Advanced Programme - Planning, Design _ Construction of Long Span Bridges- (Batch I) - 22

CHARACTERISATION OF GROUND & FOUNDATIONS FOR BRIDGES

National Rural Infrastructure Development Agency

Ministry of Rural Development

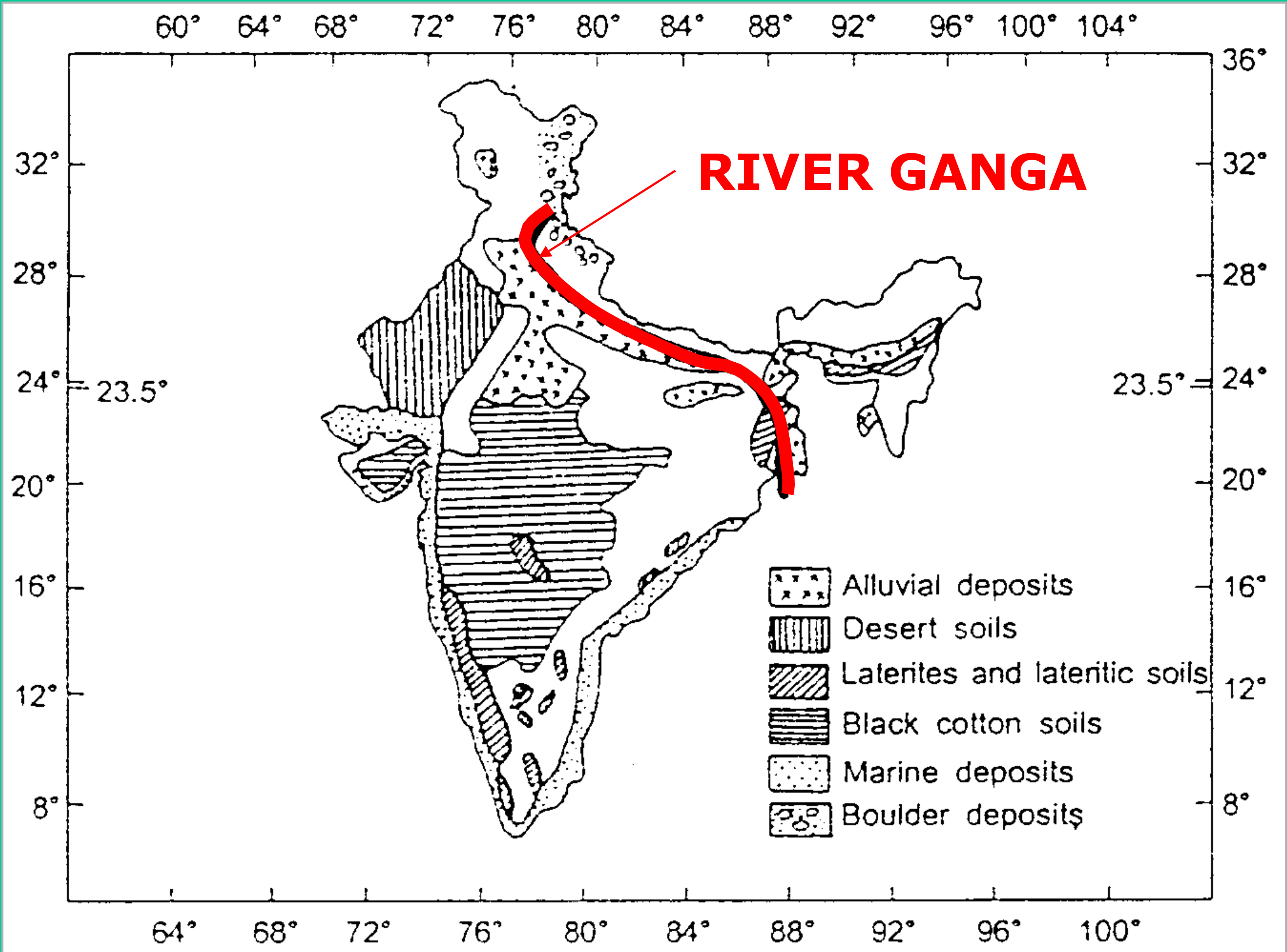
Engineering Staff College of India (ESCI)

Hyderabad

Lecture 1

CHARACTERISATION OF GROUND & FOUNDATIONS FOR BRIDGES

DEPOSITS OF INDIA



THE GROUND

- Qualitative
  - Reconnaissance
  - Google Maps
  - Site History
  - Adjacent Structures
- Quantitative
  - Limits - Liquid, Plastic, Shrinkage, etc.
  - Grain Size, Shape, Clay Content, Mineral Type
  - Relative Density (State Parameter)

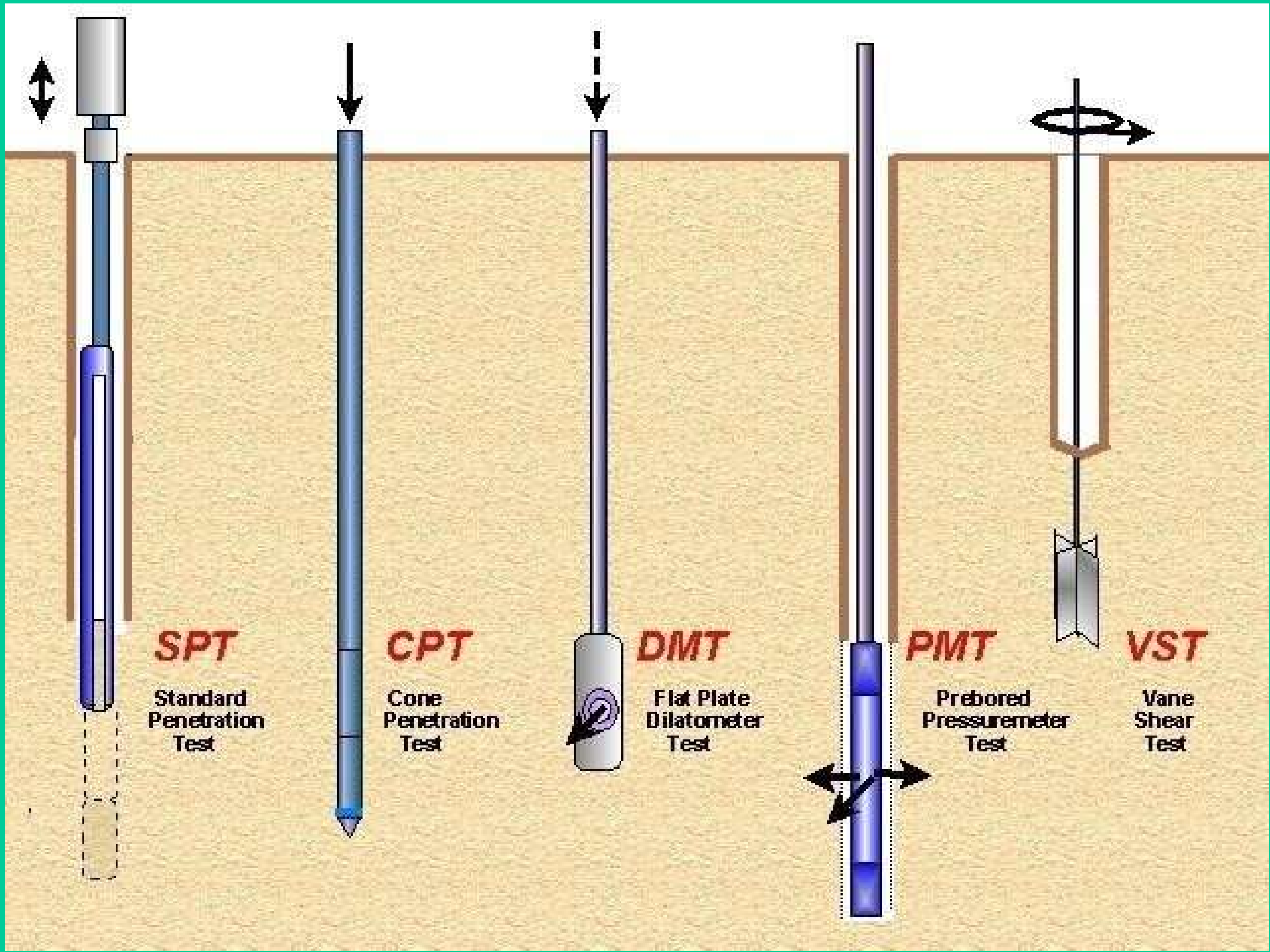
Quantitative Tests

- Routine Lab. Tests
  - Compressibility, Consolidation
  - Permeability
  - Direct Shear
  - Triaxial
- In Situ Tests
  - Standard Penetration
  - Static/Dynamic Cone
  - Vane Shear
  - Plate/Pile Load tests

Advanced/Specialized Tests

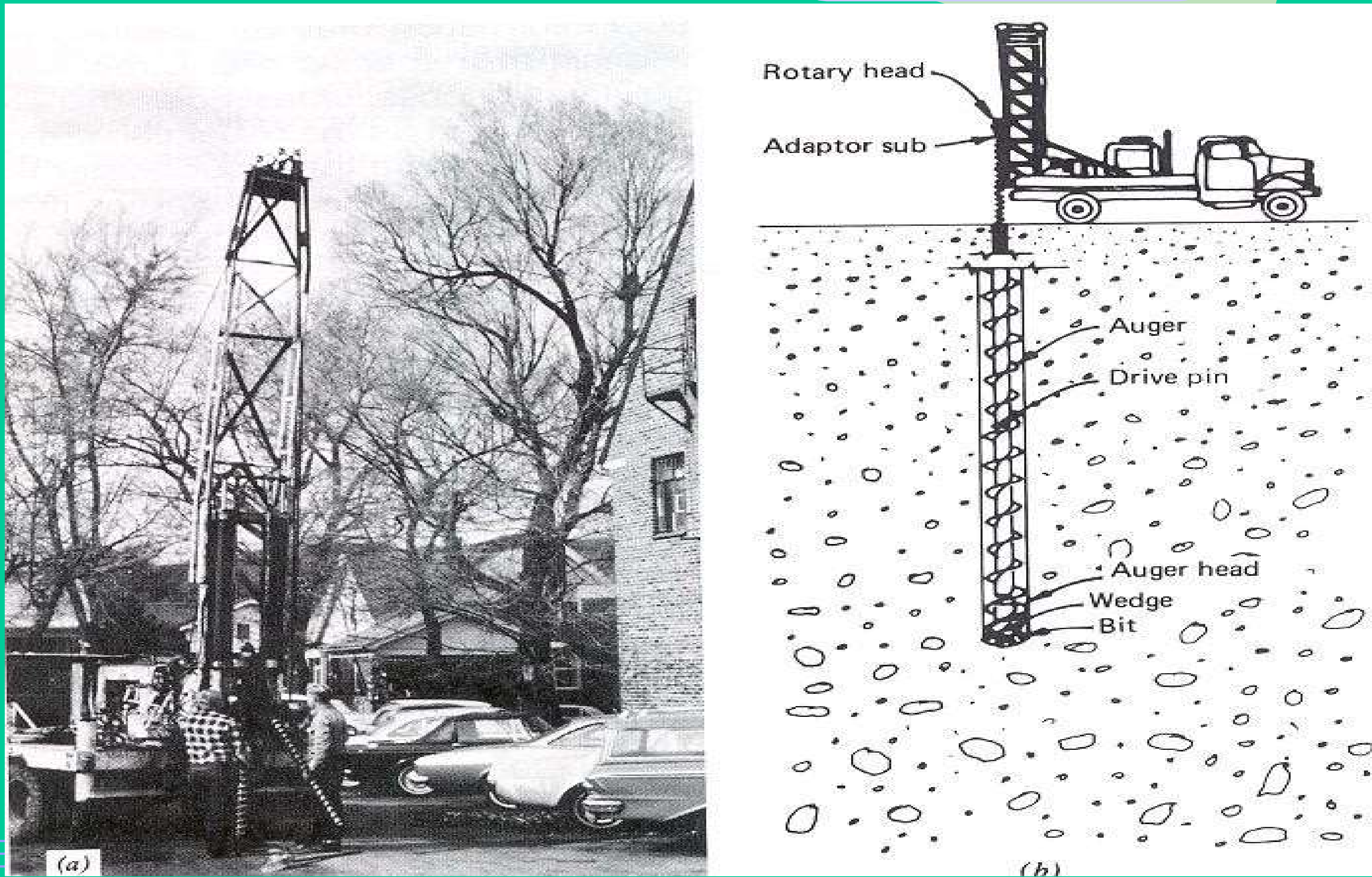
- Laboratory
  - Simple Shear
  - Stress Path Controlled
  - Plane Strain
  - True Triaxial
- In Situ
  - Pressuremeter
  - Dilatometer
  - Piezo-cone, Seismic Cone
  - SASW, etc.

In-Situ Tests



Rotary Drilling

Progress faster Disturbance - slight



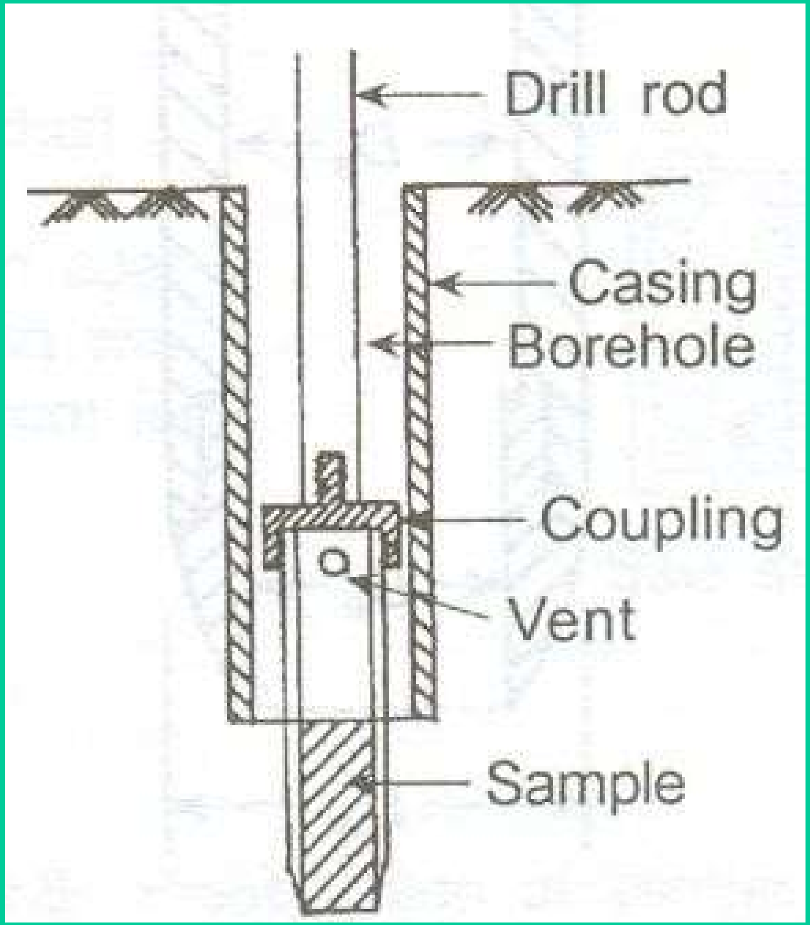
Sampling

<u>Types</u>

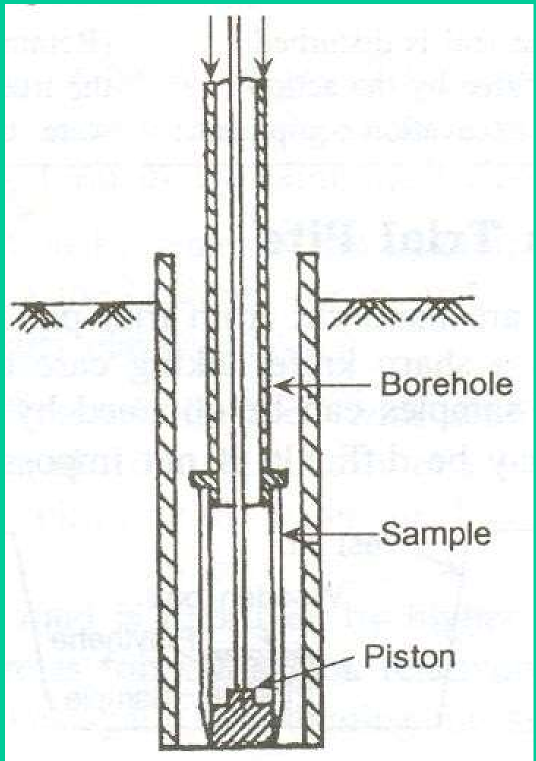
– Disturbed sample

– Undisturbed sample

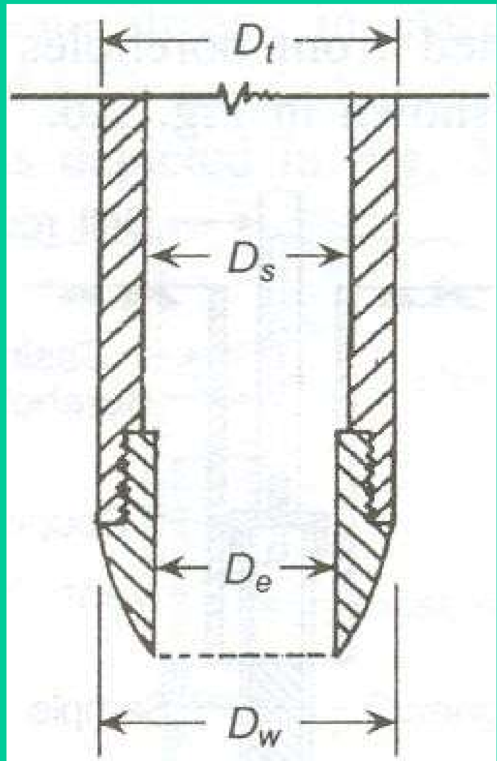
Sampling



Samplers

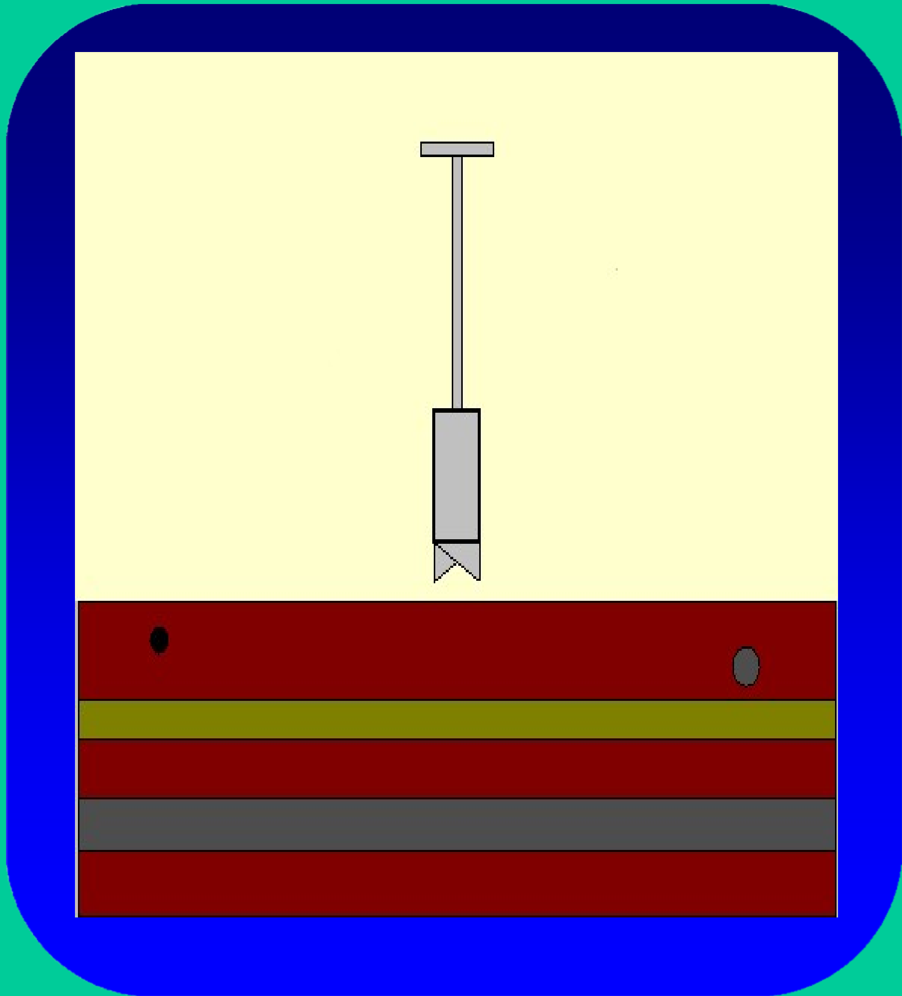


Piston Sampler



Sampling tube

Undisturbed Sample

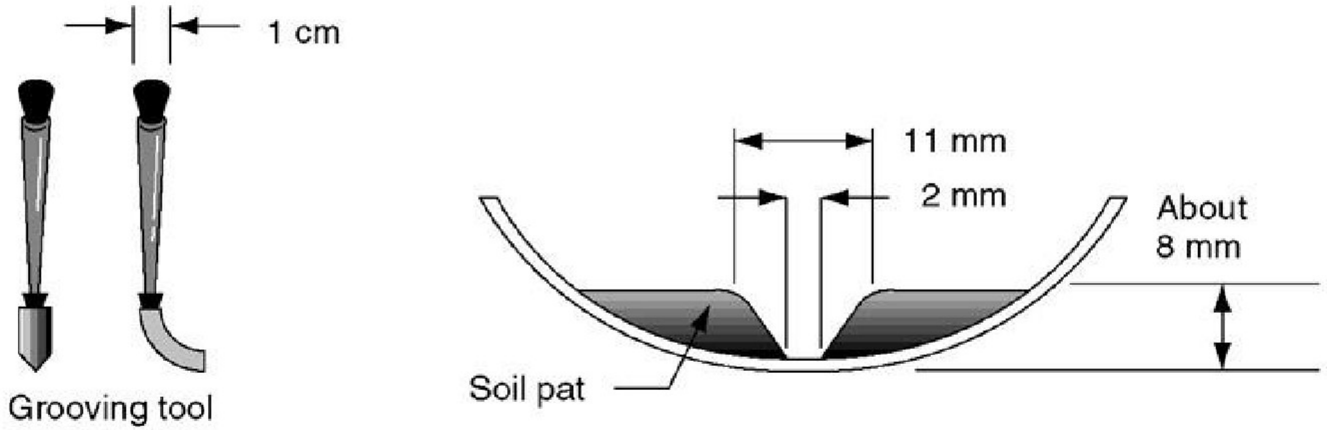


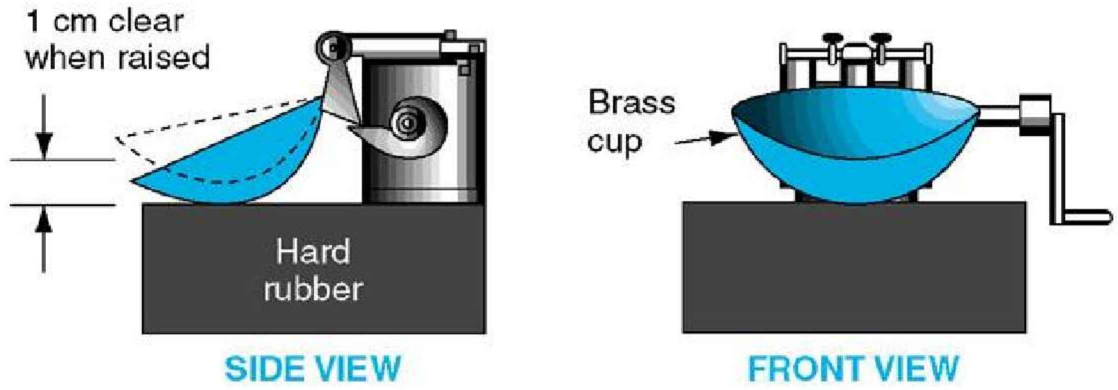
Laboratory Tests

- ✓ Moisture Content
- ✓ Density/Unit Weight
- ✓ Atterberg Limits
- ✓ Particle Size Distribution
- ✓ Specific Gravity of Soil Solids

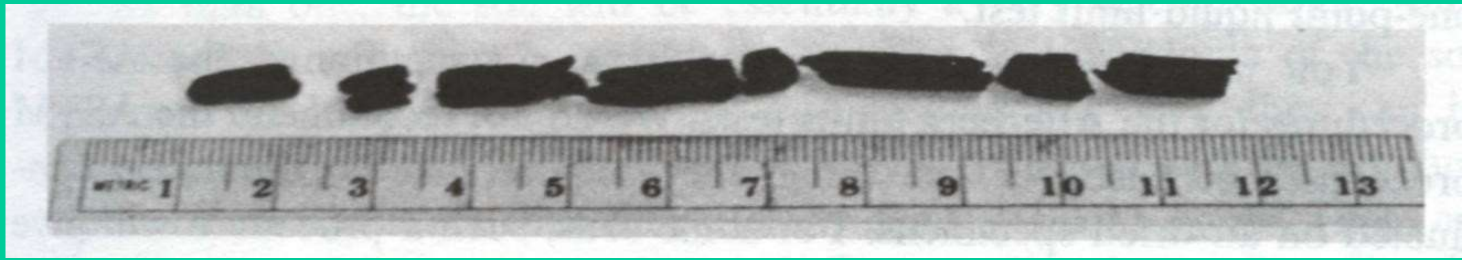
Liquid Limit

Check the fall distance of the cup in the liquid limit device and adjust, if necessary, so that the height of fall is exactly 1 cm. It is important that this measurement be made between the base and the point on the cup that comes in contact with the base. The grooving tool handle is a 1-cm rule.

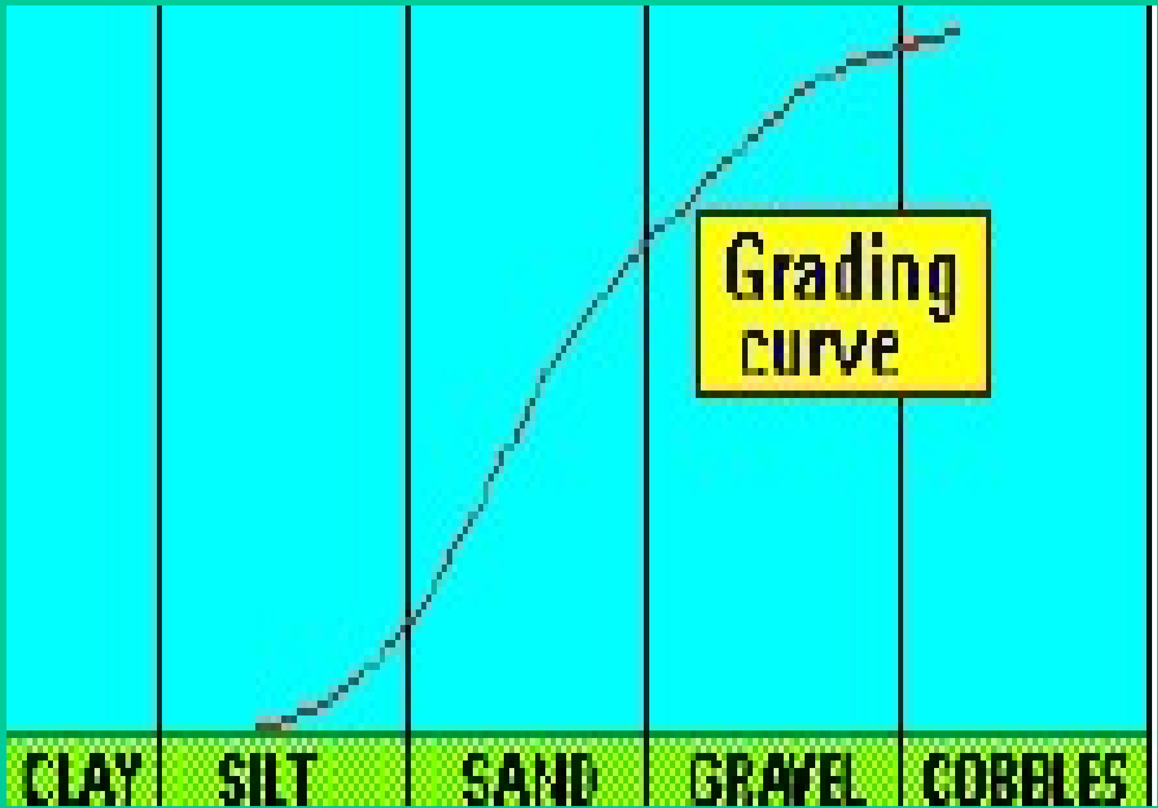




Plastic limit

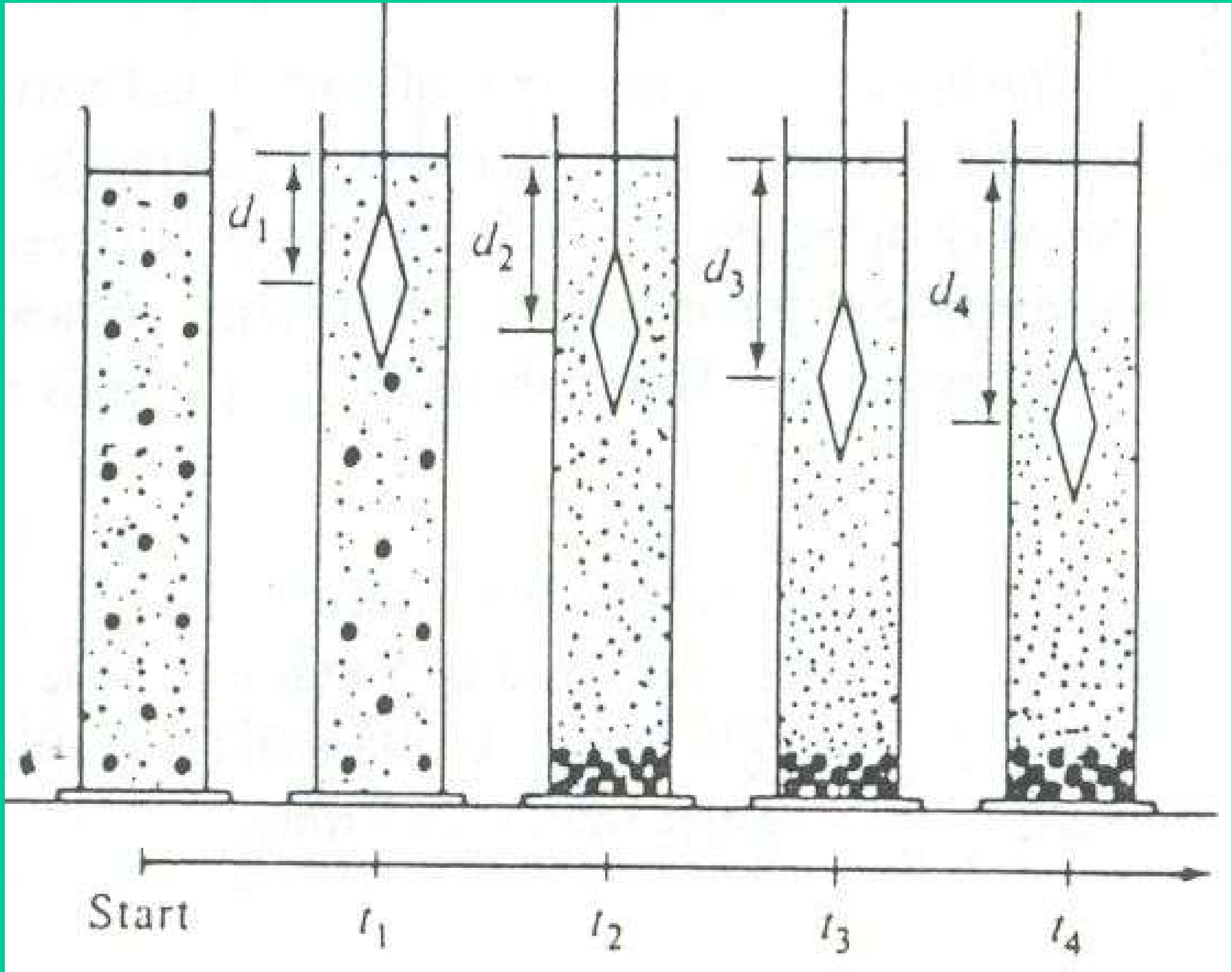


Particle Size-Sieving



Grading Curve

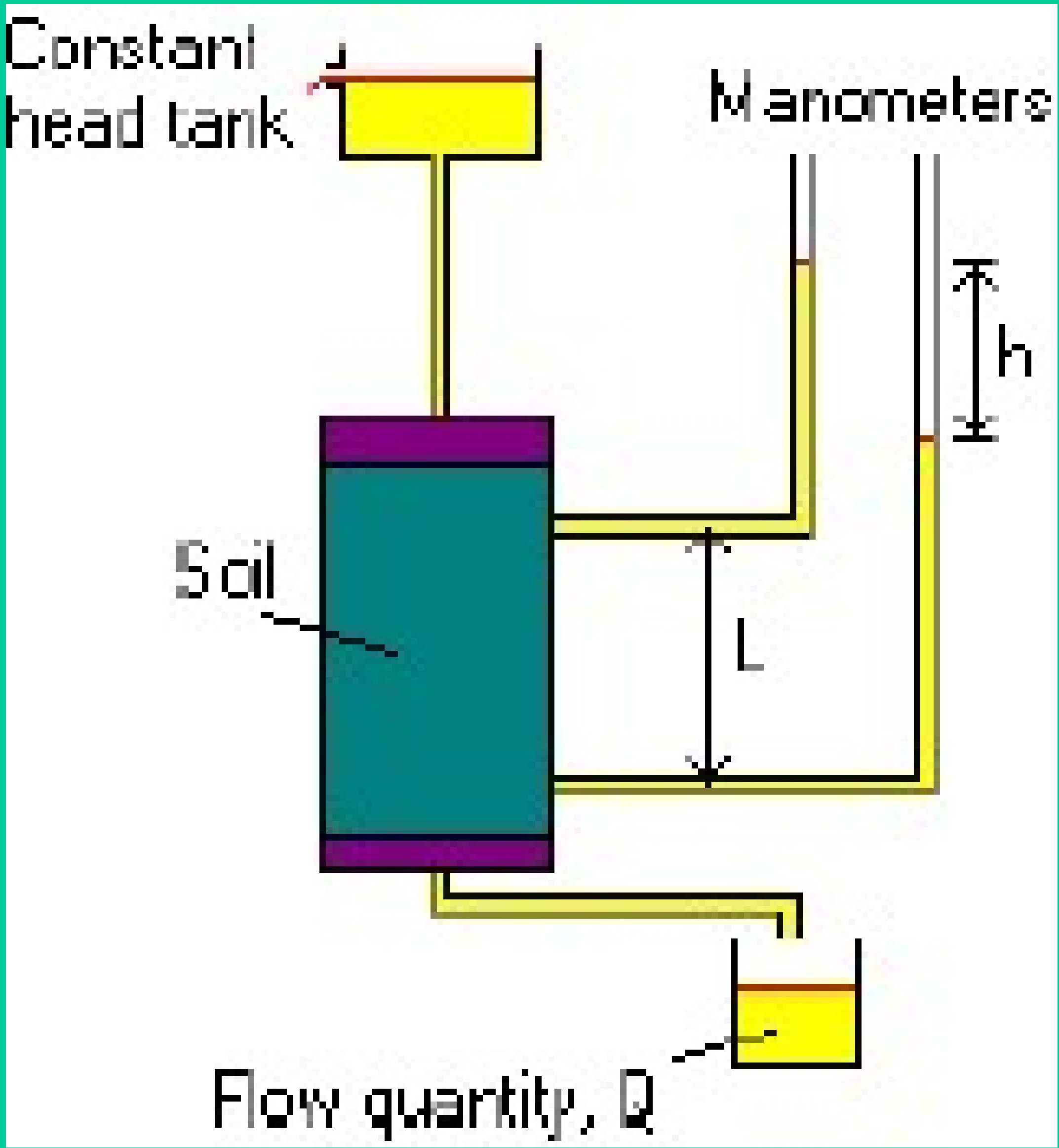
Hydrometer Analysis



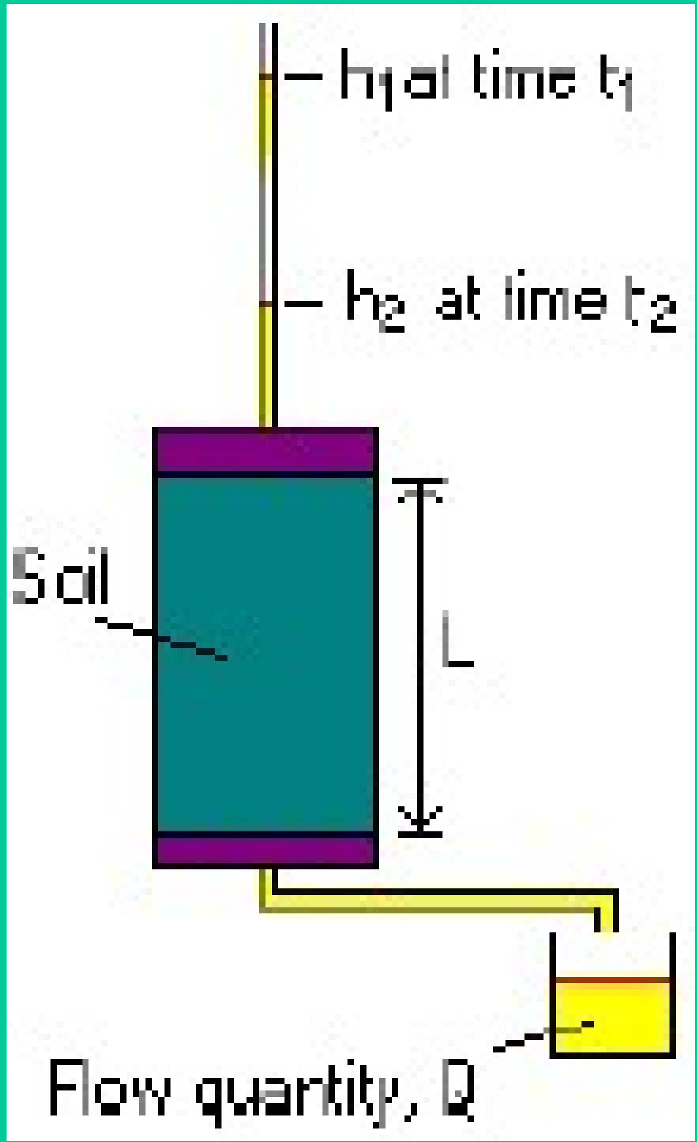
Permeability - Tests

- ✓ Constant Head
- ✓ Falling Head

Constant Head Test

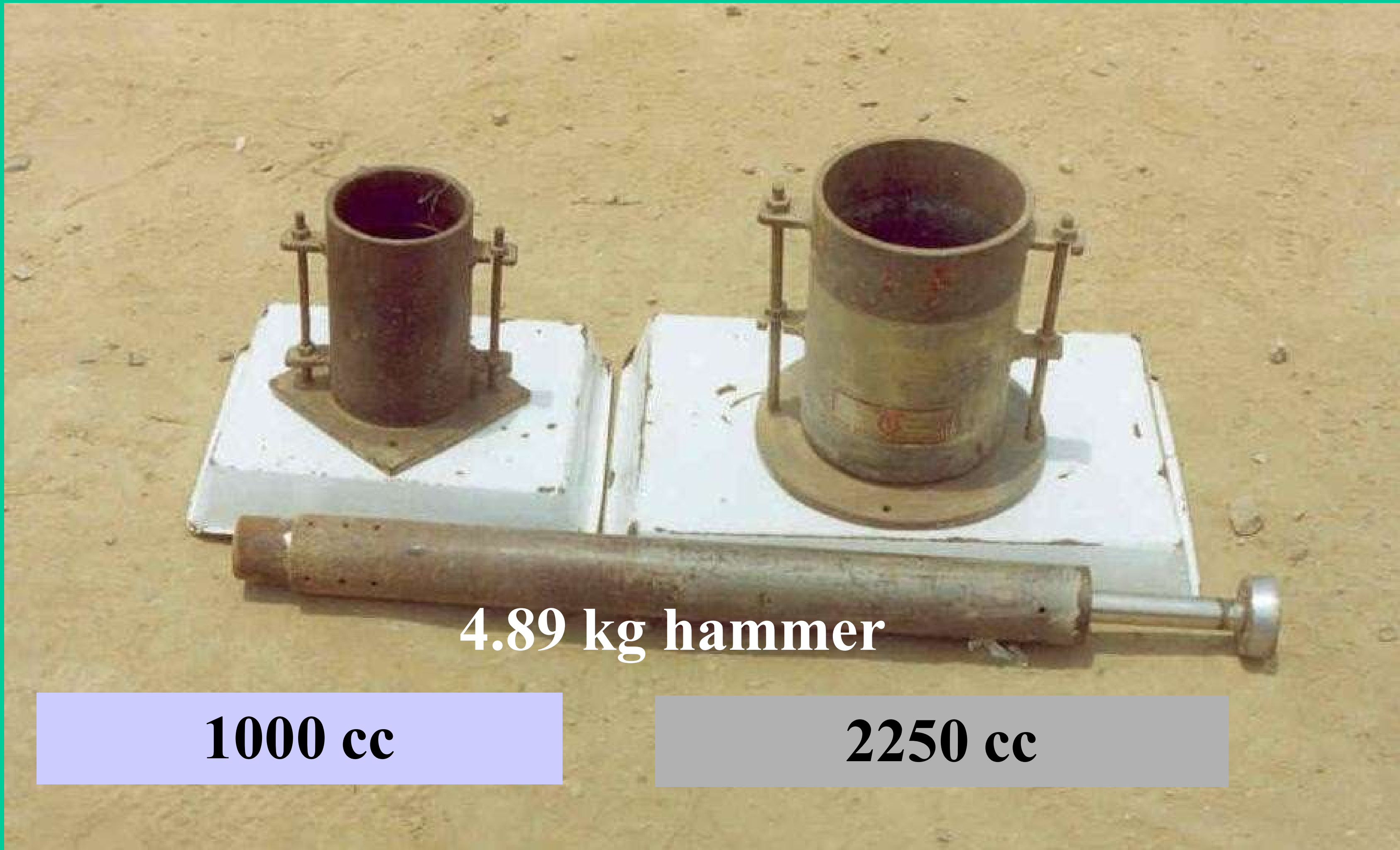


Falling Head Test



Compaction Tests

- Density/Moisture Content Relationship
- California Bearing Ratio (CBR) Test
- Maximum/Minimum Density Test



Mould and Hammer for compaction Tests

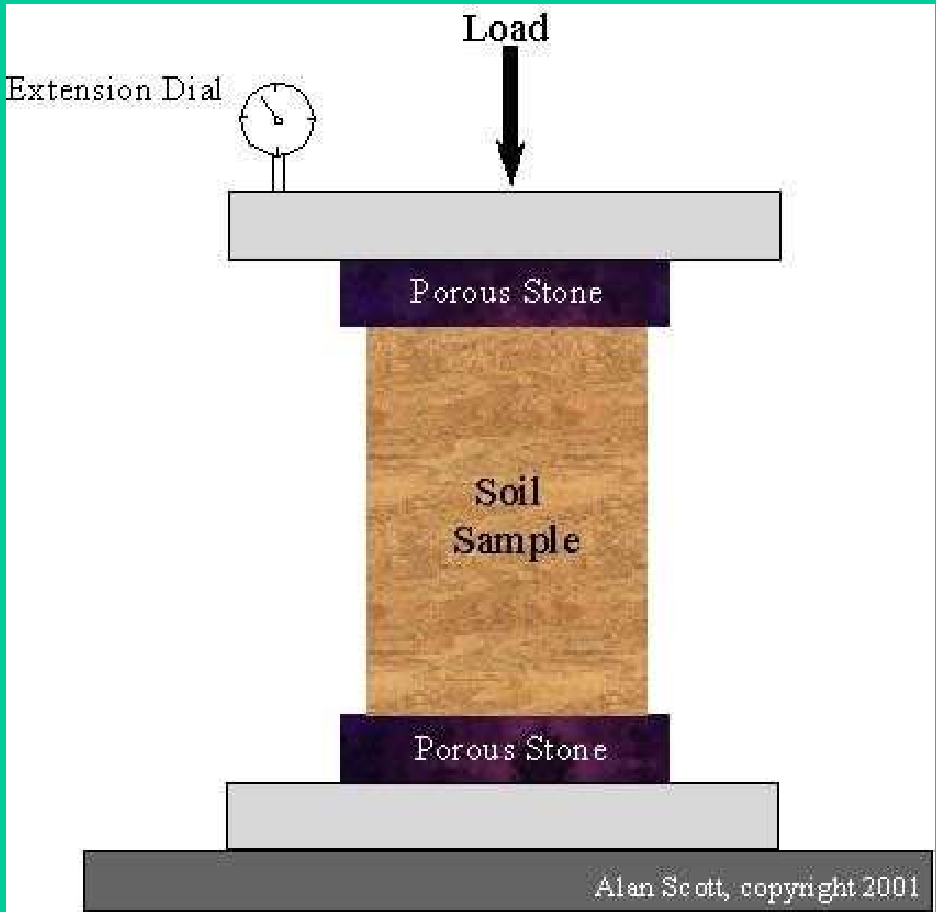
CBR Test


Photo by: Dr. Rachid Hankour, Geocomp Corp
Available by the Geoengineer Website
http://www.geoengineer.org

