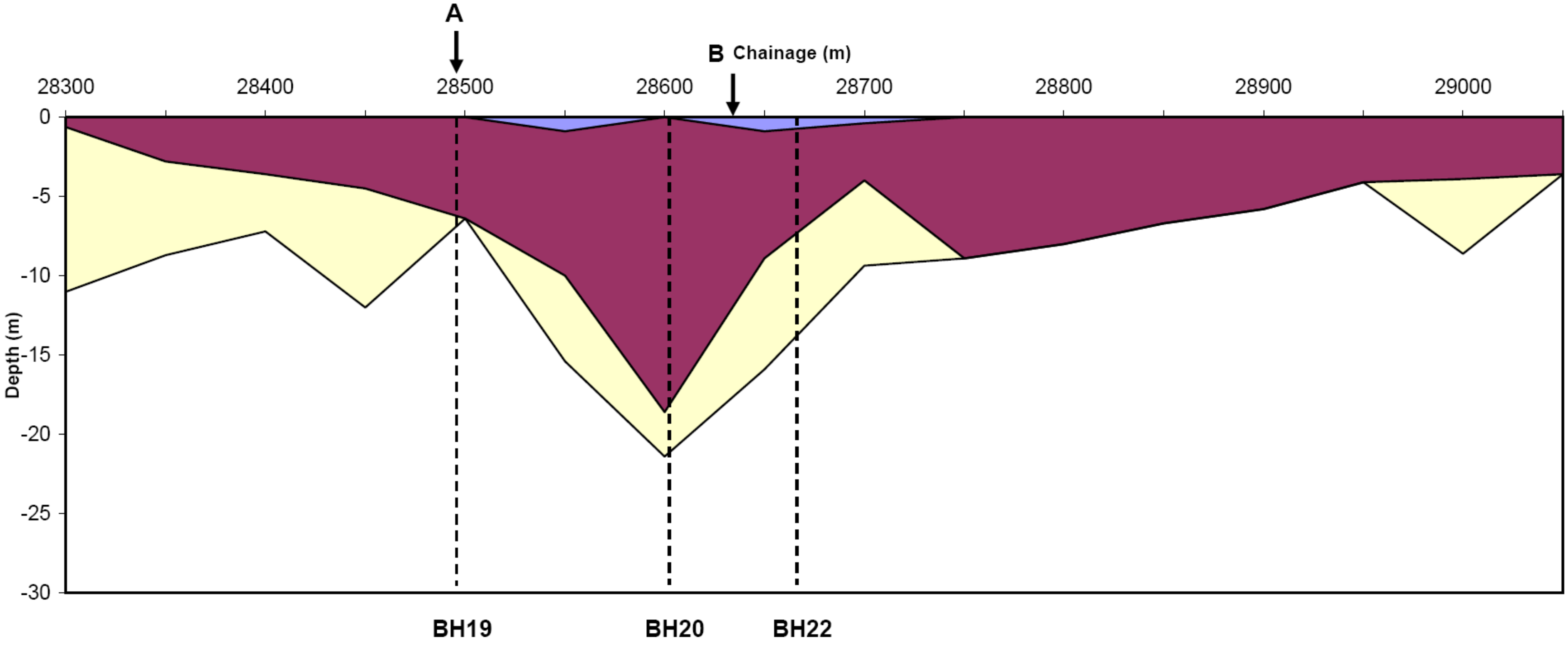
- Trial embankment for Sunshine Motorway on soft clays built in 1992
- Assess feasibility of
  - 2 stage construction in 300 days
  - First lift: 2.6m
- Investigate
  - In-situ compressibility & consolidation
  - Effectiveness of wick drains for settlement acceleration

Sunshine Motorway Site

2-a Difficulty of working on the site.

Sunshine Motorway

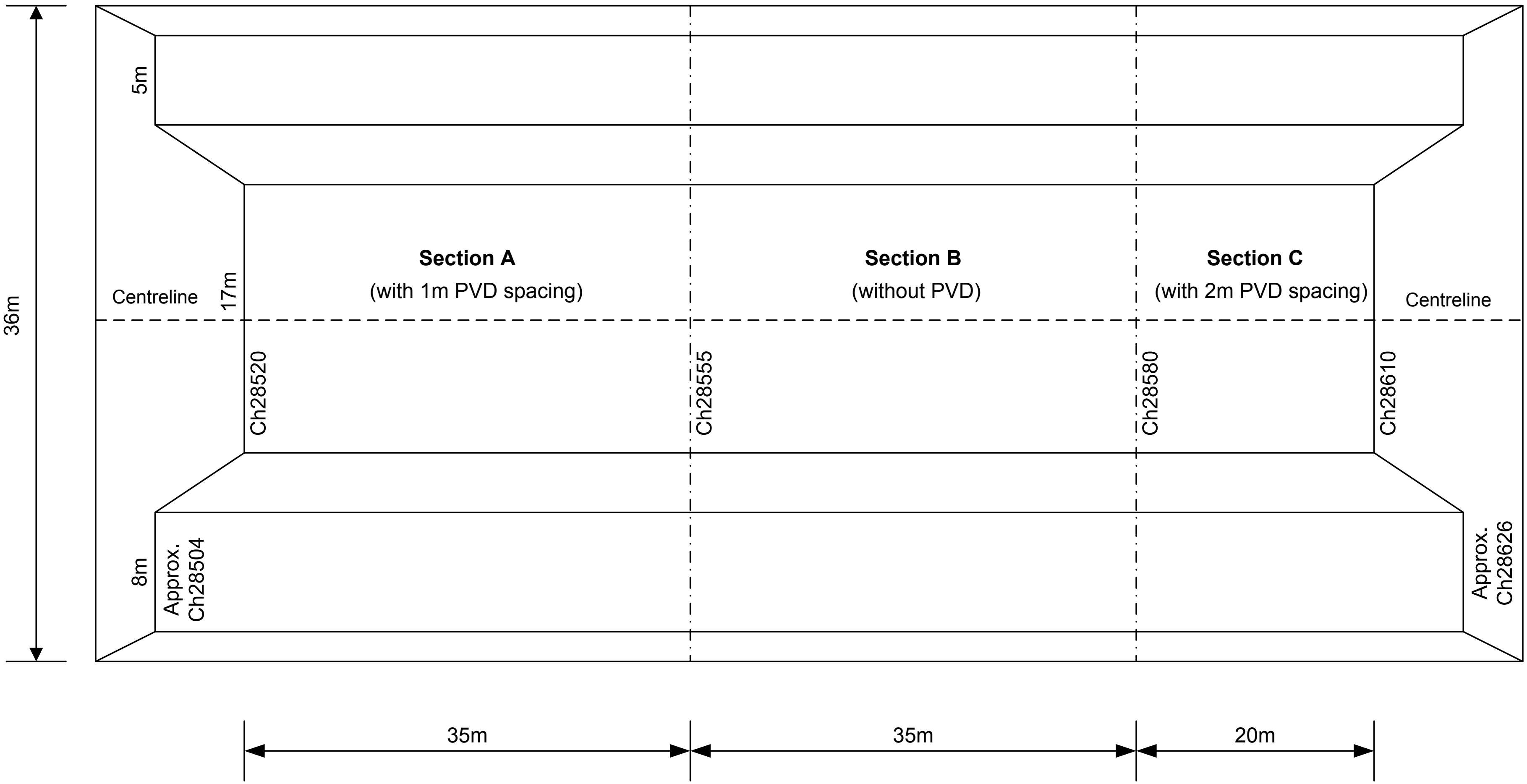
Trial Embankment



Note:
1. Start of test embankment is indicated as mark A
2. End of test embankment is indicated as mark B
3. BH 19, BH20 and BH 22 are also indicated

Sunshine Motorway Stage 2, Area 2 (Longitudinal Profile)

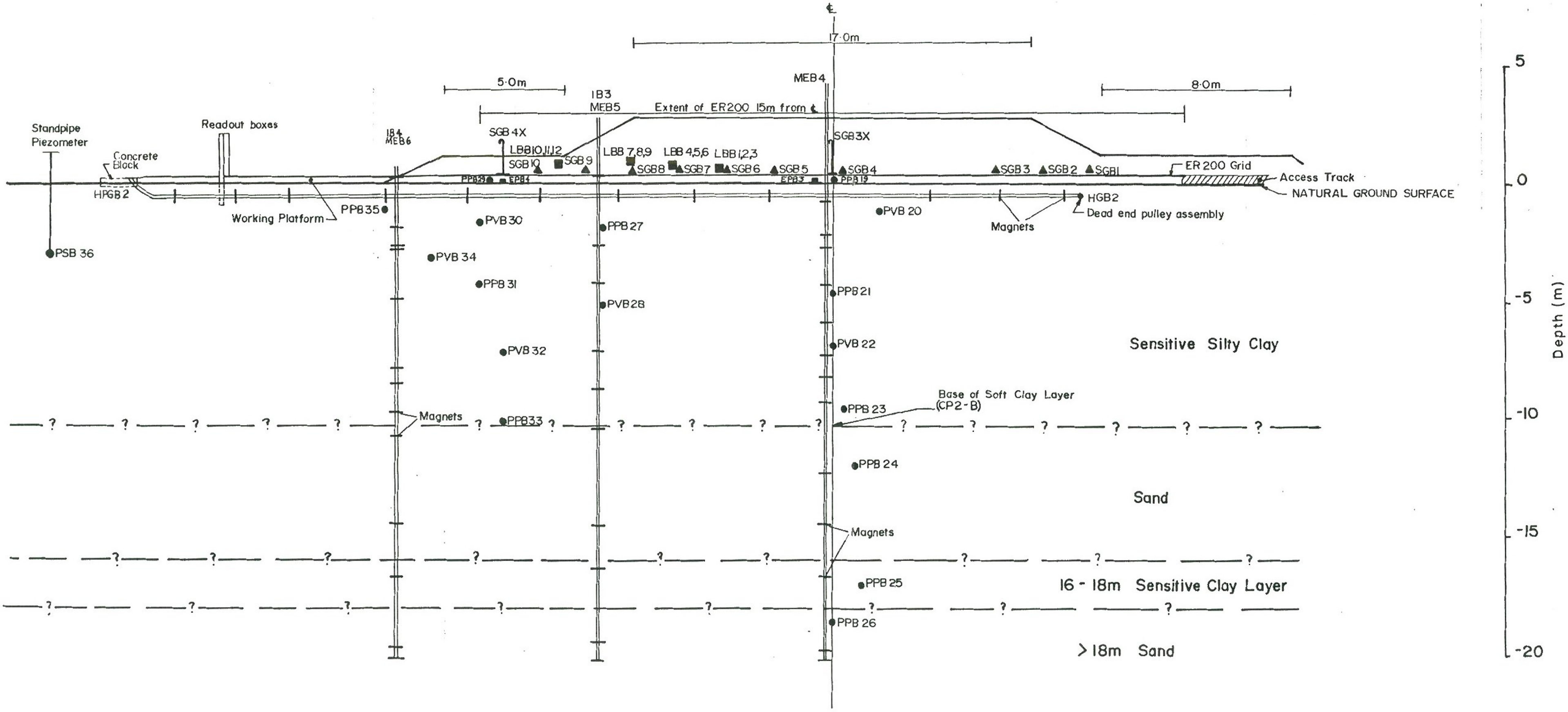
Sunshine Motorway



Locations and Dimensions of Test Embankment with Section A (with 1m PVD spacing), Section B (without PVD) and Section C (with 2m PVD spacing)

Sunshine Motorway

PLAN VIEW OF SECTION B

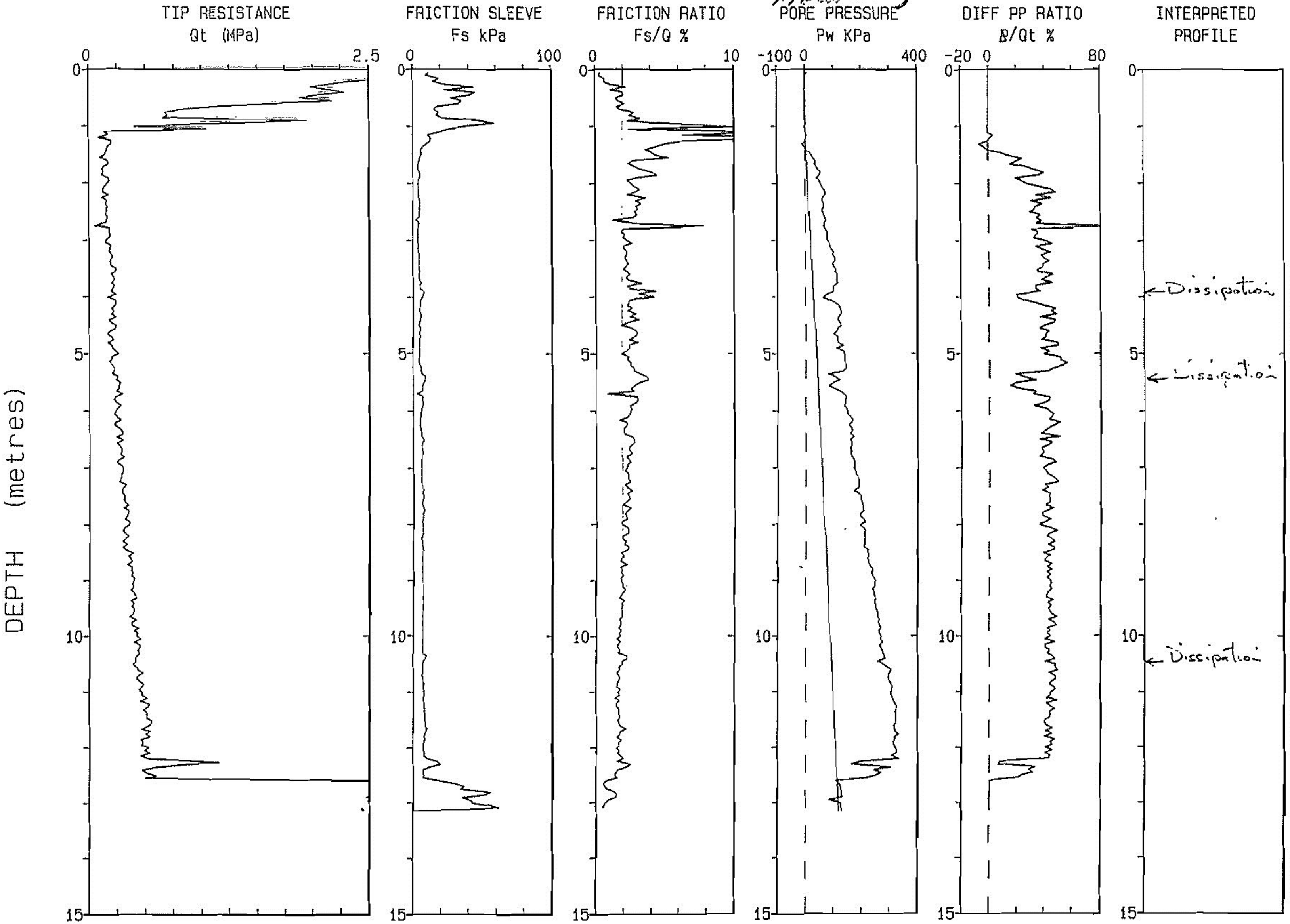


CROSS SECTION B-B'

Cross Section Showing Instrumentation

QUEENSLAND TRANSPORT

Operator : SG
CPT Date : 05/18/94 13: 38
Sounding PCP4__ Pg 1 / 1
Location OUTSIDE EMBANK'T
Cone Used 0380
Sunshine
[illegible]
Job # R62007



Depth Increment : .05 m
Max Depth : 13.15 m

Sunshine Motorway
Geotechnical Properties

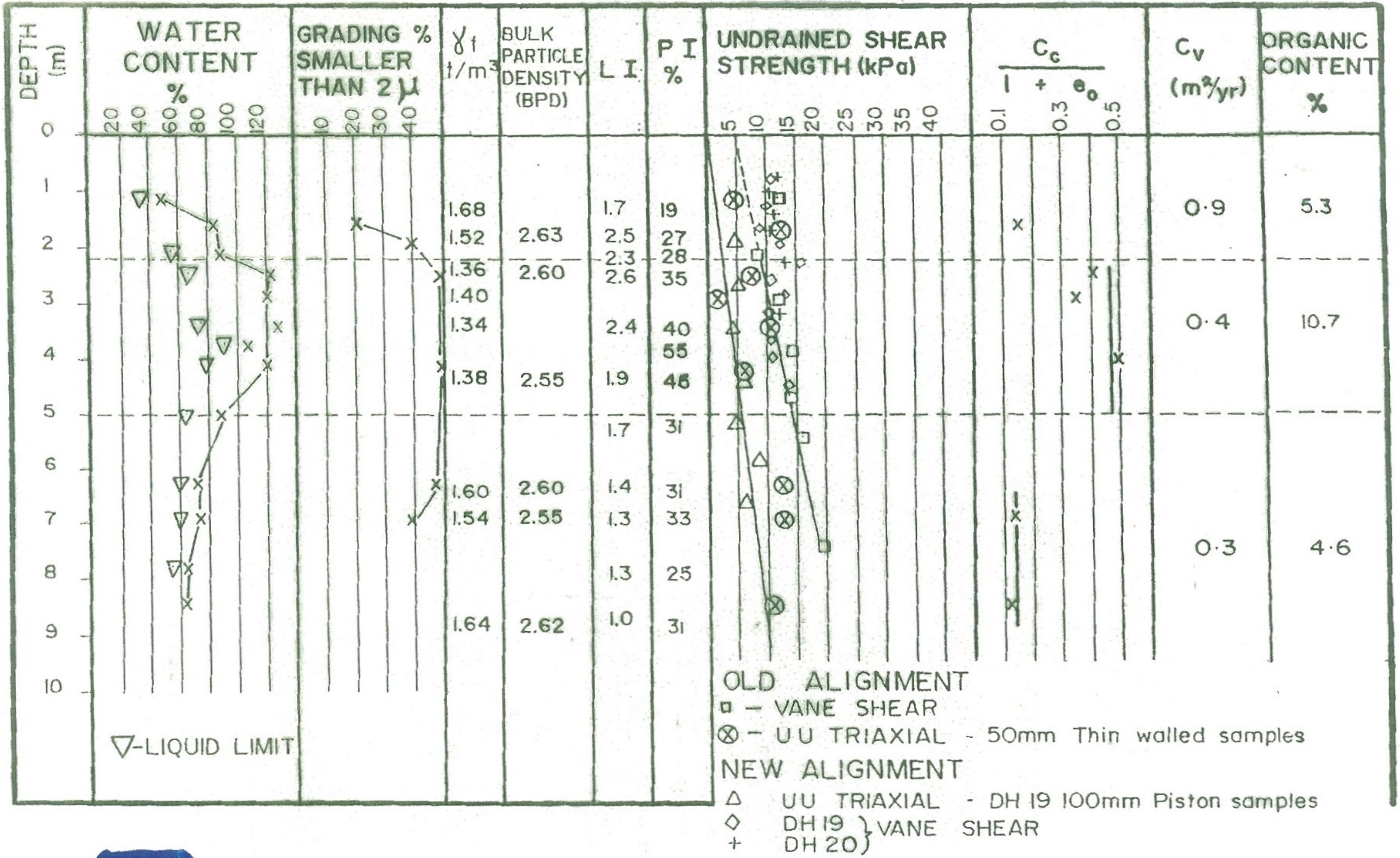
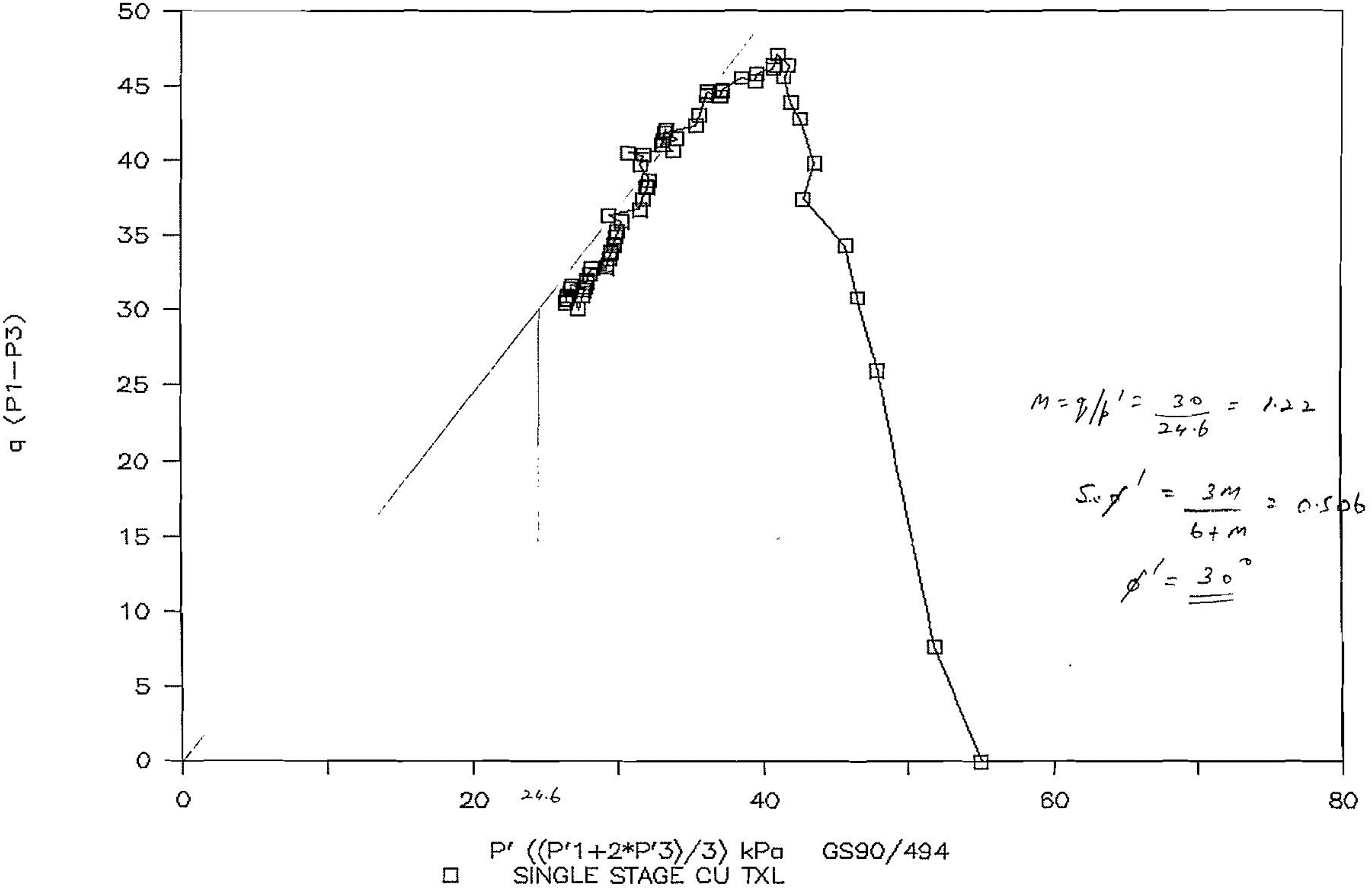


Fig. 1.1 A TYPICAL PROFILE OF THE GEOTECHNICAL CHARACTERISTICS (ch 28350m - ch 28740m) - DH 22 (Old Alignment)

SUNSHINE MOTORWAY (STAGE 2) G.I.

