Soft Clay Engineering– Monday December 4

Monday-1: Introduction to Soft Clay Deposits
Subsurface Exploration
Sampling and Sample Disturbance
Laboratory Testing

Residual Soils

Sedimentary Soils

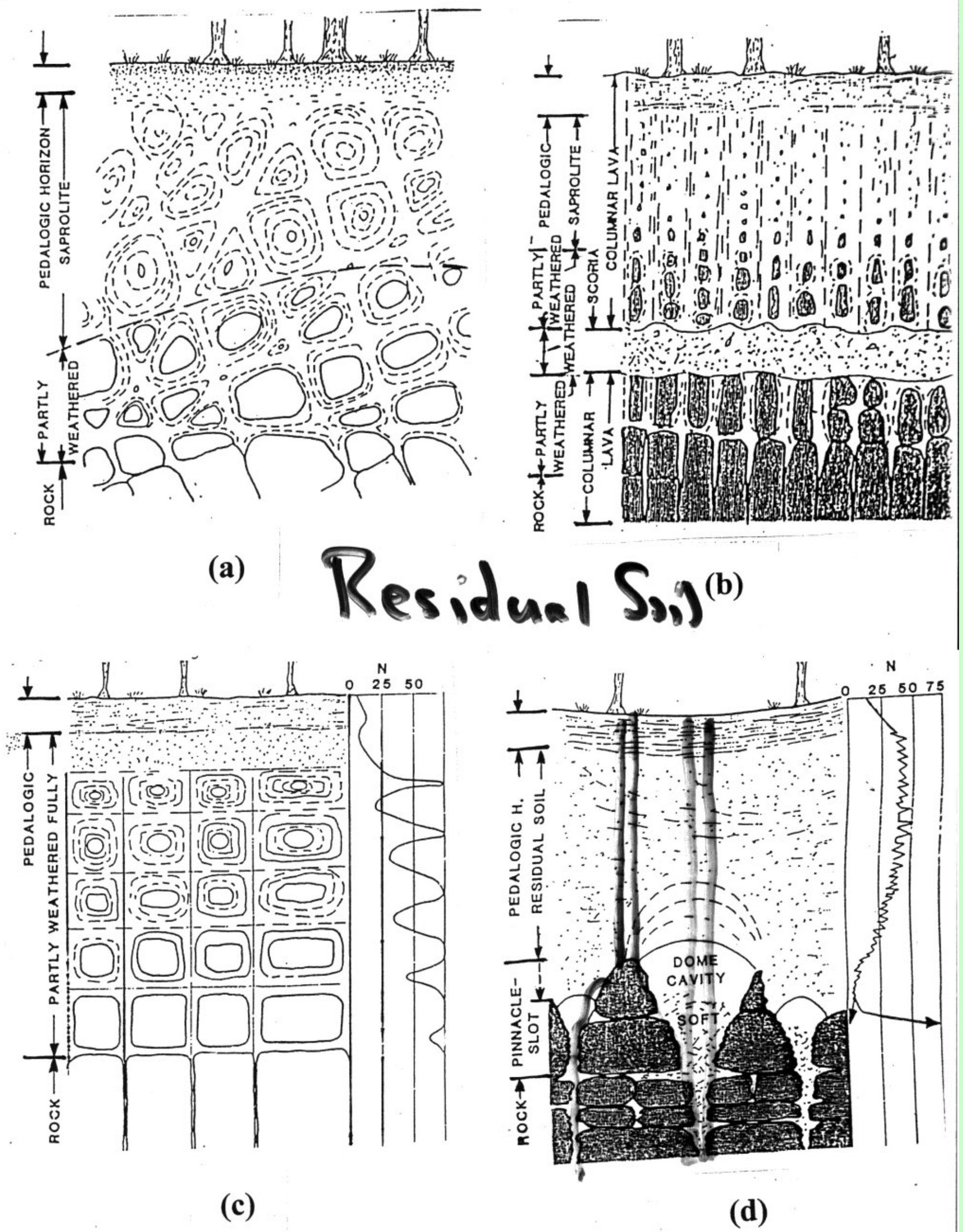


Figure 1 Weathering Profiles

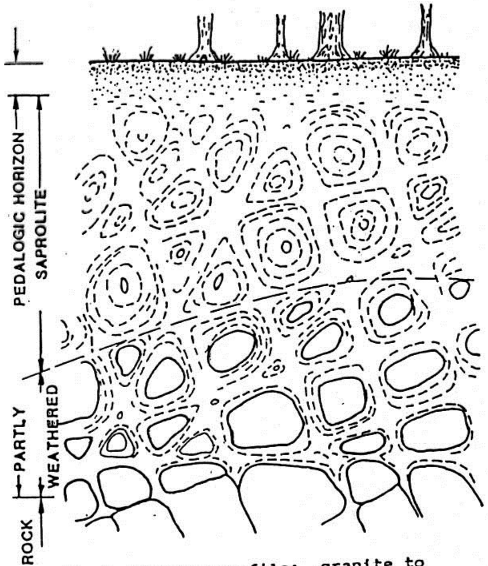


Fig. 3 Weathering profile: granite to gabbro.

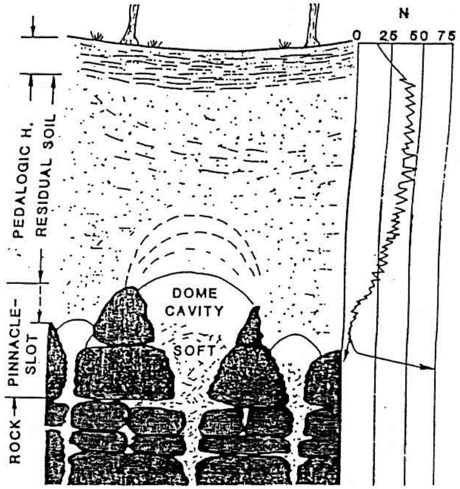


Fig. 10 Weathering profile: limestone, dolomite, marble.

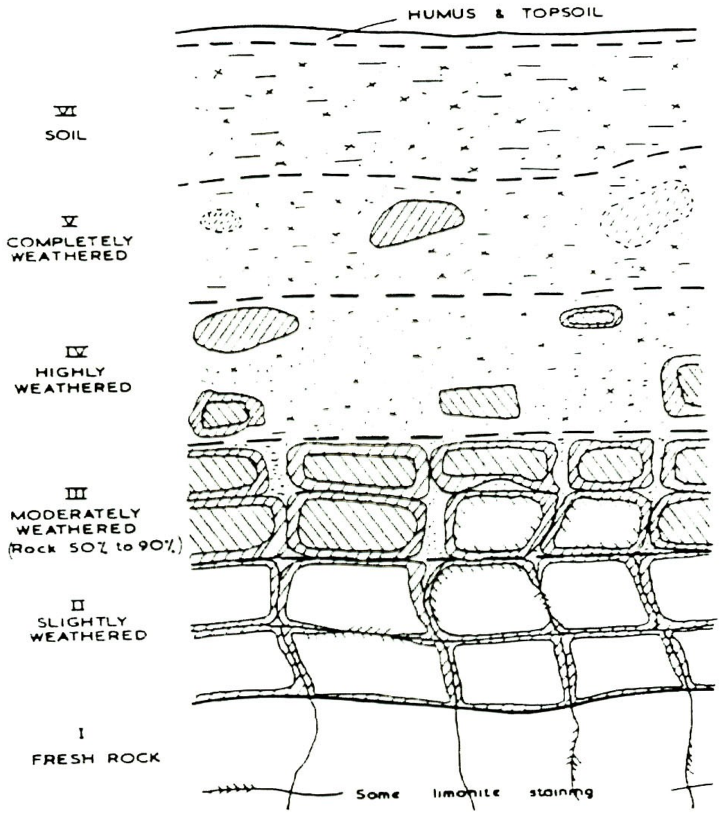
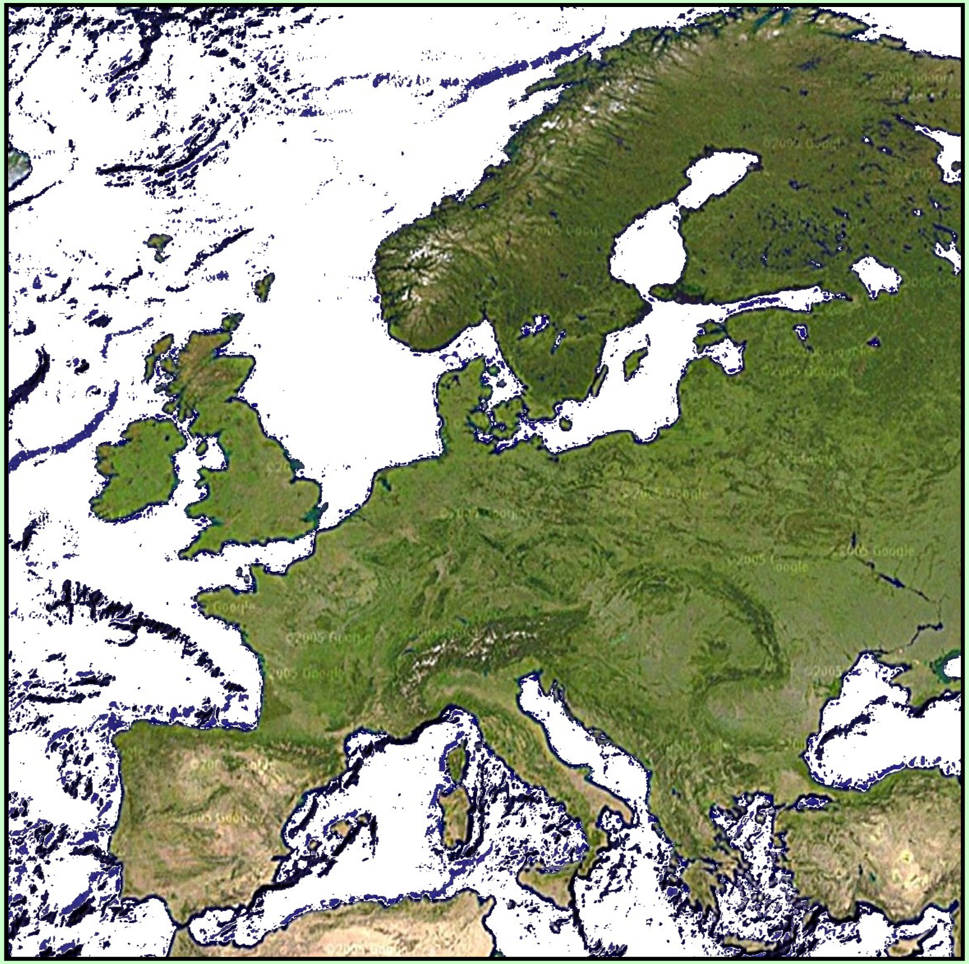
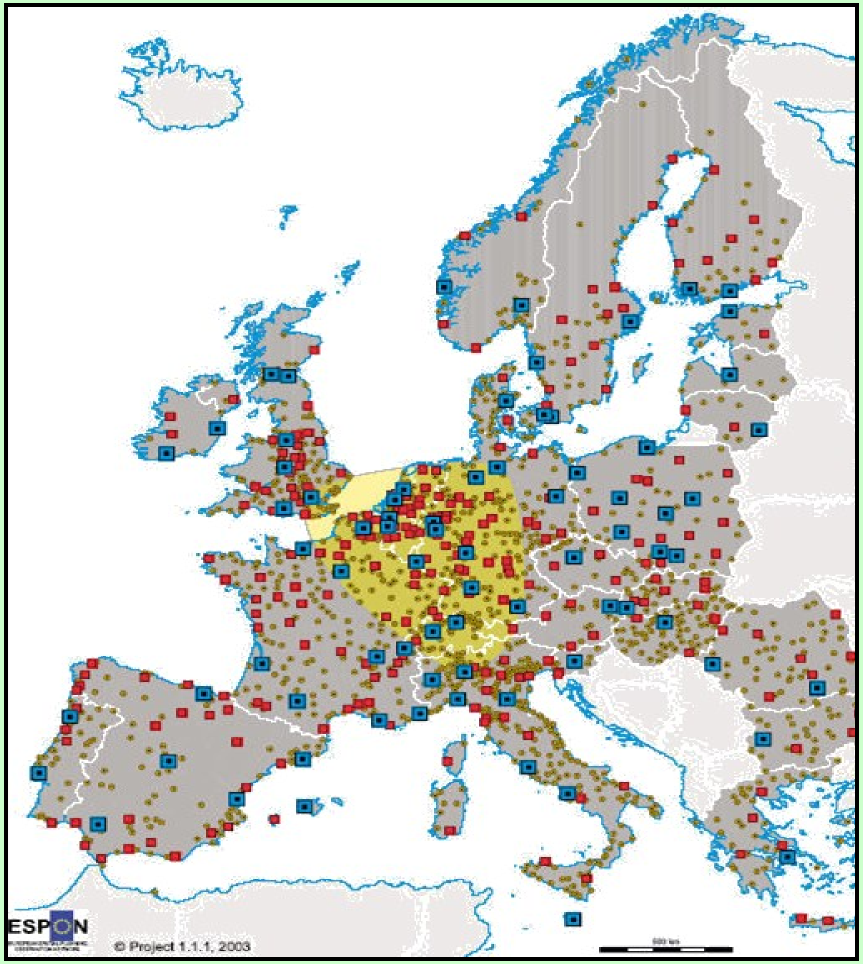


Fig. 1 : Classification of residual soils by degree of weathering (after Little, 1969)

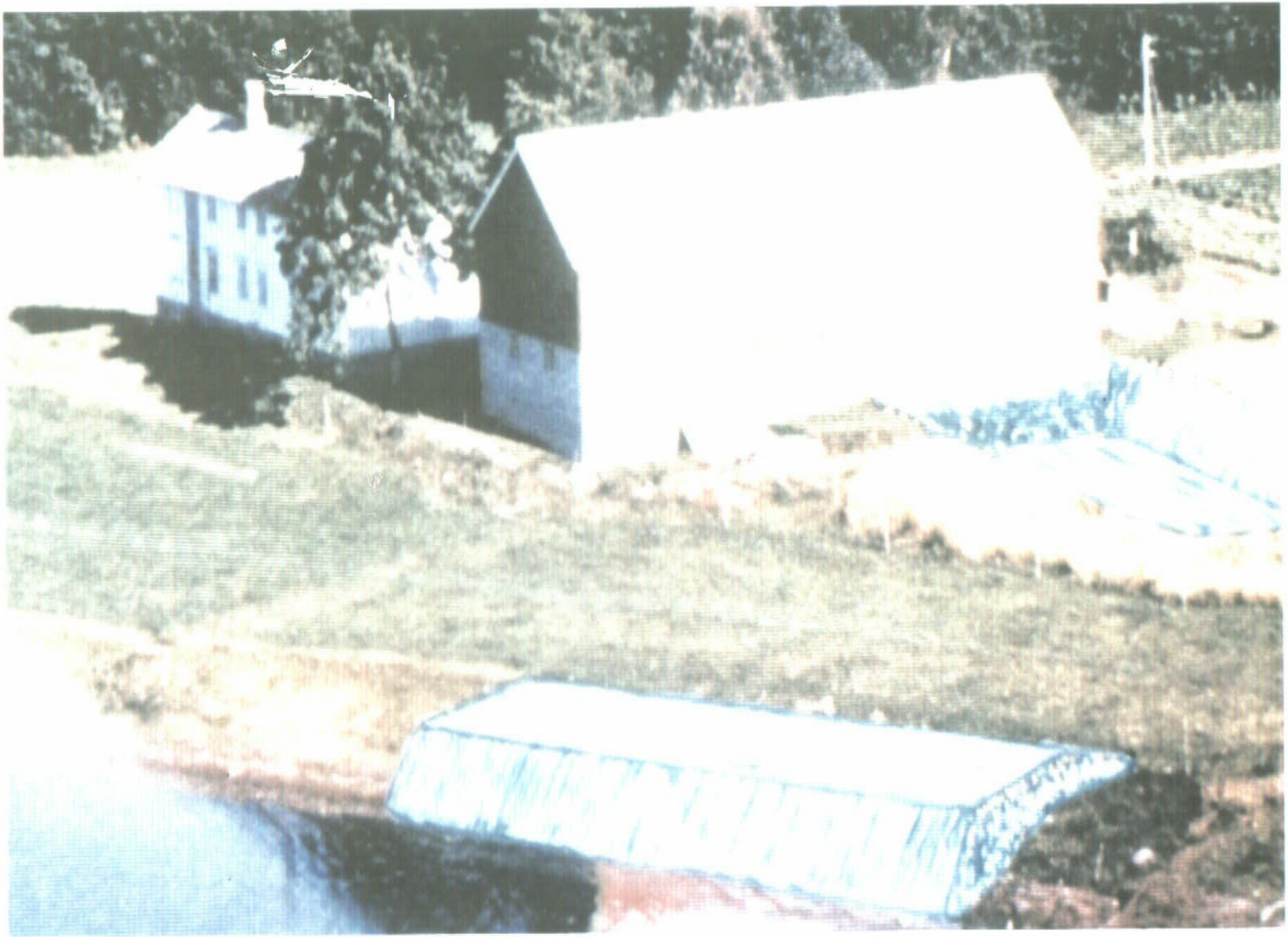
residue resulting from the weathering of igneous rocks in the humid tropics. This is a significant and important limitation to the usefulness

