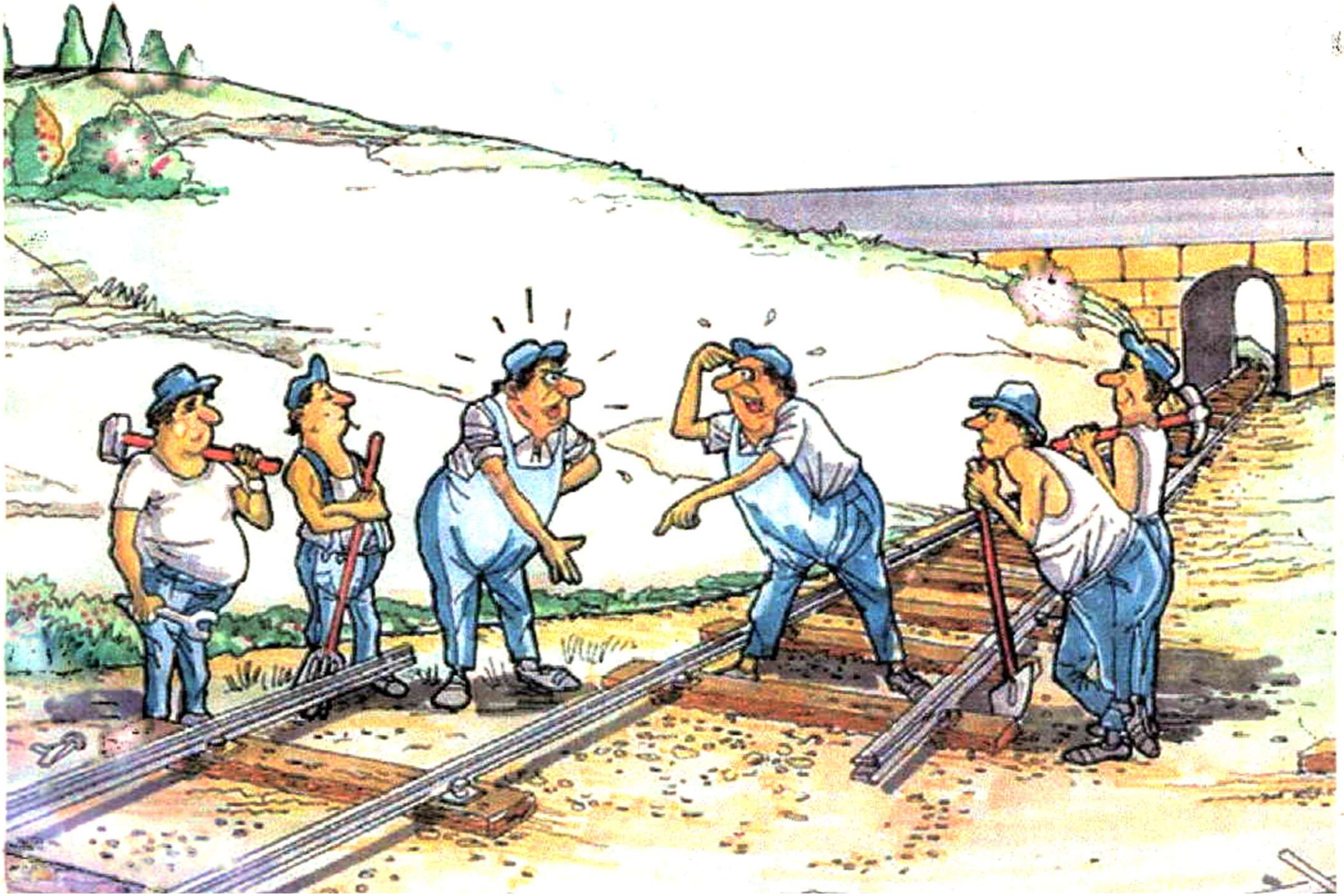
Team Work



Geotechnical Aspects of Foundations for Tall Structures

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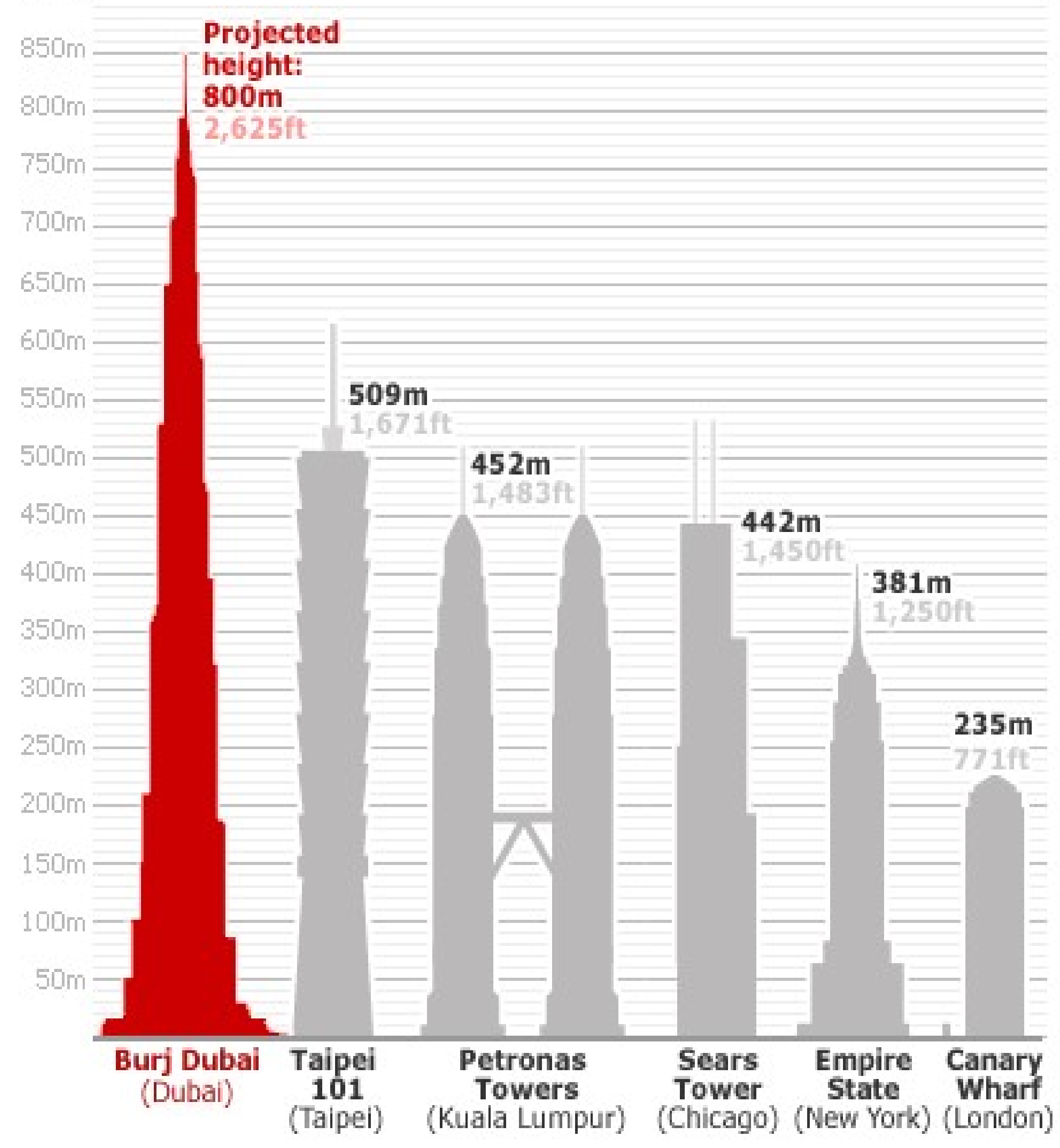


World's Tallest Structures

Structural & Geotechnical Design

- Structural Mechanics – Given Geometry, Material Properties and Loading – Theoretical Solutions Possible
- Design Code Based
- Geotechnical Engineering –
  - Highly Variable Geometry
  - Material Properties NOT Precisely Determinable
  - Loading Complex

Practice **Judgement** Based

Structural & Geotechnical Engineers

- Structural Engineers
- Steel –Quality Assured
- Concrete -Manufactured Material - RMC or At Site
- Geotechnical Engineers – Material Made by Nature or God - Highly Variable Properties – No Choice

Structural & Geotechnical Engineers

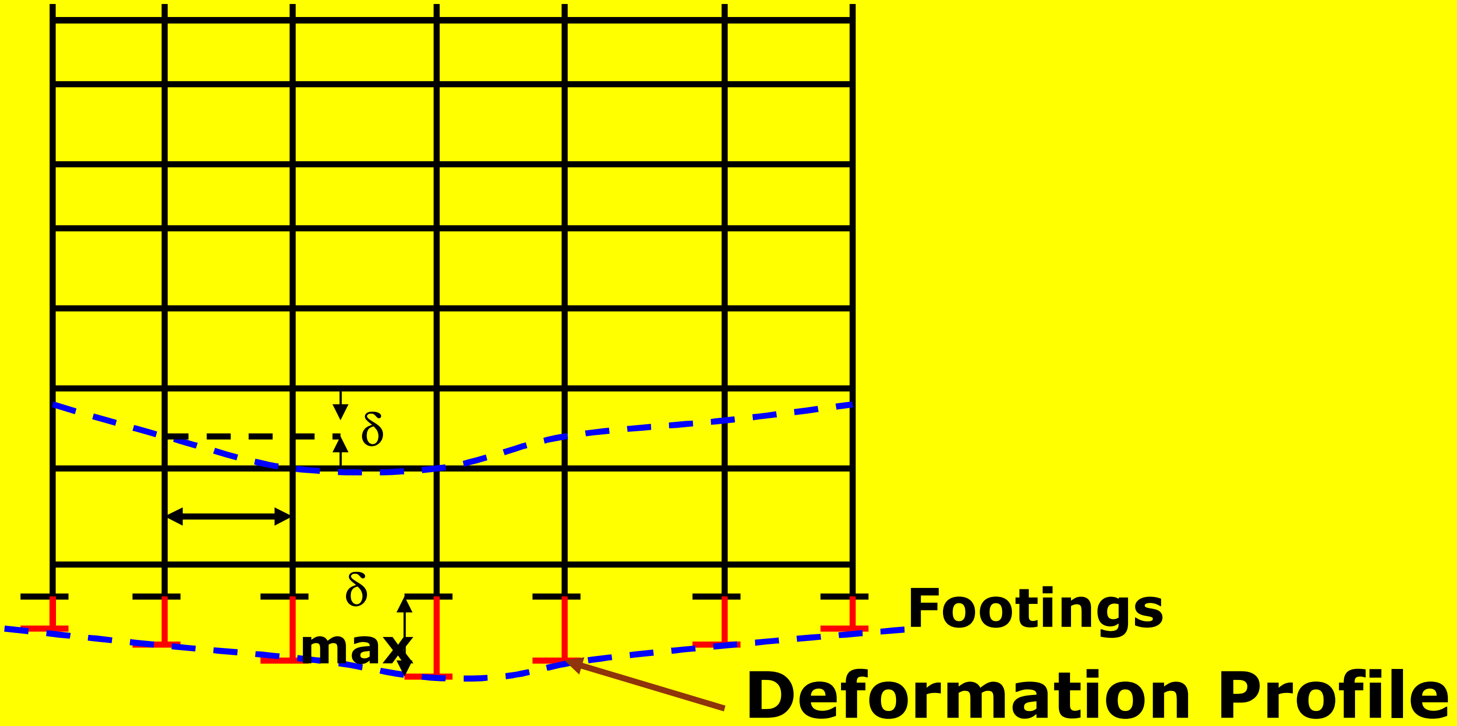
- Men are from Mars and
- Women are from Venus – John Gray
- Structural Engineers are from Mars
- &
- Geotechnical Engineers are from Venus!!!