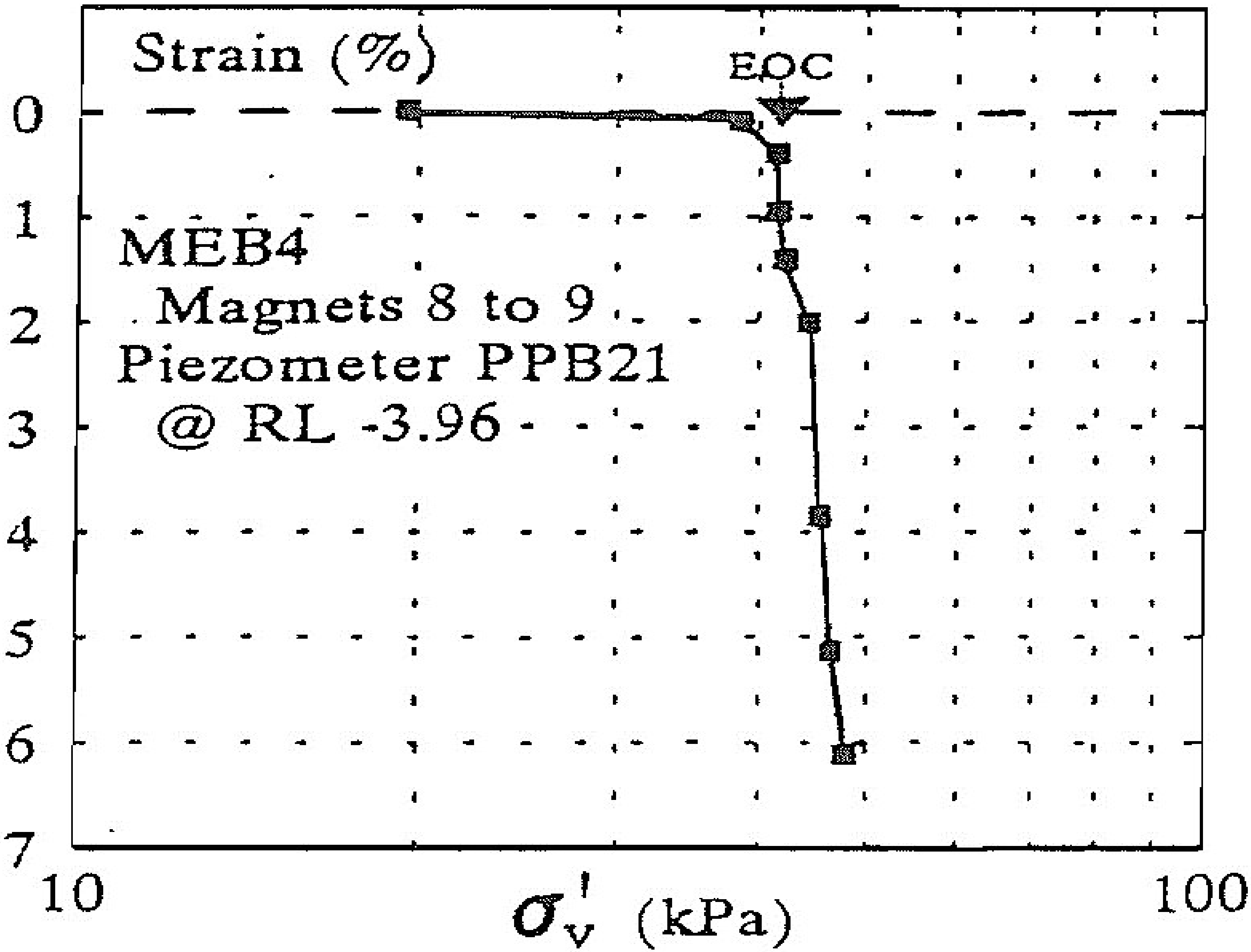
STRESS PATH PLOT



$M = q/p' = \frac{30}{24.6} = 1.22$

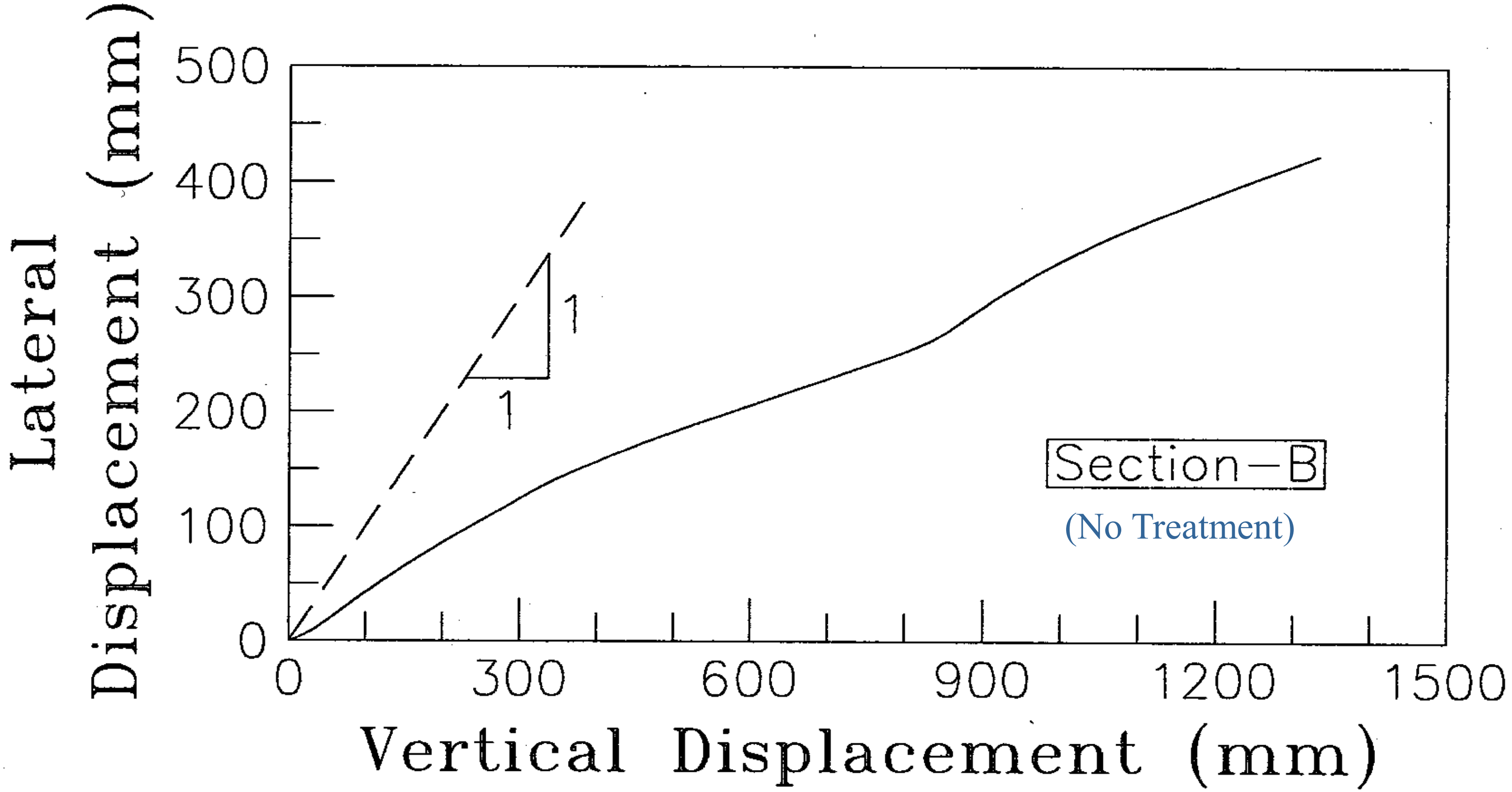
$\sin \phi' = \frac{3M}{6+M} = 0.506$

$\phi' = \underline{\underline{30^\circ}}$

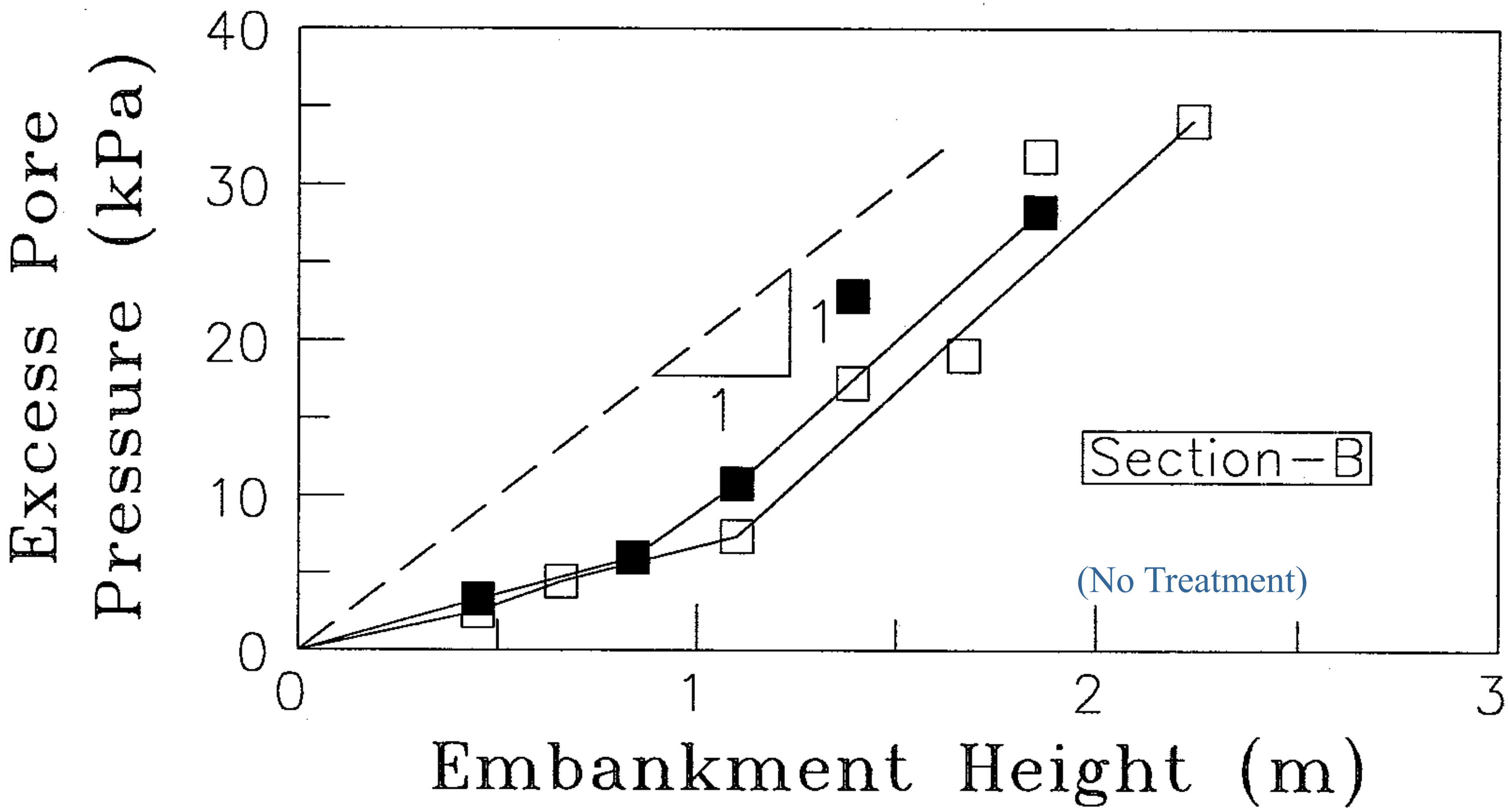


Insitu stress-strain curve (Layer 2)

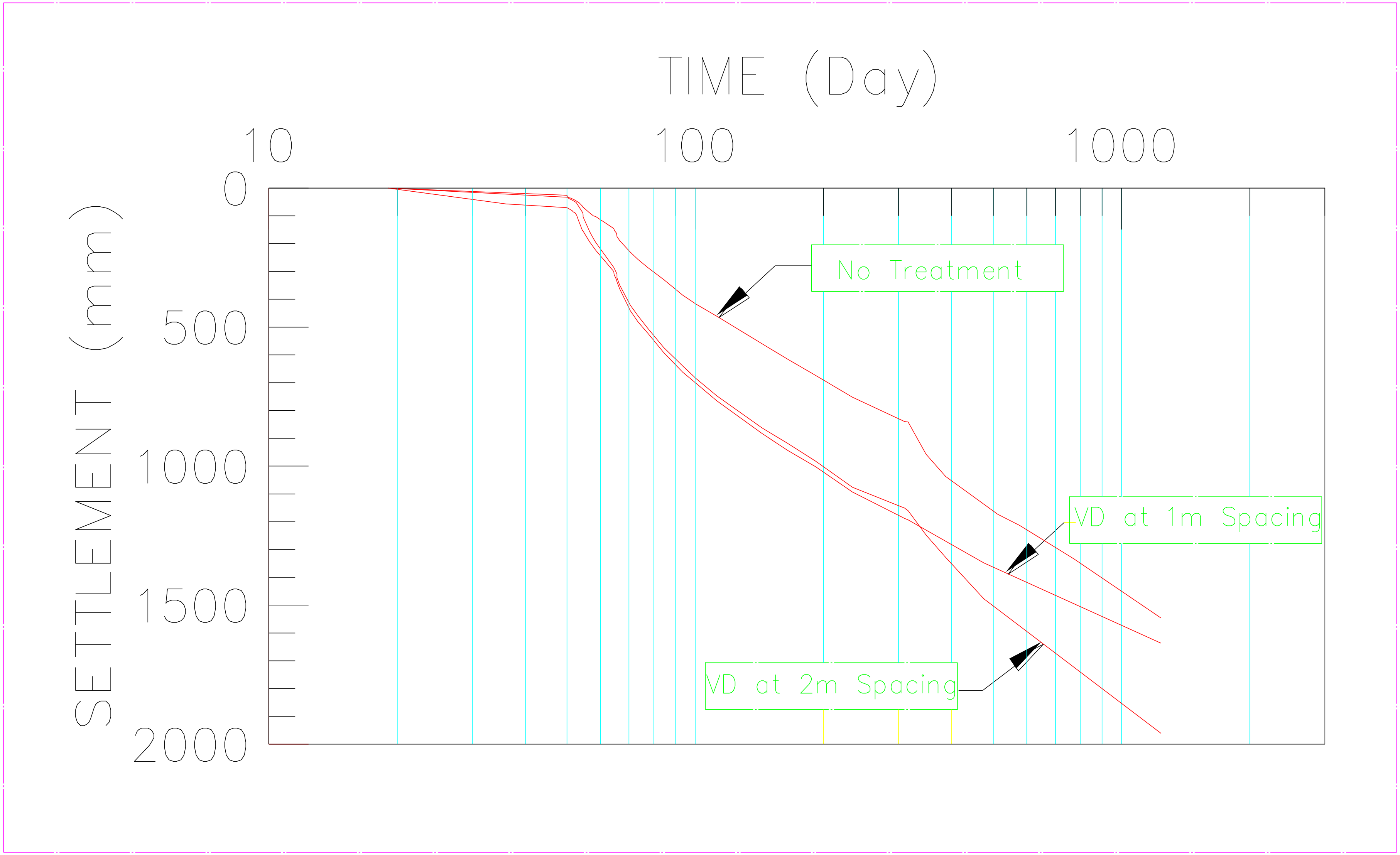
Sunshine Motorway Lateral Movement



Sunshine Mwy Pore Pressure Vs Vertical Total Stress



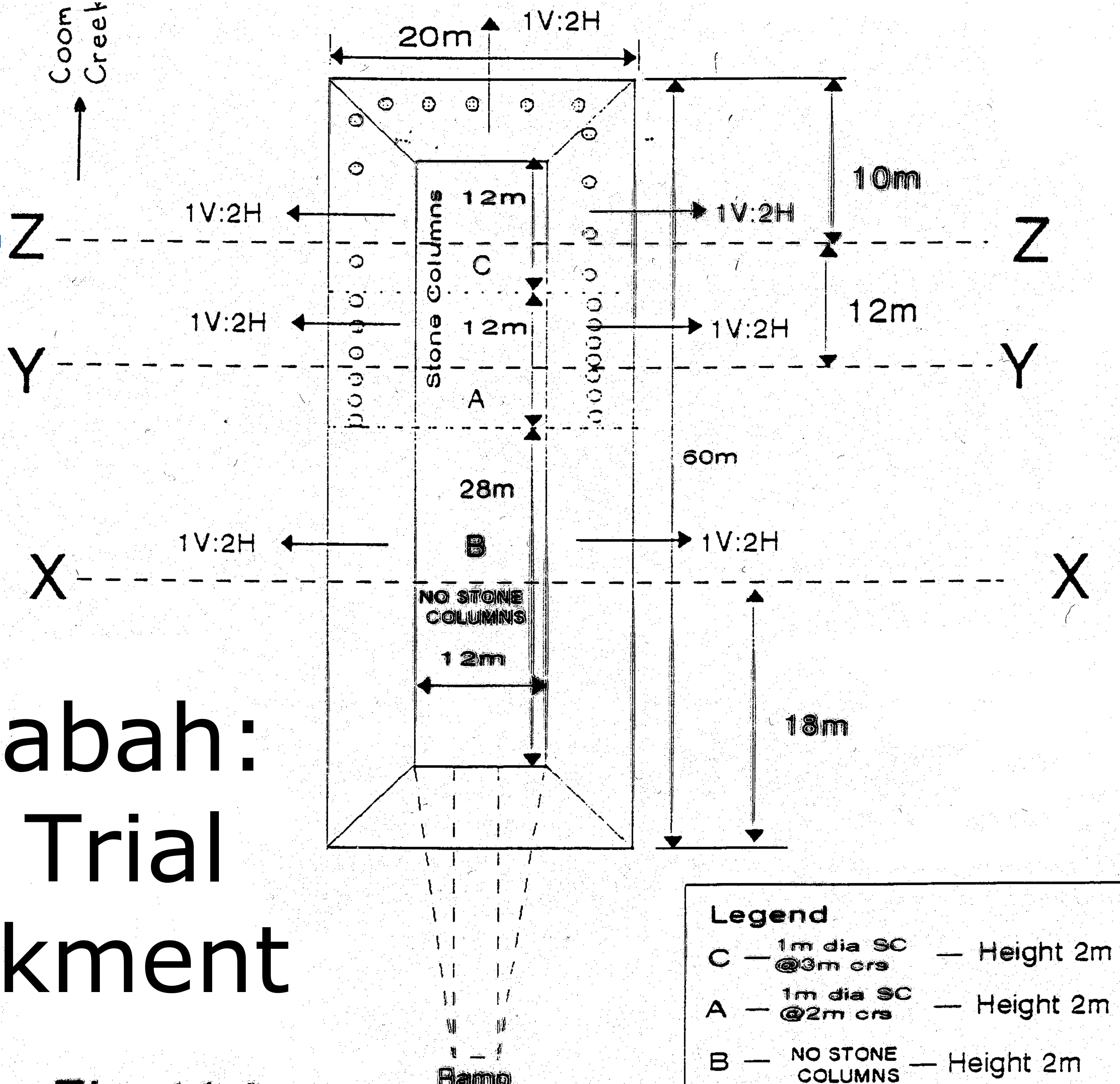
Sunshine Mwy Settlements



Case Study: Coombabah Creek

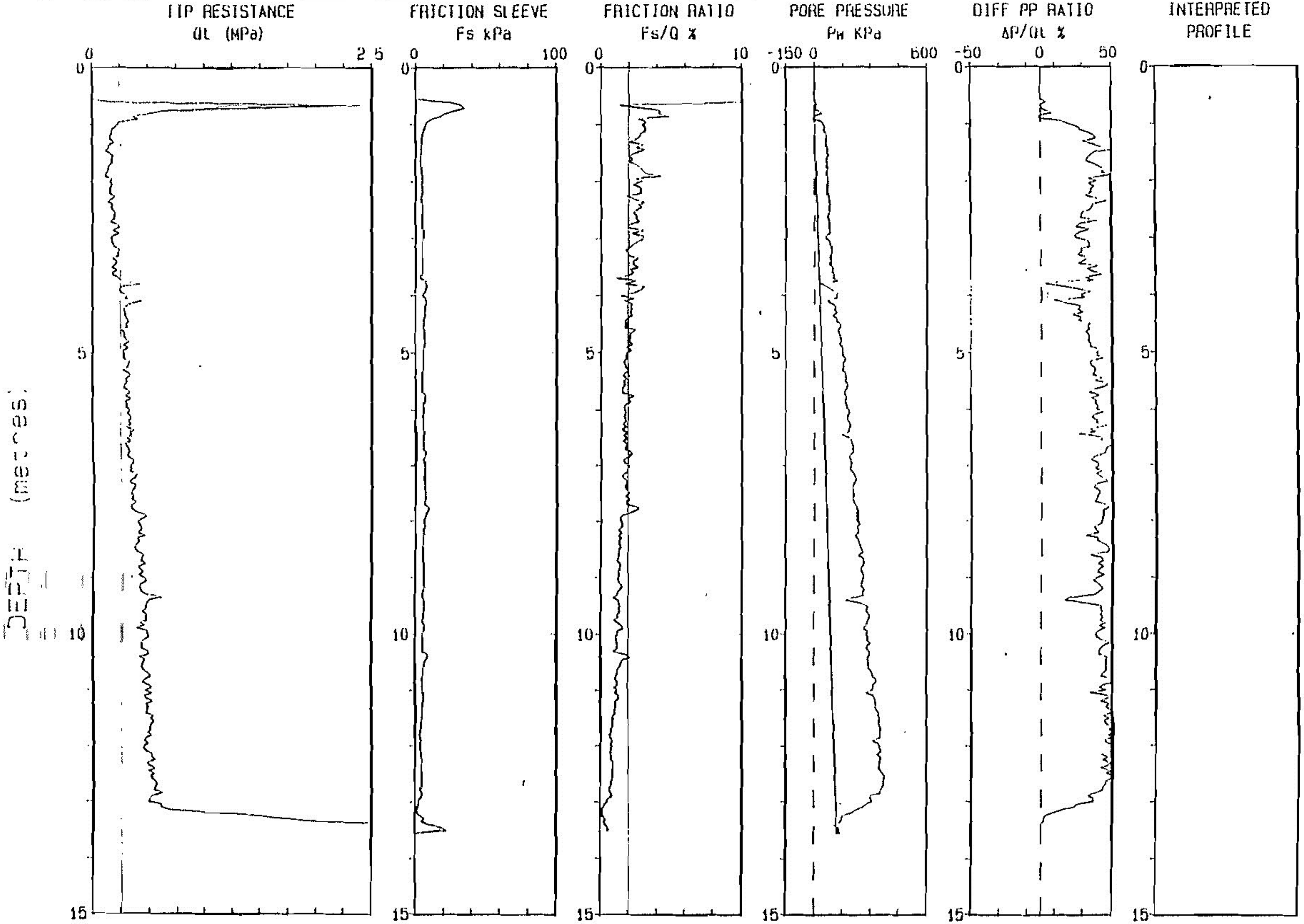
- Trial Embankment on the Gold Coast (1995) on soft clays
- Compressibility and consolidation
- Effectiveness of stone columns for:
  - Settlement reduction
  - Settlement acceleration