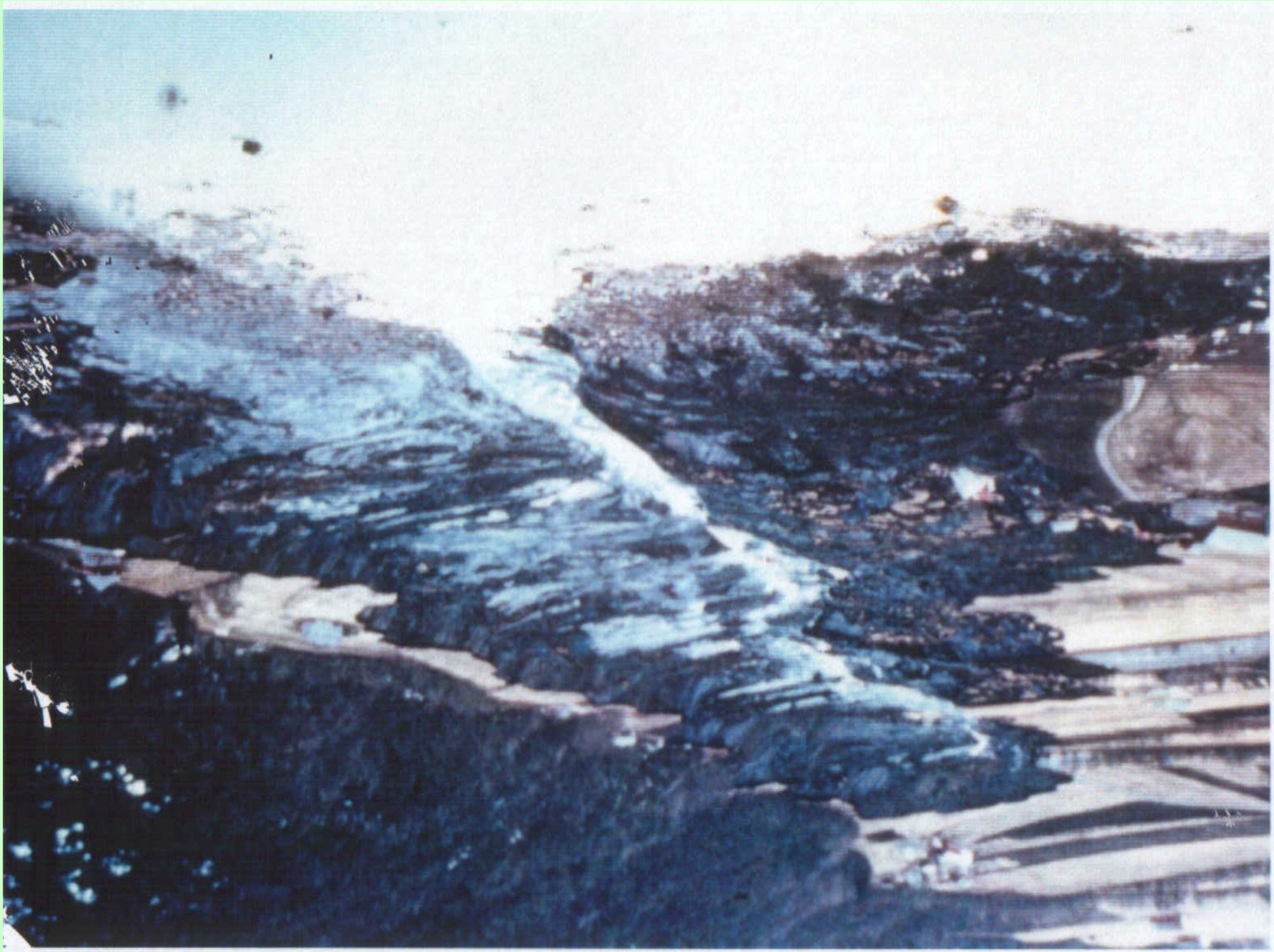
The European Setting





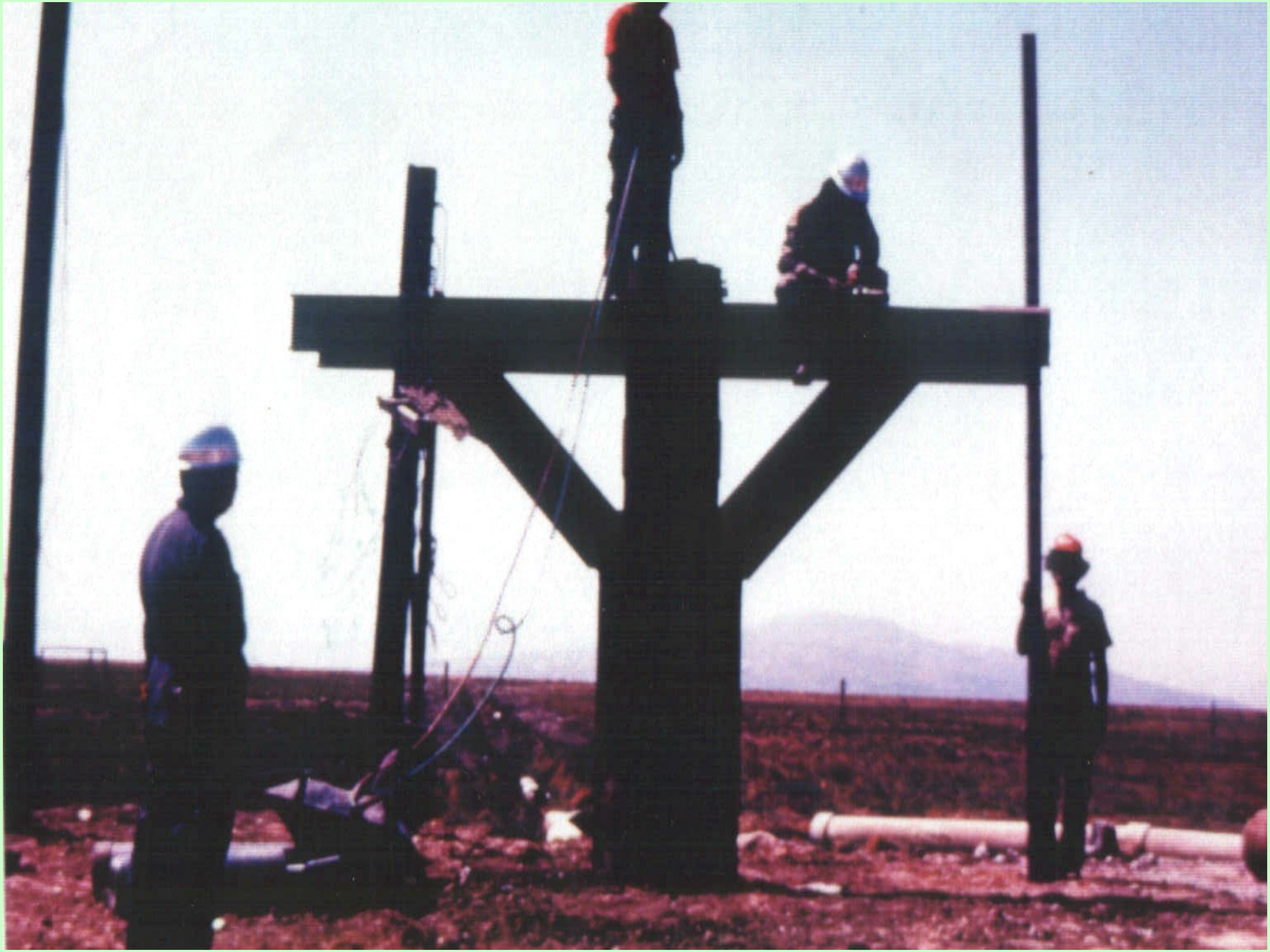
Quick Clays

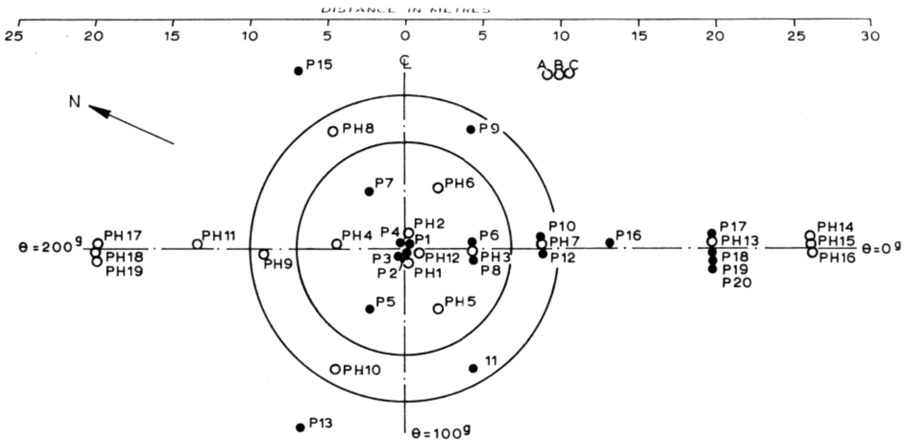




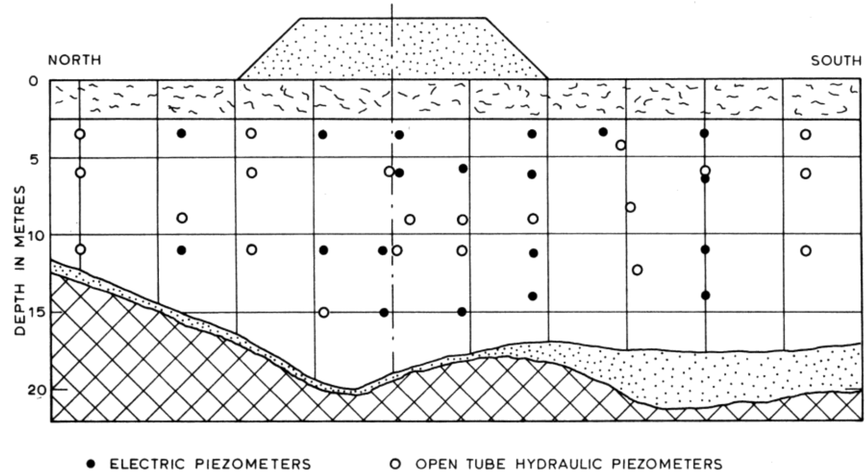
Soft clays– Mexico City

Subsidence





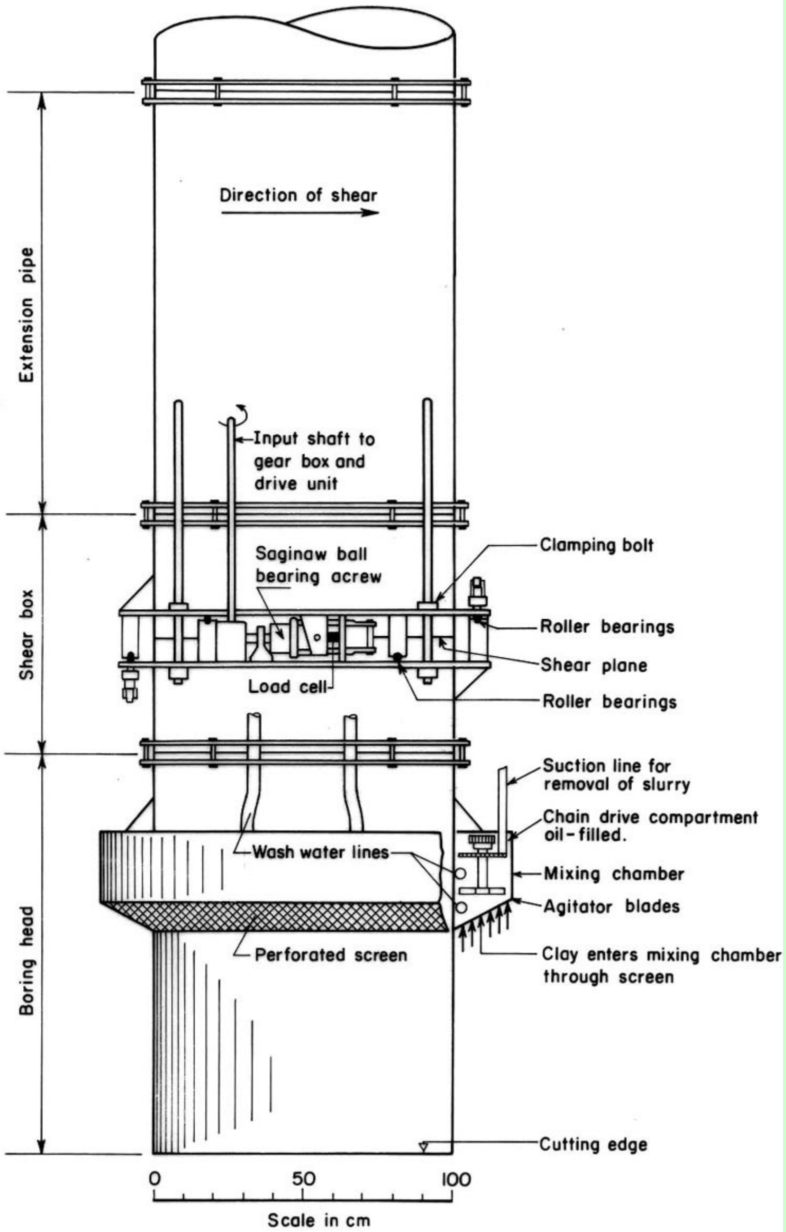
LOCATION OF PIEZOMETERS



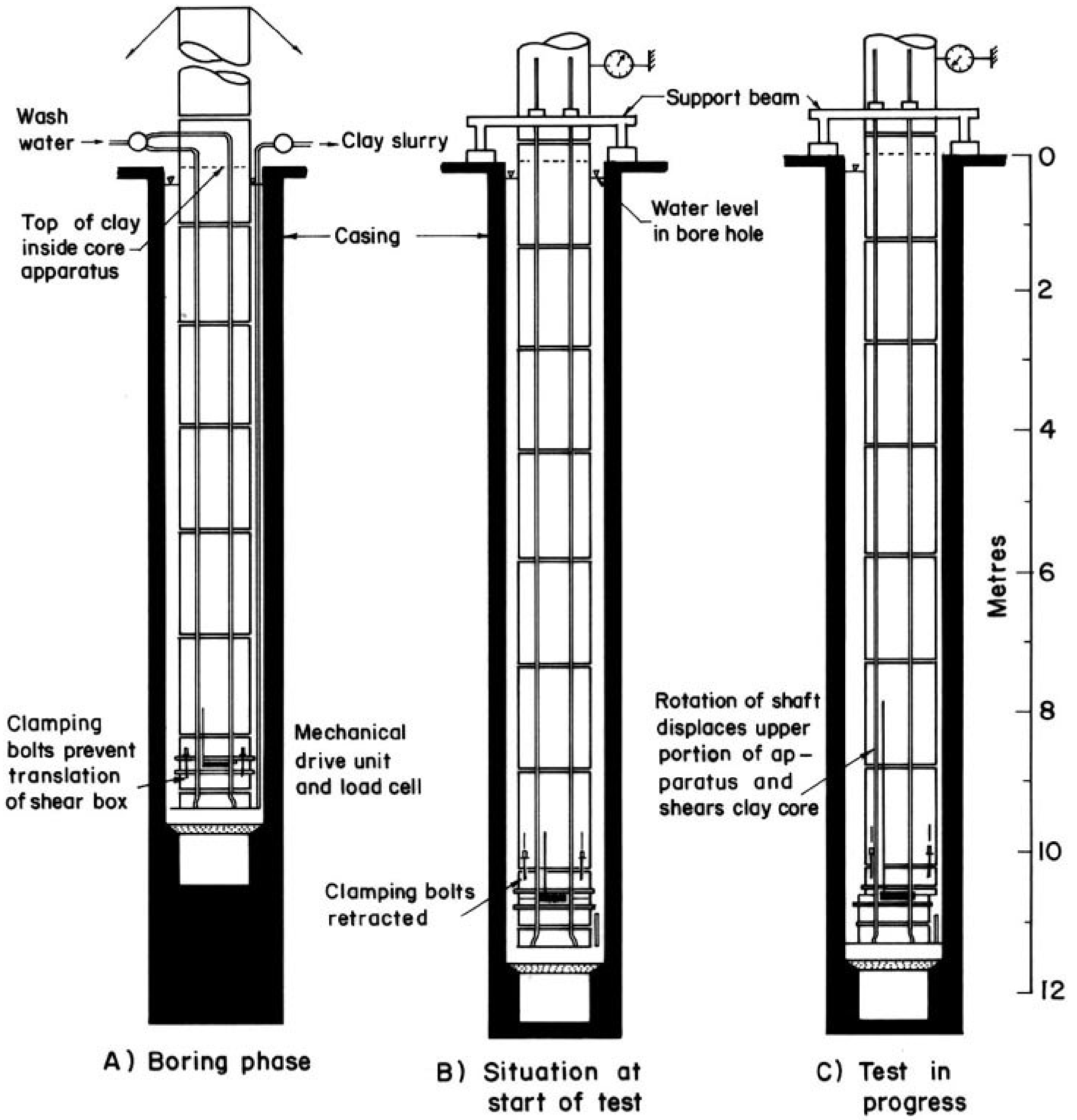
GAUGE NO	DEPTH M	RADIUS M	θ DEGREES[x)]
P1	3.5	0.5	374.0
P2	6.0	0.2	63.8
P3	11.0	0.5	132.0
P4	15.0	0.5	271.0
P5	3.5	4.5	133.3
P6	6.0	4.5	395.3
P7	11.0	4.5	266.6
P8	15.0	4.5	10.6
P9	3.5	9.0	333.2
P10	6.0	9.0	395.0
P11	11.0	9.0	66.6
P12	14.0	9.0	2.5
P13	3.5	13.5	133.3
P15	11.0	13.5	266.6
P16	3.5	13.5	398.5
P17	3.5	20.0	397.4
P18	6.0	20.0	0.7
P19	11.0	20.0	2.4
P20	14.0	20.0	4.0
PH1	6.0	1.0	85.0
PH2	11.0	1.1	314.0
PH3	9.0	4.5	2.8
PH4	15.0	4.5	202.8
PH5	11.0	4.5	66.6
PH6	6.0	4.5	333.3
PH7	9.0	9.0	398.6
PH8	11.0	9.0	266.6
PH9	6.0	9.0	198.6
PH10	3.5	9.0	133.3
PH11	9.0	13.5	201.3
PH12	9.0	1.0	13.0
PH13	6.0	20.0	399.0
PH14	3.5	26.5	398.4
PH15	6.0	26.5	399.6
PH16	11.0	26.5	0.8
PH17	3.5	20.0	200.7
PH18	6.0	20.0	199.0
PH19	11.0	20.0	197.4
PH20	2.5	40.0	0.0
PH21	2.0	30.0	200.0
A	4.2	14.7	344.0
B	8.2	15.2	346.0
C	12.2	15.7	348.0

x) 400 Degree circle

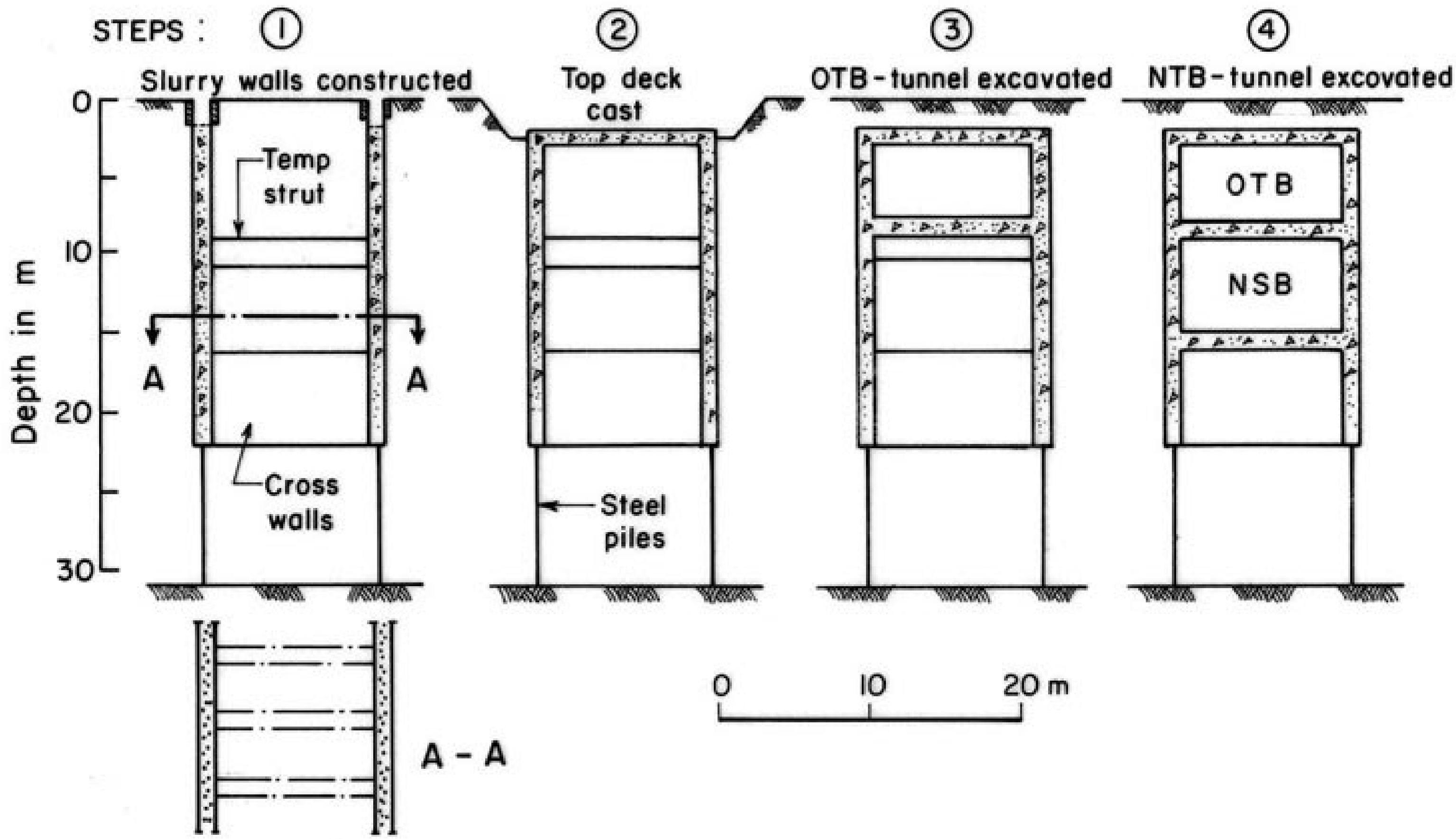
Large Scaled Tests
and
Instrumentation



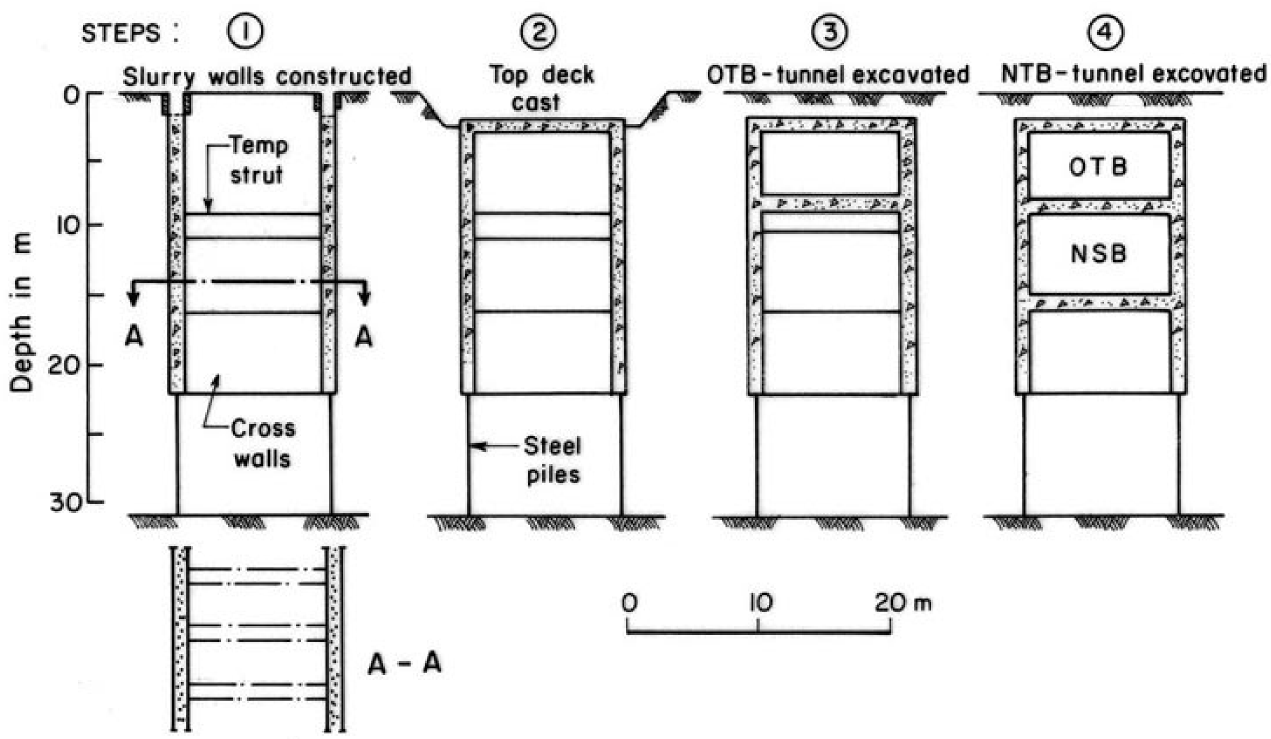
Details of the direct shear field apparatus for measuring the undrained shear strength on a horizontal failure plane.



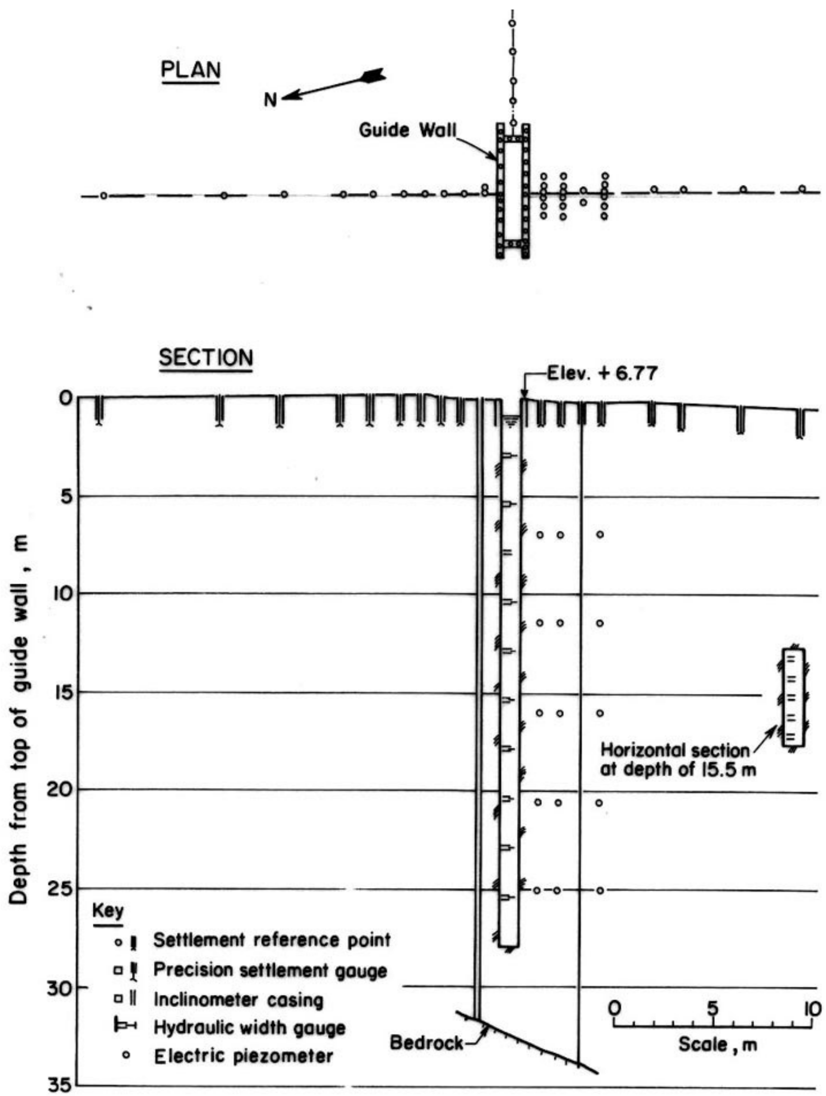
Scheme showing the operating principle of the in-situ direct shear apparatus



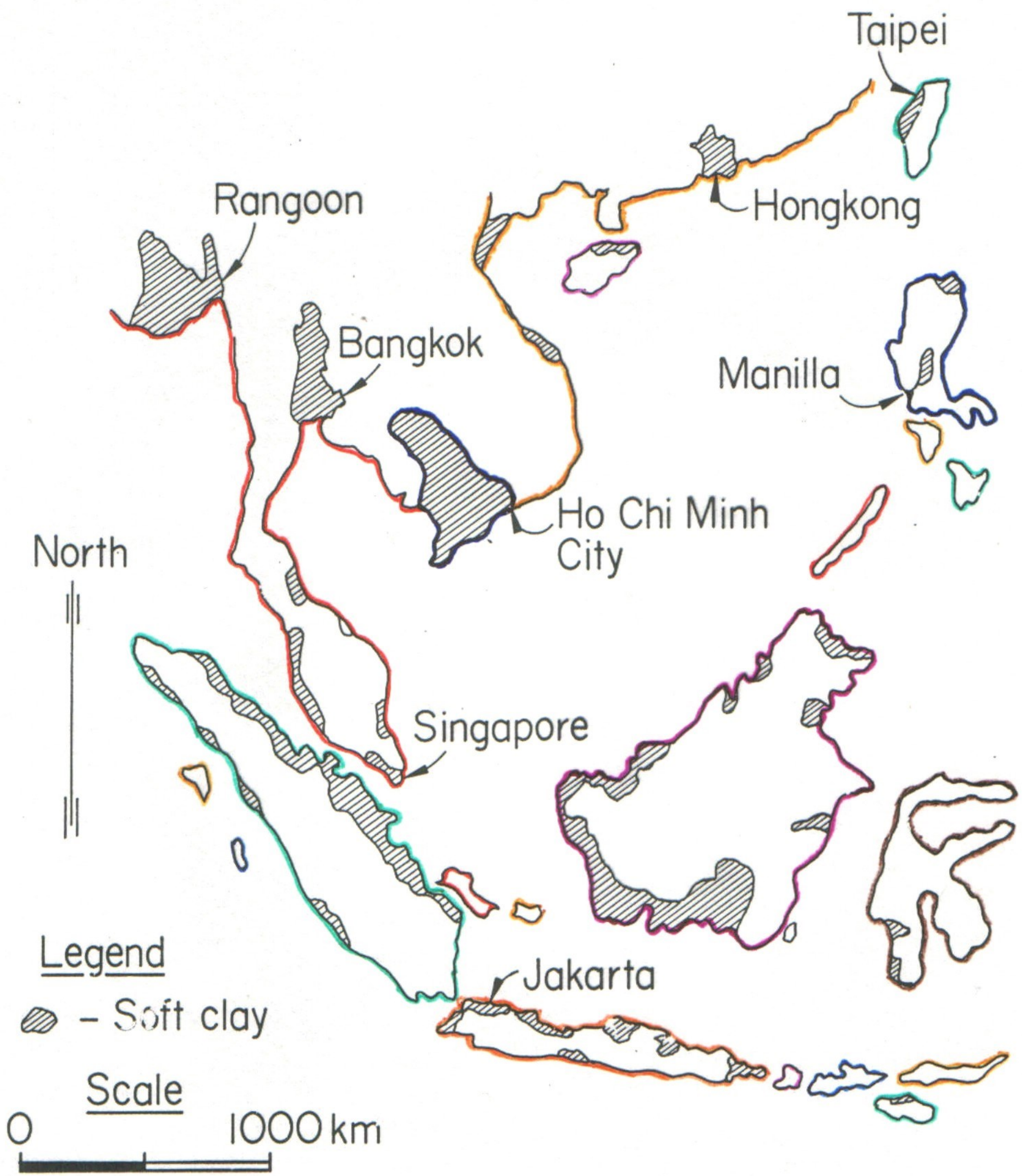
Construction sequence, Studenterlunden.



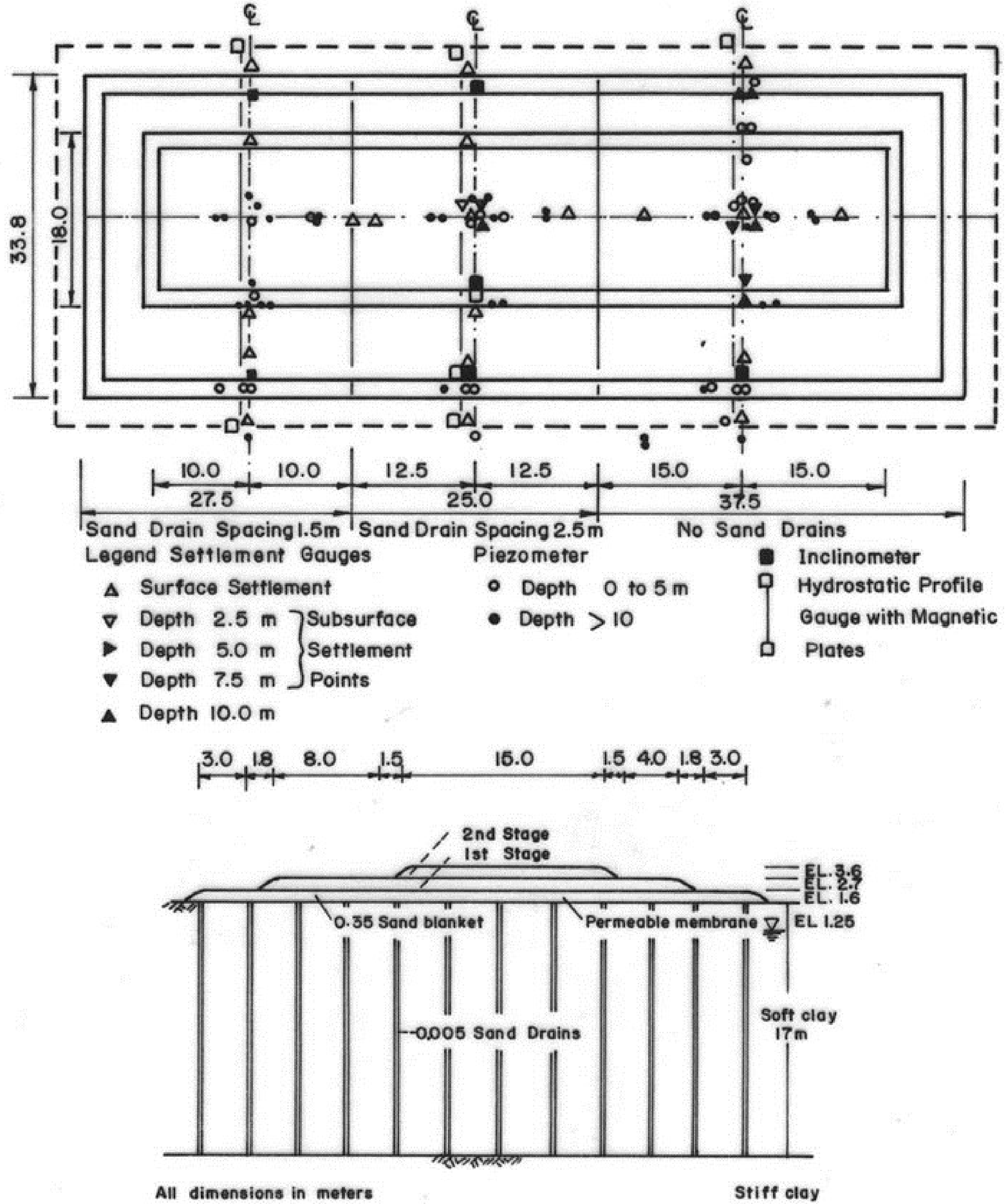
Construction sequence, Studenterlunden.