Complexity in Ground – Foundation- Structural Interaction

- Uncertainty in In Situ Ground Conditions
- Limited Exploration
- Intrinsic Soil Behaviour Complex
- Interface Conditions-Difficult to Predict
- Nature and Condition of Existing Buildings
- Response of Building?
- Lack of Symmetry of Building-3D Effect
- Methods of Construction-Varied

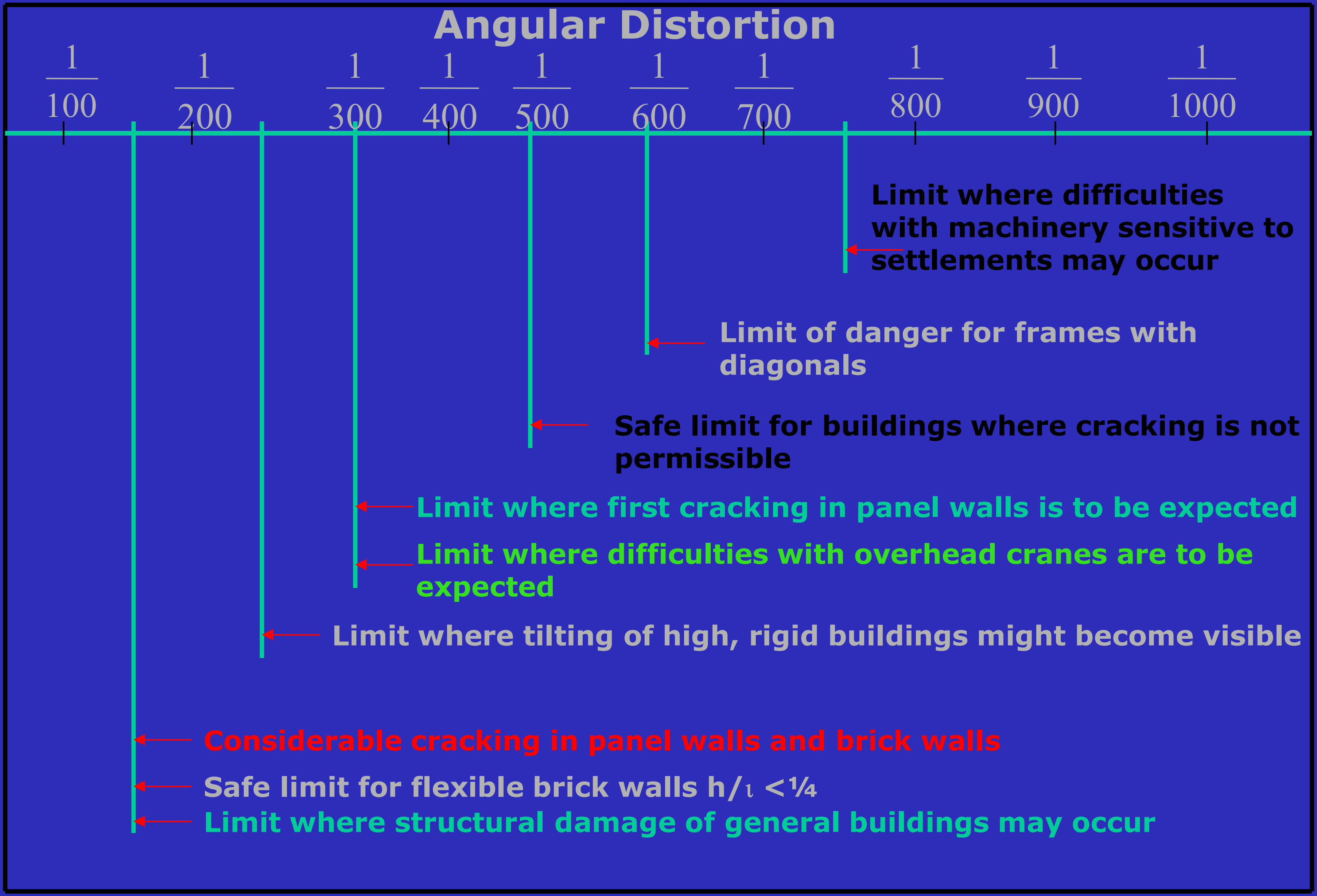
DESIGN CRITERIA

1. Collapse – Bearing/Ultimate Capacity failure
2. Serviceability - Excessive Settlement - Cracks & Tilt



- Maximum Settlement : δ_{max}
- Angular Distortion : δ/ι

- Uniform settlement
- Non – uniform settlement - structural distress and ultimate collapse



Angular Distortion

$\frac{1}{100}$ $\frac{1}{200}$ $\frac{1}{300}$ $\frac{1}{400}$ $\frac{1}{500}$ $\frac{1}{600}$ $\frac{1}{700}$ $\frac{1}{800}$ $\frac{1}{900}$ $\frac{1}{1000}$

Limit where difficulties with machinery sensitive to settlements may occur

Limit of danger for frames with diagonals

Safe limit for buildings where cracking is not permissible

Limit where first cracking in panel walls is to be expected

Limit where difficulties with overhead cranes are to be expected

Limit where tilting of high, rigid buildings might become visible

Considerable cracking in panel walls and brick walls

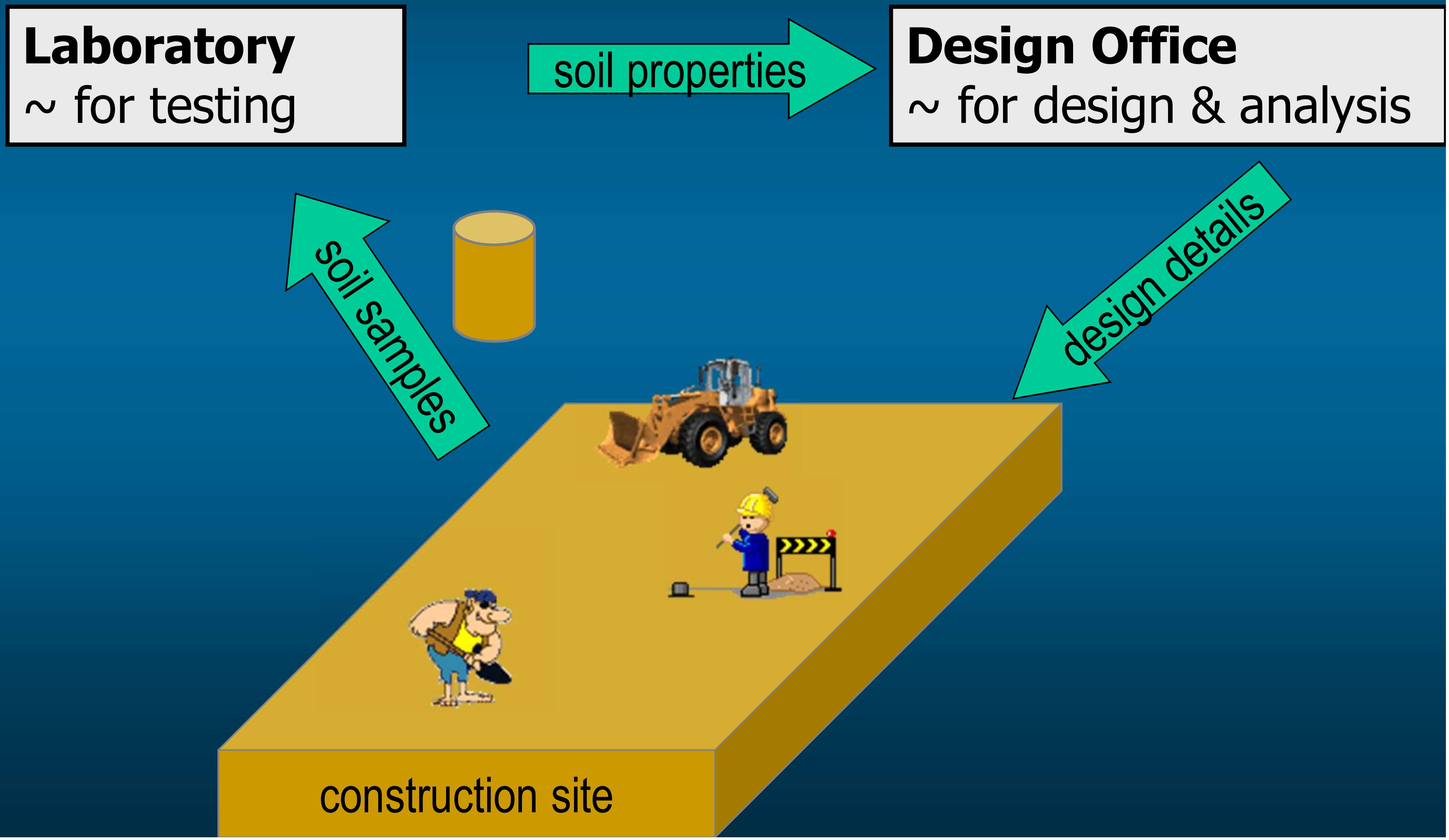
Safe limit for flexible brick walls h/ι <¼

Limit where structural damage of general buildings may occur

LIMITING ANGULAR DISTORTION FOR STRUCTURES

(BJERRUM 1993)

Typical Geotechnical Project



Laboratory
~ for testing

soil properties

Design Office
~ for design & analysis

soil samples

design details

construction site


Porous (sandy)
Clays

CHARACTERISE THE GROUND

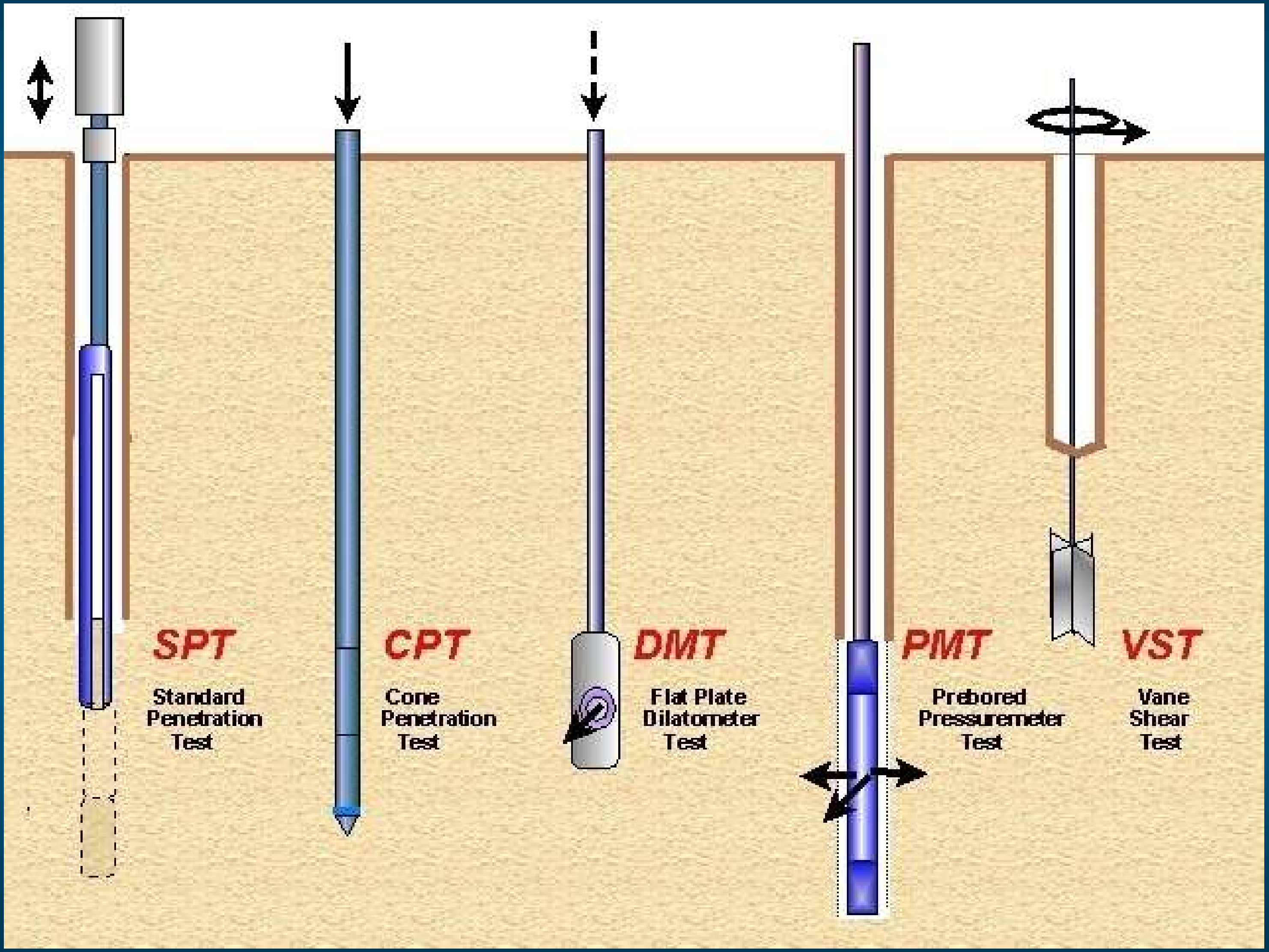
> “If you do not know
> what you are looking for
> in
> site investigation,
> you are not likely to find
> much of value.”

R. Glossop-

8th Rankine Lecture

- You
- PAY
- for Geotechnical Investigations whether you get them done or NOT

In-Situ Geotechnical Tests



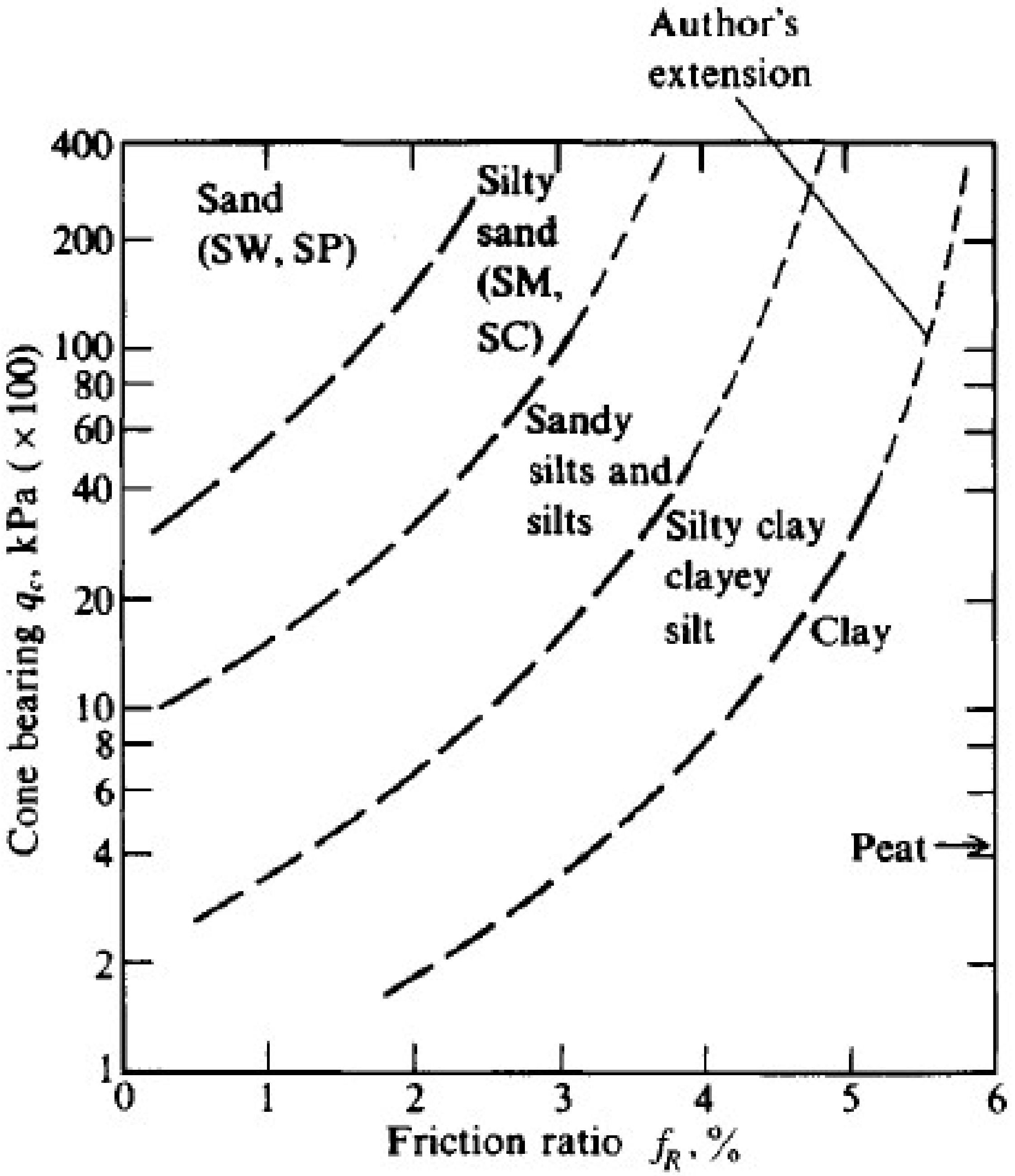
Relative density from SPT N

No of blows (N/30 cm)	*Relative density* $RD = \frac{(emax - e)}{(emax - emin)} x100\ \%$	*Degree of compaction*
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