Coombabah: Plan of Trial Embankment



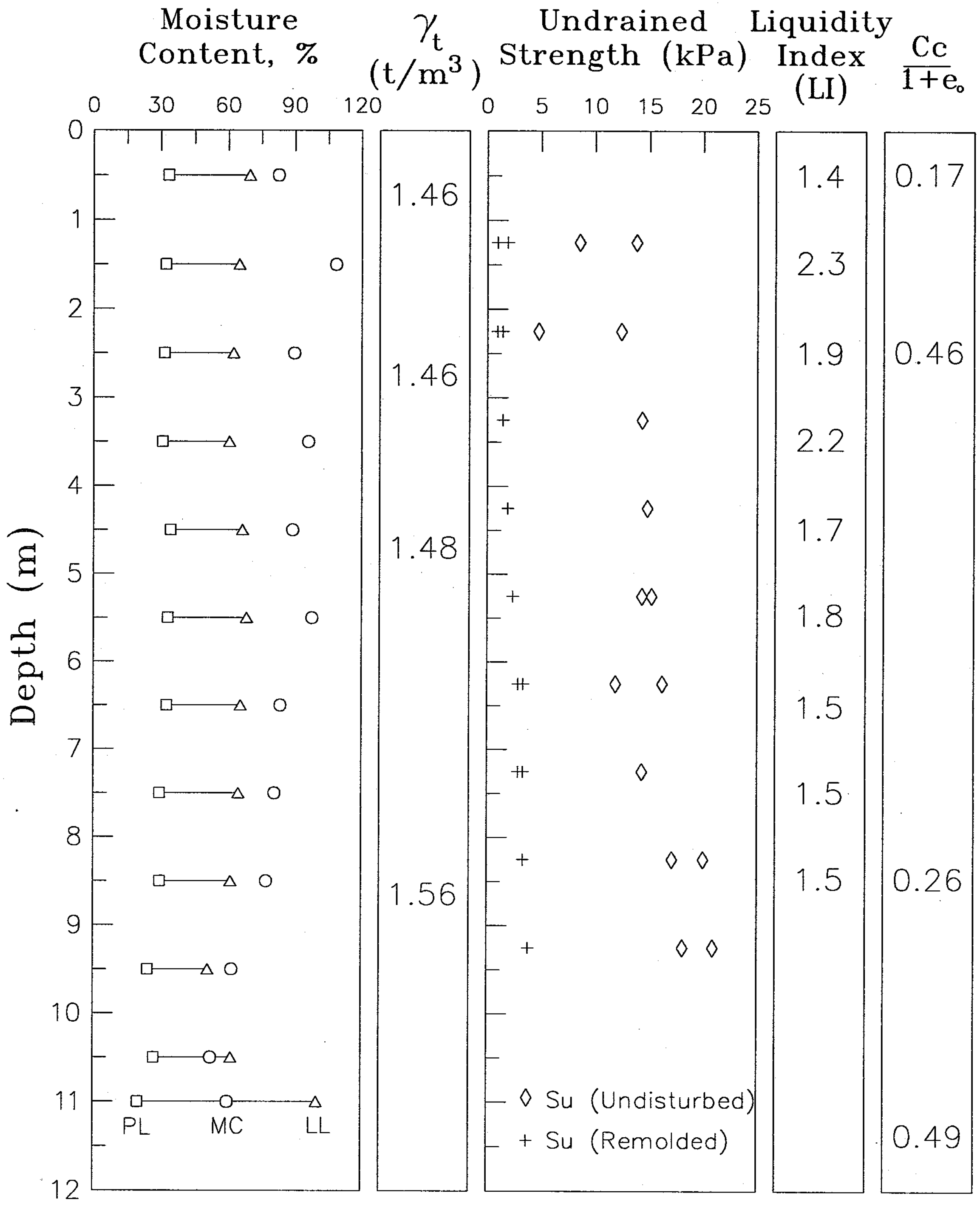
QUEENSLAND TRANSPORT

Operator : SG
CPT Date : 08/10/94 08:47
Sounding : HTPCP2
Pg 1 / 1
Location : HELENSVALE
Cone Used : 0351
Job# : MG0104