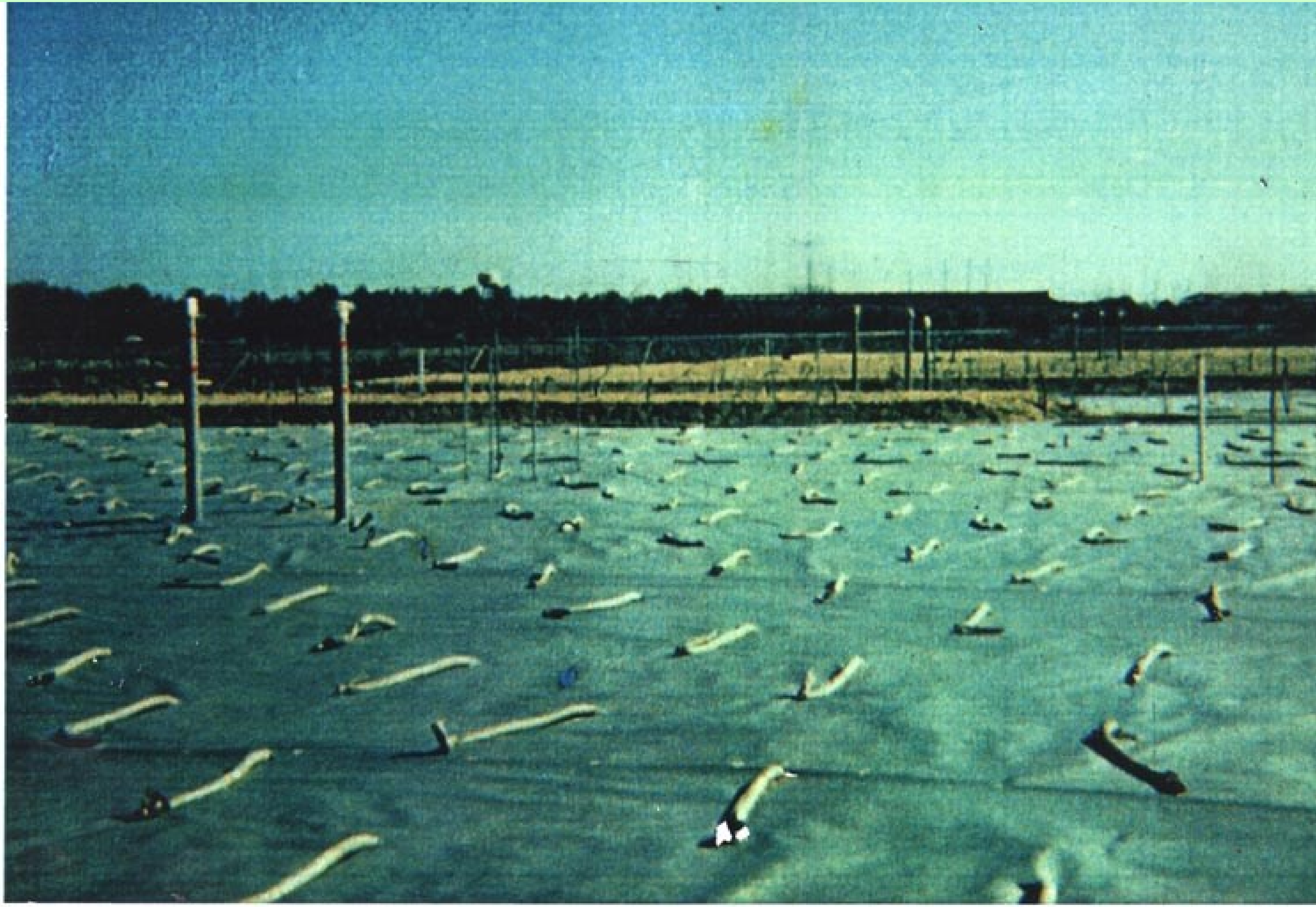
Details of test trench at Studenterlunden



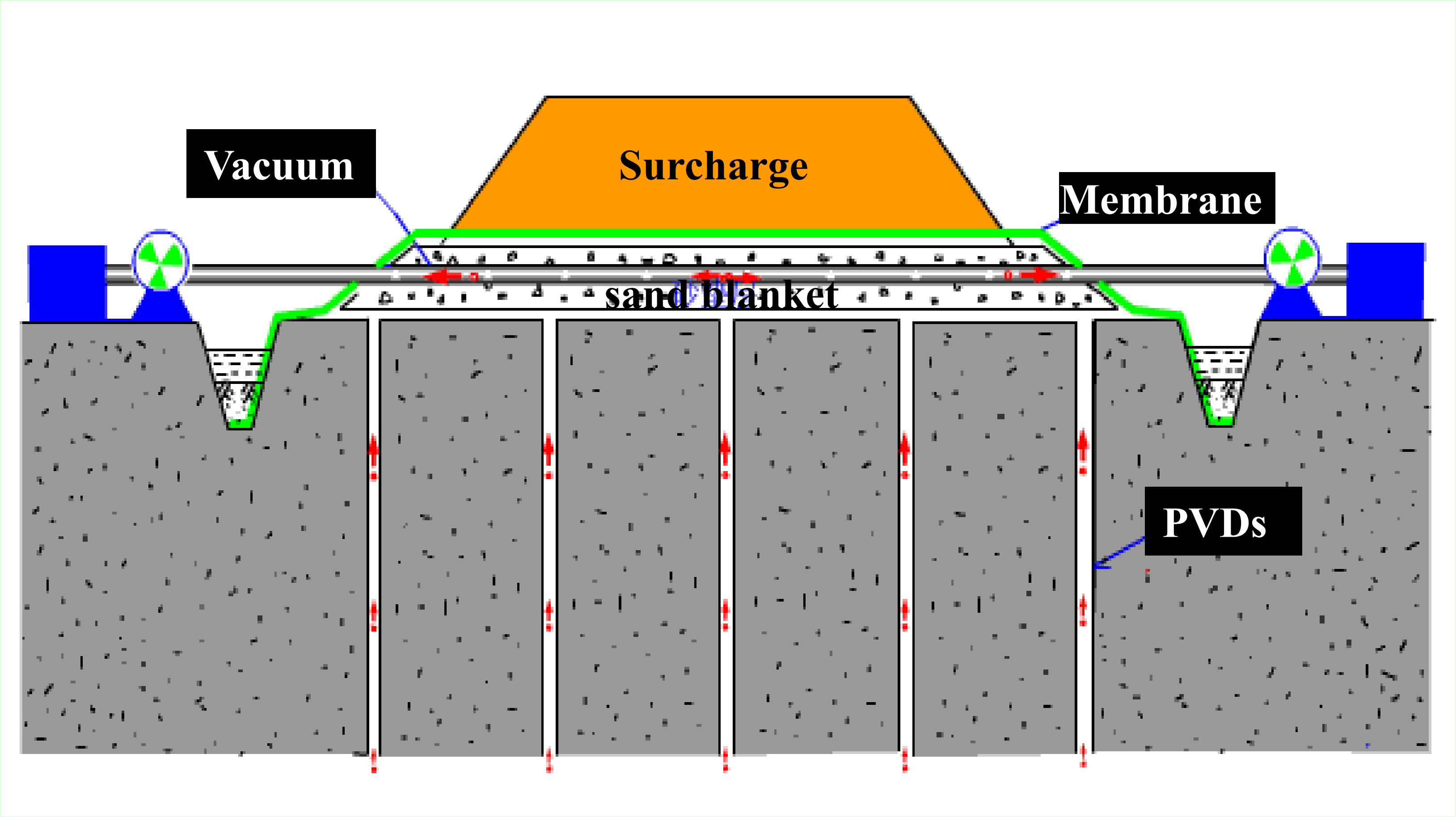
Distribution of soft clay in Southeast Asia



33.8
18.0
10.0 10.0 12.5 12.5 15.0 15.0
27.5 25.0 37.5
Sand Drain Spacing 1.5m
Sand Drain Spacing 2.5m
No Sand Drains
Legend Settlement Gauges
Surface Settlement
Depth 2.5 m
Depth 5.0 m
Depth 7.5 m
Subsurface Settlement Points
Depth 10.0 m
Piezometer
Depth 0 to 5 m
Depth > 10
Inclinometer
Hydrostatic Profile Gauge with Magnetic Plates
3.0 1.8 8.0 1.5 15.0 1.5 4.0 1.8 3.0
2nd Stage
1st Stage
EL. 3.6
EL. 2.7
EL. 1.6
EL 1.25
0.35 Sand blanket
Permeable membrane
0.005 Sand Drains
Soft clay 17m
All dimensions in meters
Stiff clay

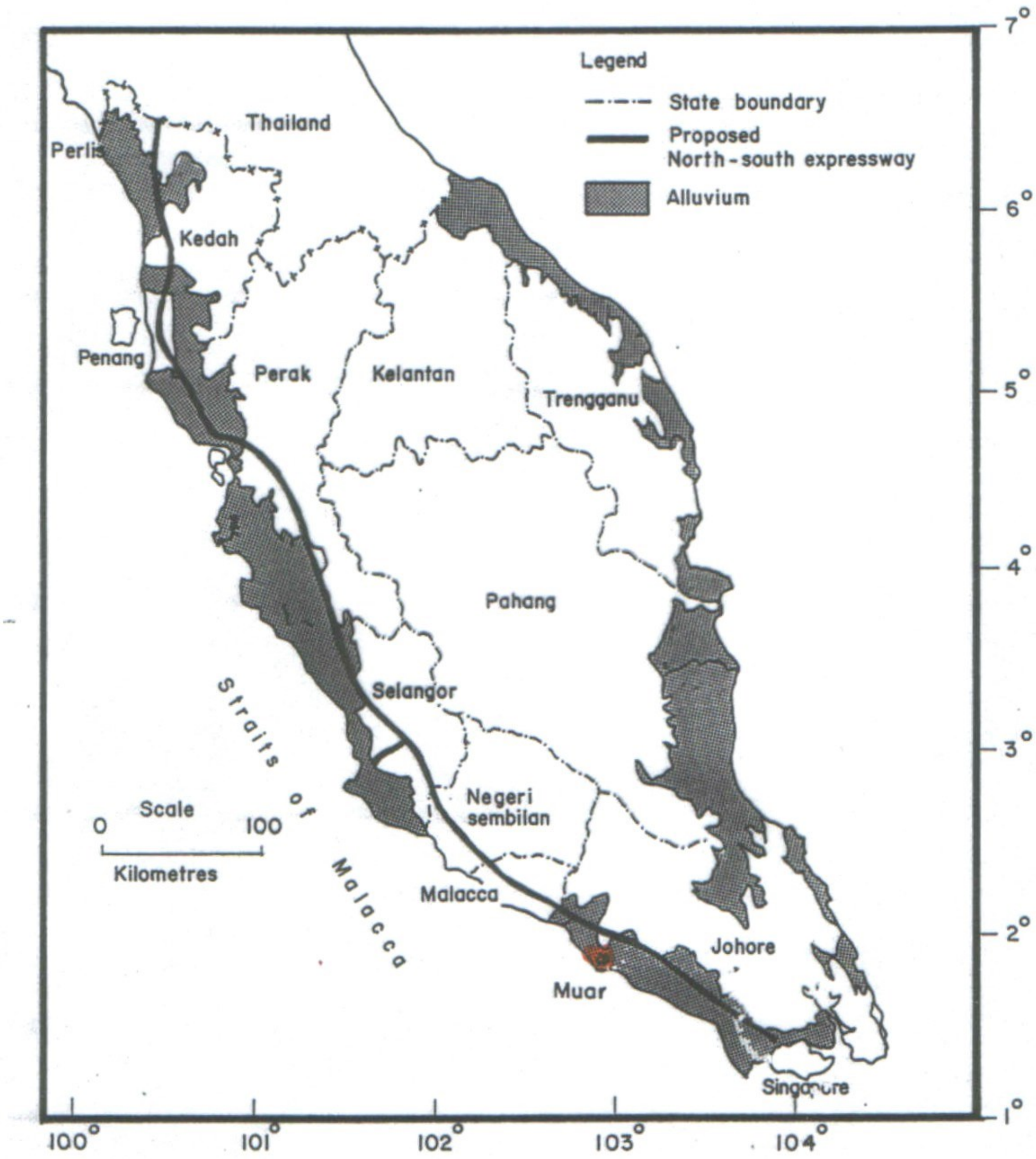


Principle



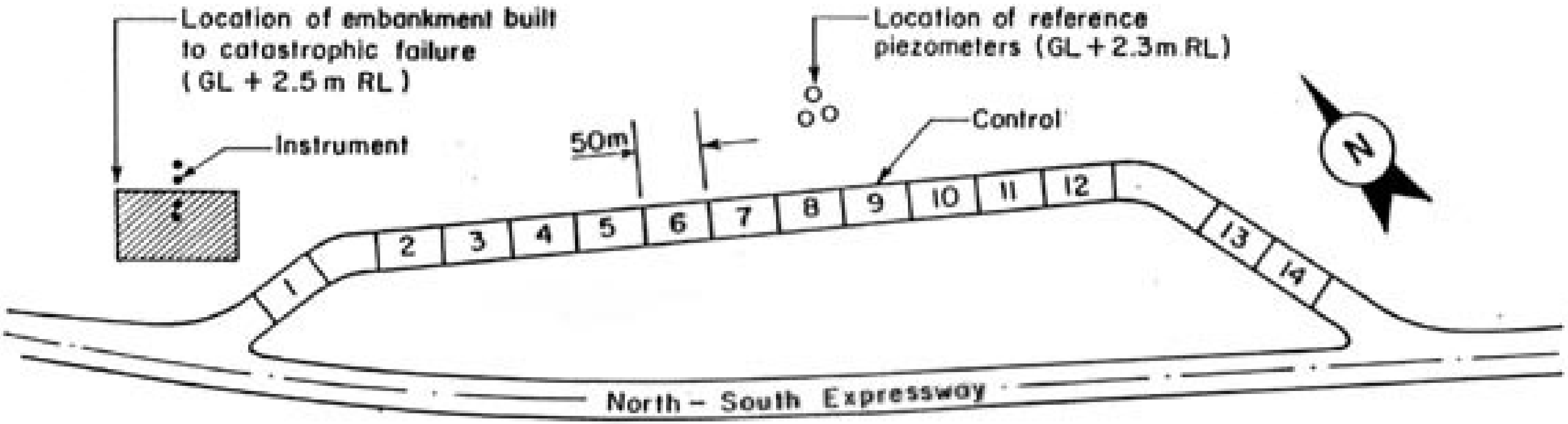
Geotechnical Investigation at Nong Ngo Hao Airport Site

Phase	Year	Title
I	1972 - 1974	Geotechnical Investiga-tions by Asian Institute of Technology and N.D. Lea and Associates, Kampsax
II	1983 - 1984	Pre-loading with Sand Drains, and , Vacuum-Drains; Moh and Associates and NACO
III	1992	An Independent Soil Engineering Study; Norwegian Geotechnical Institute in cooperation the STS Engineering Consultant Co. Ltd.
IV	1993 - 1995	Full scale Field test of Prefabricated vertical drains by the Asian Institute of Technology



River and Coastal Alluvium of Peninsular Malaysia

LEMBAGA LEBUHRAYA MALAYSIA
TRIAL EMBANKMENTS

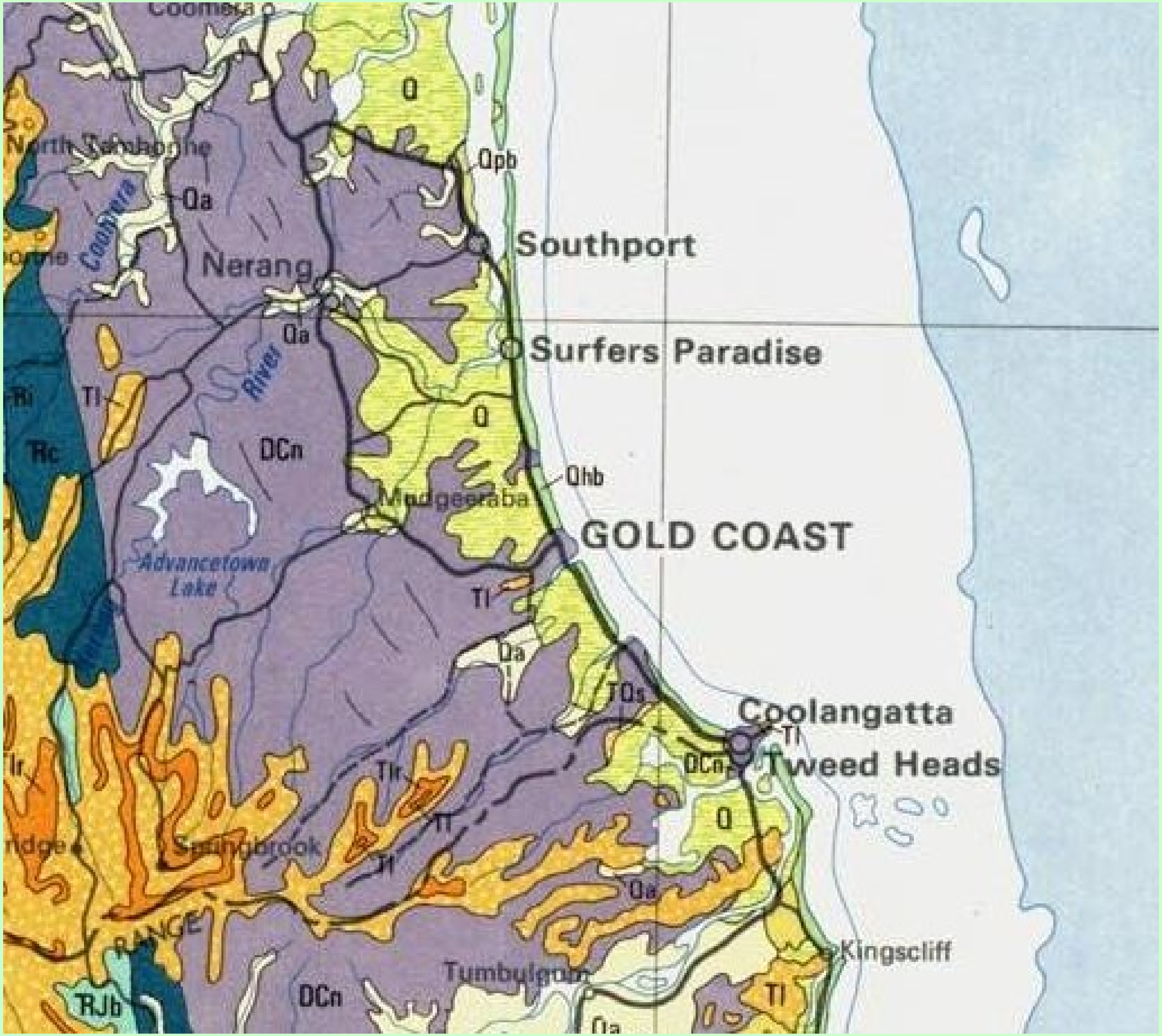


Method of Ground Improvement :

- Electro - osmosis (6)
- Chemical Injection (1 & 4)
- Sand Sandwich (13)
- Preloading & Drains (11, 12 & 14)
- Micro Piles (3)
- Vacuum Preloading (10)
- Sand Compaction Piles (8)
- Well-point Preloading (5)

Prestressed Spun Piles (7)

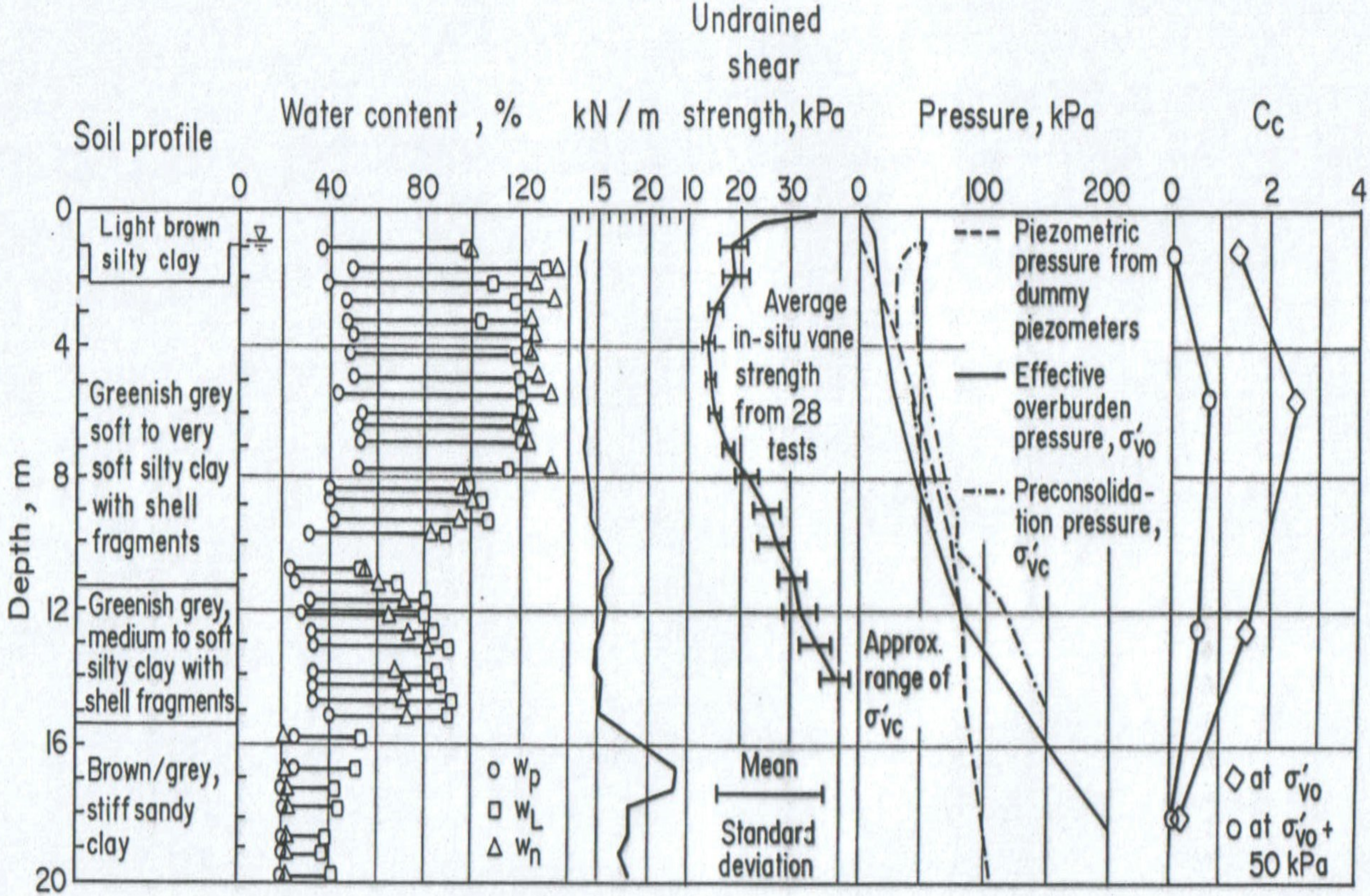
Layout of Trial Embankments



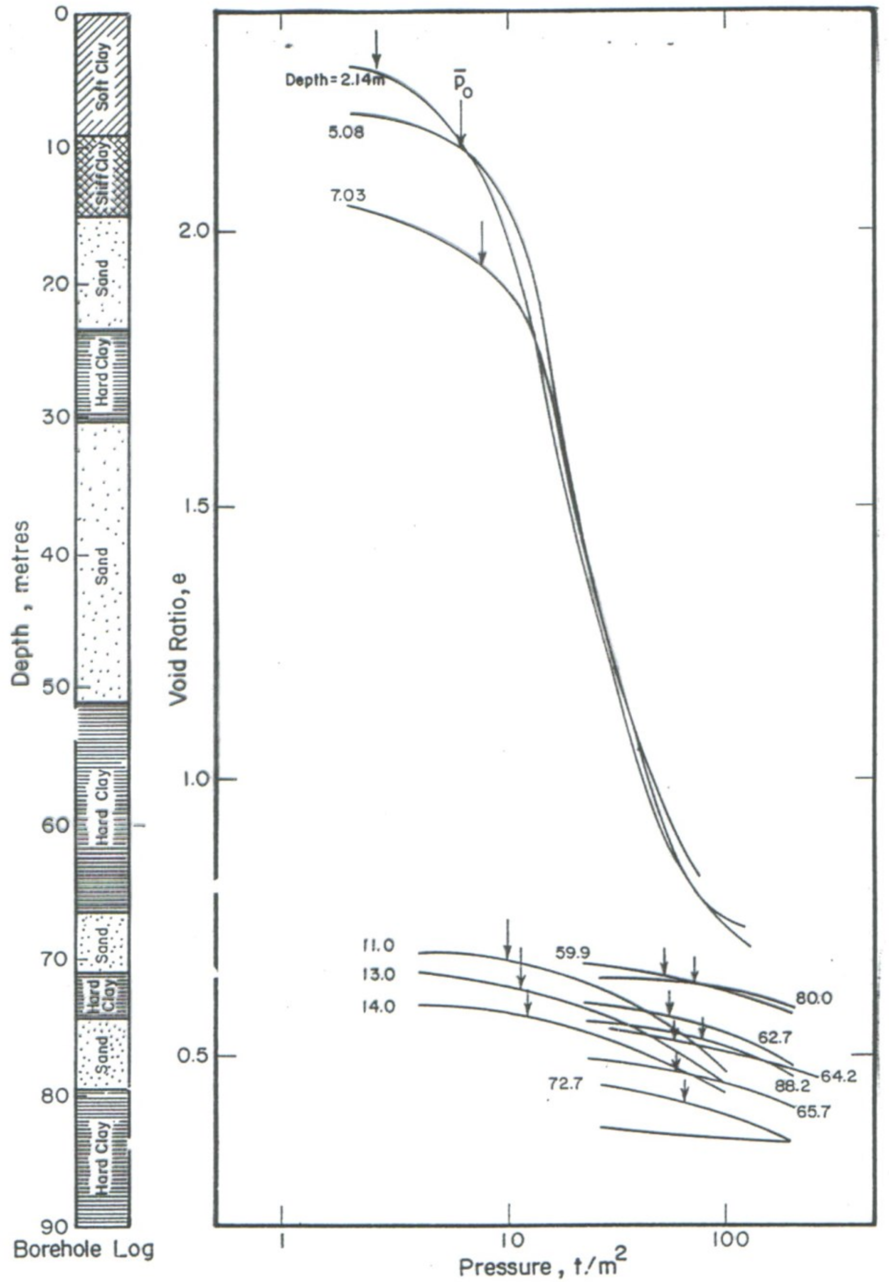
Coomera
Q
Qpb
North Tamborine
Coomera
Qa
Southport
Nerang
Qa
River
Surfers Paradise
Ri
Tl
Q
Rc
DCn
Qhb
Mudgeeraba
GOLD COAST
Advancetown Lake
Tl
Qa
TQs
Coolangatta
Tl
DCn
Tweed Heads
Tlr
Tlr
Q
Tl
Springbrook
Tl
Qa
RANGE
Kingscliff
Tumbulgum
RJb
DCn
Tl
Qa