Shear Strength Tests

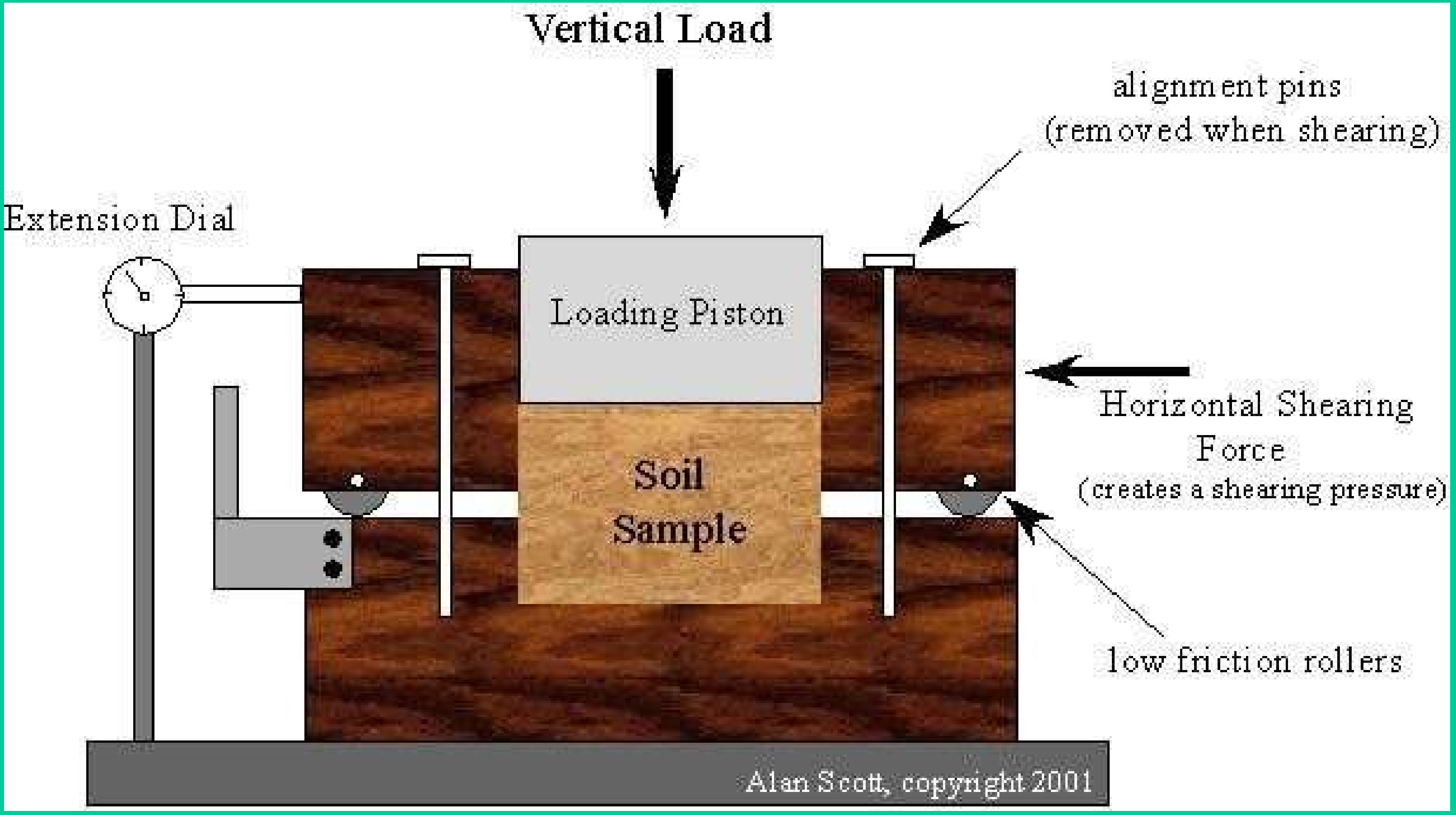
- ✓ Shear Box
- ✓ Vane Shear
- ✓ Unconfined Compression Test
- ✓ Undrained Triaxial Test (Total Stress)
- ✓ Consolidated Undrained Triaxial Test (Effective & Total Stress)
- ✓ Drained Triaxial Test (Effective Stress)

UCC Test

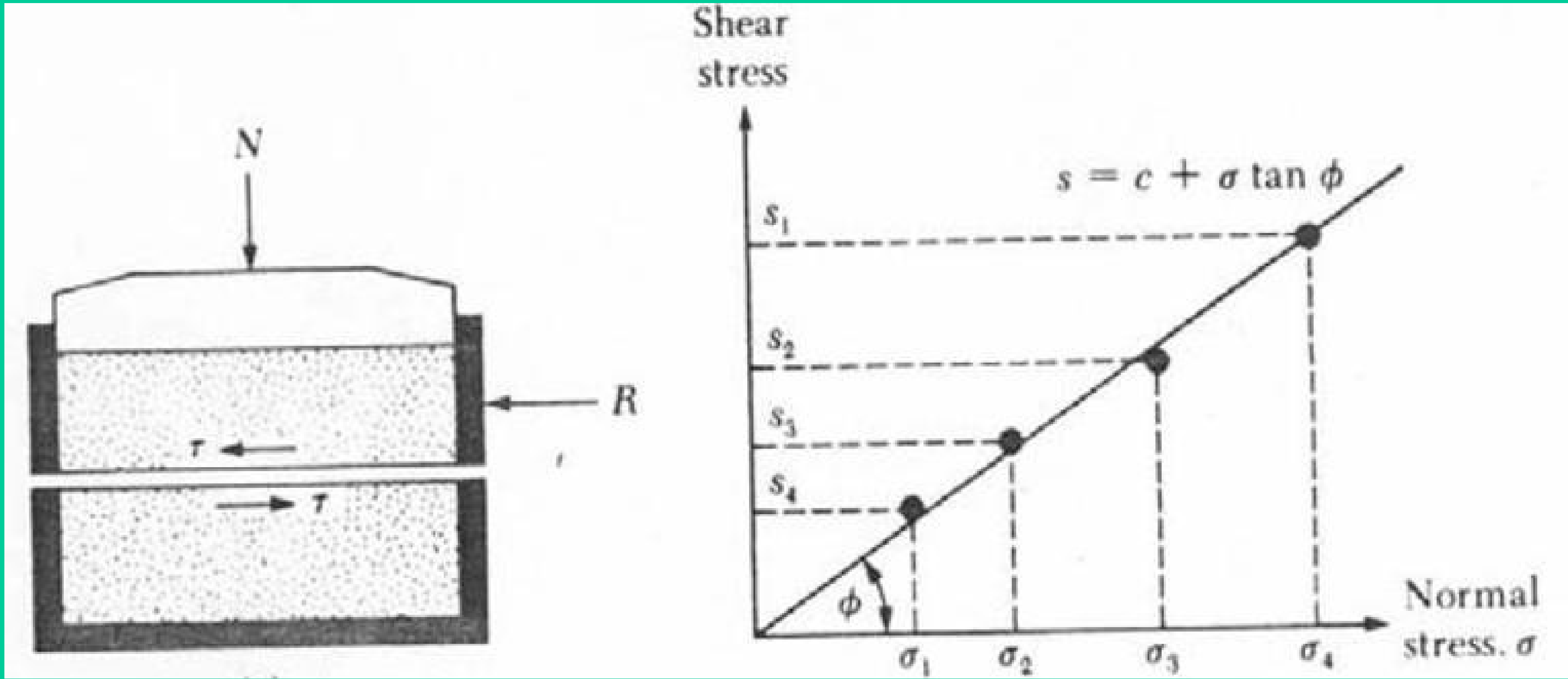


Load
Extension Dial
Porous Stone
Soil
Sample
Porous Stone
Alan Scott, copyright 2001

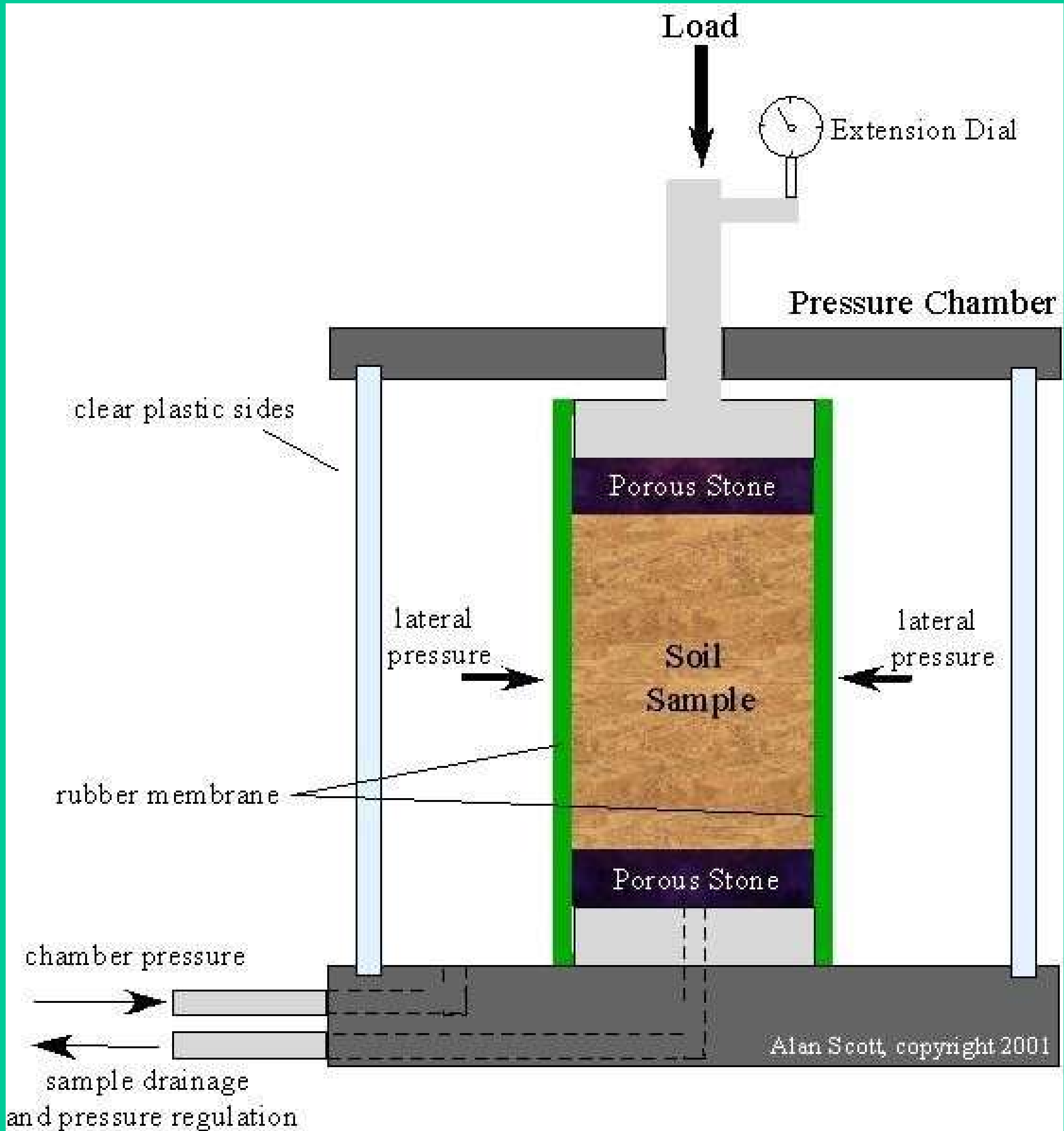
Direct Shear Test



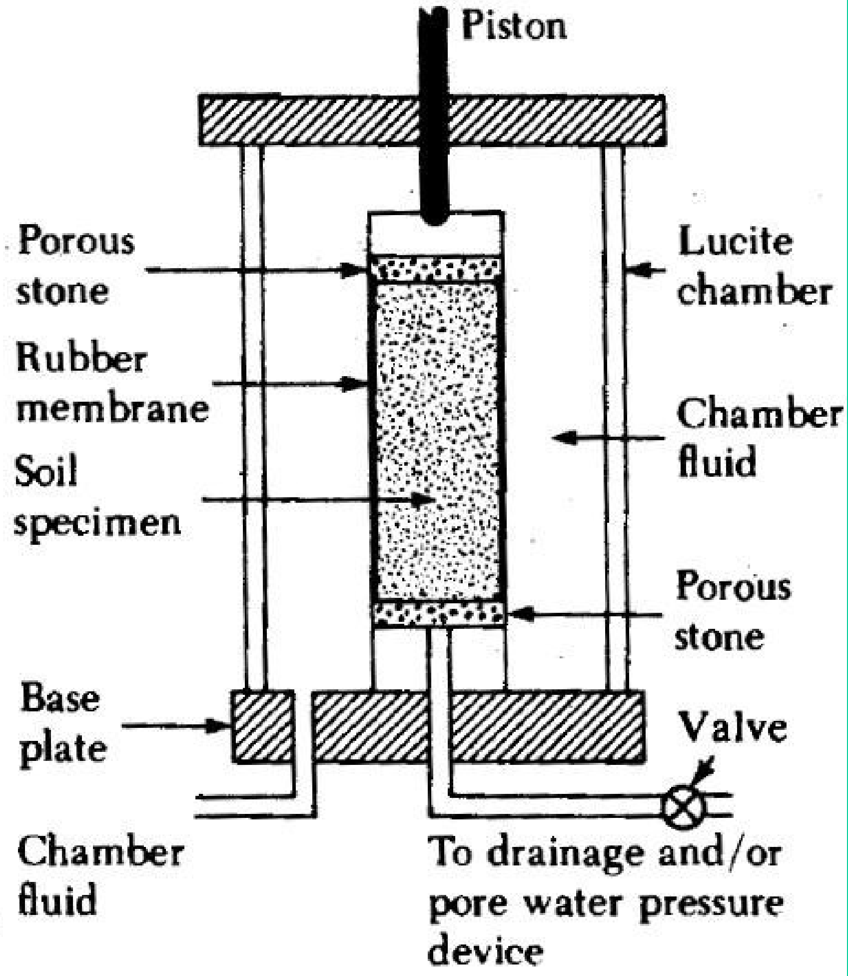
Direct shear test



Triaxial Test

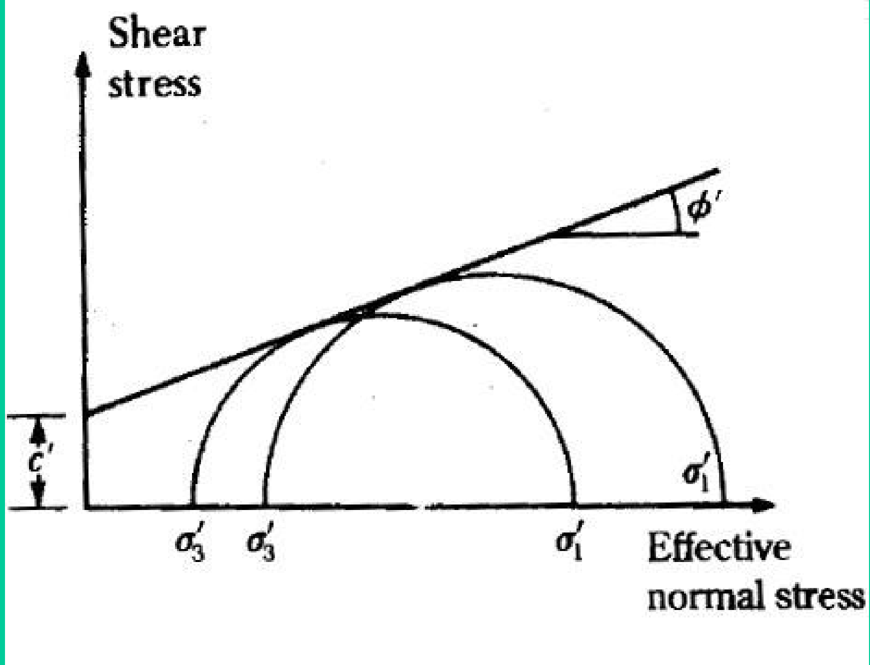


Triaxial Test



Schematic diagram of triaxial test equipment

Consolidated Drained Test

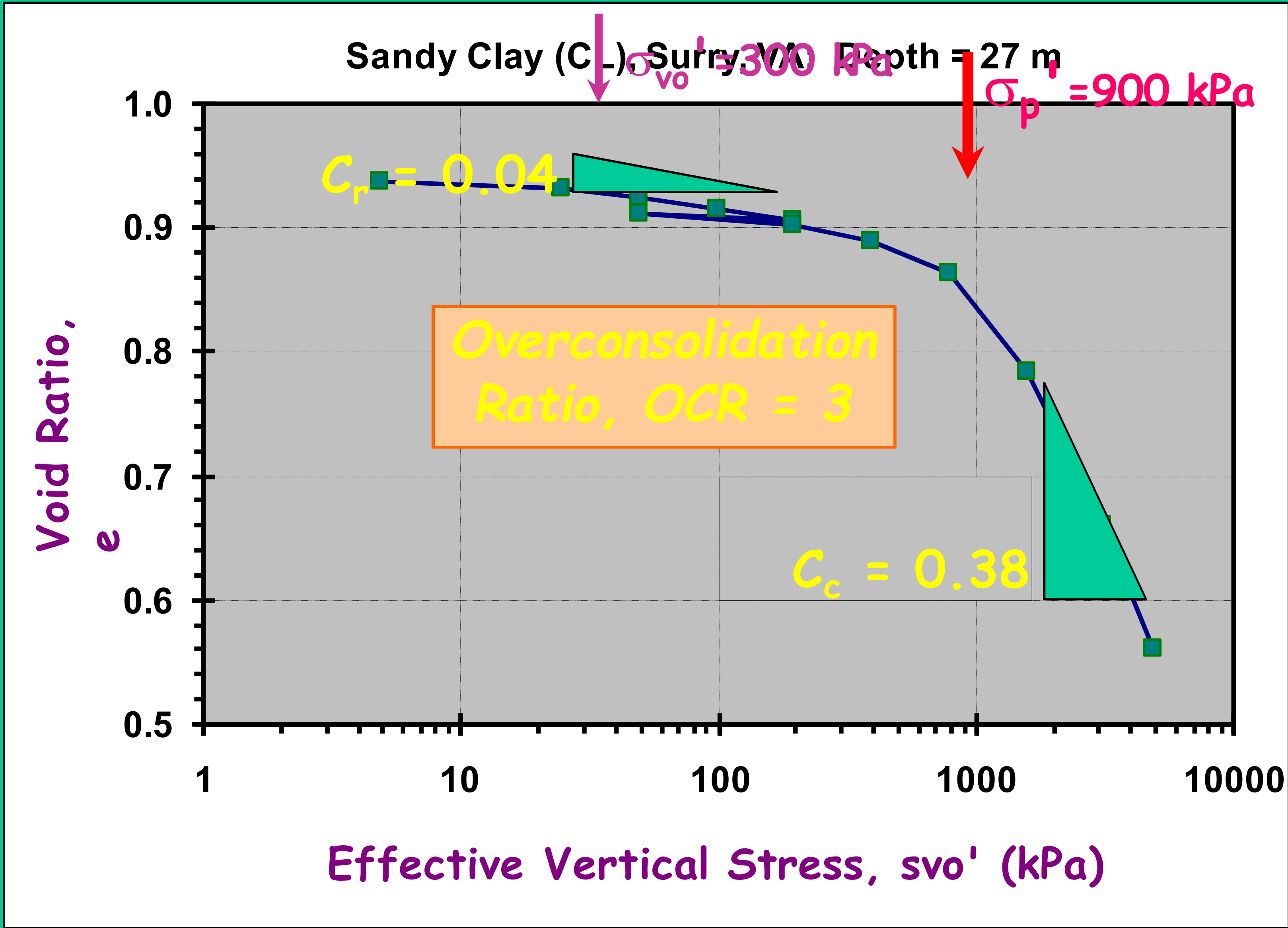


Consolidated-drained test

Compressibility & Consolidation Tests

- ✓ Oedometer/One Dimensional Consolidation
- ✓ Triaxial Consolidation
- ✓ Swelling Tests

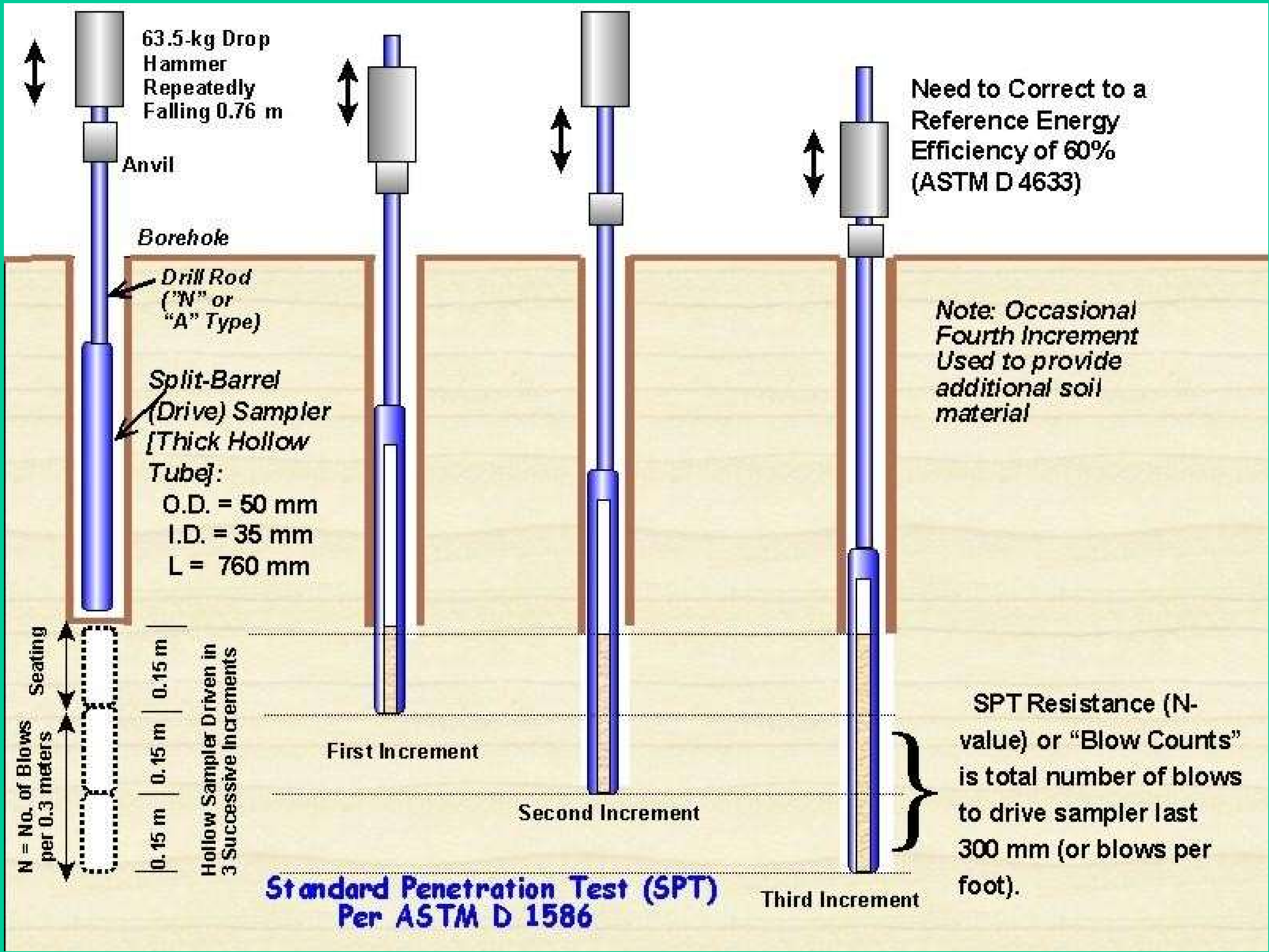
Void ratio vs log (effective stress) &Preconsolidation Stress of Clays



Standard Penetration Test

- **Most common geotechnical test**
- **Been in use for over 75 years**
- **Universal availability of equipment**
- **Fairly well known outside of geotechnical community**

Standard Penetration Test (SPT)



Standard Penetration Test

- **Disturbed sample from SPT Sampler**

Testing of soils

No of blows (N/30 cm)	*Relative density* $RD = \frac{(e_{max} - e)}{(e_{max} - e_{min})} \times 100\ \%$	**Relative State**
0 – 4	**0 – 15 %**	**Very loose**
4 – 10	**15 – 35 %**	**Loose**
10 – 30	**25 – 65 %**	**Medium**
30 – 50	**65 – 85 %**	**Dense**
>50	**>85%**	**Very dense**

Shear strength of cohesive soils		
Consistency	Undrained strength, c_u (kPa)	N
Very soft	0 – 12.5	0 - 2
Soft	12.5 - 25.0	2 – 4
Medium	25.0 - 50.0	4 - 8
Stiff	50.0 - 100.0	8 - 16
Very Stiff	100.0 - 200.0	16 - 32
Hard	> 200.0	32

Stop Test If

- **More than 50 blows required for any interval**
- **If more than 100 total blows required**
- **Either of these events known as:**
- ***Refusal***
- **Will be so noted on borings**

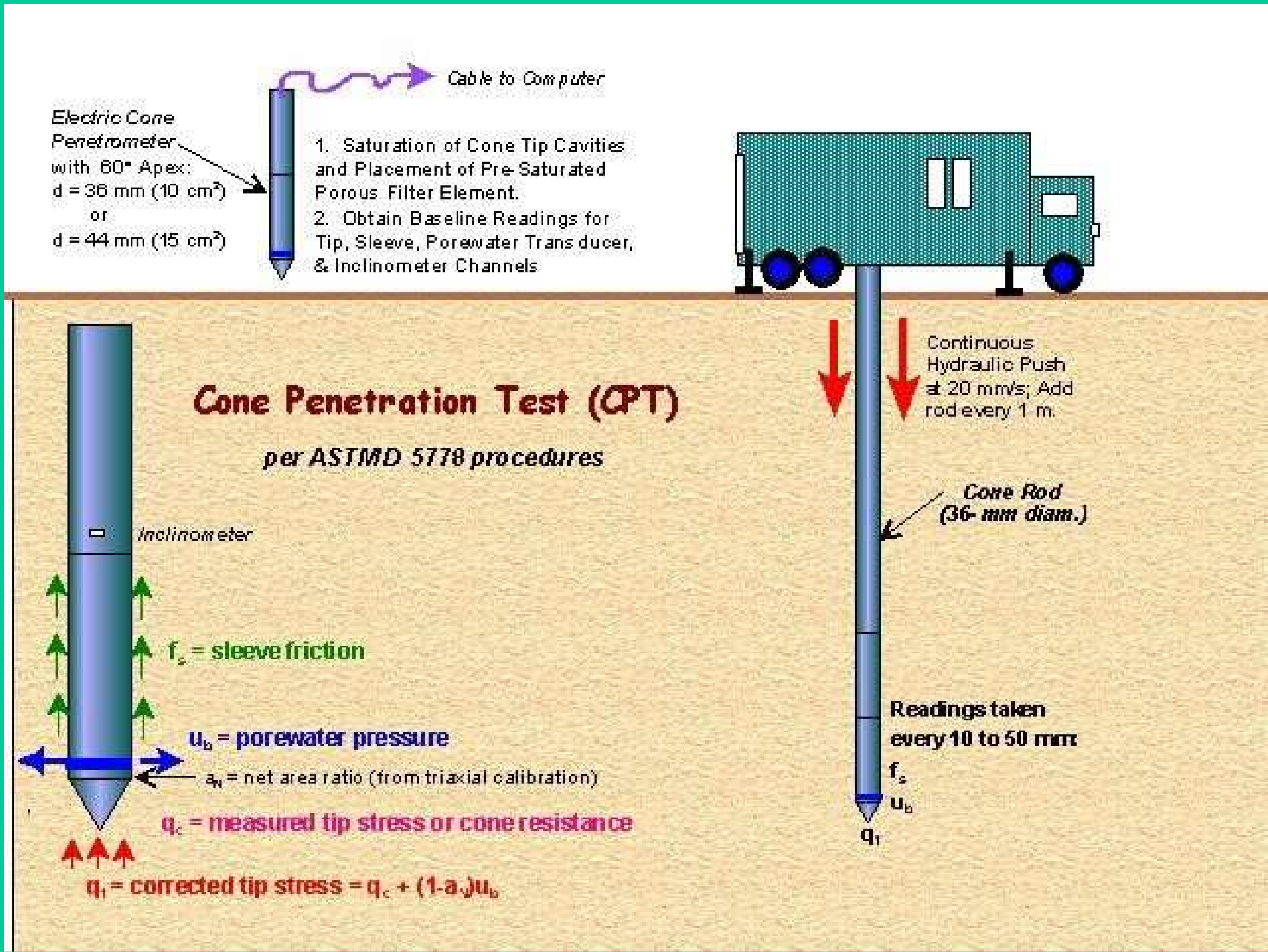
Cone Penetration Test

Instrumented steel cone is pushed into the ground at a rate of 2 cm/sec

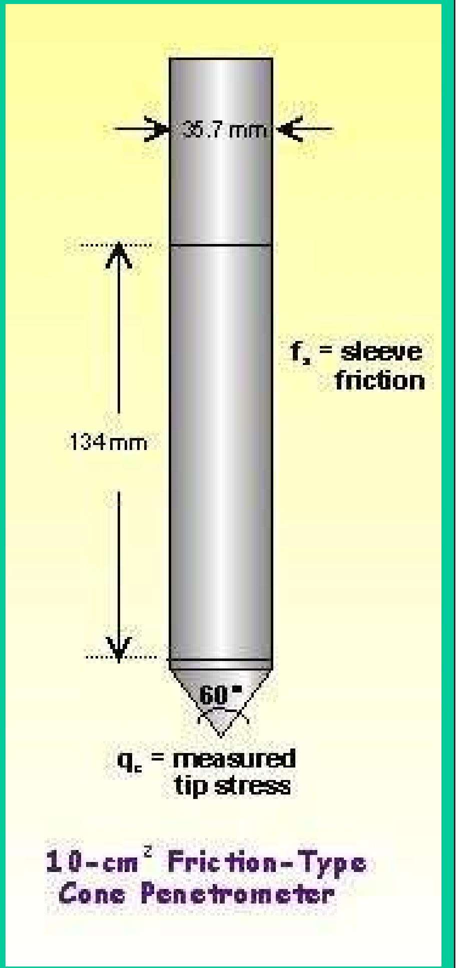
Measurements include:

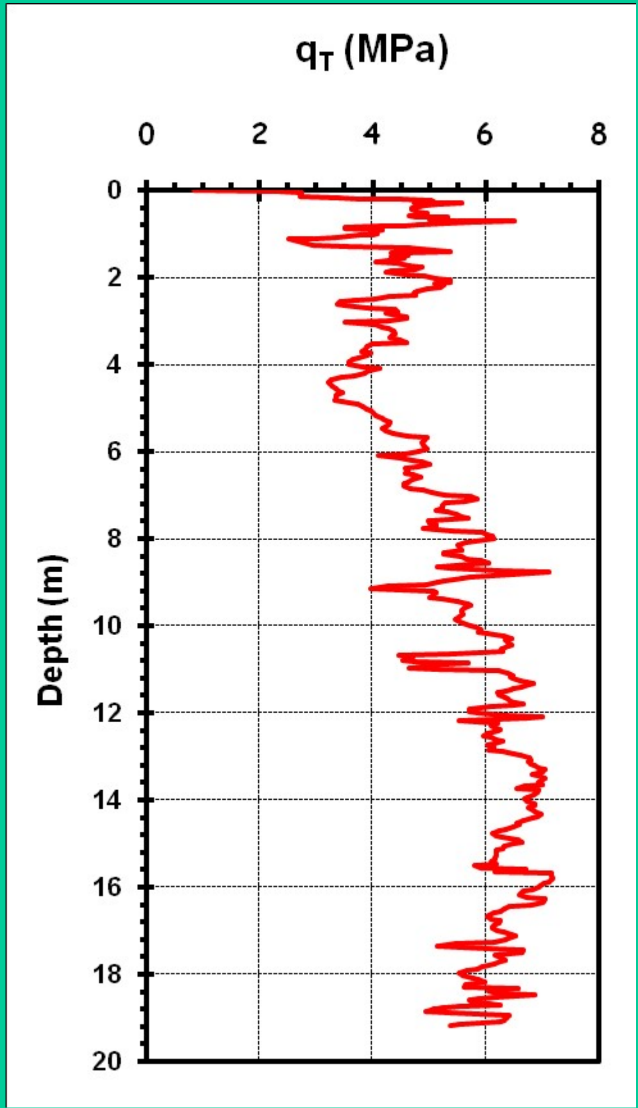
- **tip resistance**
- **sleeve friction**
- **pore water pressure**
- **shear wave velocity**

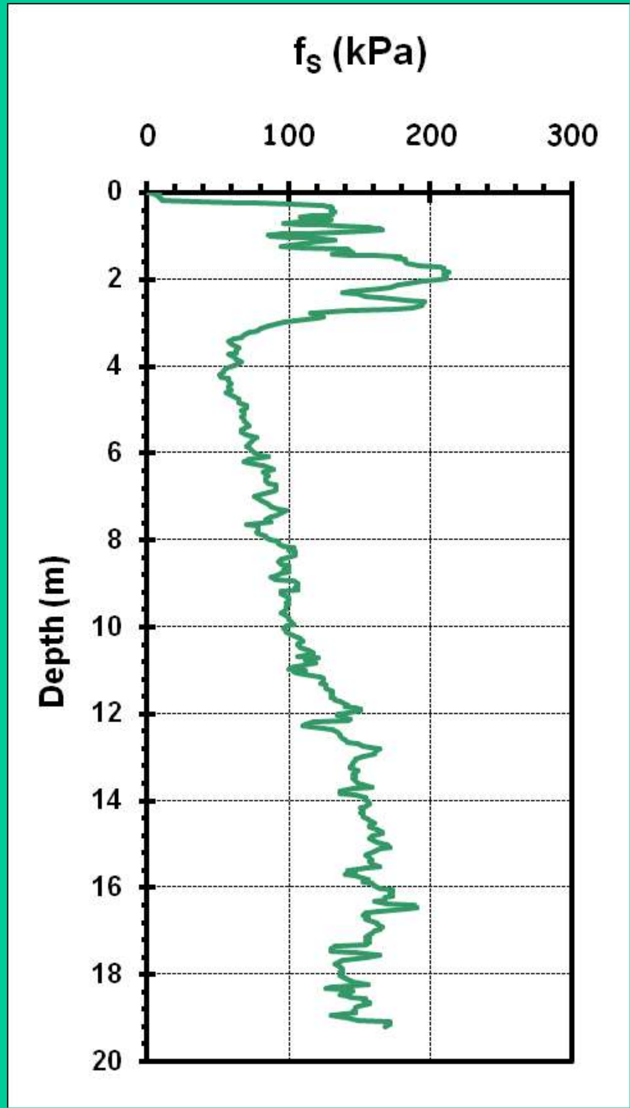
Cone Penetration Testing



Cone Penetrometer

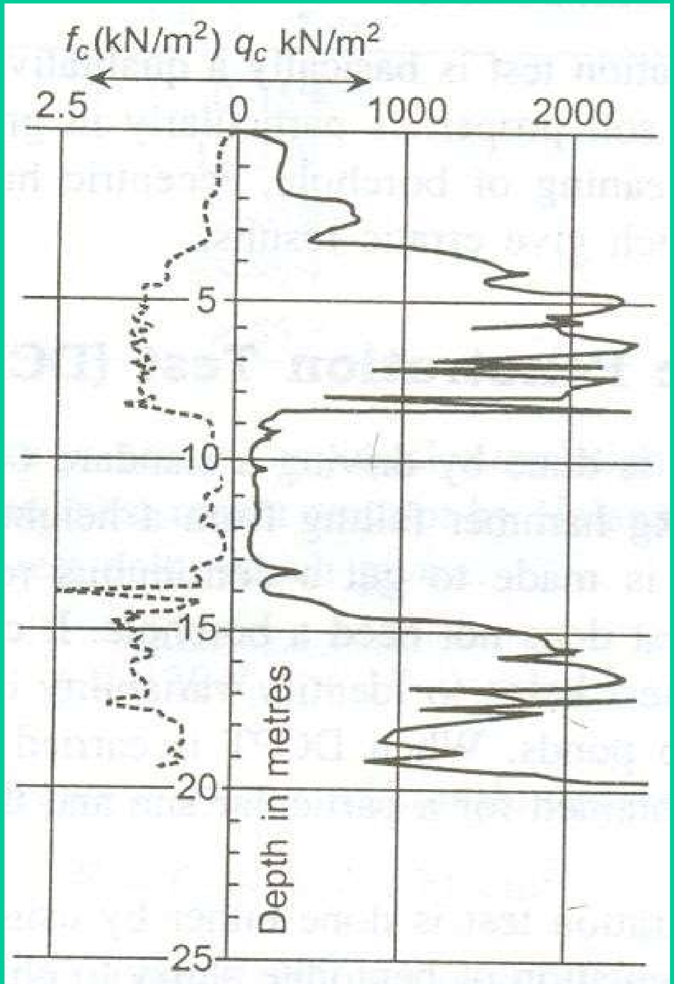






Cone Penetration Test

Data



Classification of Soils by CPT

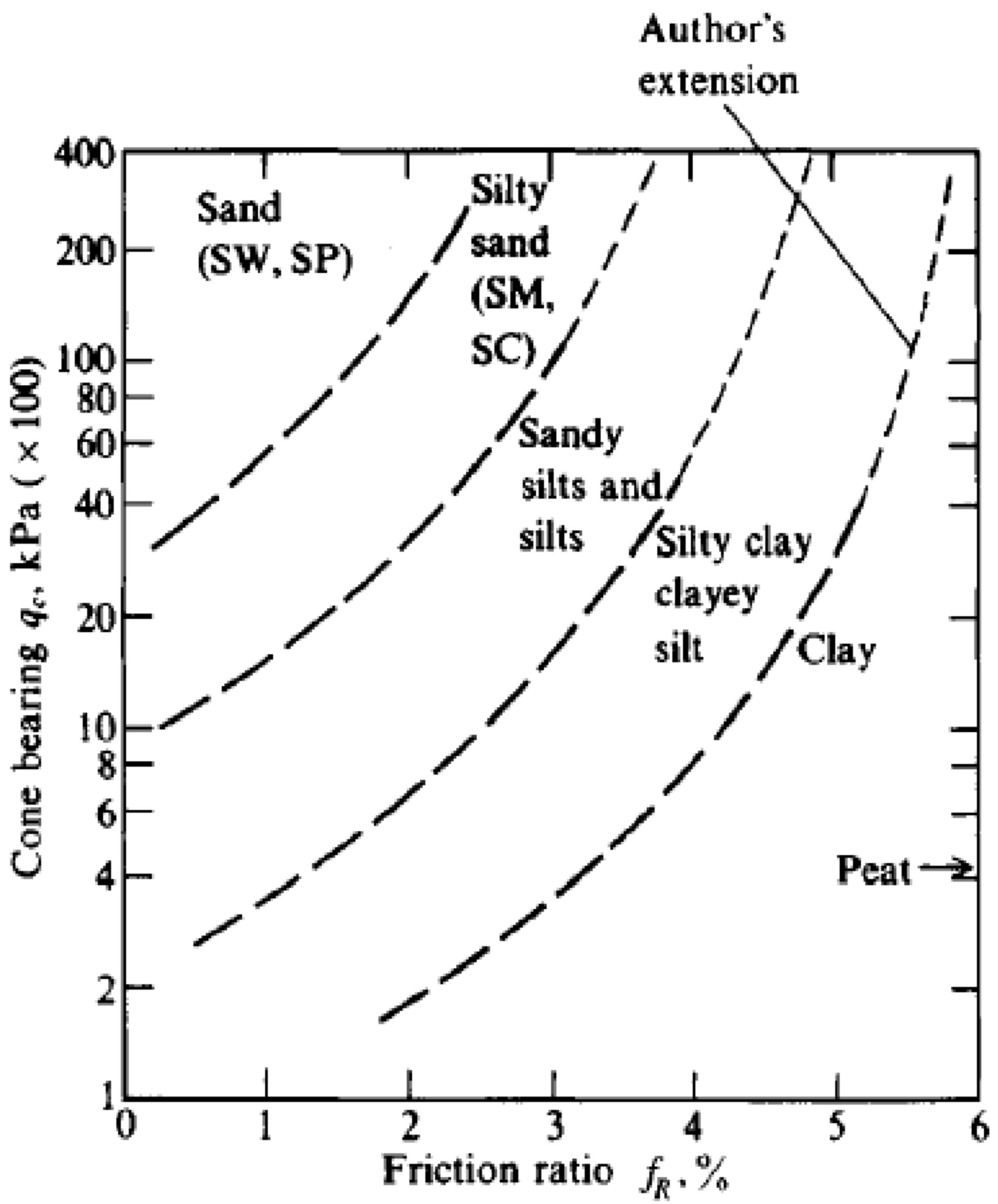
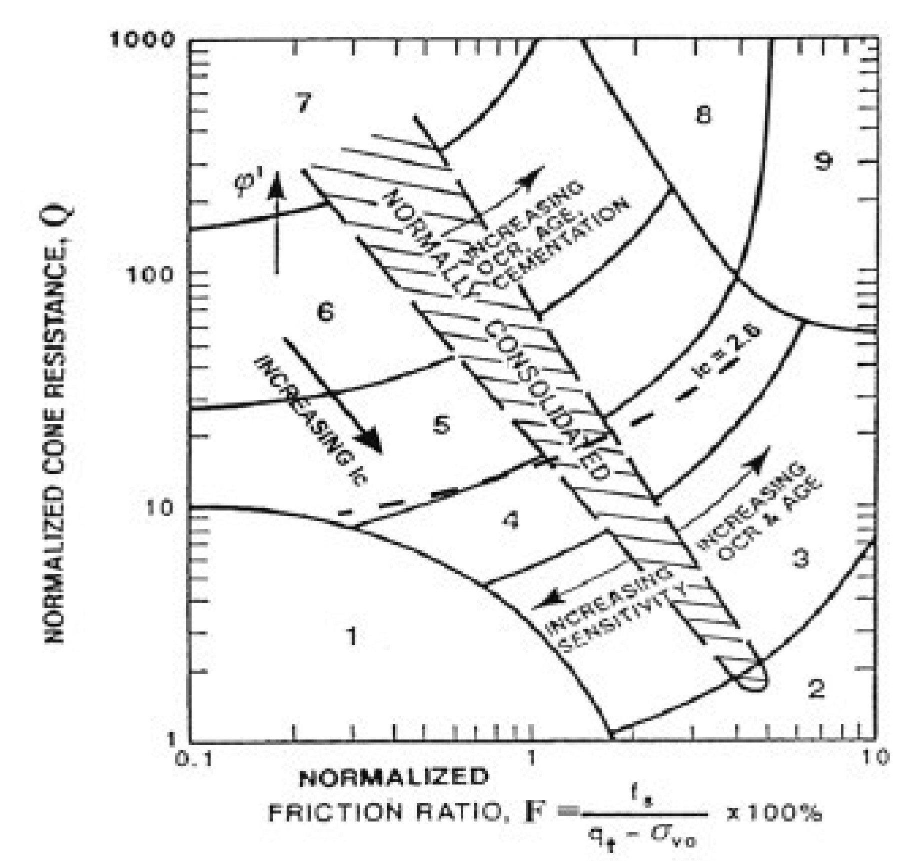


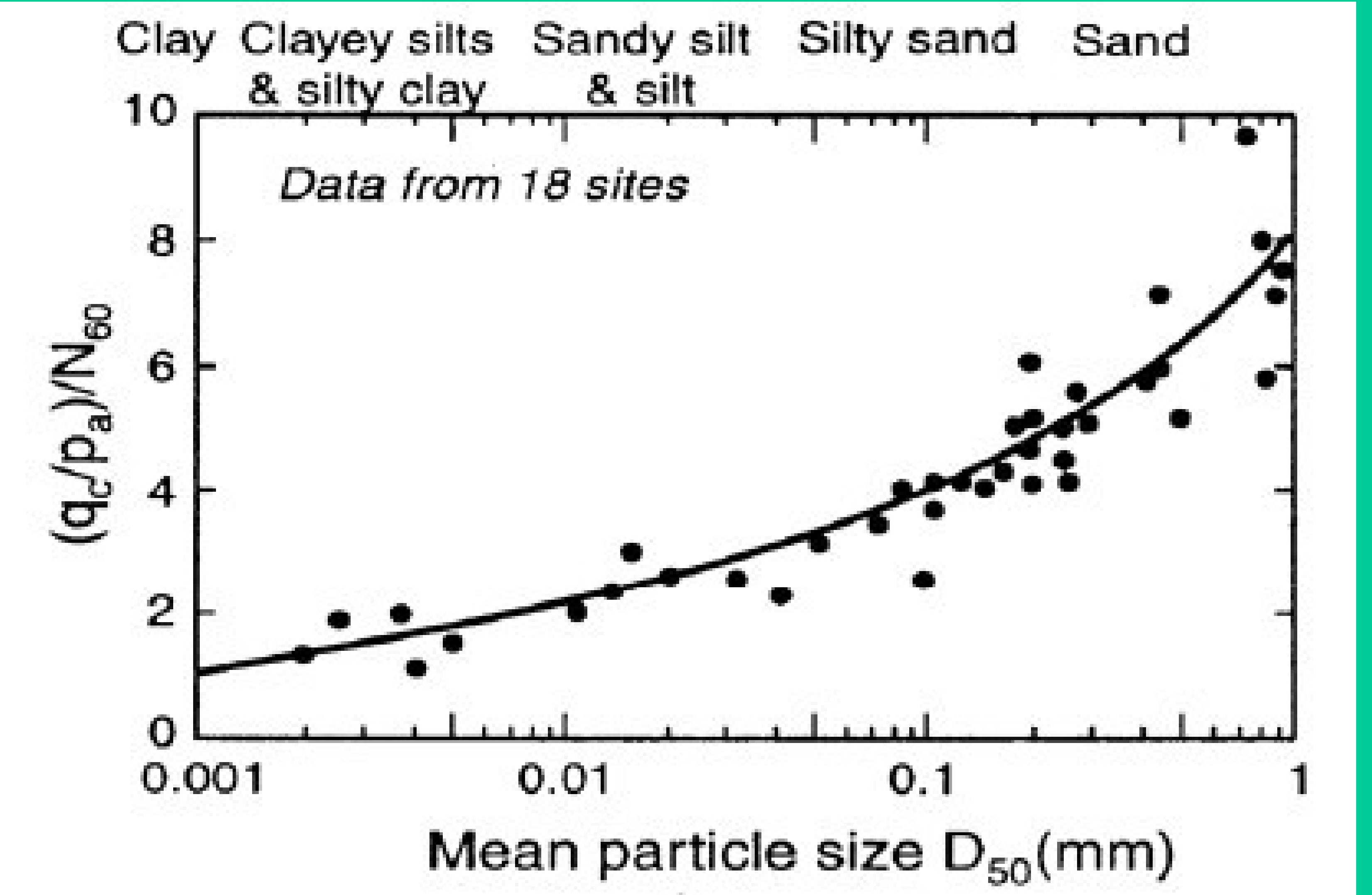
Chart based on Normalised Values



Zone	Soil Behavior Type	I_c
1	*Sensitive, fine grained*	N/A
2	*Organic soils – peats*	> 3.6
3	*Clays – silty clay to clay*	2.95 – 3.6
4	*Silt mixtures – clayey silt to silty clay*	2.60 – 2.95
5	*Sand mixtures – silty sand to sandy silt*	2.05 – 2.6
6	*Sands – clean sand to silty sand*	1.31 – 2.05
7	*Gravelly sand to dense sand*	< 1.31
8	*Very stiff sand to clayey sand**	N/A
9	*Very stiff, fine grained**	N/A

* *Heavily overconsolidated or cemented*

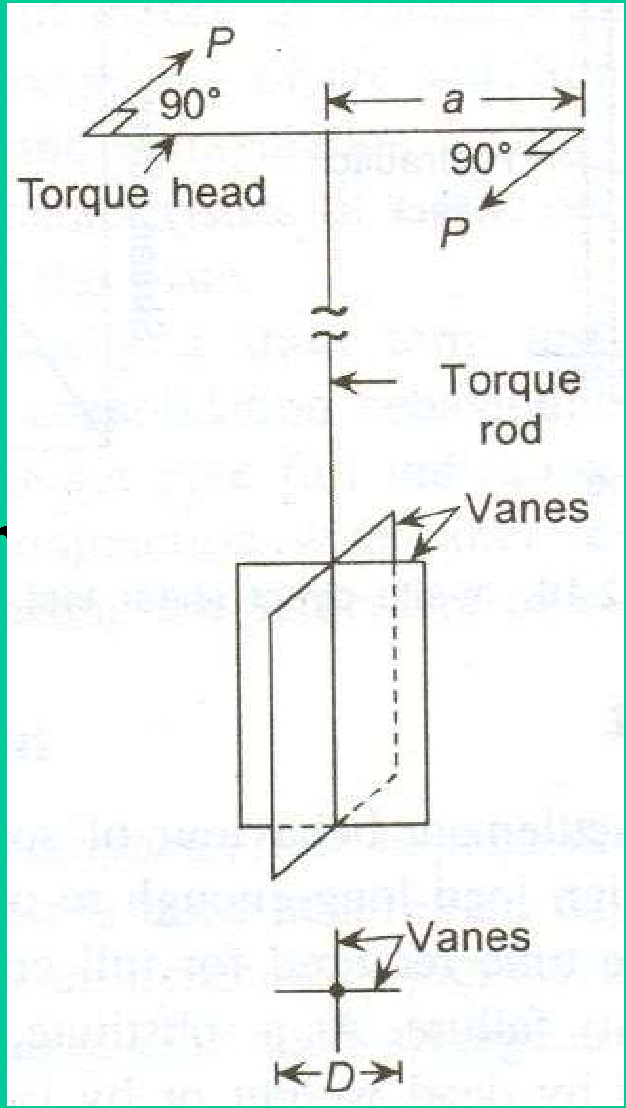
CPT – SPT Correlation



Vane Shear Test (VST)