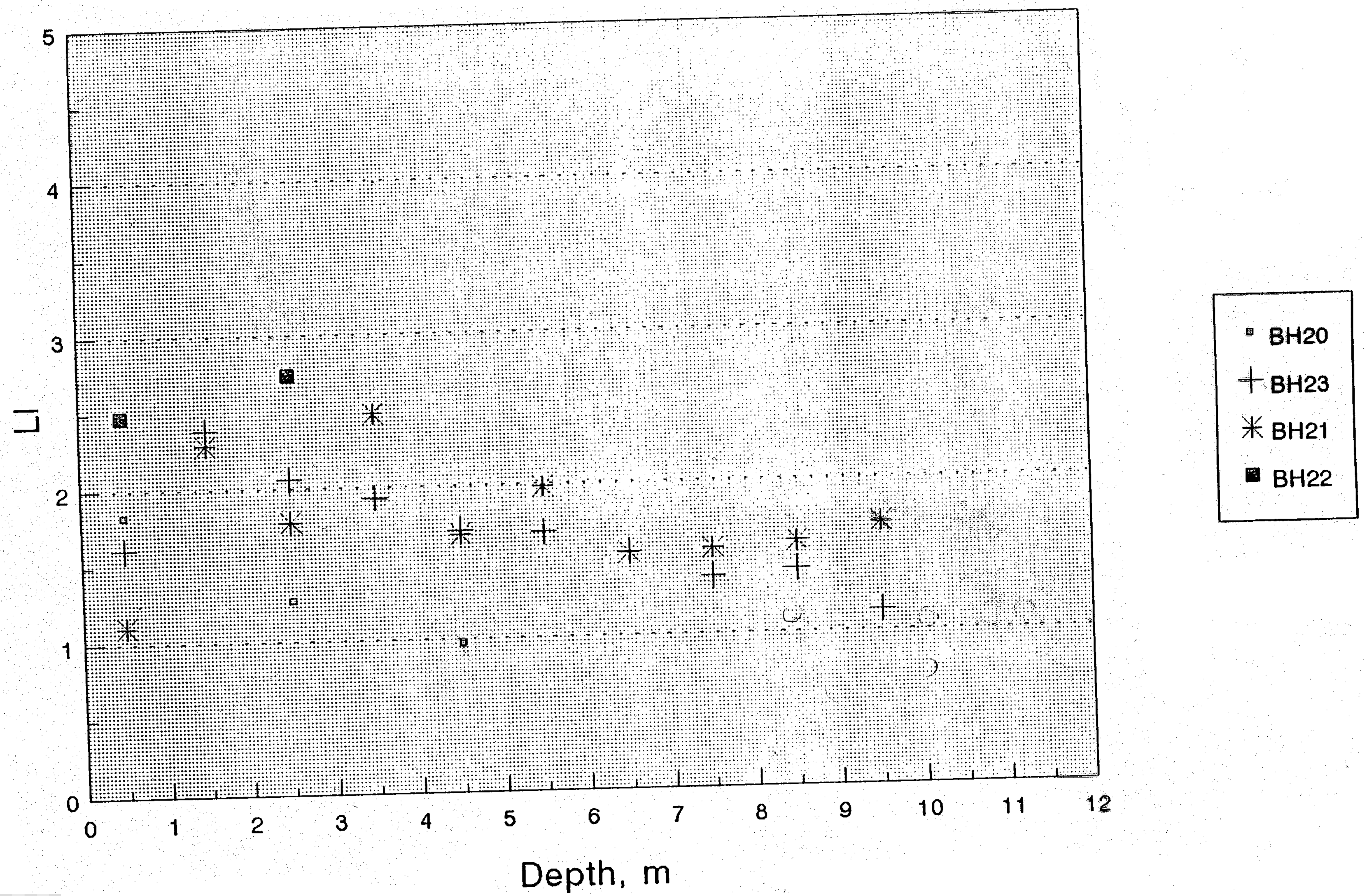


Depth Increment : .05 m
Max Depth : 13.55 m

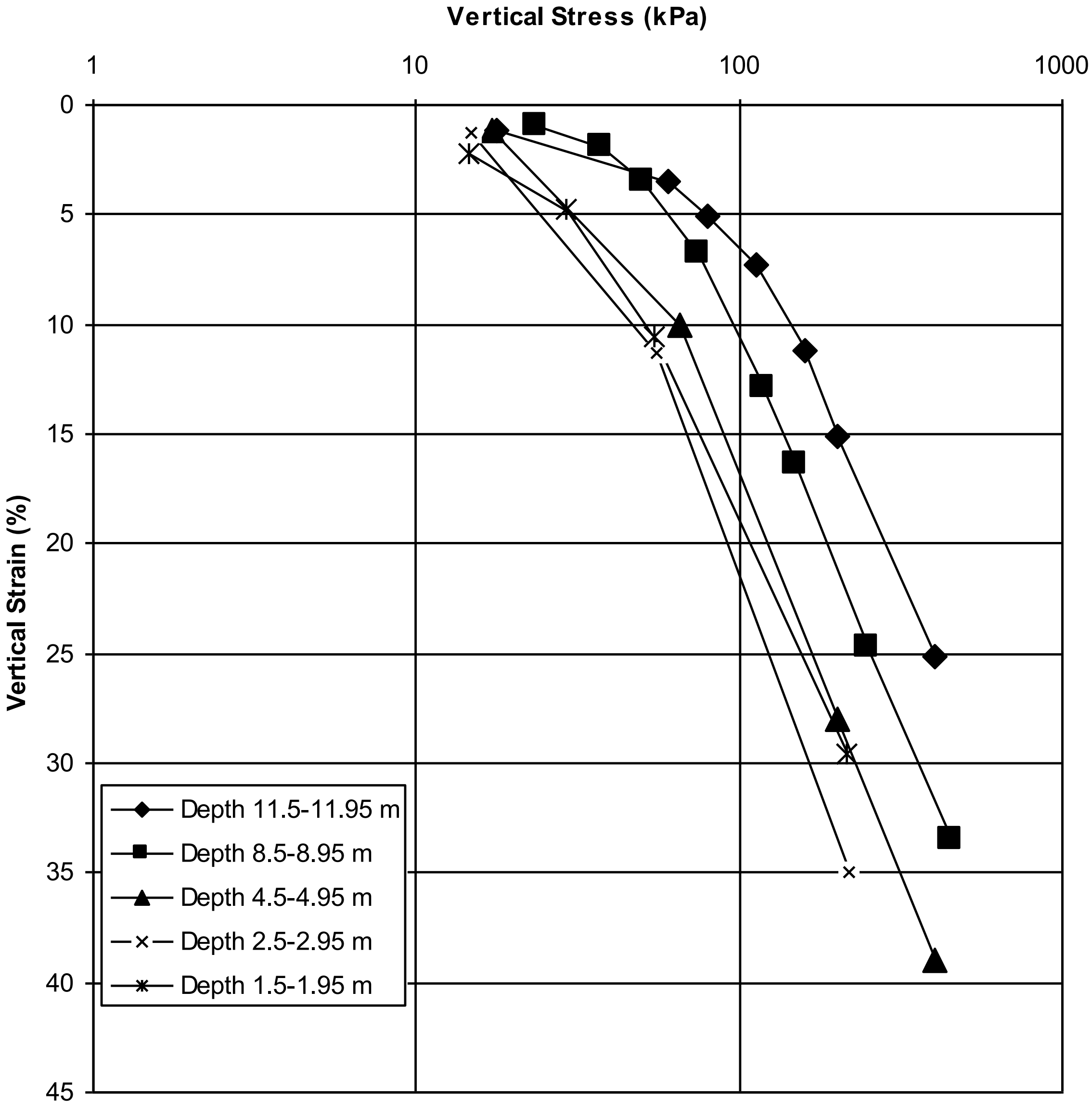
Coombabah Geotechnical Properties



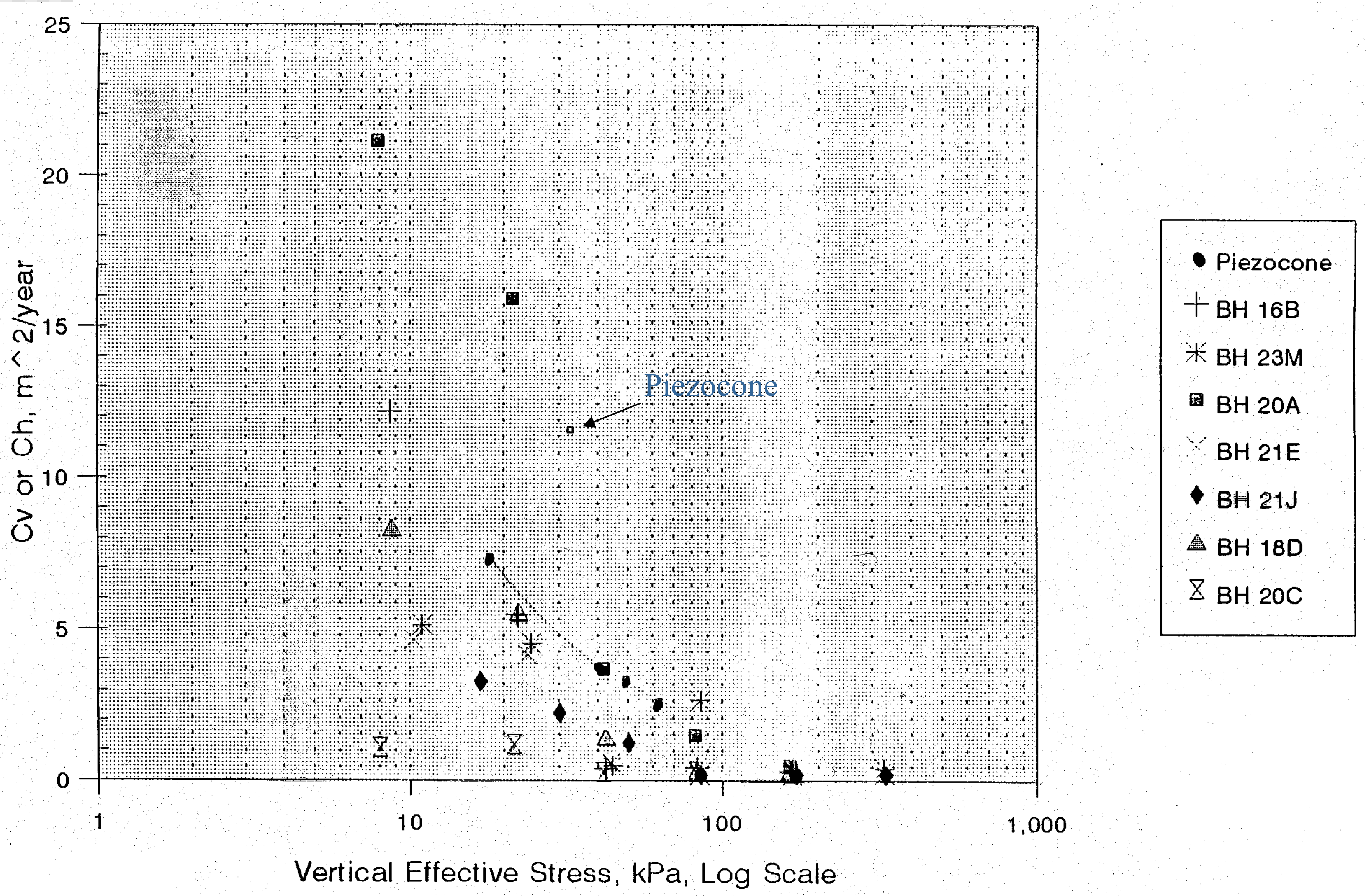
Liquidity Index Profile

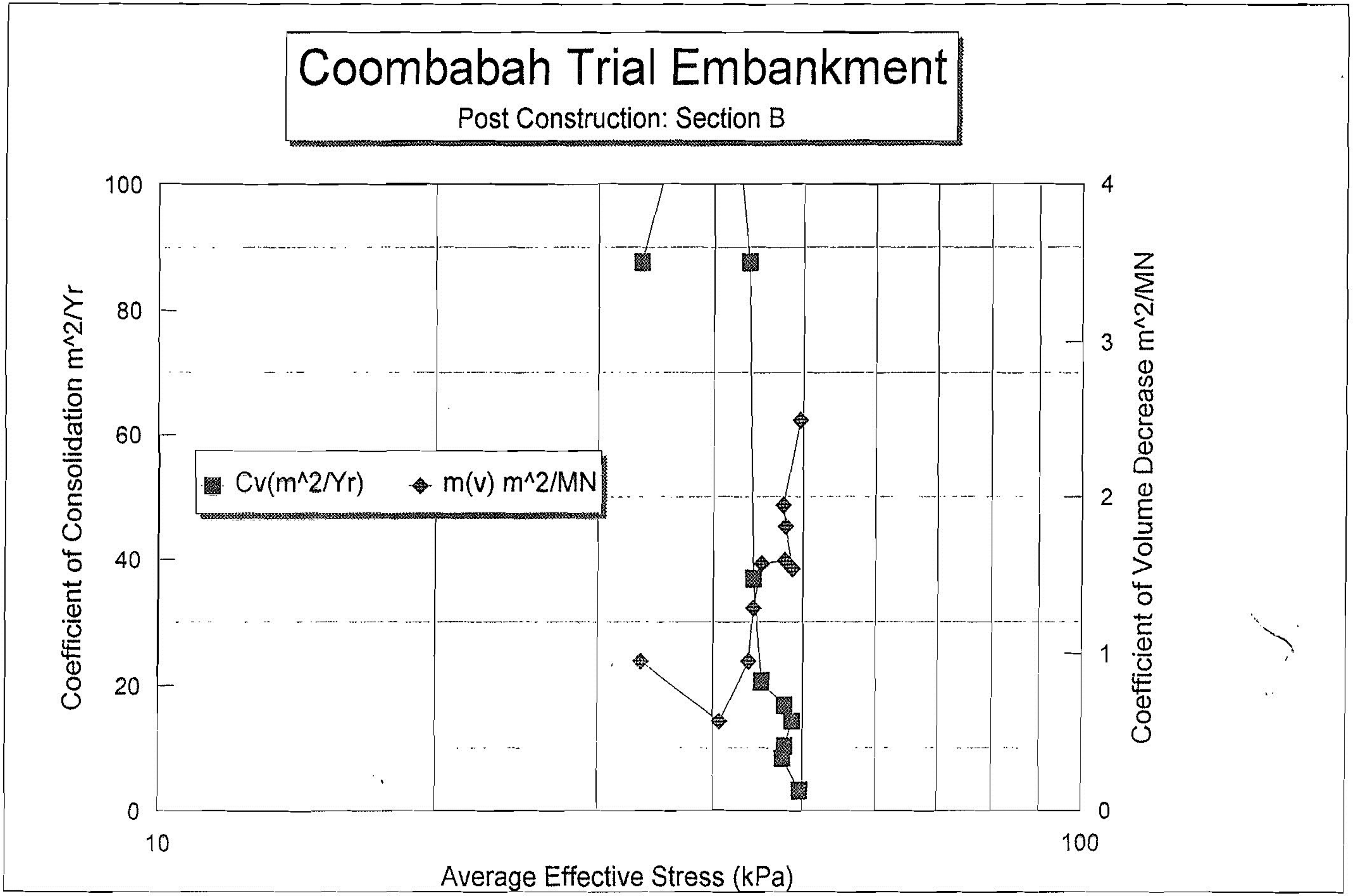


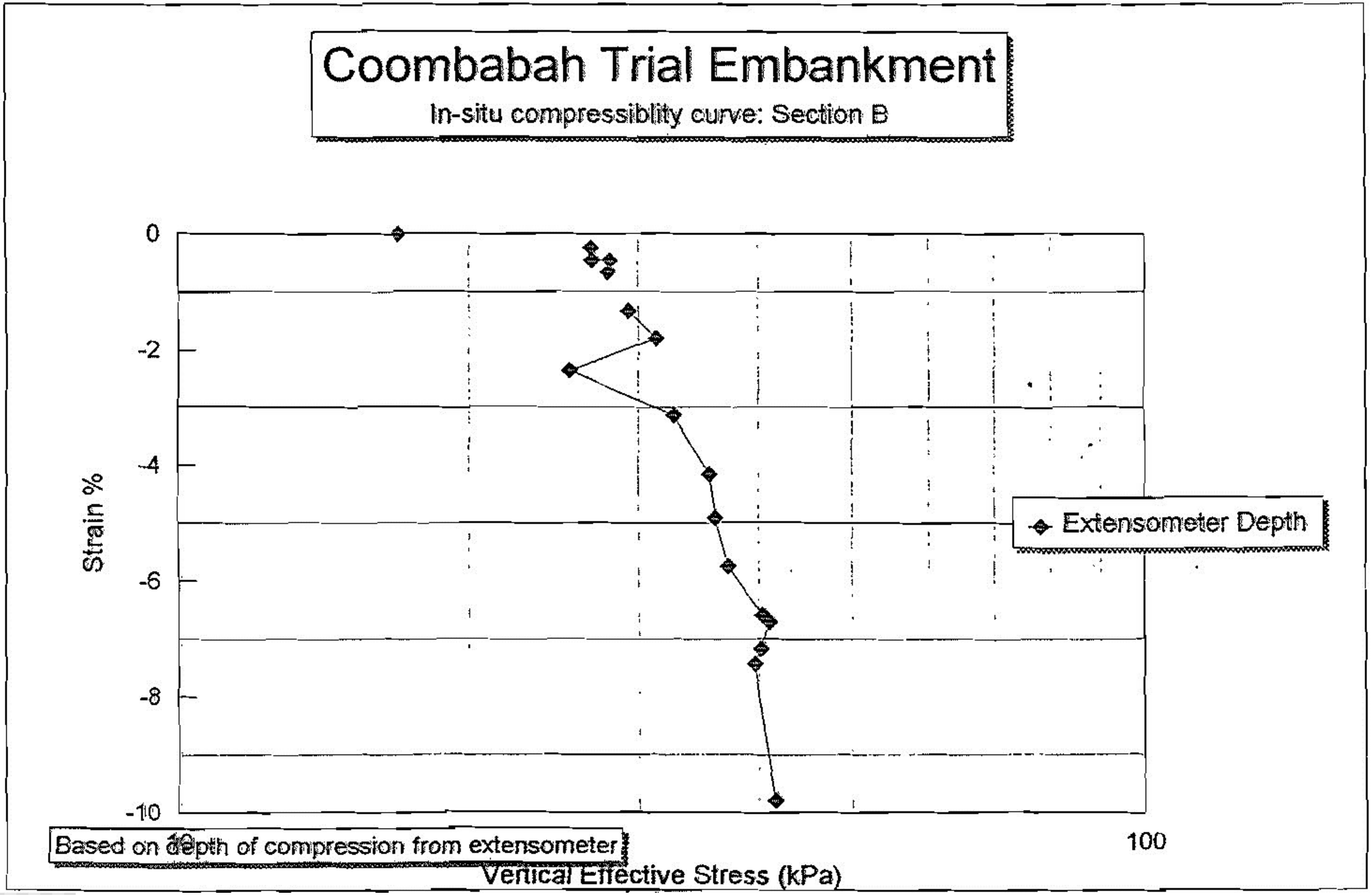
Compressibility Curves



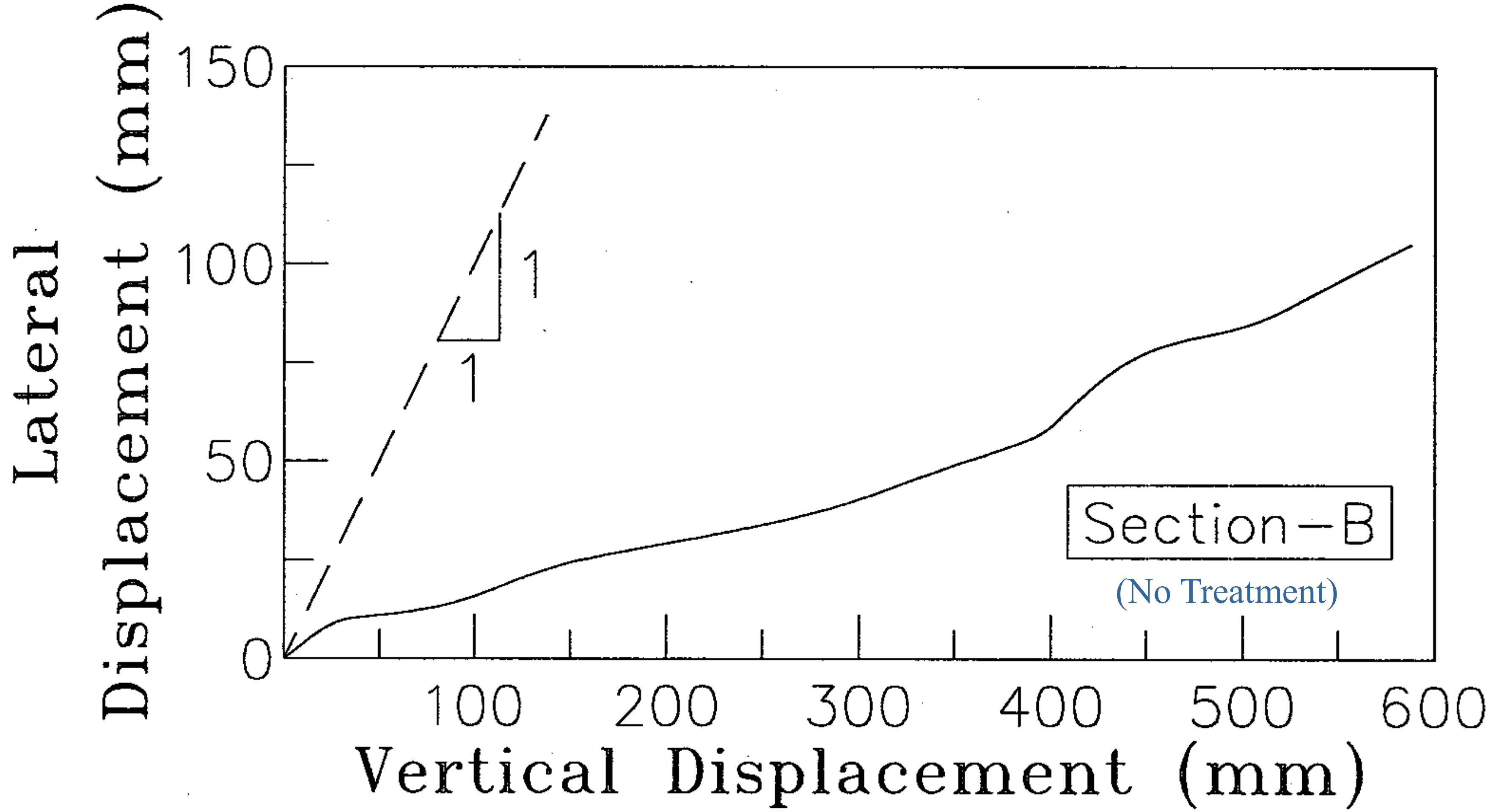
Effective Stress & Piezocone Ch



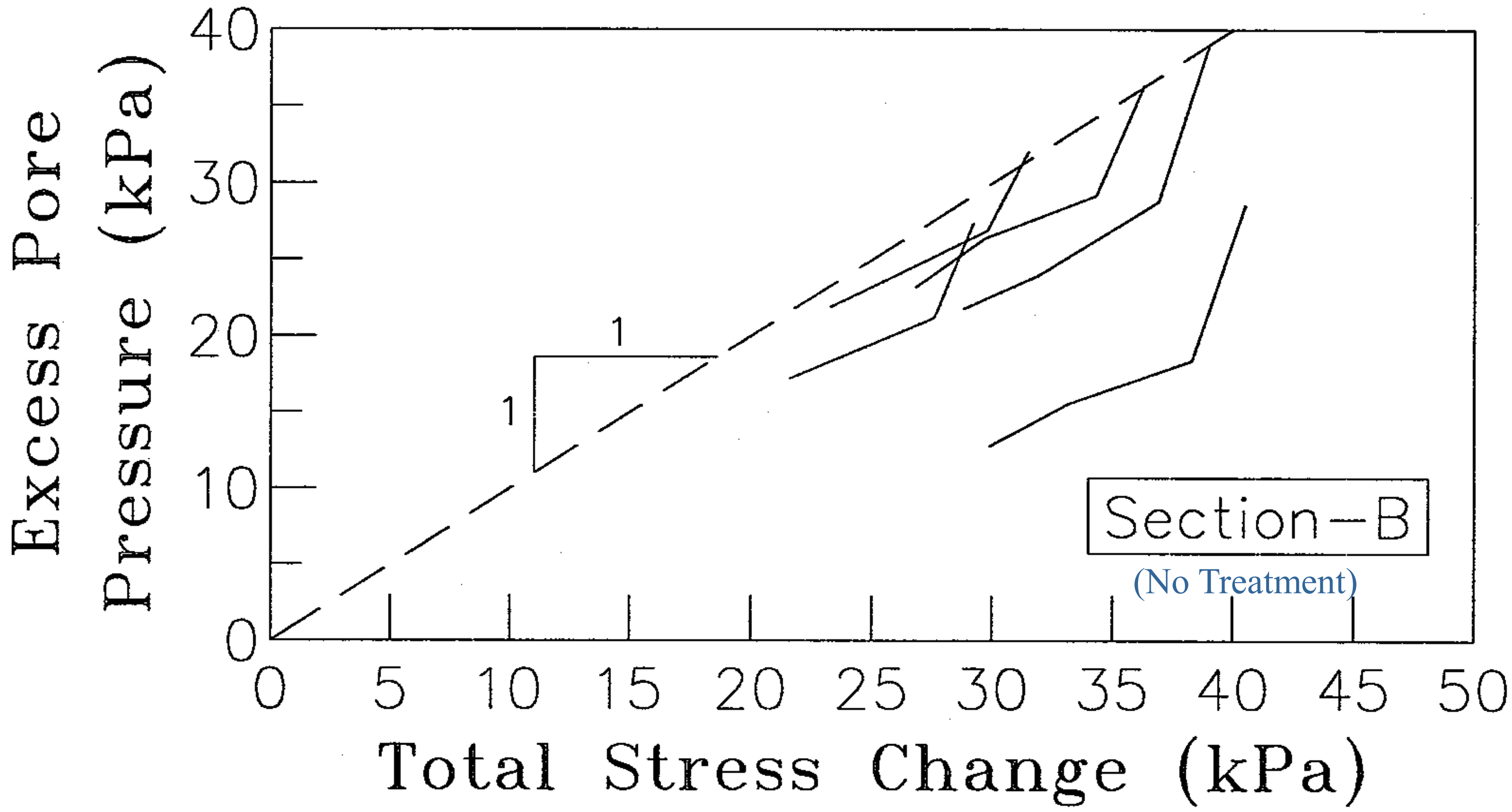

Coombabah Trial Embankment
Post Construction: Section B
Cv(m^2/Yr)
m(v) m^2/MN
Coefficient of Consolidation m^2/Yr
Coefficient of Volume Decrease m^2/MN
Average Effective Stress (kPa)
100
80
60
40
20
0
4
3
2
1
0
10
100


Coombabah Trial Embankment
In-situ compressiblity curve: Section B
Strain %
0
-2
-4
-6
-8
-10
10
100
Vertical Effective Stress (kPa)
Extensometer Depth
Based on depth of compression from extensometer

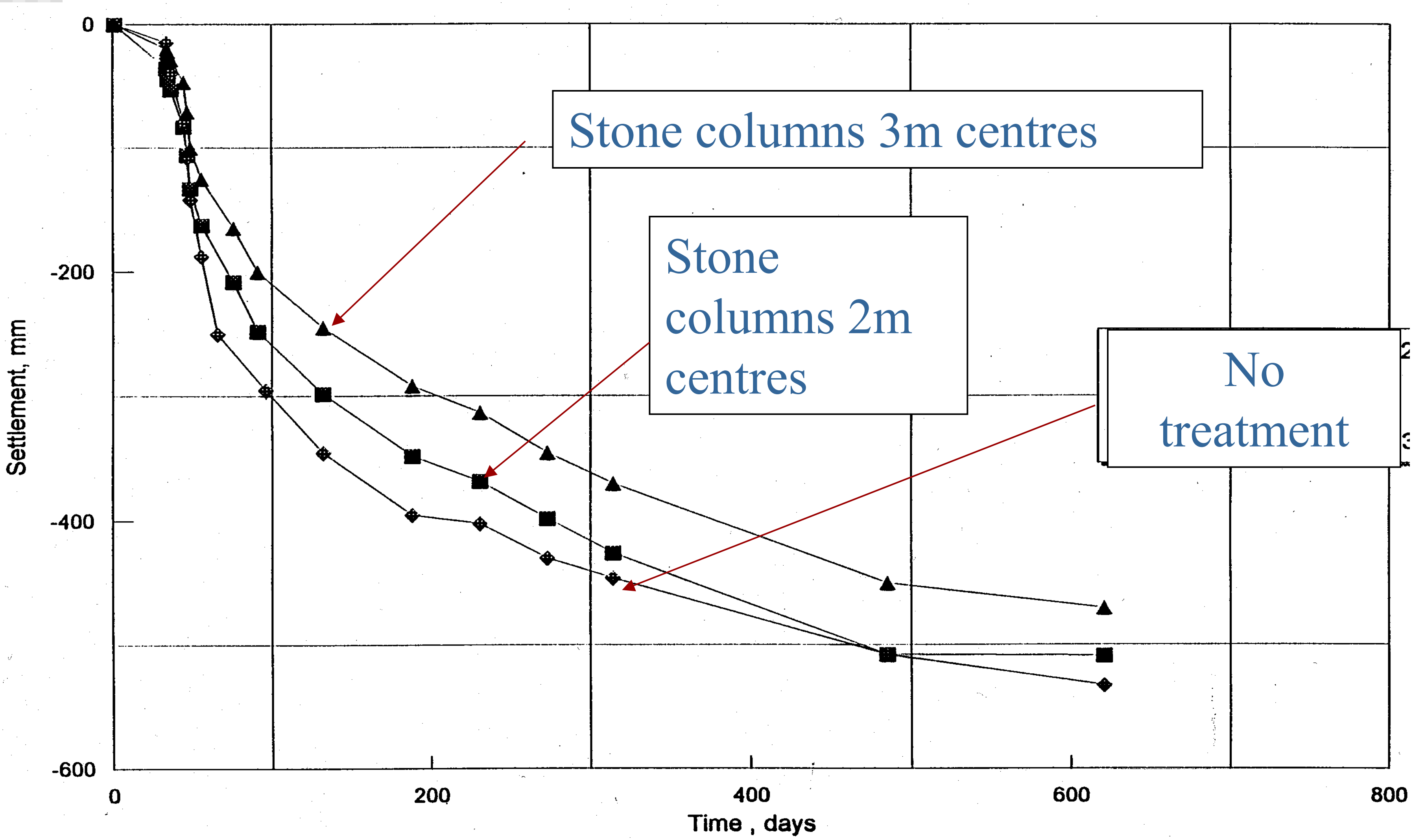
Coombabah
Lateral Movement



Coombabah Pore Pressure Vs Vertical Total Stress



Settlement vs treatment



Stone columns 3m centres

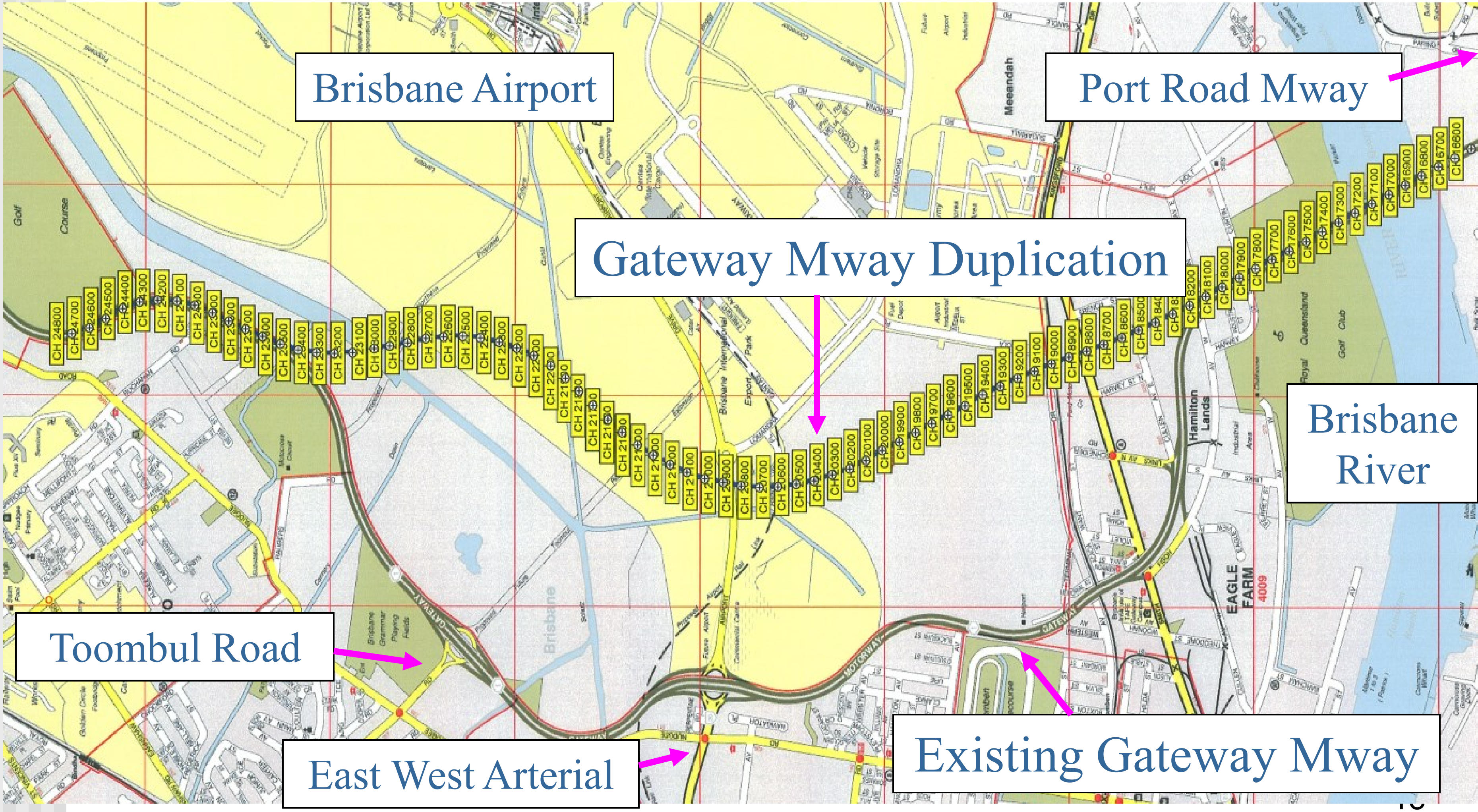
Stone columns 2m centres

No treatment

Gateway Arterial

- Soft Clays along the alignment – 15m thick
- Some past projects in the area:
  - East-West Arterial (mid 80’s)
  - Toombul Road (1992/93)
  - West of Bald Hills Creek (1994)