1. **Gold Coast Highway (stone columns)**
2. **Sunshine Coast Motorway (Vertical drains-PVD)**
3. **Port of Brisbane Motorway (Vertical drains-PVD)**

Figure 1: Project route plan



Geotechnical characteristics of soft Bangkok clay at Bangpli



Typical Clay Compression Curves at AIT (after TAESIRI, 1976 & KANJANAKAROON, 1977)

Chapter 8

Laboratory testing

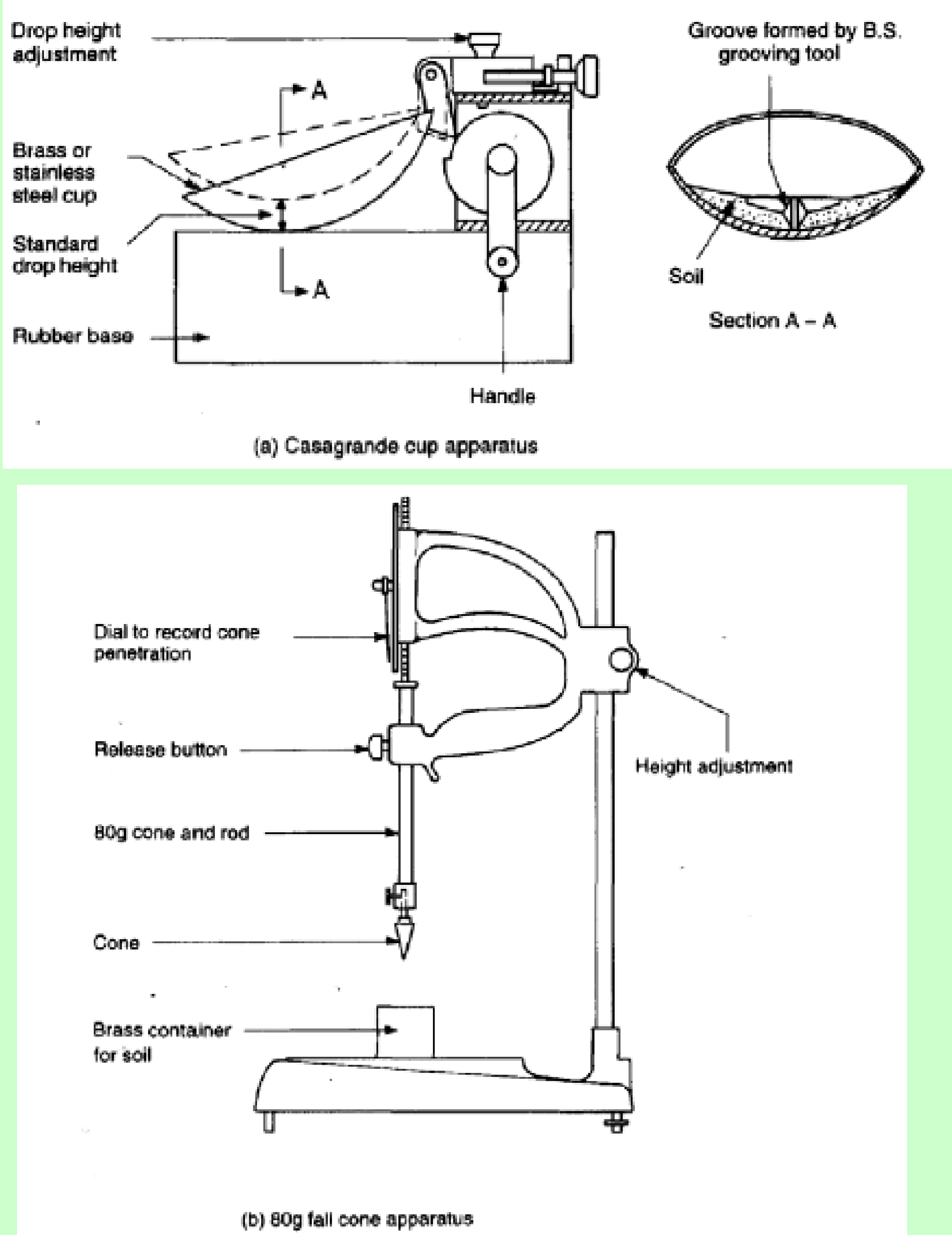


Fig. 8.2 Casagrande cup and cone penetrometer for liquid limit testing. (Clayton *et al*, 1995)

Geo-1.1: Boring & Soil Sampling

Boring & Sampling

a. Borings

b. Soil Sampling (General)

c. Test Borings

d. Soil sampling- Samplers

e. Block sampling

f. Summary

Soil Sampling-General

What is Purpose of Samples?

Fig. 4

Purpose of samples??:

- general soil profile
- soil classification
- soil classification + index tests
- soil classification + index tests + engineering properties

Sample Disturbance

- **physical disturbance during sampling**
- **changes in water content**
- **changes in temperature**
- **changes in pore liquid and gas pressure**
- **handling, sampling and storage**

Full sample recovery often does not imply an undisturbed sample was collected

Soil Sampling Equipment

- Hand tools
- Split spoon barrel
- California barrel
- Thin walled tube
- Fixed piston
- Denison/Pitcher
- Continuous tube
- Internal sleeve with wire-line
- Block Sampling

Fig. 5

Sample Disturbance - Ranking

Most disturbed → least disturbed

- **cuttings from hand holes or drill string**
- **drive samples – SPT**

- **push samples with thin walled tube**
- **push samples with fixed piston**
- **block samples**

Summary of Sampling Methods

Sampler	State	Soil Types	Penetration	% use
Split Barrel	D	Sand, silts, clays	Hammer	85
Thin-walled Shelby Tube	U	Clays, silts, fine-grained soils, clayey sands	Mechanical push	6
Continuous Push	D/U	Sands, silts, clays	Hydraulic push	4
Piston	U	Silts and clays	Hydraulic push	1
Pitcher	U	Stiff to hard clay, silt, sand and partially weathered rock	Rotation and hydraulic pressure	<1
Denison	U	Stiff to hard clay, silt, sand and partially weathered rock	Rotation and hydraulic pressure	<1
Bulk	D	All	hand	<1
Block	U	Cohesive soils	Hand/special sampler	<1

D = disturbed; U = undisturbed

Table 1

After FHWA NHI-01-031; see also ASTM 4700

Boring Equipment

Truck/Rig Mounted Test Borings

- Solid-Stem Continuous Flight Augers
- Hollow-Stem Augers
- Open Hole Mud Rotary Drilling
- Drive Casing Mud Rotary Drilling
- Air-Rotary Drilling
- Wireline/Cable tooling

Solid stem augers

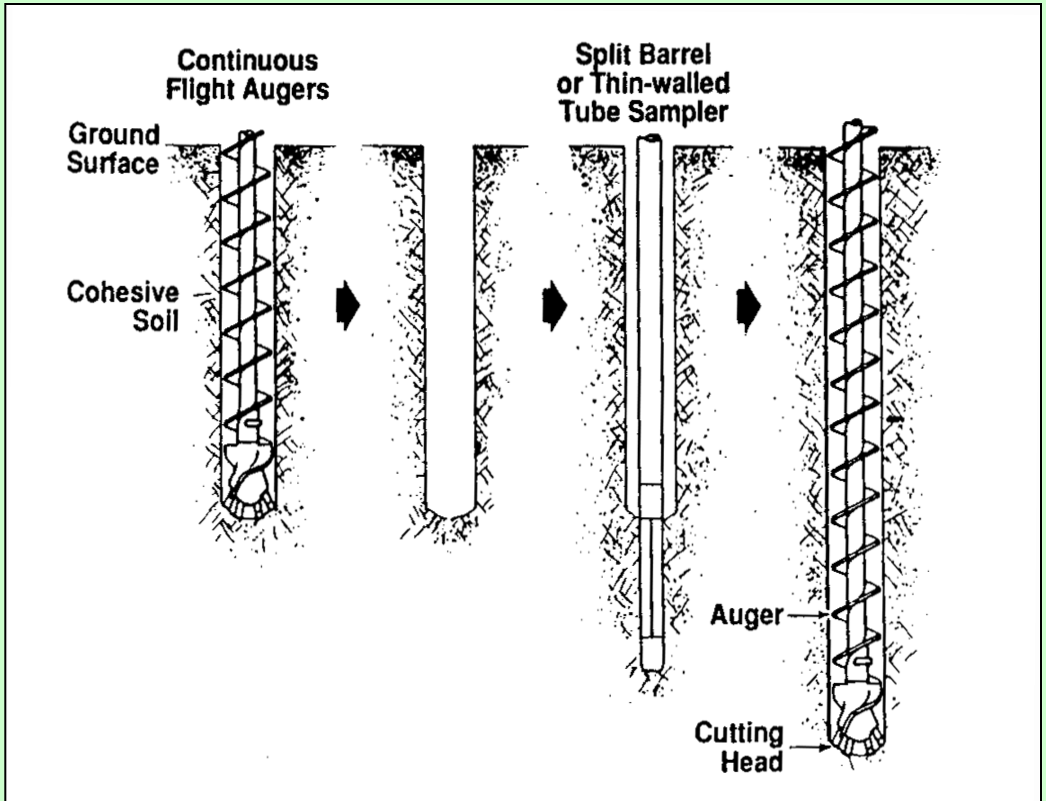


Fig. 6

Fig. 7

Soil sampling is performed by removing augers and introducing sampling tools (i.e., open hole); augers are then reinserted to advance the borehole

Hollow-Stem Augers

Fig. 8

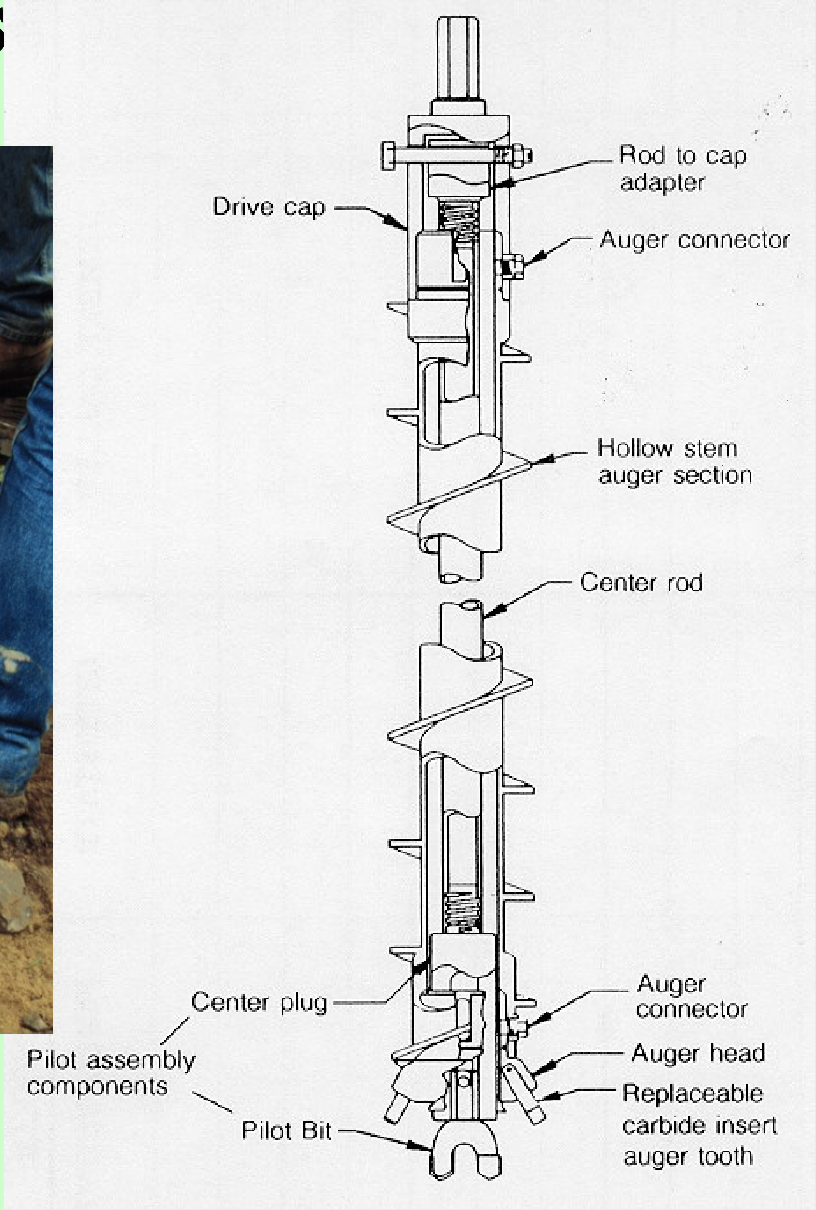


Fig. 9

Augers act as a casing

Sampling with Hollow Stem Augers

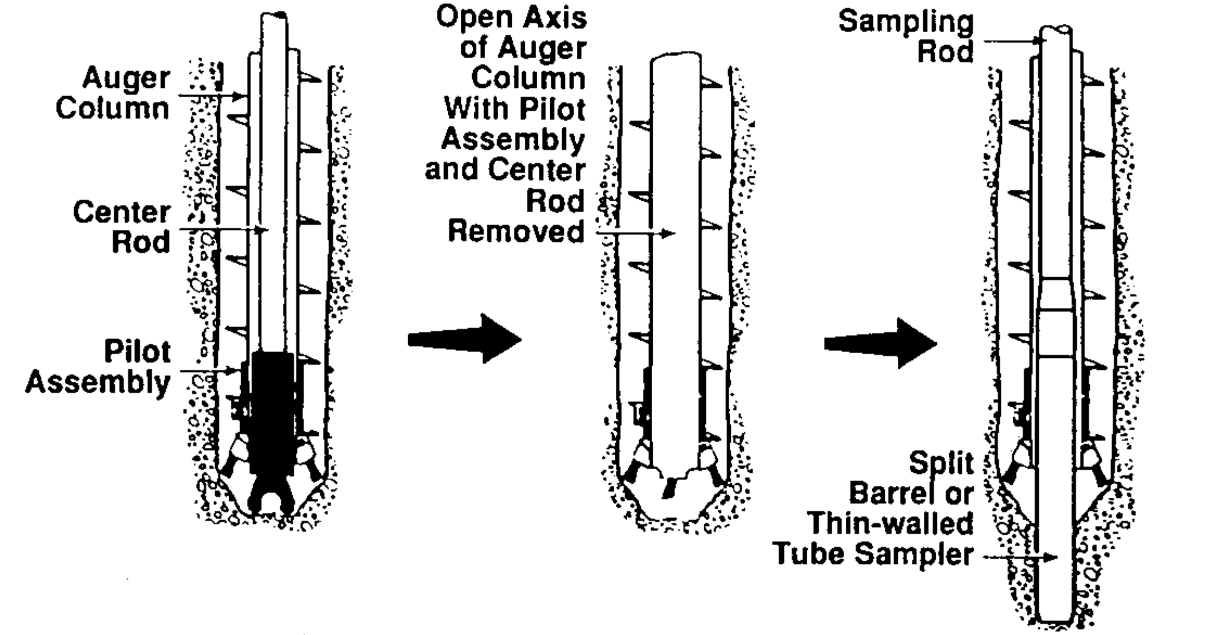


Fig. 10 Hollow-Stem Auger Sampling

Fig. 11

ASTM D 6151 "Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling"

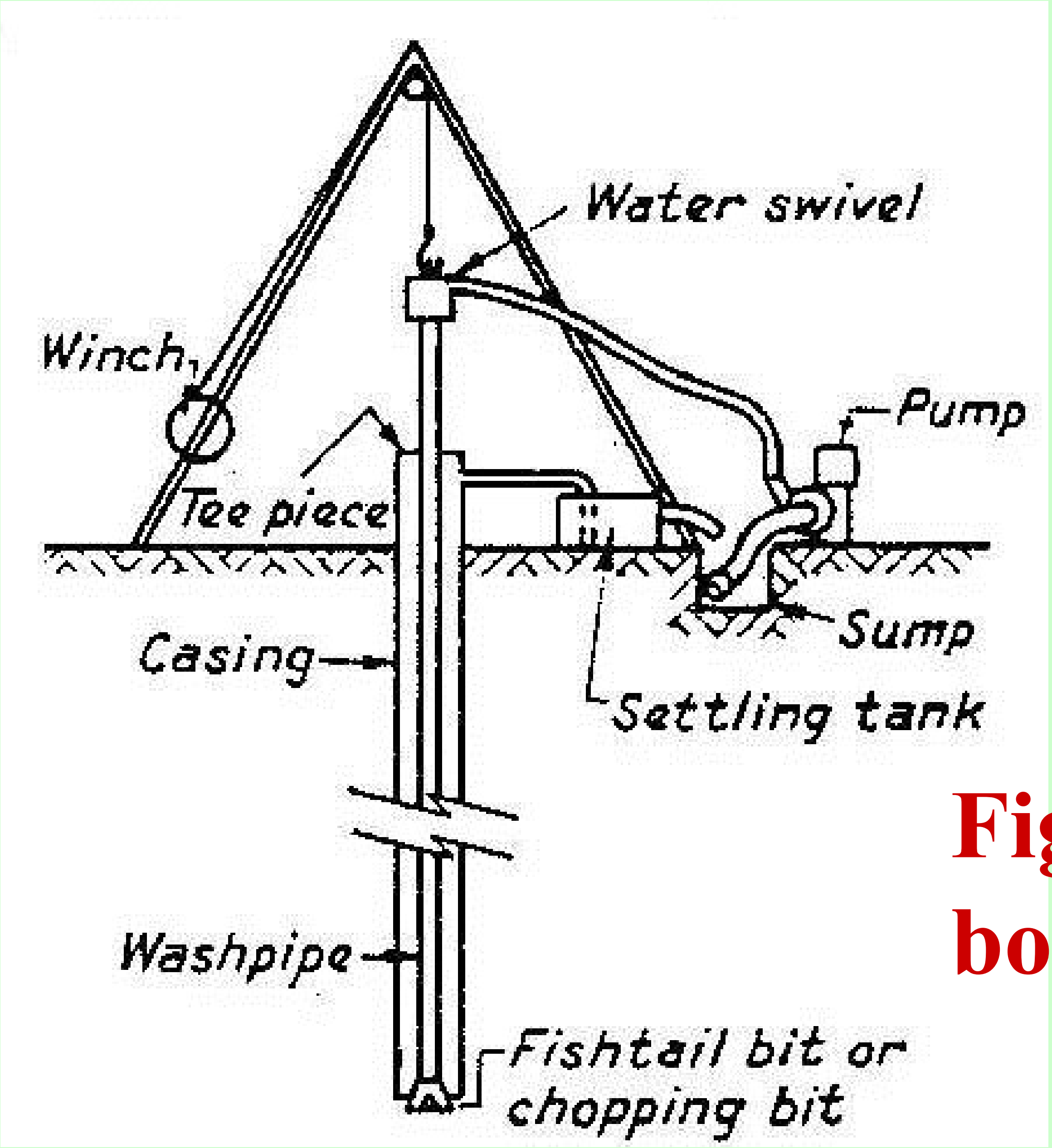


Fig. 12 Wash boring

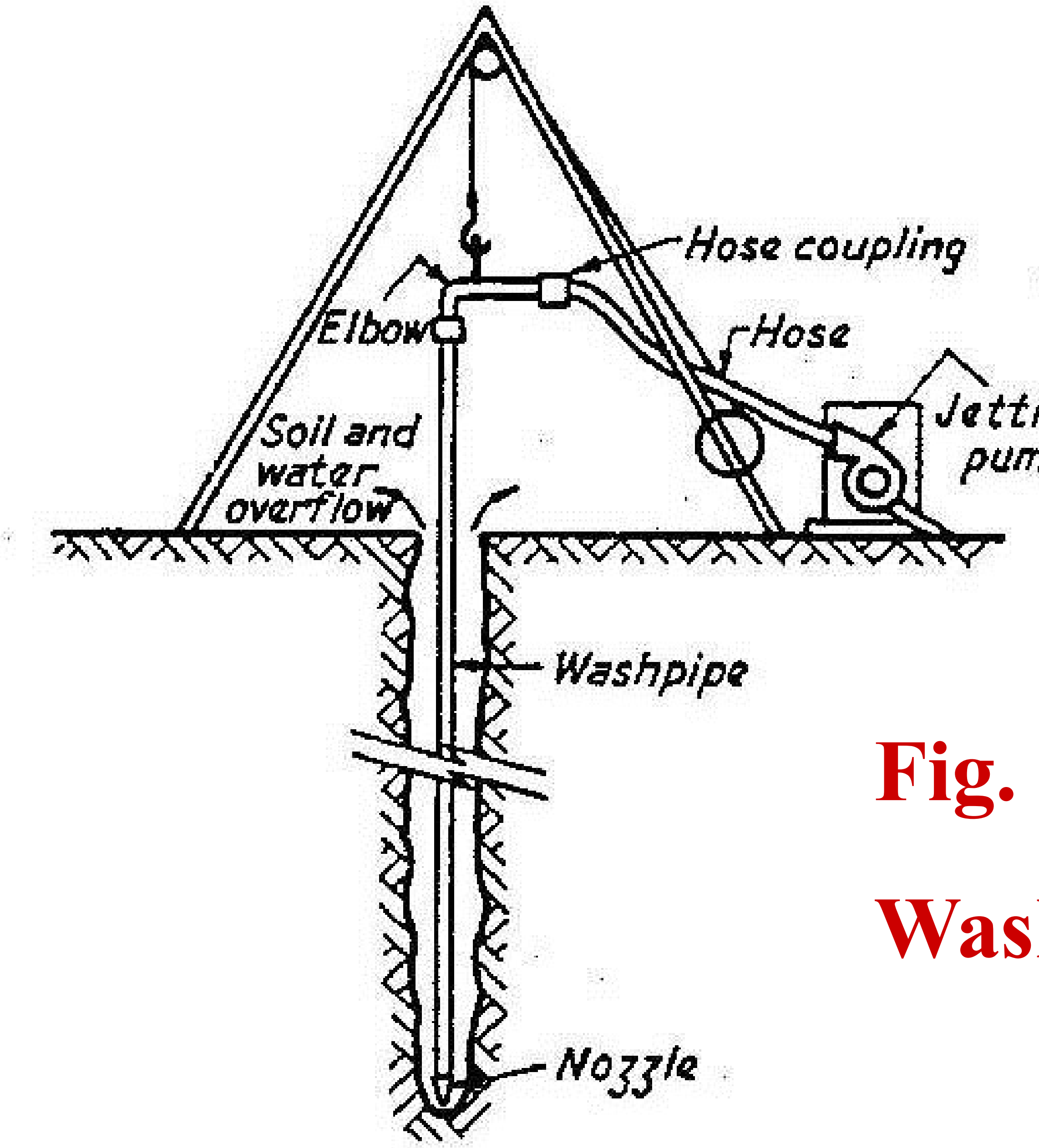


Fig. 13

Wash probing

Mud Rotary (Wash Boring) Drilling

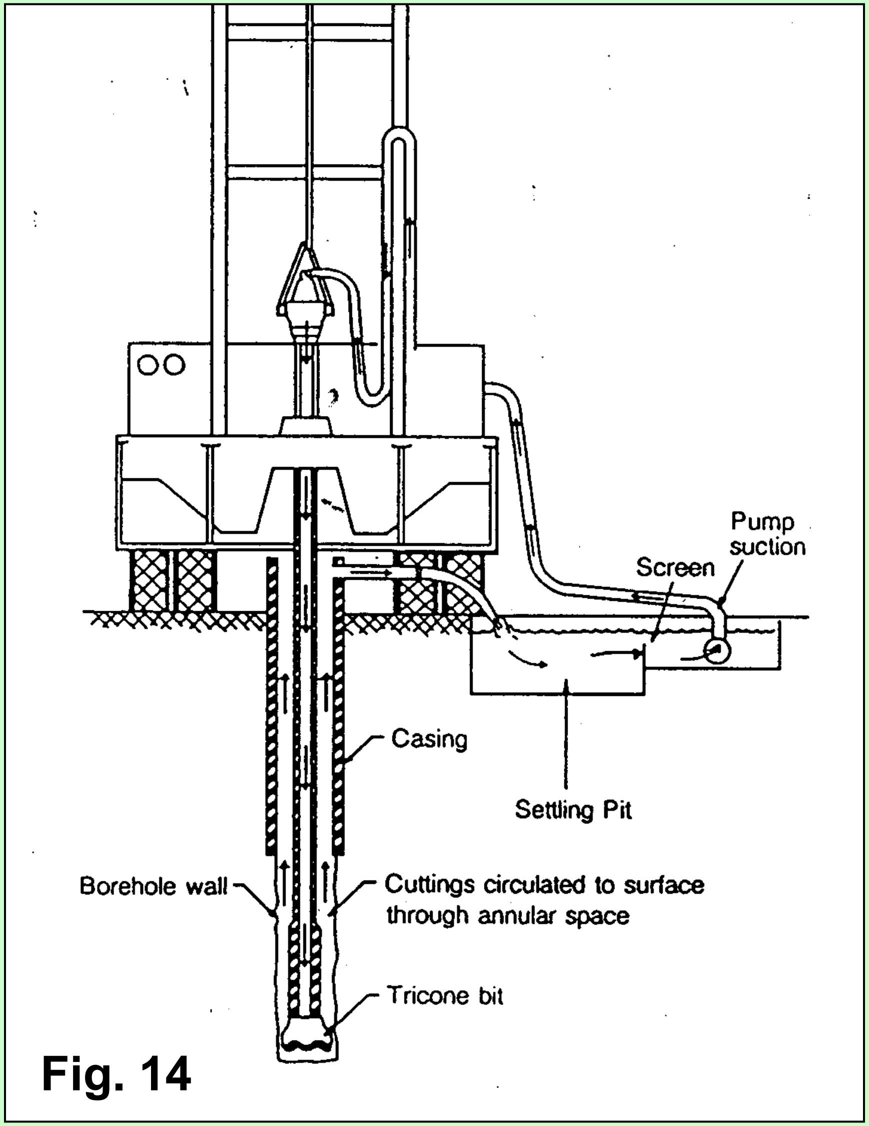


Fig. 14


Fig. 15

ASTM D 5783 "Guide for Use of Direct Rotary Drilling With Water-Based Drilling Fluid for Geoenvironmental Exploration and Installation of Subsurface Water Quality Monitoring Devices"