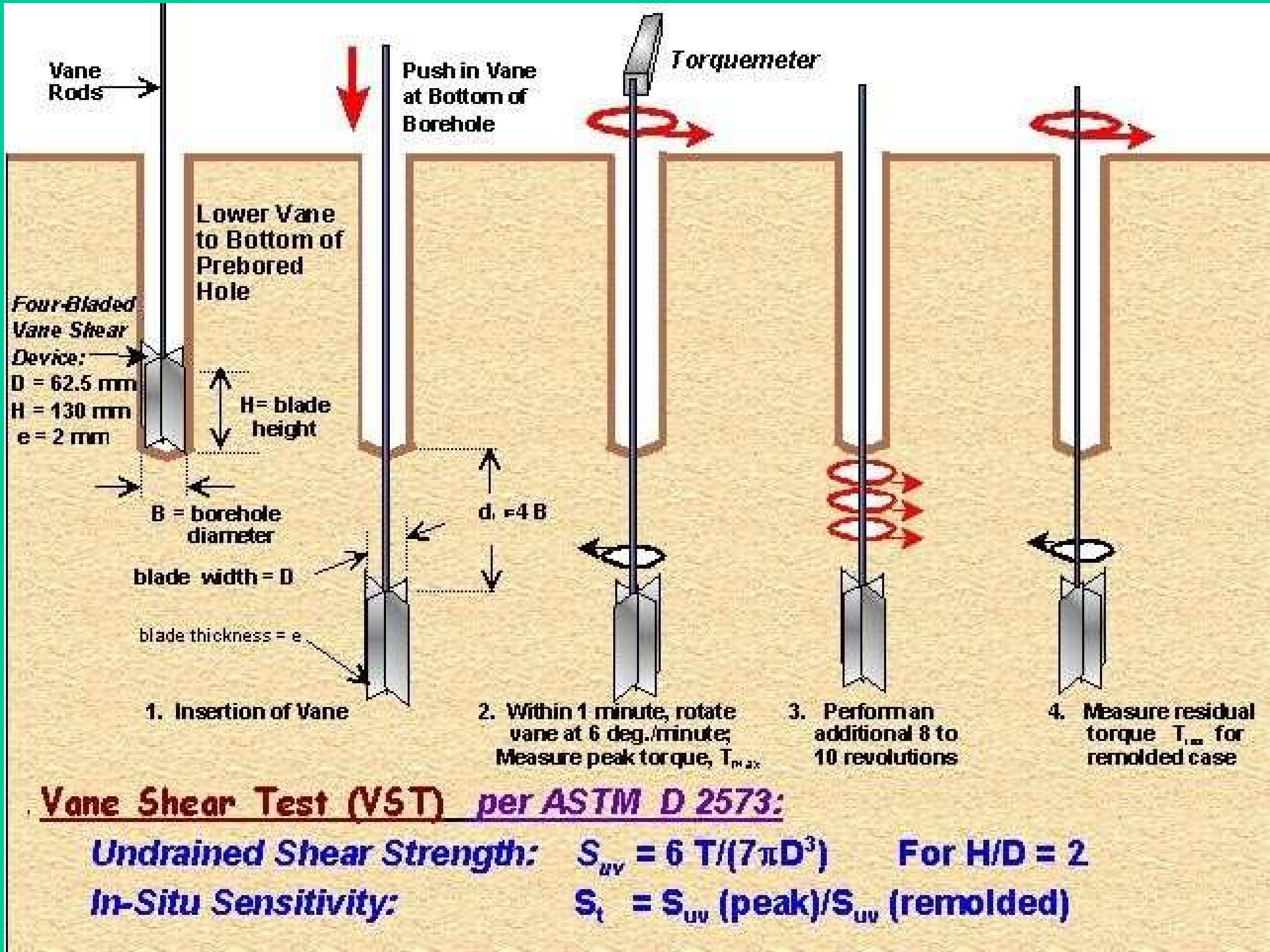
- Performed at bottom of boring

•Four-sided blade pushed into clays and silts to measure:

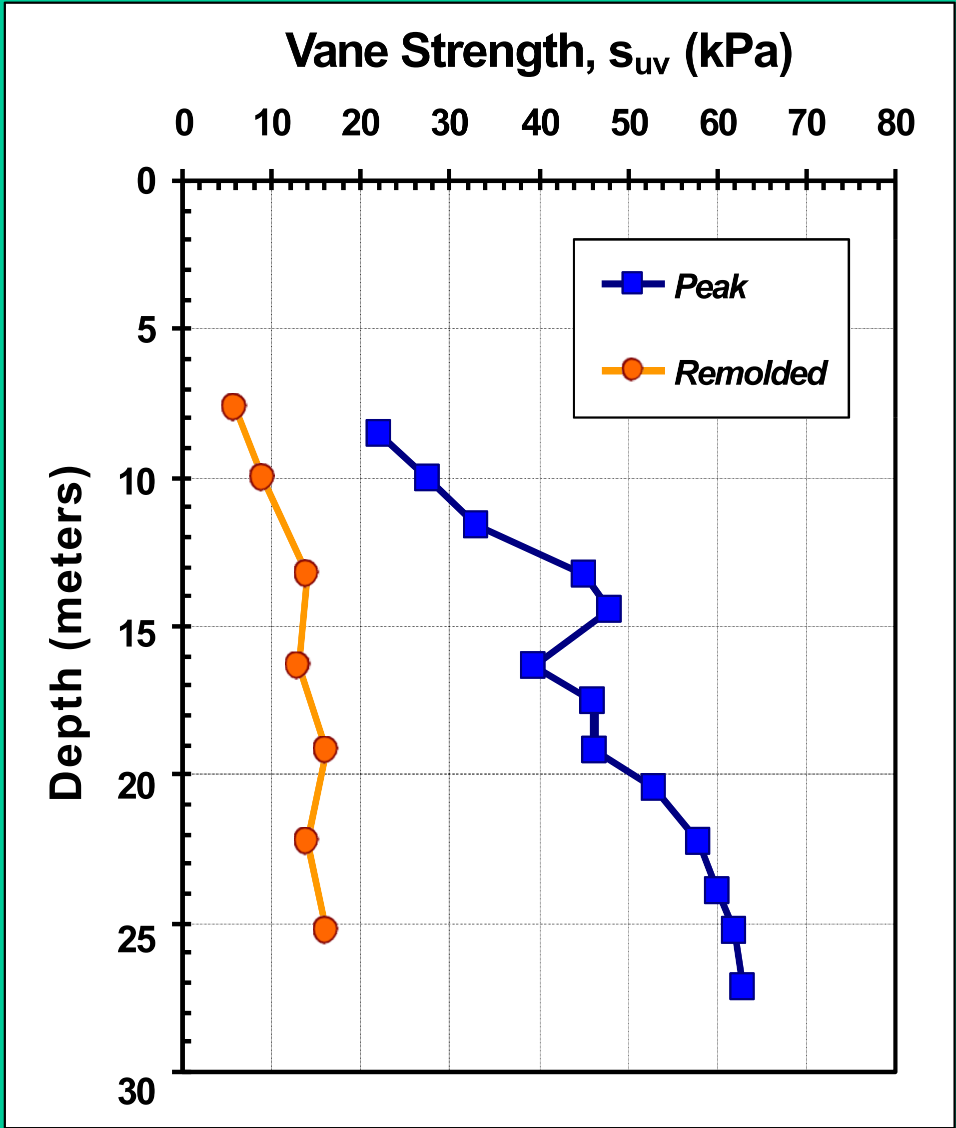


- **s_{uv} (peak) = Peak Undrained Strength**
- **s_{uv} (remolded) = Remolded Strength (after 10 revolutions)**
- **Sensitivity, S_t = s_{uv}(peak)/s_{uv} (remolded)**

Vane Shear Test (VST)



Results from Vane Shear Tests



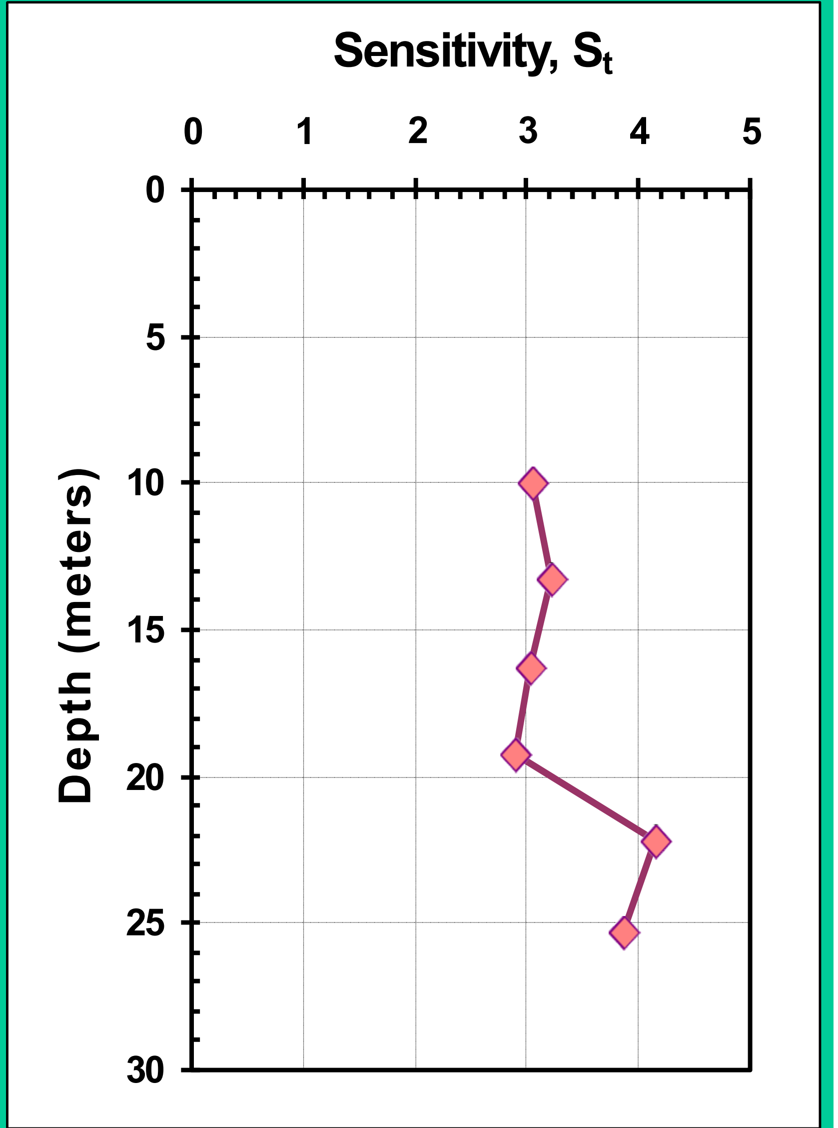
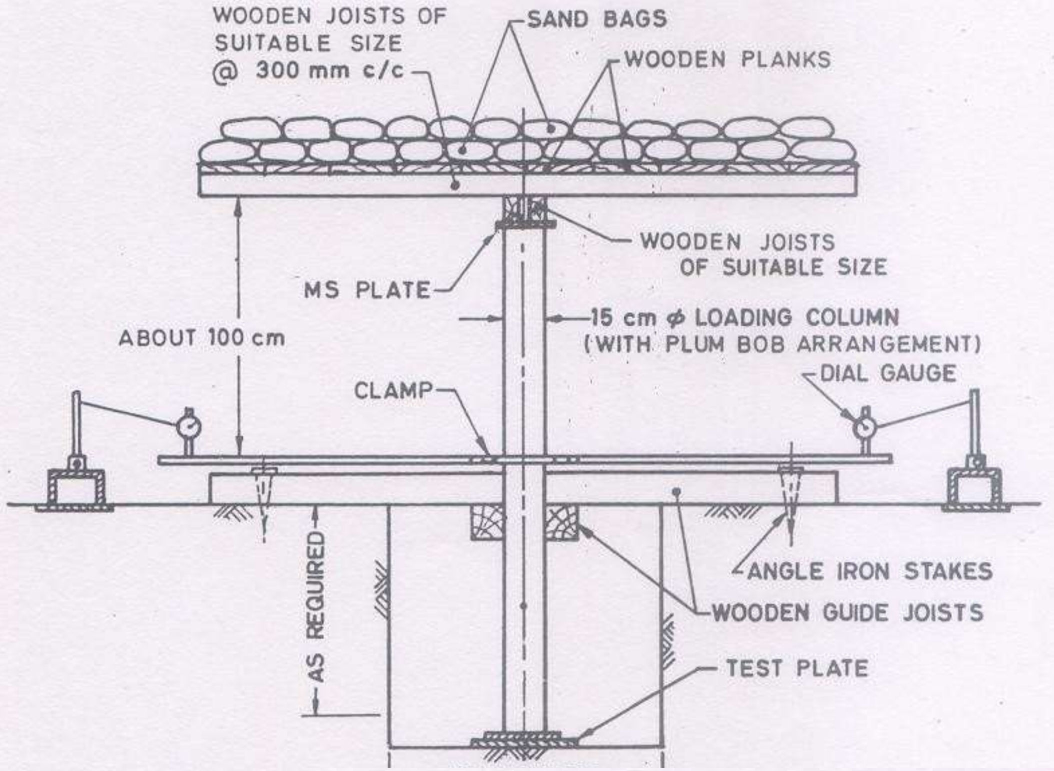
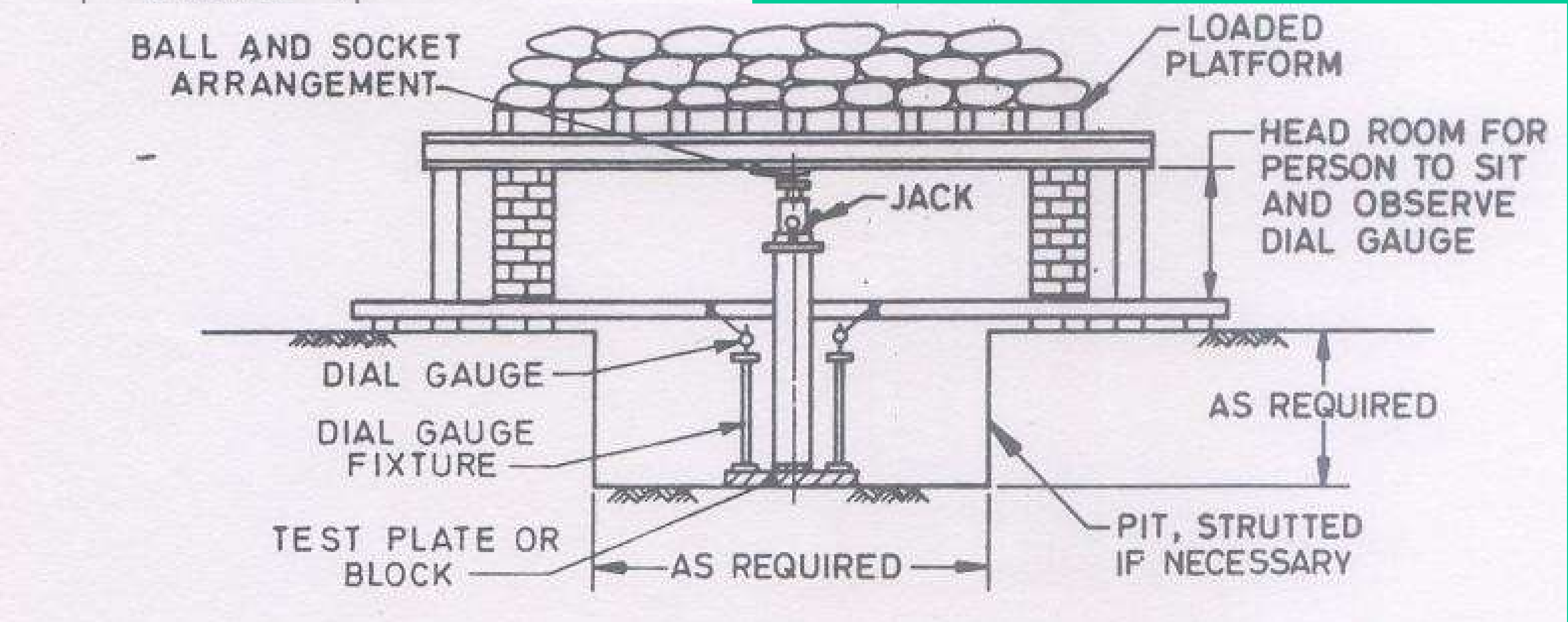
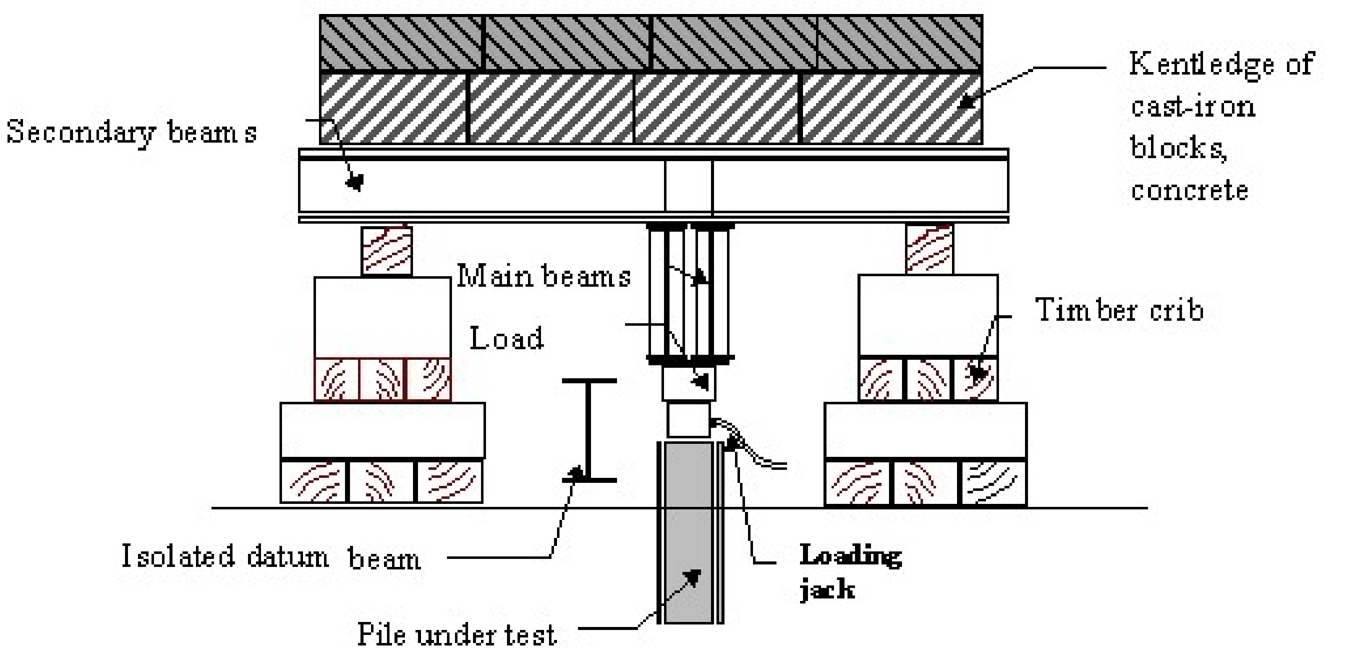


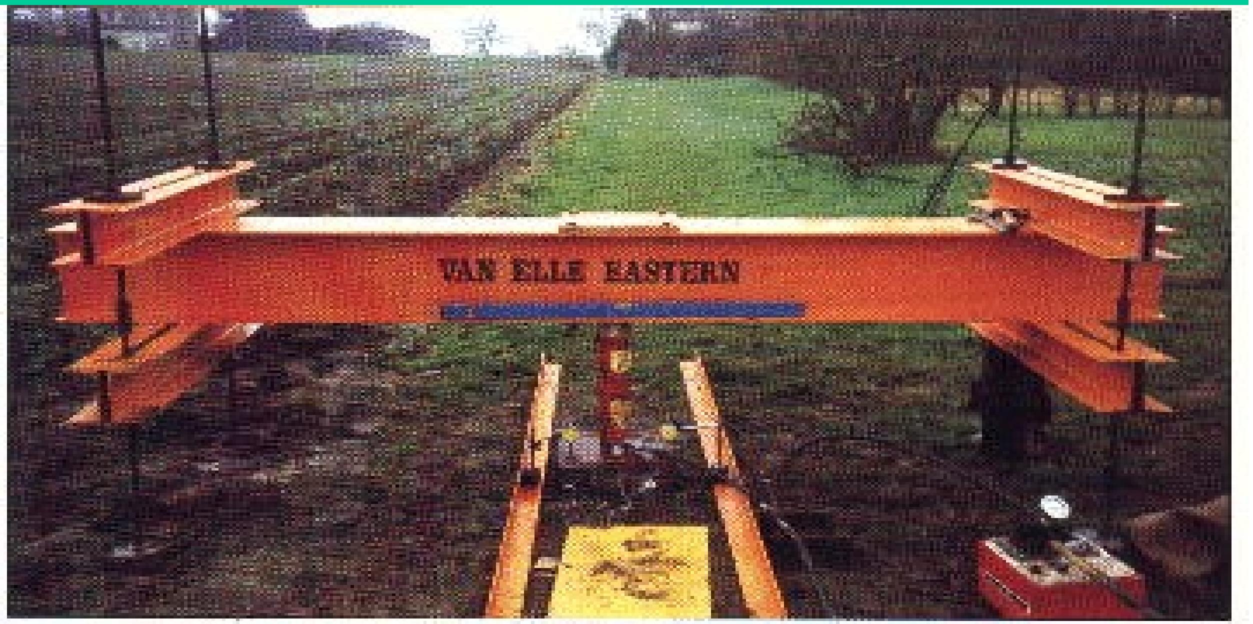
Plate Load Test



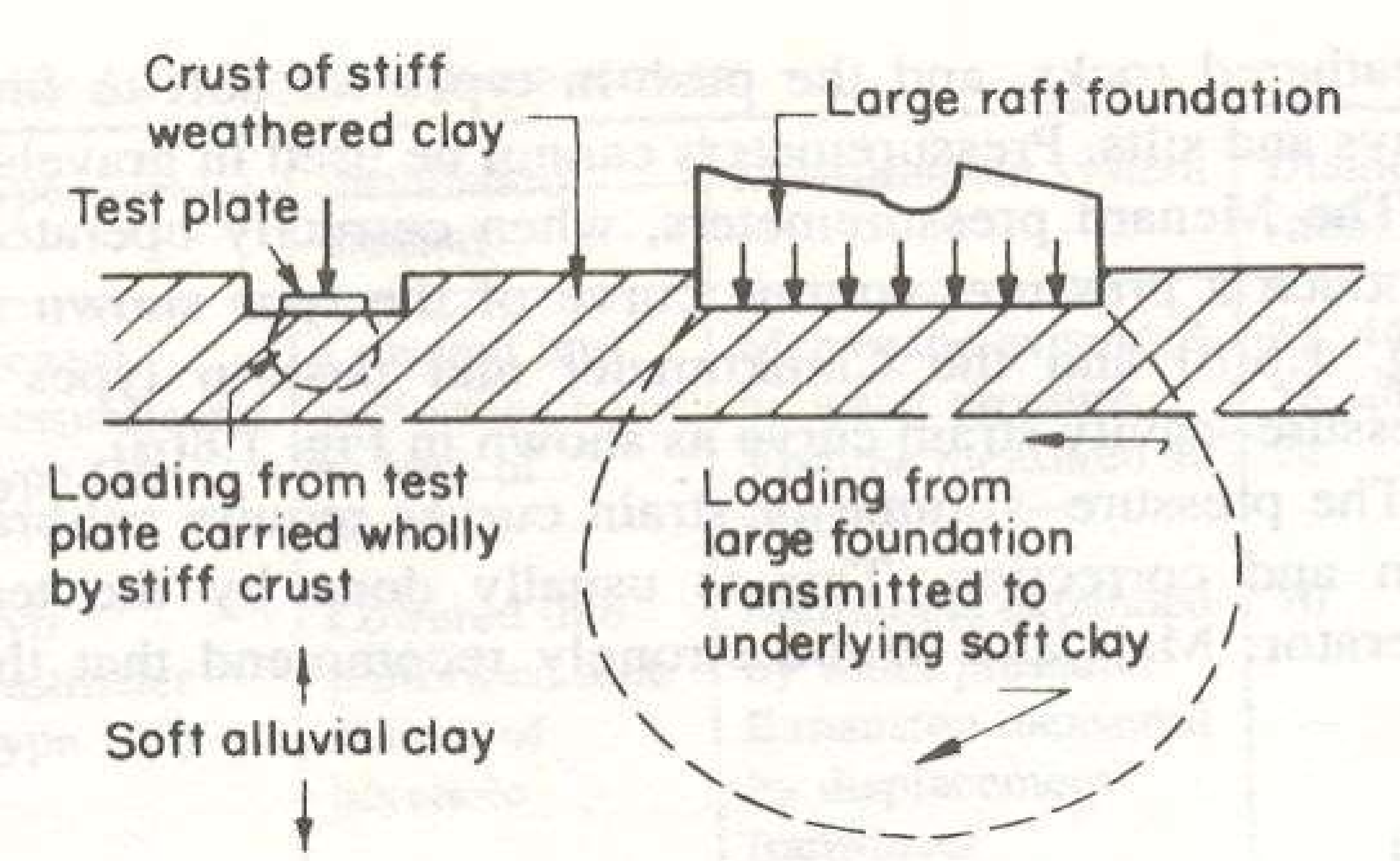


Pile Load Test

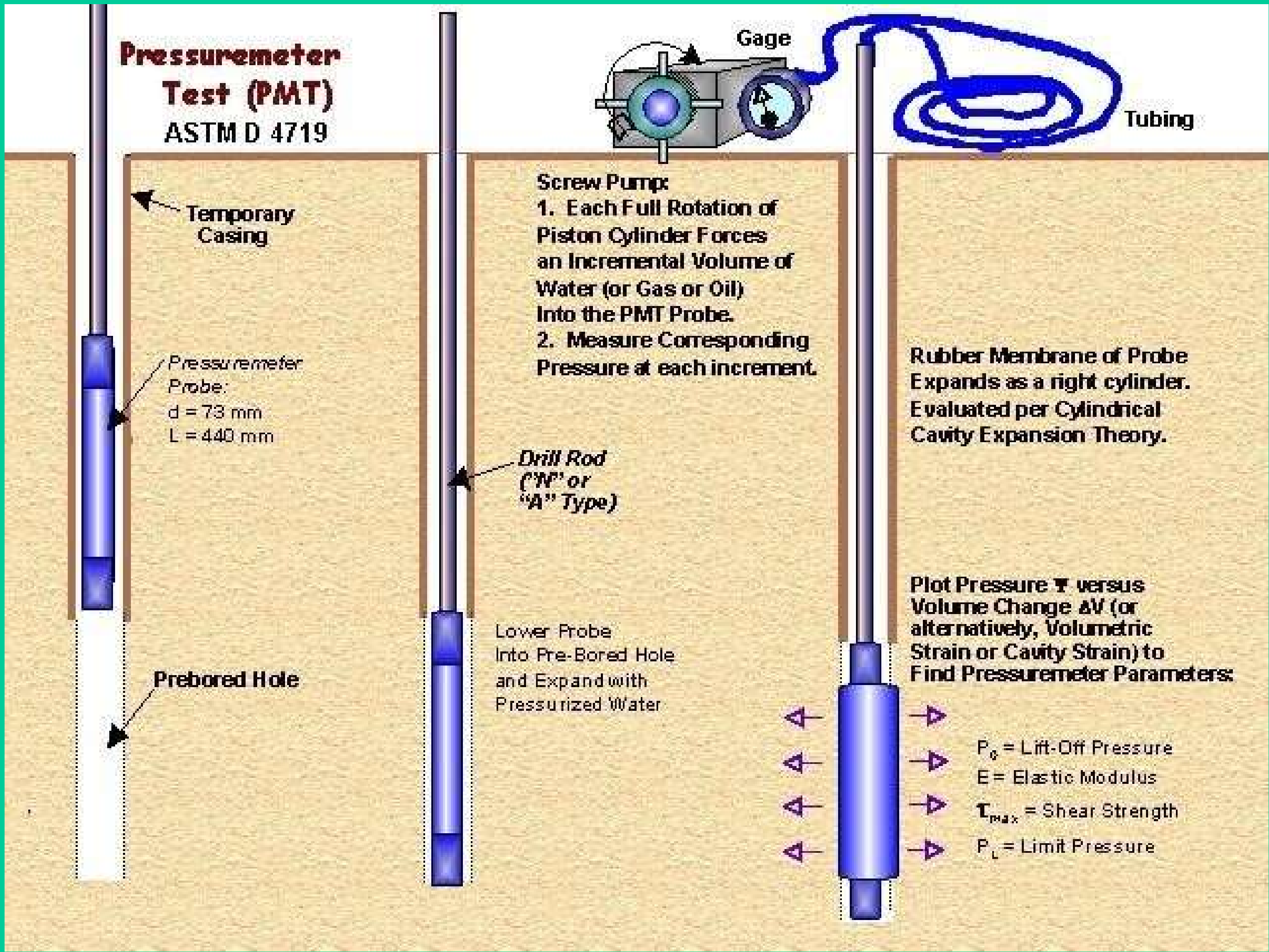




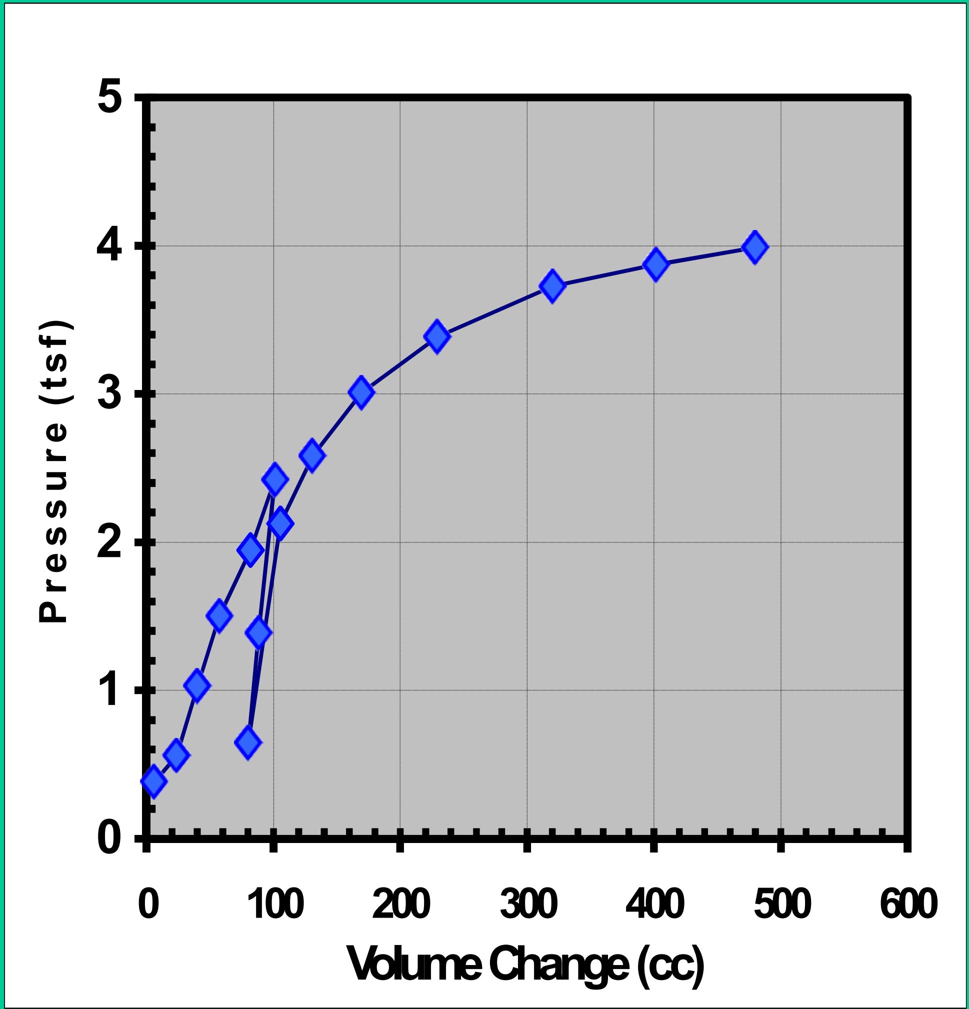
Limitation of Plate Load Test

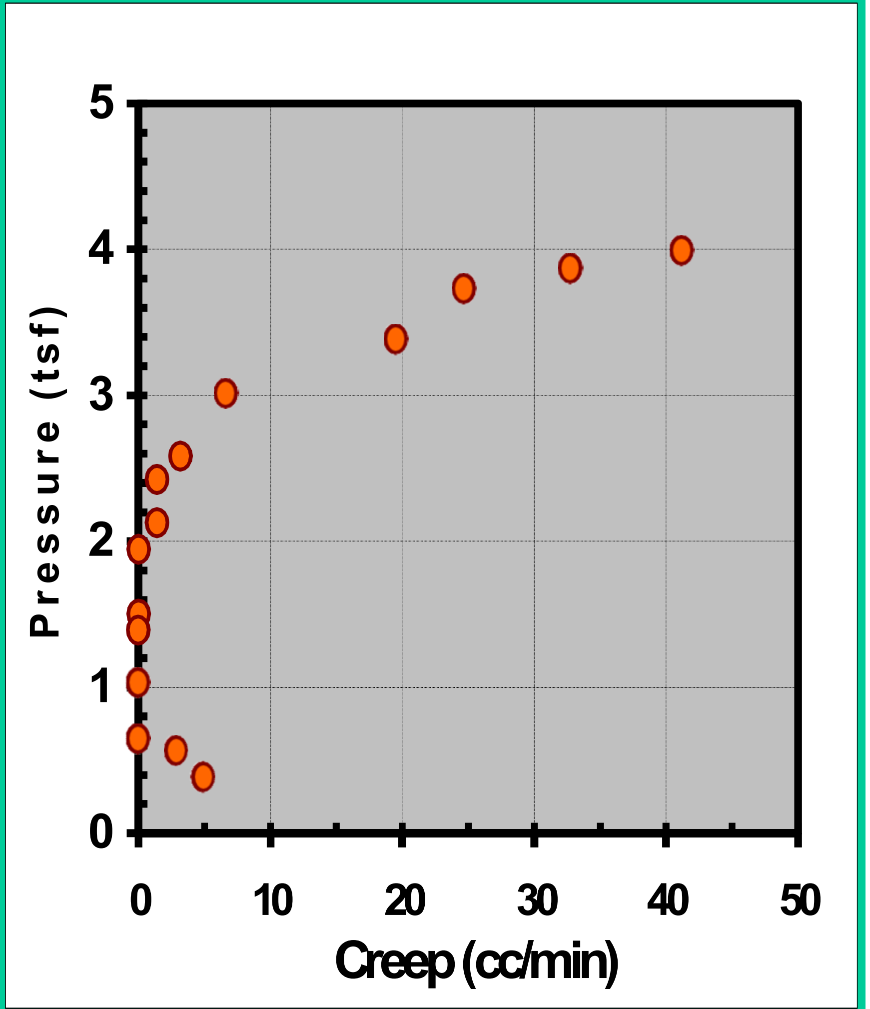


Pressuremeter Test (PMT)

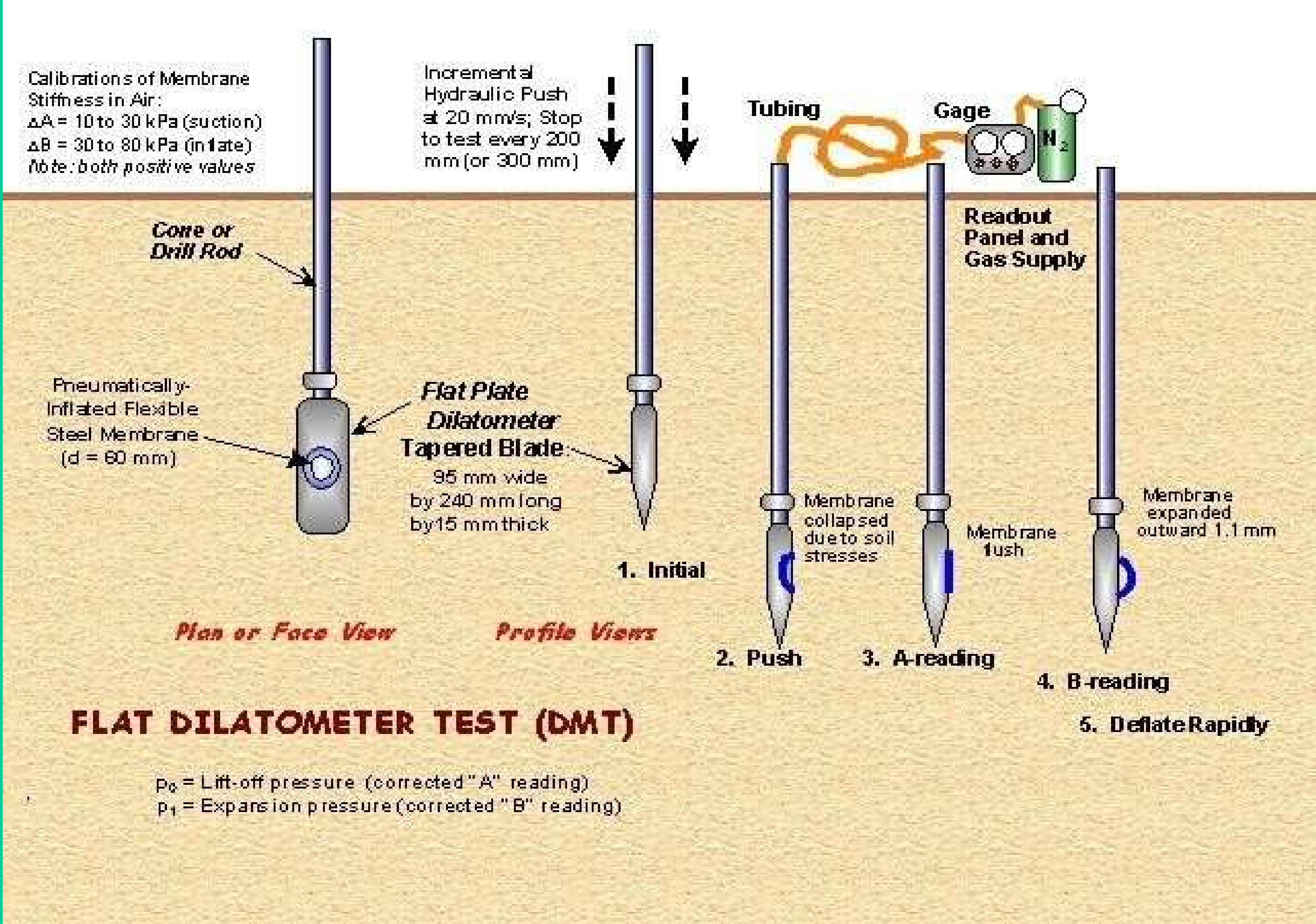


Pressuremeter Test (PMT) Data

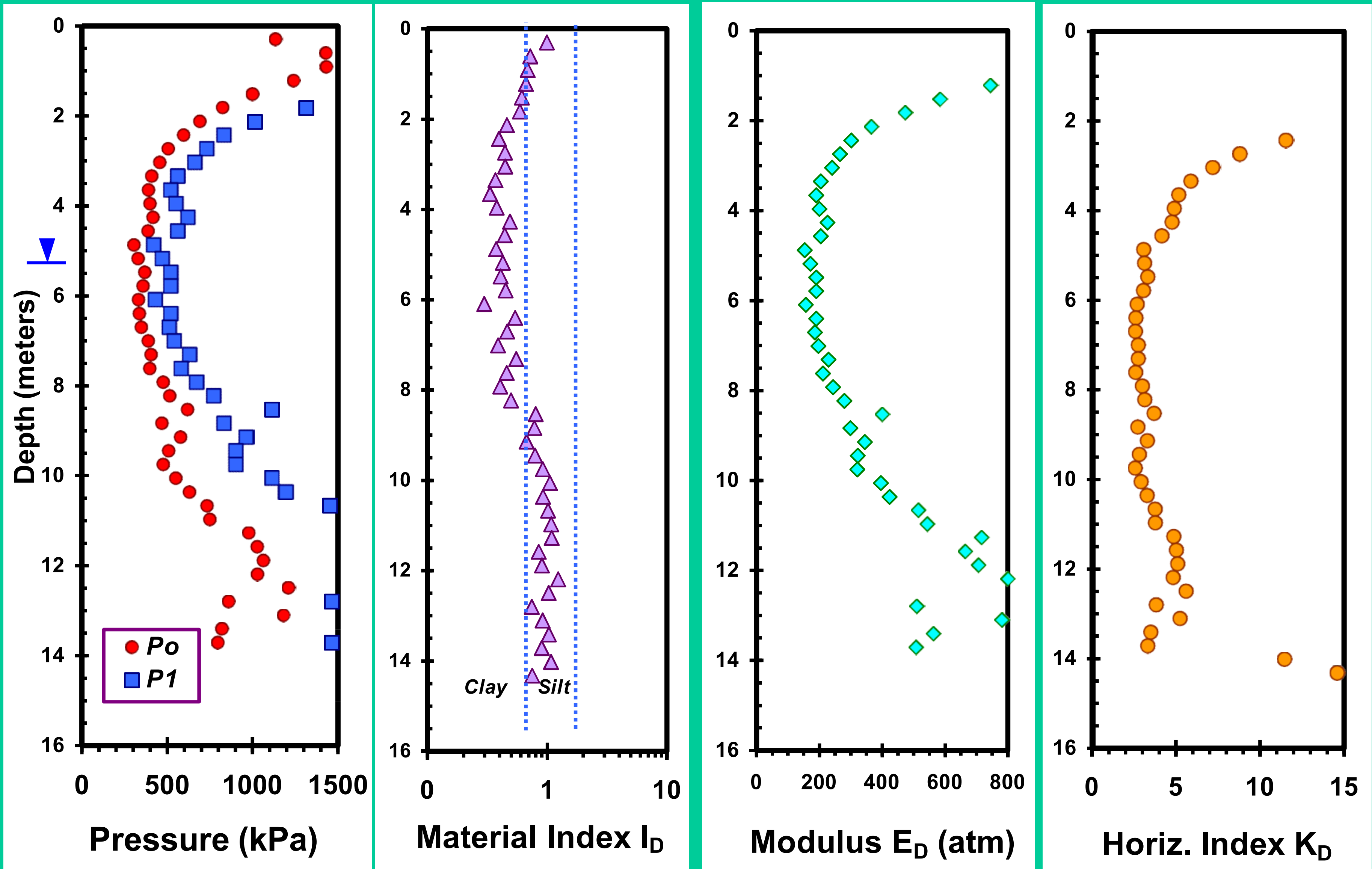




Dilatometer Test (DMT)