Alignment



Brisbane Airport

Port Road Mway

Gateway Mway Duplication

Brisbane River

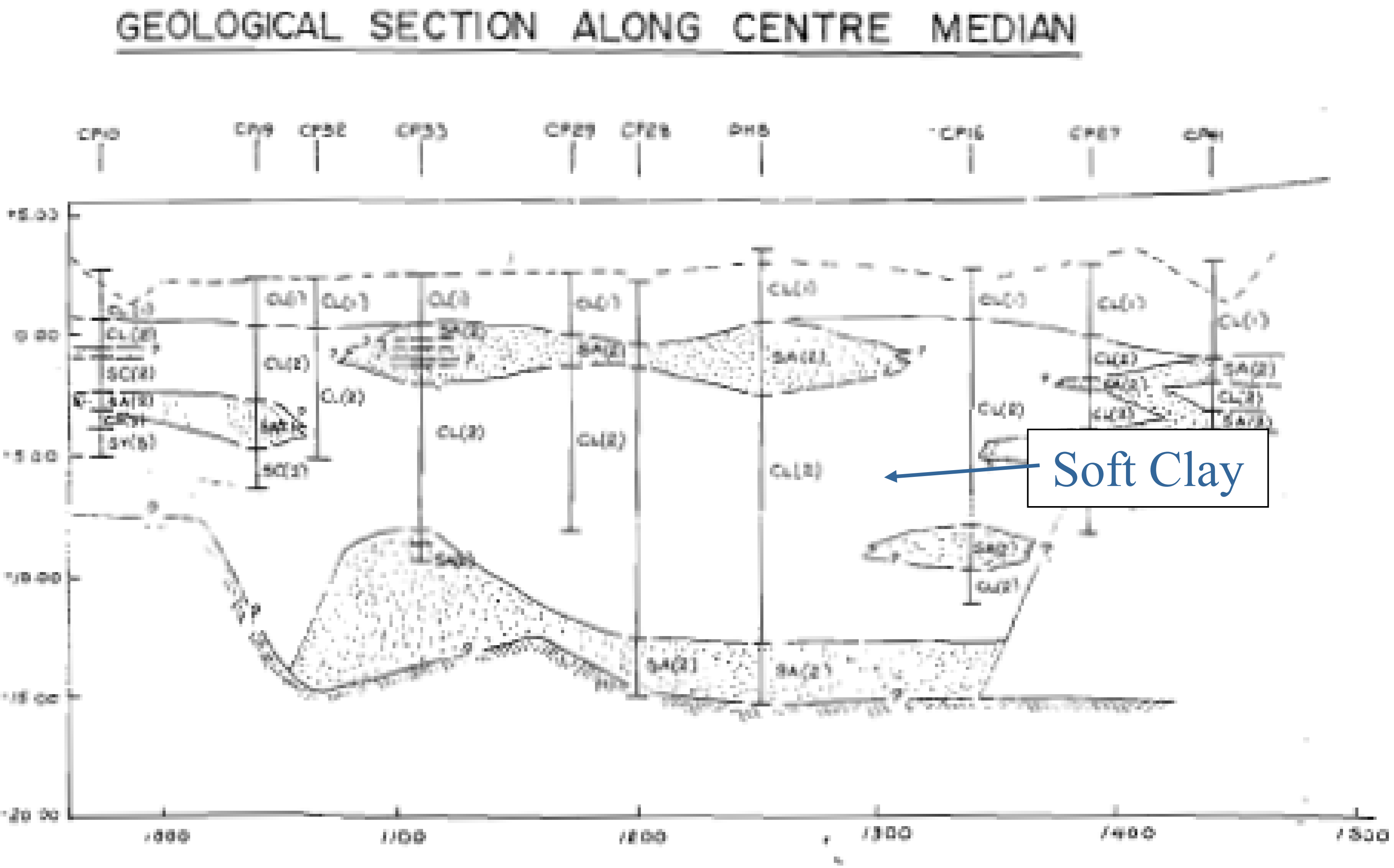
Toombul Road

East West Arterial

Existing Gateway Mway

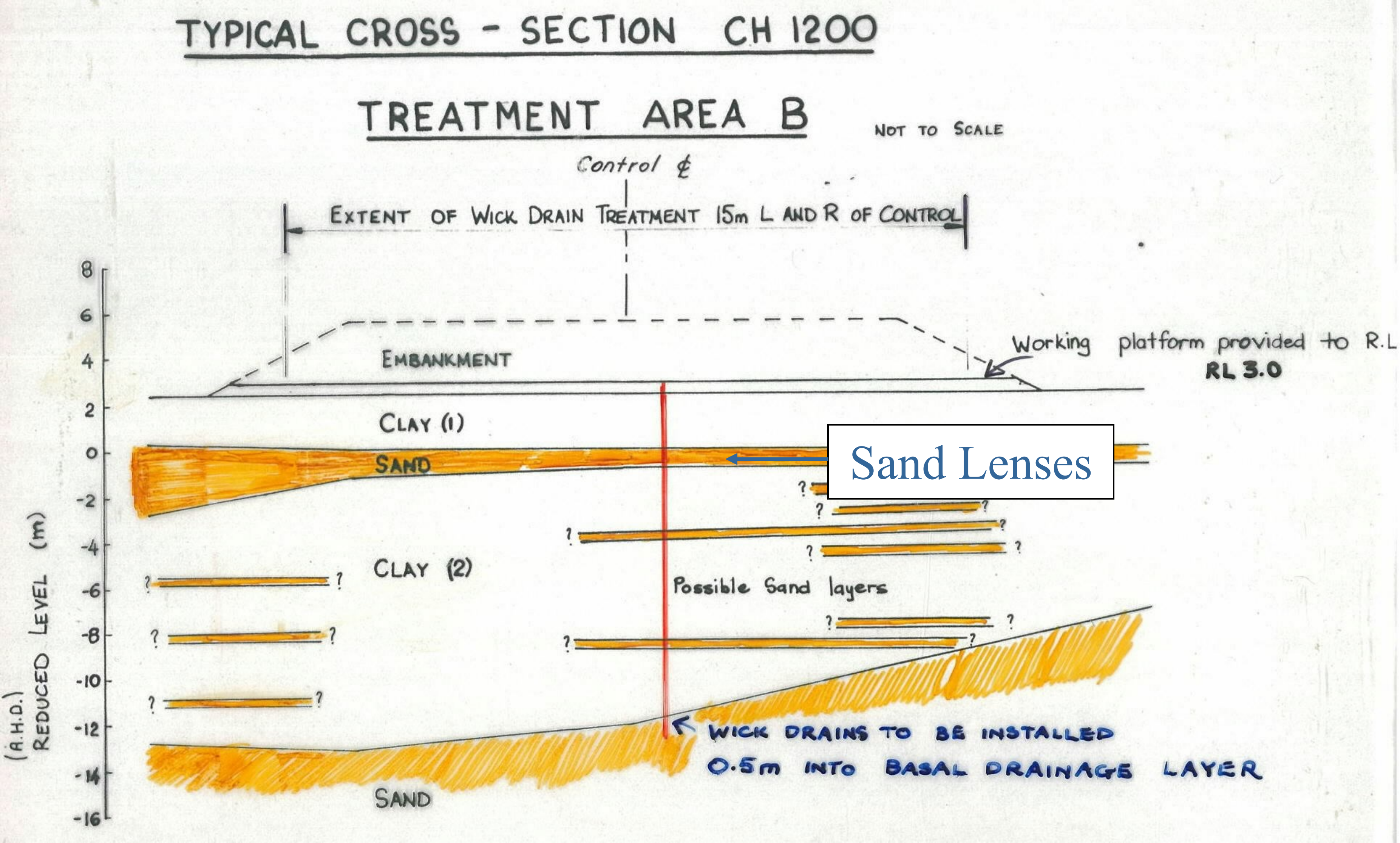
Case Study: East West Arterial

Long Section


GEOLOGICAL SECTION ALONG CENTRE MEDIAN

Soft Clay

Cross-Section



East-West

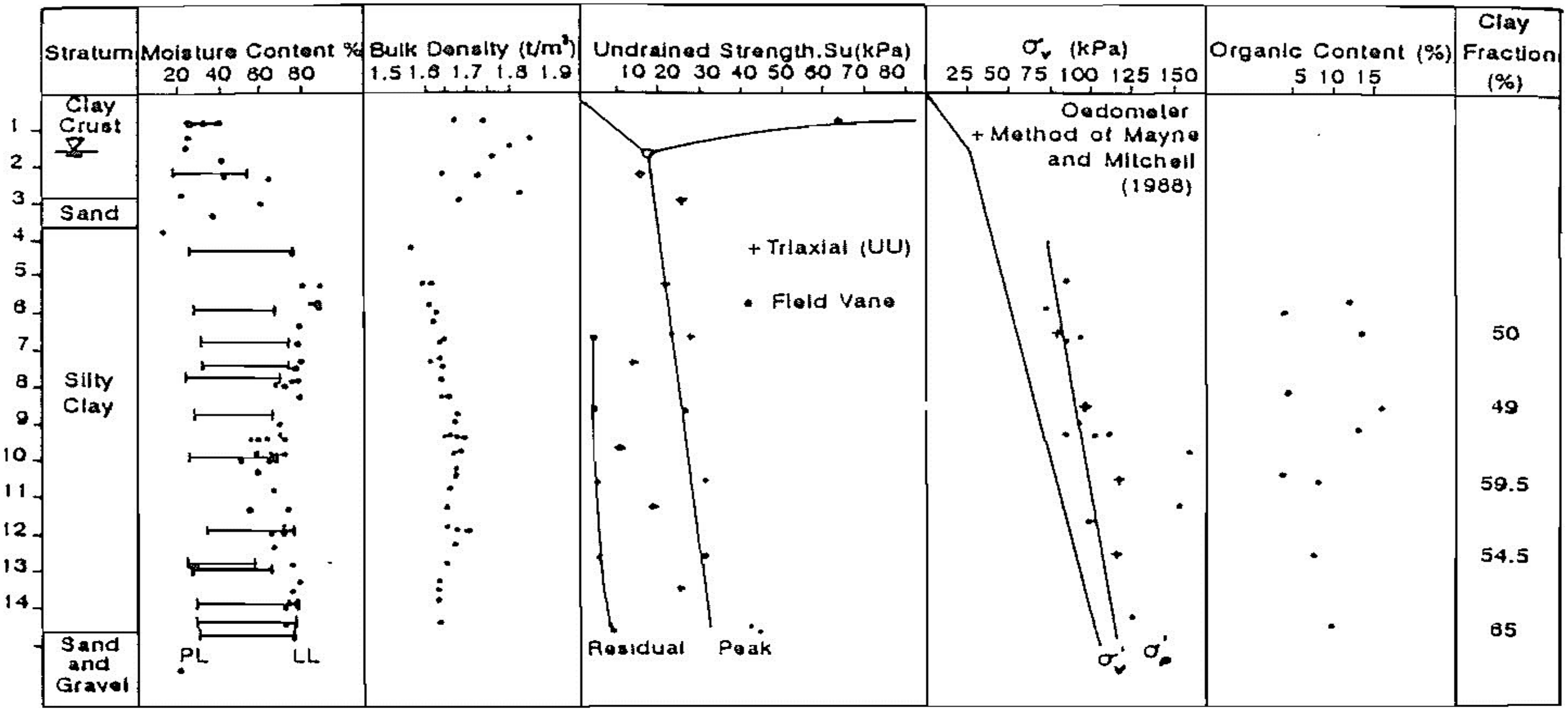


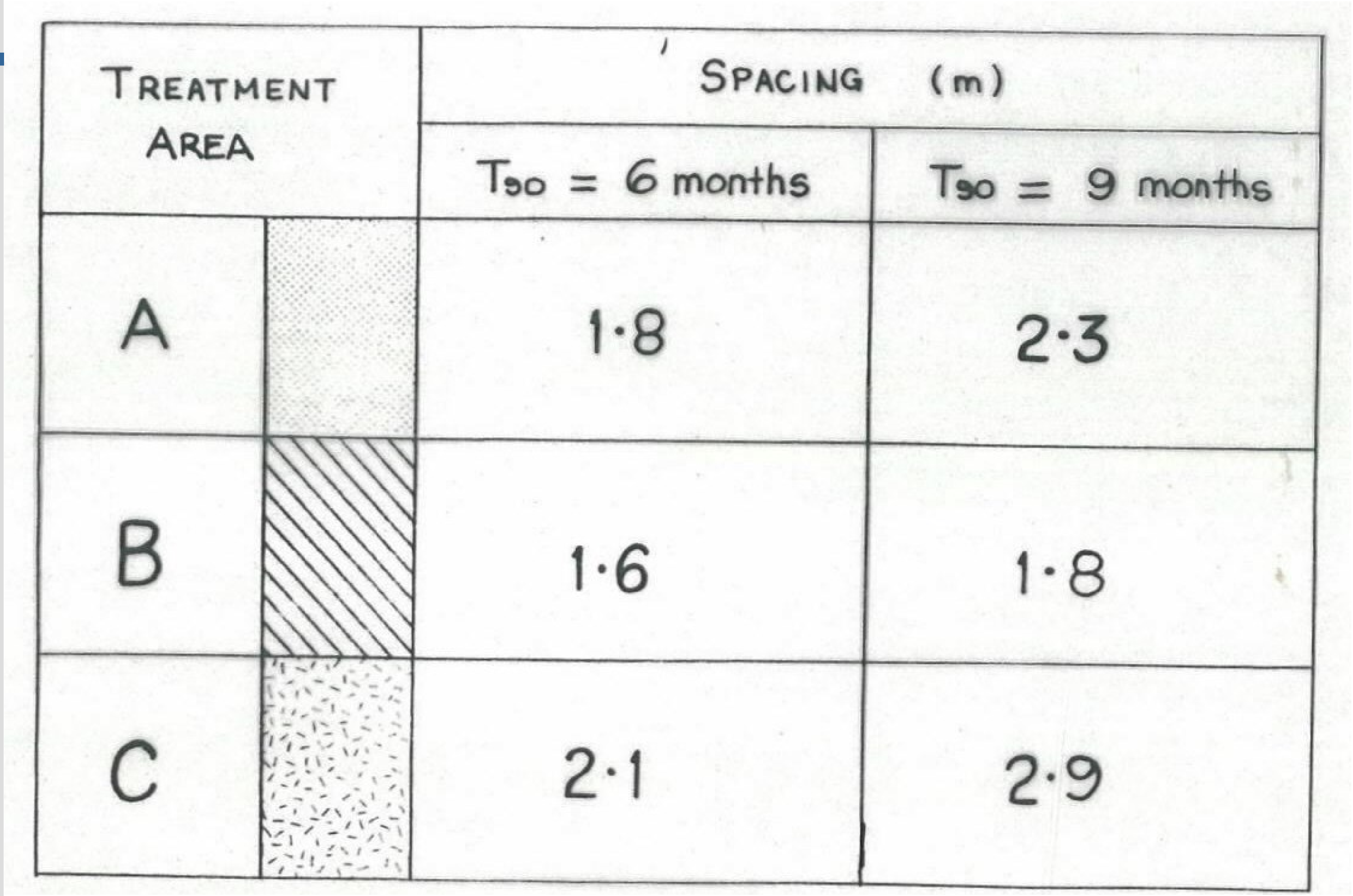
Fig.2 Subsurface Profile at Chainage 1200

Table 1 Consolidation Characteristics of the Silty Clay

Parameter	Typical Value
C_c	0.8 - 1.0
C_s	0.1 - 0.2
$C_c/1+e_0$.	0.31 - 0.36
m_v	0.7 - 1.2 m^2/MN *
c_v	0.08 - 1.2 m^2/yr *
c_h	0.12 - 1.5 m^2/yr *
$C_{\alpha\epsilon}$	0.005 - 0.015

* Parameters corresponding to the field stress range of 40 to 210 kPa.

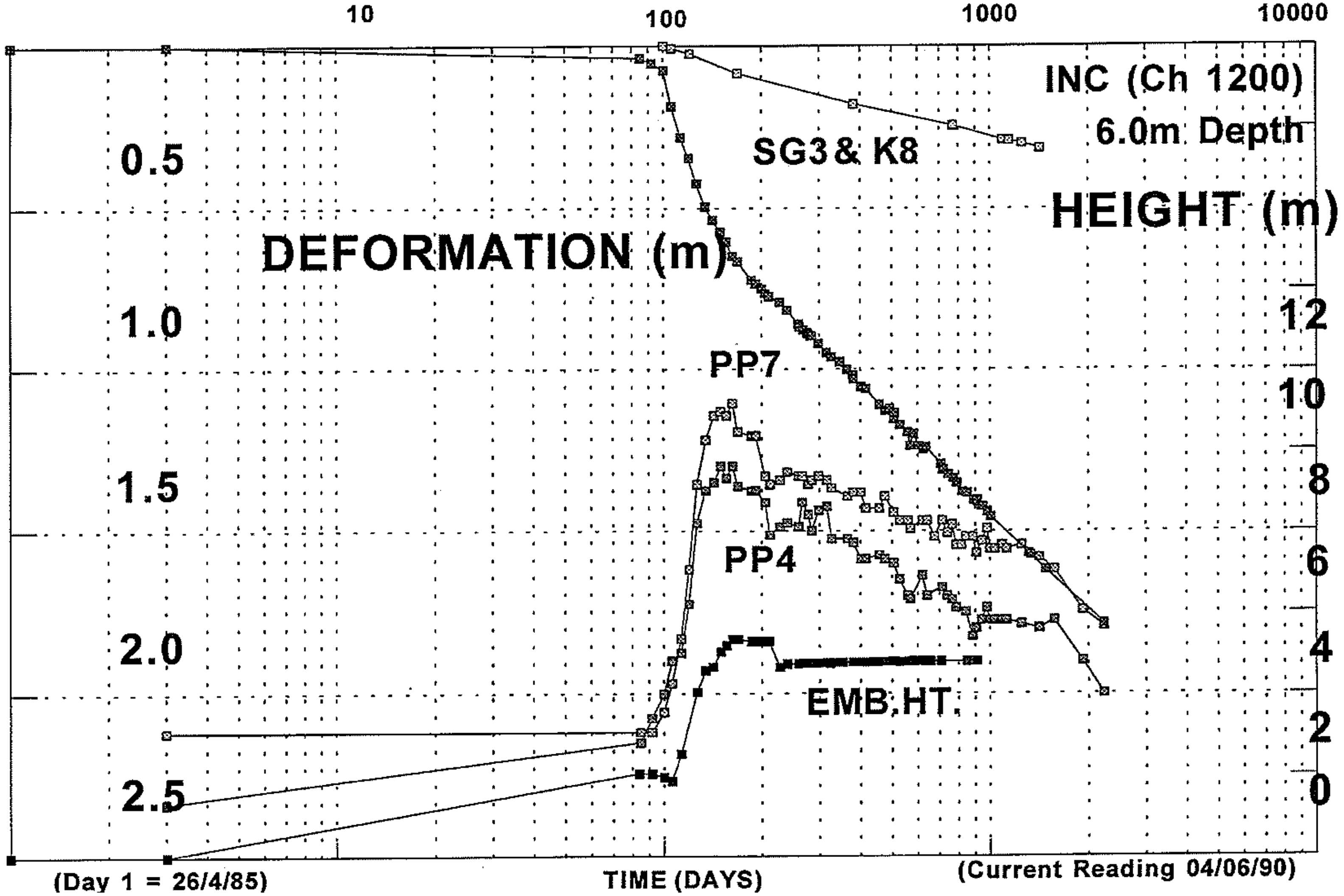
Design Wick Drain Spacing

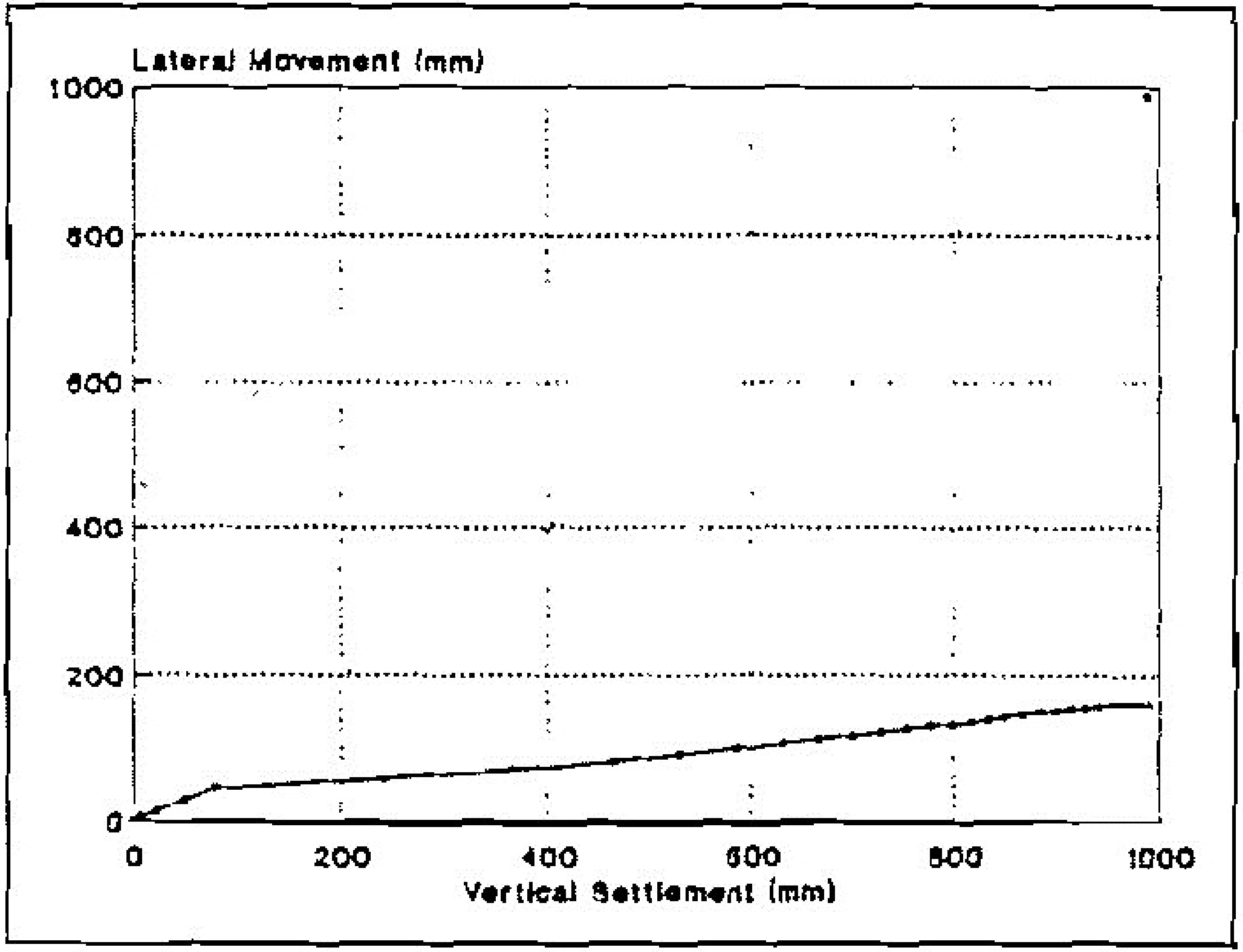


TREATMENT AREA		SPACING (m)	
		T_{90} = 6 months	T_{90} = 9 months
A	░	1·8	2·3
B	▨	1·6	1·8
C	▒	2·1	2·9

EAST-WEST ARTERIAL

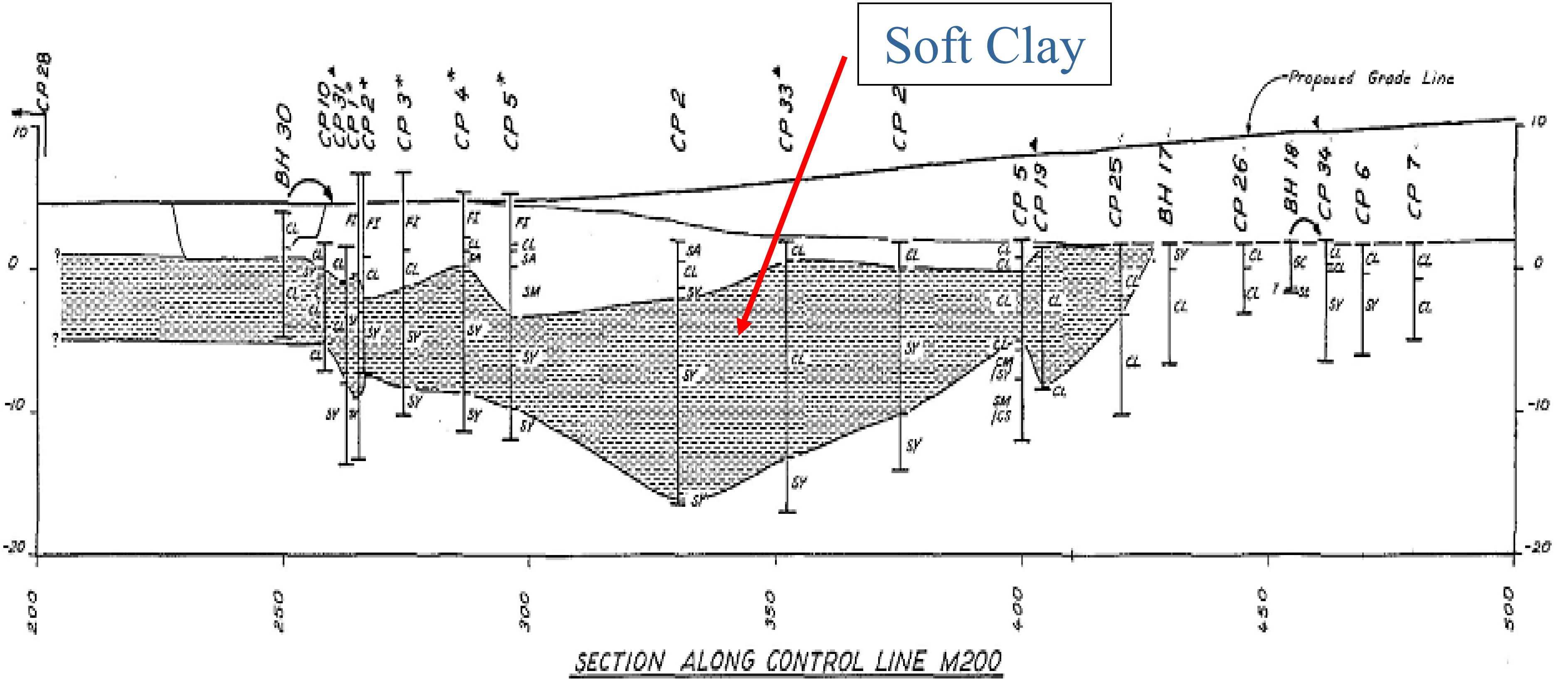
PLOT OF SETTLEMENT, PORE PRESSURE vs EMBANKMENT HEIGHT