Soil sampling & samplers

Soil sampling

- Disturbed samples from boring tools, augur parings, split spoon sampler etc.; used for natural moisture content, index tests, particle size distribution etc.
- Undisturbed samples, used in compressibility and strength determination

Quality of undisturbed sampling

- Research class: best quality samples, considerable care and special equipment used
- Routine class: Reasonably good quality with simple equipment
- Simple class: taken without any delay and with simple equipment

Soft clays; Low strength and highly compressible

Research class :

(1) Block sampling

(2) piston samplers and thin walled sampling tubes, sampler hydraulically pushed in the soft clay

Routine class : Piston samplers

Simple class: say open drive sampler

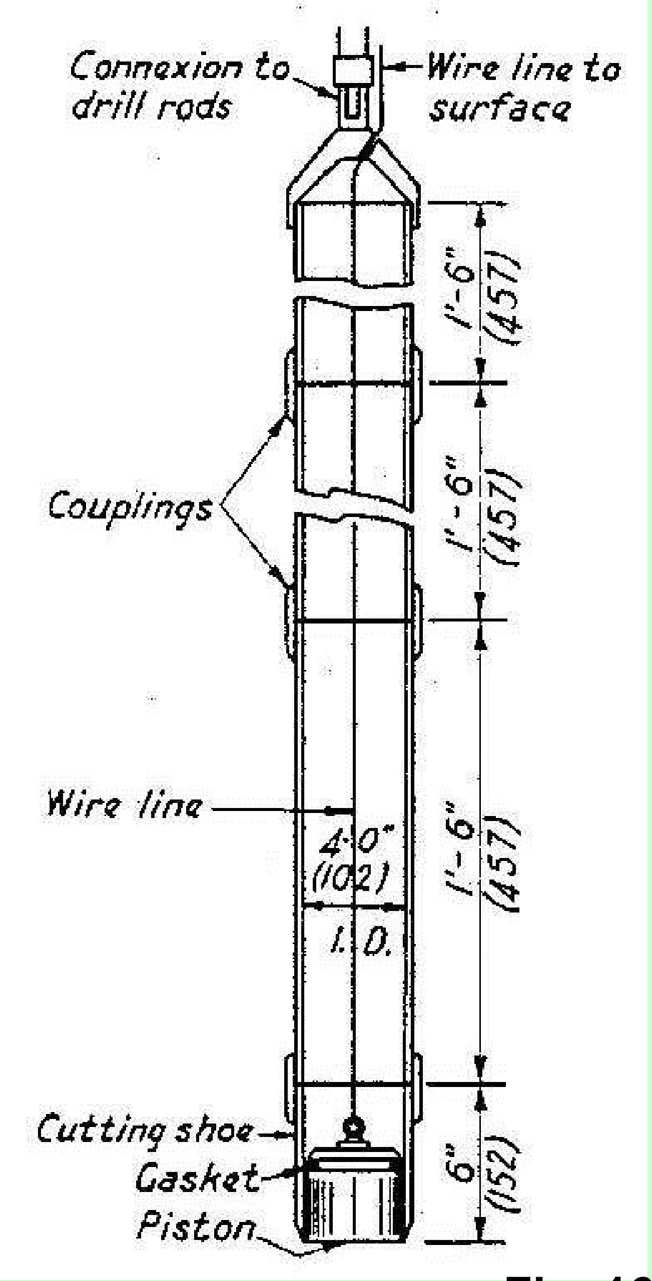


Fig. 16

Floating piston sampler:

Piston remains in close contact with the sample.

Piston samplers should never be driven down.

Fixed piston samplers have many operational advantages

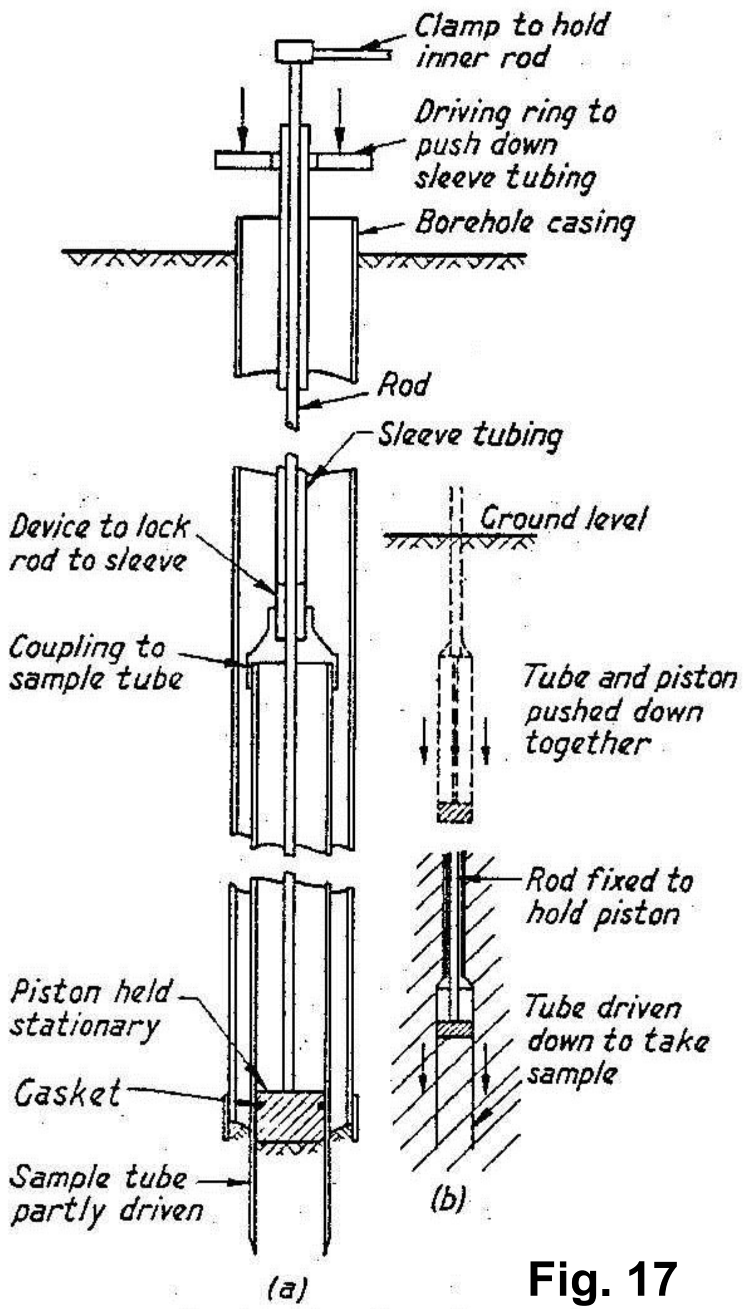


Fig. 17

Fixed piston sampler

Used with soft compressible clays.

-can avoid zone of disturbance during boring

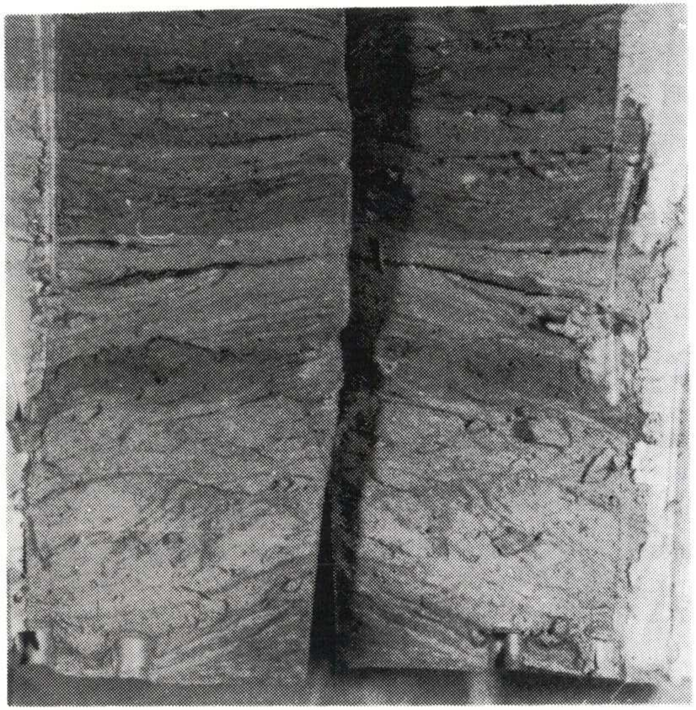
- should not be driven down

Driven Samples - SPT

- ASTM 1586 Standard Test Method for *Penetration Test and Split-Barrel Sampling of Soils*
- Good for soil classification and index tests (grain size, Atterberg Limits, etc.)
- Disturbed samples that cannot be used for engineering properties
- Measure recovery, determine soil units, presence of water, bag or jar samples for water content, classification tests, etc.

Comparison of hammer and push samples from Frigg field, NS

(a)



(b)

Fig. 23

Comparison of (a) hammered and (b) push samples from East Shetland Basin. Note stronger bending of layers at edge of hammered sample.

Push Samples – Thin Walled Tube Sampling

- **ASTM 1587 *Standard Practice for Thin Walled Tube Sampling of Soils***
- **Fixed piston better than push**
- **Actuating rod vs hydraulic piston sampler**
- **NW rods vs AW rods**

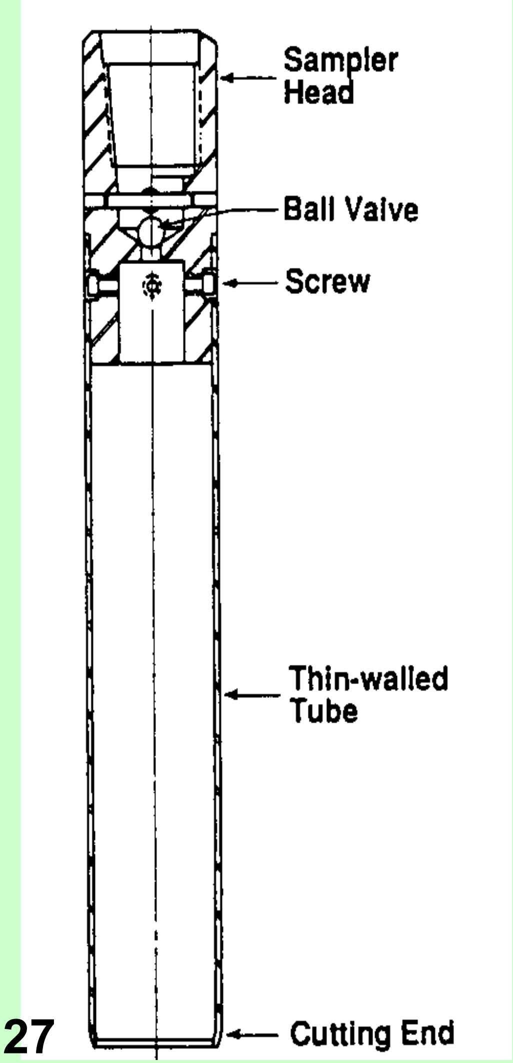


Fig. 27

Thin Walled Sampling Tubes

<u>Focus on</u>:
- Area Ratio (AR)
- Inside Clearance Ratio (ICR)
- Cutting angle

- Diameter D ³ 75 m, AR < 10%
- Diameter/thickness ratio, D/t ³ 45
- Inside Clearance Ratio, ICR » 0
- Sharp cutting angle, » 5°
- JPN sampler (Tanaka et al. 1996)

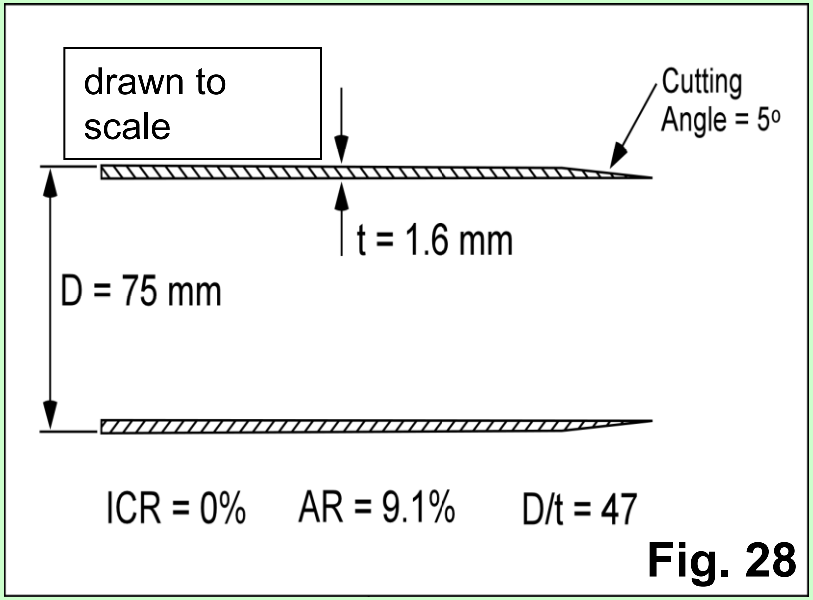
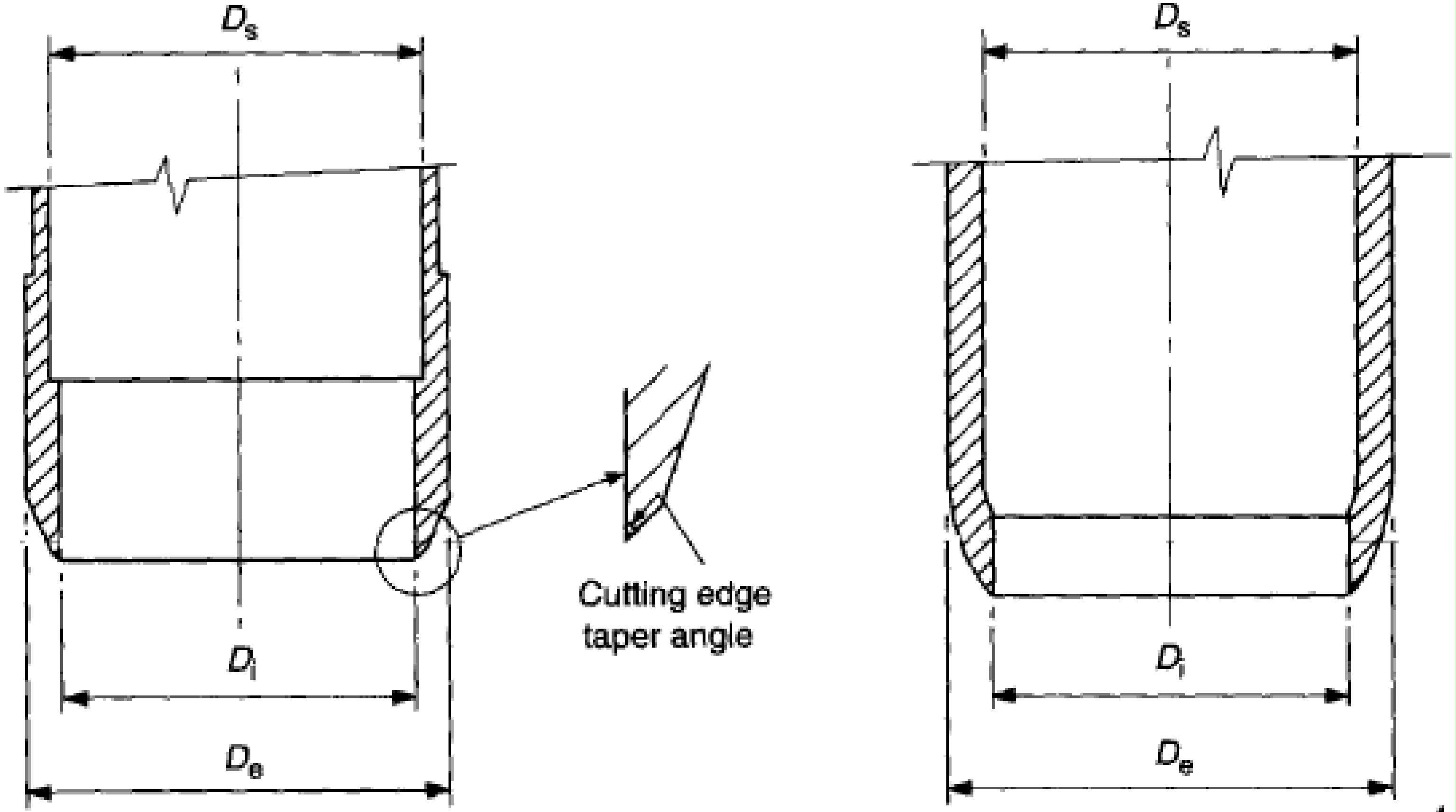


Fig. 28

Modified thin-walled (Shelby) tube

Fig. 29



(a) Sampler with screw-on cutting shoe

$$\text{Area ratio} = \frac{(D_e^2 - D_i^2)}{D_i^2}$$

(b) Rolled and reamed cutting edge

$$\text{Inside clearance} = \frac{D_s - D_i}{D_i}$$

Fig. 30 Definition of area ratio and inside clearance. **(Clayton *et al*, 1995)**

Table 2 Combinations of area ratios and cutting edge taper **(Clayton *et al*, 1995)**

Area ratio (%)	Cutting edge taper (deg.)
5	15
10	12
20	9
40	5
80	4

Table 3 Dependence of permissible length to diameter ratio on soil type

Type of soil	Greatest length to diameter ratio
Clay (sensitivity> 30)	20
Clay (sensitivity 5—30)	12
Clay (sensitivity < 5)	10
Loose frictional soil	12
Medium loose (?) frictional soil	6

(Clayton *et al*, 1995)

Sample tube: length to diameter ratio

Piston Sampling

Fig. 32

Recommendation:
Use fixed piston - better control of entering soil + better recovery

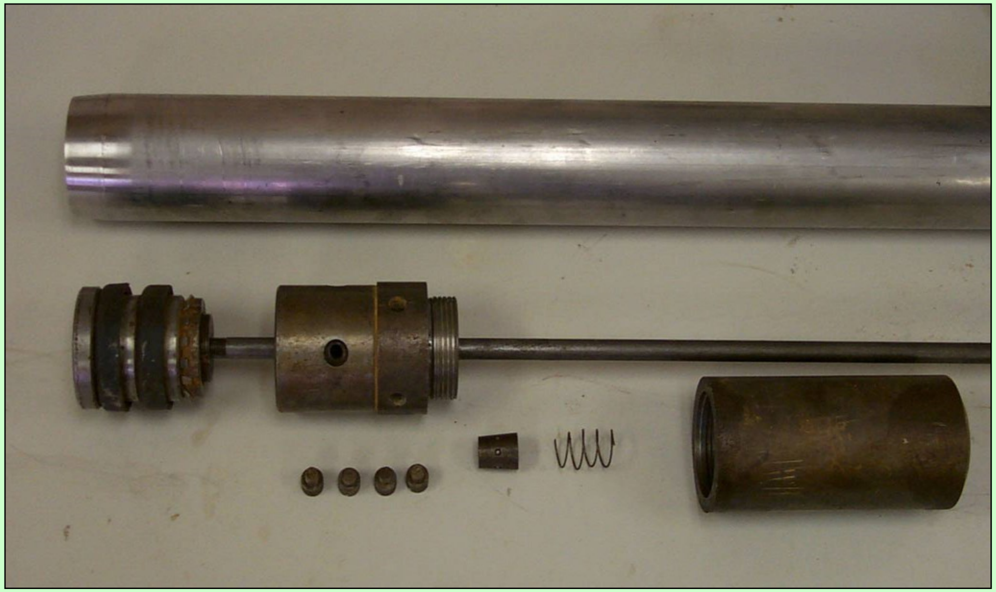


Fig. 31

Mechanical or hydraulic piston

Fig. 33

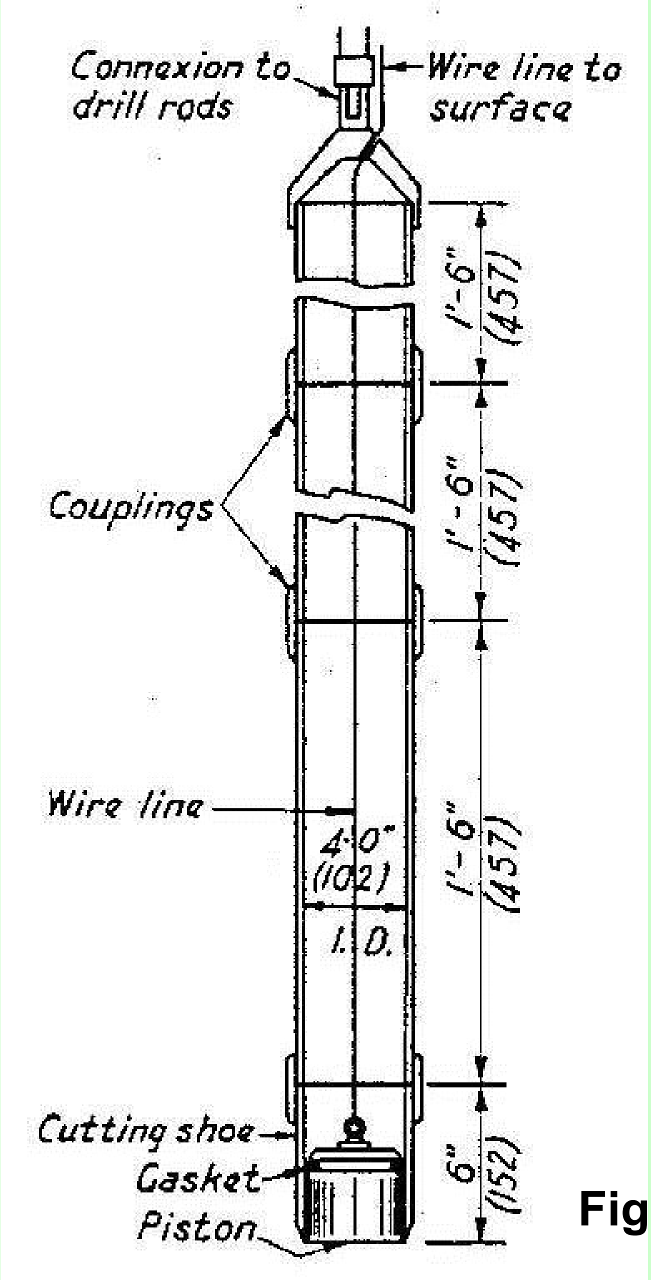


Fig. 34

Floating piston sampler

Piston remains in close contact with the sample.

Piston samplers should never be driven down.

Fixed piston samplers have many operational advantages

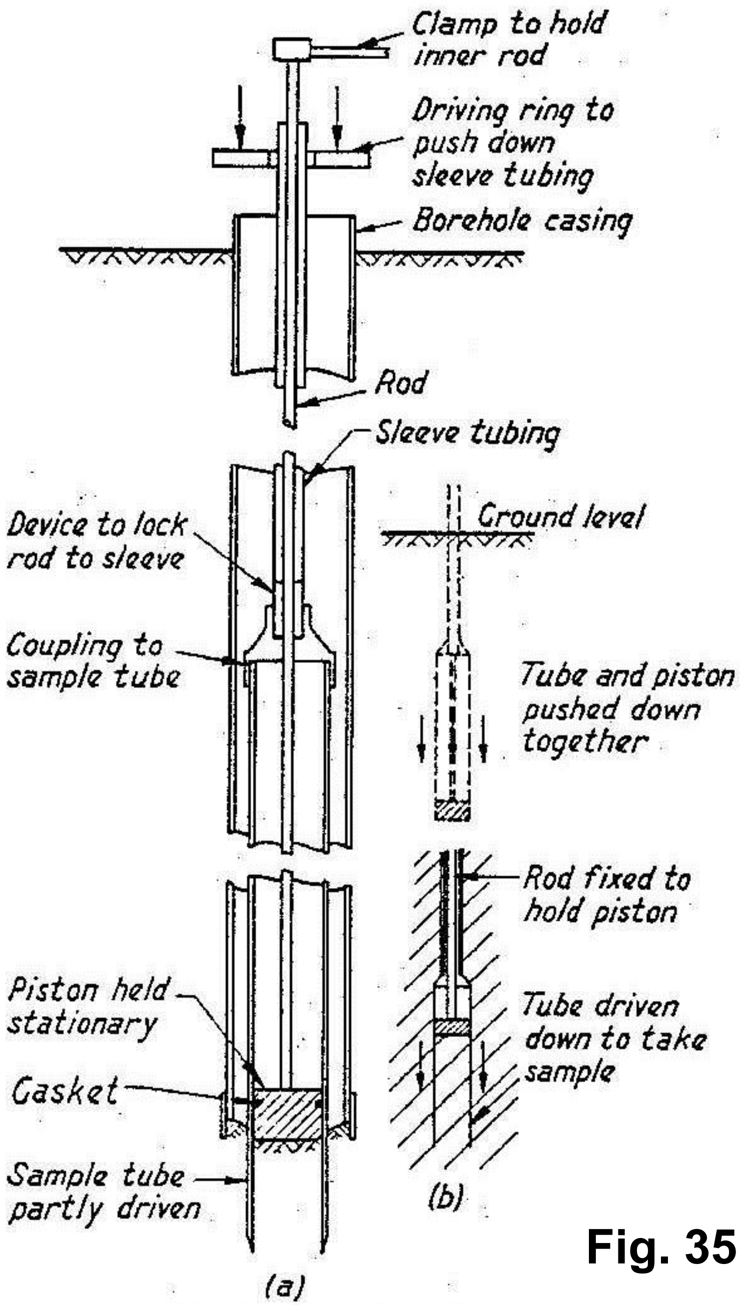


Fig. 35

Fixed piston sampler

Used with soft compressible clays.