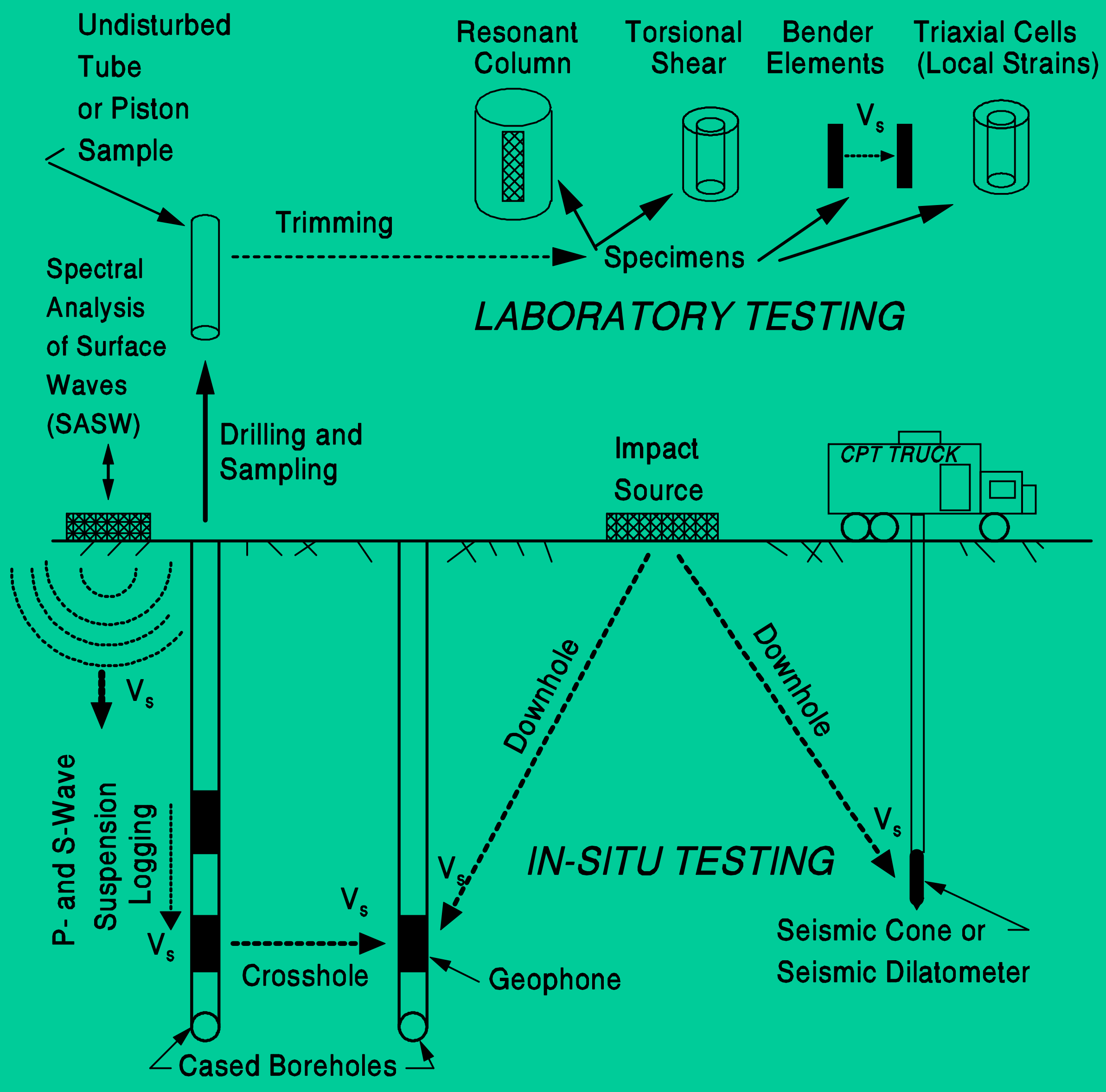
Shear strength of cohesive soils

Consistency	Undrained shear strength, c_u (kPa)	N (Blows per 30 cm)
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

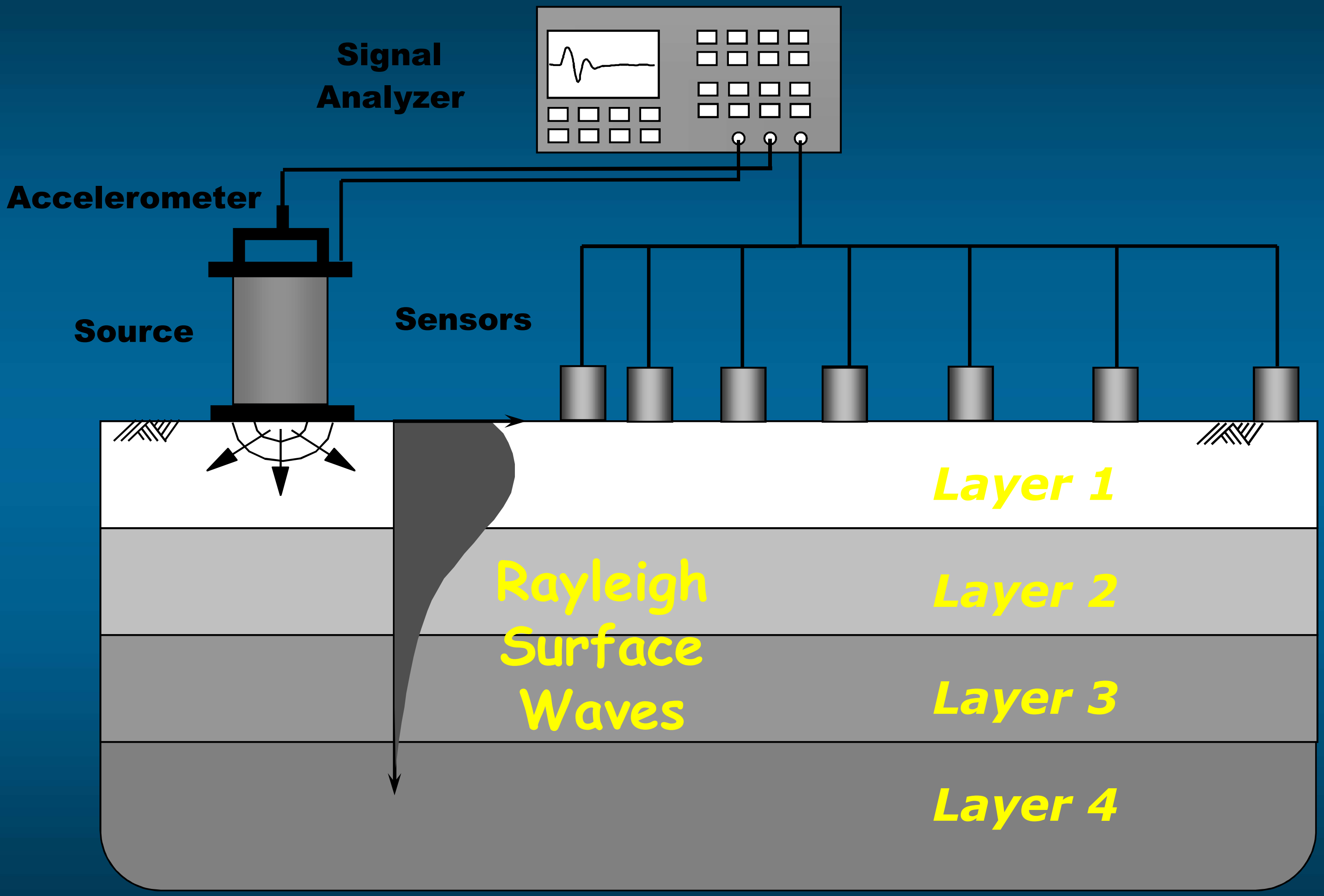
Classification of Soils by CPT



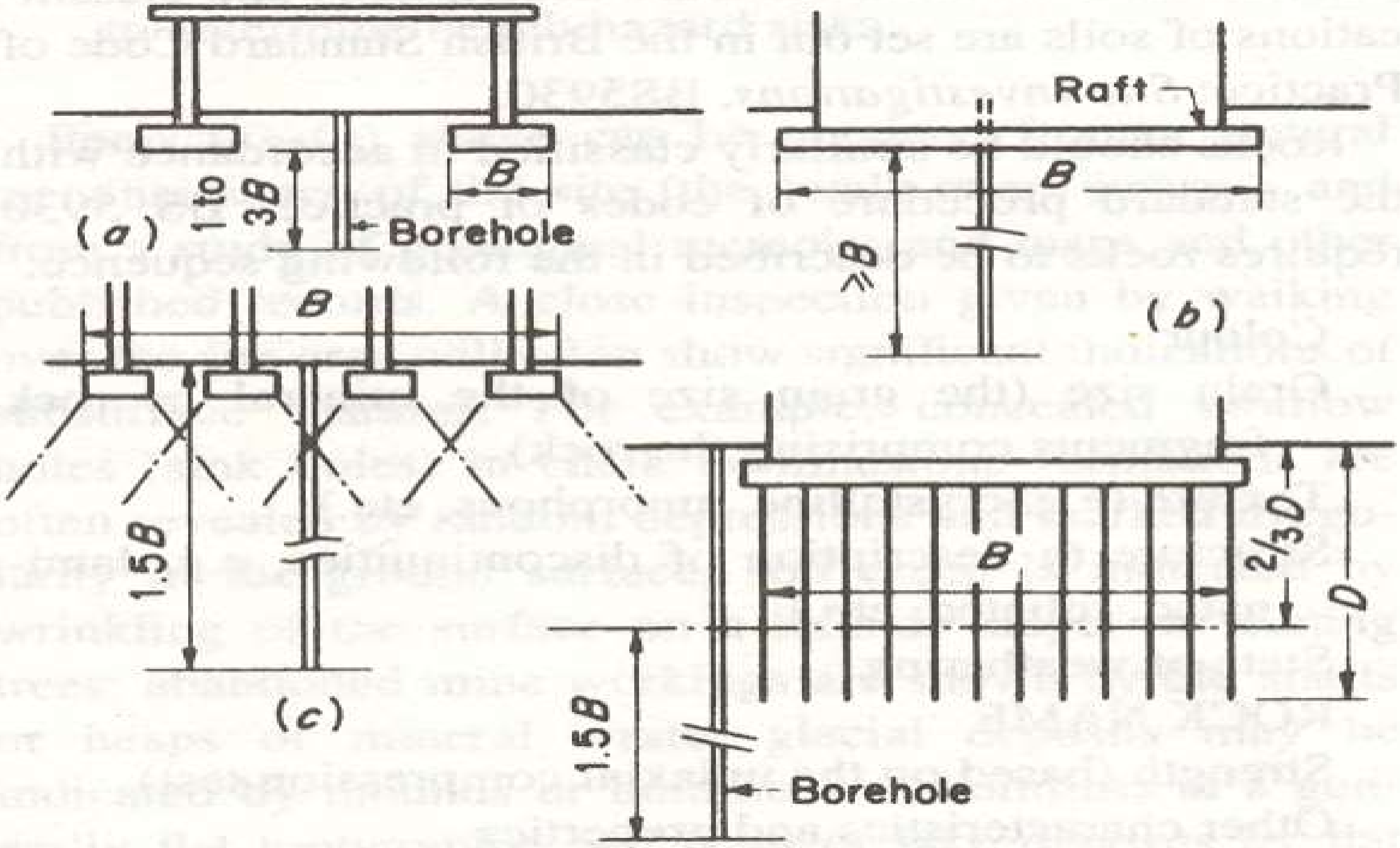
In Situ Dynamic Tests with Shear Wave Measurements