Centreline Vertical Settlement Versus Toe Lateral Movement

Case Study: Toombul Road Subsoil Profile

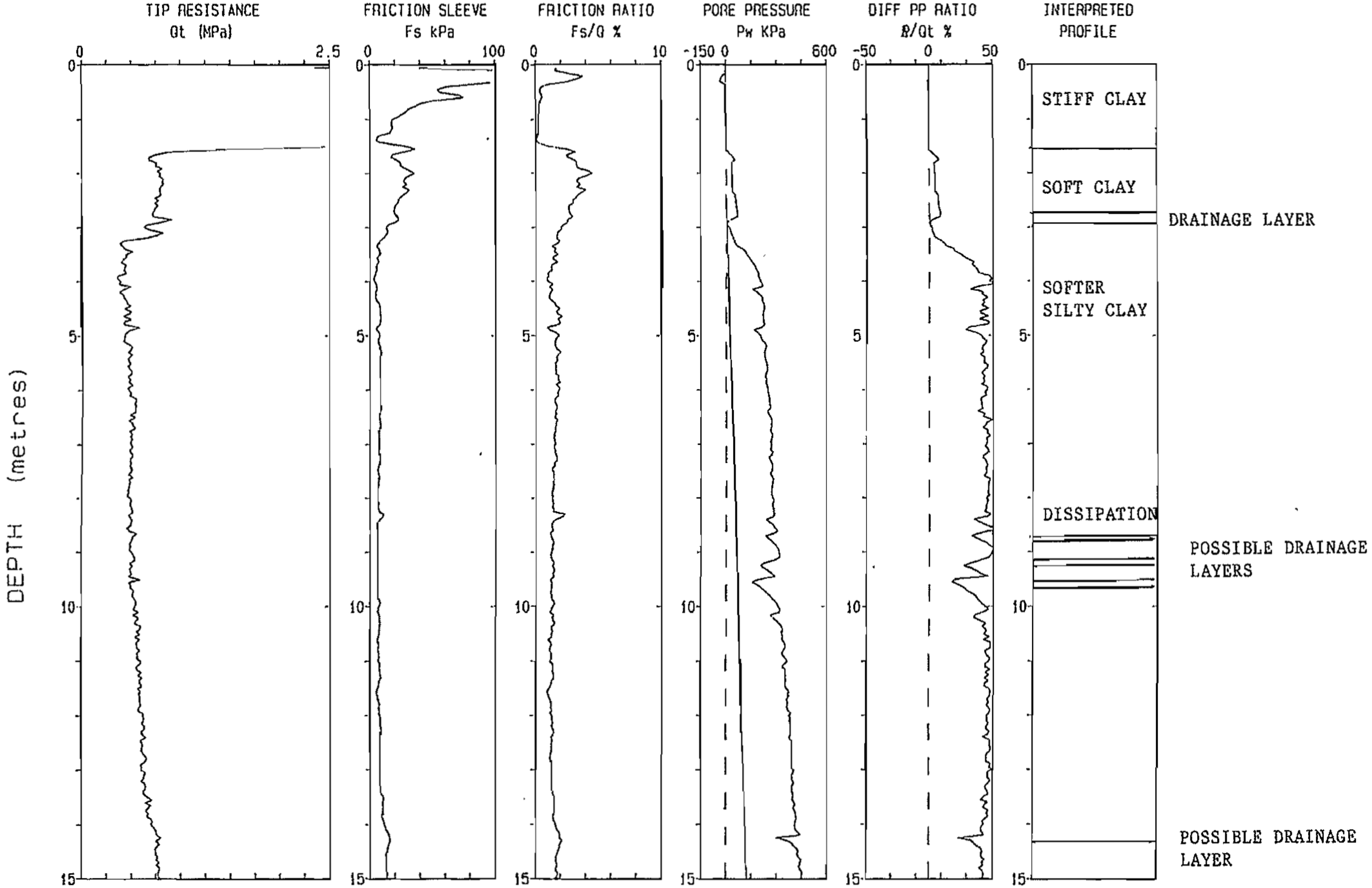


SECTION ALONG CONTROL LINE M200

Toombul

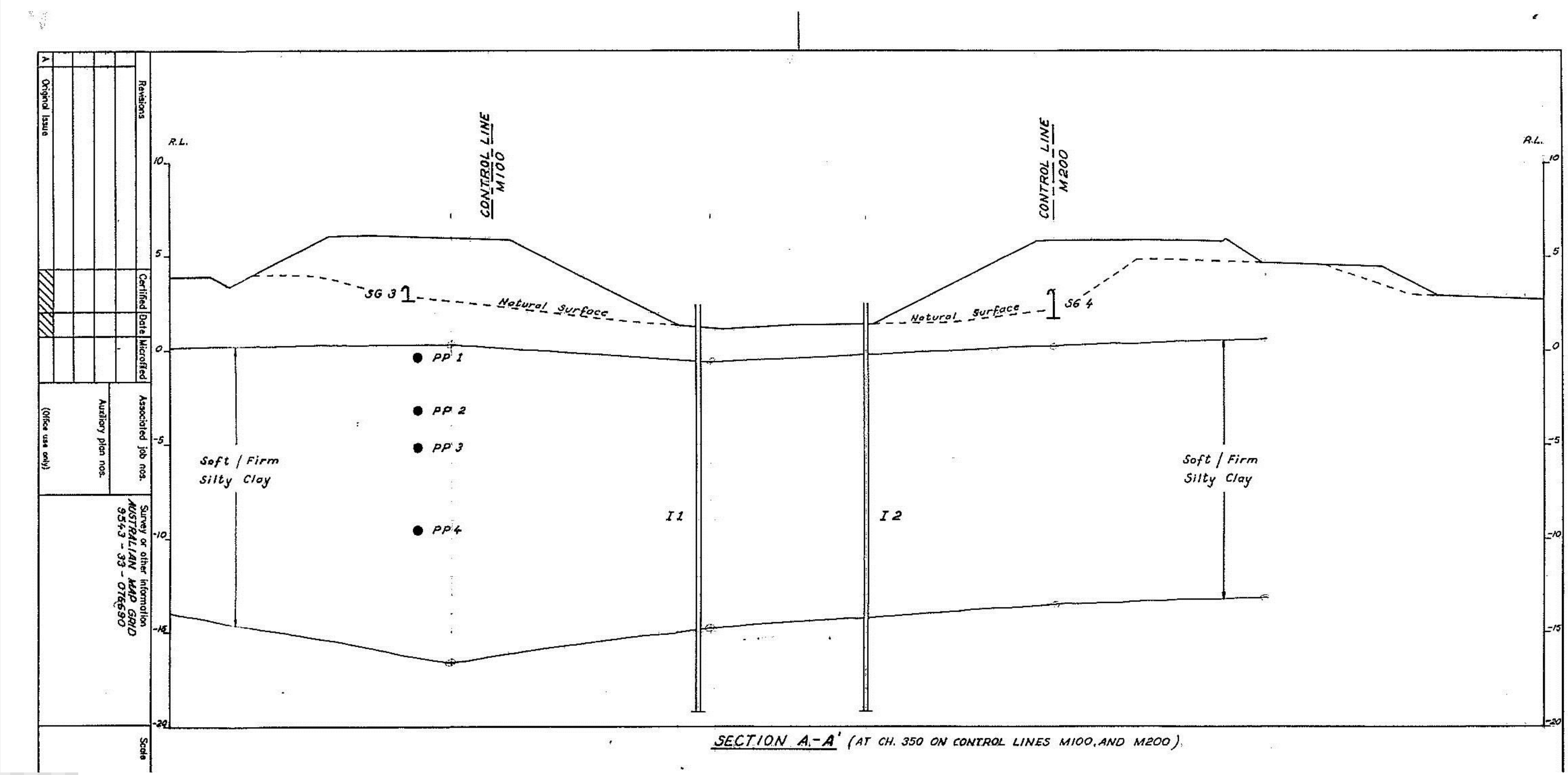
QUEENSLAND TRANSPORT

Operator : SG
CPT Date : 10/13/92 11:00
Sounding PCP2__ Pg 1 / 2
Location CH.350 M200
Cone Used 0351
Job # R62007



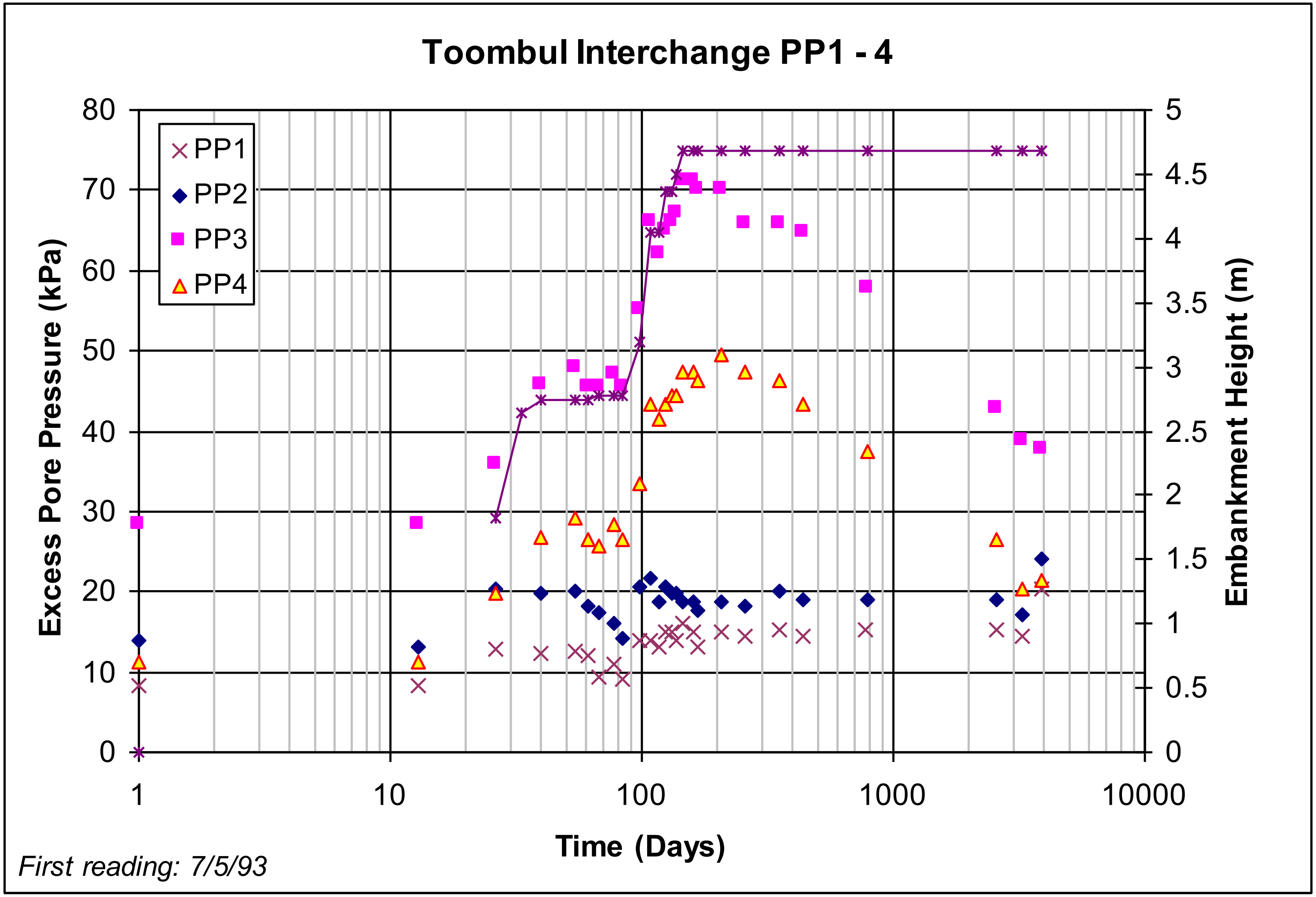
Depth Increment : .05 m
Max Depth : 16.00 m

Instrumentation at Ch 350



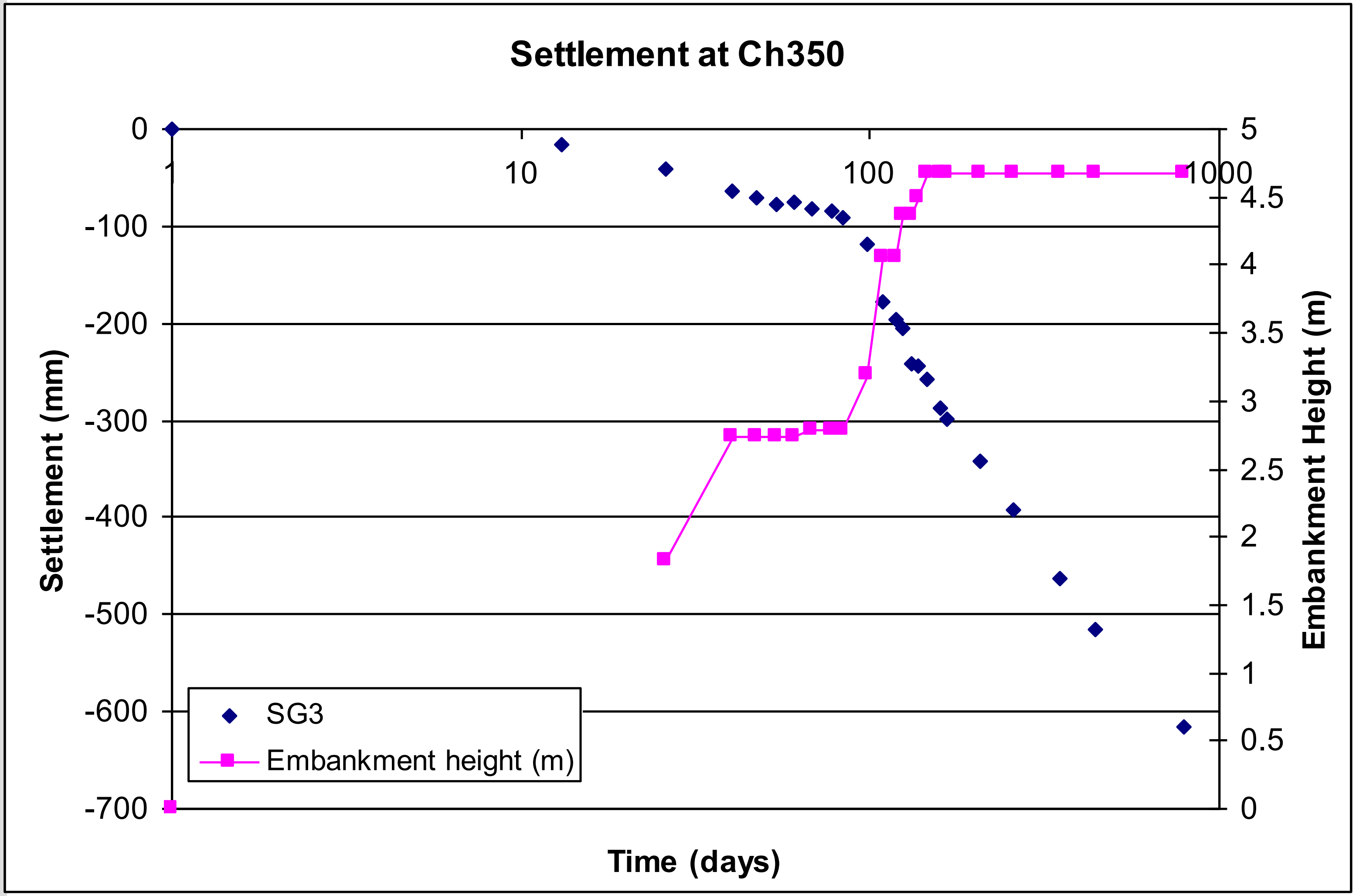
SECTION A.-A' (AT CH. 350 ON CONTROL LINES M100 AND M200).

Monitoring at Ch 350

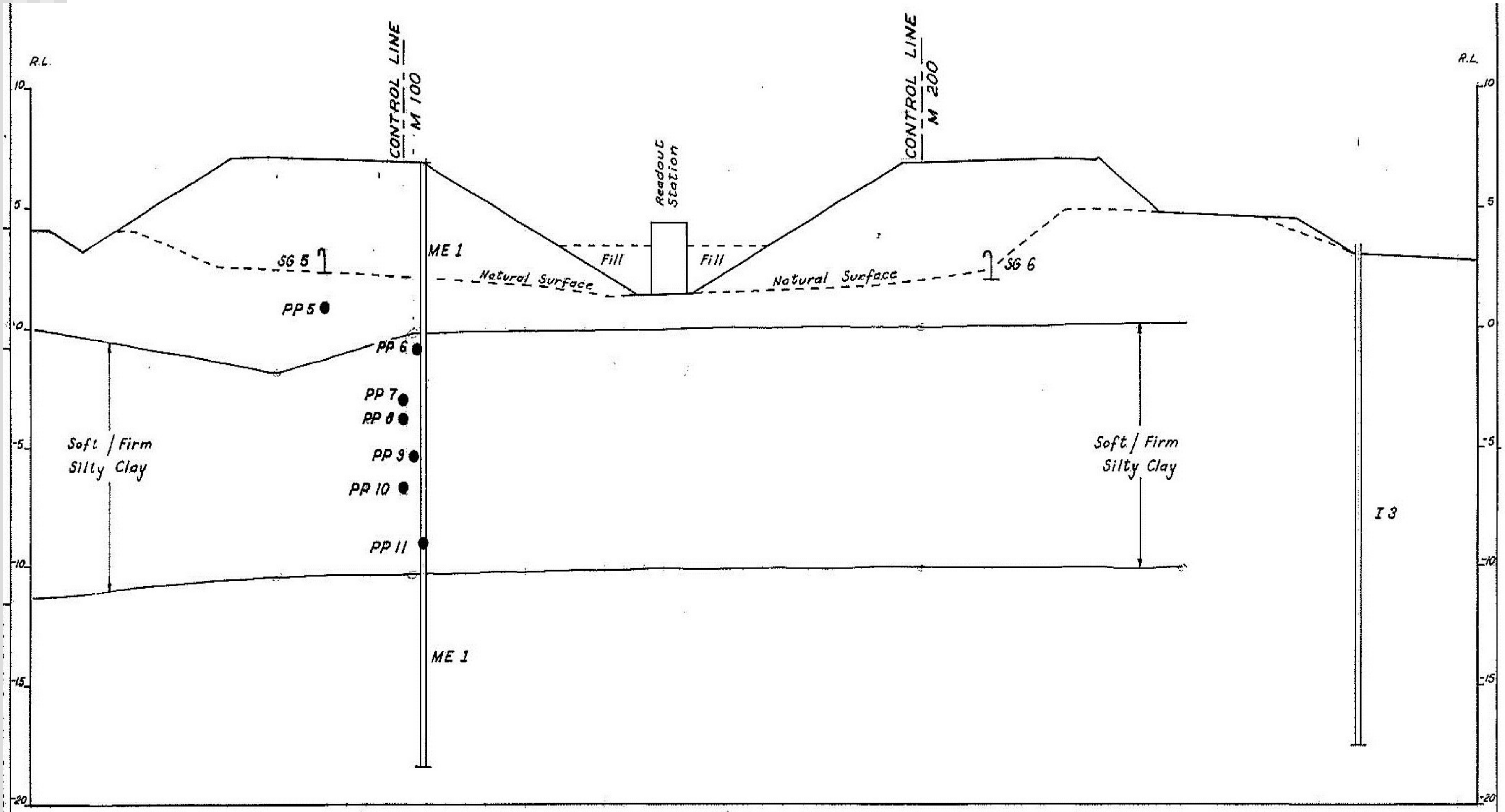


First reading: 7/5/93

Settlement at Ch350

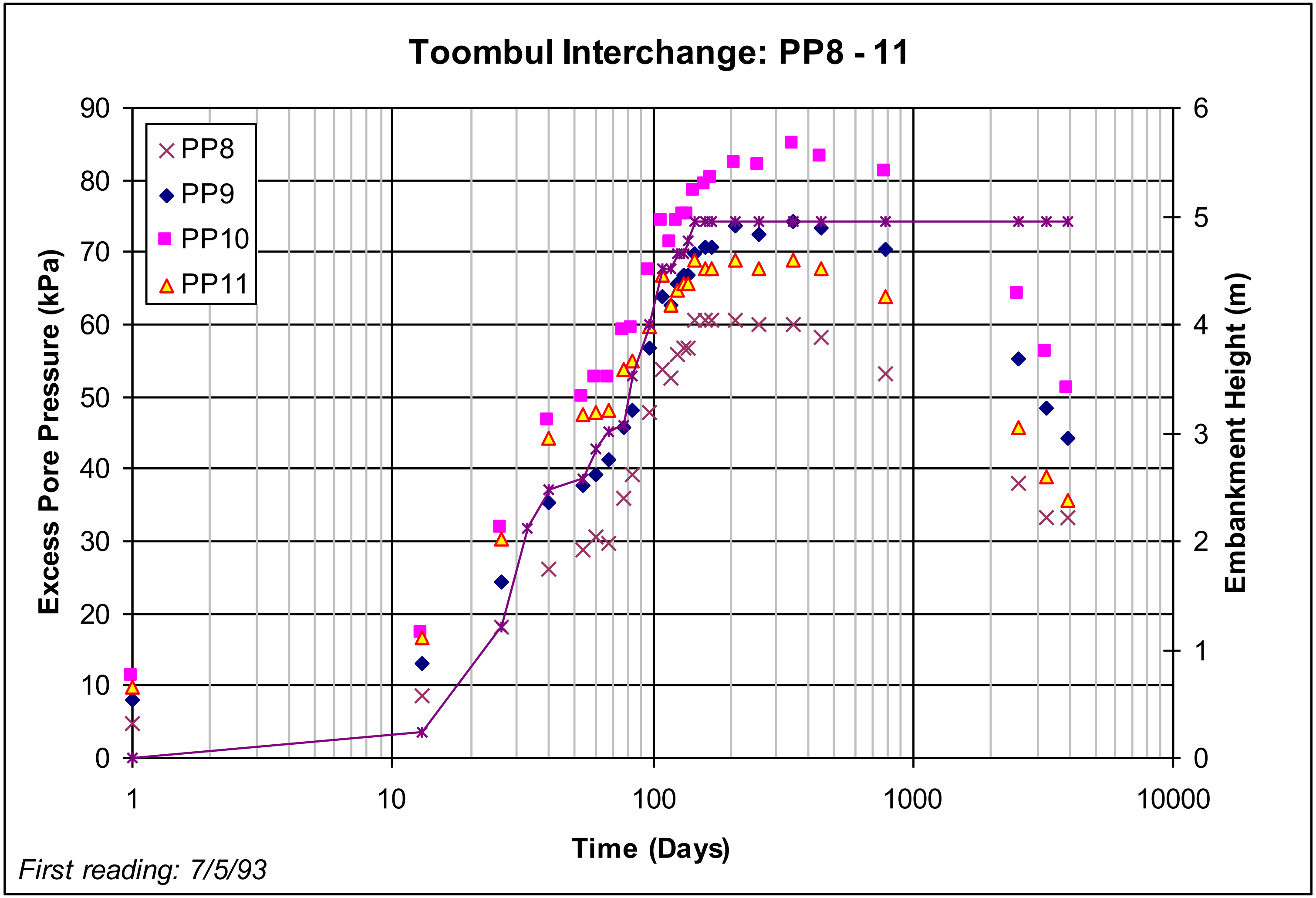


Instrumentation at Ch 375



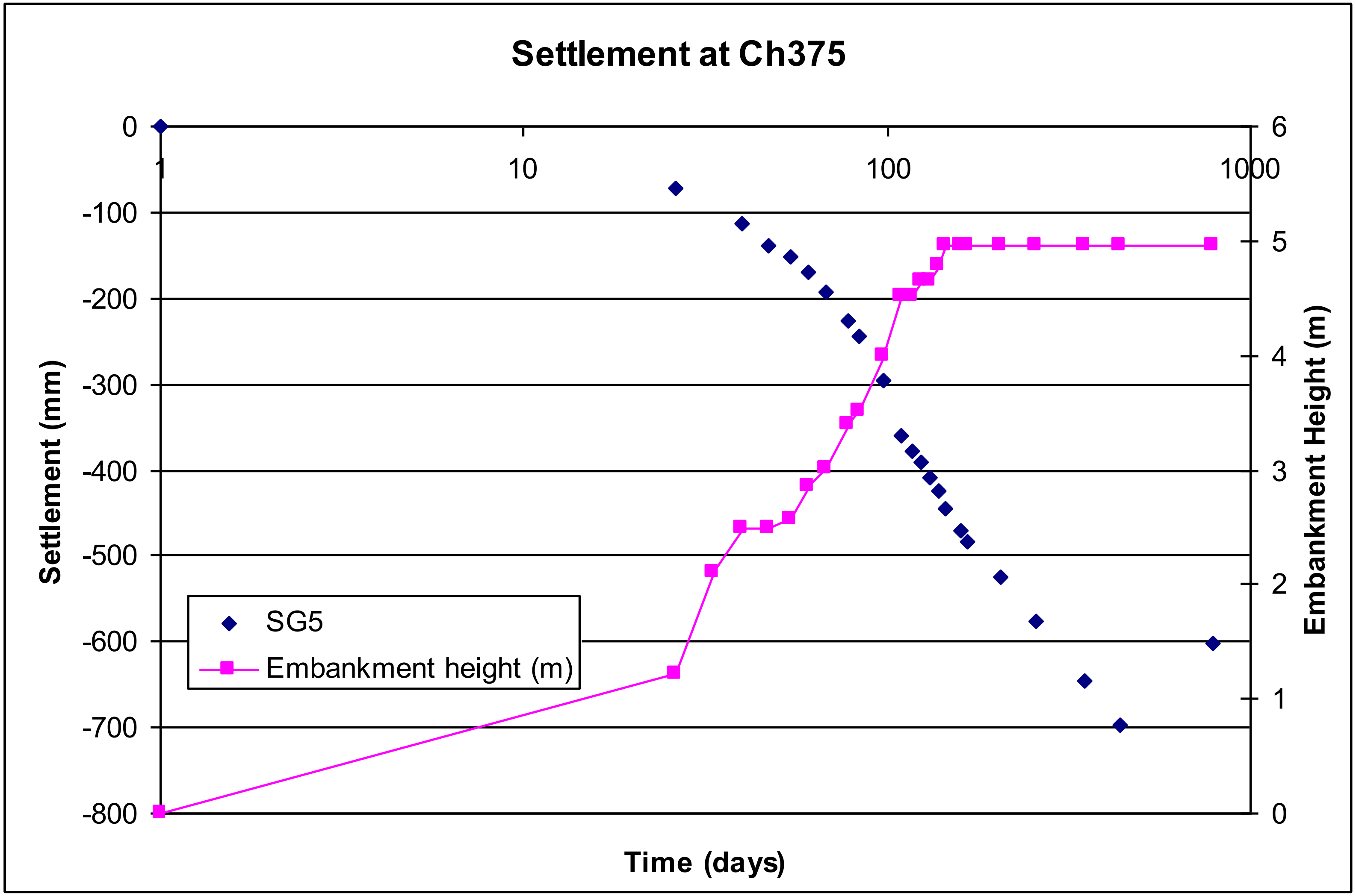
SECTION B-B' (AT CH. 375 ON CONTROL LINES M100 AND M200)