-can avoid zone of disturbance during boring

- should not be driven down

Tube Walled -Tube Sample Field Inspection

- Remove loose material from ends
- Measure recovery
- Conduct index tests, e.g., TV, PP, LV, etc.
- Remove sample for water content and field classification
- Seal ends with 50:50 mix paraffin wax and petroleum jelly and mechanical O-ring packer

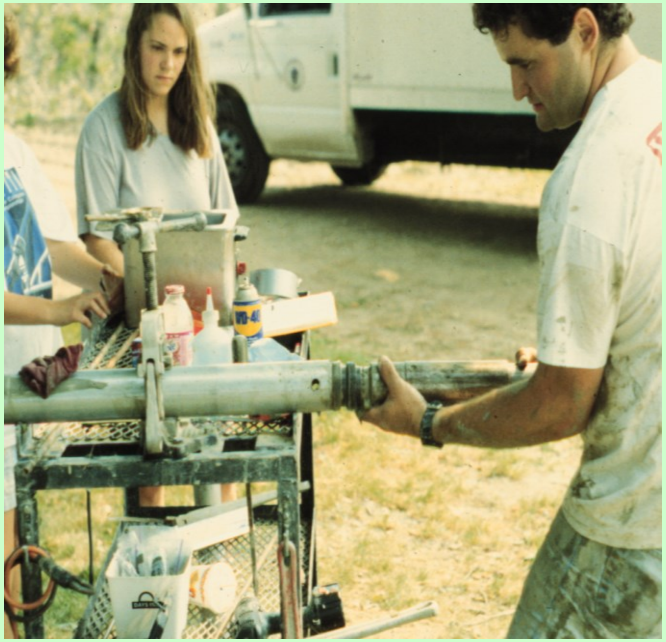


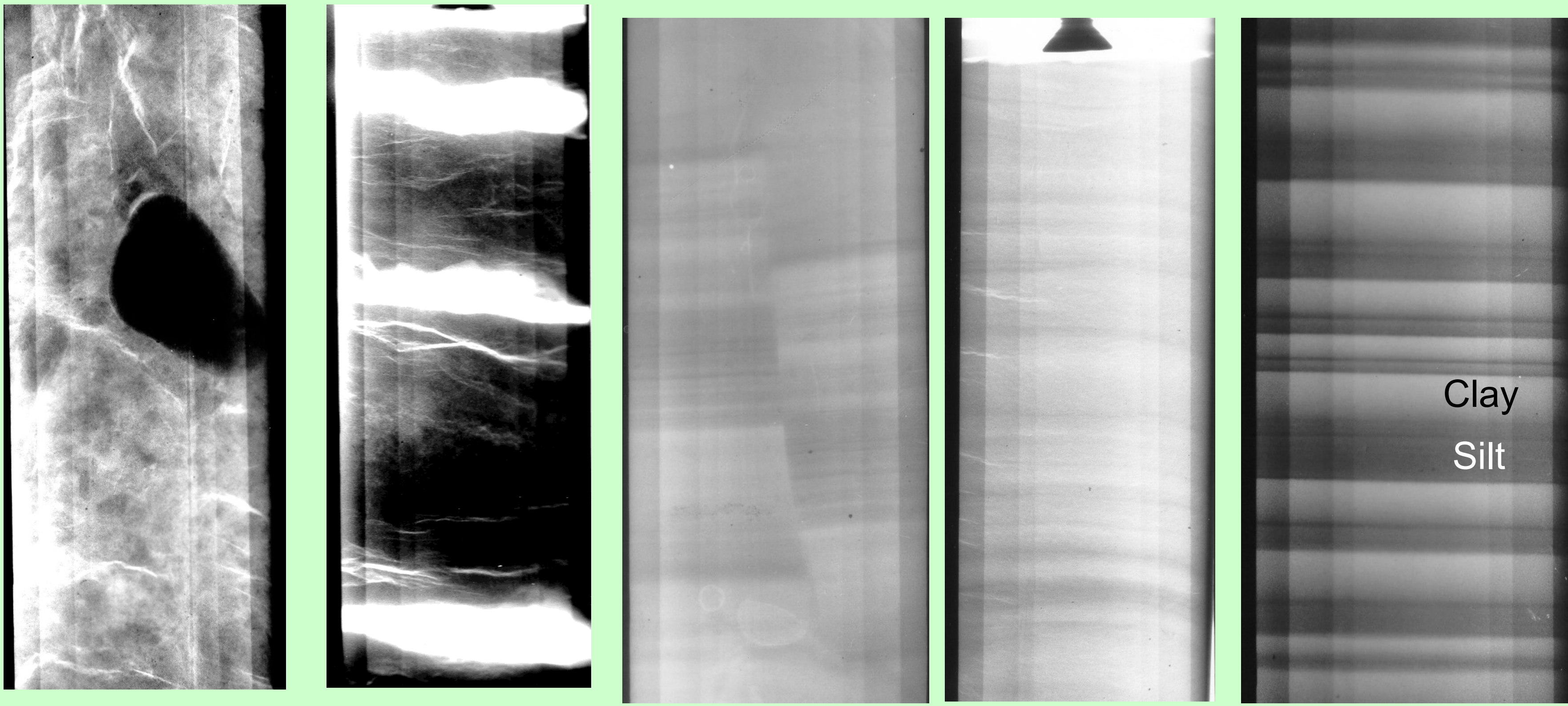
Fig. 38

Extrusion of Undisturbed Tube Samples

- **X-Ray tubes if possible: ASTM 4220 *Standard Test Methods for X-Ray Radiography of Soil Samples***
- **Cut tube rather than full length extrusion – especially if stored for long durations**
- **Break bond between soil and tube with wire saw**

X-rays of Tube Samples

Soil Macrofabric | **Sample disturbance** | **Intrusions**

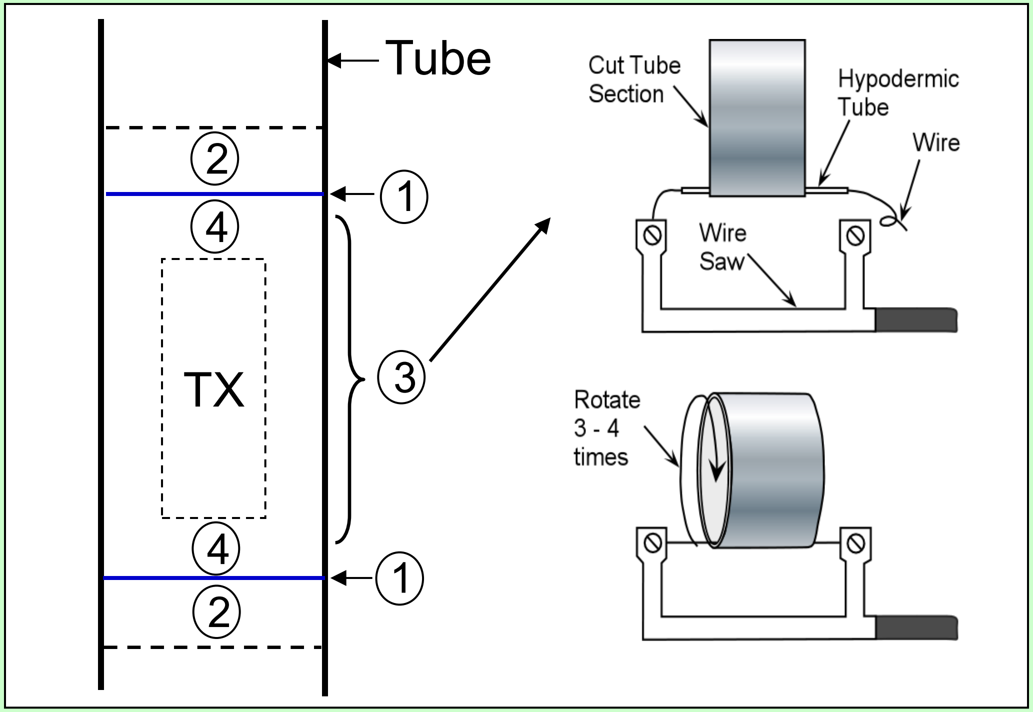


[75 mm tube samples]

NGI now doing CAT scans of tube samples

Fig. 39

Sample Extraction – Thin walled tubes



① Cut tube and soil

② Water content and/or strength index tests

③ Debond and extrude

④ Trim specimen

Fig. 40

Block Sampling

Sherbrook Block Sampler

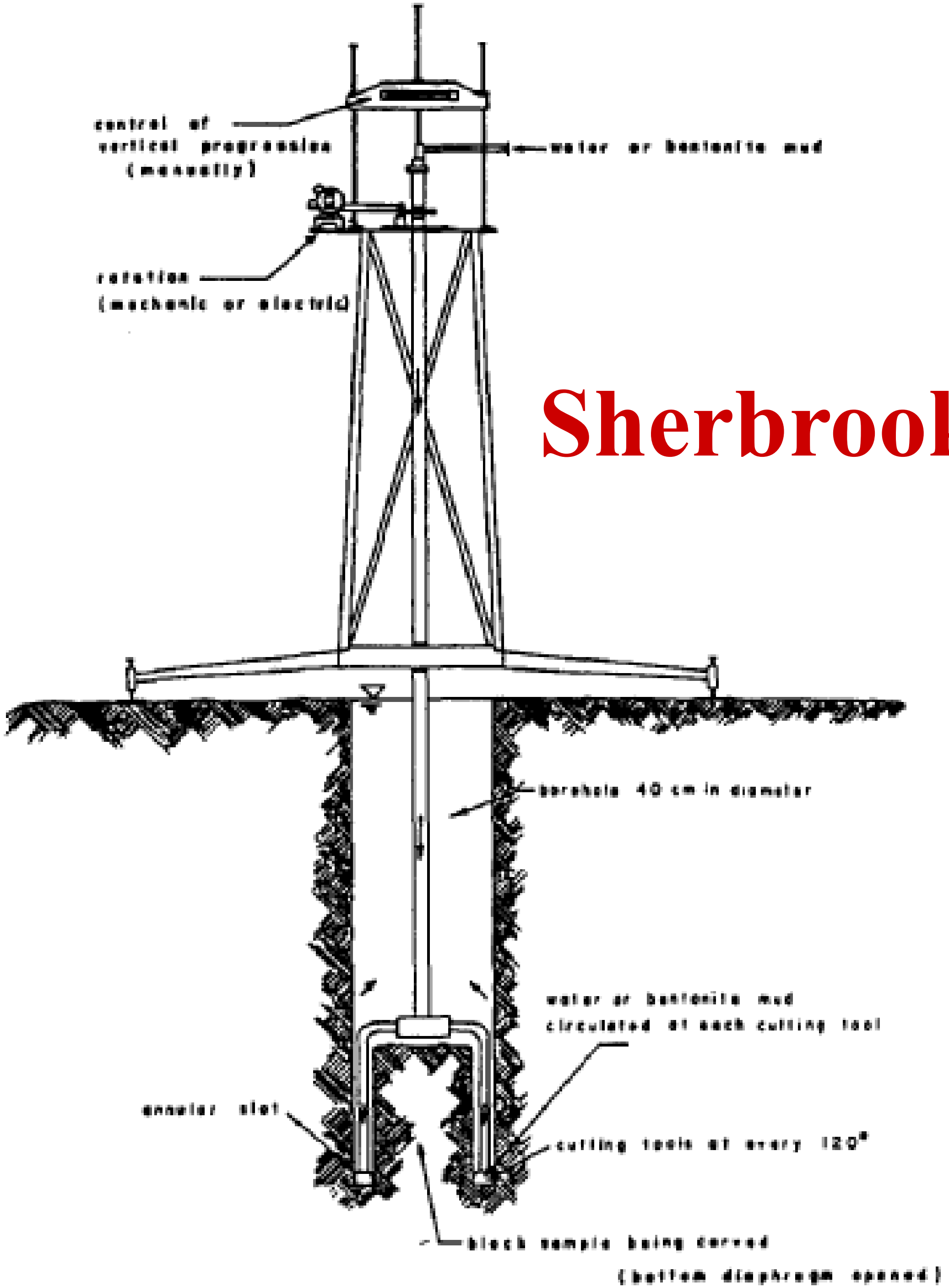


Fig. 46

Fig. 47

Sampler is lowered into borehole

Fig. 48

Sample as recovered

Fig. 49

Spoil is gently removed by hand

Block sampling with Sherbrooke sampler

Block sampling with Sherbrooke sampler

Fig. 50

Complete sample prior to protection

Fig. 51

sample initially protected by cling film,
tin foil and tape, finally being waxed

Fig. 52

Sample ready for transportation

SOA Solution to tube sampling:

Block Sampling → best quality

Sherbrooke Block Sampler

- successfully used on several commercial projects (e.g., NGI, Boston Central Artery)

Fig. 53

Block sampling – sensitive Leda Gloucester Clay (Ottawa, Canada)

Fig. 54

Table 4 Stress changes occurring in a saturated clay

Stresses	Soil in ground	After sampling
Total stresses	↓ σ_v ← σ_h	↓ 0 ← 0
Pore pressure	$+ u_0$	$+ u_k$
Effective stresses	$p' = \sigma_v - u$ ↓ ← $K_0 p'$	p'_k ↓ ← p'_k $= -u_k$

(Clayton *et al*, 1995)

Summary

- **Many options for soil sampling, although often there are regional practices**
- **Sample disturbance is a critical issue**
- **Disturbed samples are suitable for soil identification and basic classification tests**

- **Undisturbed samples are essential for accurate measurement of engineering properties**

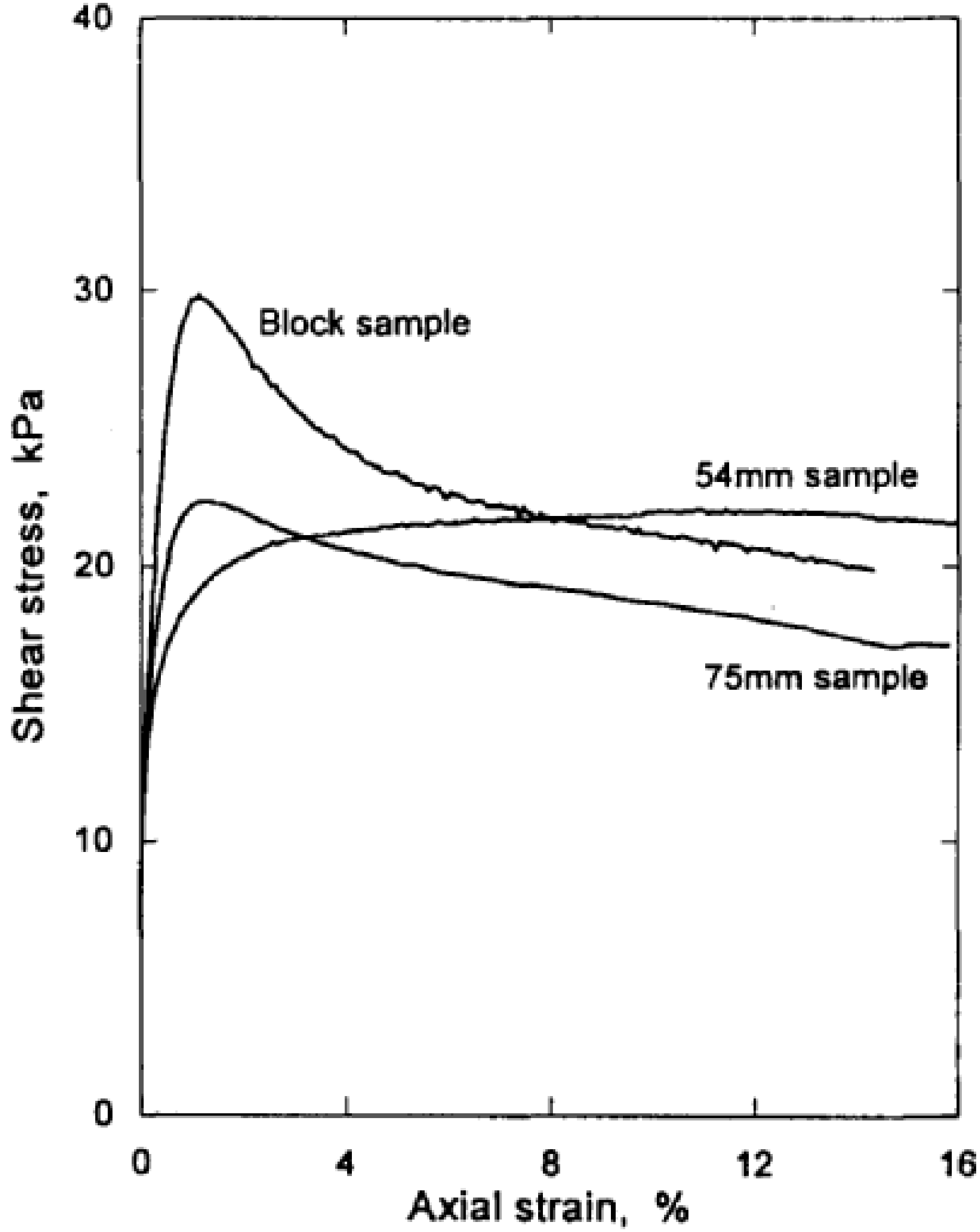


Fig. 55 Shear stress vs axial strain for CAUC tests at 6.1 m depth **(Lunne *et al*, 1980)**

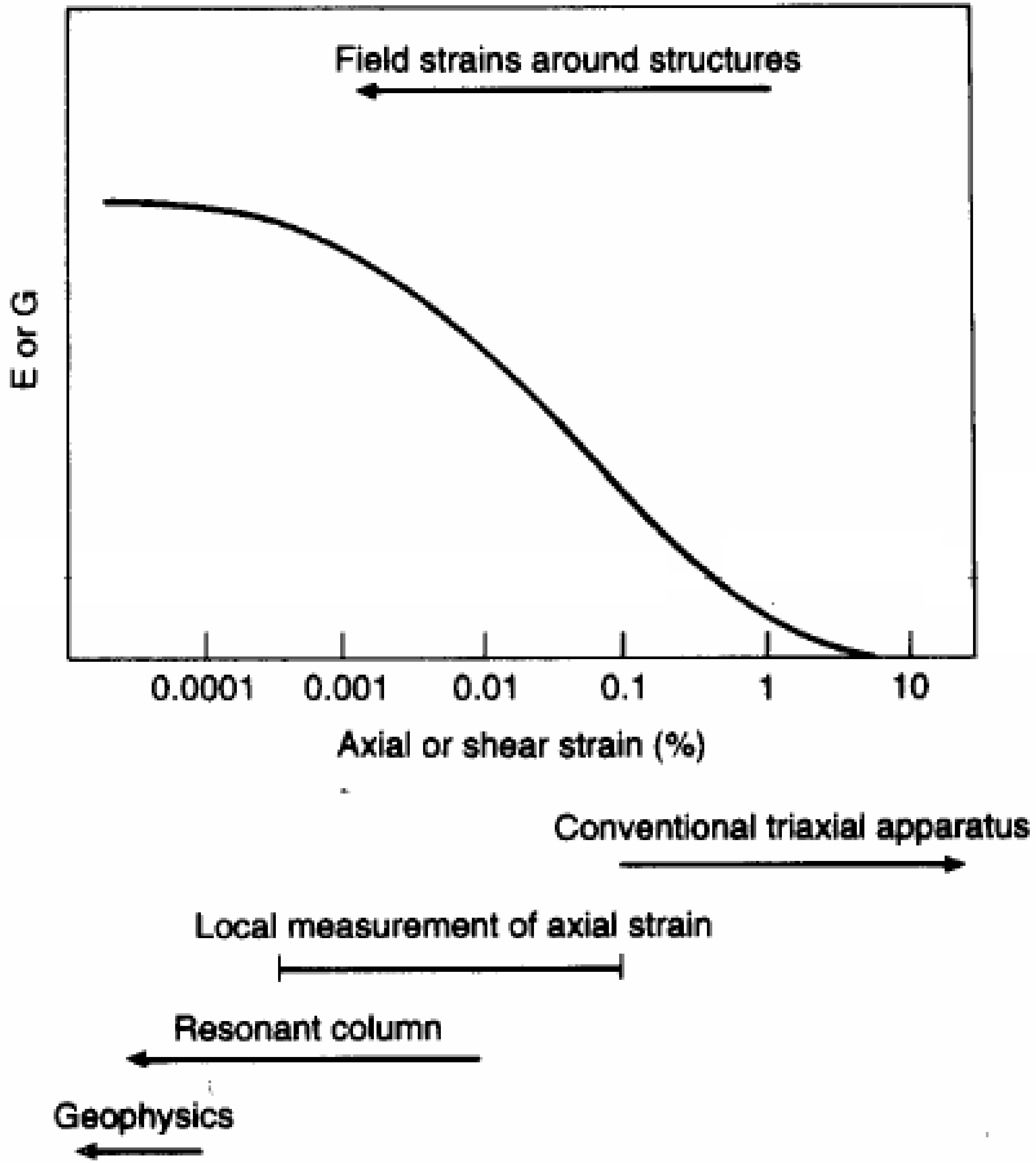
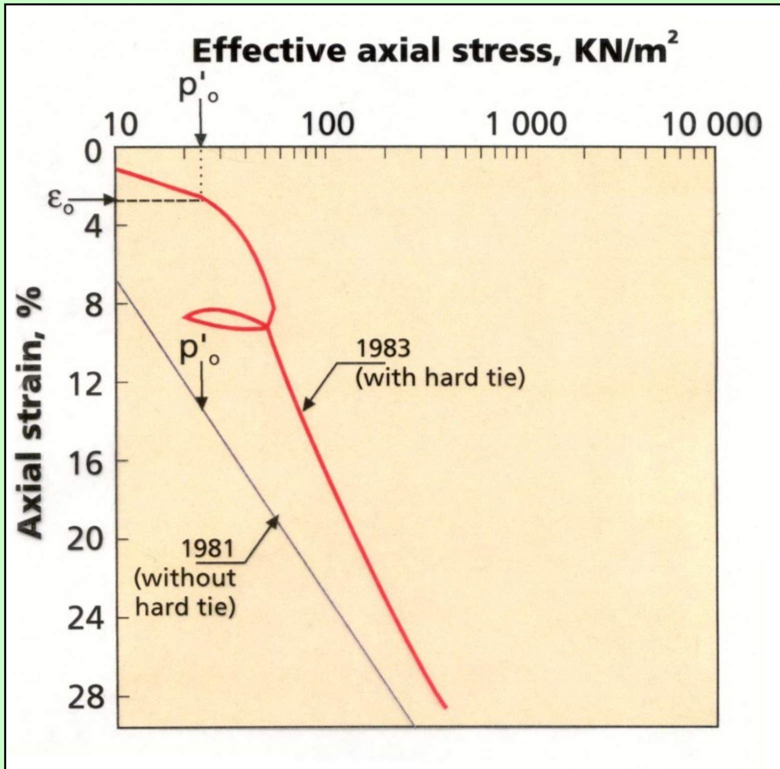


Fig. 56 Typical relationship between stiffness and strain for soils. (Clayton *et al*, 1995)

Criteria for quantifying sample disturbance

Volume change when consolidating a sample back to in situ stresses expressed as change in void ratio: $\Delta e/e_i$

Fig. 57

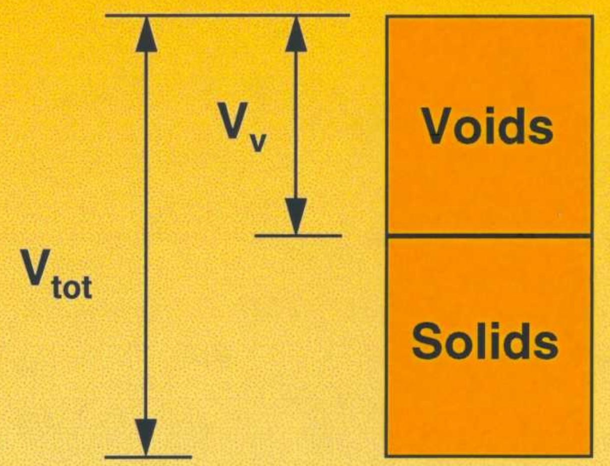


Oedometer test results on good and severely disturbed sample from Troll field illustrating strain (equivalent to $\Delta e/e_i$) as indicator of sample disturbance

Result from consolidation phase of CAU test

$$\varepsilon_{vo} = \frac{\Delta V_v}{V_{tot,o}}$$

$$\frac{\Delta e}{e_o} = \frac{\Delta V_v}{V_{v,o}}$$



e = void ratio = w·G·S
w = water content
G = specific weight of solid particles
S = degree of saturation