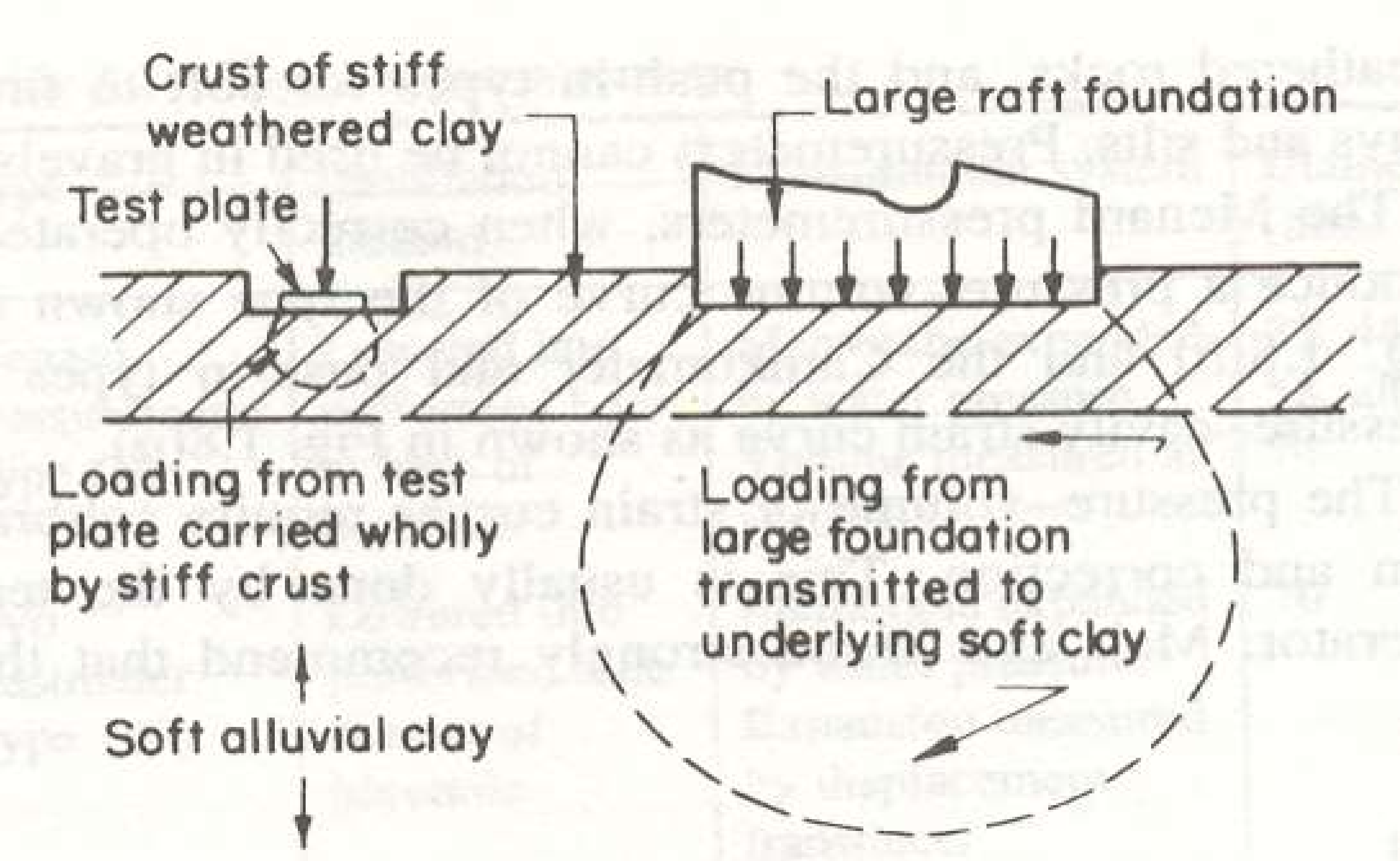
In-Situ Surface Wave Testing



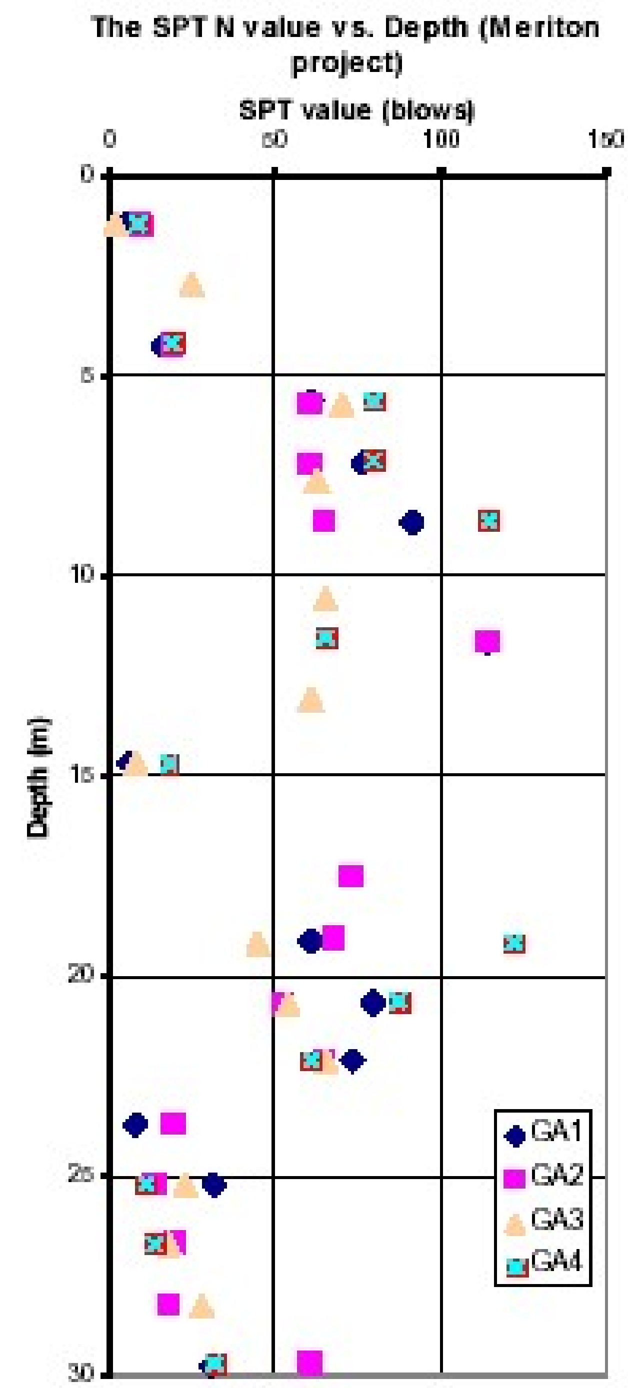
Depth of Boreholes

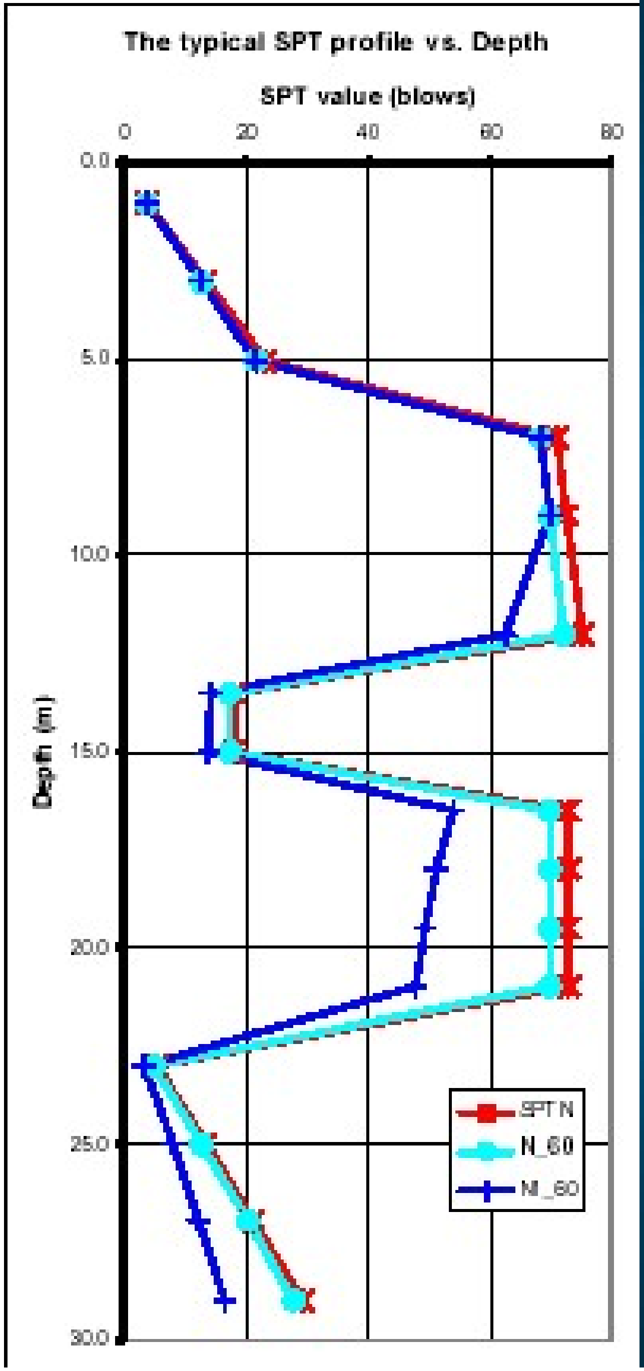


Limitation of Plate Load Test

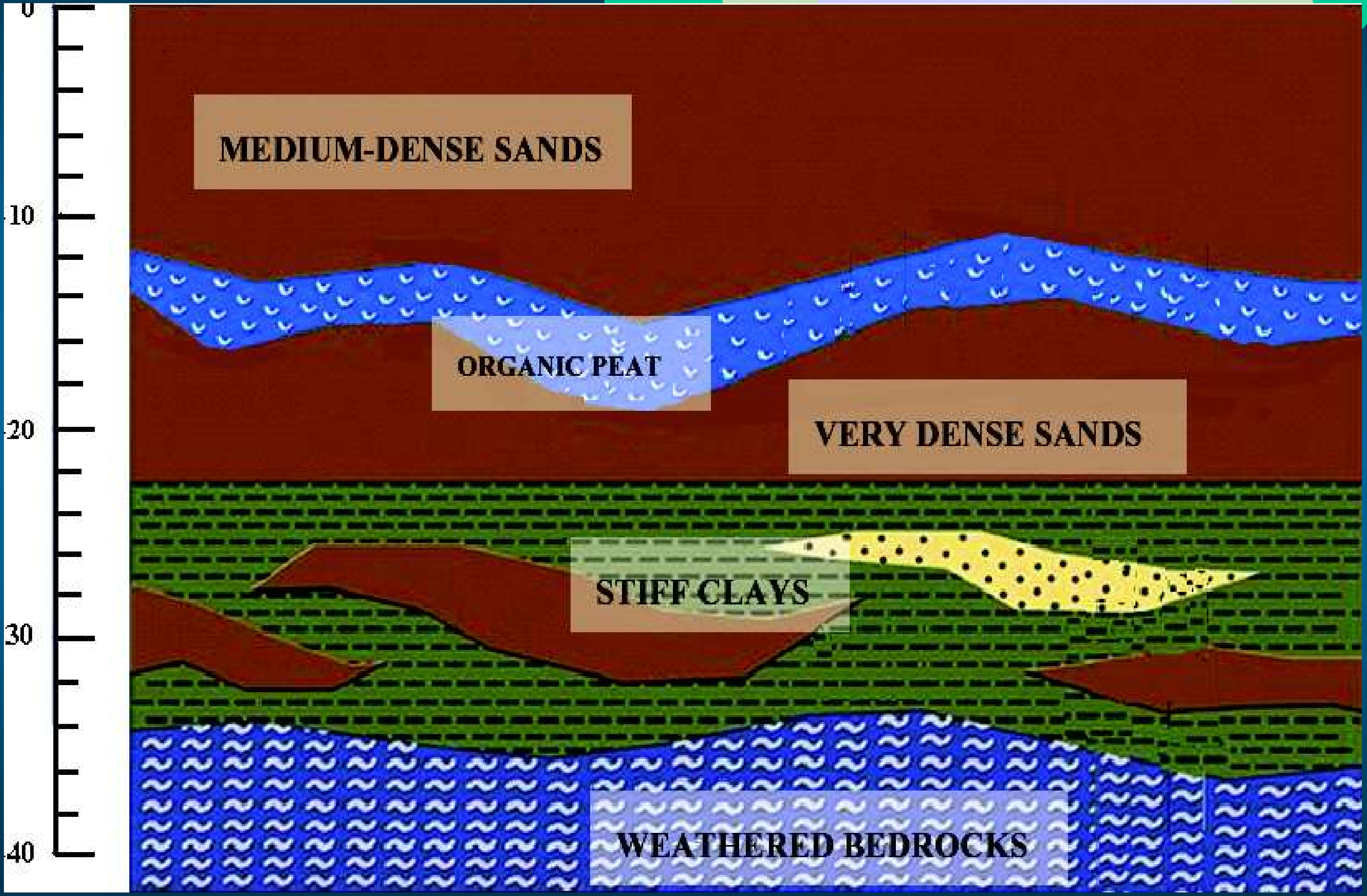


Typical SPT N Profile

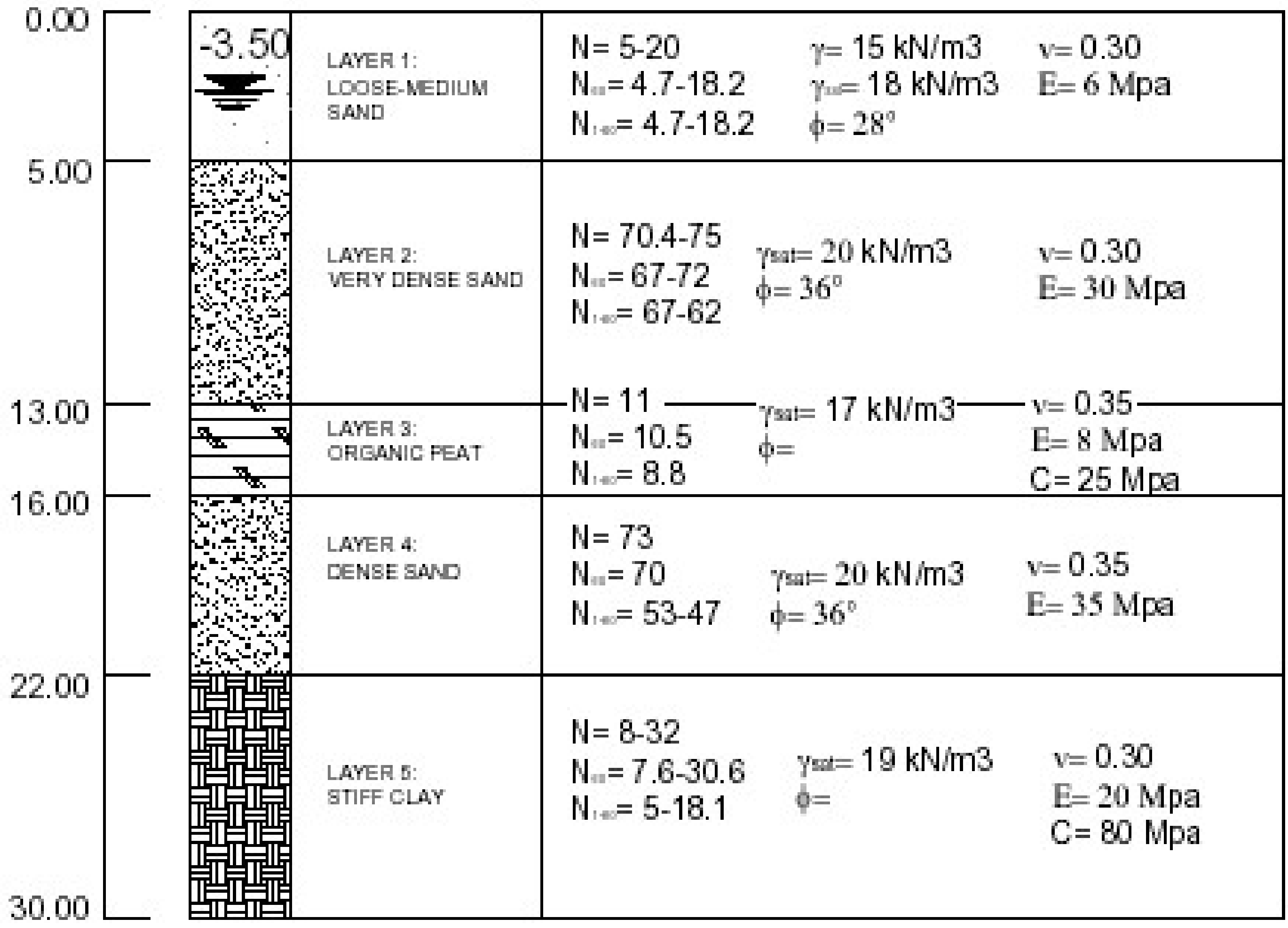




Typical Ground/Soil Profile

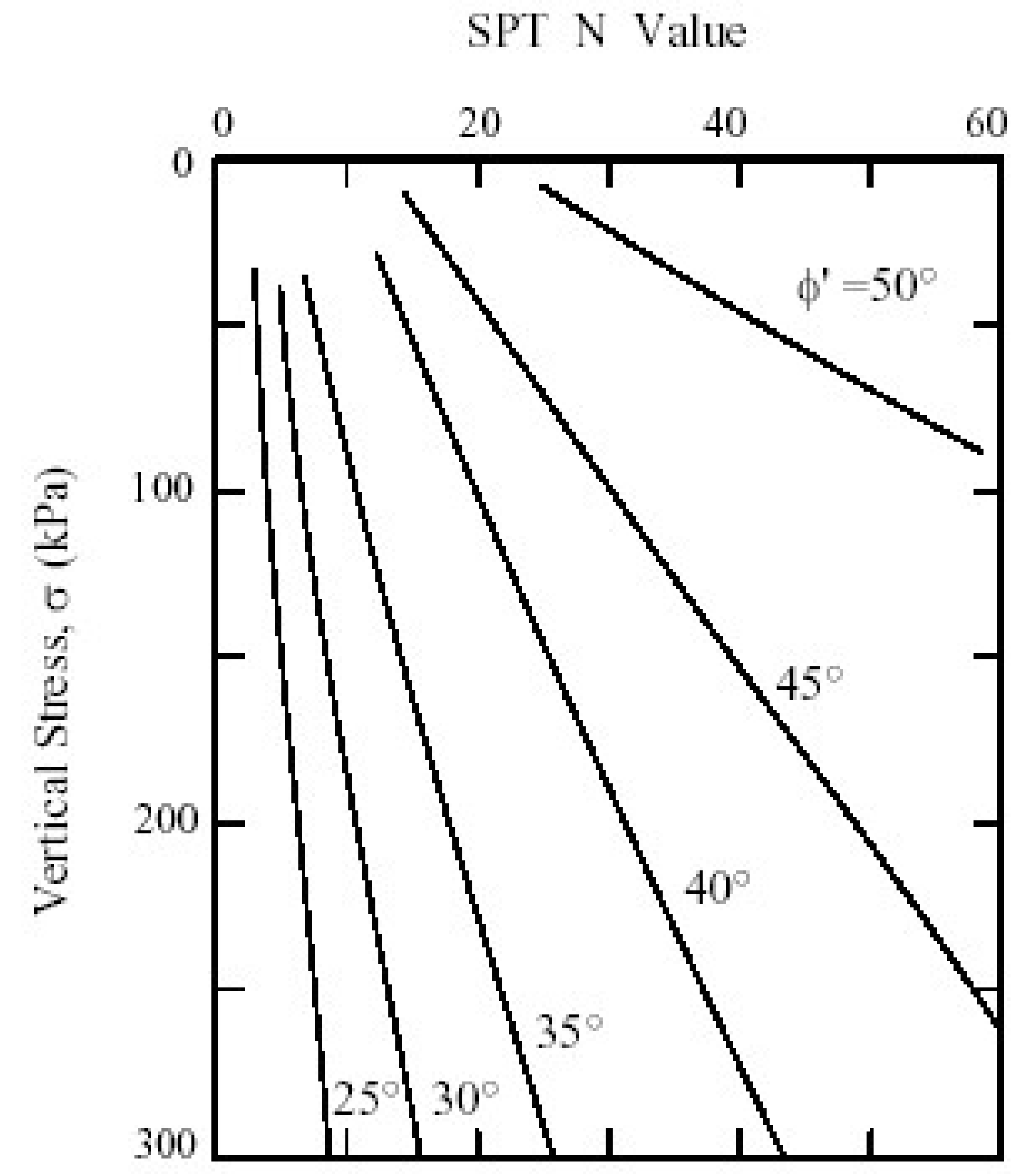


Summary of Ground Profile and Properties

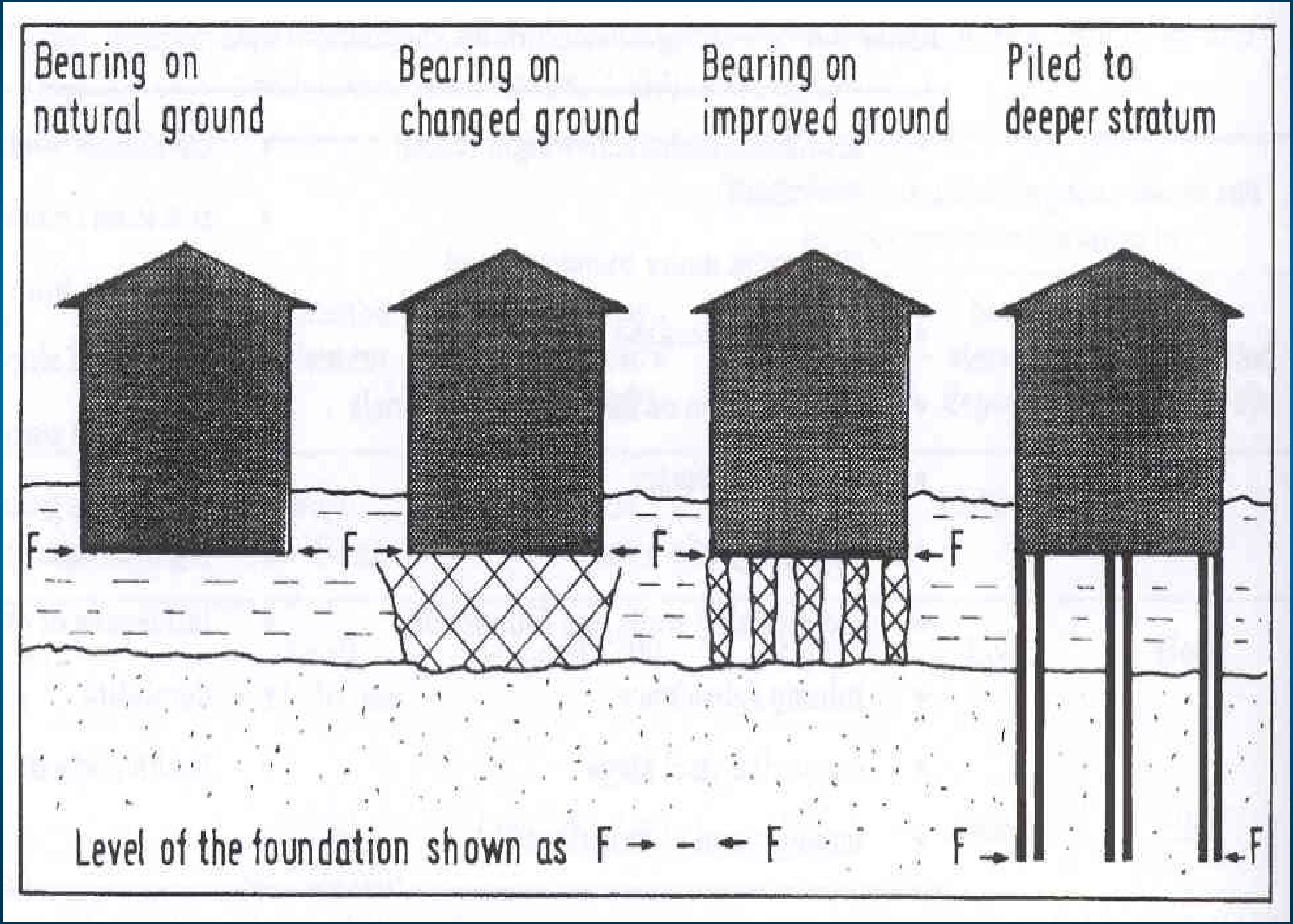


0.00	-3.50	LAYER 1: LOOSE-MEDIUM SAND	N= 5-20 N_{60}= 4.7-18.2 N_{1-60}= 4.7-18.2	γ= 15 kN/m3 γ_{sat}= 18 kN/m3 ϕ= 28°	ν= 0.30 E= 6 Mpa
5.00		LAYER 2: VERY DENSE SAND	N= 70.4-75 N_{60}= 67-72 N_{1-60}= 67-62	γ_{sat}= 20 kN/m3 ϕ= 36°	ν= 0.30 E= 30 Mpa
13.00		LAYER 3: ORGANIC PEAT	N= 11 N_{60}= 10.5 N_{1-60}= 8.8	γ_{sat}= 17 kN/m3 ϕ=	ν= 0.35 E= 8 Mpa C= 25 Mpa
16.00		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		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
30.00					

SPT N vs ϕ (Schmertman 1975)