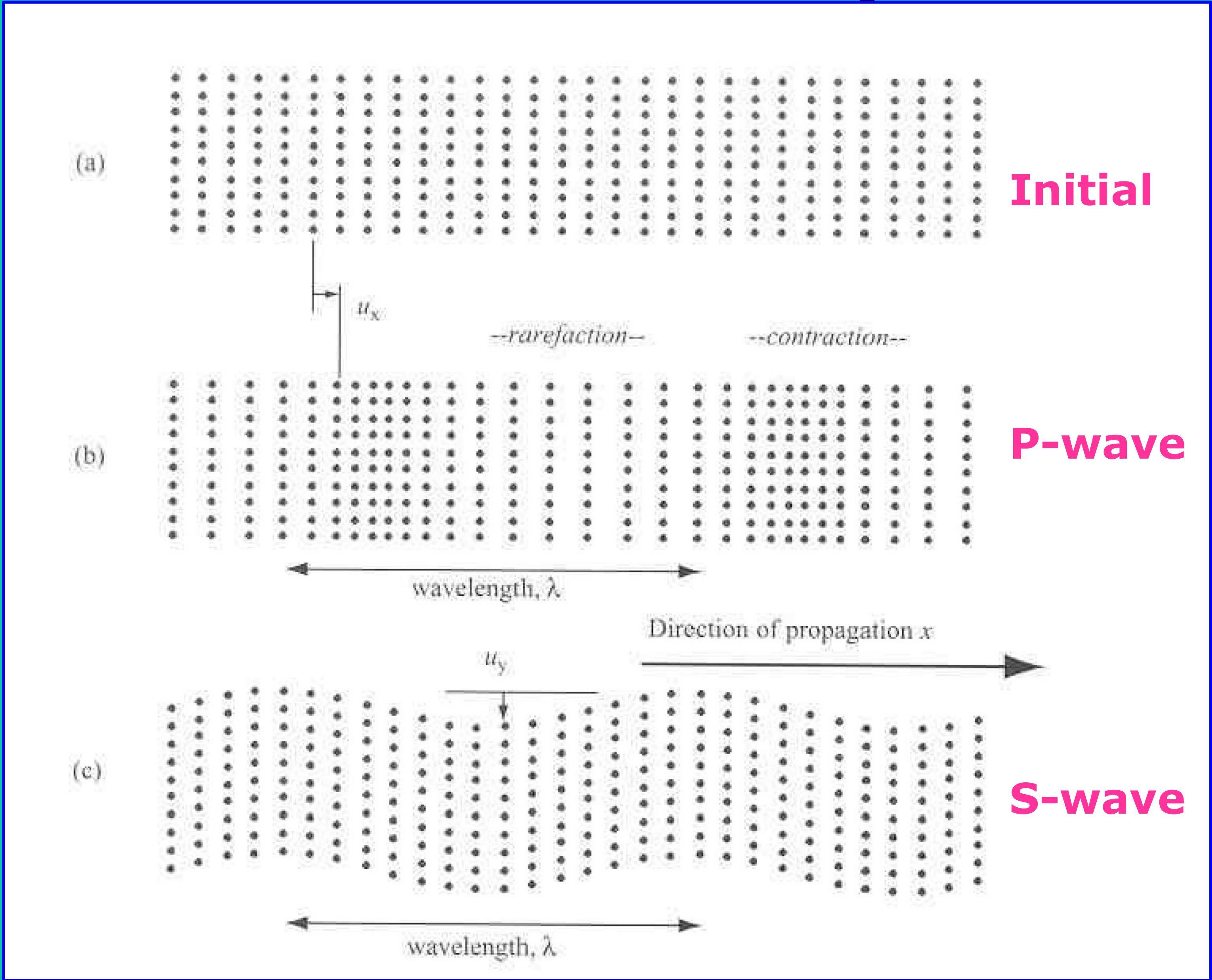
Typical Results



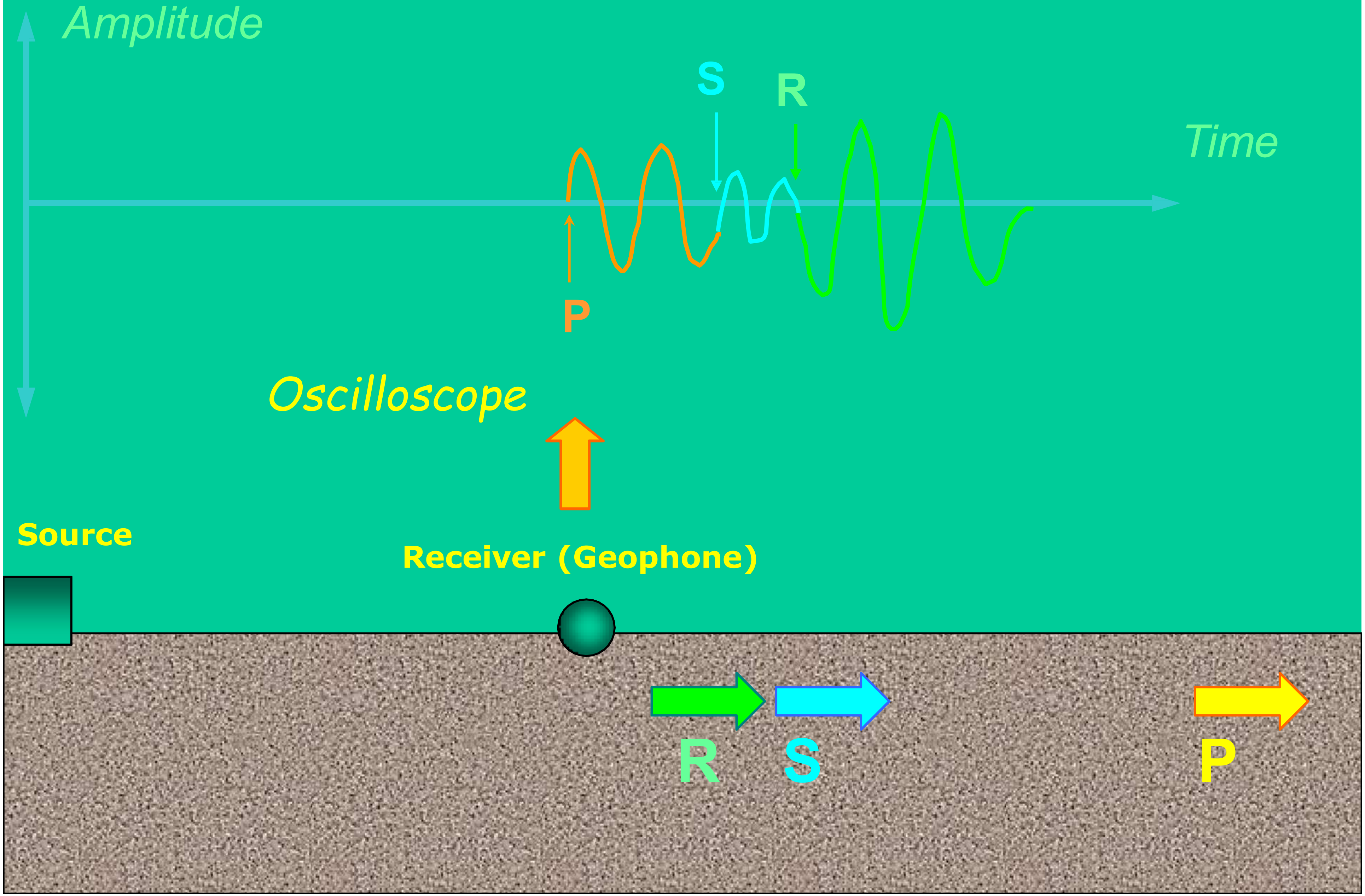
GEOPHYSICS

- Mechanical Wave Measurements
- Electromagnetic Wave Techniques

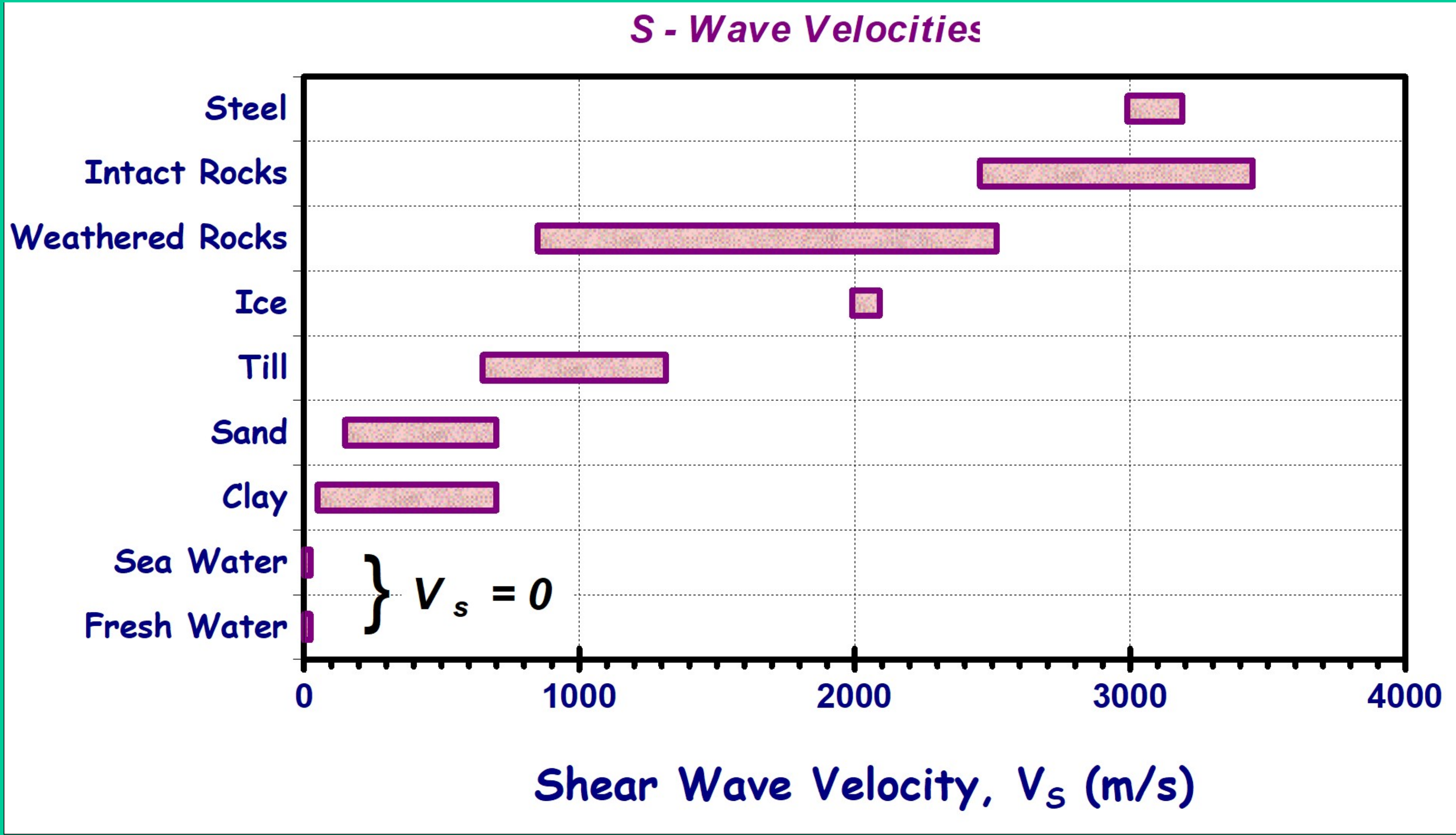
Mechanical Body Waves

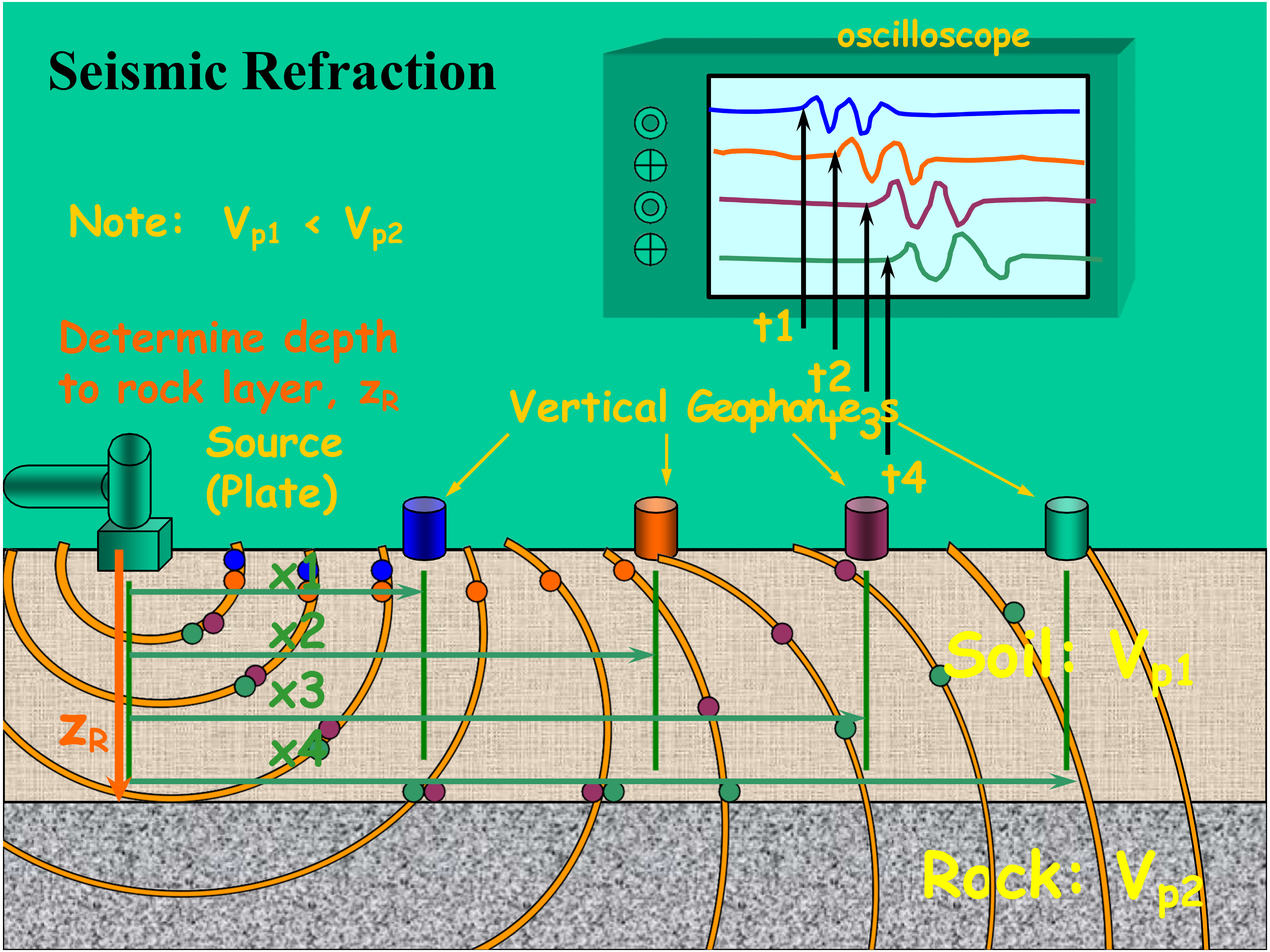


Mechanical Body Waves

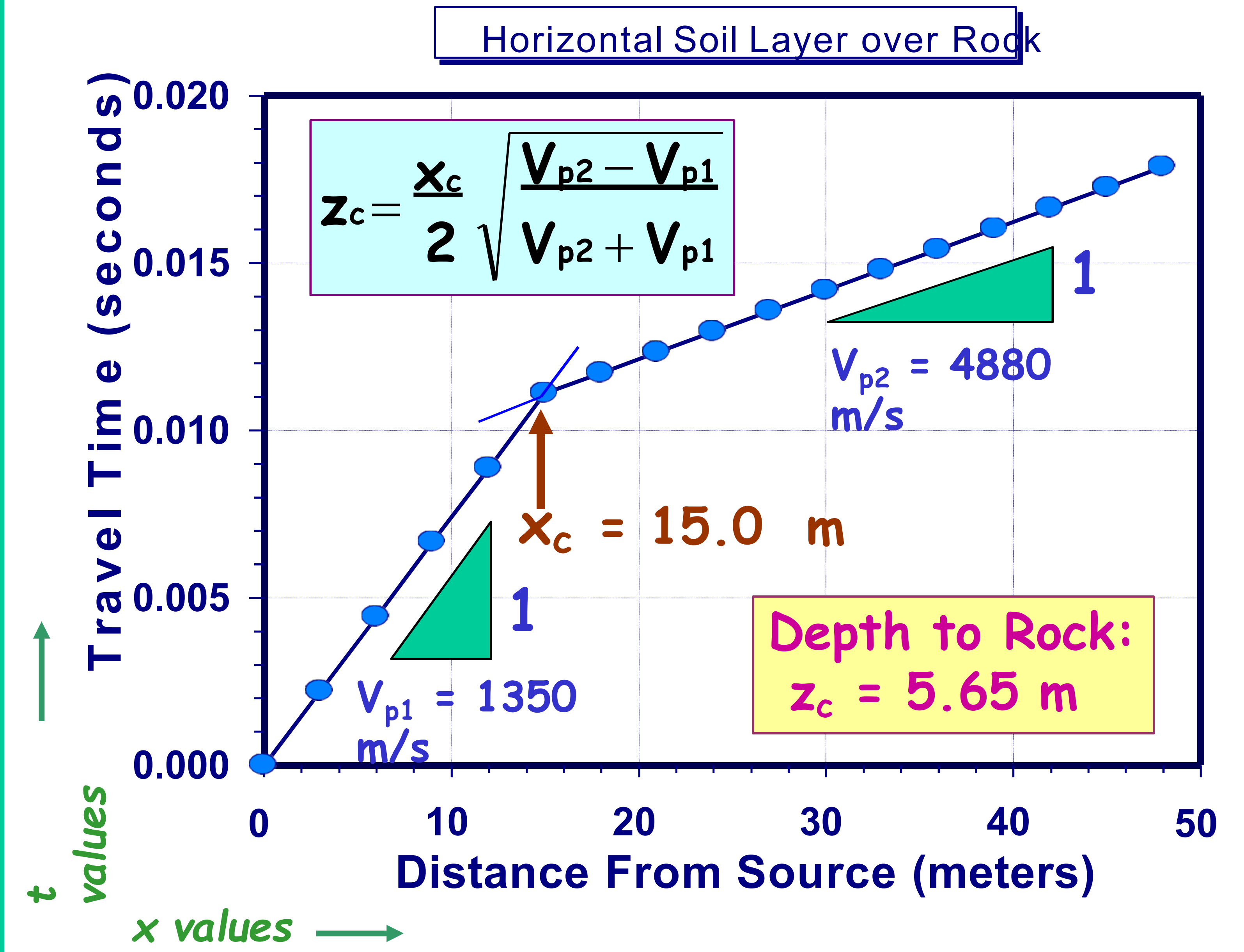


Shear Waves


S - Wave Velocities
Steel
Intact Rocks
Weathered Rocks
Ice
Till
Sand
Clay
Sea Water
Fresh Water
V s = 0
0
1000
2000
3000
4000
Shear Wave Velocity, VS (m/s)

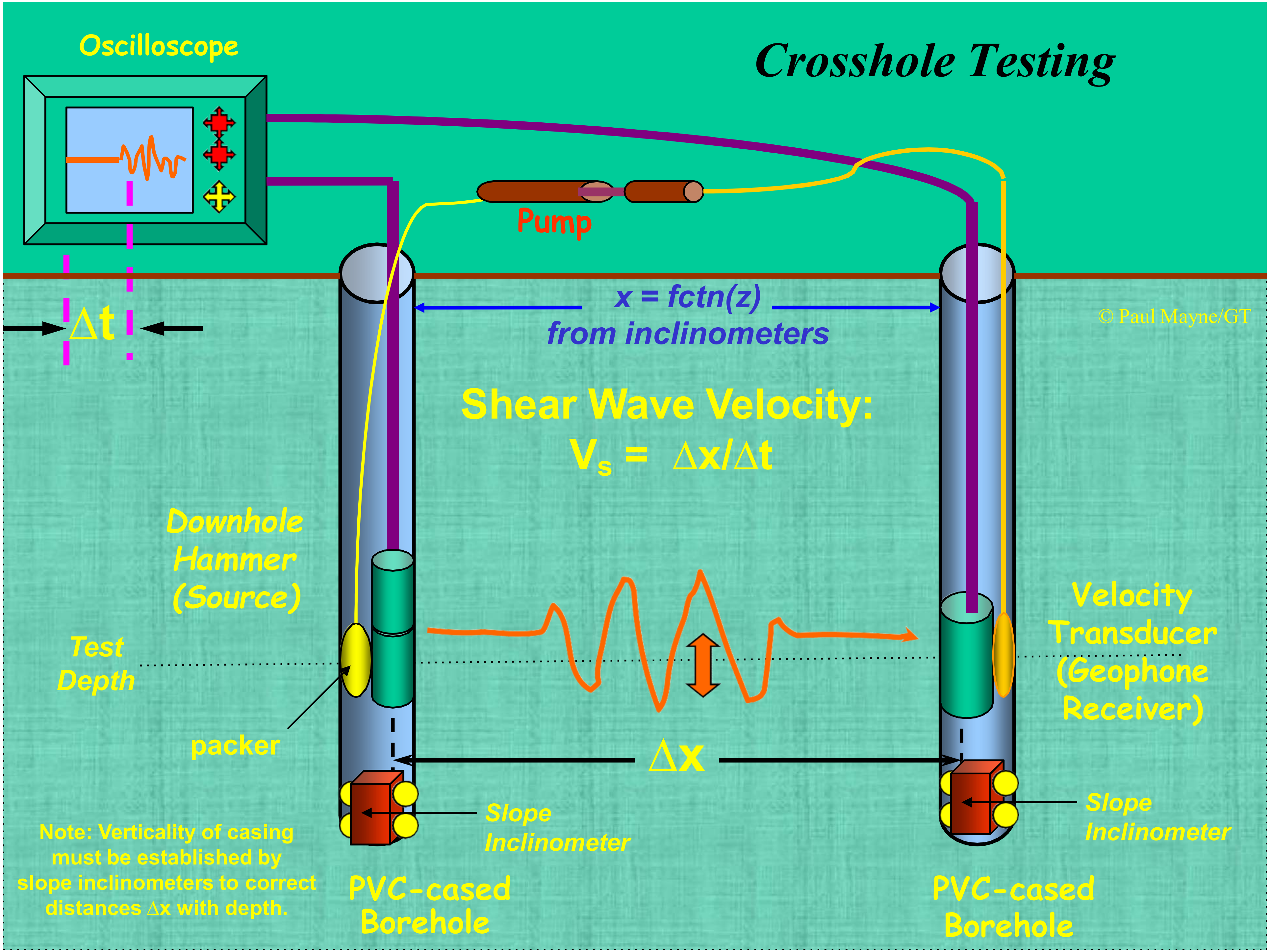

Seismic Refraction
oscilloscope
Note: Vp1 < Vp2
Determine depth to rock layer, zR
t1
t2
t3
t4
Vertical Geophones
Source (Plate)
x1
x2
x3
x4
zR
Soil: Vp1
Rock: Vp2

Seismic Refraction

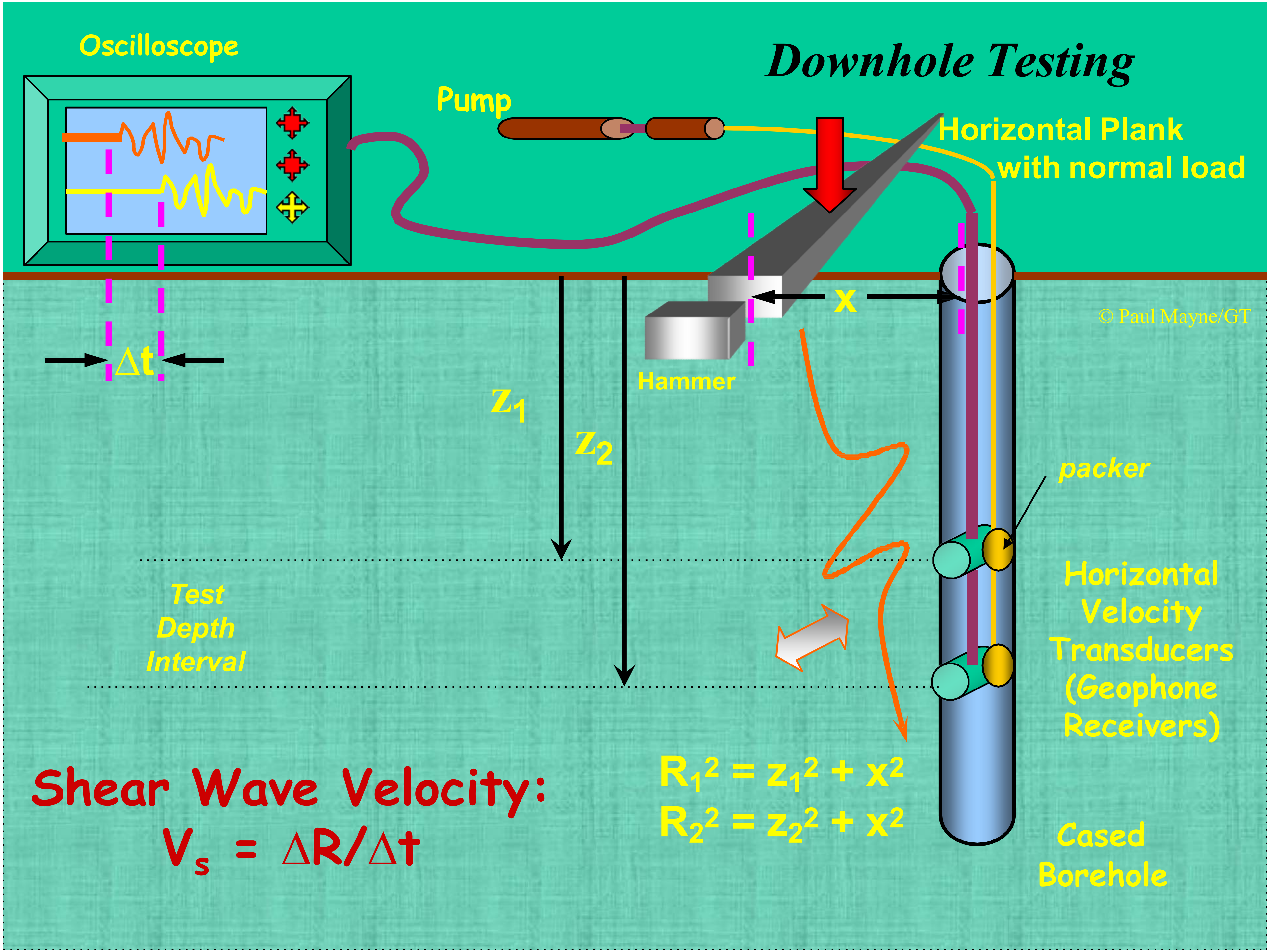


Shear Wave Velocity, V_s

- Fundamental measurement in all solids (steel, concrete, wood, soils, rocks)
- Initial small-strain stiffness represented by shear modulus: $\mathbf{G_0 = \rho_T V_s^2}$
- ($G_{dyn} = G_{max} = G_0$)
- Applies to all static & dynamic problems at small strains ($\gamma_s < 10^{-6}$)
- Applicable to both undrained & drained loading cases in geotechnical engineering.

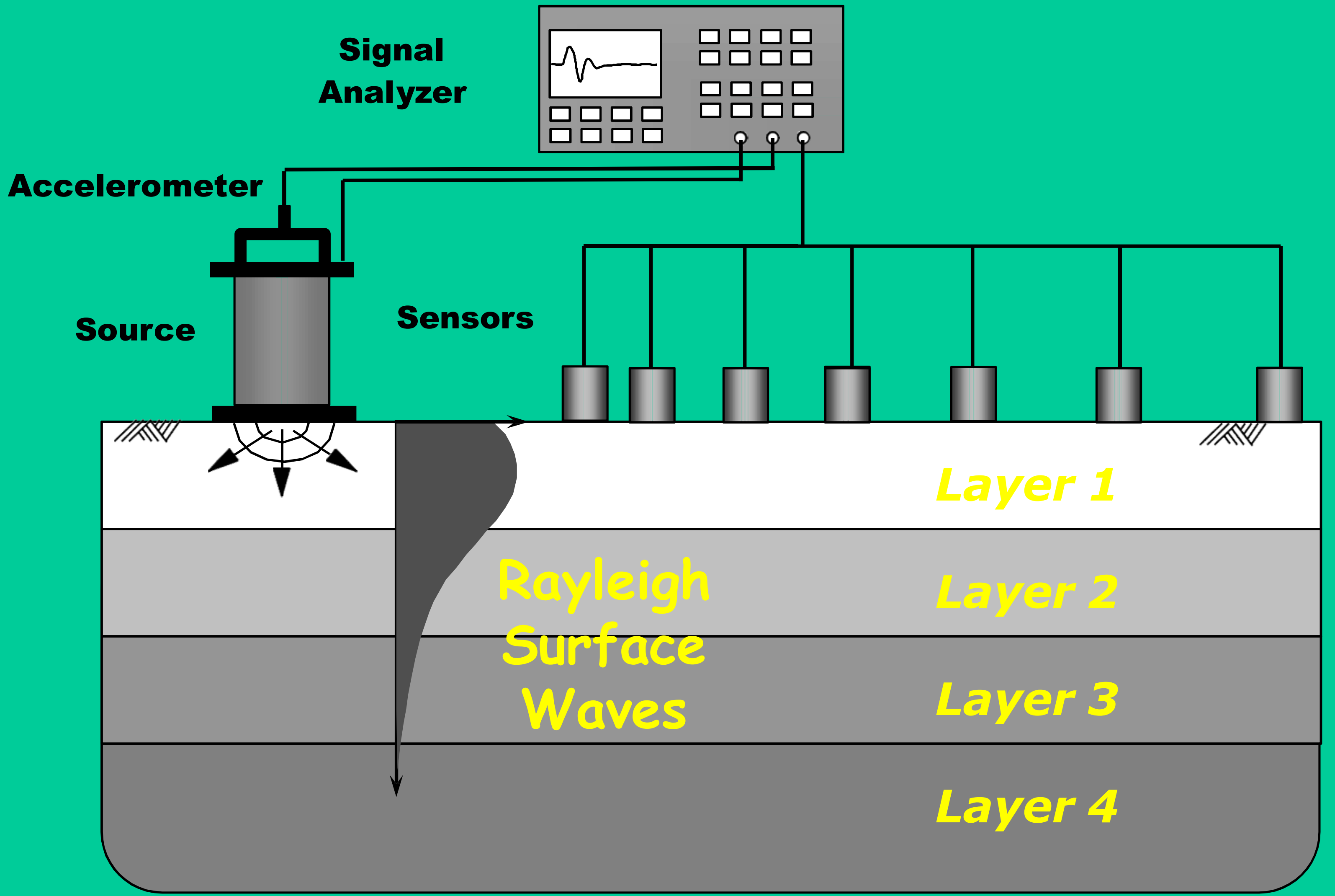


Crosshole Testing
Oscilloscope
Pump
Δt
x = fctn(z)
from inclinometers
© Paul Mayne/GT
Shear Wave Velocity:
$V_s = \Delta x / \Delta t$
Downhole Hammer (Source)
Test Depth
packer
Velocity Transducer (Geophone Receiver)
Δx
Slope Inclinometer
Slope Inclinometer
Note: Verticality of casing must be established by slope inclinometers to correct distances Δx with depth.
PVC-cased Borehole
PVC-cased Borehole

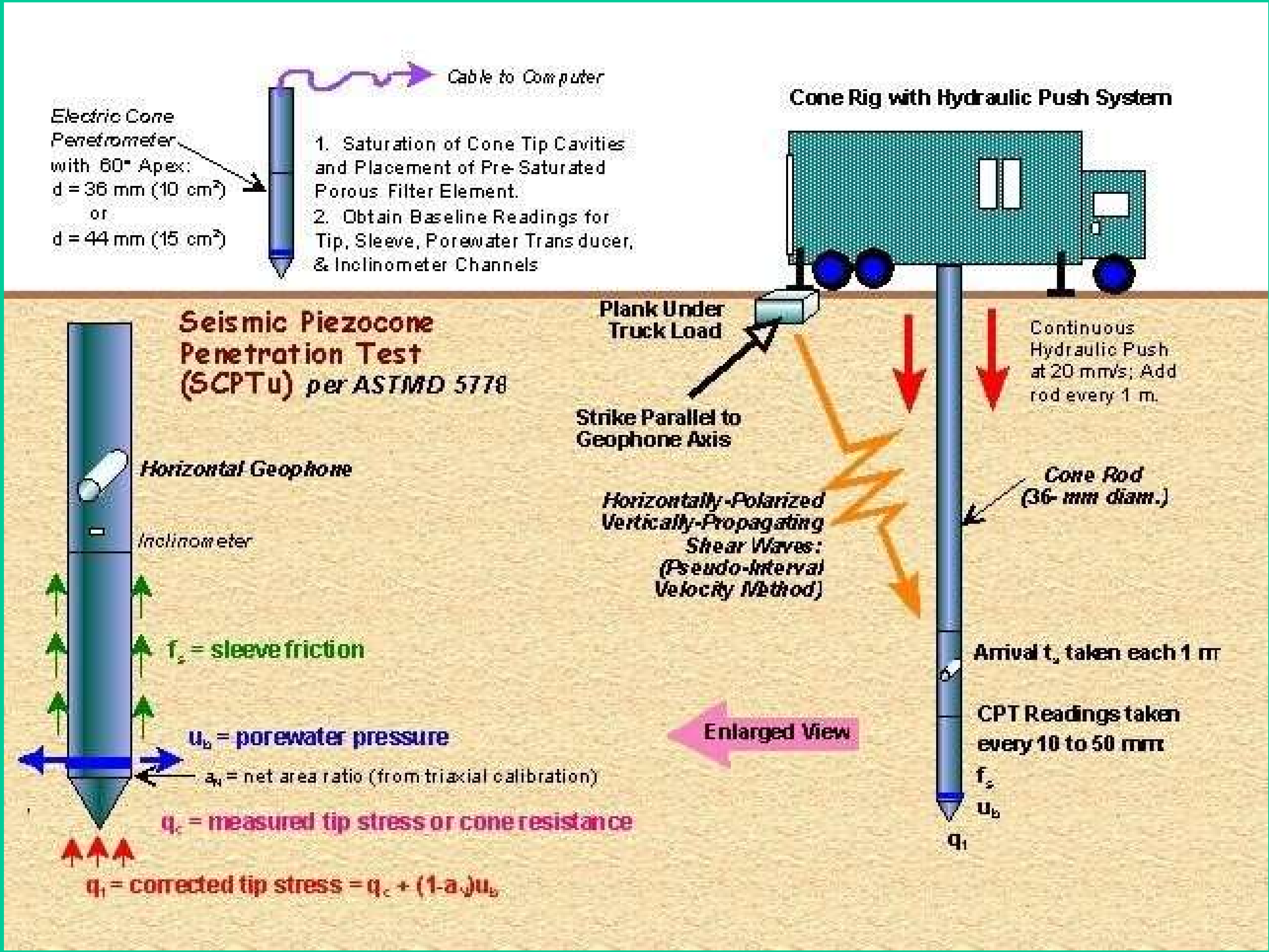


Oscilloscope
Downhole Testing
Pump
Horizontal Plank
with normal load
Δt
Hammer
x
© Paul Mayne/GT
z1
z2
packer
Test
Depth
Interval
Horizontal
Velocity
Transducers
(Geophone
Receivers)
R1² = z1² + x²
R2² = z2² + x²
Cased
Borehole
Shear Wave Velocity:
Vs = ΔR/Δt

Surface Wave Testing



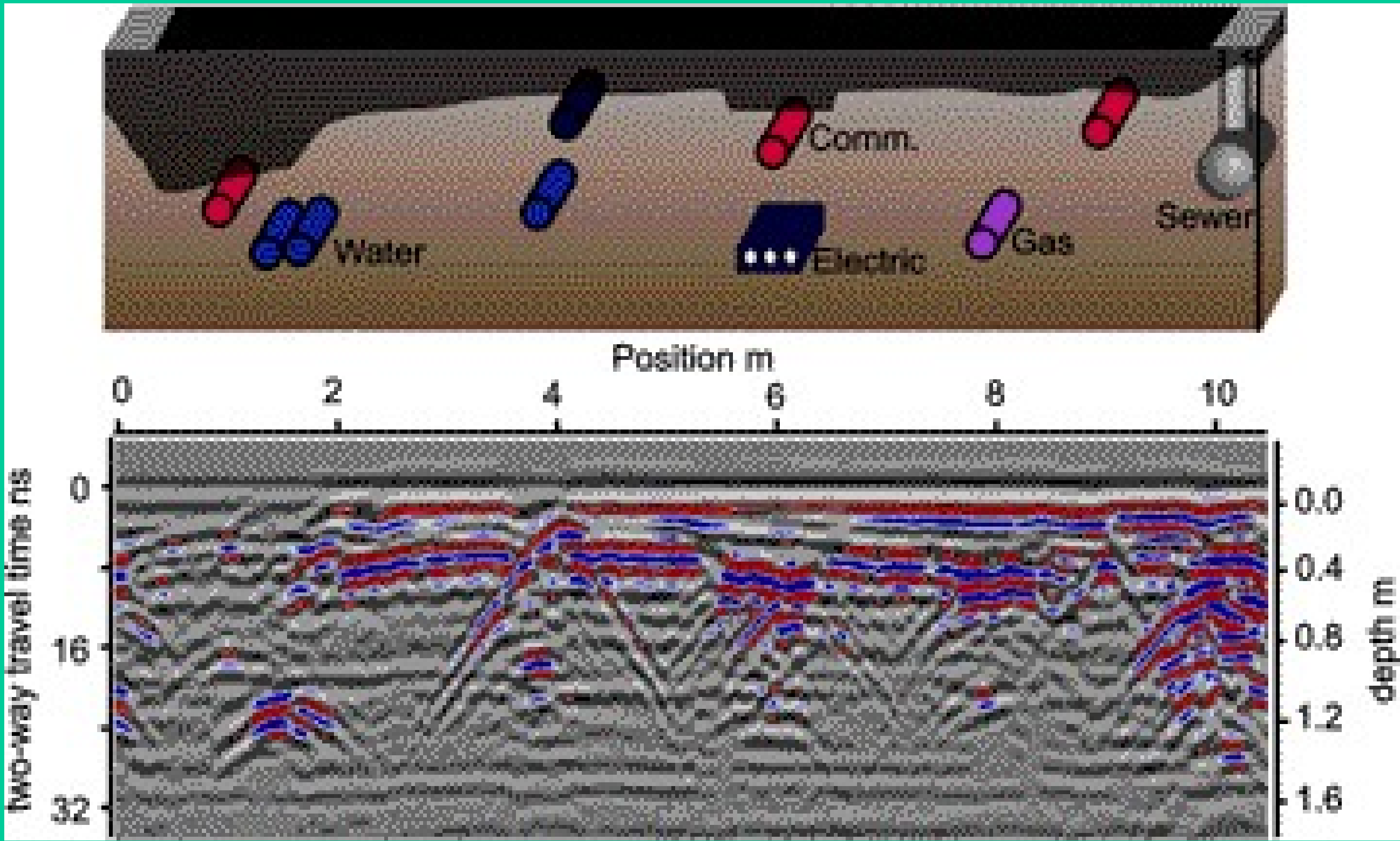
Seismic Piezocone Test (SCPTu)



Ground Penetrating Radar (GPR)

Radar | Sensors & Software | GeoRadar

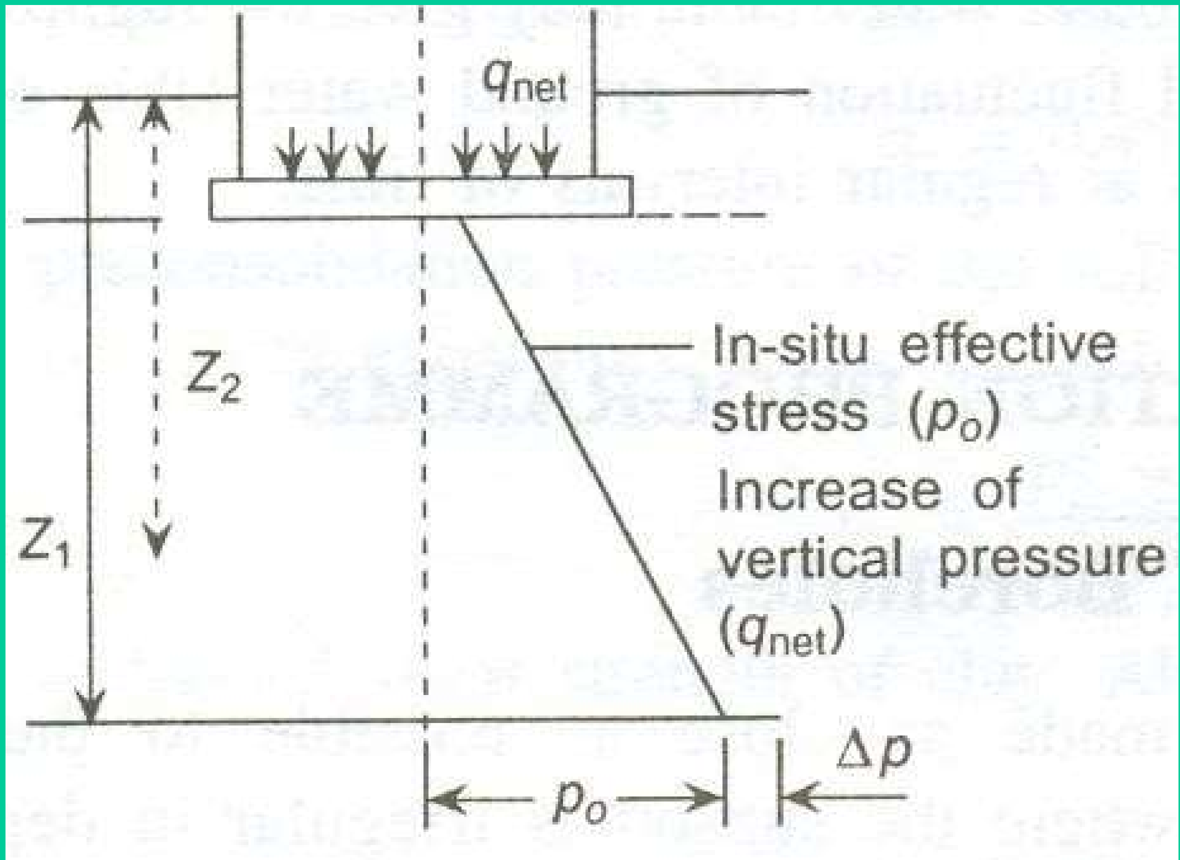
Illustrative Results from GPR



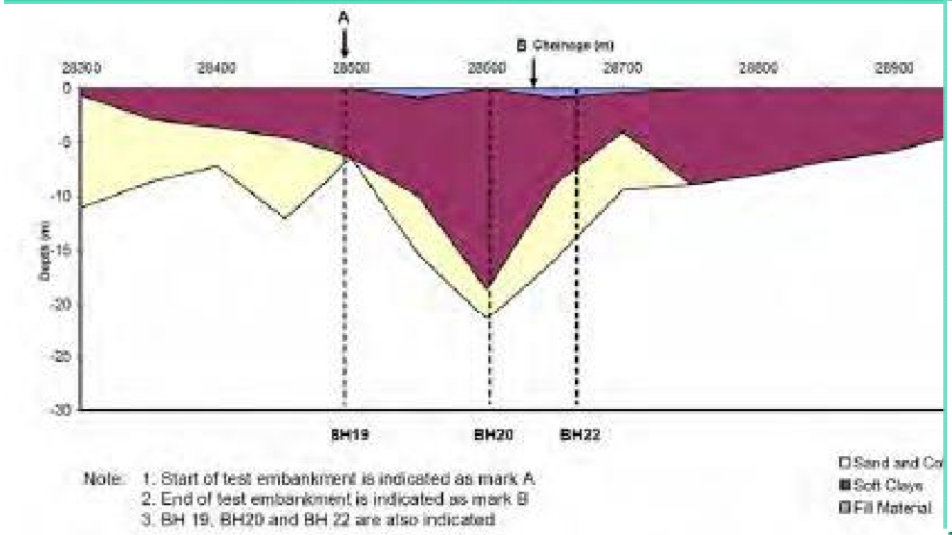
Spacing & Depth of boreholes

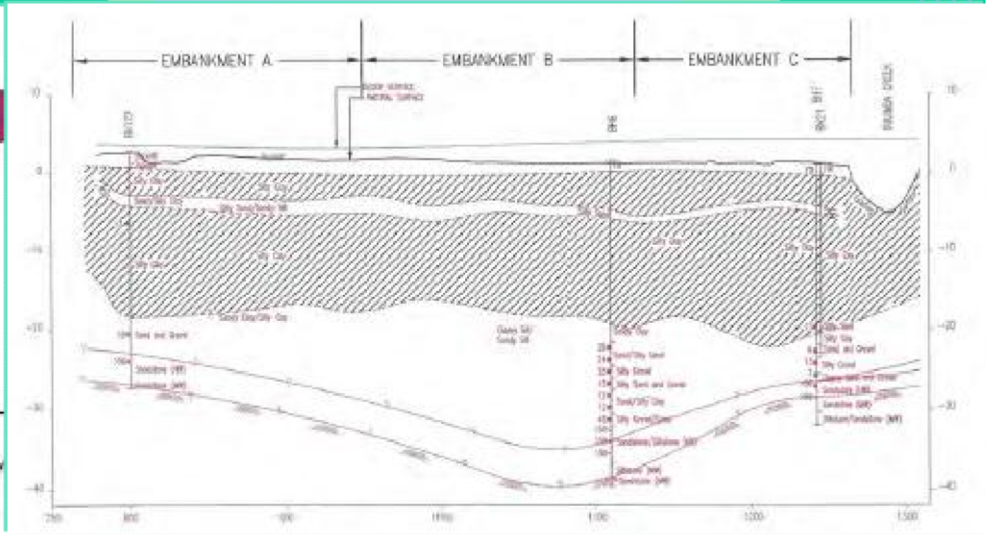
- Spacing:
  - buildings 10 – 30 m apart
  - bridges one/two per pier & abutment
  - road lines 30 – 300 m apart
  - landslides at least 5 in line for profile
- Depth:
  - 1.5 x foundation width + 2-5 m control hole
  - 3 m below rock head