Fig. 58 **Volume change when consolidating back to in situ stresses**

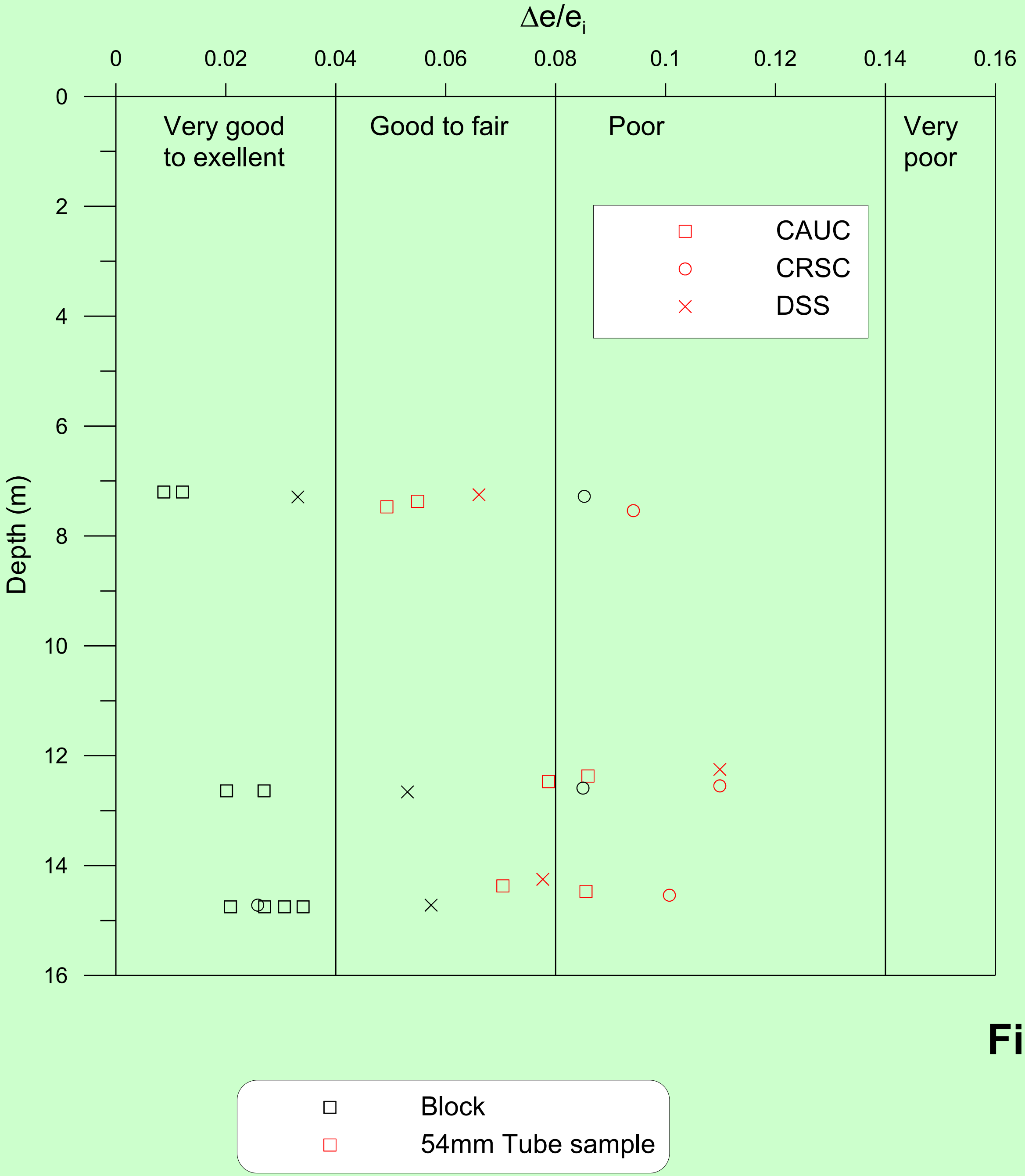
NGI's Criteria For Sample Disturbance

Over con-solidation ratio	$\Delta e/e_o$			
	Very good to excellent	Good to fair	Poor	Very poor
1 - 2	<0.04	0.04-0.07	0.07-0.14	>0.14
2 - 4	<0.03	0.03-0.05	0.05-0.10	>0.10

Table 5

Based on CAUC and CRSC tests on Sherbrooke block samples and tube samples in Norwegian soft clays

Valid for mechanical properties



Onsøy clay $\Delta e/e_i$ from CRSC,CAU and DSS tests

Fig. 59

Influence of sample disturbance on laboratory measurements : summary

- ε_{vo} or $\Delta e/e_o$
- D

Most consistently influenced

- Su_{uu}
- su_{CAUC}
- ε_f
- P_c'

Significantly influenced

- M, C_v
- U_r
- G_{max}

Not so consistent

Based on the laboratory tests)

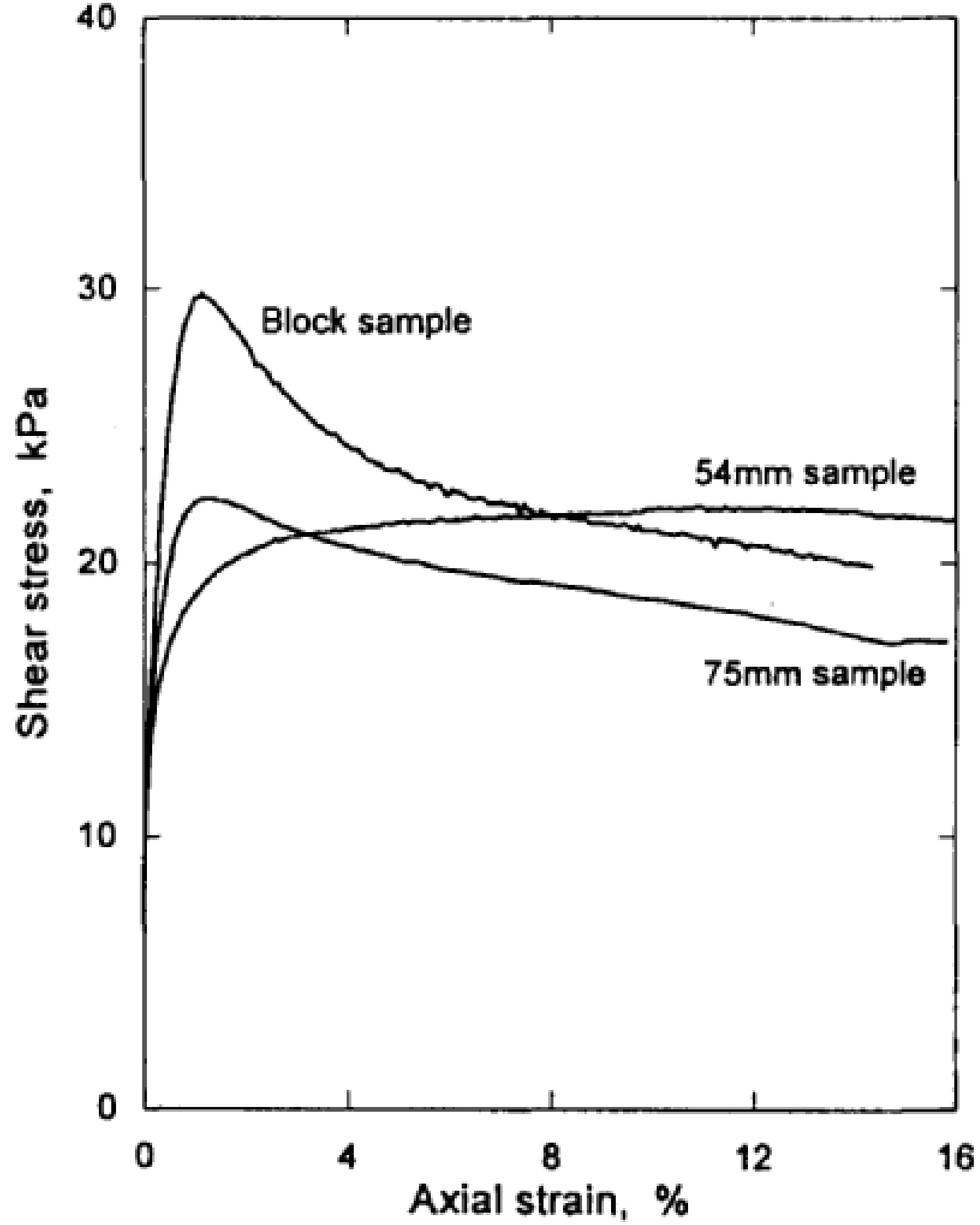


Fig. 9 Shear stress vs axial strain for CAUC tests at 6.1 m depth **(Lunne *et al*, 1980)**

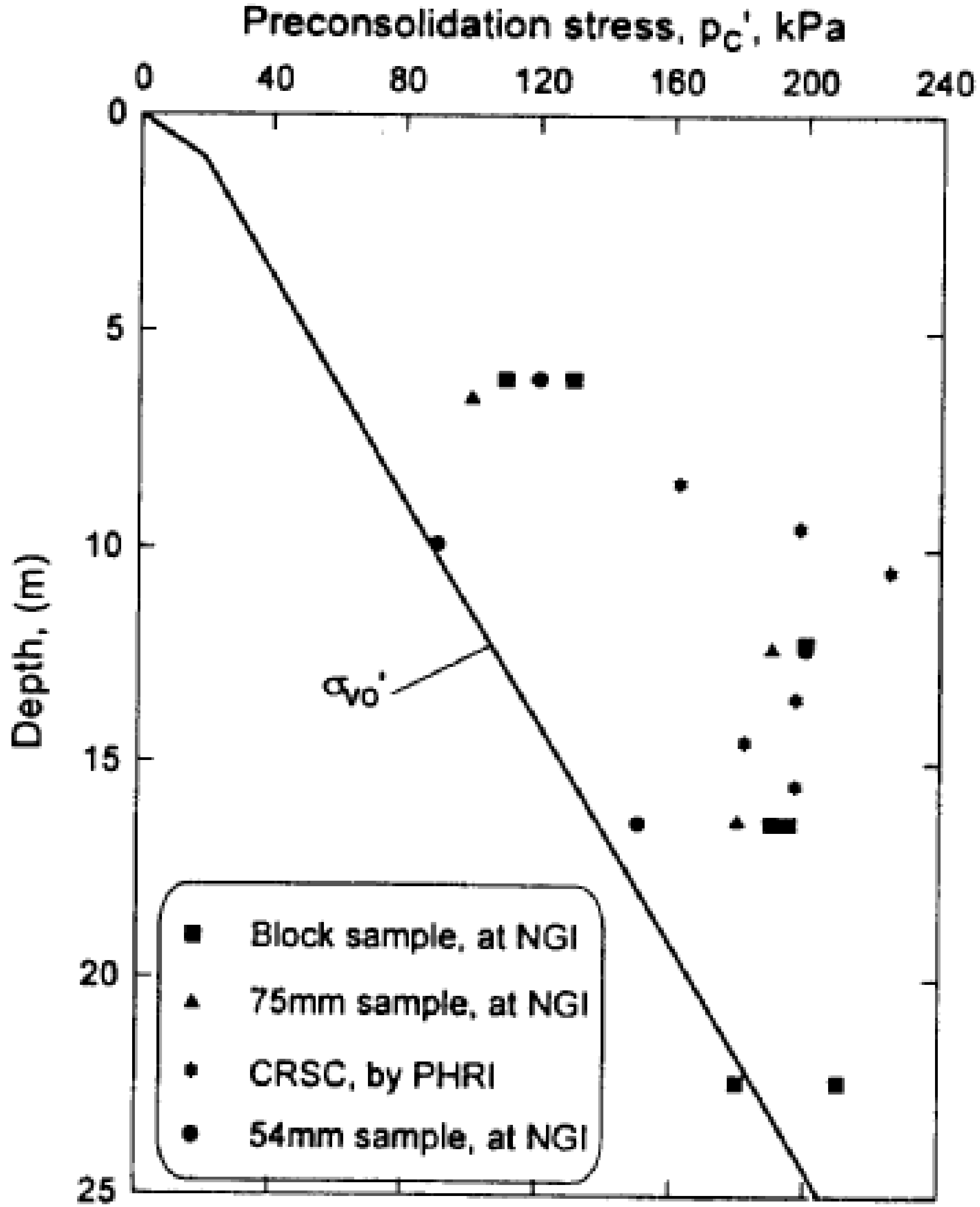
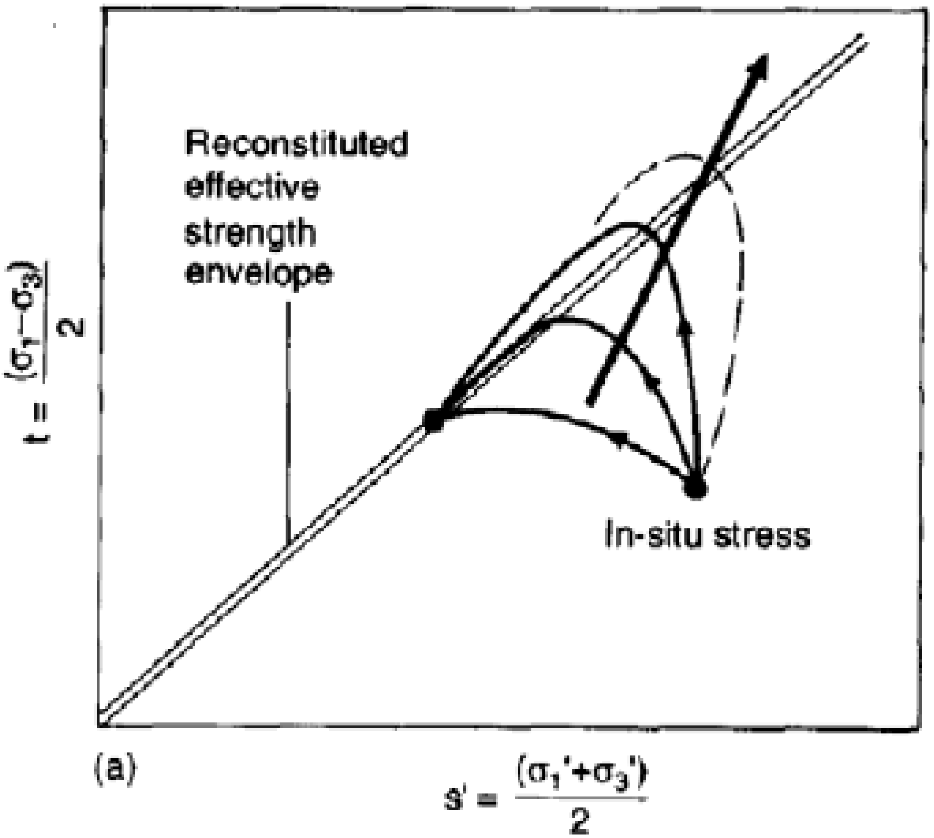


Fig. 18 p$_c$' vs depth **(Lunne *et al*, 1980)**



Arrow indicates effect of improving sample quality on undrained effective stress paths (after reconsolidation to in-situ effective stress)

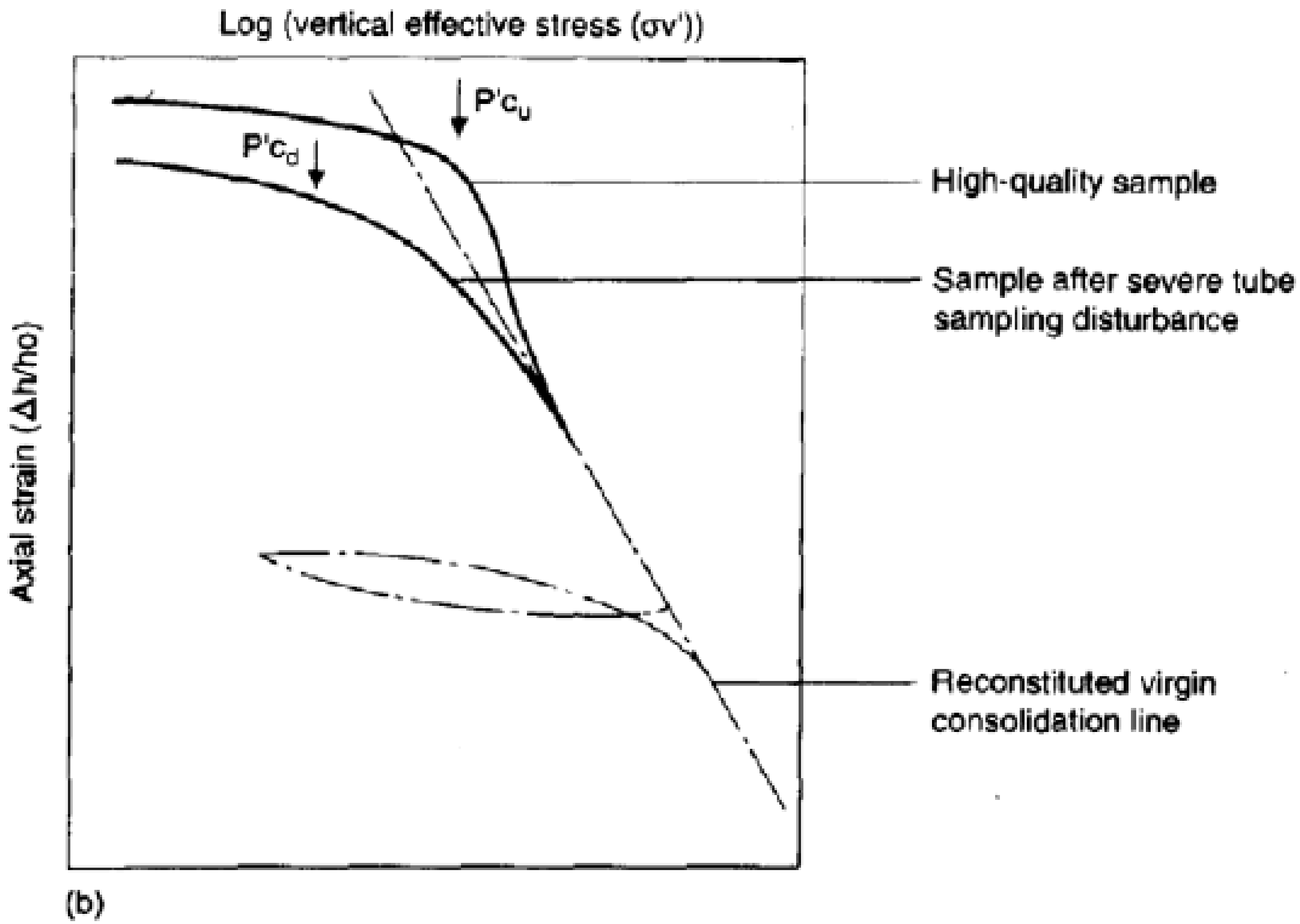


Fig. 6.14 Effects of tube sampling disturbance of lightly overconsolidated natural ('structured') clay on: (a) stress path and strength during undrained triaxial compression (b) one-dimensional compressibility during oedometer testing.

(Clayton *et al*, 1995)

Table 8.2 Results of comparative testing programme

	Soil B	Soil G	Soil W
Plastic limit (%)			
Mean	18	25	25
Range	13—24	18—36	20—39
S.D.	2.4	3.2	3.1
Coefficient of variation	13.1	12.8	12.7
Liquid limit (%) (Four-point method)			
Mean	34	69	67
Range	29—38	59—84	55—85
S.D.	2.4	5.2	5.3
Coefficient of variation	7.1	7.5	7.9

(Clayton *et al*, 1995)

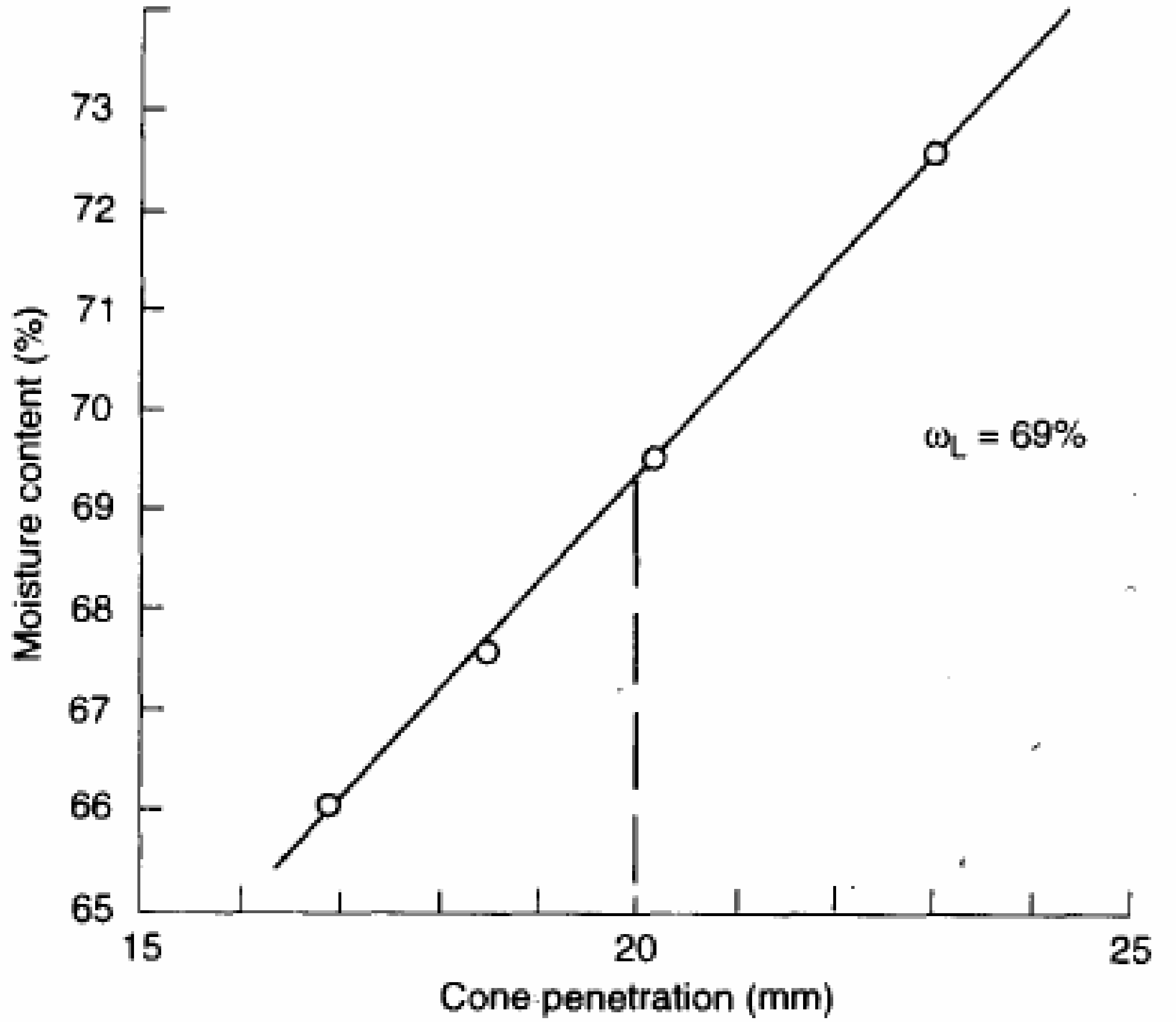


Fig. 8.3 Liquid limit result by four-point cone method. **(Clayton *et al*, 1995)**

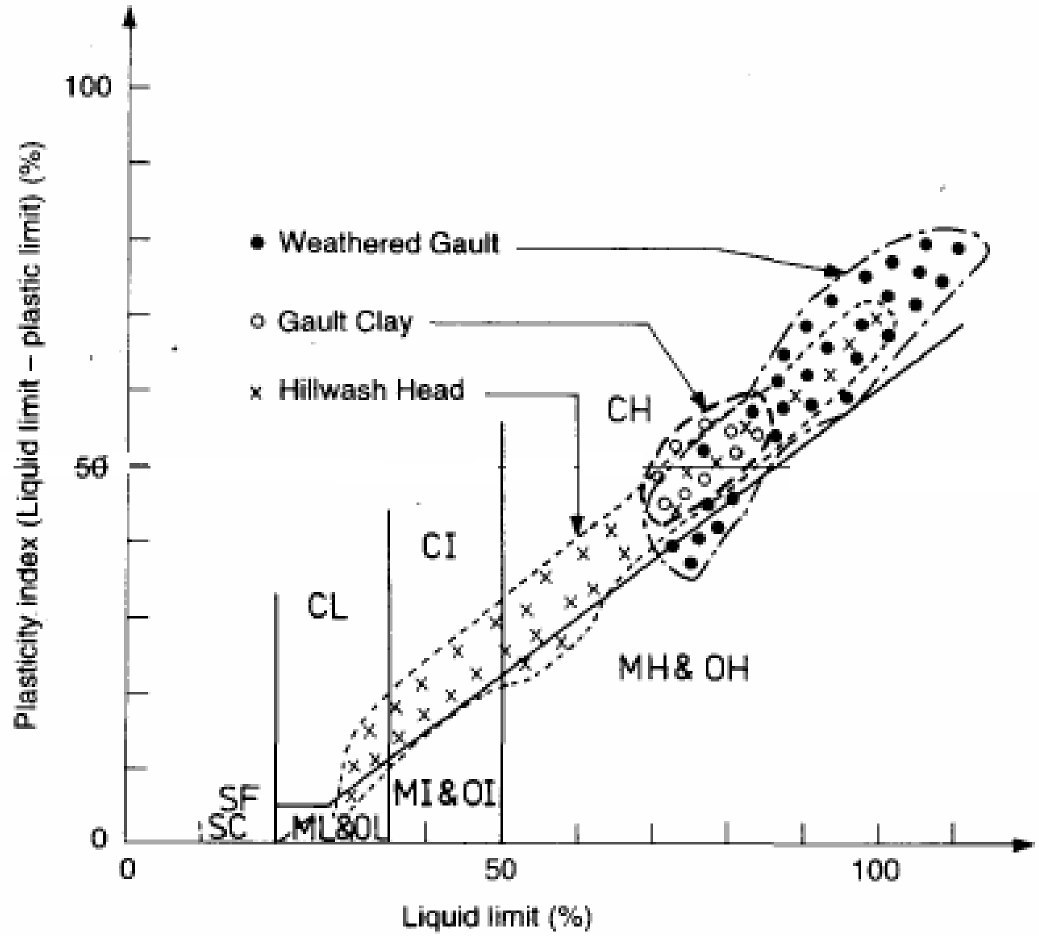


Fig. 8.4 Casagrande plot showing classification of soil into groups.