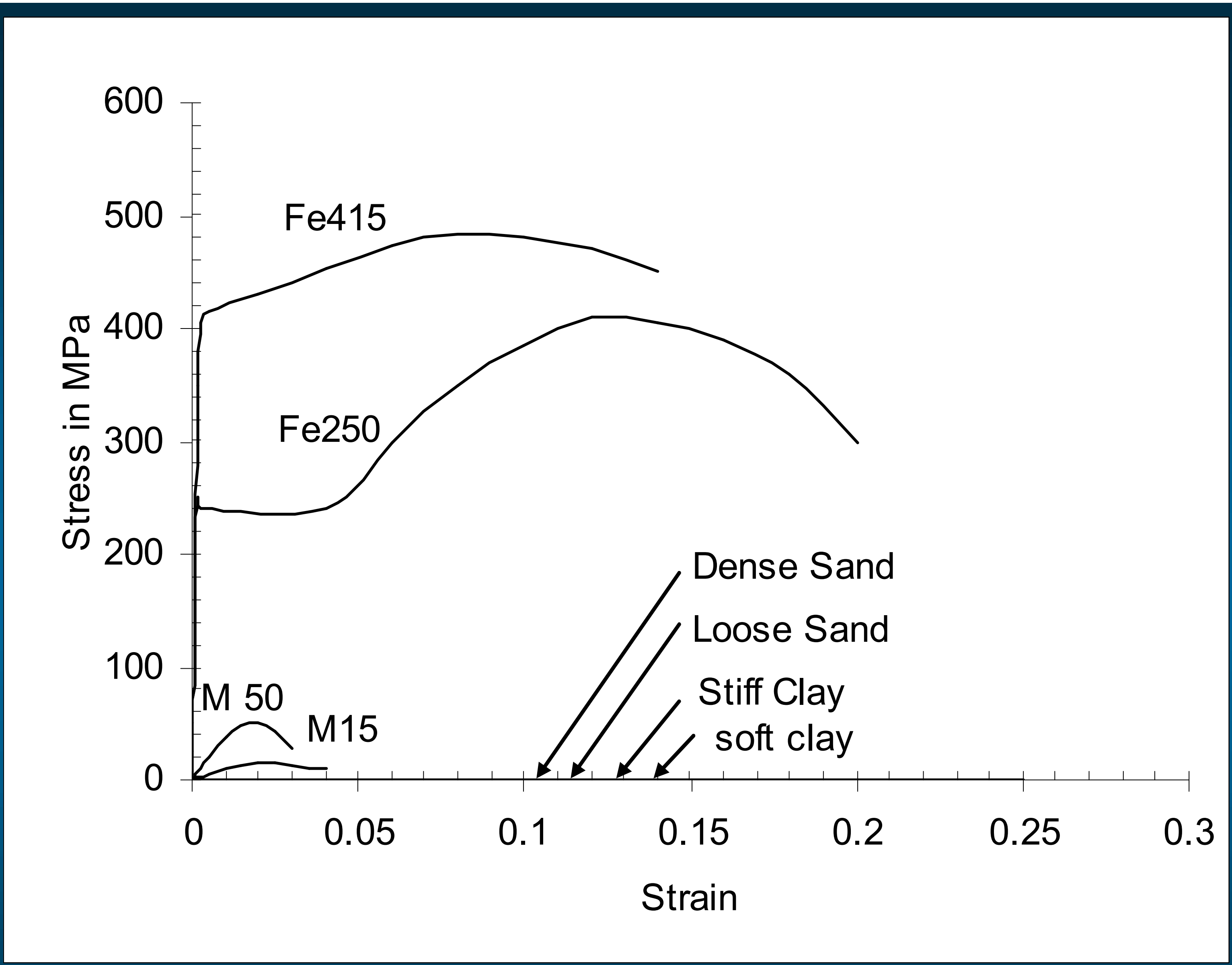


Foundation Options

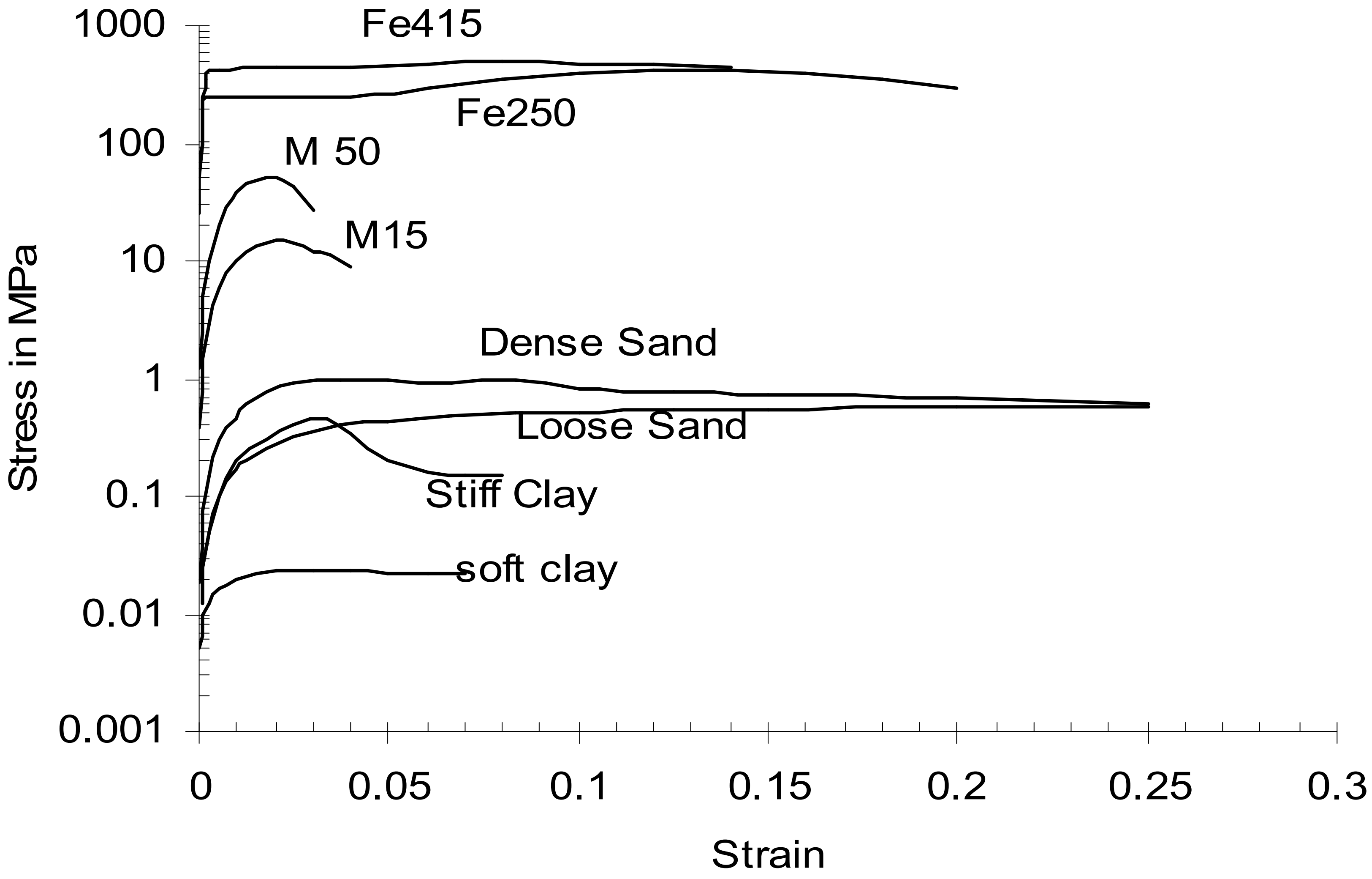


Structure & Ground

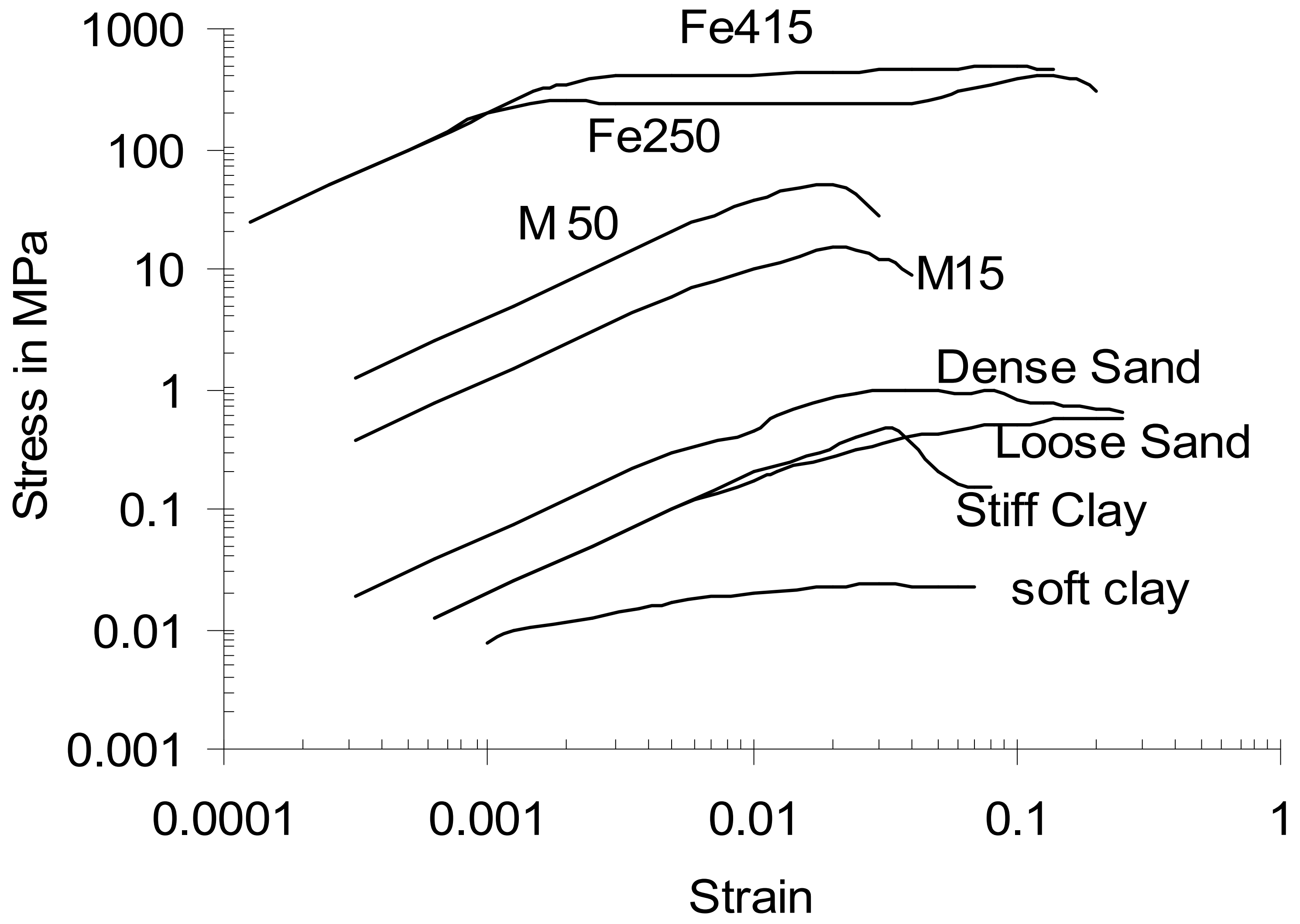
Structure Ground	Light	Medium	Heavy
Soft	Shallow Found./G.I	Gr. Impr. (G.I.)	Deep Found.
Medium Stiff	Shallow Found.	Gr. Impr. (G.I.)	Deep Found./ (G.I.)
Hard	Shallow Found.	Shallow Found./G.I .	Shallow Found./G.I