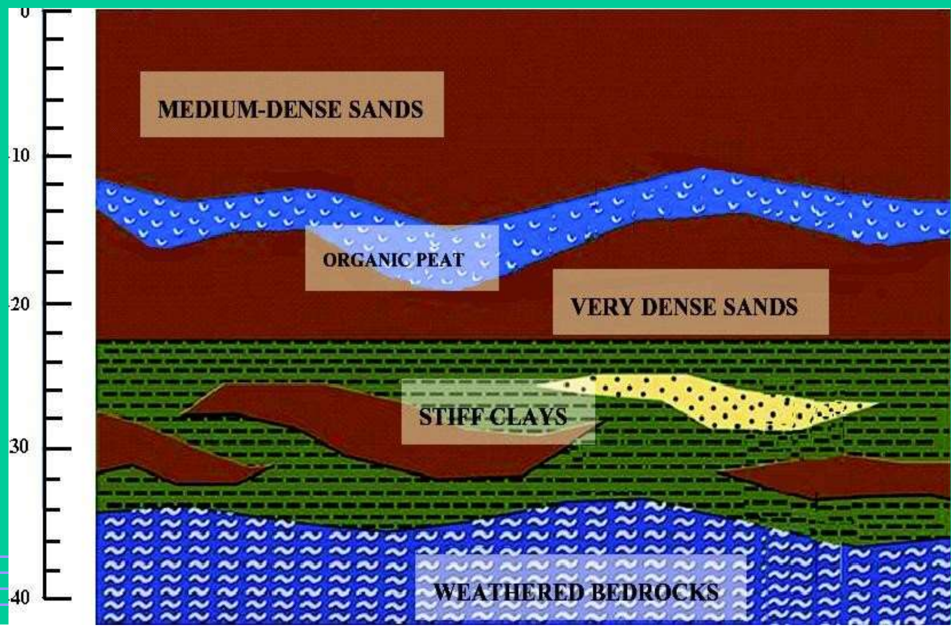
Depth of Boreholes



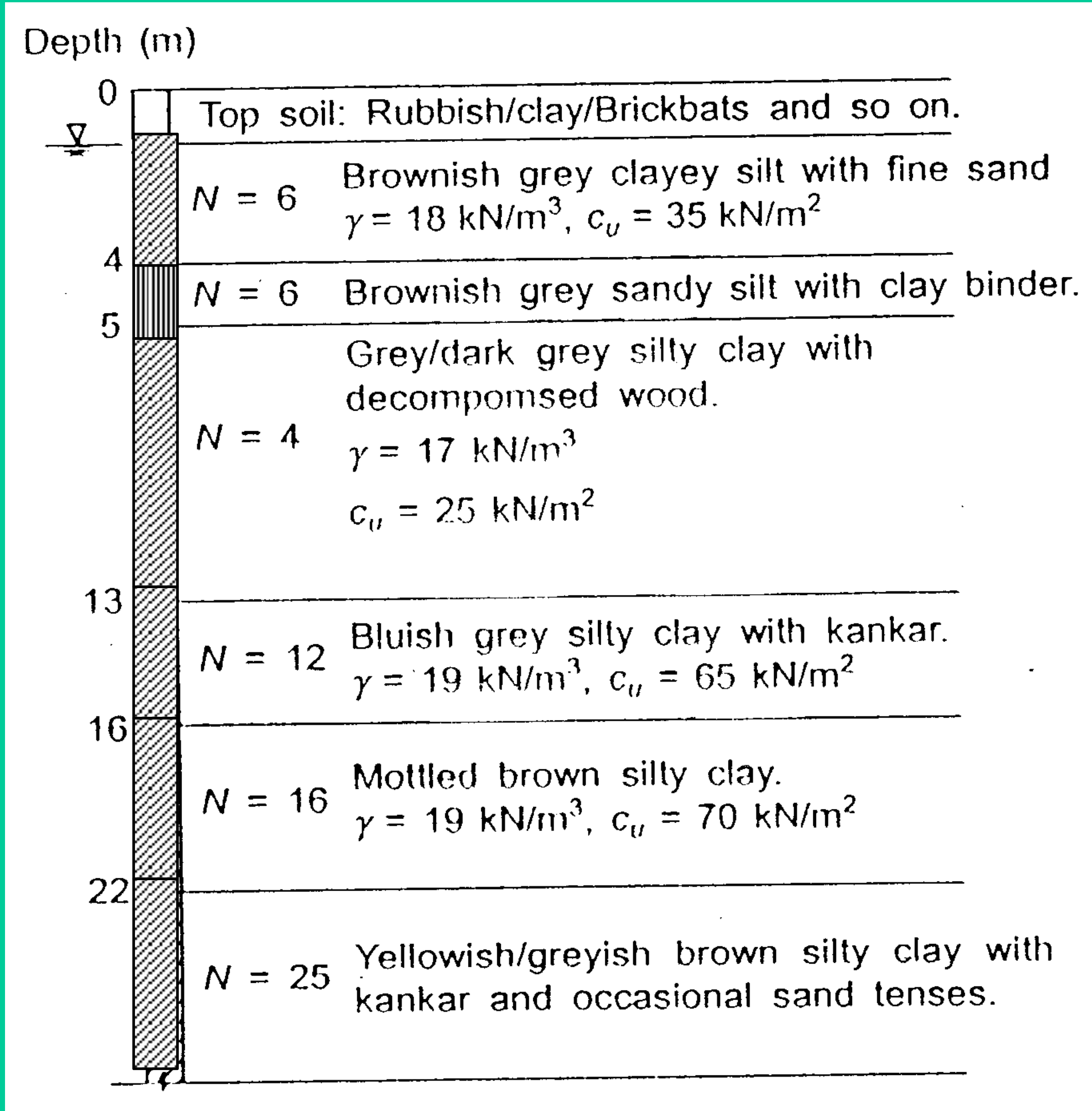
Typical Ground Profile







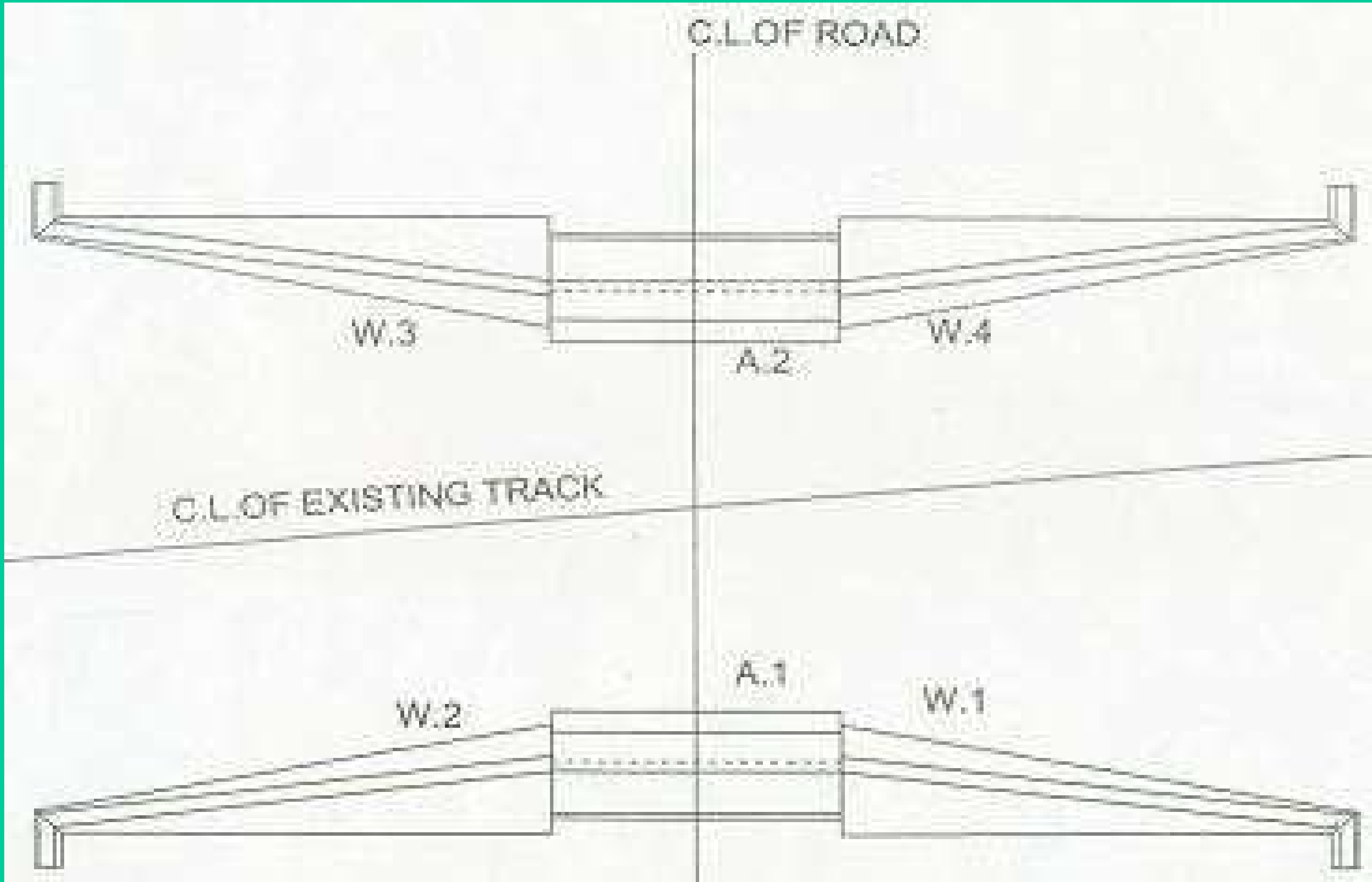
TYPICAL SOIL PROFILE



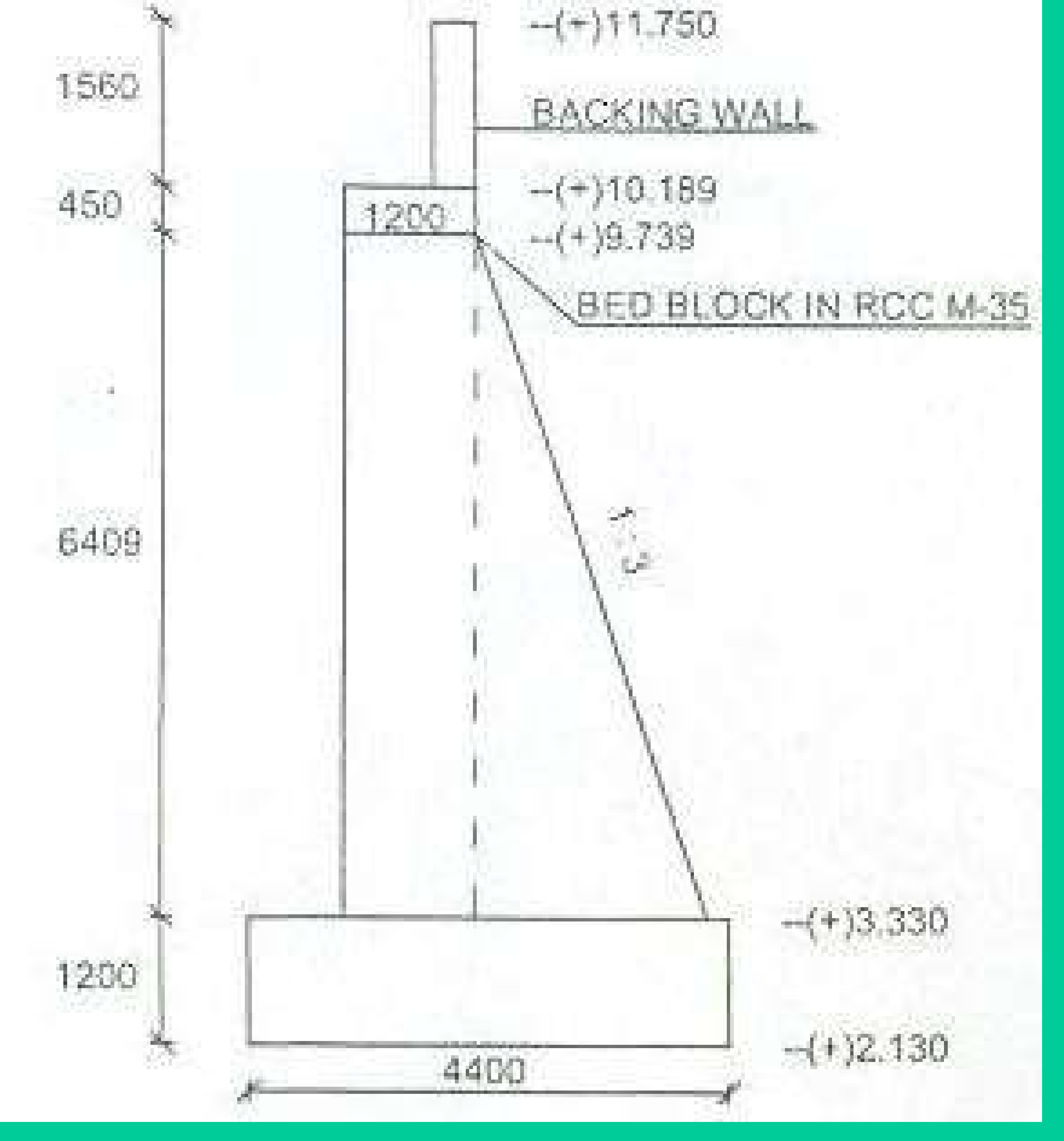
Geotechnical Considerations for Design of Culvert & Bridge Foundations

Damages due to Non-Consideration of Bridge and Approach Interactions

Plan of ROB

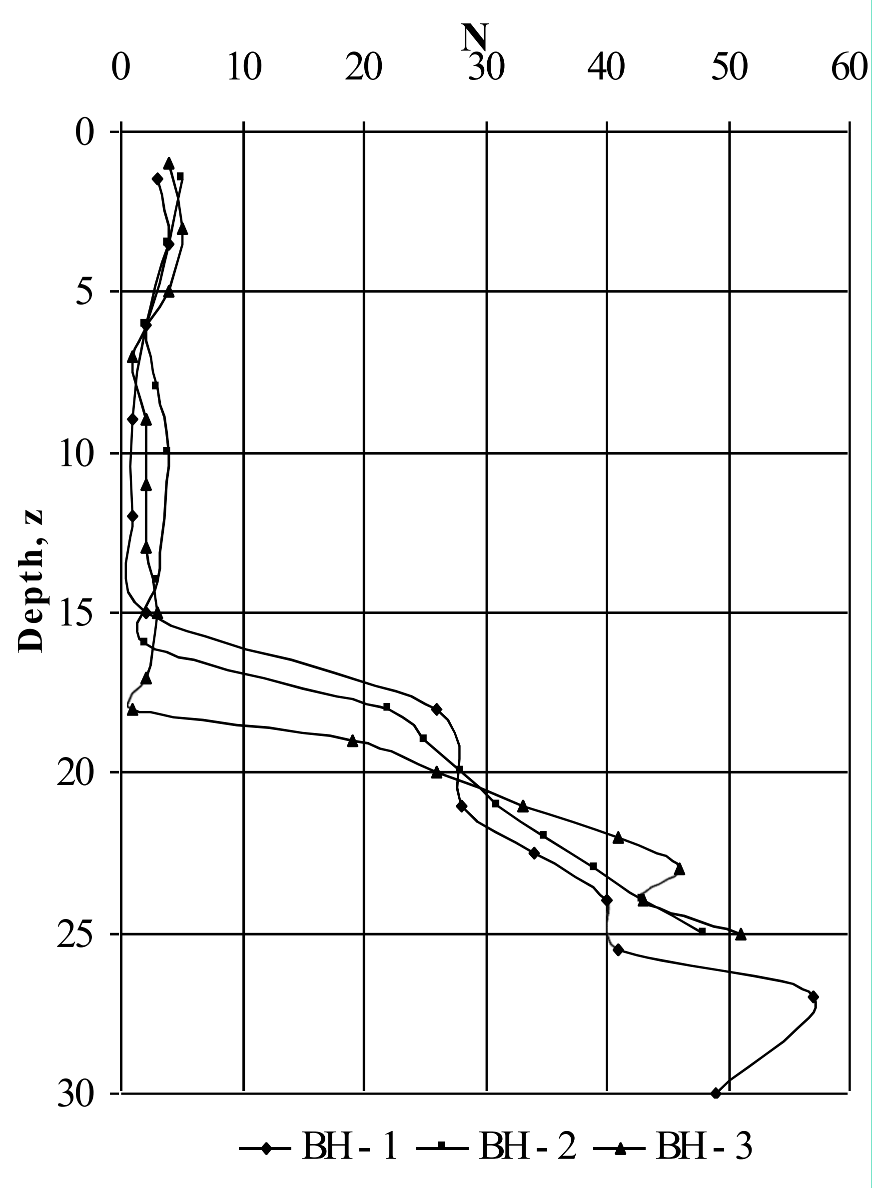


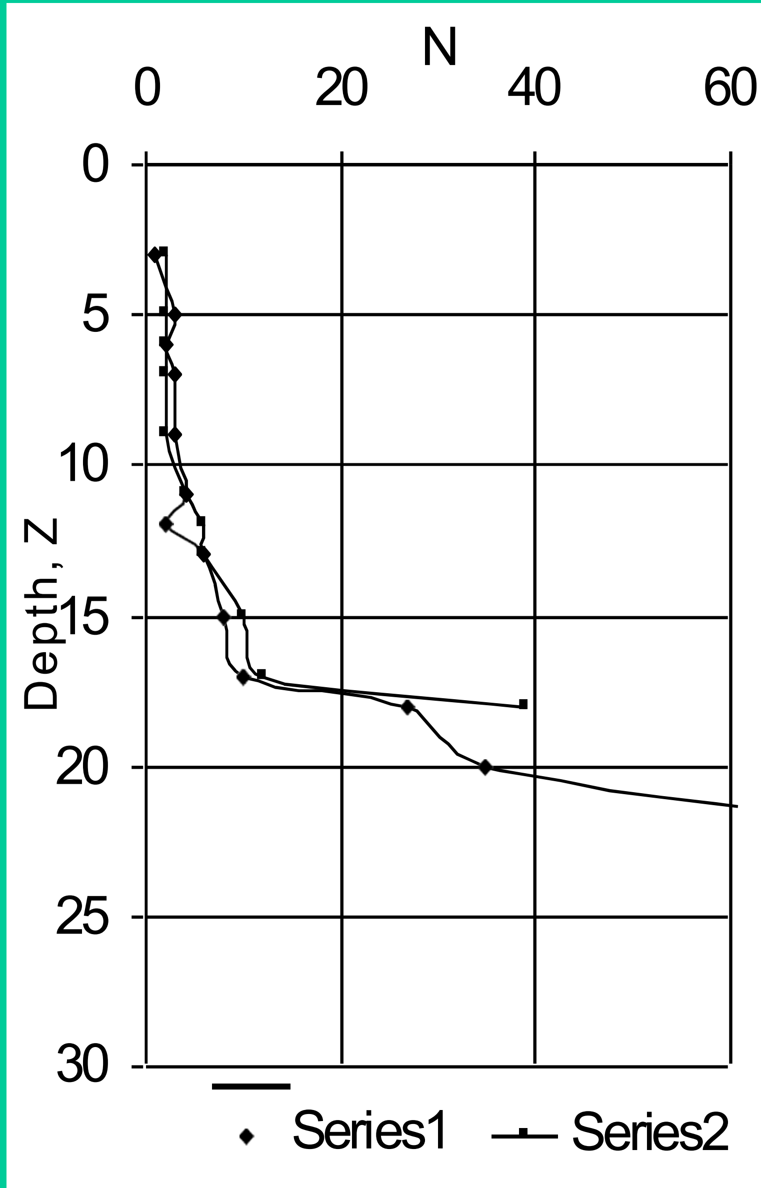
Abutment

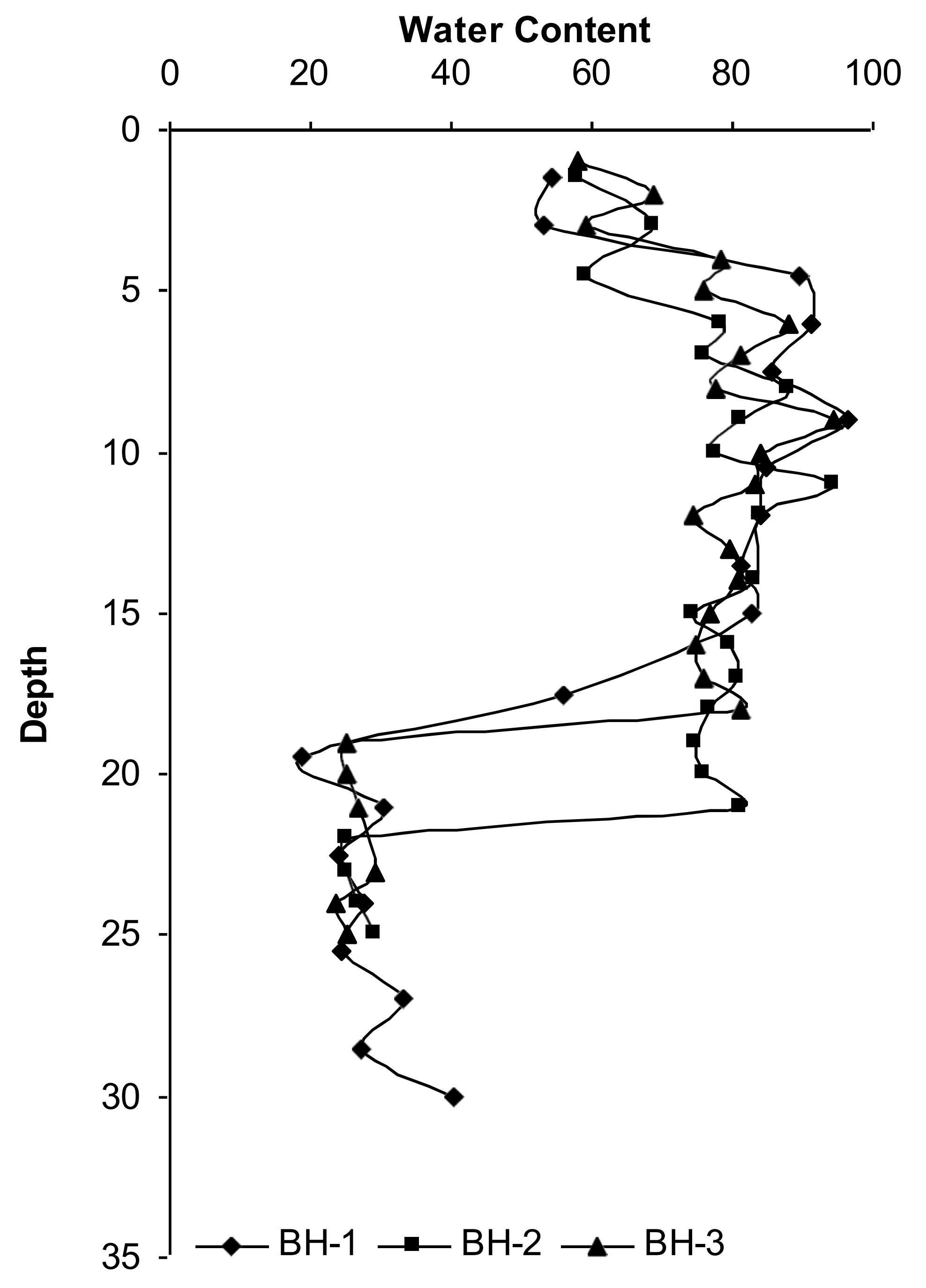


--(+)11.750
1560
BACKING WALL
450
--(+)10.189
1200
--(+)9.739
BED BLOCK IN RCC M-35
6409
--(+)3.330
1200
--(+)2.130
4400

SPT N


N
0
10
20
30
40
50
60
0
5
10
15
20
25
30
Depth, z
BH - 1
BH - 2
BH - 3

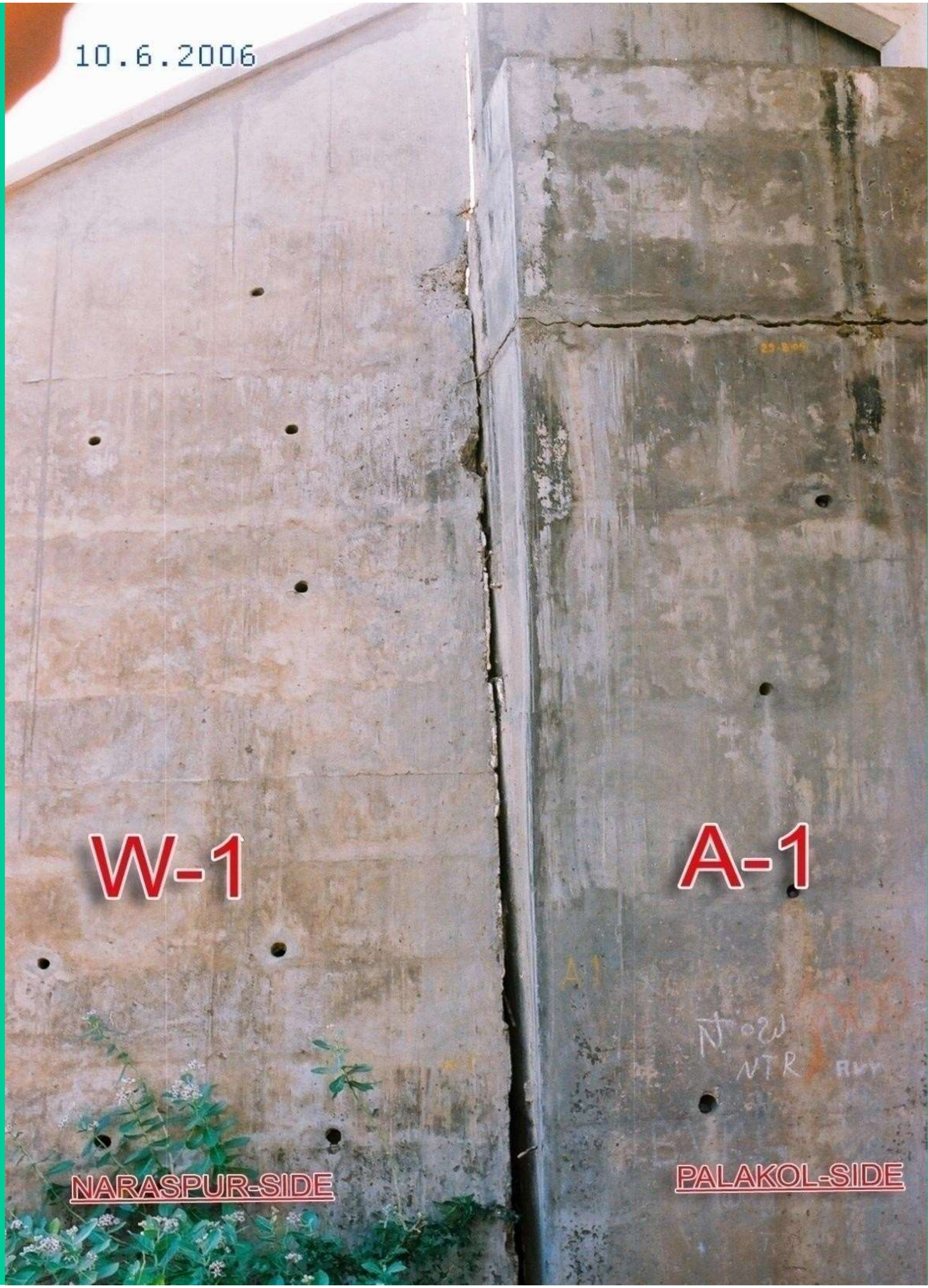

N
0
20
40
60
0
5
10
15
20
25
30
Depth, Z
Series1
Series2



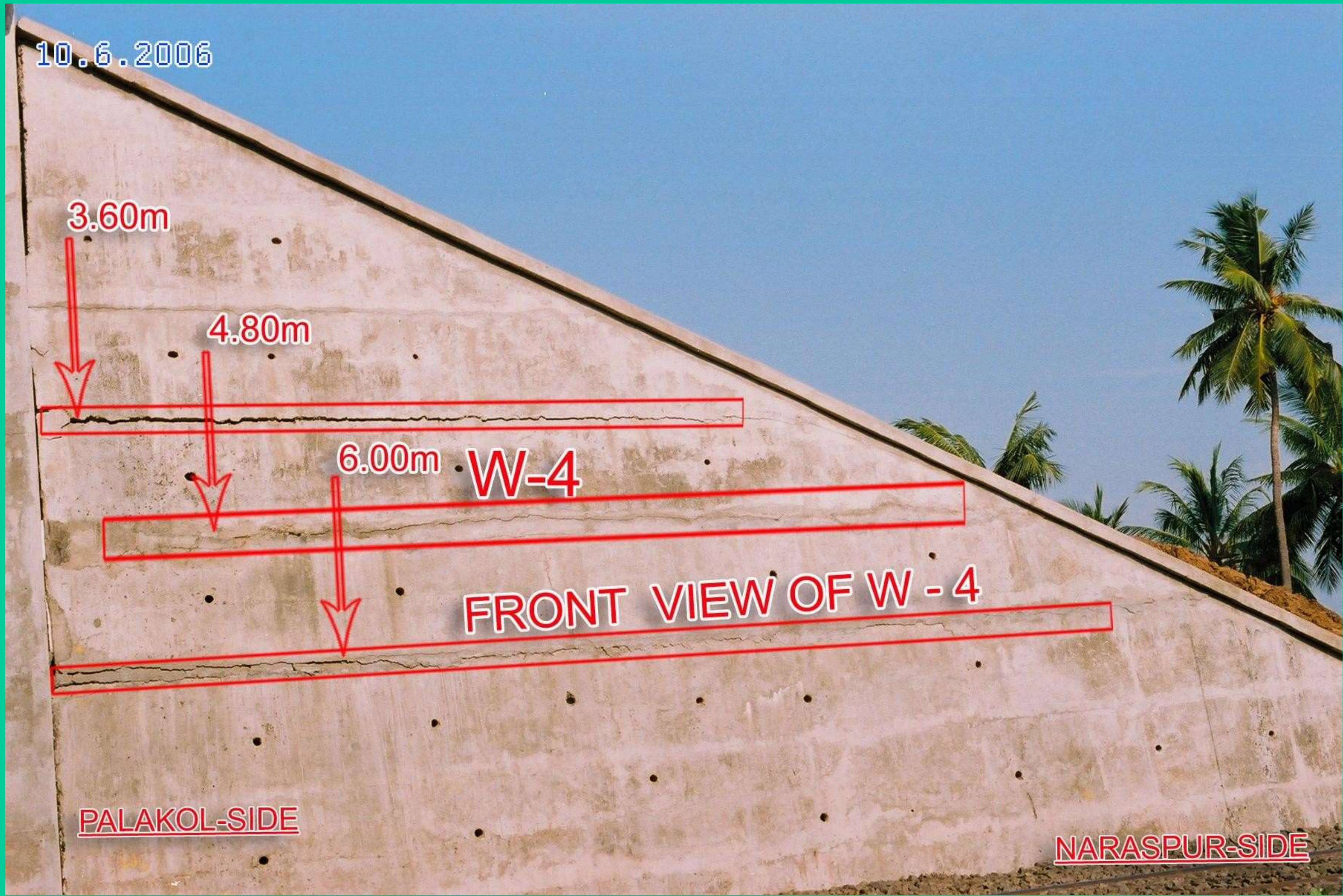
Natural Water Content


10.6.2006
PALAKOL-SIDE
A-1
A-2
NARASPUR-SIDE

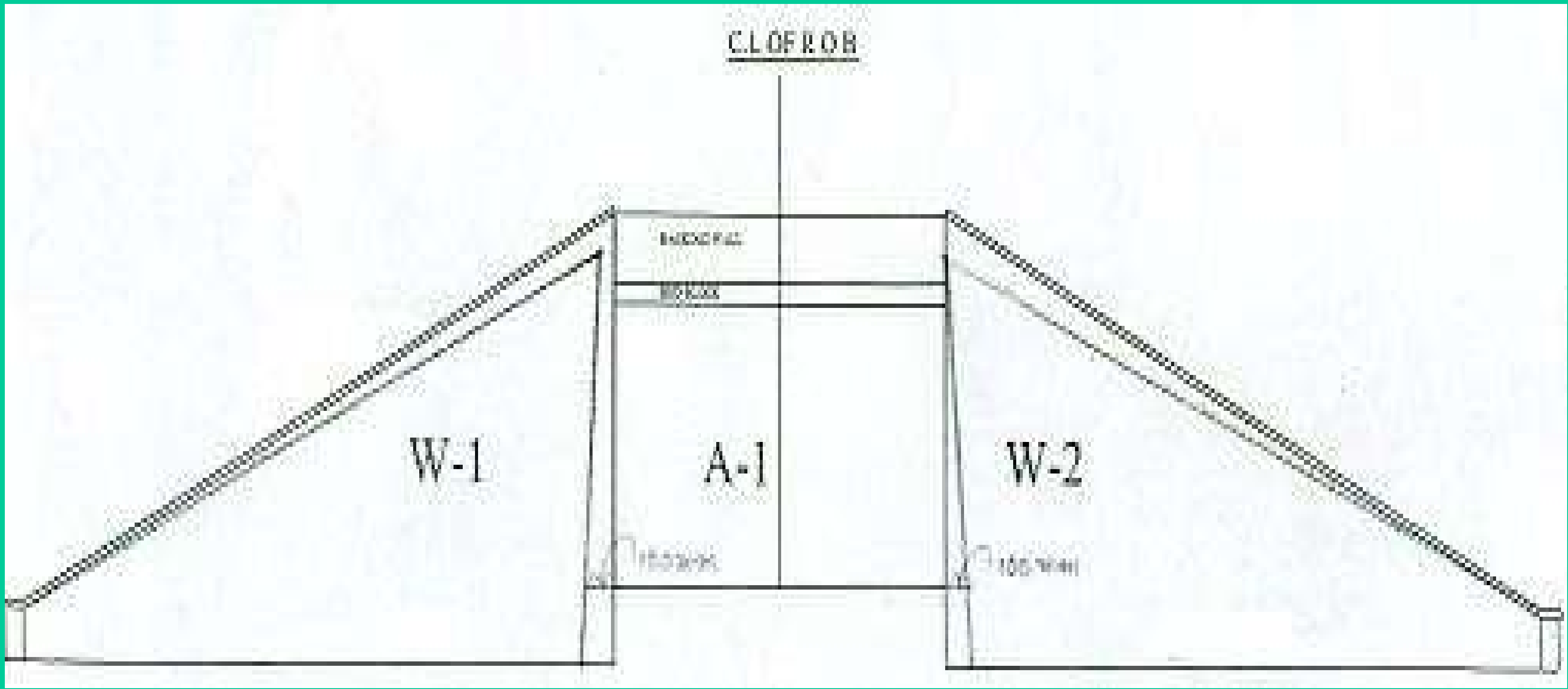

10.6.2006
A-1
W-2
SIDE VIEW OF ABUTMENT -1
SHOWING THE
CRACK DEVELOPED
AT BOTTOM OF BED BLOCK

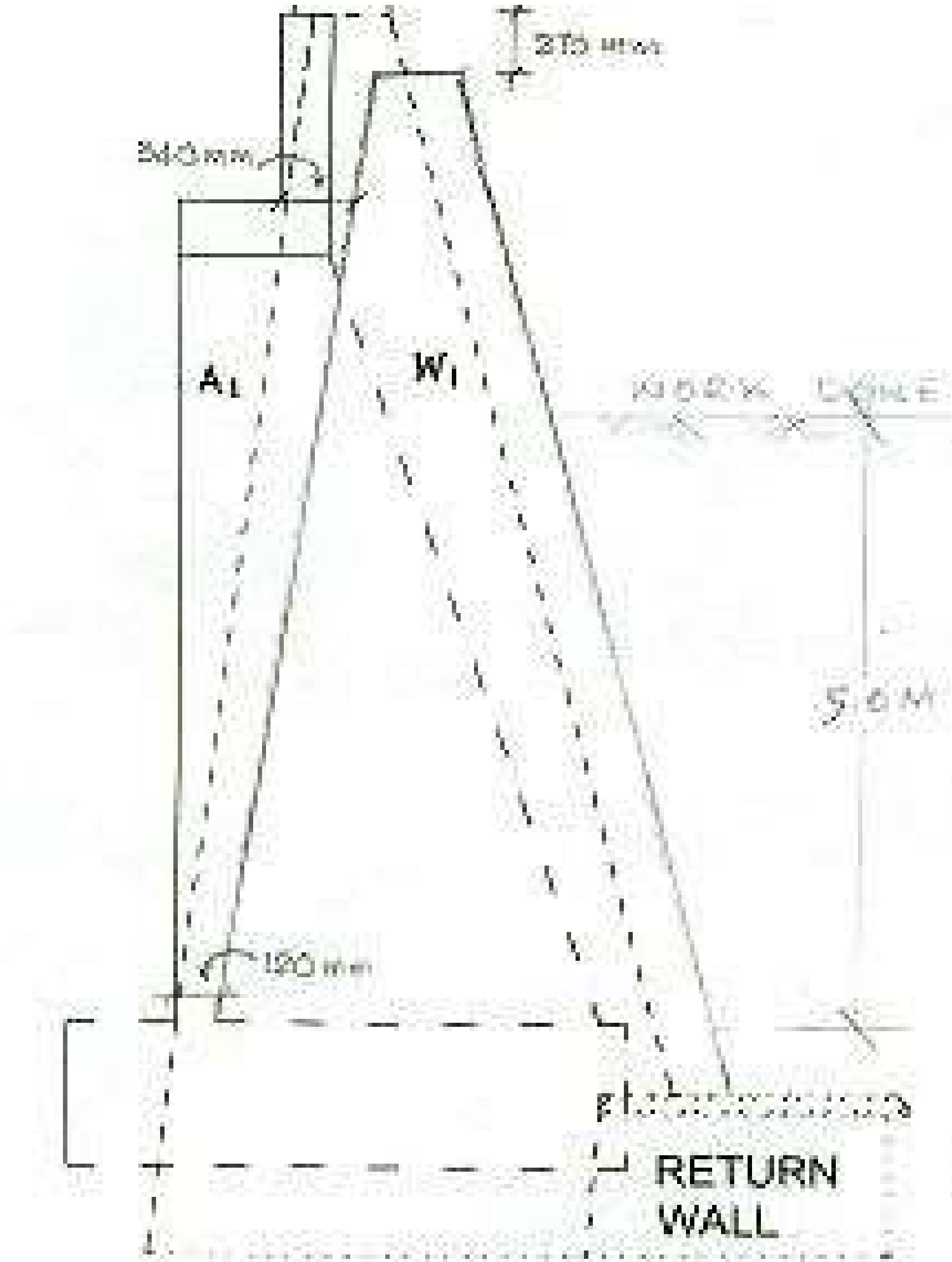

10.6.2006
W-1
A-1
NARASPUR-SIDE
PALAKOL-SIDE


10.6.2006
PALAKOL-SIDE
WING WALL- 2
REAR VIEW OF W-2

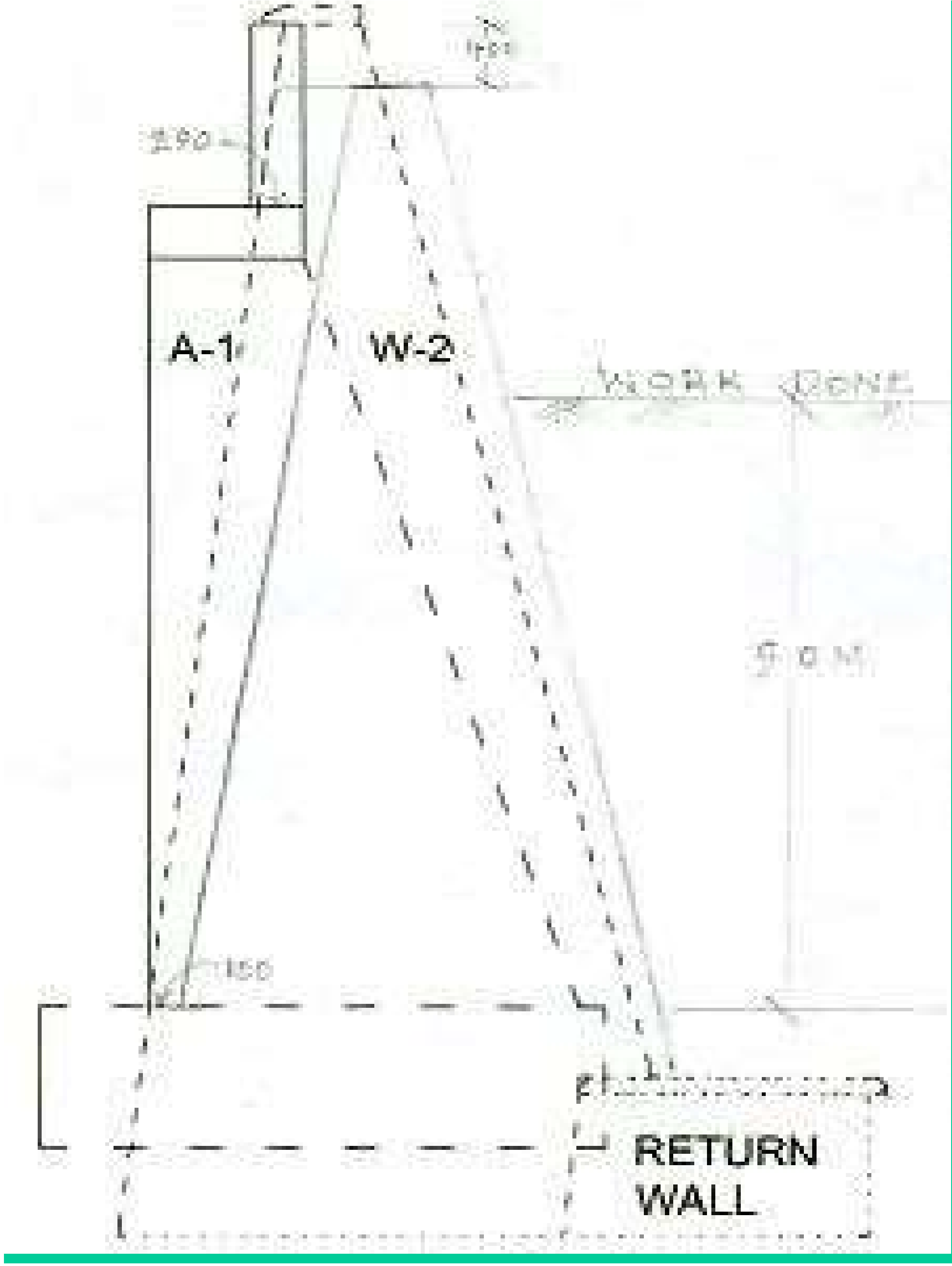

10.6.2006
3.60m
4.80m
6.00m
W-4
FRONT VIEW OF W - 4
PALAKOL-SIDE
NARASPUR-SIDE

Overall View with Deformations



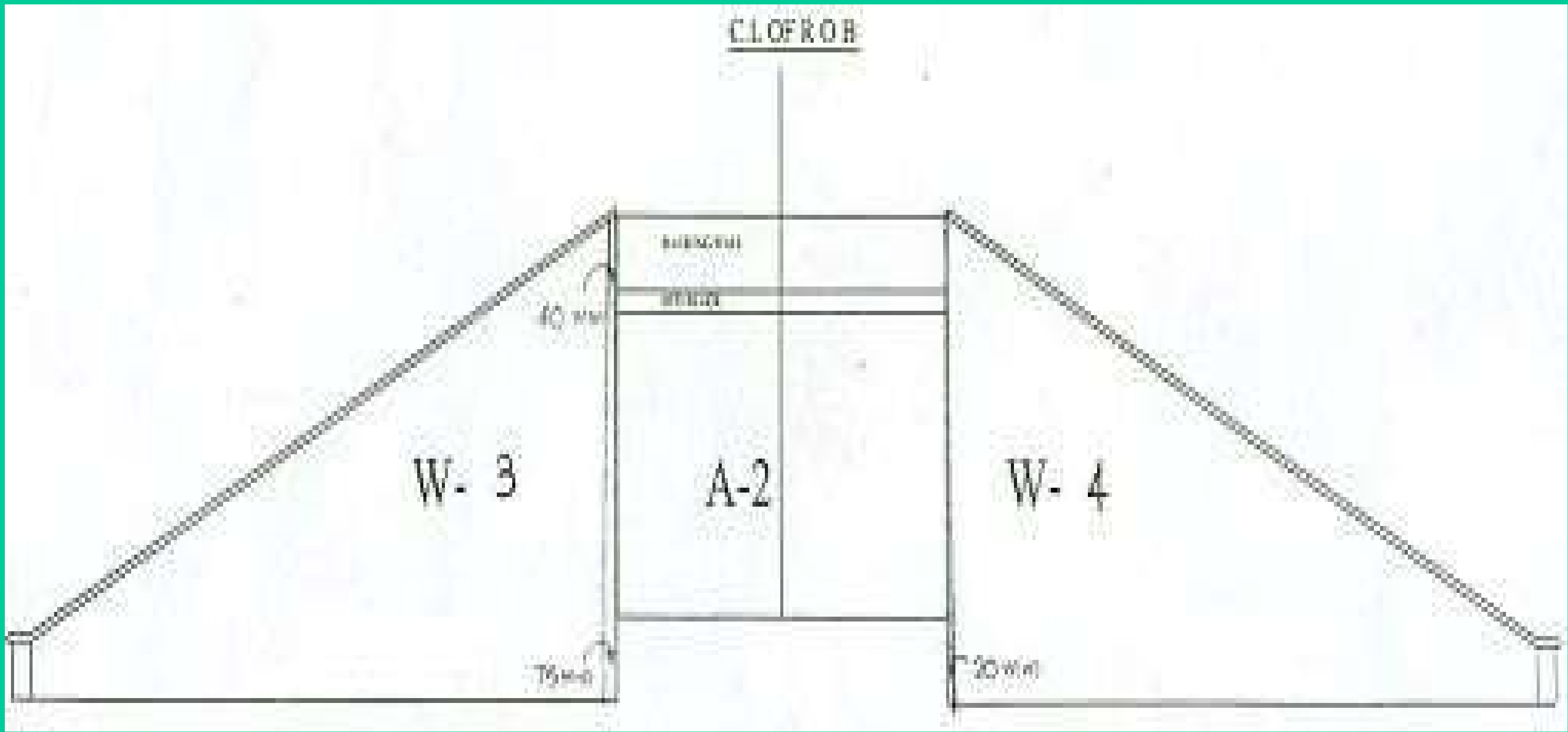


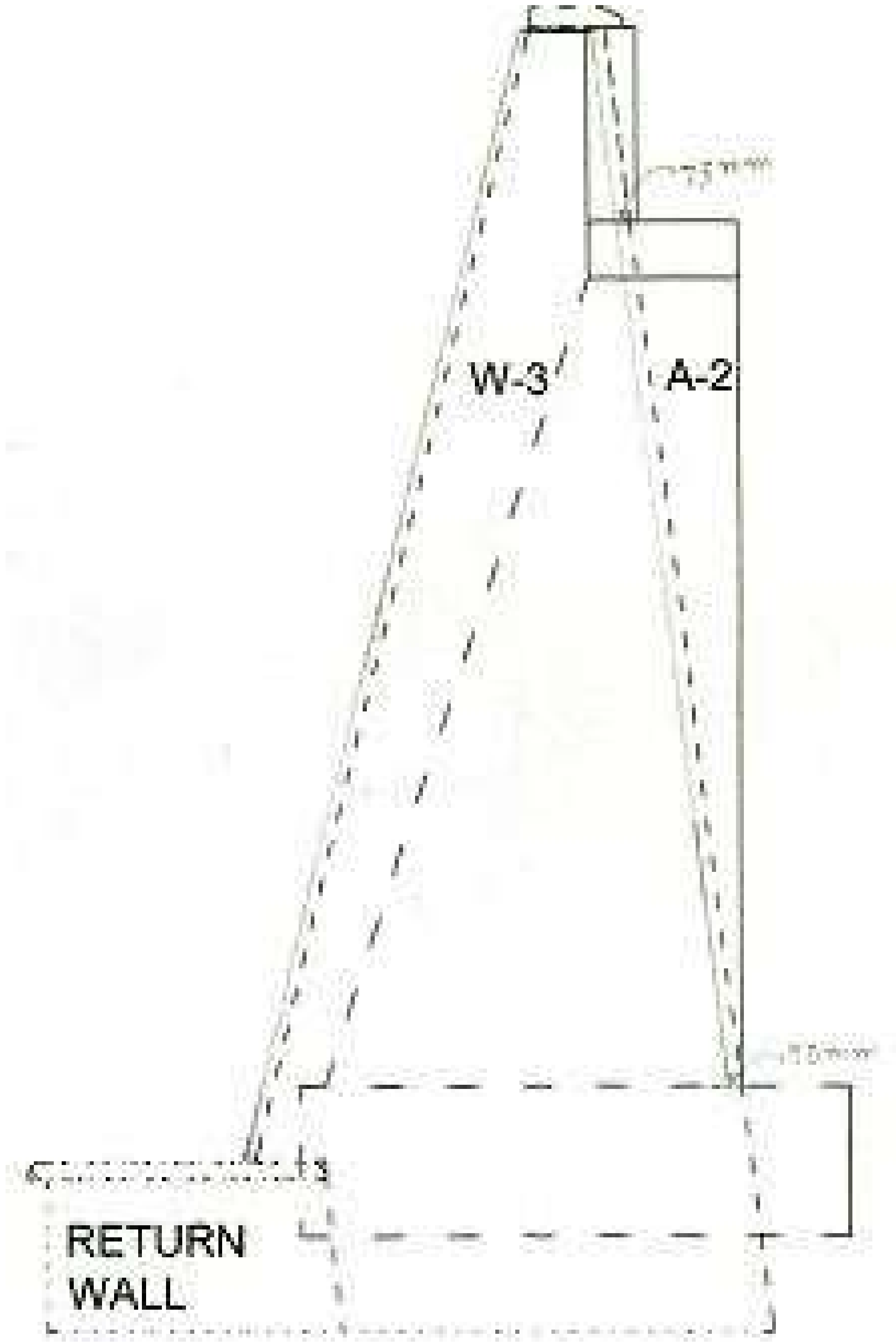
Movements of Wing Wall 1



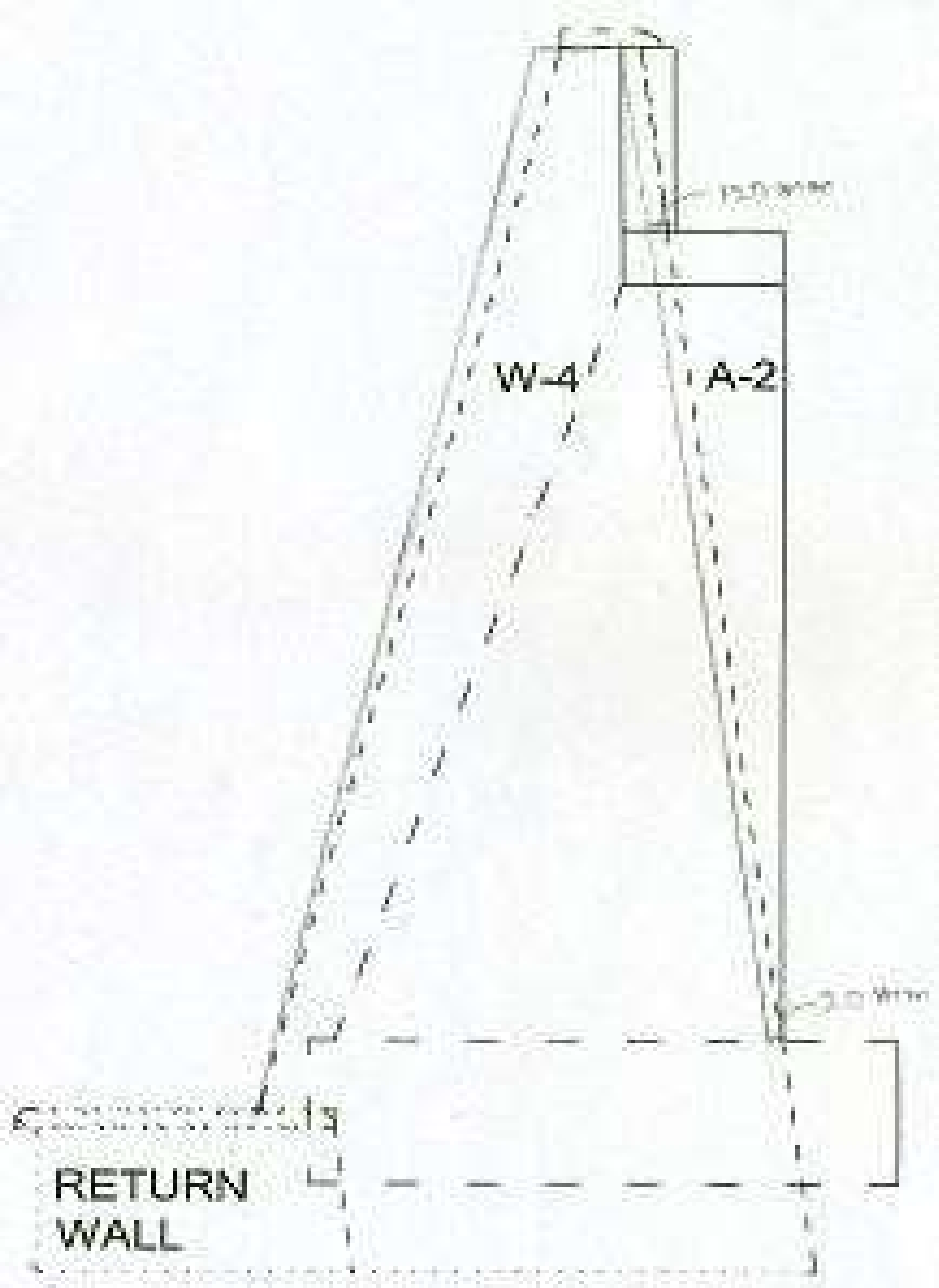
Movements of Wing Wall 2

Abutment 2 with Wing Walls 3 & 4





Movements of Wing Wall 3



Movements of Wing Wall 4

Abutment & Return Wall Incompatibility

Culvert & Wing Wall

Foundation Design

Foundation type depends on combinations of:

Foundation Materials & Conditions

Structure Type & Loads

Performance Criteria

Site Conditions/Construction Constraints

Extreme Event Effects

Seismic Loads (Liquefaction Potential)

Scour Depths

Costs & Construction Time

Foundation Design Process

Other Considerations:

- In-Water Work Periods
- Environmental Restrictions
  - Noise or Vibration Constraints
- Construction Access/Traffic Control

Types of Foundations

Shallow Foundations
Spread Footings (on engineered fill)
MSE Abutment Wall / Spread Footing
Deep Foundations
Driven/Driven Cast In situ/Bored Piles/
Drilled Shafts/ Well Foundations

Pile Design

Bearing Resistance (compression and tension)
Lateral Resistance
Settlement and Downdrag Analysis
Corrosion Potential/Protection
Tip Protection
Pile Drivability (construction)
Group Settlement, Group Effects

FOUNDATION FAILURE

1. **Bearing Capacity failure**

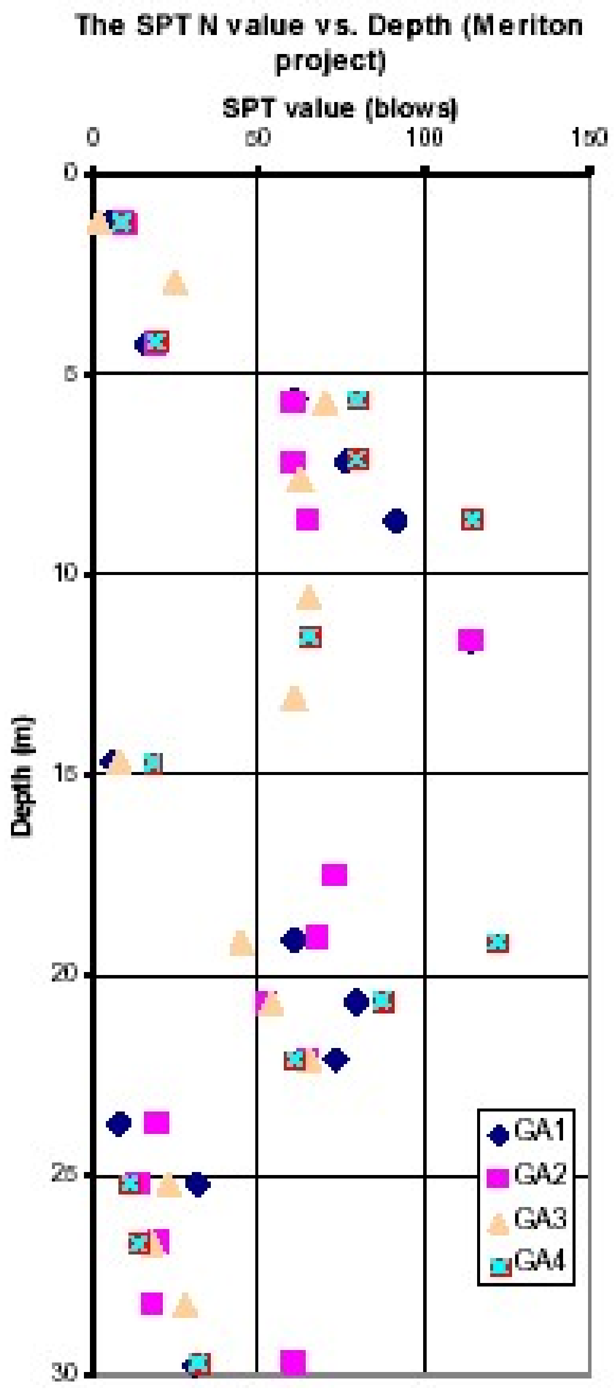
   Collapse

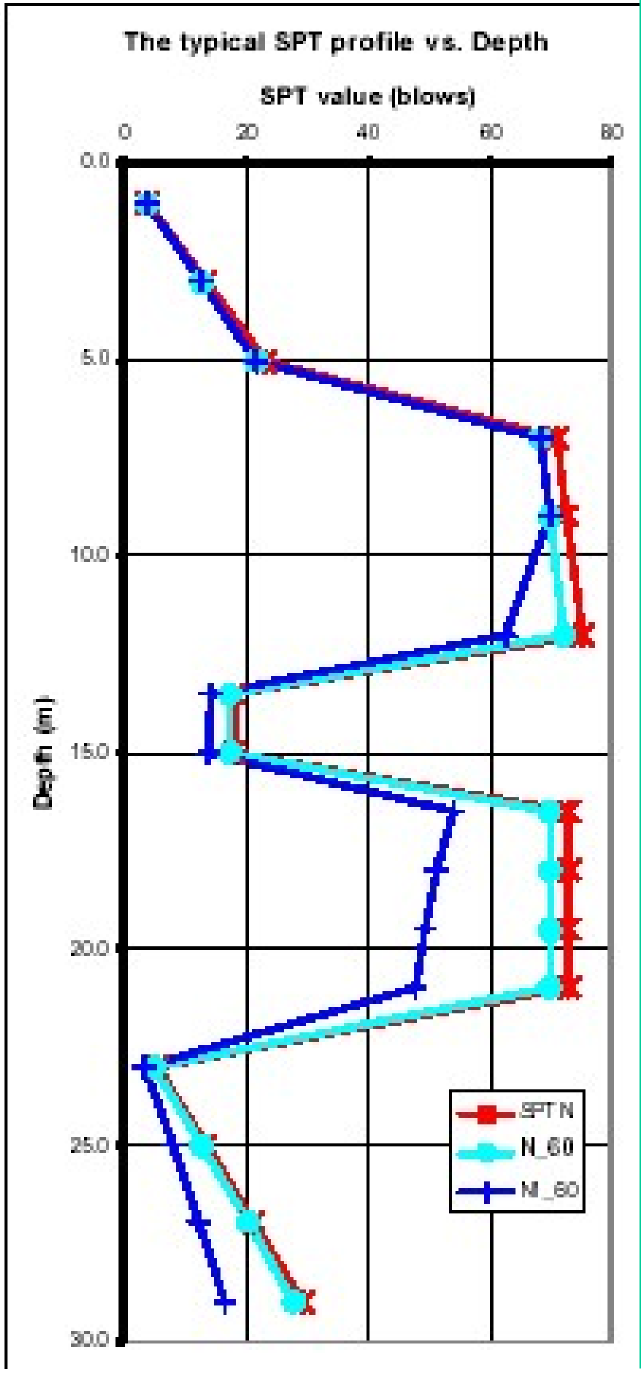
2. **Excessive Settlement**

   Cracks

   Tilt

Typical SPT N Profile

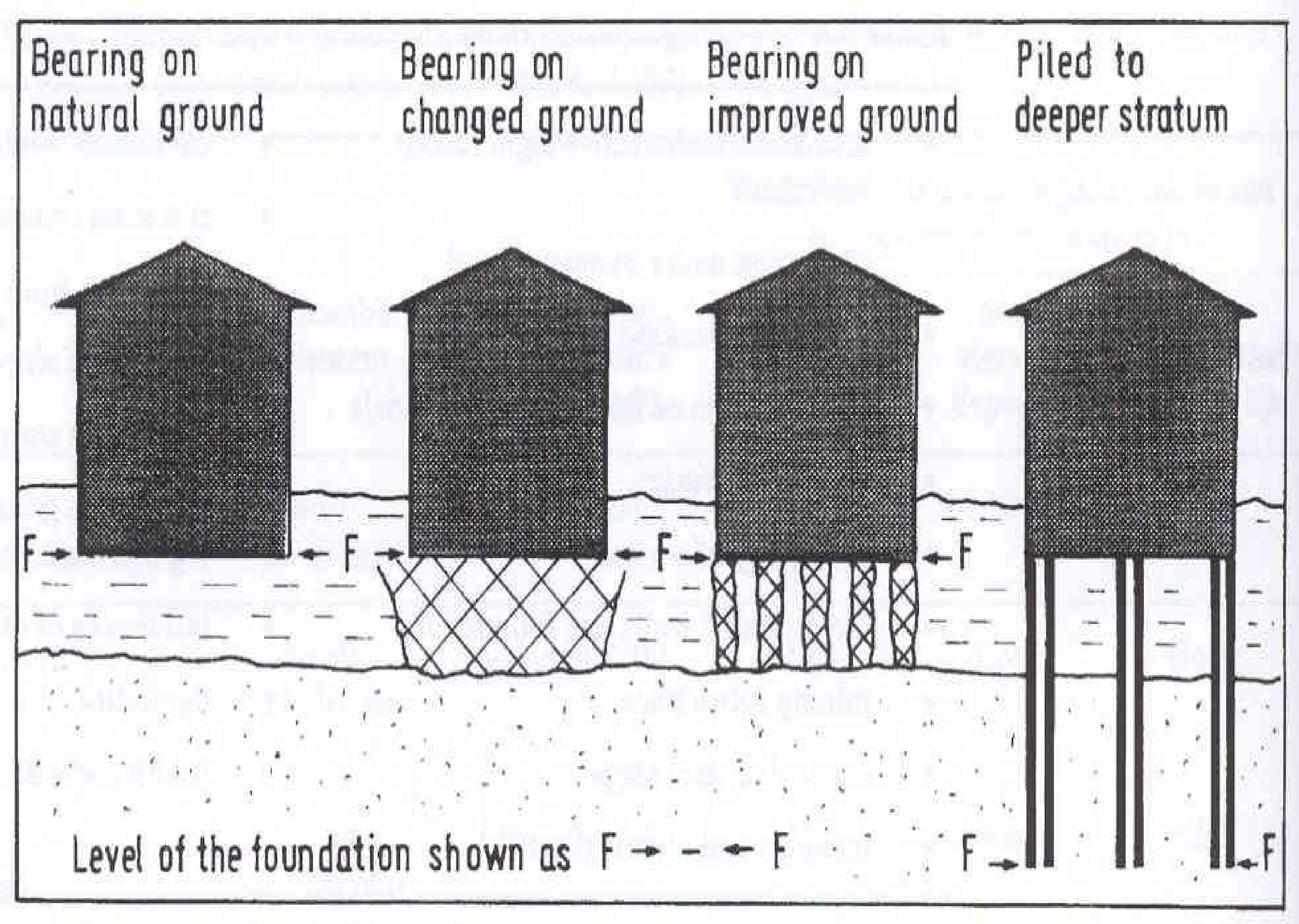




Summary of Ground Profile and Properties

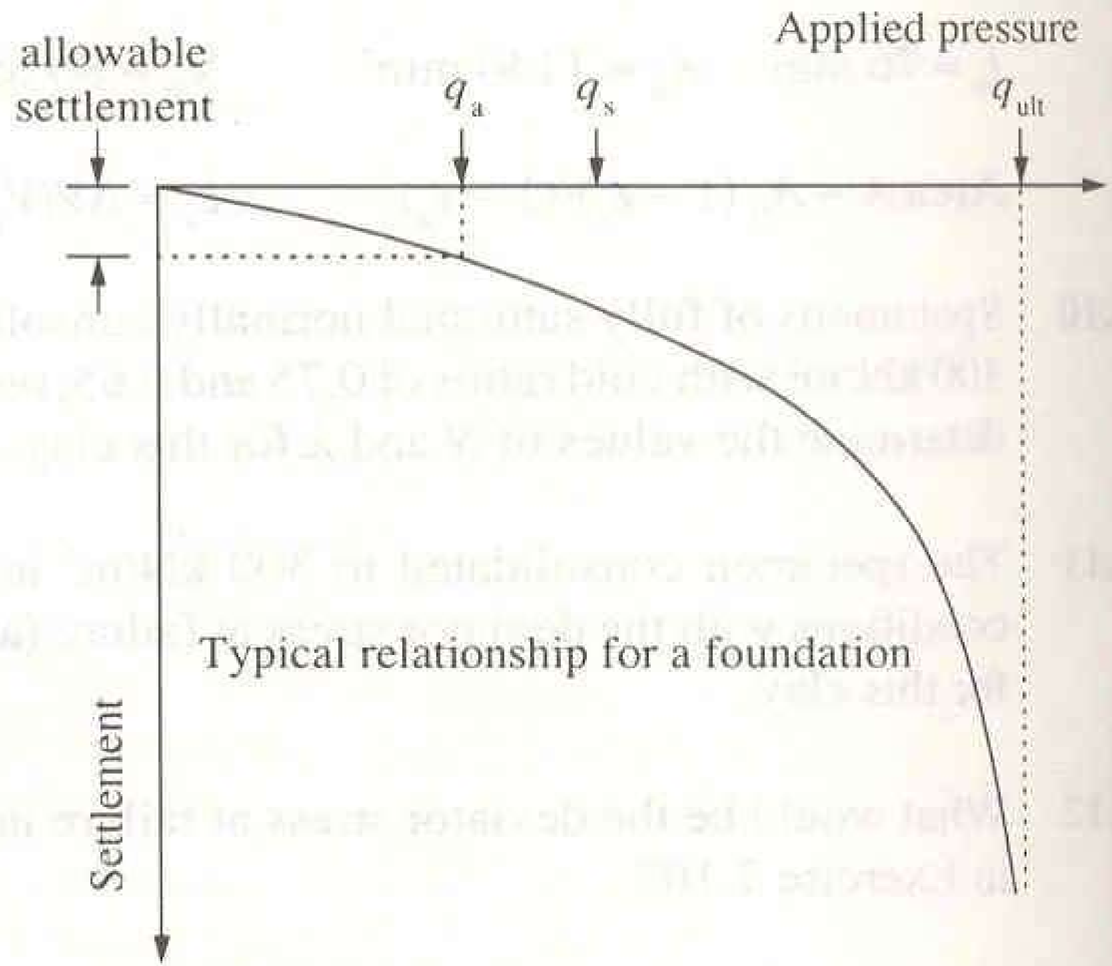
Depth (m)	Layer	Properties		
0.00 – 5.00 (water table -3.50)	LAYER 1: LOOSE-MEDIUM SAND	N= 5-20 N_{60}= 4.7-18.2 N_{1-60}= 4.7-18.2	γ= 15 kN/m3 γ_{sat}= 18 kN/m3 ϕ= 28°	ν= 0.30 E= 6 Mpa
5.00 – 13.00	LAYER 2: VERY DENSE SAND	N= 70.4-75 N_{60}= 67-72 N_{1-60}= 67-62	γ_{sat}= 20 kN/m3 ϕ= 36°	ν= 0.30 E= 30 Mpa
13.00 – 16.00	LAYER 3: ORGANIC PEAT	N= 11 N_{60}= 10.5 N_{1-60}= 8.8	γ_{sat}= 17 kN/m3 ϕ=	ν= 0.35 E= 8 Mpa C= 25 Mpa
16.00 – 22.00	LAYER 4: DENSE SAND	N= 73 N_{60}= 70 N_{1-60}= 53-47	γ_{sat}= 20 kN/m3 ϕ= 36°	ν= 0.35 E= 35 Mpa
22.00 – 30.00	LAYER 5: STIFF CLAY	N= 8-32 N_{60}= 7.6-30.6 N_{1-60}= 5-18.1	γ_{sat}= 19 kN/m3 ϕ=	ν= 0.30 E= 20 Mpa C= 80 Mpa

Foundation Options



Structure & Ground

Structure / Ground	Light	Medium	Heavy
Soft	Shallow Found./G.I	Gr. Impr. (G.I.)	Deep Found.
Medium Stiff	Shallow Found.	Gr. Impr. (G.I.)	Deep Found./ (G.I.)
Hard	Shallow Found.	Shallow Found./G.I.	Shallow Found./G.I



q_{ult} = ultimate bearing capacity

q_s = safe bearing capacity

$$= \frac{q_{ult}}{F} \quad F = \text{factor of safety}$$

q_a = allowable bearing pressure

(related to allowable settlement of structure)

Allowable Bearing Capacity

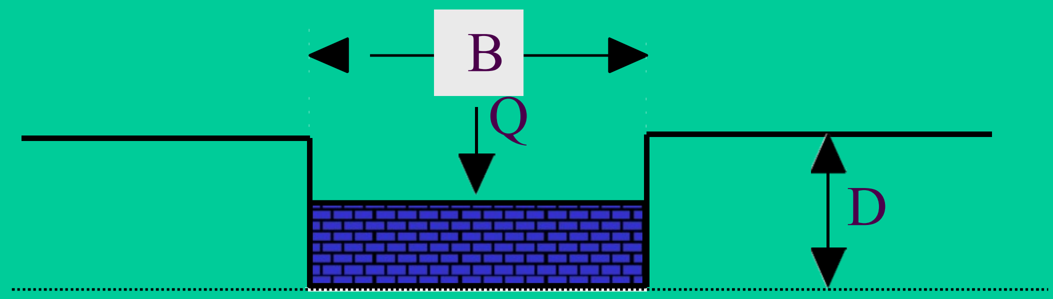
$$q_a = \frac{q_{ult} - q_0}{F} + q_0$$

q_a ….. **Allowable Bearing Capacity**

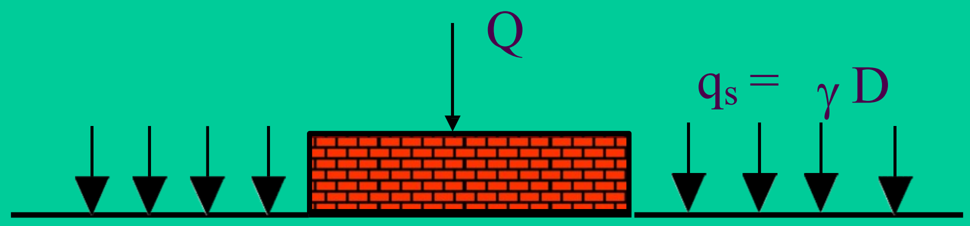
F …. **Factor of safety**

Shallow Foundations

Typical
Buried
Footing



Equivalent
Surface
Footing



Bearing Capacity - Definitions

- Gross Ultimate BC, $q_u = cN_c + q_0N_q + 0.5\gamma BN_\gamma$
- Net UBC, $q_{u,net} = q_u - q_0$
- Safe BC, $q_s = q_u/FS$ – Not Proper
- **$q_s = (q_u - q_0)/FS + q_0 = q_{u,net}/FS + q_0$ – Proper**
- Allowable BC, $q_a <$ or $= q_s$
- Net Allowable BC, $q_{a,net} = q_a - q_0$

Terzaghi Bearing Capacity Formulas

For Continuous foundations:

$$q_{ult} = c' N_c + \sigma'_{zD} N_q + 0.5 \gamma' B N_\gamma$$

For Square foundations:

$$q_{ult} = 1.3 c' N_c + \sigma'_{zD} N_q + 0.4 \gamma' B N_\gamma$$

For Circular foundations:

$$q_{ult} = 1.3 c' N_c + \sigma'_{zD} N_q + 0.3 \gamma' B N_\gamma$$

Terzaghi Bearing Capacity Factors

$$N_q = \frac{a_\theta^2}{2\cos^2(45 + \phi'/2)}$$

$$a_\theta = \exp\left[\pi(0.75 - \phi'/360)\tan\phi'\right]$$

$$Nc = 5.7 \qquad when \quad \phi' = 0$$

$$N_c = \frac{N_q - 1}{\tan\phi'} \qquad when \quad \phi' > 0$$

$$N_\gamma = \frac{\tan\phi'}{2}\left(\frac{K_{p\gamma}}{\cos^2\phi'} - 1\right)$$

Vesic′ Formula Shape Factors

$$s_c = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right)$$

$$s_q = 1 + \left(\frac{B}{L}\right)\tan\phi'$$

$$s_\gamma = 1 - 0.4\left(\frac{B}{L}\right)$$

Vesic′ Formula Depth Factors

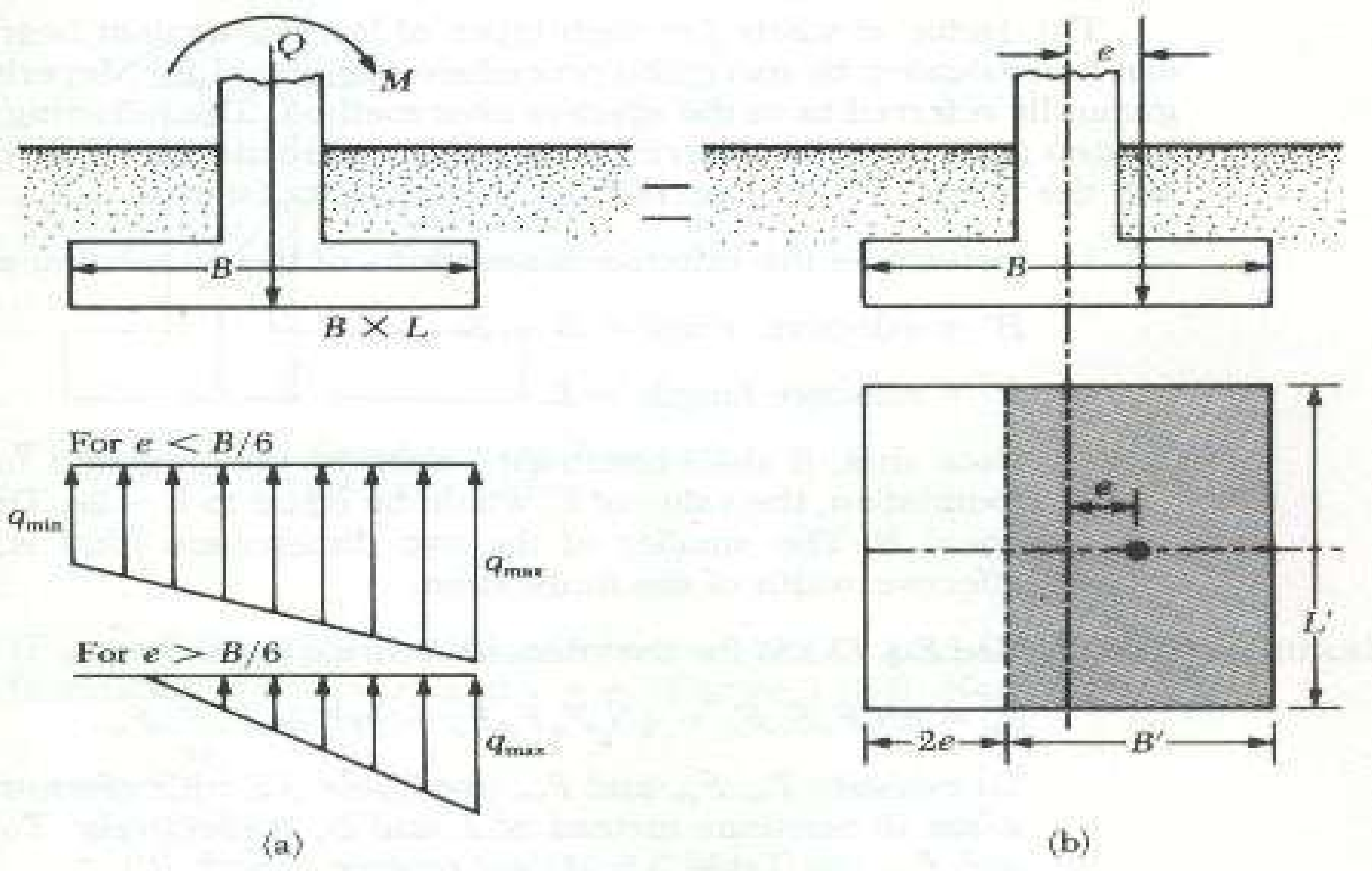
$$k = \tan^{-1}\left(\frac{D}{B}\right)$$

$$d_c = 1 + 0.4k$$

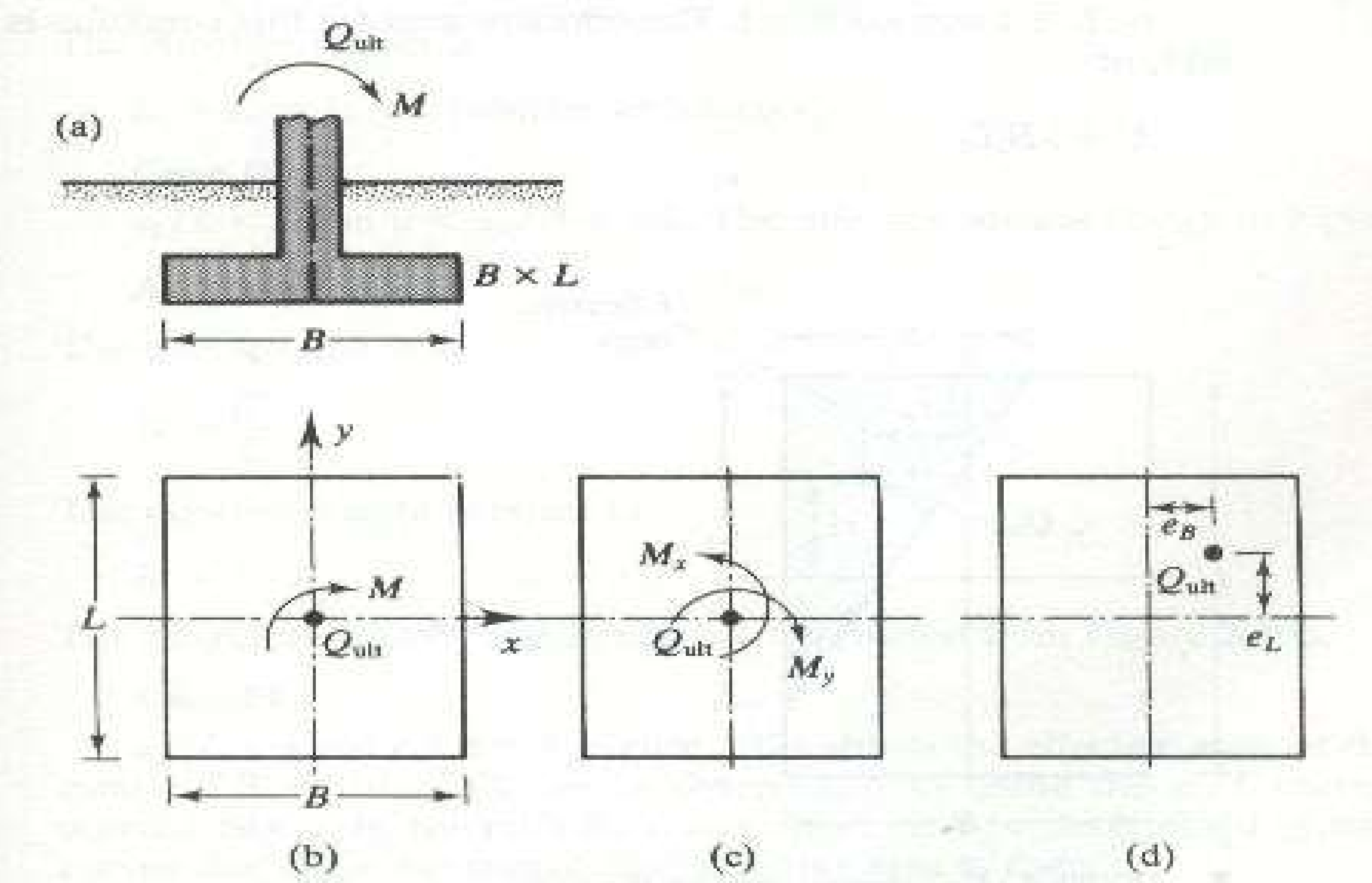
$$d_q = 1 + 2k\tan\phi'(1 - \sin\phi')^2$$

$$d_\gamma = 1$$

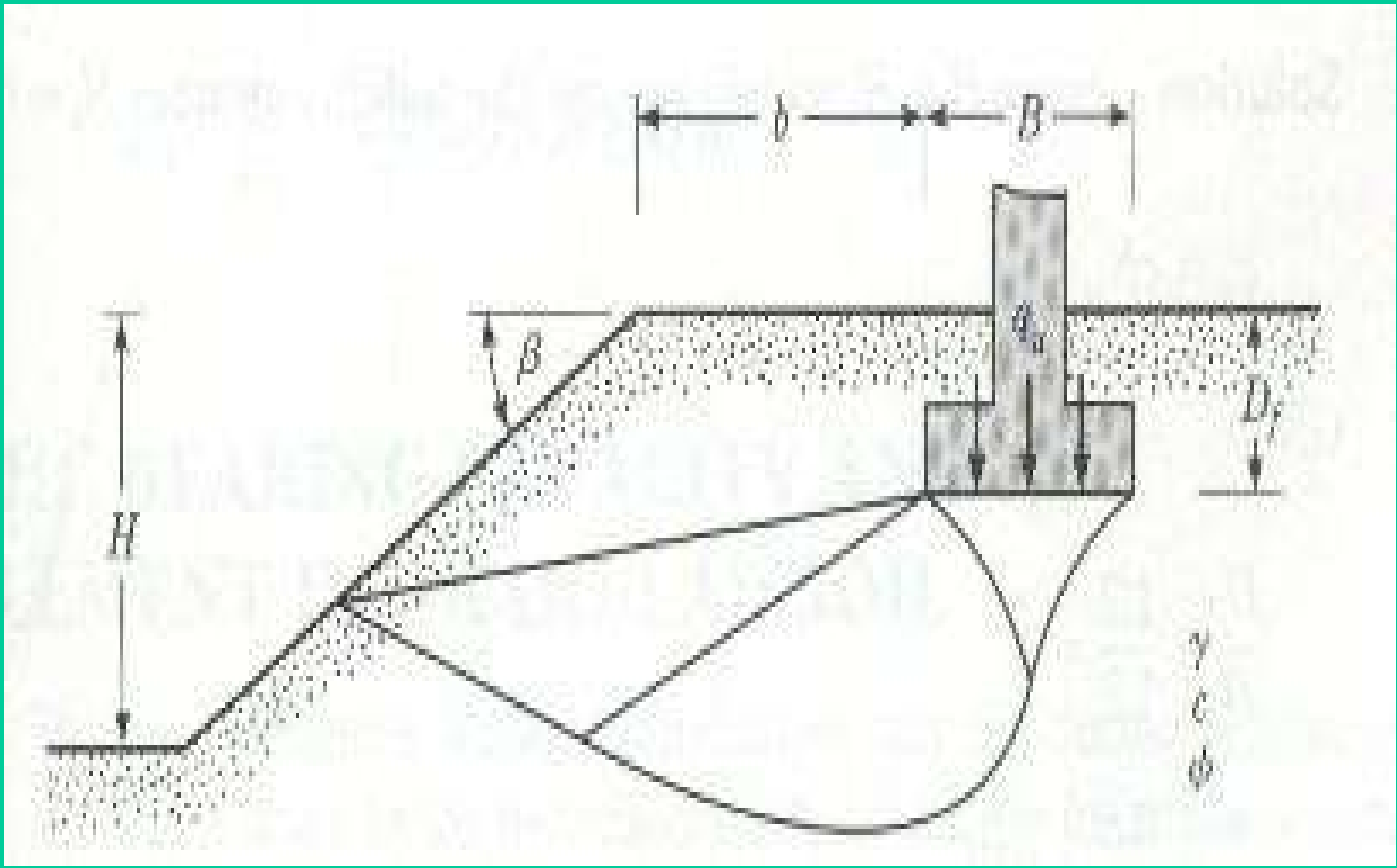
Eccentrically Loaded Footing



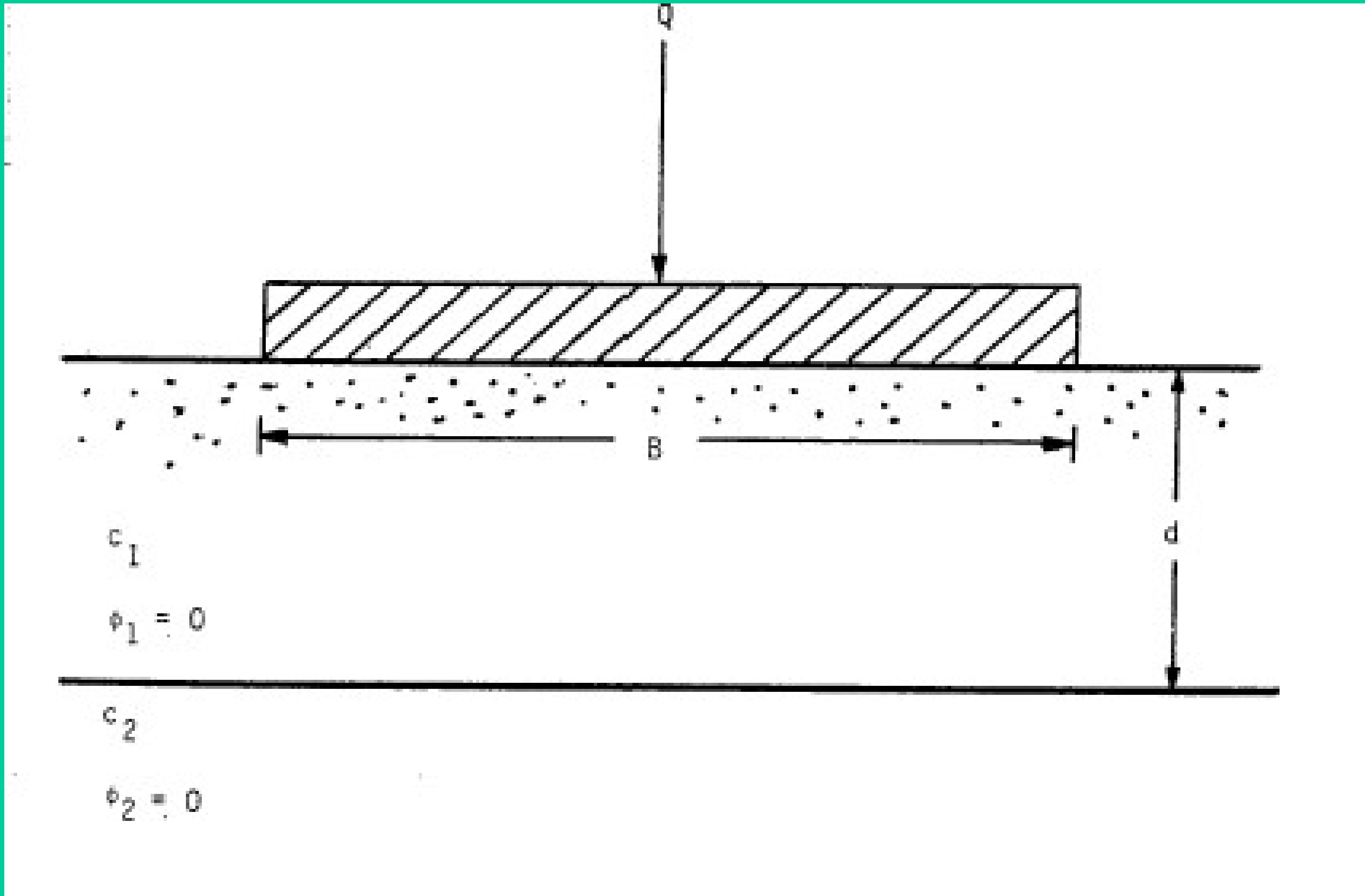
Two-Way Eccentricity



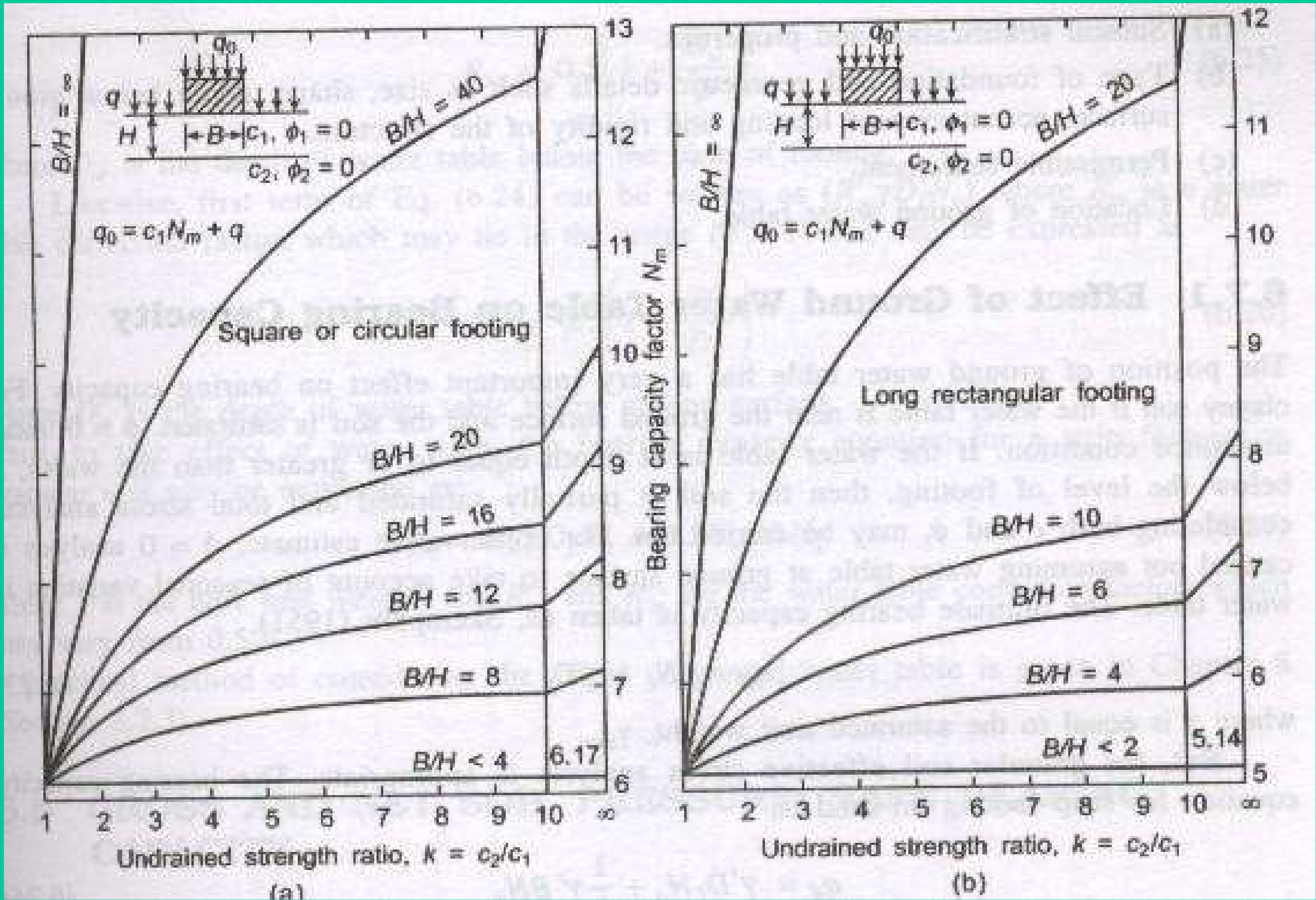
Footing on Slope



Two-Layered Soil



Bearing Capacity Factors for Two-Layered Soil



Allowable Bearing Pressure

$$q_{n\rho} = 1.37(N'-3)\left(\frac{B+0.3}{2B}\right)^2 R'_w R_{D1} S_a$$
kN/m^2

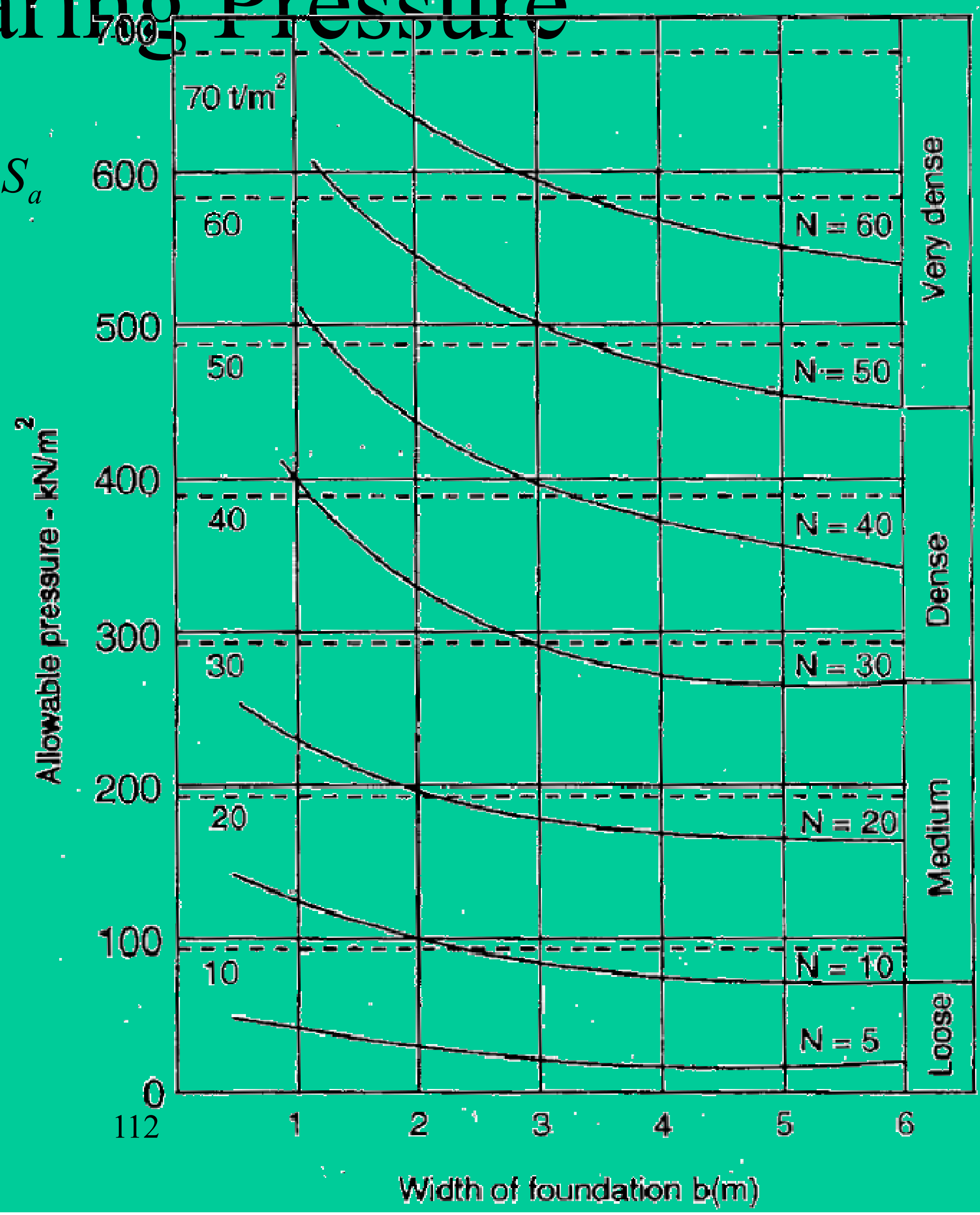
S_a in mm and all other dimensions in meter.