Monitoring at Ch 375



First reading: 7/5/93

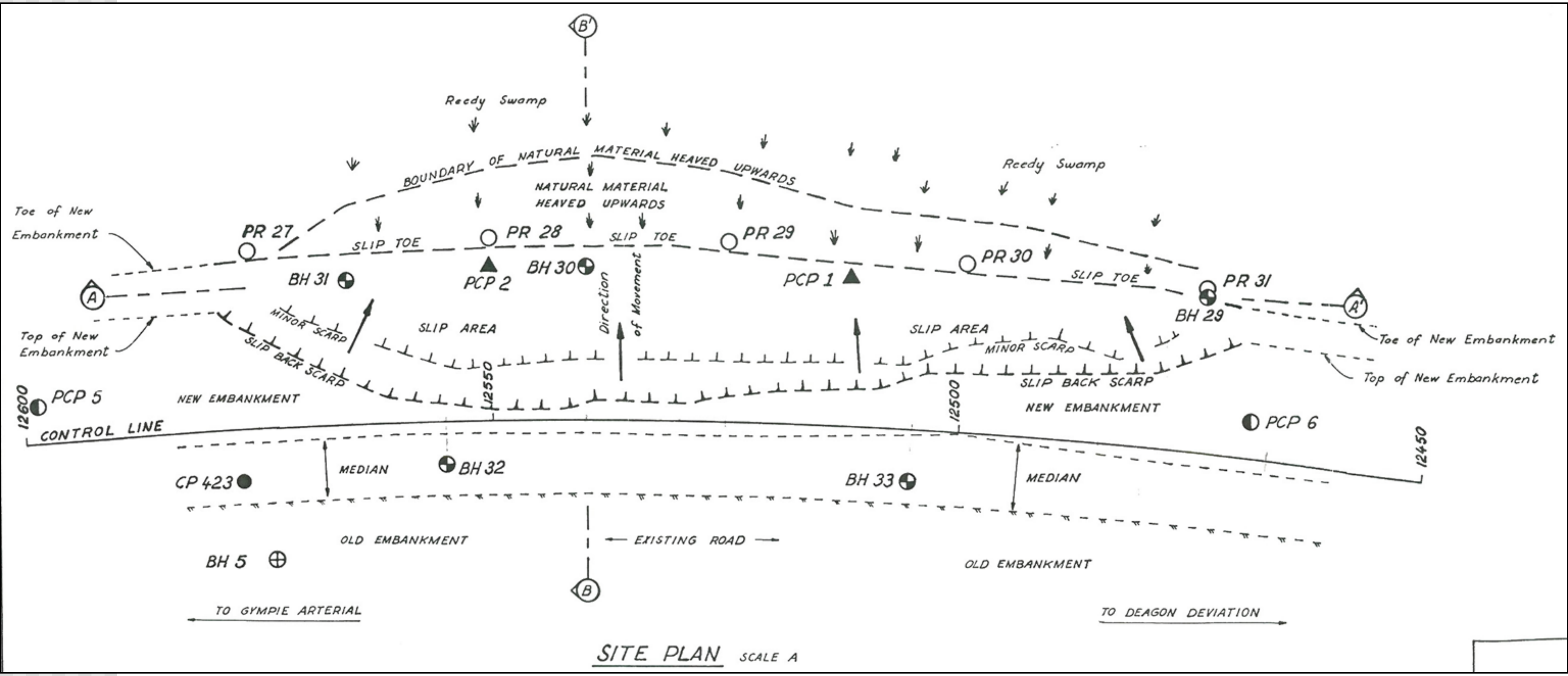
Settlement at Ch375



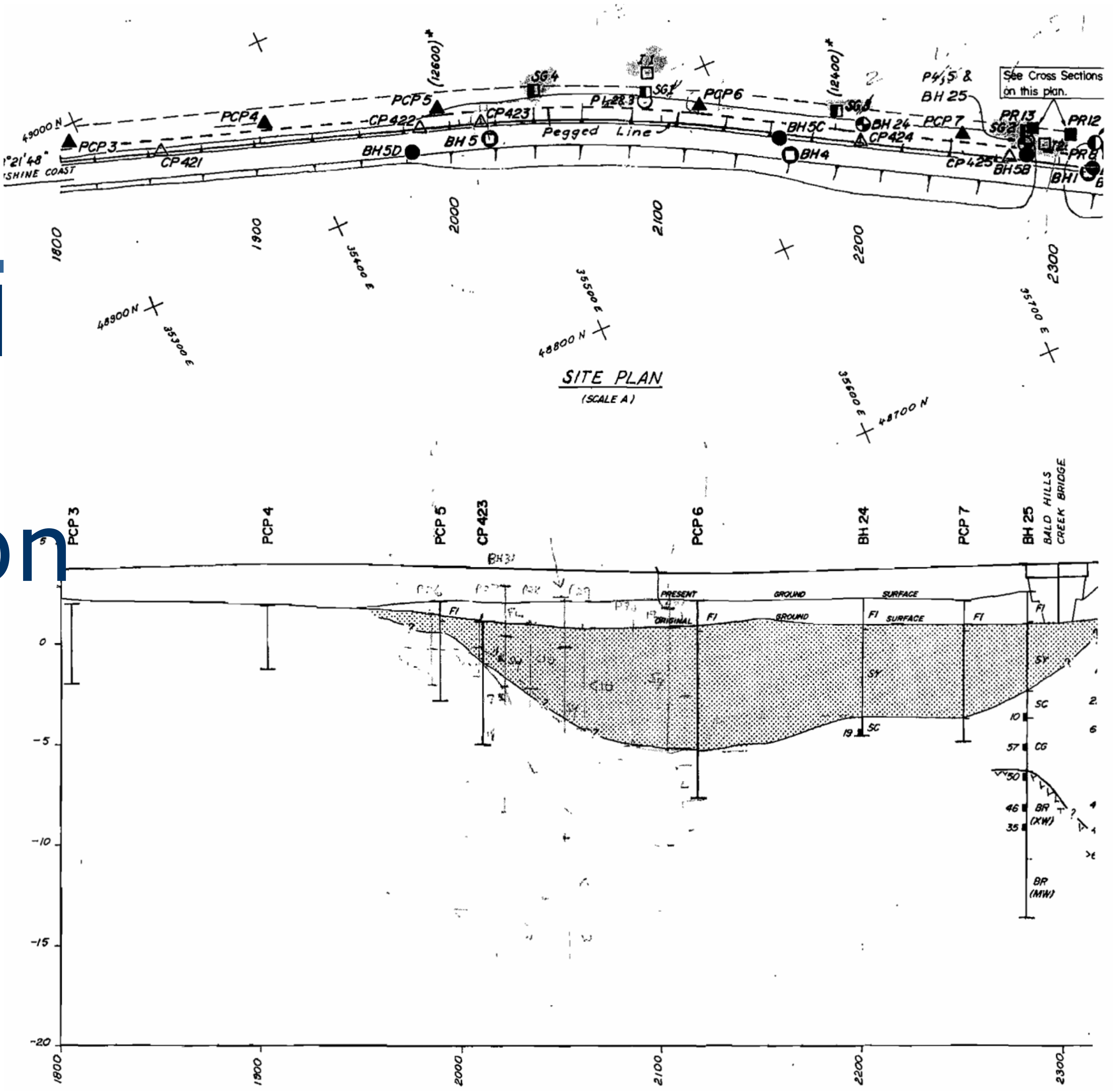
Case Study: Bald Hills Ck

- 3m high embankment
- 100m failure during construction
- Boreholes 150m apart
- Buried channel of soft clay (10 kPa)

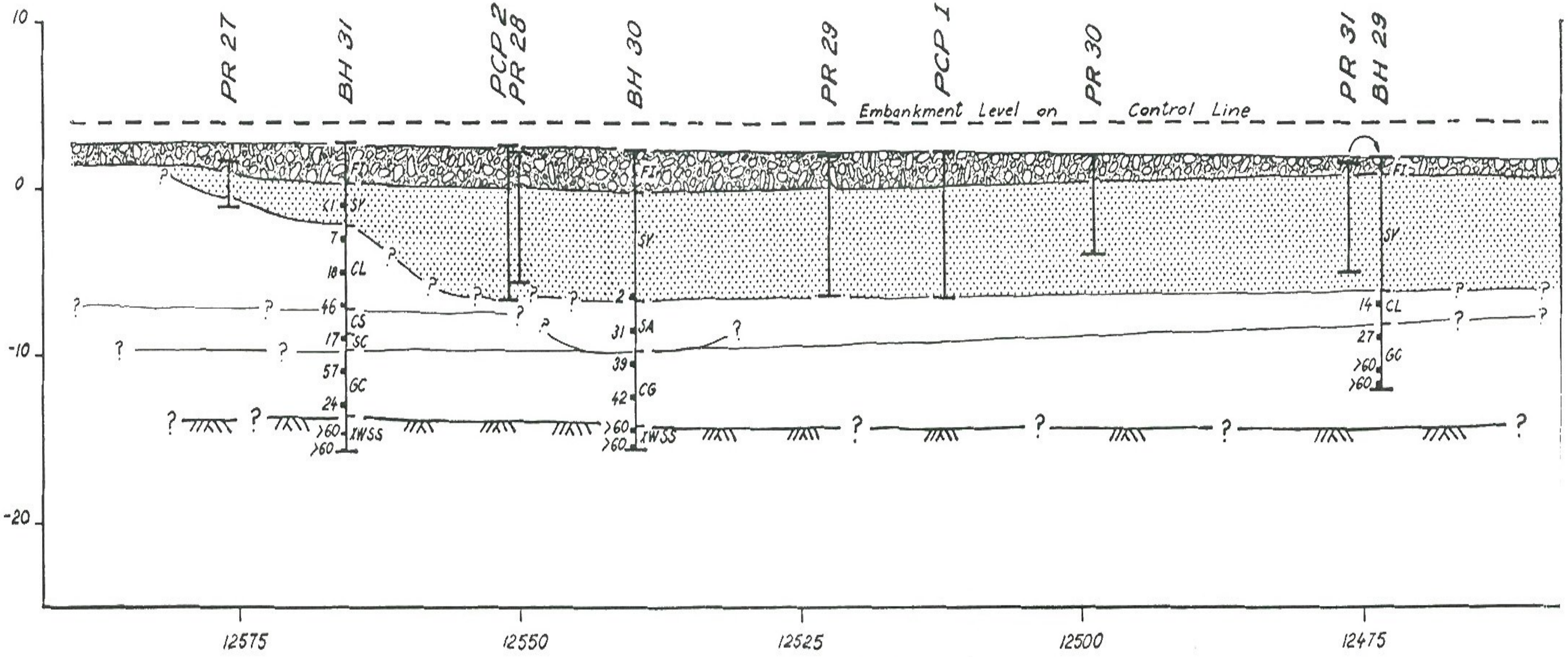
SITE PLAN – Bald Hills Creek



Initial long section



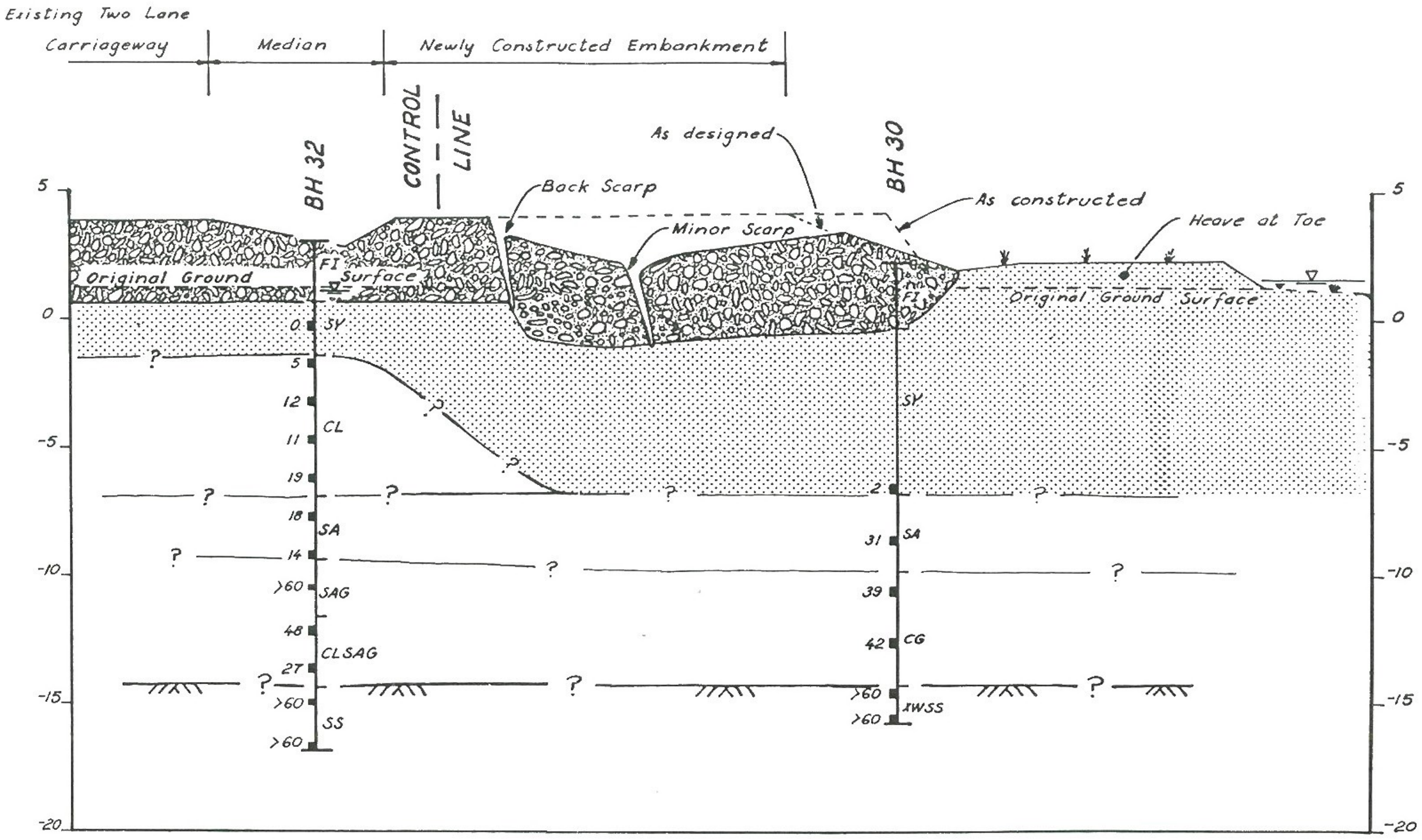
Long Section after failure investigation



SECTION ALONG A-A' SCALE A

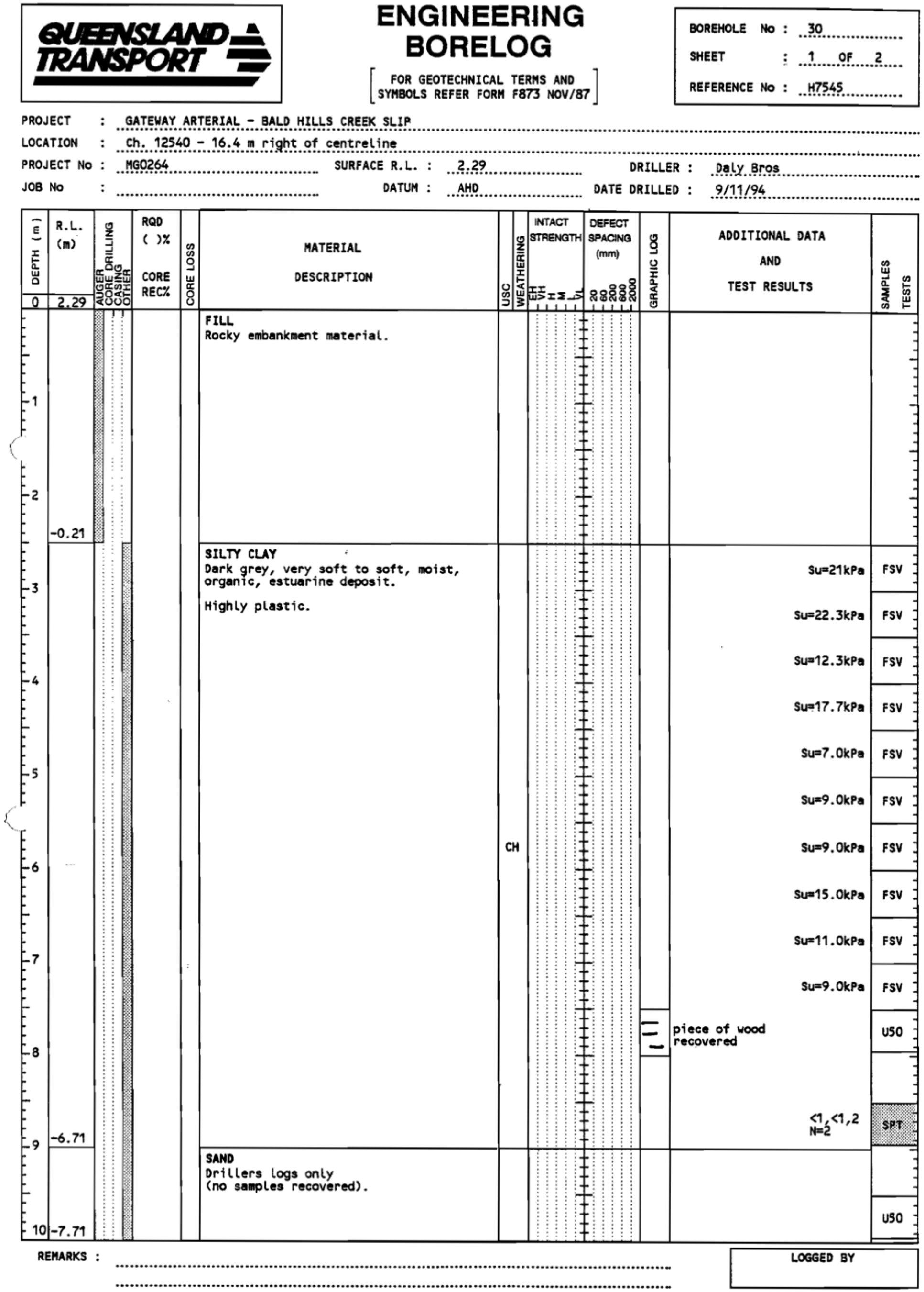
Chainages shown are projected from Control Line

Cross Section



SECTION B-B' SCALE B

Borelog BH30



QUEENSLAND TRANSPORT

ENGINEERING BORELOG

[FOR GEOTECHNICAL TERMS AND SYMBOLS REFER FORM F873 NOV/87]