Stress – Strain Relation-ships



Stress – Strain Relation-ships

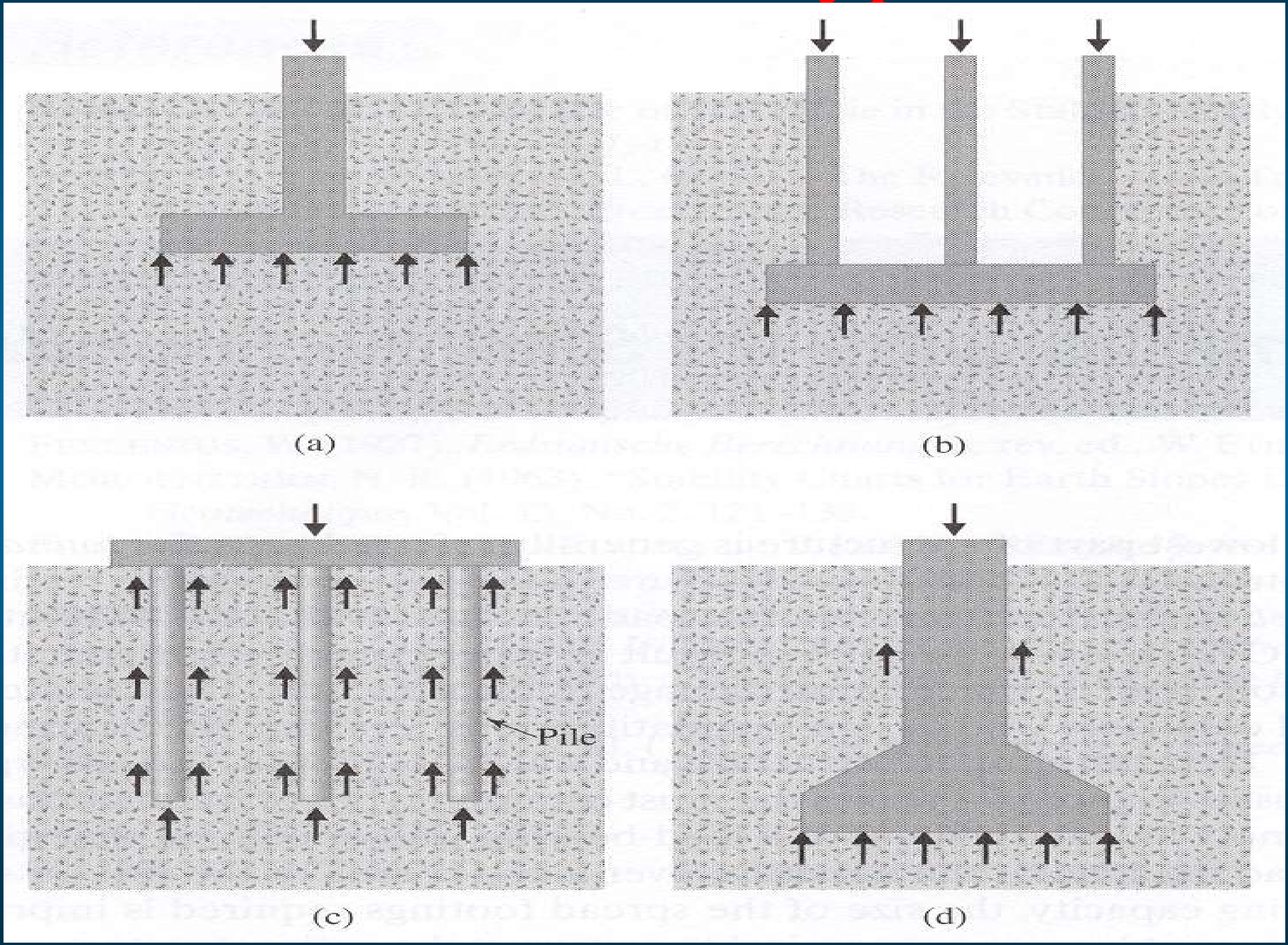


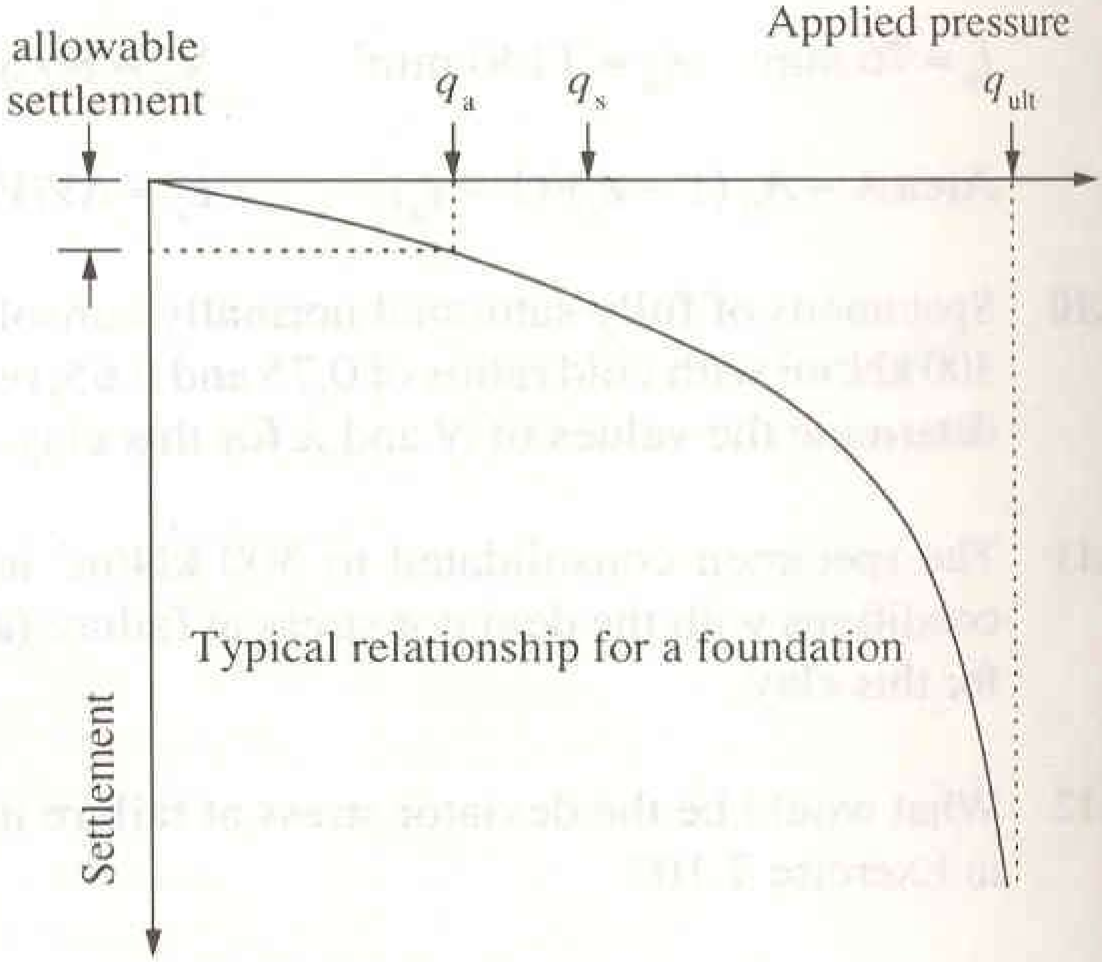
Stress – Strain Relation-ships

Ultimate Values of Stresses – Strains at Failure

	415 Steel	250 Steel	**concrete** M50	concrete M15	Dense Sand	Loose Sand	Stiff clay	Soft clay
Ult. Stress (MPa)	415	250	50	15	1 - 2	0.3 - 1	0.1 - 0.2	0.01 - 0.05
E (MPa)	$2x10^5$	$2x10^5$	4000	1200	50 - 80	10 - 25	15 - 100	2 - 25
strain at failure (%)	0.02	0.2 - 0.5	2 - 3	2 - 4	3 - 5	10 - 20	3 - 6	10 - 15

Foundation Types





Typical relationship for a foundation

q_{ult} = ultimate bearing capacity

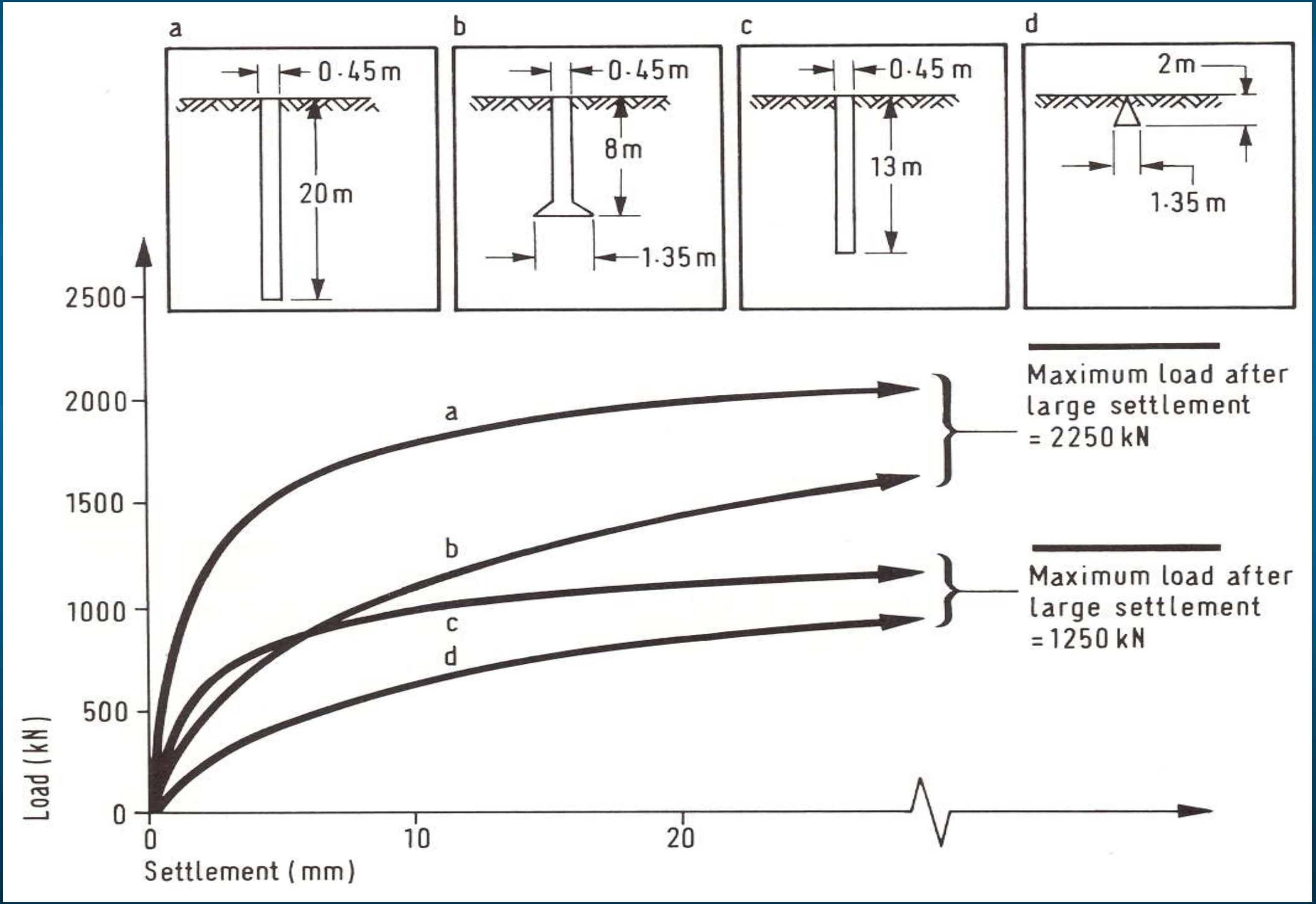
q_s = safe bearing capacity

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

q_a = allowable bearing pressure

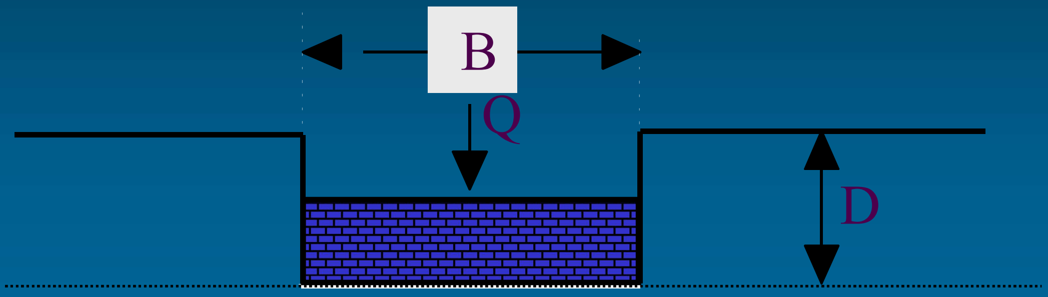
(related to allowable settlement of structure)