$S_a =$ Permissible settlement in mm. (25 mm)

$$R'_w = 0.5\left(1 + \frac{D_w - D_f}{D_f}\right) \qquad [R'_w \le 1$$

$R_{D1} =$ depth correction factor

$$= 1 + 0.2\frac{D_f}{B} \le 1.2$$



Meyerhof (1965)

$$\delta_{\text{footing}}(\text{mm}) = \frac{1.33q(\text{kPa})}{N_{60}}\left(1 - \frac{D_f}{4B}\right) \quad \text{for } B \leq 1.22 \text{ m}$$

$$\delta_{\text{footing}}(\text{mm}) = \frac{0.53q(\text{kPa})}{N_{60}}\left(\frac{2B}{B+0.3}\right)^2\left(1 - \frac{D_f}{4B}\right) \quad \text{for } B > 1.22 \text{ m}$$

Burland & Burbridge (1985) with $z_I = B^{0.7}$

NC Soils

$$\delta_{\text{footing}} = q_{\text{net}} \frac{1.71}{\bar{N}_{60}^{1.4}} B^{0.7}$$

OC Soils

$$\delta_{\text{footing}} = \left(q_{\text{net}} - \frac{2}{3}\sigma'_p \right) \frac{1.71}{\bar{N}_{60}^{1.4}} B^{0.7} \quad \text{if } q \geq \sigma'_p$$

Shape Factor

$$f_s = \left(\frac{1.25 L/B}{0.25 + L/B} \right)^2$$

Finite Layer

$$f_l = \frac{H_s}{z_I}\left(2 - \frac{H_s}{z_I} \right)$$

Creep Factor

R_3=0.3 to 0.7 &

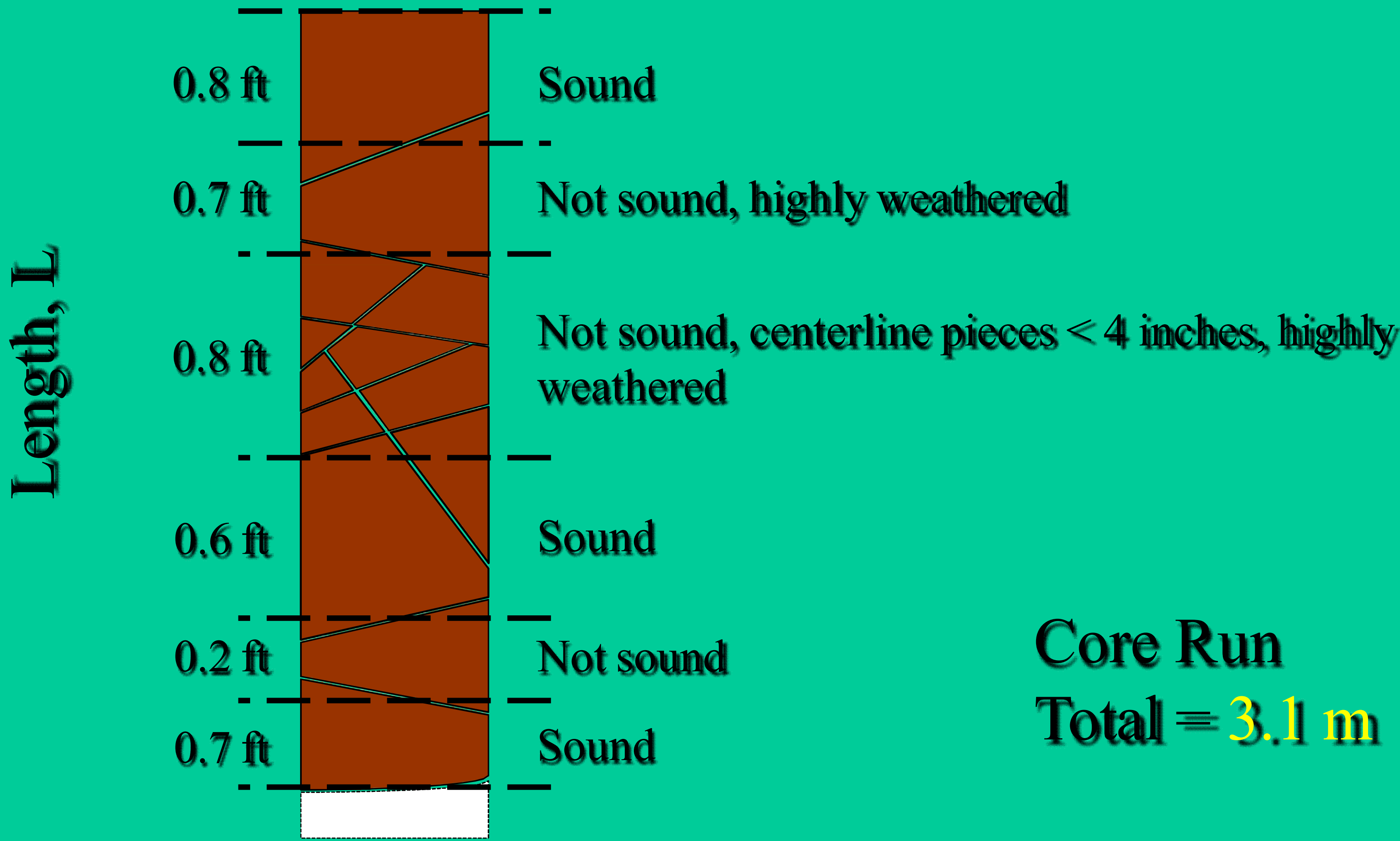
R_t=0.2 to 0.8

$$f_t = 1 + R_3 + R_t \log \frac{t'}{3}$$

Foundations on Rock

- Drilling required at least 5m below the lowest cellar floor level.
- Core recovery, RQD and water levels required.
- Site geology (spacing and nature of discontinuities)
- Unconfined Compressive Strength.
- Interaction between geotechnical and structural engineers.

Rock Quality



Core Run
Total = 3.1 m

$CR = 95\%$ $RQD = 53\%$

Weathering

- Fresh
- Very light
- Slight
- Moderate
- Moderately severe
- Severe
- Very severe
- Complete

Engineering Judgment

Rock Parameters

- Core recovery (CR)
- Rock Quality Designation (RQD)

RQD Rating of rock mass

RQD, %	**Rock Description**
< 25	Very poor
25 – 50	Poor
50-75	Fair
75-90	Good
>90	Excellent

Rock Mass Rating (RMR)

0 – 100 Rating

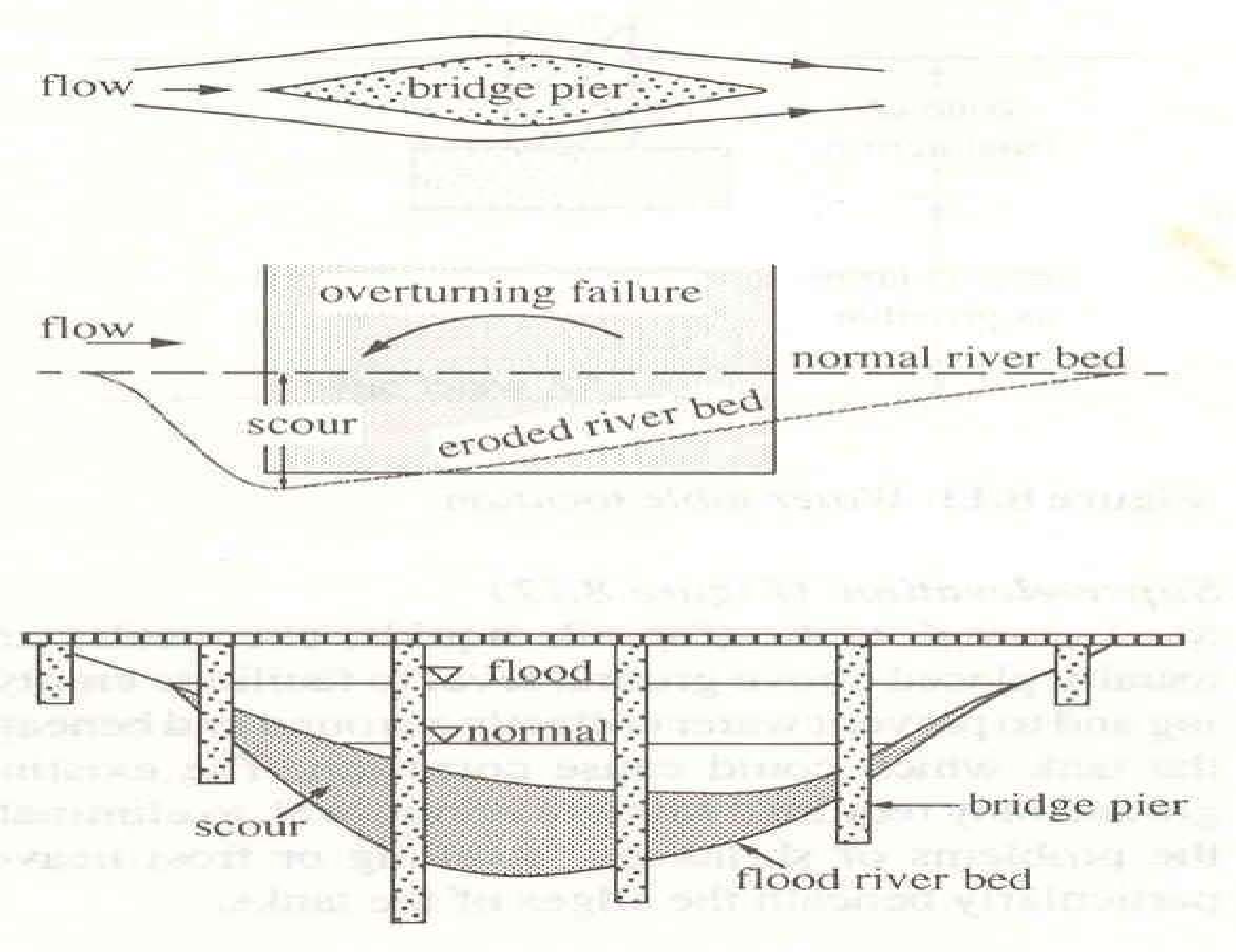
- UCC
- Spacing of discontinuities
- Condition of discontinuities
- Ground water conditions
- Orientation of discontinuities

Safe Bearing Capacity

Net safe bearing pressures based on RMR (IS : 12070-1987)

Classification No.	I	II	III	IV	V
Description of Rock	Very good	Good	Fair	Poor	Very poor
R M R	100 – 81	80 – 61	60 – 41	40 – 21	20 – 0
Net safe bearing pressure, kN /sq m	6000 - 4480	4480 – 2880	2800 – 1510	1450 – 900 – 580	550 – 450-400

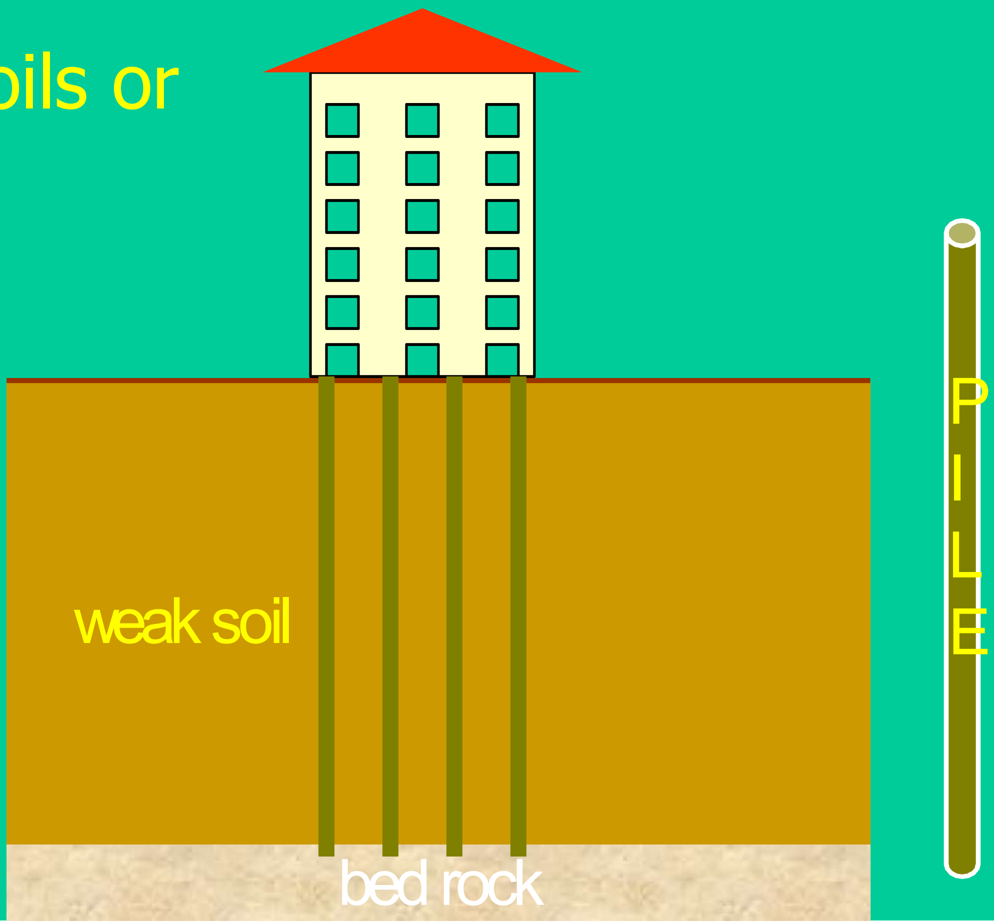
Effect of Scour



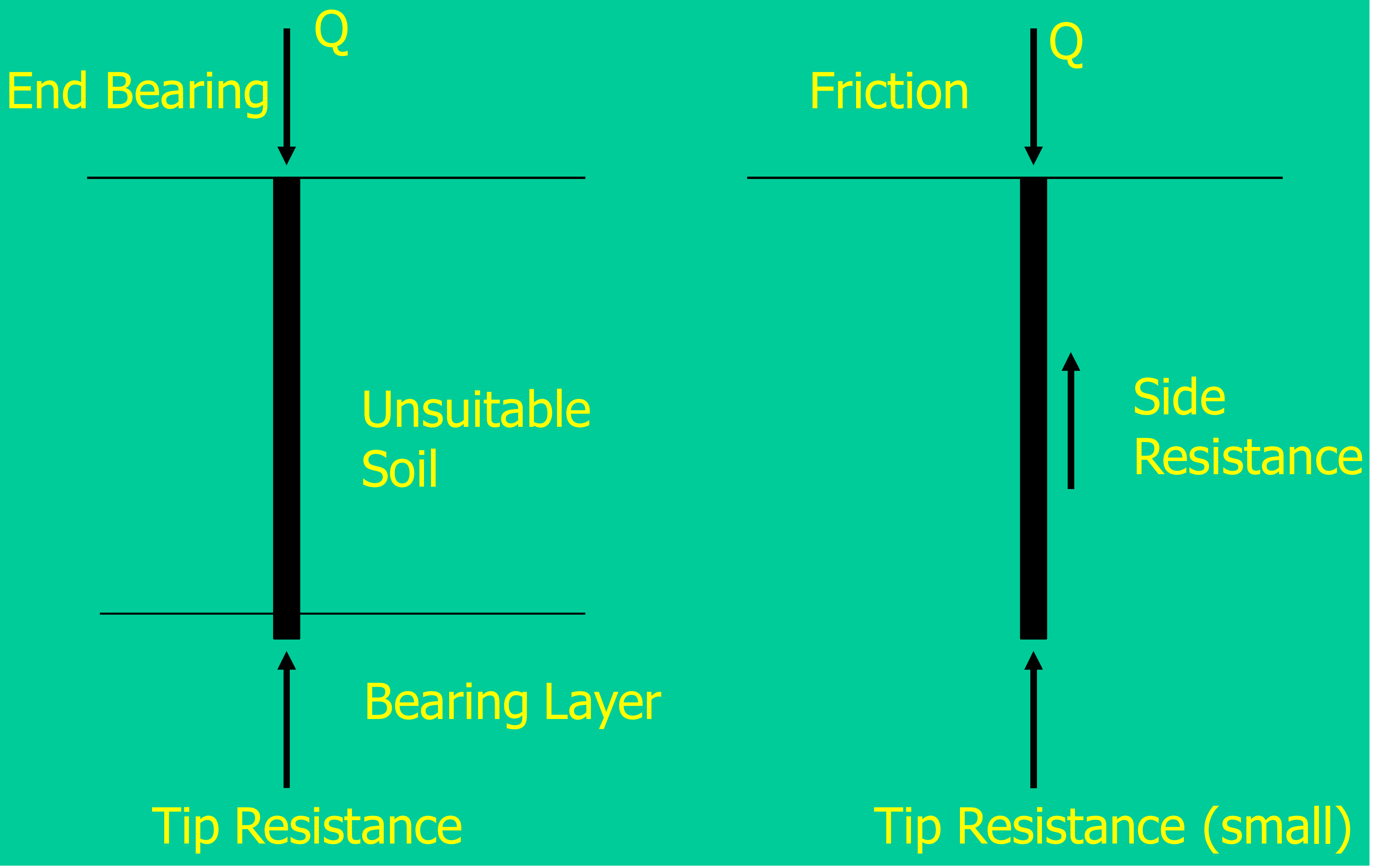
Deep Foundations

~ For transferring building loads to underlying ground

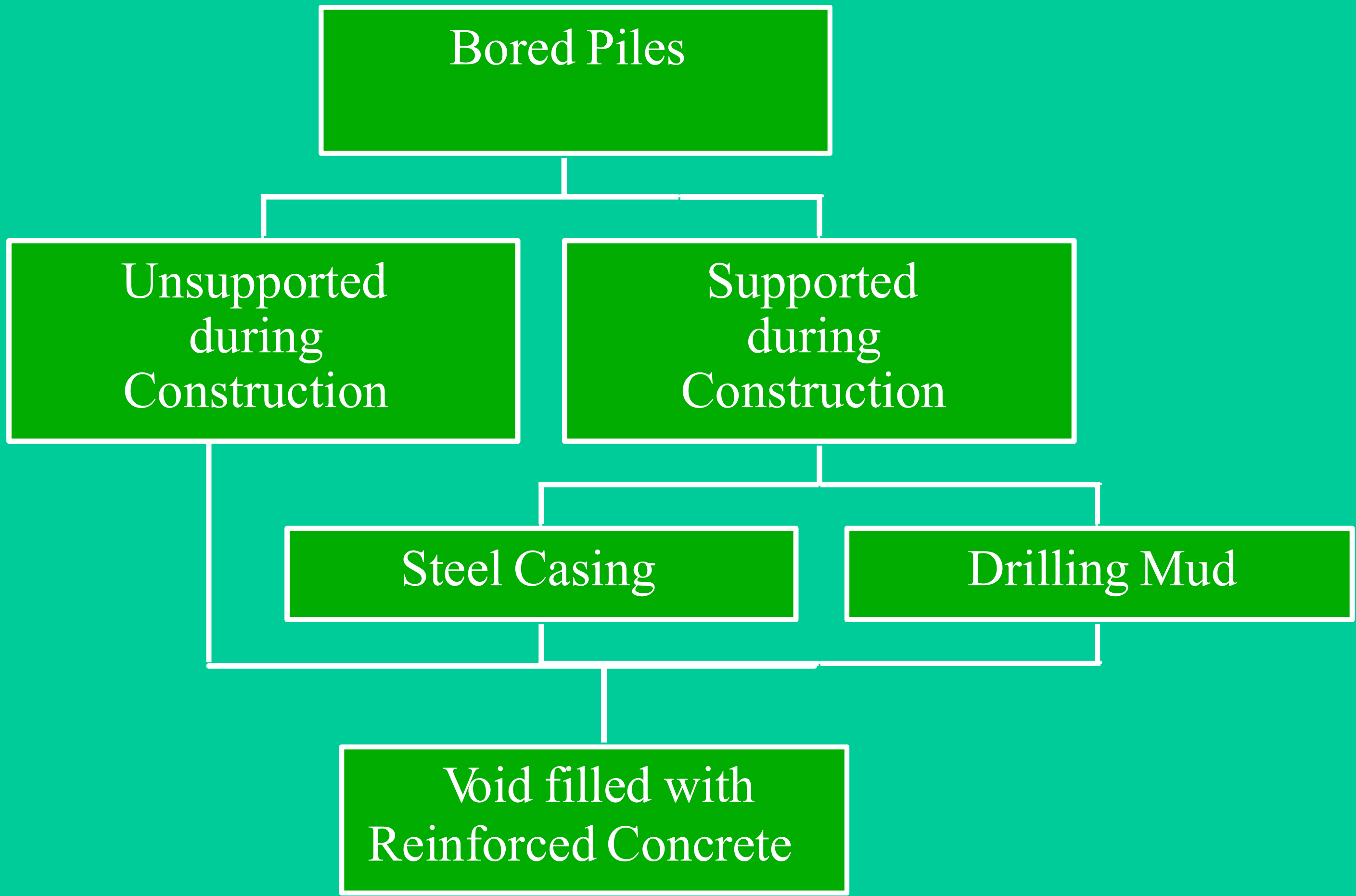
~ Mostly for weak soils or heavy loads



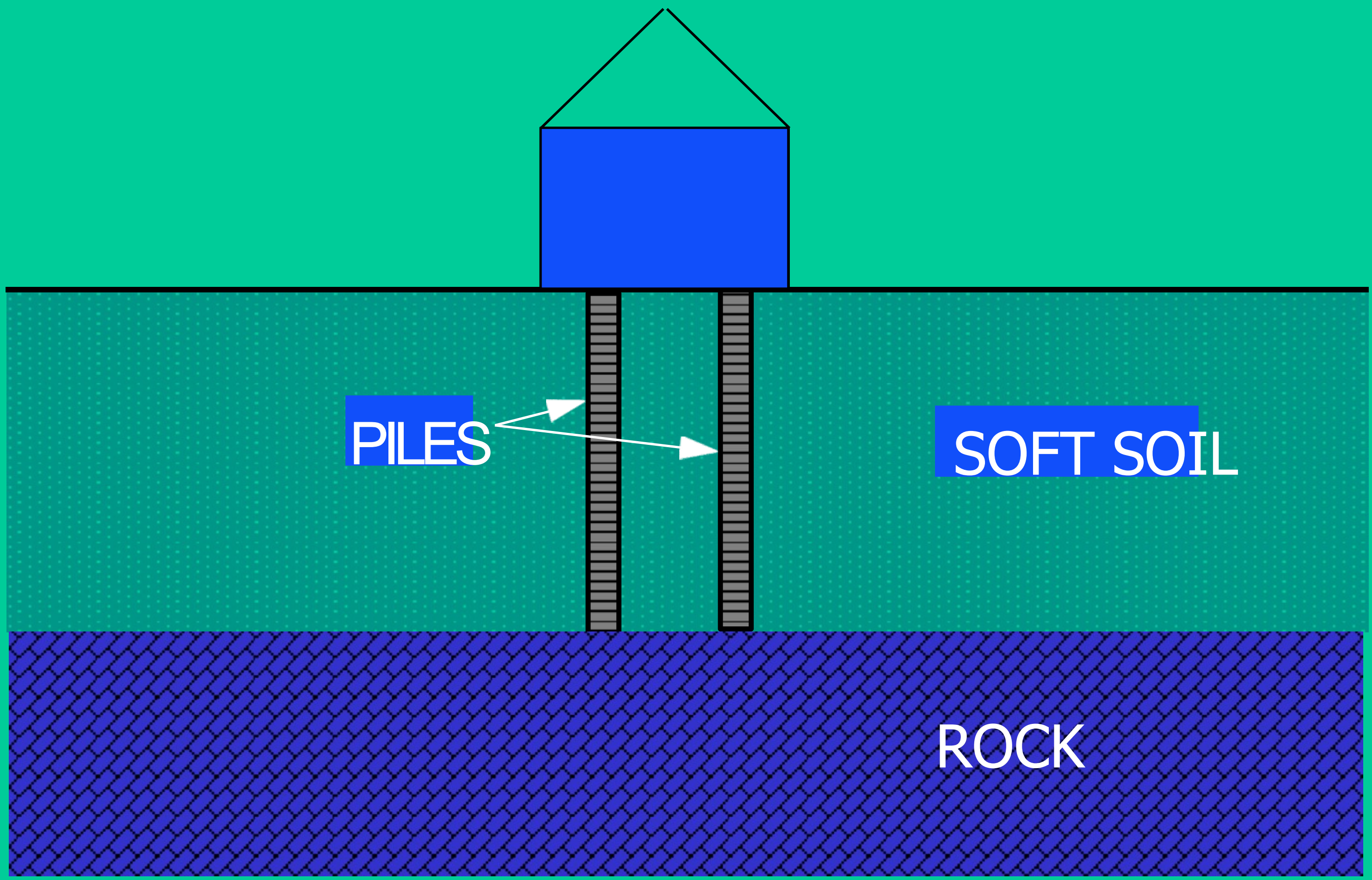
Deep Foundations Overview



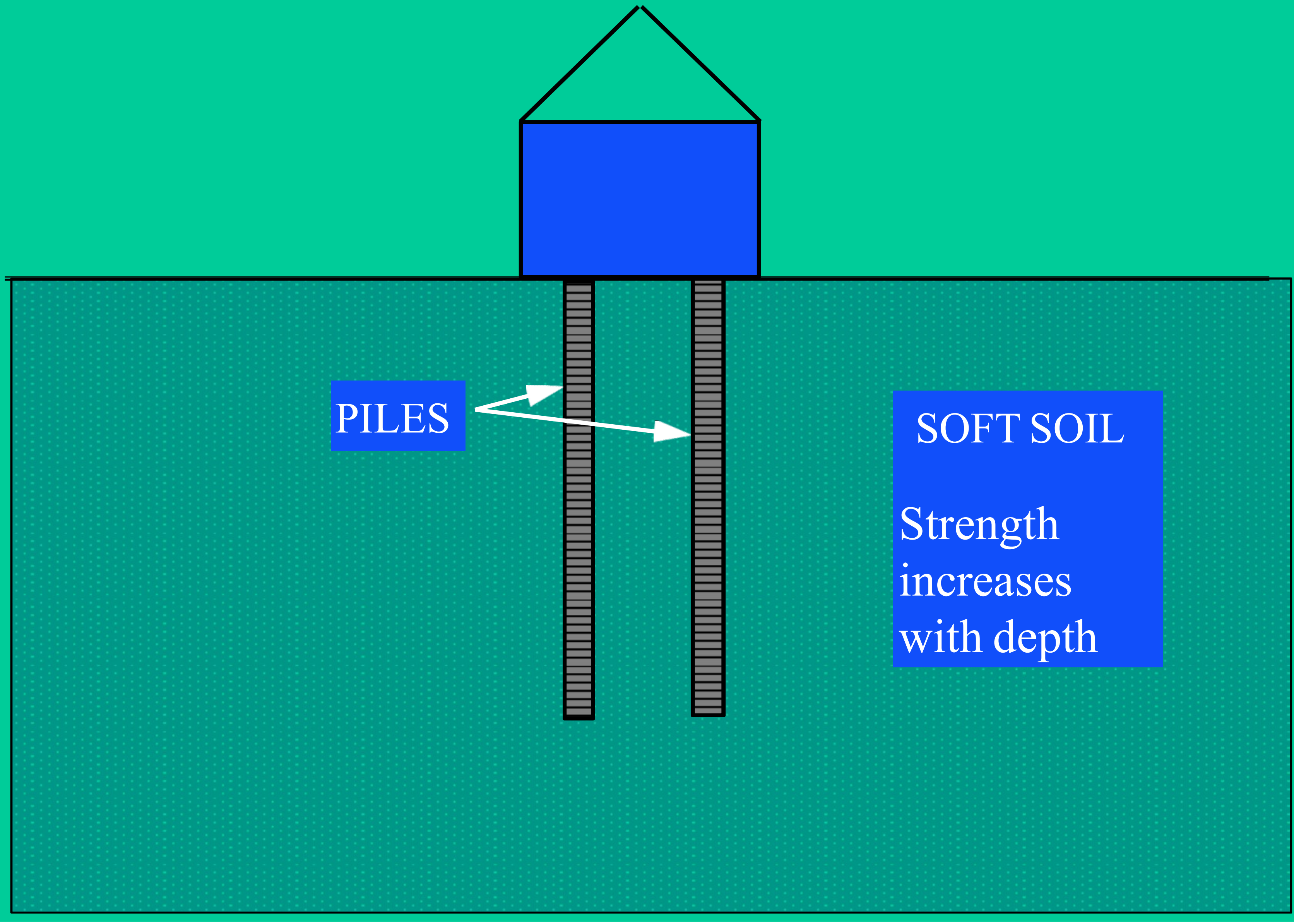
Types of Bored Piles



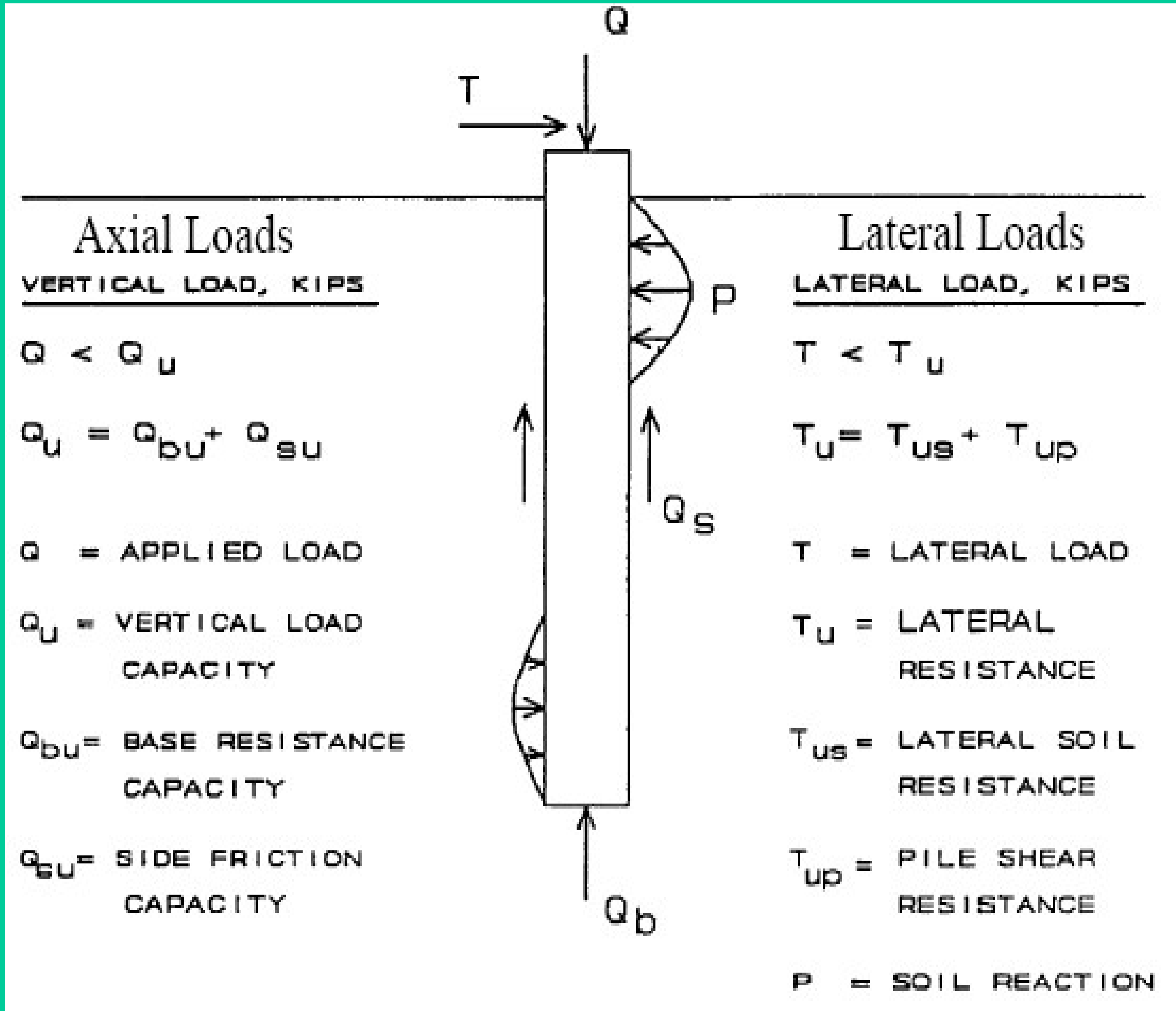
End Bearing Piles



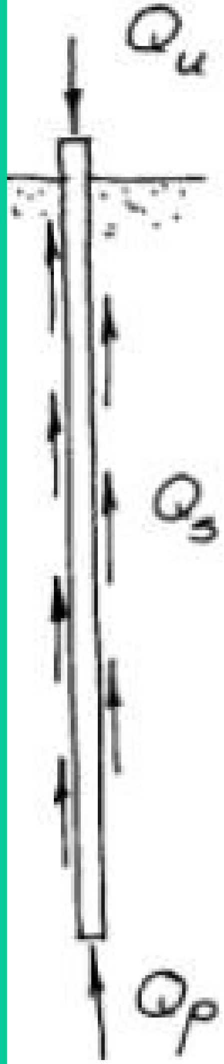
Friction Piles



Load Transfer



Basics



Compression.

$$Q_u = Q_s + Q_p$$

(a) $Q_{allow} = \frac{Q_u}{F}$ ← 2.5 to 4

(b) $Q_{allow} = \frac{Q_s}{F_a} + \frac{Q_p}{F_b}$

F_a, F_b ← Factor of safety

Tension.

$$T_u = Q_s + W$$

W ← weight of pile

(a) $T_{allow} = \frac{T_u}{F}$

(b) $T_{allow} = \frac{Q_s}{F_c} + \frac{W}{F_d}$

Tip Resistance in Sands

$$q'_t = B\gamma N^*_\gamma + \sigma'_{zD} N^*_q$$

- q'_t = net unit toe-bearing resistance
- B = pile diameter
- N^*_γ, N^*_q = bearing capacity factors
- γ = unit weight of soil immediately below the pile toe (use submerged weight below the phreatic surface
- σ'_{zD} = vertical effective stress at pile toe

Piles in Clay

$$q'_t = N^*_c s_u$$

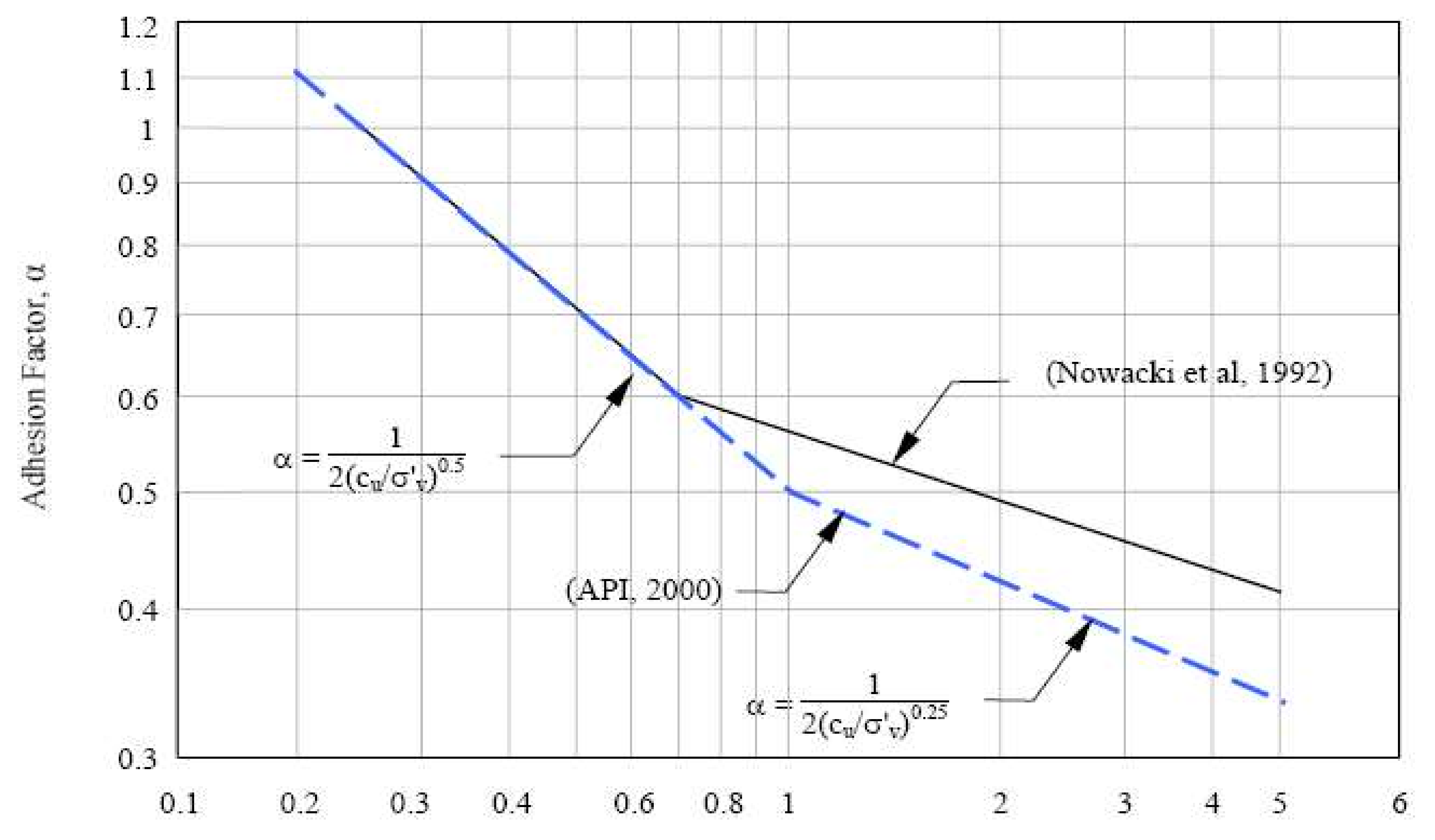
- q'_t = net unit toe-bearing pressure
- N^*_c = bearing capacity factor
  - 6.5 at $s_u < 25$ kPa (500 psf)
  - 8.0 at 25 kPa (500 psf) $< s_u <$ 100 kPa (1000 psf)
  - 9.0 at $s_u >$ 100 kPa (2000 psf)
- s_u = undrained shear strength between the toe and 2B below the toe

Shaft Resistance

$$f_s = \sigma'_x \tan \phi_f$$

- f_s = unit shaft friction resistance
- σ'_x = horizontal effective stress (i.e., perpendicular to the foundation axis)
- $\tan \varphi_f = \mu$ = coefficient of friction between the soil and the foundation
- φ_f = soil-foundation interface friction angle (some notations use δ)

Adhesion Factor, α - Bored Piles



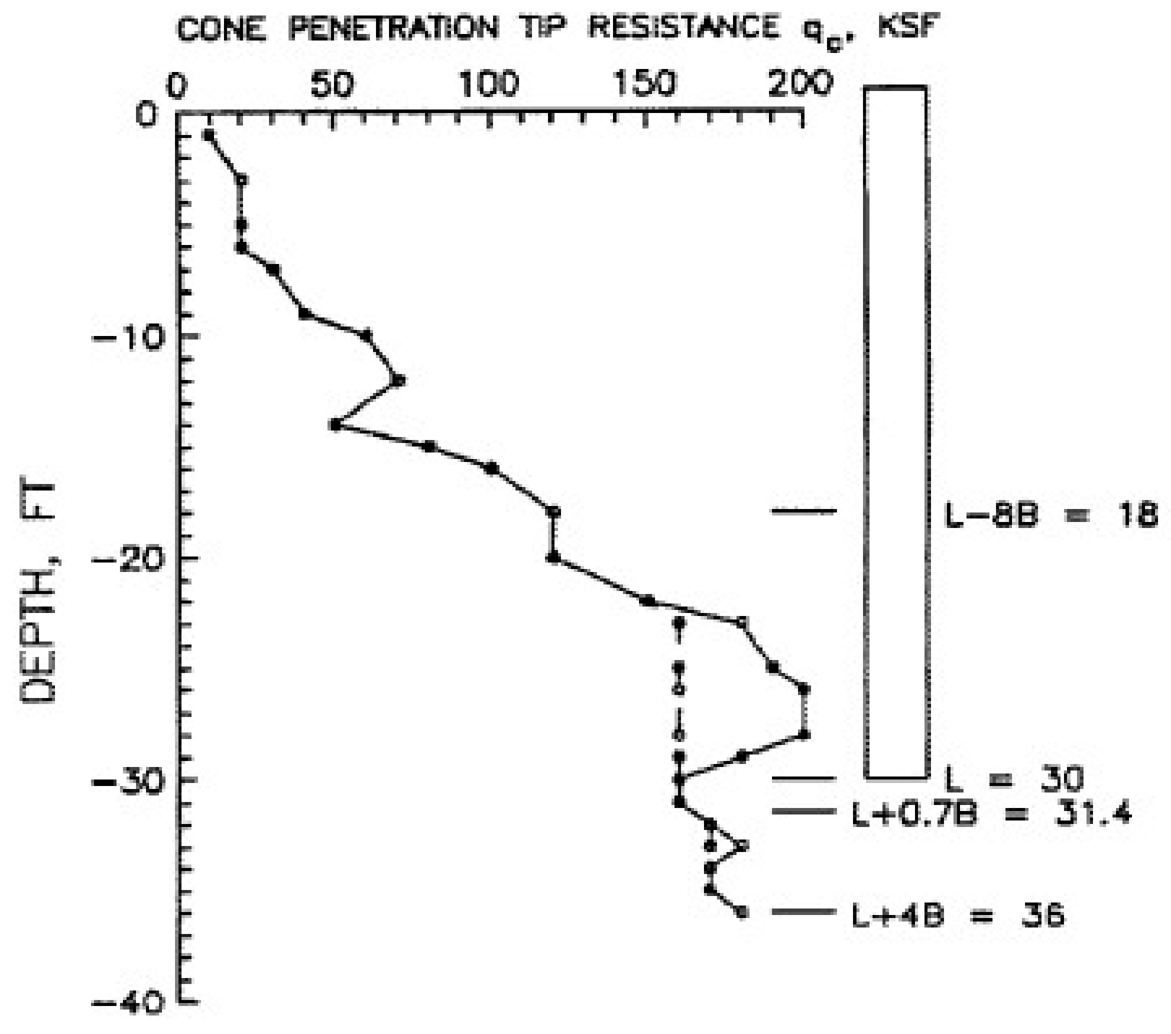
Design Based on SPT N

- q_{bu} (at S=0.01d) = (6 to 13)N
- q_{bu} = 5N below GWL in Soils
- q_{bu} = 10N above GWL

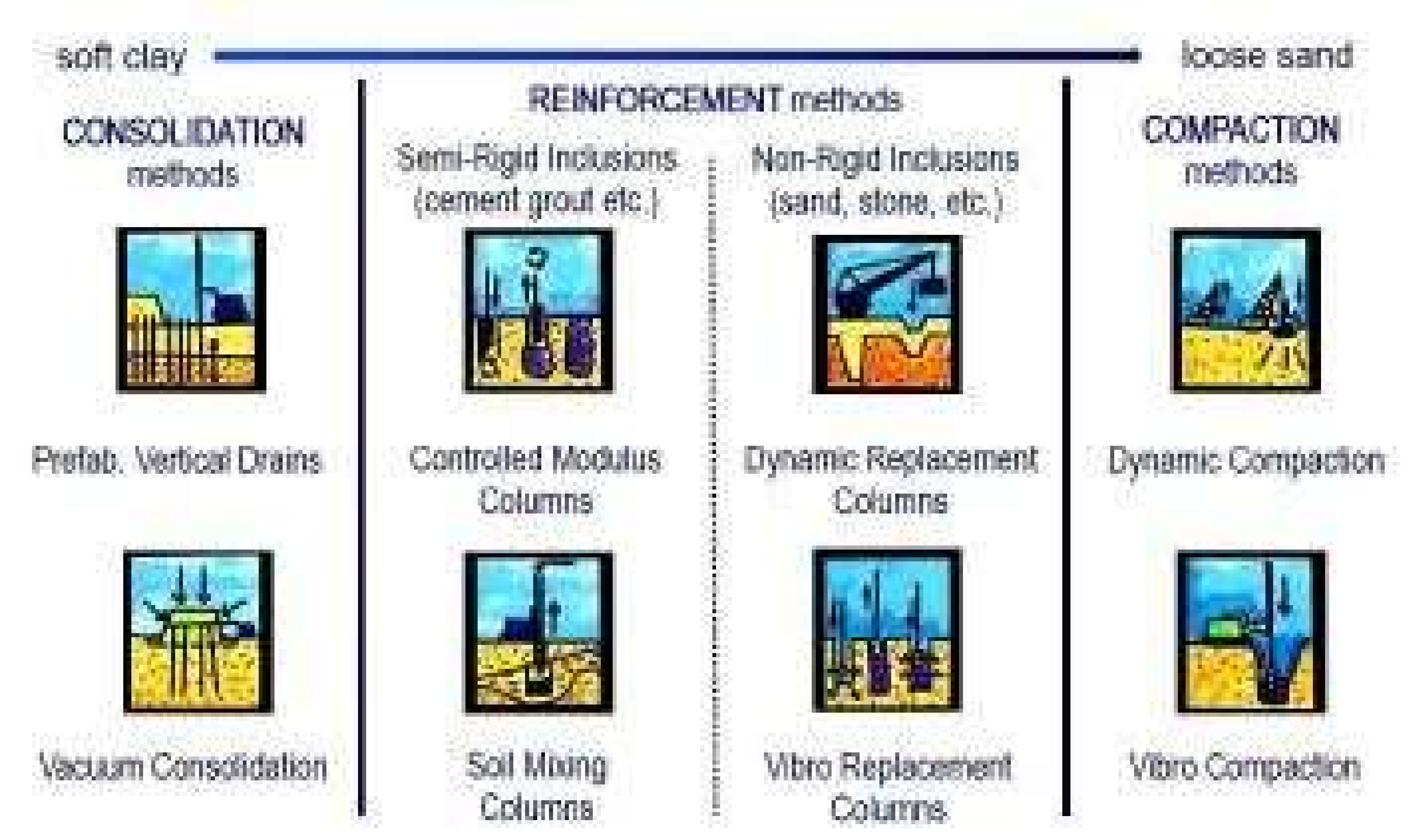
$q_{u,b}$ (from CPT)$=(q_{c1}+q_{c2})/2$

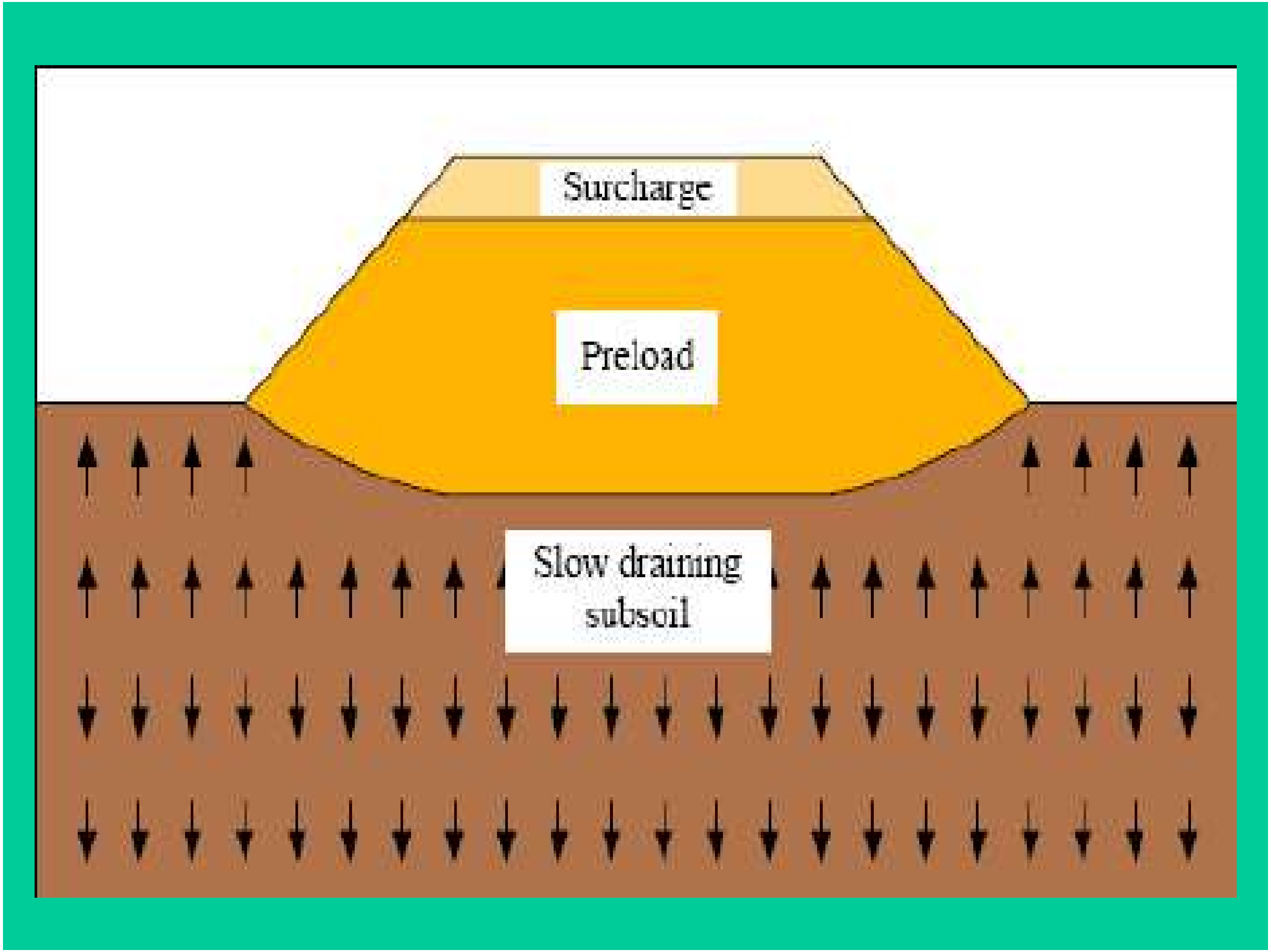
q_{c1}=Av. of q_c (L+0.7B to L+4B) &

q_{c2}=Av. of q_c(L-8B to L)