BOREHOLE No : 30
SHEET : 1 OF 2
REFERENCE No : H7545

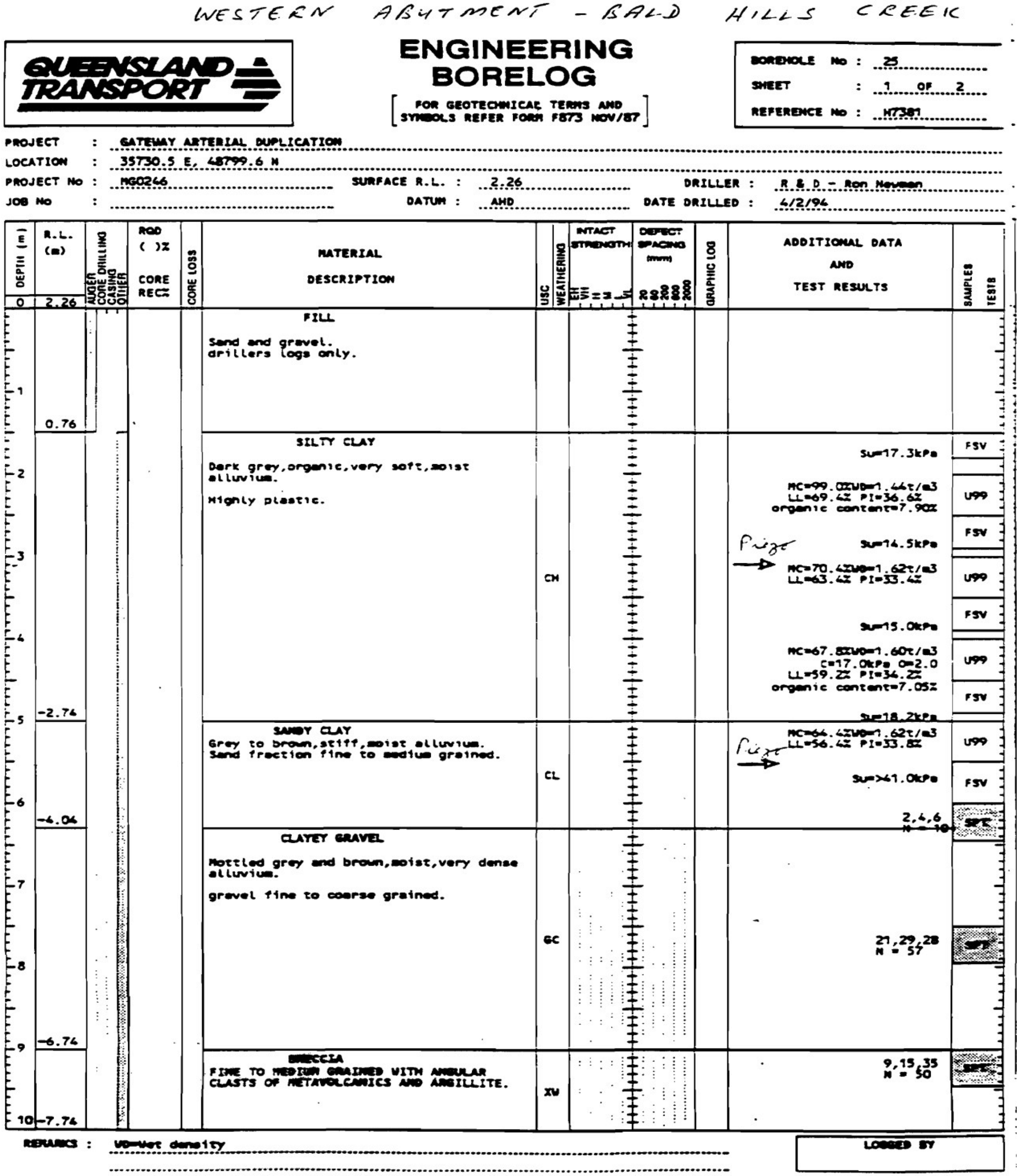
PROJECT : GATEWAY ARTERIAL - BALD HILLS CREEK SLIP
LOCATION : Ch. 12540 - 16.4 m right of centreline
PROJECT No : MG0264
SURFACE R.L. : 2.29
DRILLER : Daly Bros
JOB No :
DATUM : AHD
DATE DRILLED : 9/11/94

DEPTH (m)	R.L. (m)	AUGER CORE DRILLING CASING OTHER	RQD ( )% CORE REC%	CORE LOSS	MATERIAL DESCRIPTION	USC	WEATHERING	INTACT STRENGTH EH VH H M L VL	DEFECT SPACING (mm) 20 60 200 600 2000	GRAPHIC LOG	ADDITIONAL DATA AND TEST RESULTS	SAMPLES TESTS
0	2.29				**FILL** Rocky embankment material.							
	-0.21				**SILTY CLAY** Dark grey, very soft to soft, moist, organic, estuarine deposit. Highly plastic.	CH					Su=21kPa Su=22.3kPa Su=12.3kPa Su=17.7kPa Su=7.0kPa Su=9.0kPa Su=9.0kPa Su=15.0kPa Su=11.0kPa Su=9.0kPa piece of wood recovered <1,<1,2 N=2	FSV FSV FSV FSV FSV FSV FSV FSV FSV FSV U50 SPT
	-6.71				**SAND** Drillers logs only (no samples recovered).							U50
10	-7.71											

REMARKS :

LOGGED BY

Borelog BH25



WESTERN ABUTMENT - BALD HILLS CREEK

QUEENSLAND TRANSPORT

ENGINEERING BORELOG

[FOR GEOTECHNICAL TERMS AND SYMBOLS REFER FORM F873 NOV/87]

BOREHOLE No : 25
SHEET : 1 OF 2
REFERENCE No : H7381

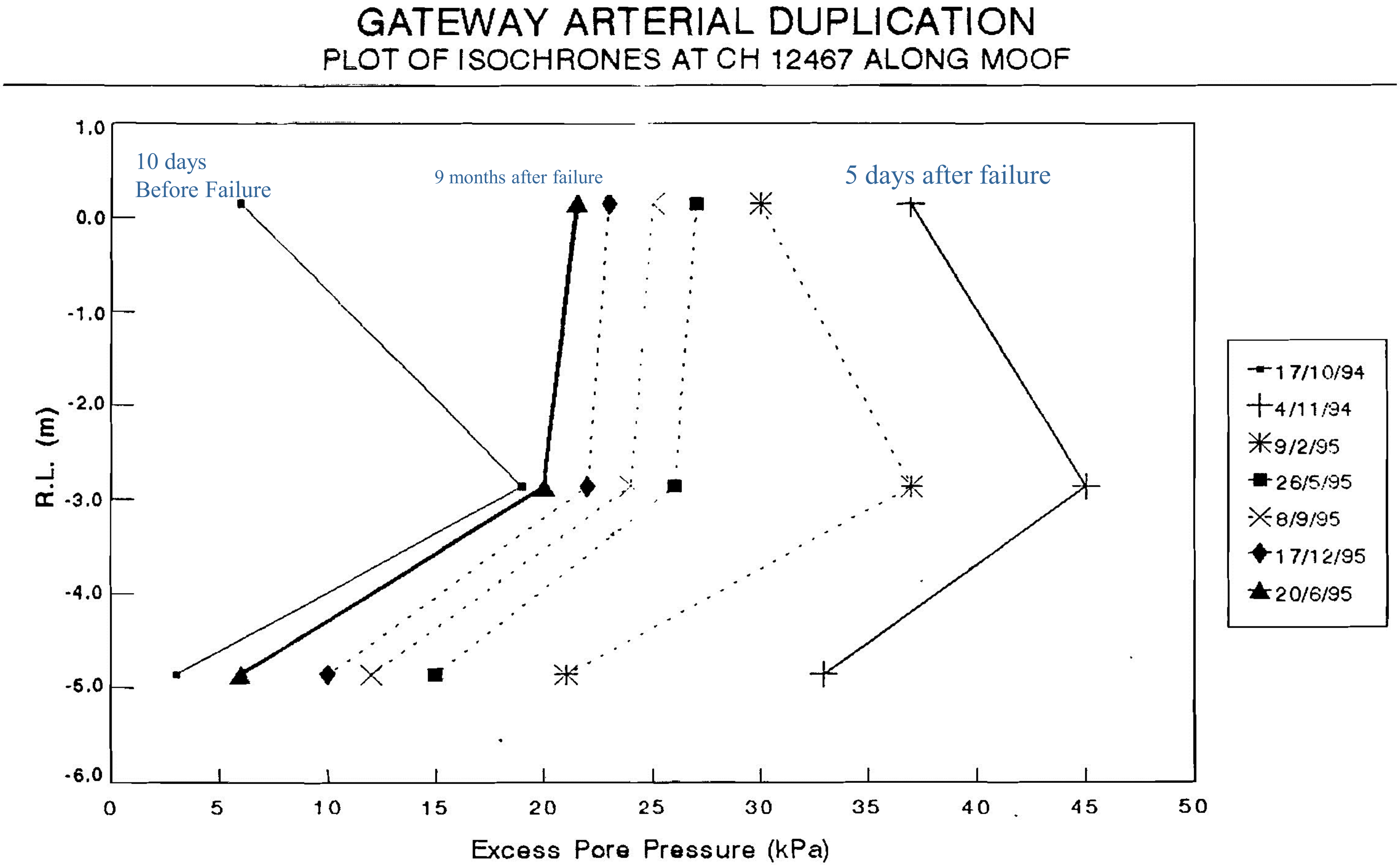
PROJECT : GATEWAY ARTERIAL DUPLICATION
LOCATION : 35730.5 E, 48799.6 N
PROJECT No : MG0246
SURFACE R.L. : 2.26
DRILLER : R & D - Ron Neuman
JOB No :
DATUM : AHD
DATE DRILLED : 4/2/94

DEPTH (m)	R.L. (m)	MATERIAL DESCRIPTION	USC	ADDITIONAL DATA AND TEST RESULTS	SAMPLES TESTS
0	2.26	**FILL** Sand and gravel. drillers logs only.			
	0.76	**SILTY CLAY** Dark grey,organic,very soft,moist alluvium. Highly plastic.	CH	Su=17.3kPa	FSV
				MC=99.0%WD=1.44t/m3 LL=69.4% PI=36.6% organic content=7.90%	U99
				Su=14.5kPa	FSV
				Piezo → MC=70.4%WD=1.62t/m3 LL=63.4% PI=33.4%	U99
				Su=15.0kPa	FSV
				MC=67.8%WD=1.60t/m3 C=17.0kPa O=2.0 LL=59.2% PI=34.2% organic content=7.05%	U99
				Su=18.2kPa	FSV
	-2.74	**SANDY CLAY** Grey to brown,stiff,moist alluvium. Sand fraction fine to medium grained.	CL	Piezo → MC=64.4%WD=1.62t/m3 LL=56.4% PI=33.8%	U99
				Su=>41.0kPa	FSV
				2,4,6 N = 10	SPT
	-4.04	**CLAYEY GRAVEL** Mottled grey and brown,moist,very dense alluvium. gravel fine to coarse grained.	GC	21,29,28 N = 57	SPT
	-6.74	**BRECCIA** FINE TO MEDIUM GRAINED WITH ANGULAR CLASTS OF METAVOLCANICS AND ARGILLITE.	XW	9,15,35 N = 50	SPT
10	-7.74				

REMARKS : WD=Wet density

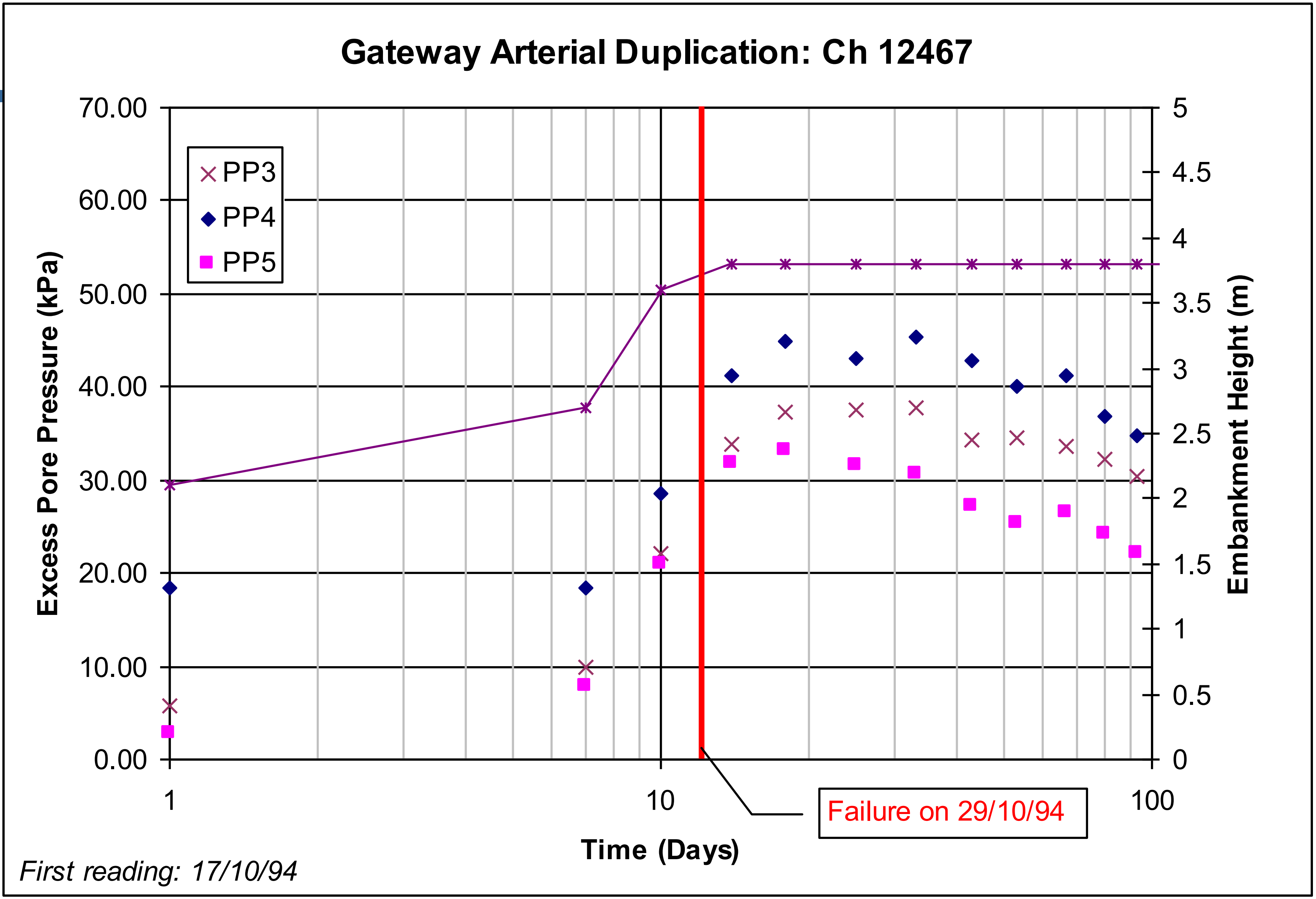
LOGGED BY

ISOCHRONES



Piezometers PP3-5

Pore Pressure

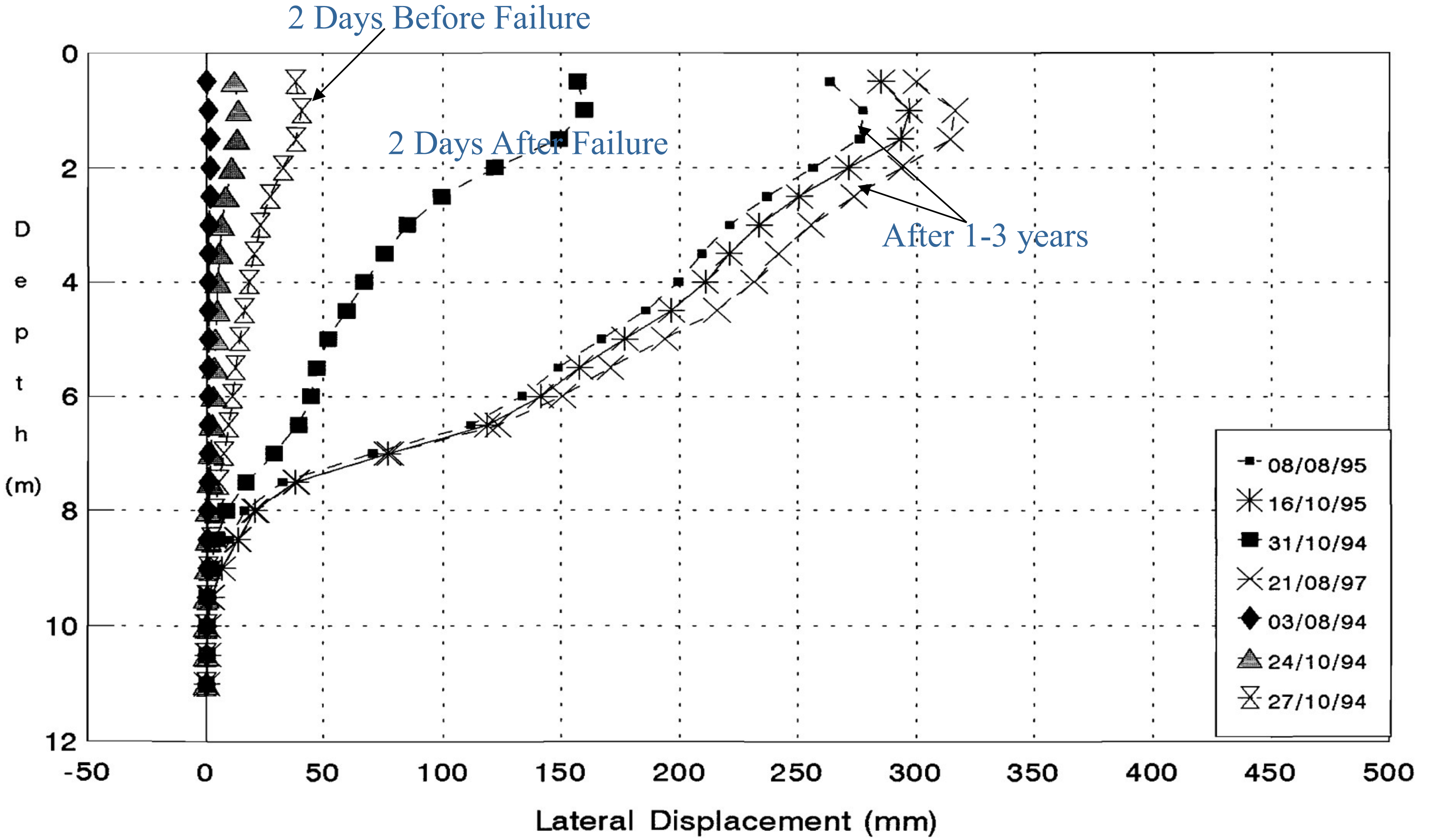


Lateral Displacement

GATEWAY ARTERIAL DUPLICATION - INSTRUMENTATION

PLOT OF INCLINOMETER MOVEMENT AT CH.12467 - No.I2

DIRECTION OF MOVEMENT (Ao) = North (TOWARDS WETLANDS)

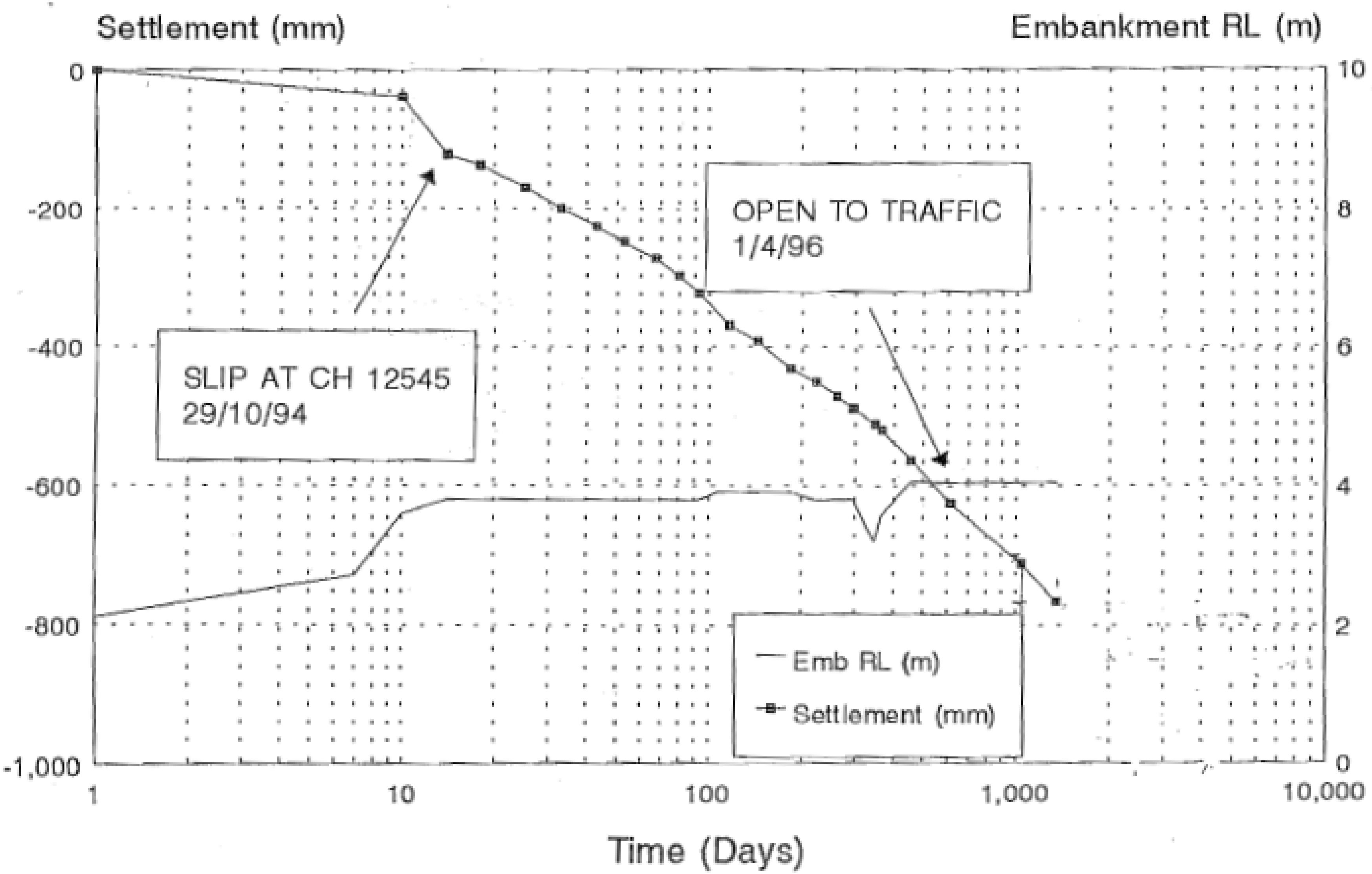


2 Days Before Failure

2 Days After Failure

After 1-3 years

Bald Hills Creek Settlement



Some Relevant Publications

- Wijeyakulasuriya, V., Hobbs, G.J. & Brandon, A. (1999). Some experiences with Performance Monitoring of Embankments on Soft Clays. Proc. 8th ANZ Geomech. Conf., Vol 2 pp783-788, Hobart.
- Litwinowicz, A., Wijeyakulasuriya, V. & Brandon, A. (1994). Performance of a Reinforced Embankment on a Structure Soft Clay Foundation. Proc. 5th Int. Conf. On Geotextiles, Geomechanics and related products, Vol 1 pp11-16, Singapore.
- Hobbs, G.J., Williams, D.J. & Wong, K.Y. (1993) Settlement Behaviour of Brisbane Clay. Proc. The Int. Conf. On Soft Soil Engineering, Guangzhou, China.

Some Relevant Publications cont.

- Litwinowicz, A. & Wijeyakulasuriya, V. (1992). Evaluation of the Effect of Geotextile Reinforcement for Embankments on Soft Clay Foundation. Panel Report, Proc. Int. Conf. On Geotechnical Engineering for Coastal Development, Yokohama.
- Litwinowicz, A. & Hobbs, G.J. (1992). Performance of a composite Foundation on Soft Clay Foundation. Panel Report, Proc. Int. Conf. On Geotechnical Engineering for Coastal Development, Yokohama.
- Litwinowicz, A. & Smith, I. K. (1988). A Brief Review of Geotechnical Aspects and Monitoring of Gateway Arterial Roadworks North of the Brisbane River. Pre, 5th ANZ Geomech. Conf., Sydney.