(Clayton *et al*, 1995)

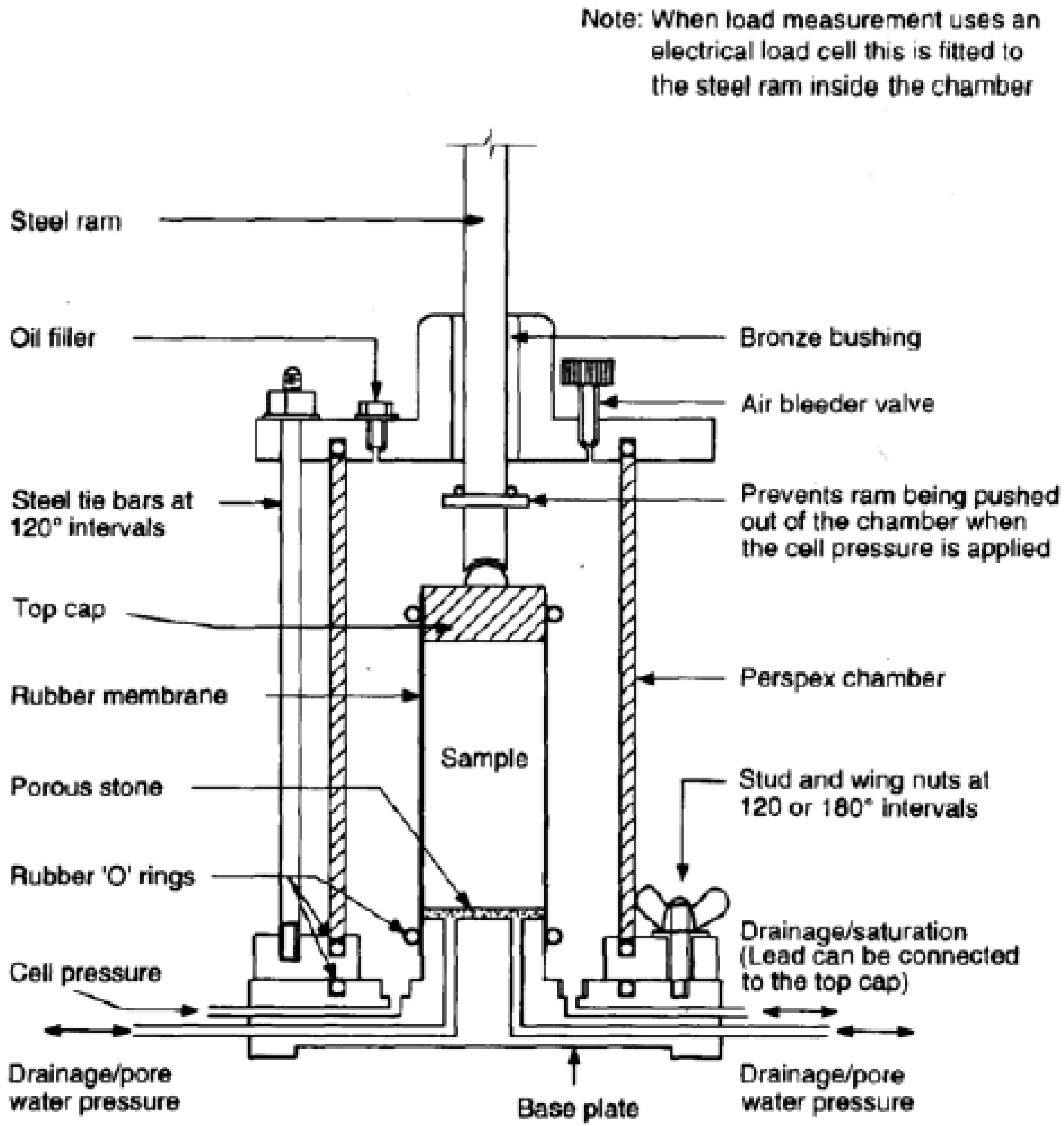


Fig. 8.11 Triaxial cell. **(Clayton *et al*, 1995)**

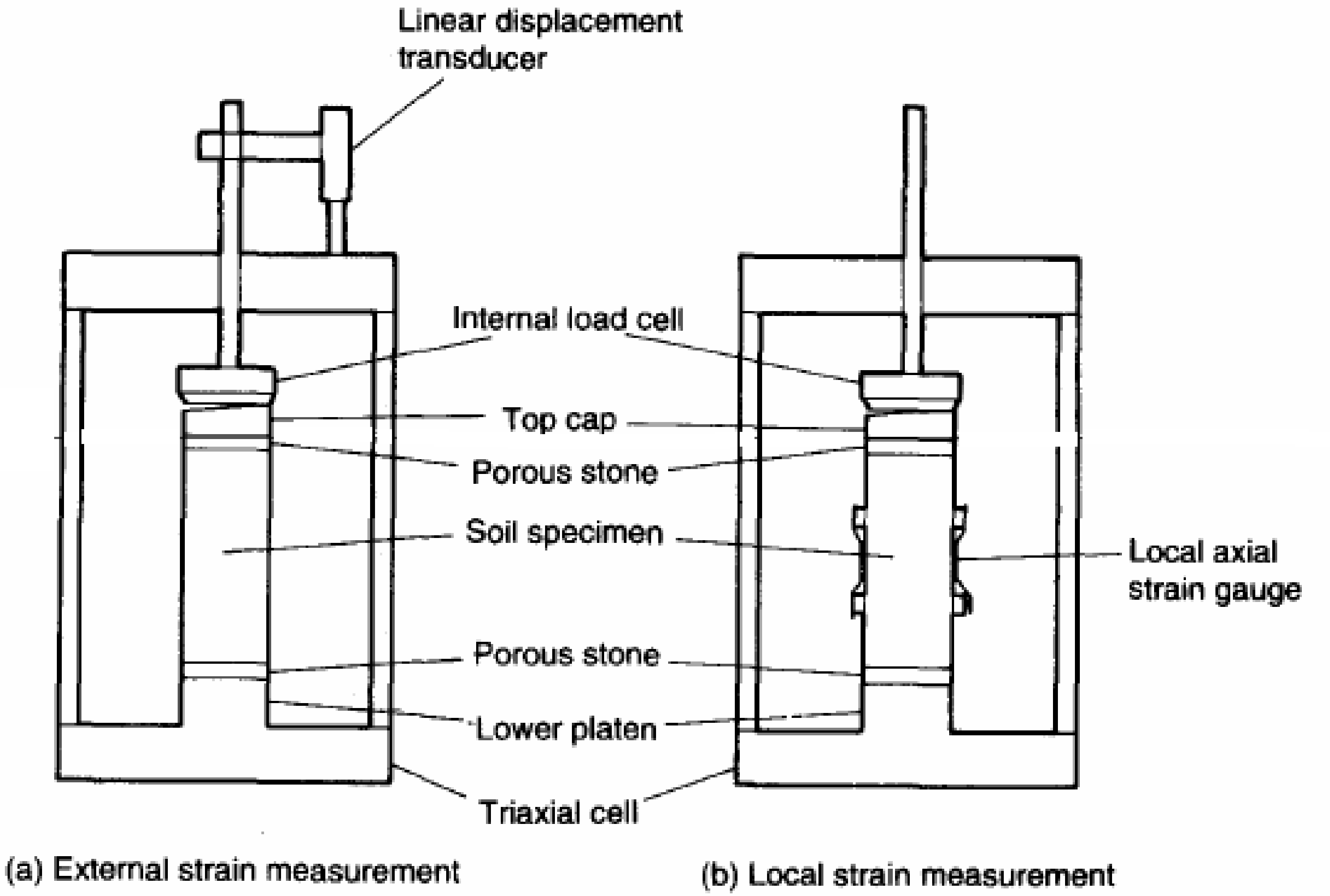


Fig. 8.14 Schematic diagram illustrating external and local strain measurement in the triaxial apparatus. **(Clayton *et al*, 1995)**

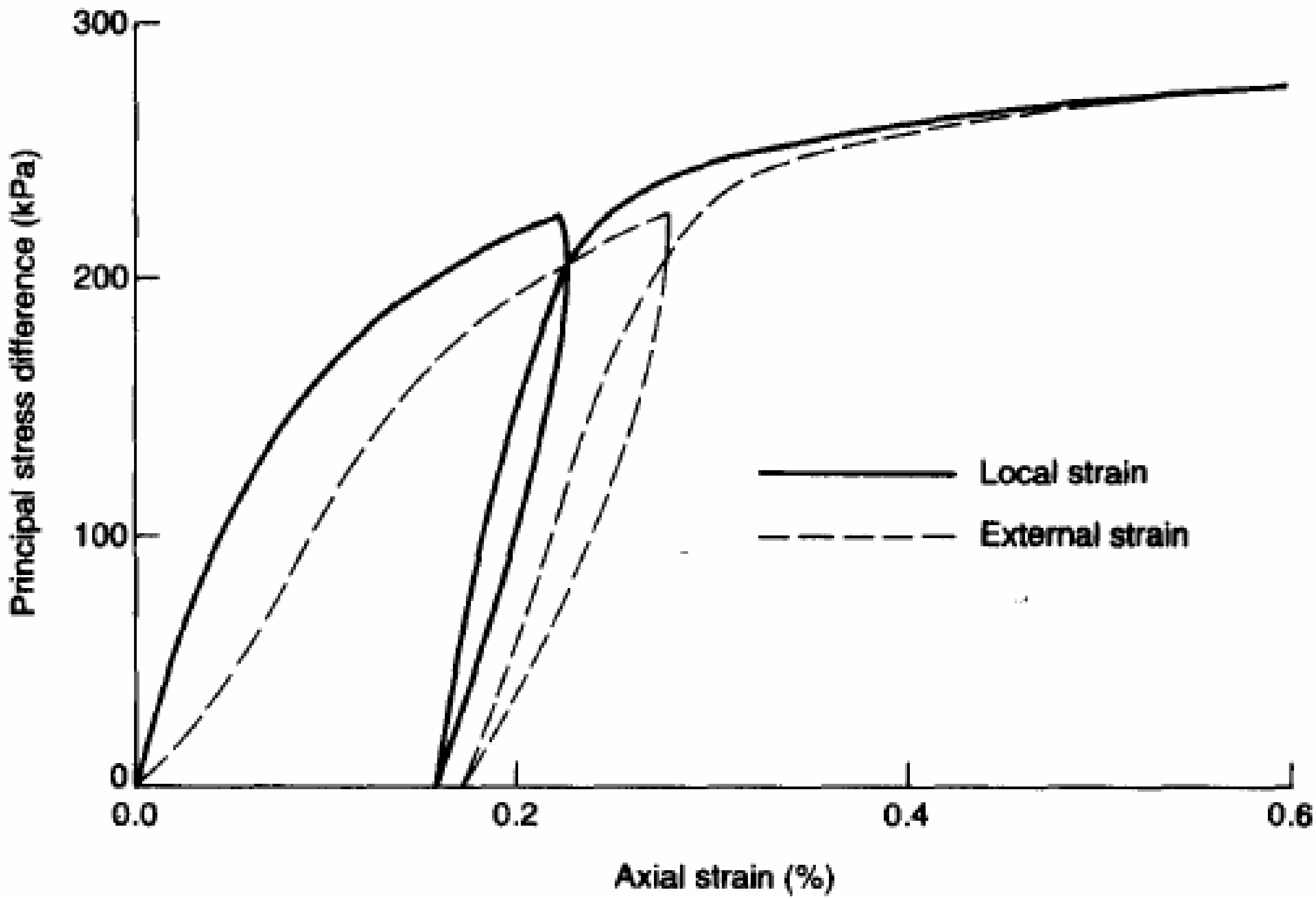


Fig. 8.15 Comparison of local and external strains (Clayton and Khatrush 1986).

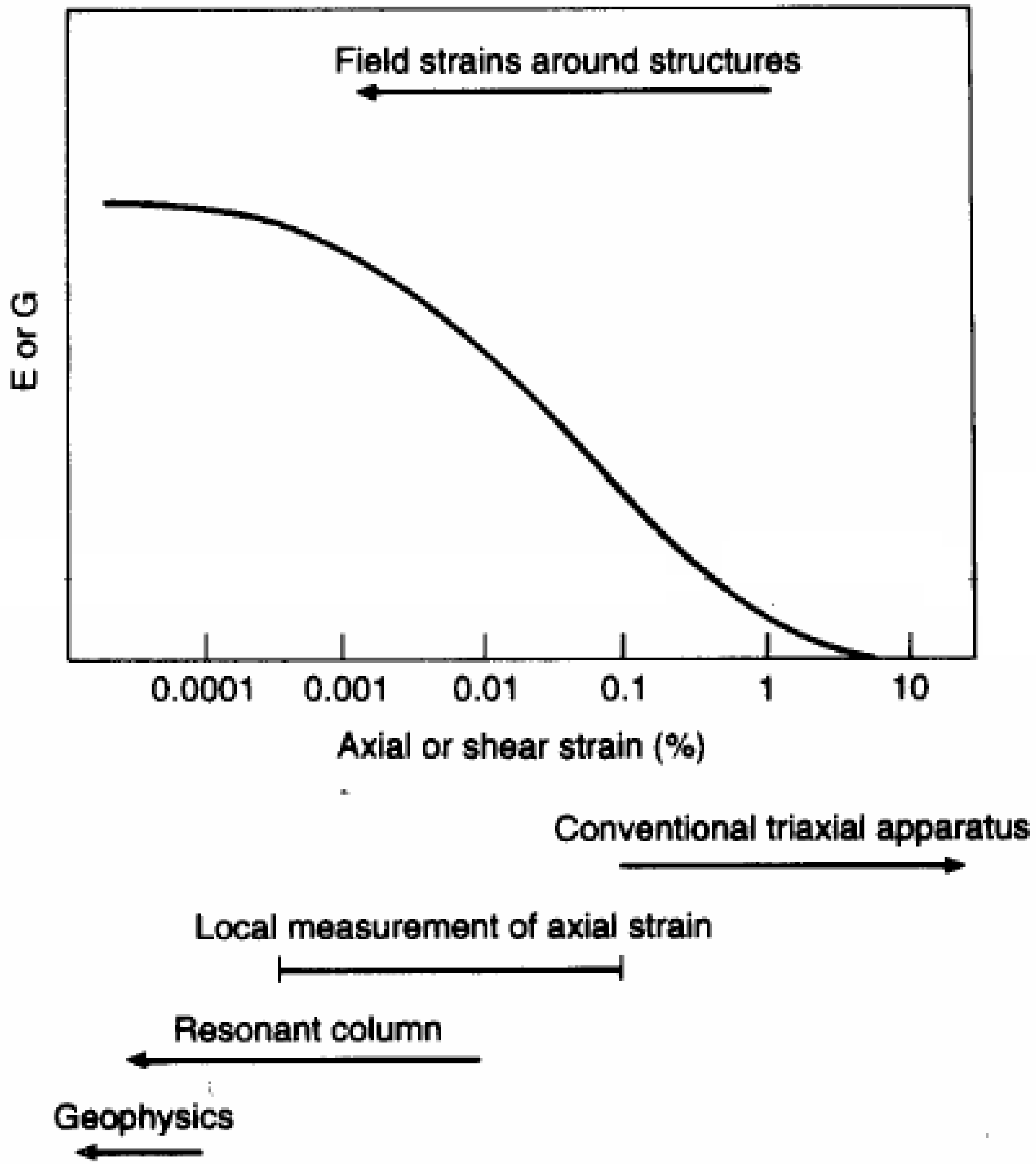


Fig. 8.17 Typical relationship between stiffness and strain for soils. (Clayton *et al*, 1995)

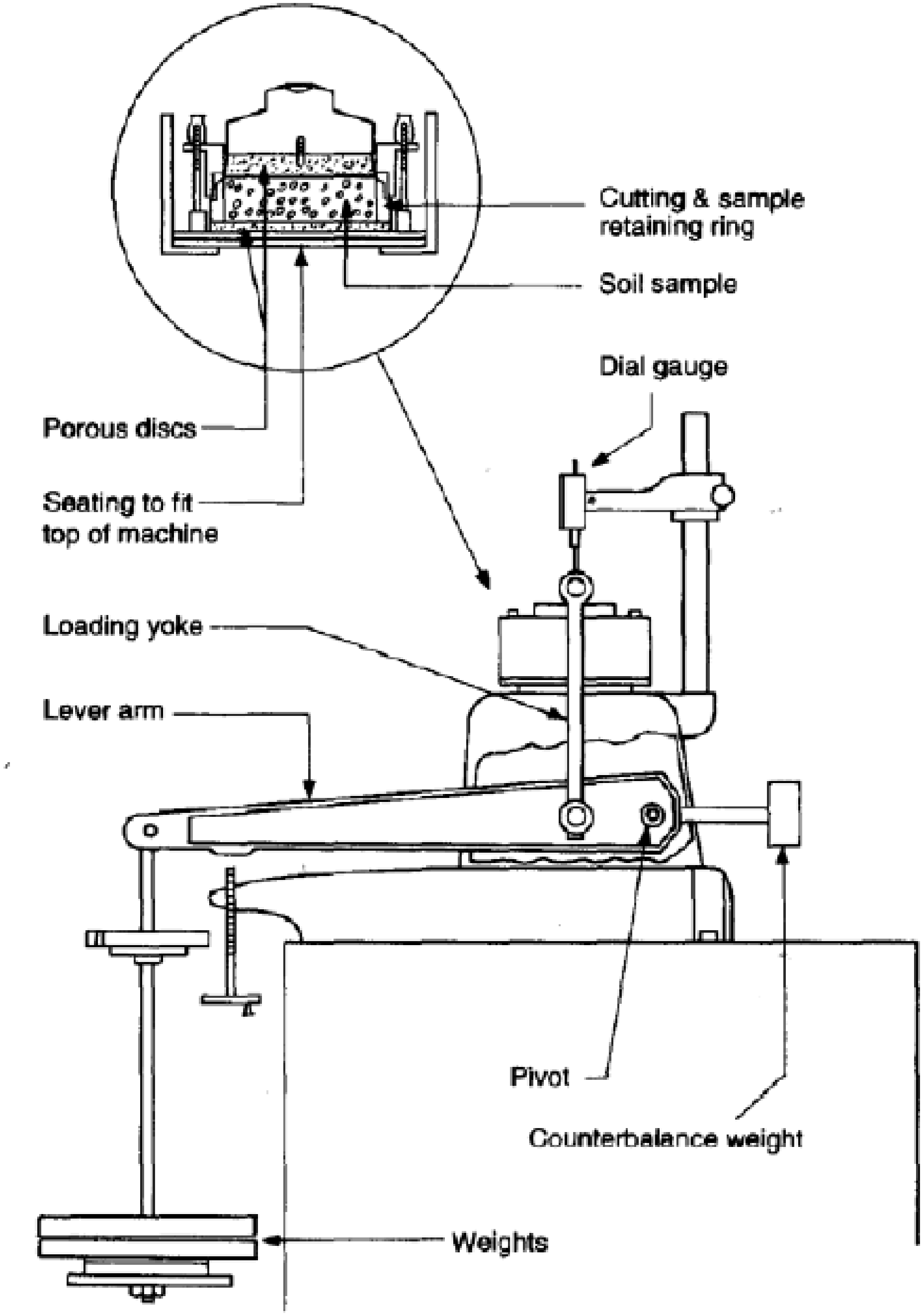


Fig. 8.19 Casagrande oedometer apparatus. (Clayton *et al*, 1995)

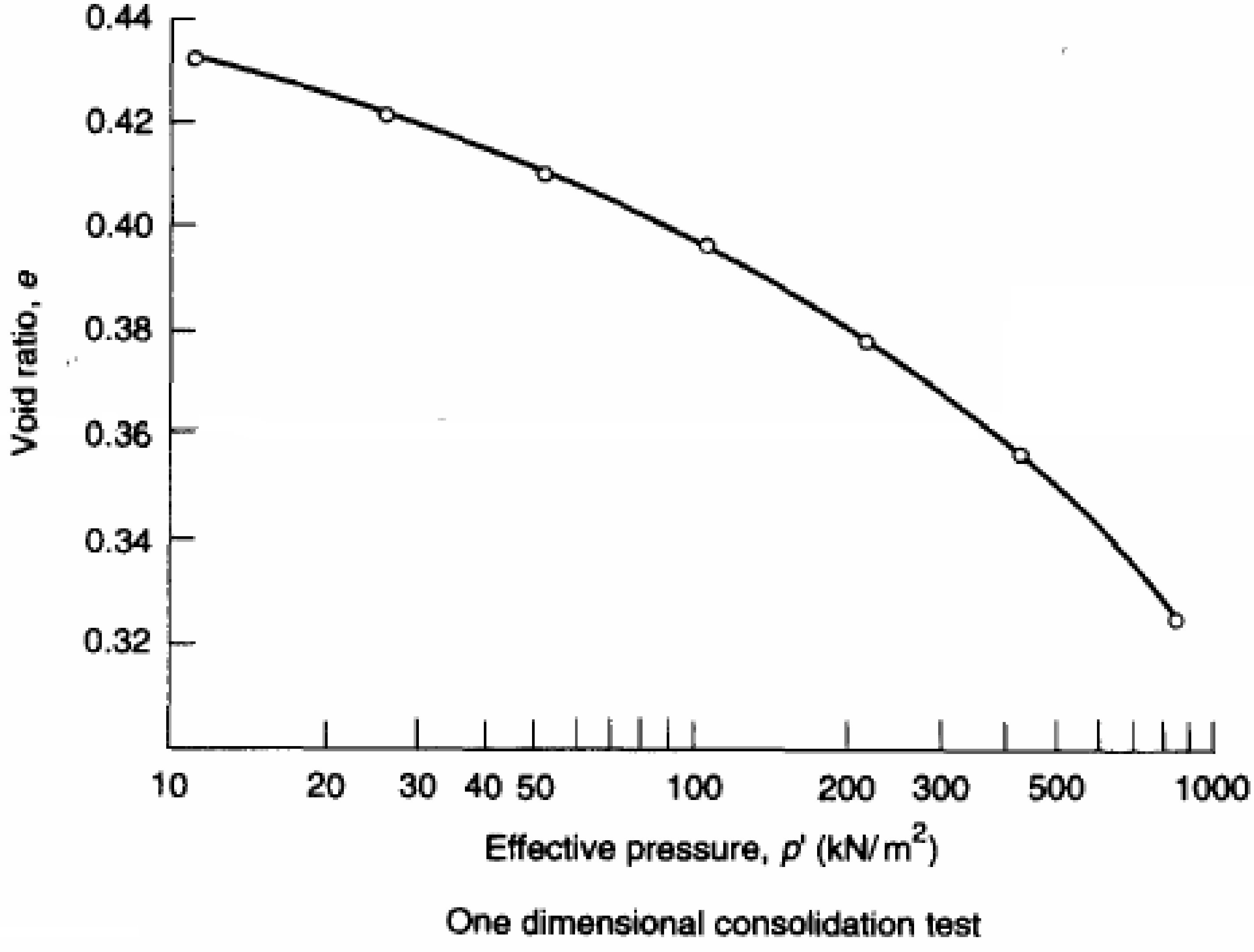


Fig. 8.20 Oedometer test result. (Clayton *et al*, 1995)

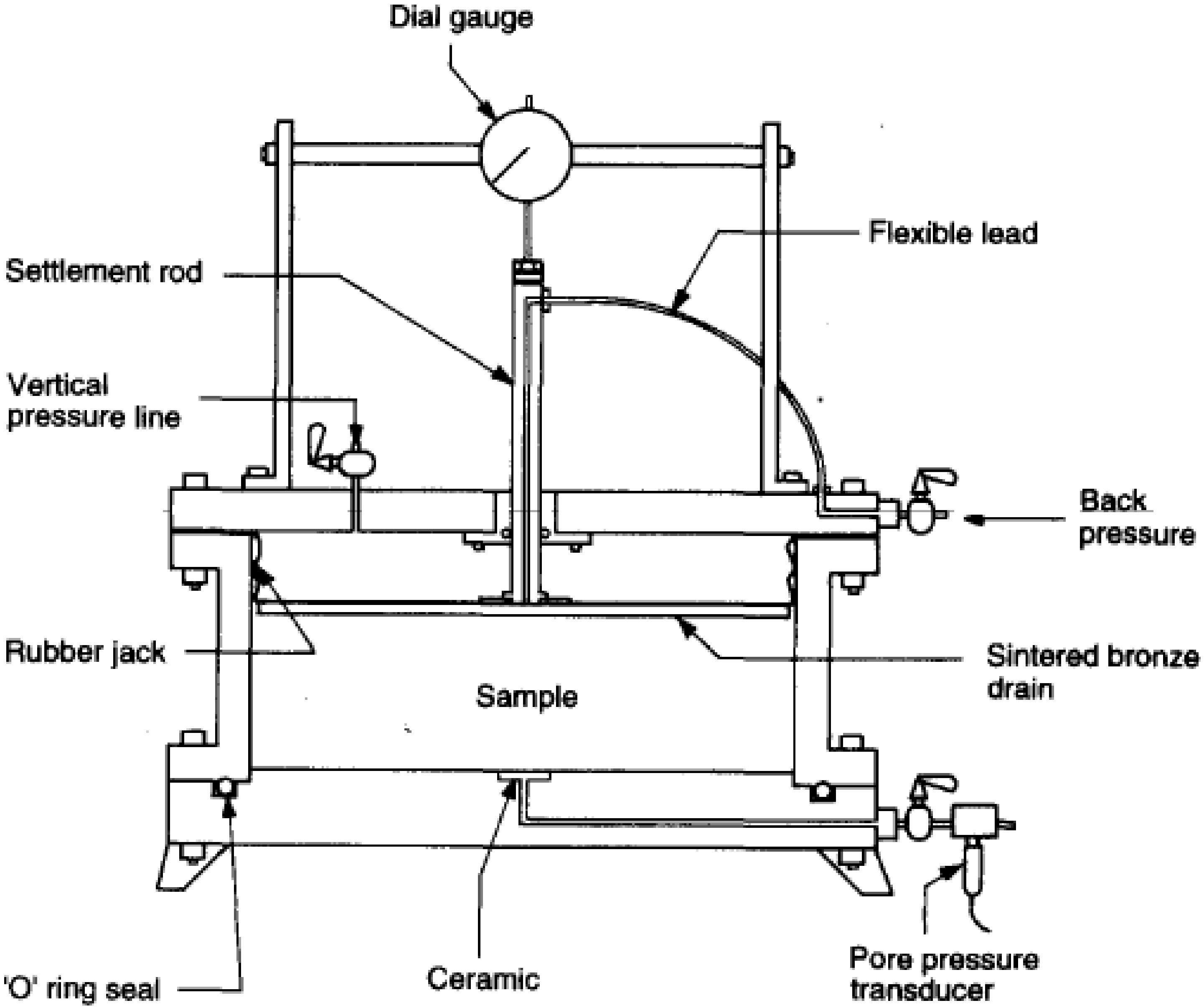


Fig. 8.22 The hydraulic oedometer (Rowe and Barden 1966).