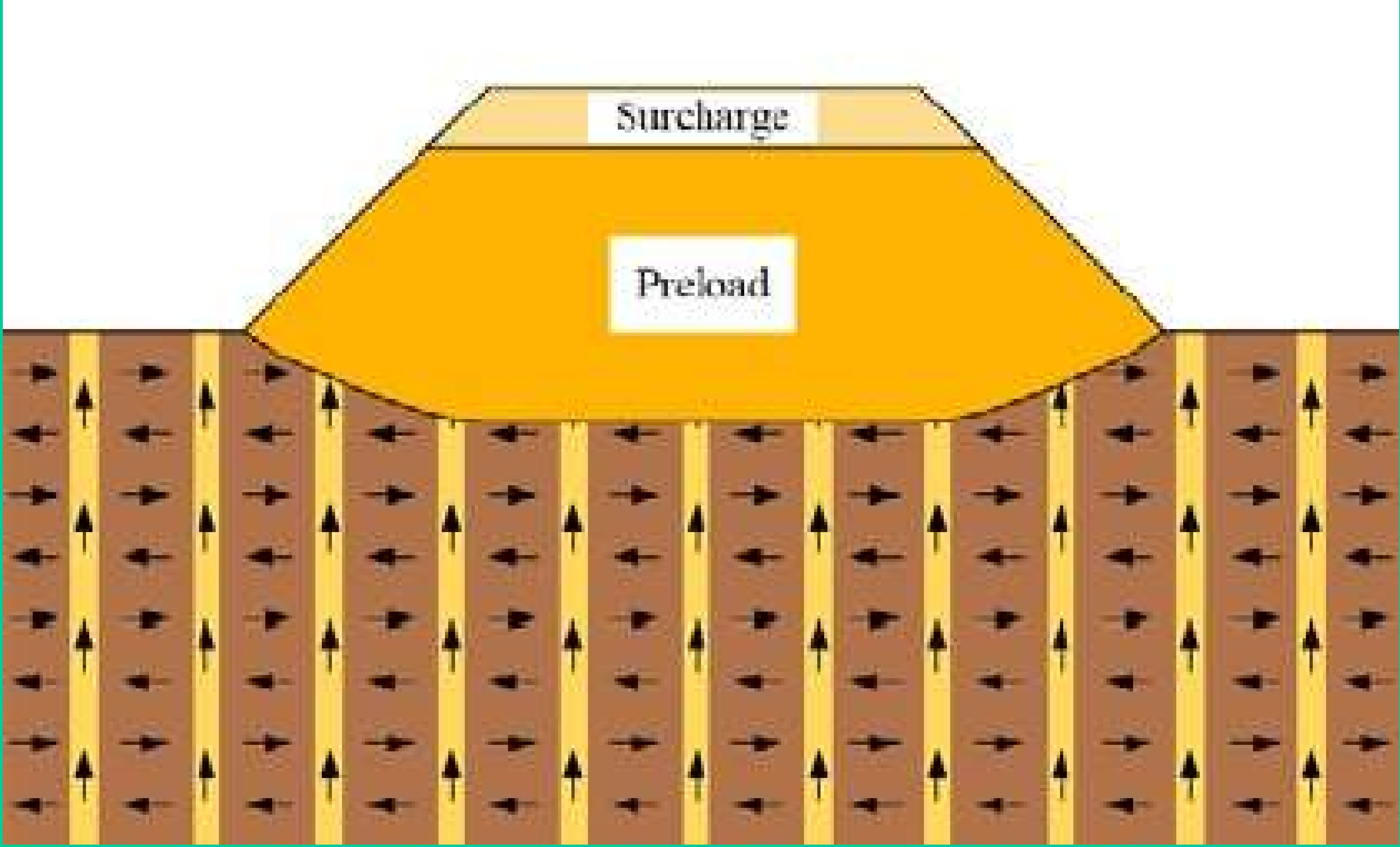
Gr. Impr. Methods



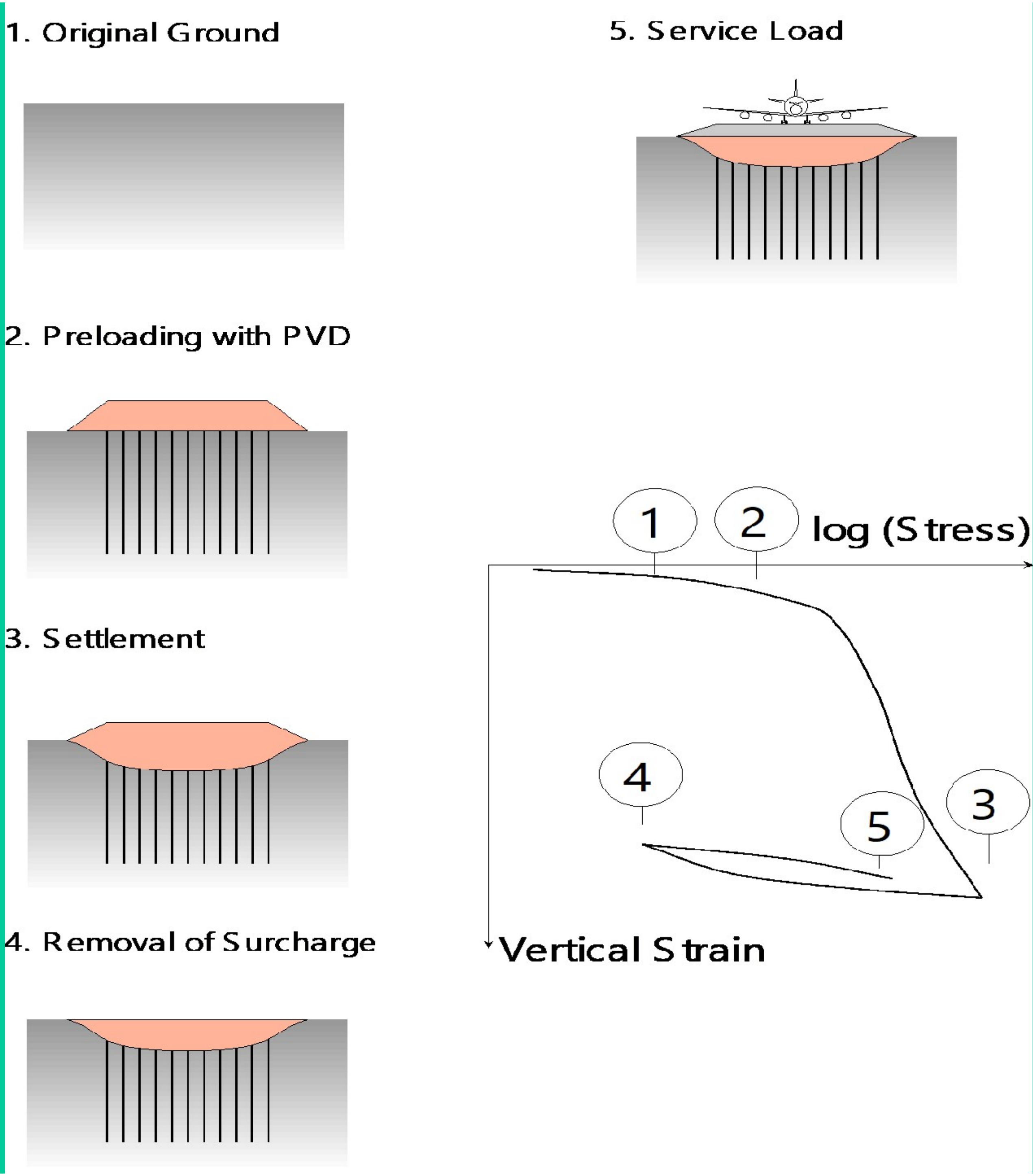


Surcharge
Preload
Slow draining
subsoil

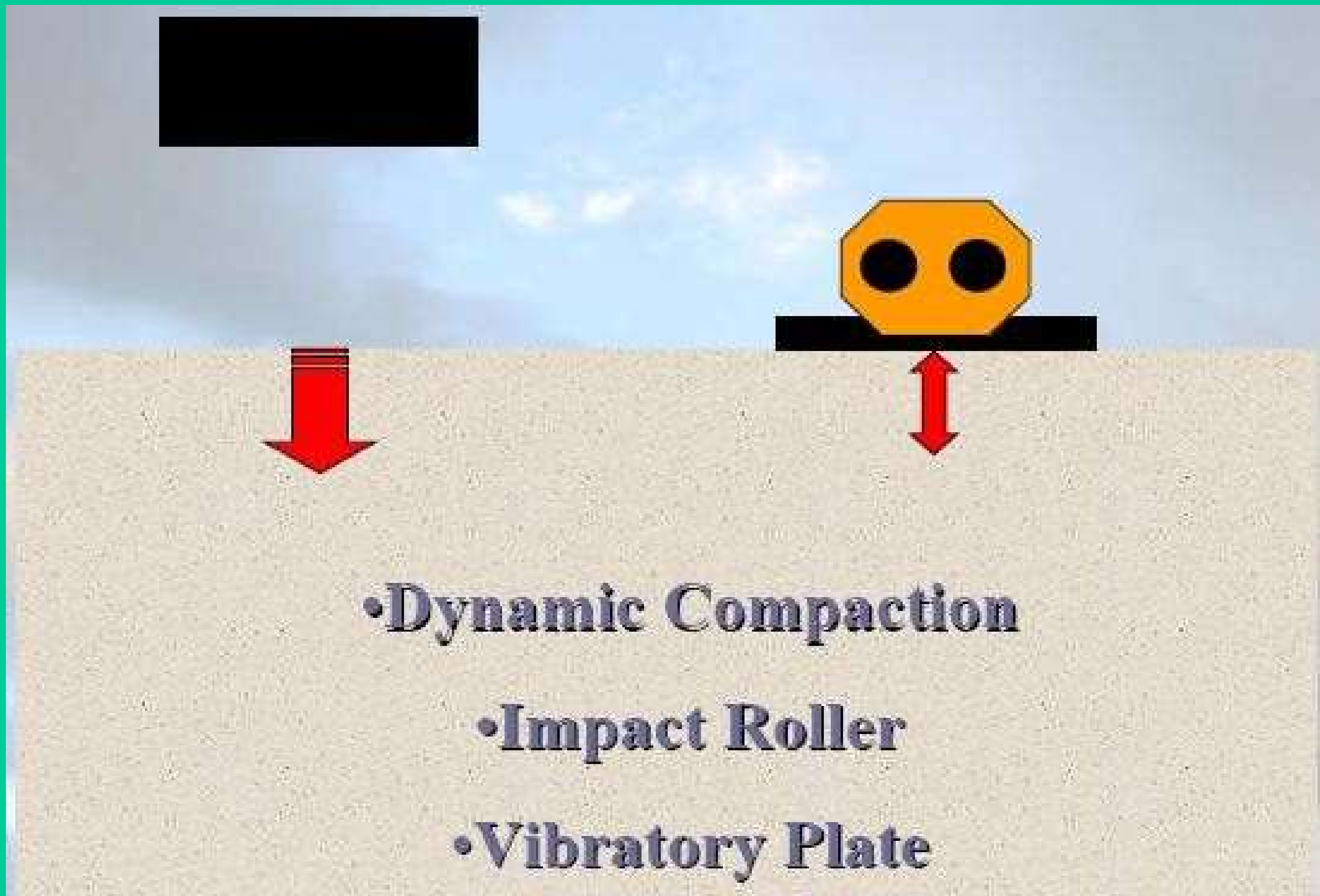
Preload + Vertical Drains



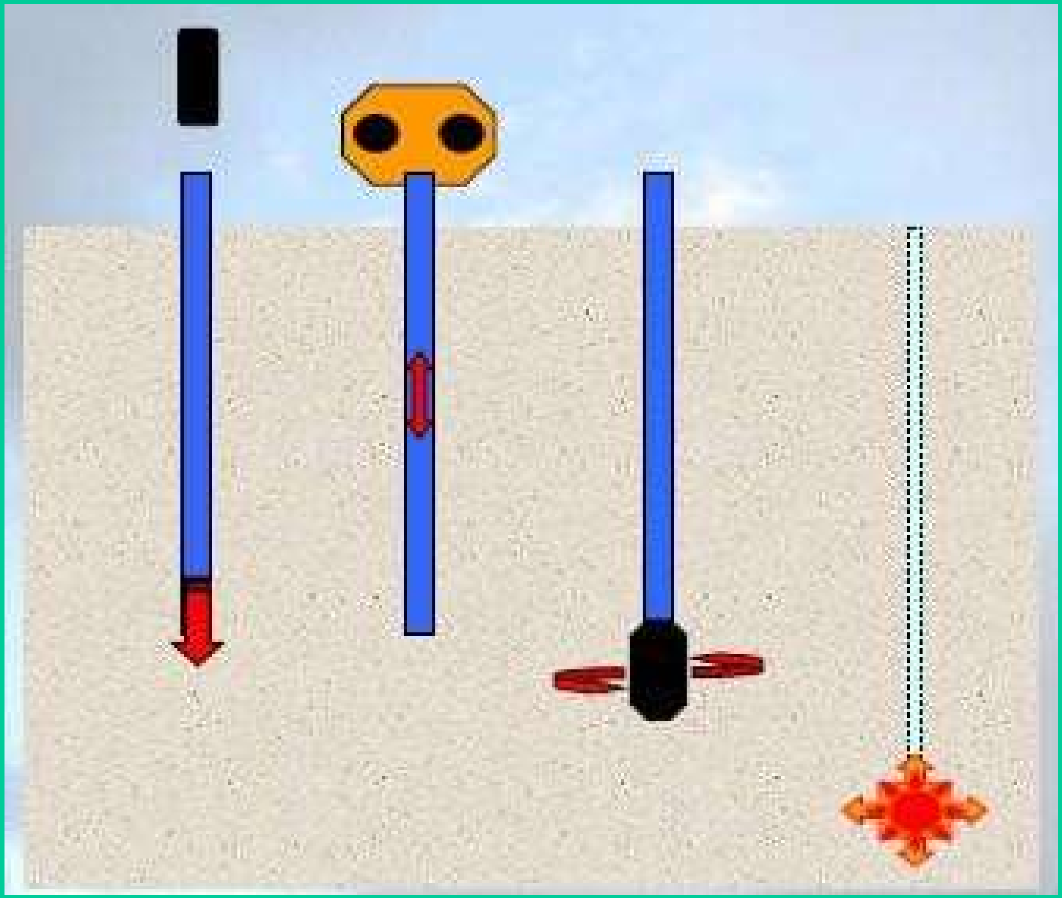
Stages in Preloading



Energy applied at Ground Surface



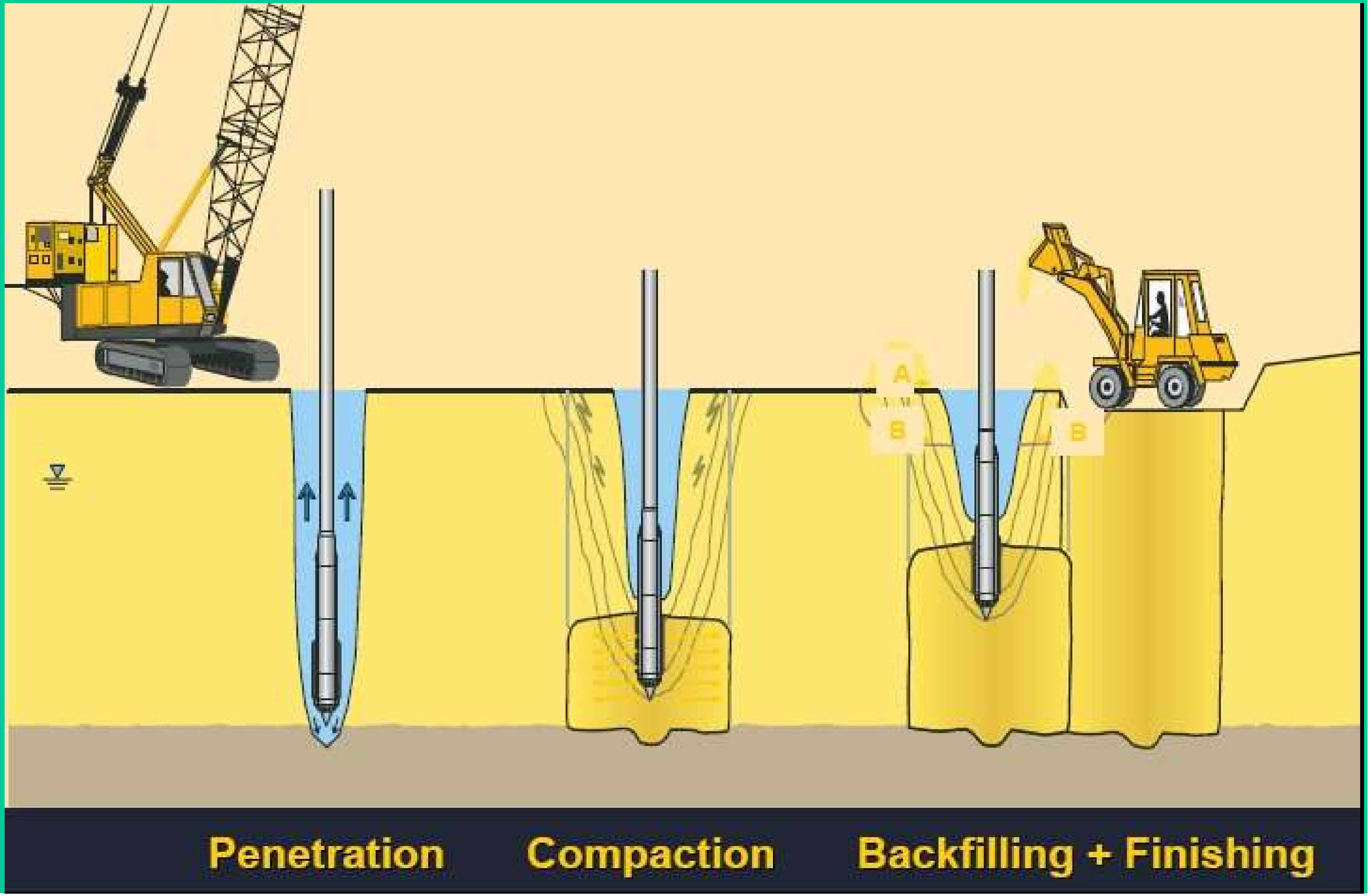
Energy Transfer below Ground Surface



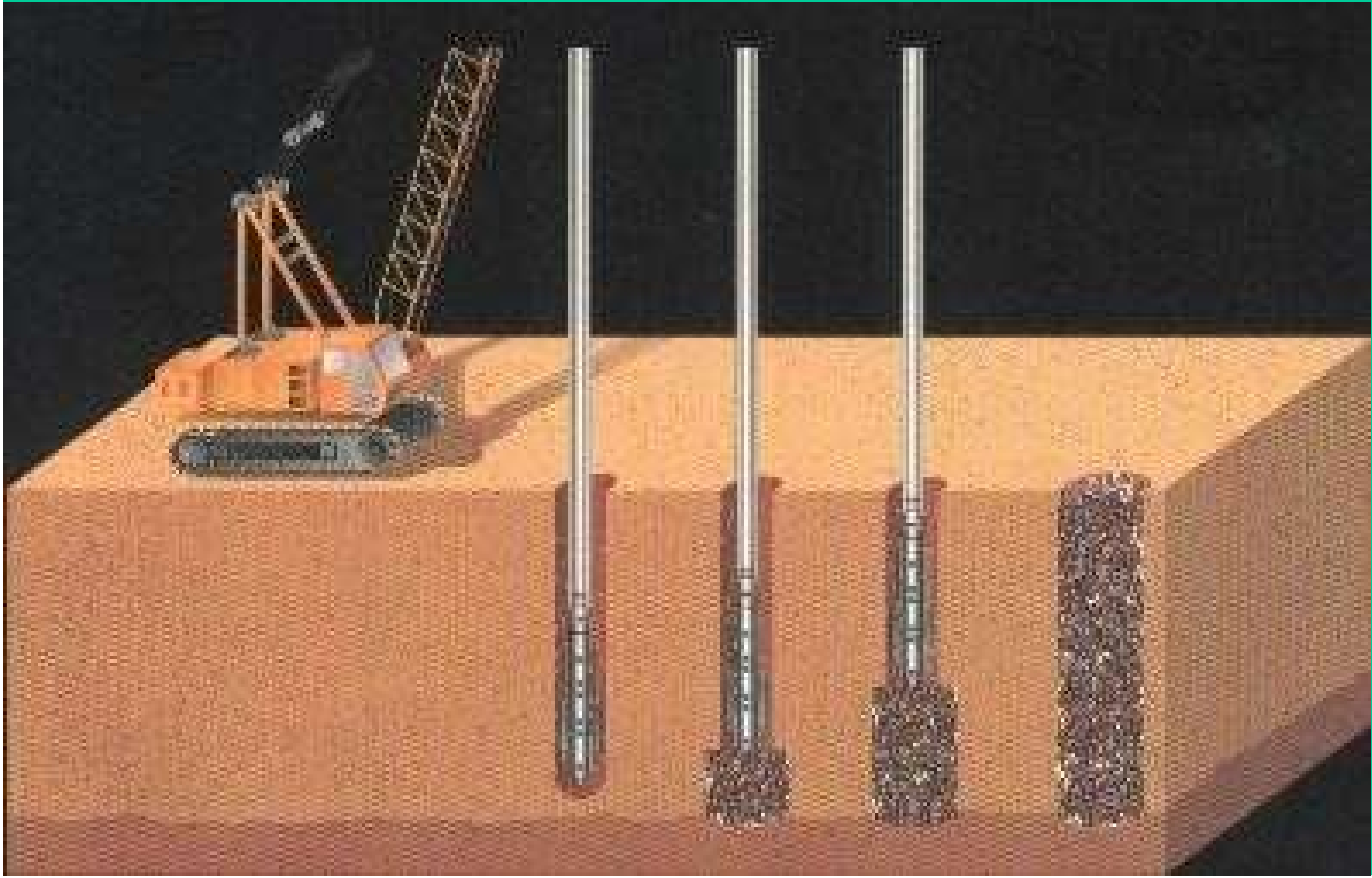
Displacement Pile Method, Driven Stone Column, Vibro--Probes

Resonance Compaction; Vibro-flotation; Explosives

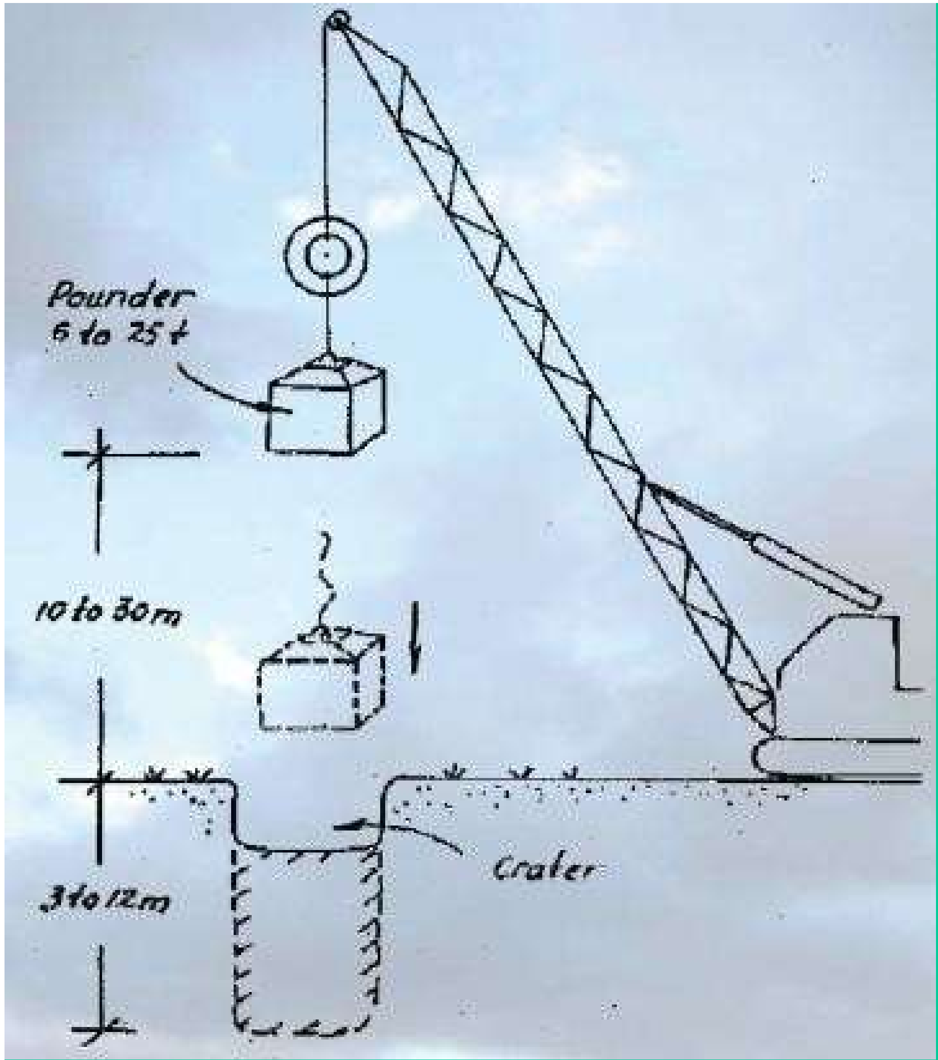
Vibro-Compaction

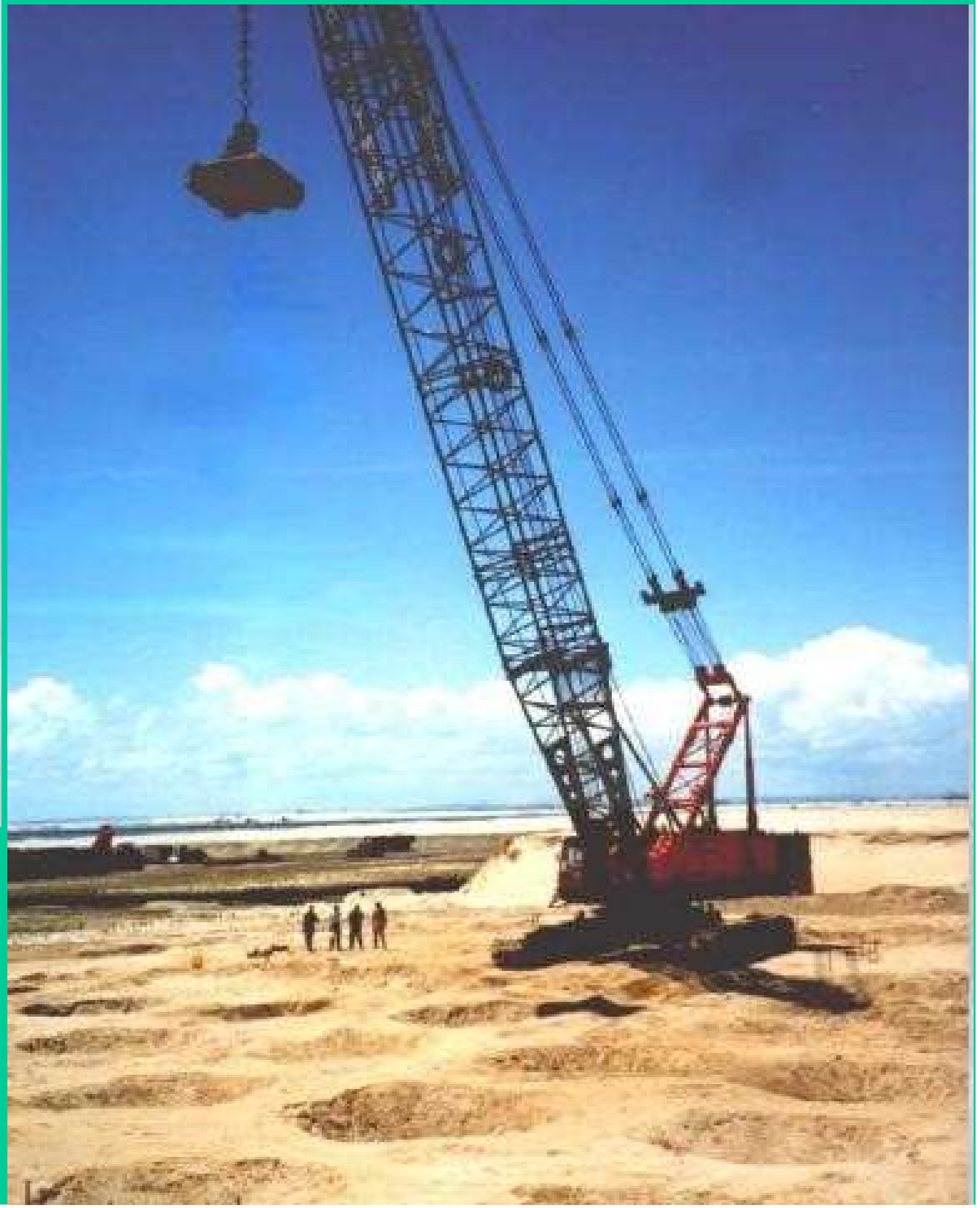


Vibro-Replacement

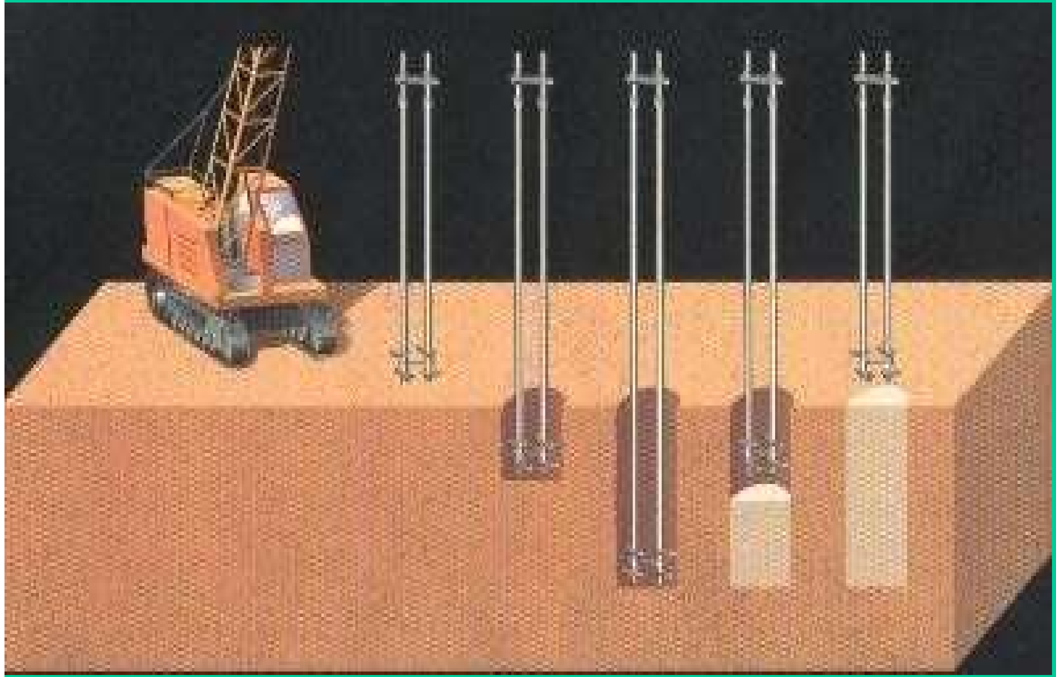


Heavy Tamping

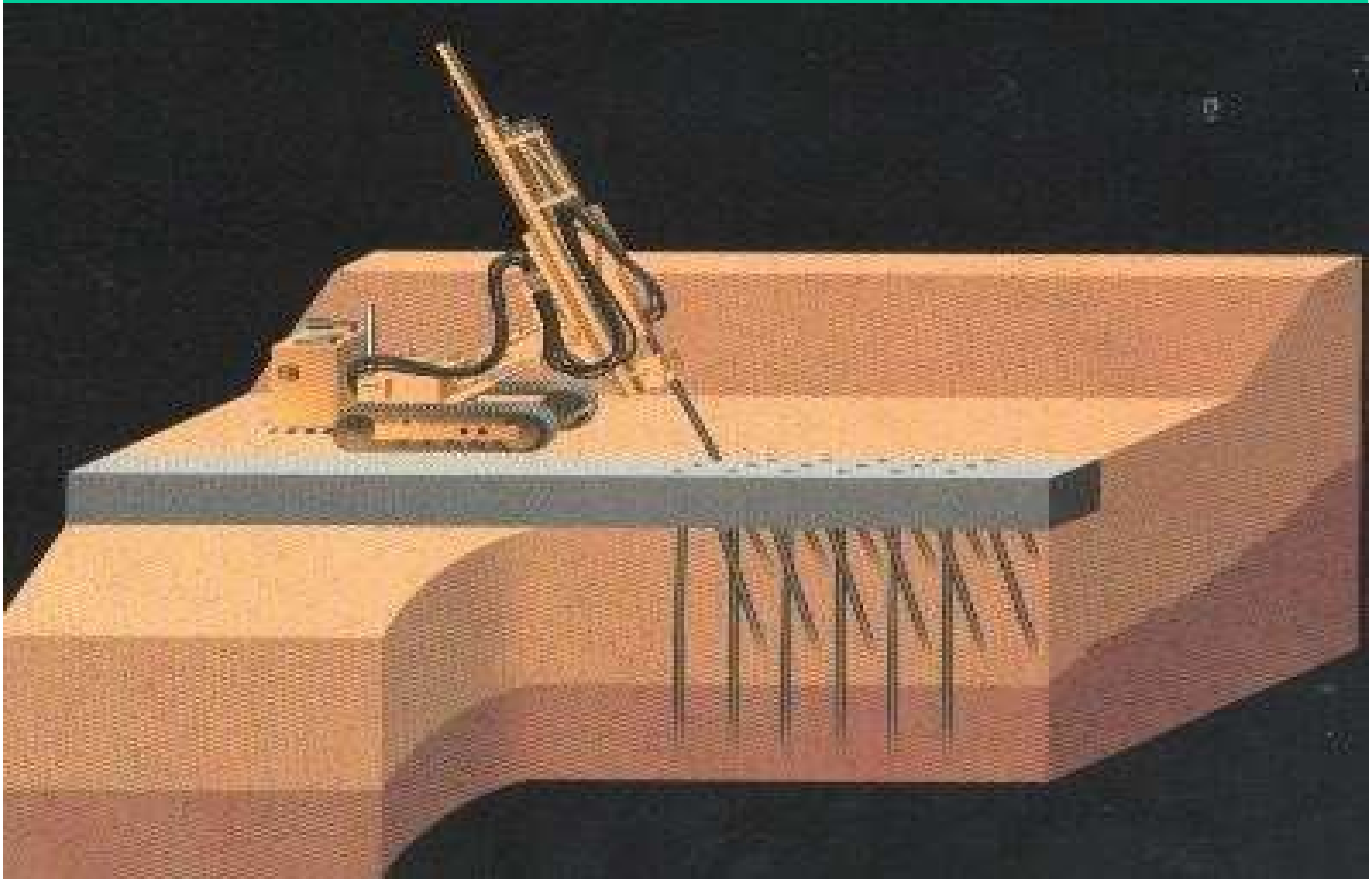




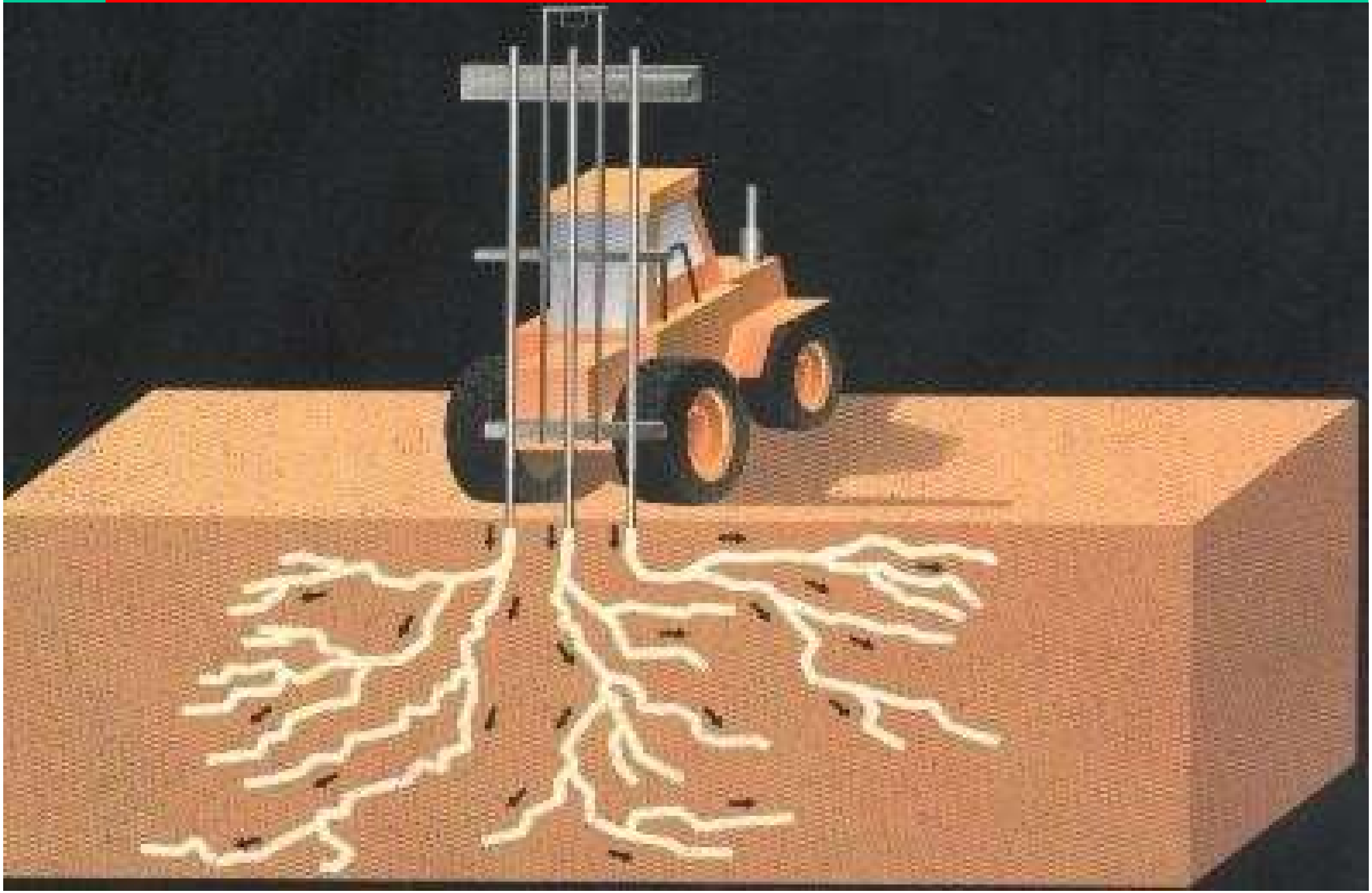
Deep Mixing – Cement/Lime



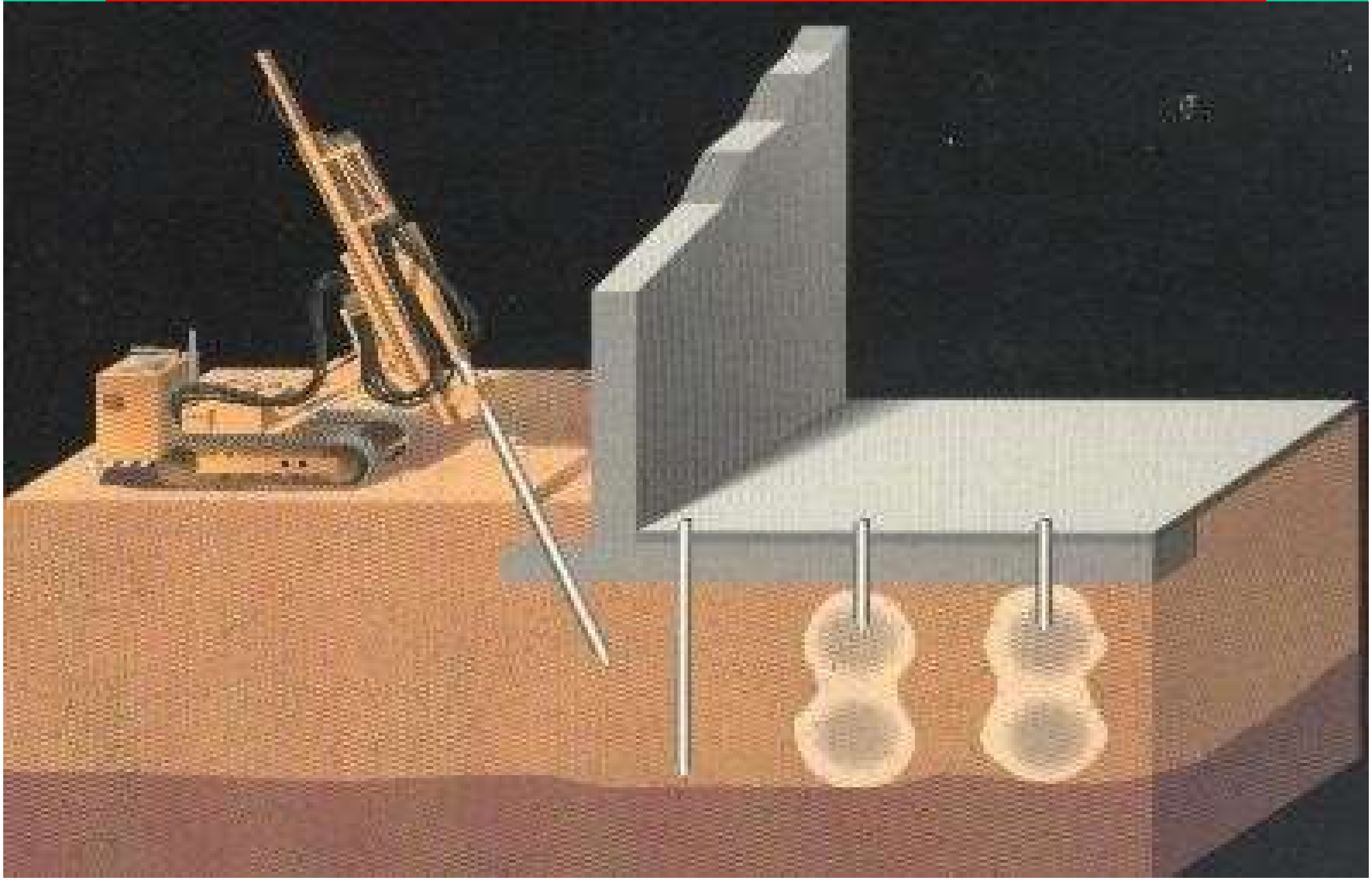
Micro-Piling



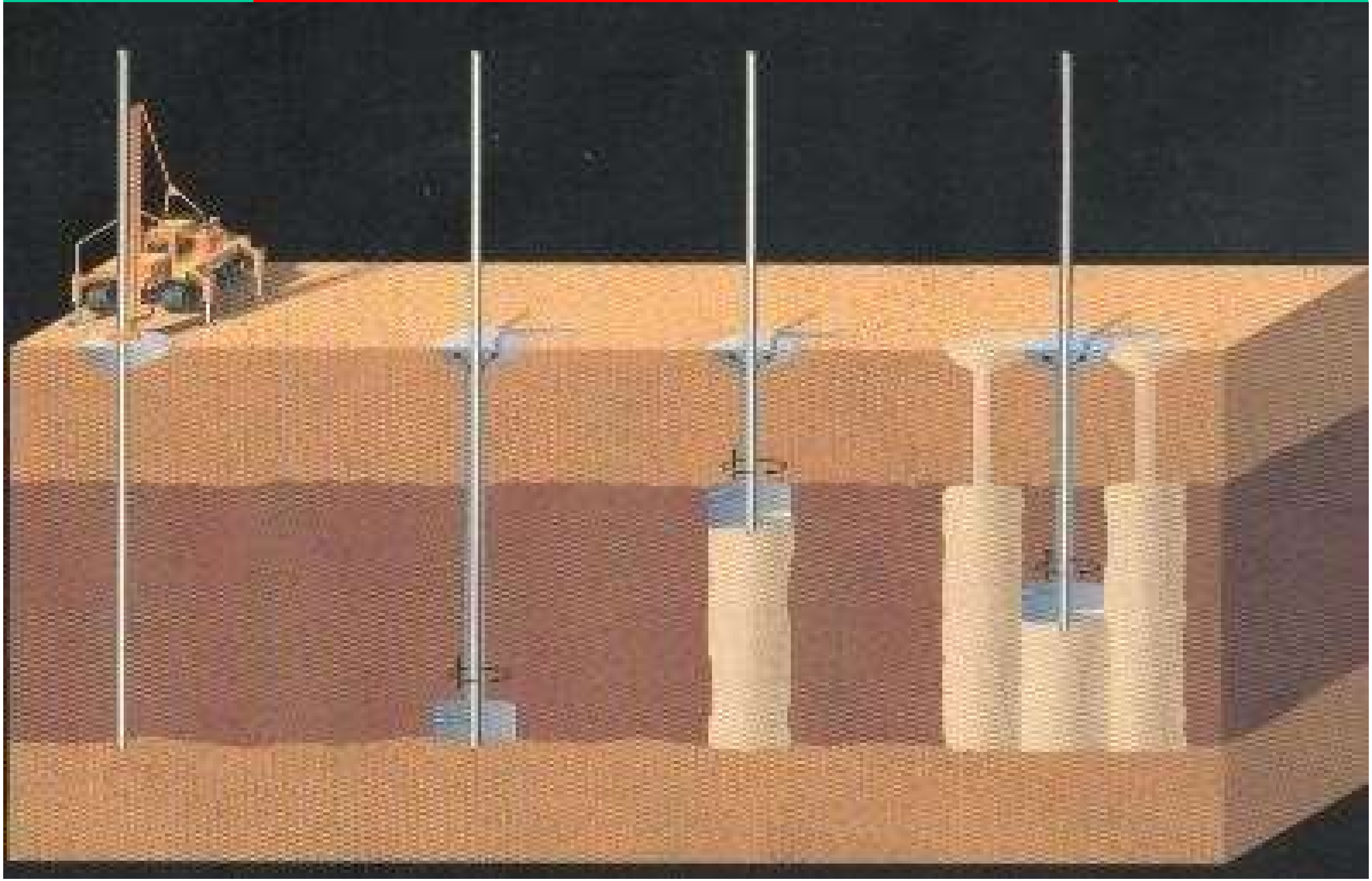
Injection Grouting



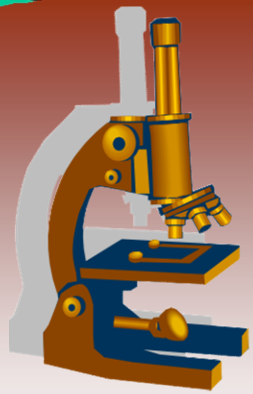
Compaction Grouting



Jet Grouting



GEOTECHNICAL ENGINEERING



IS A SCIENCE

BUT ITS PRACTICE