Load vs Settlement of Different Foundations

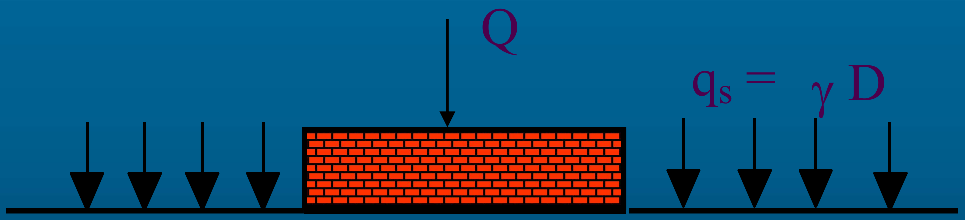


Shallow Foundations

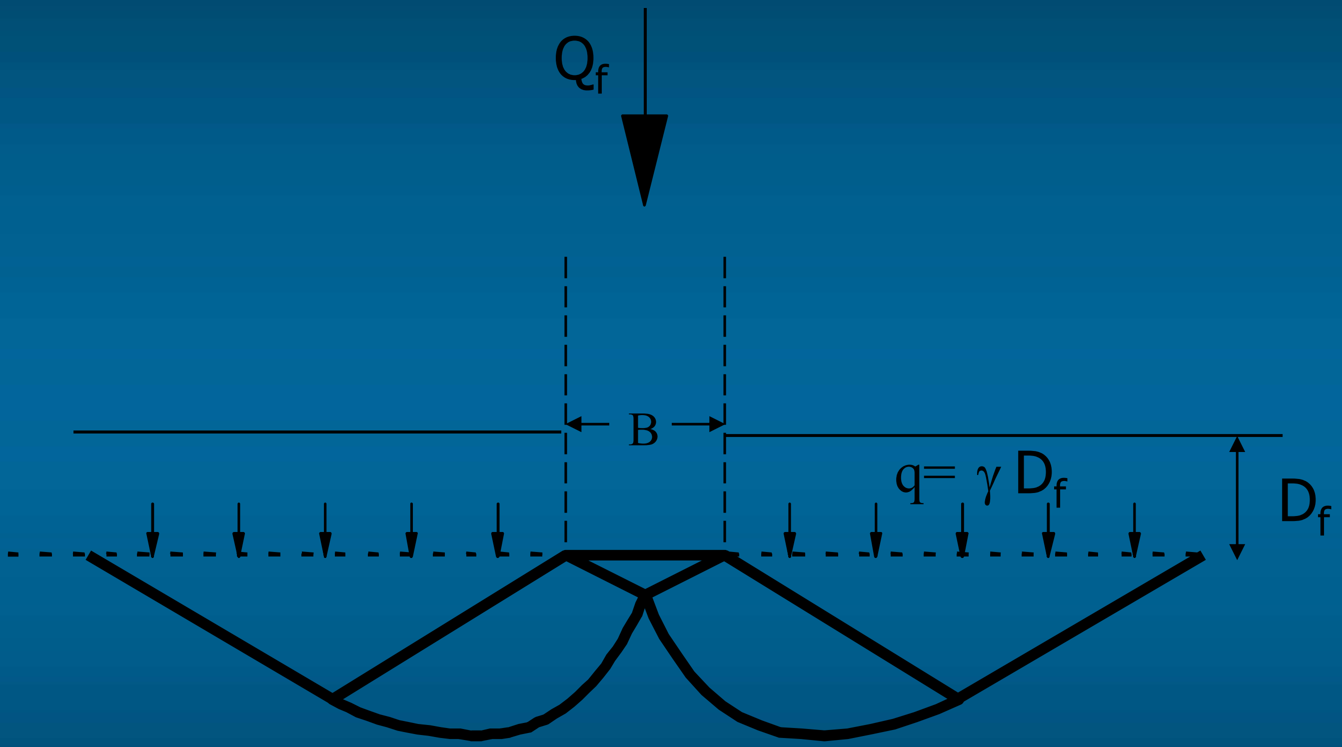
Typical
Buried
Footing



Equivalent
Surface
Footing

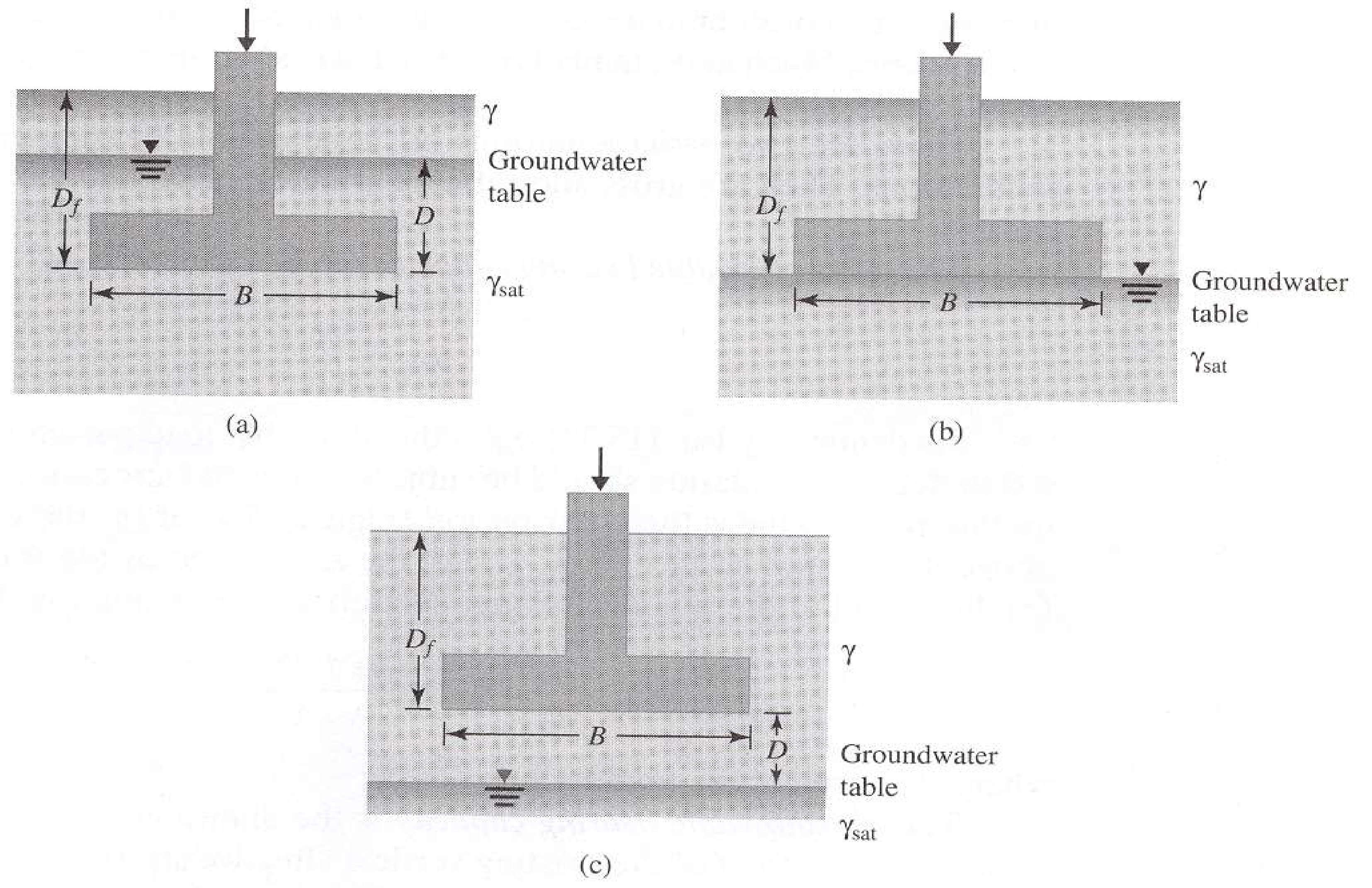


Shallow Foundations



Mechanism by Terzaghi

Effect of Depth of WT on Bearing Capacity

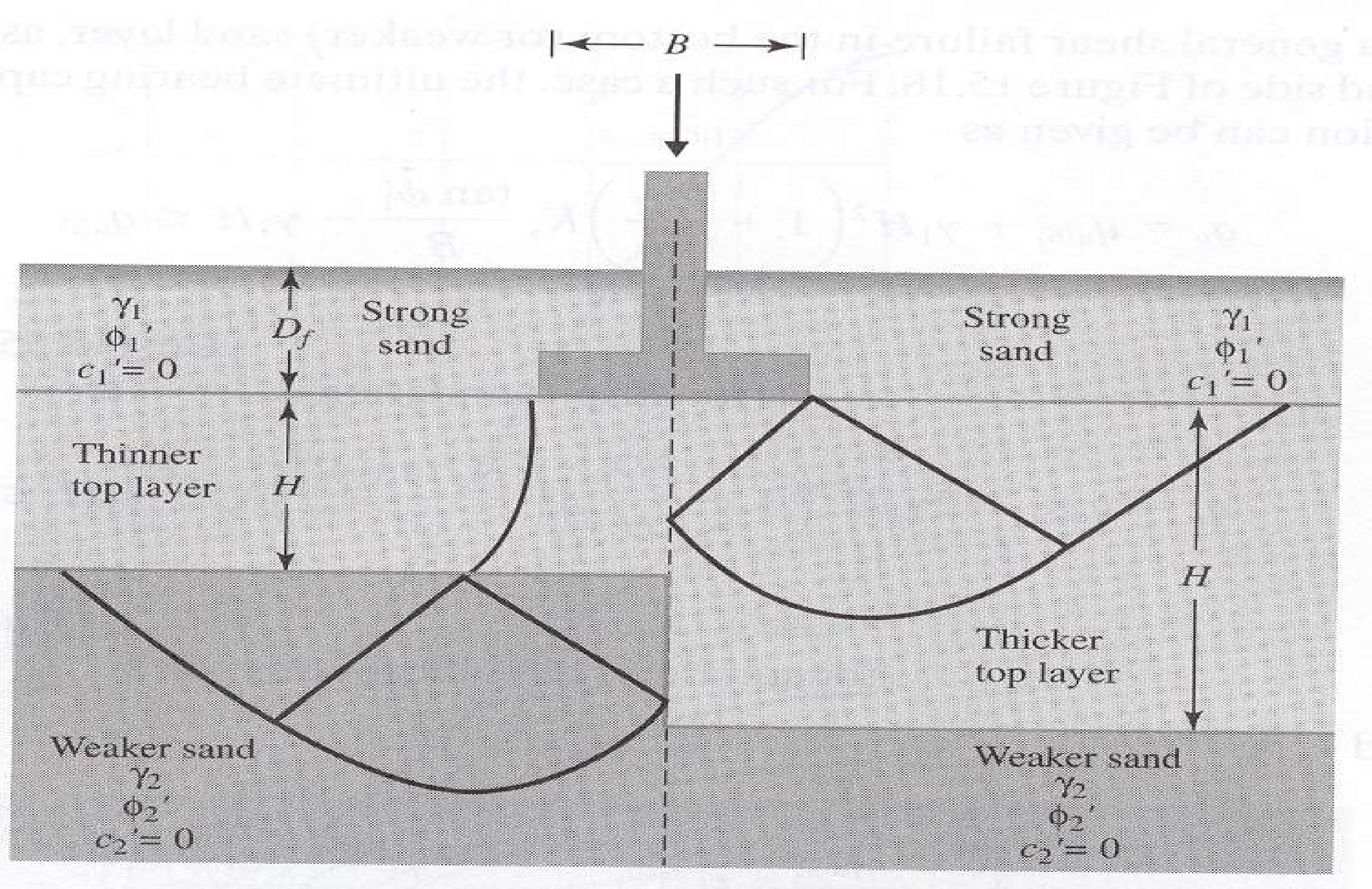


(a)

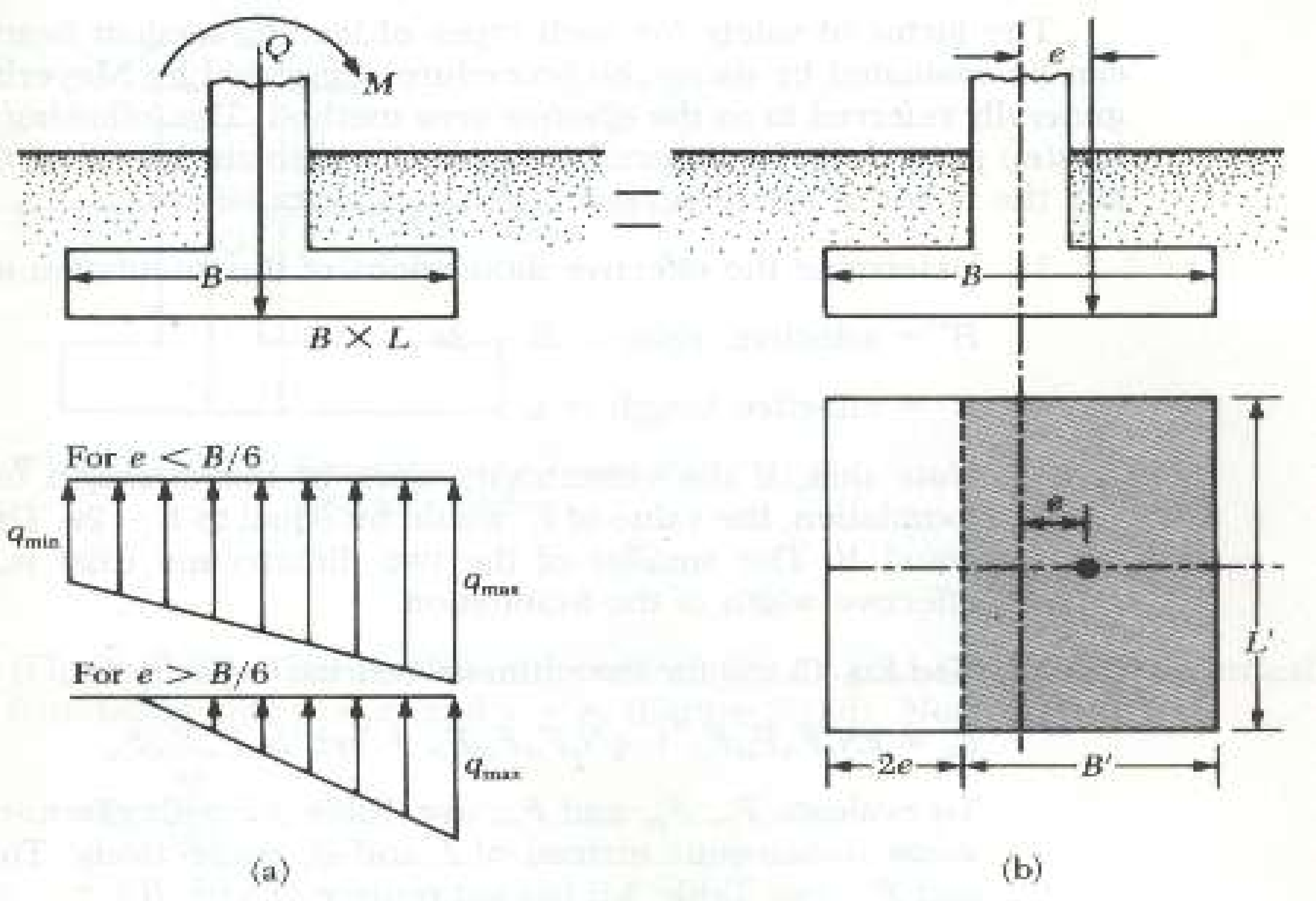
(b)

(c)

Bearing Capacity on Two Layered Soil



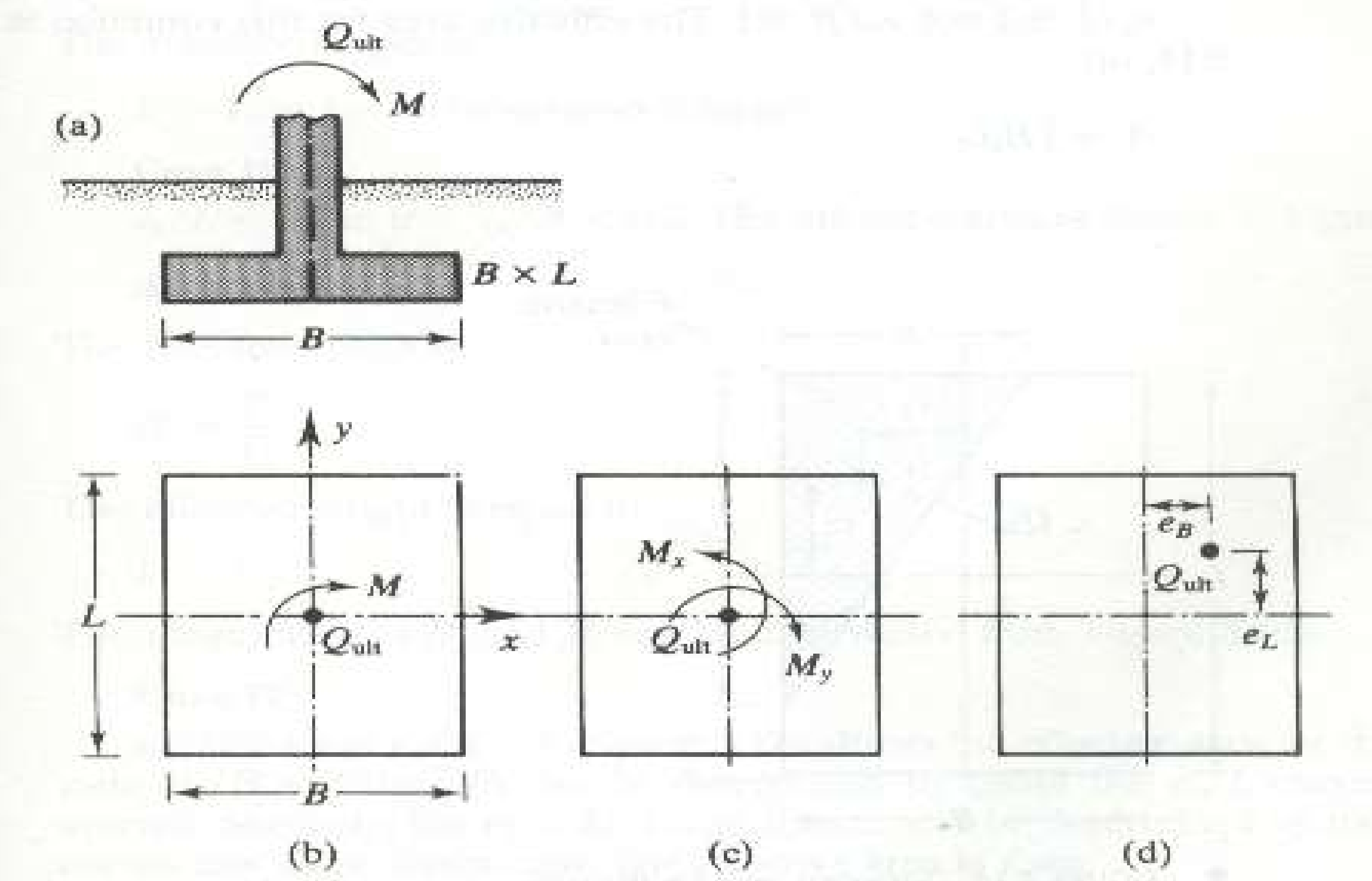
Eccentrically Loaded Footing



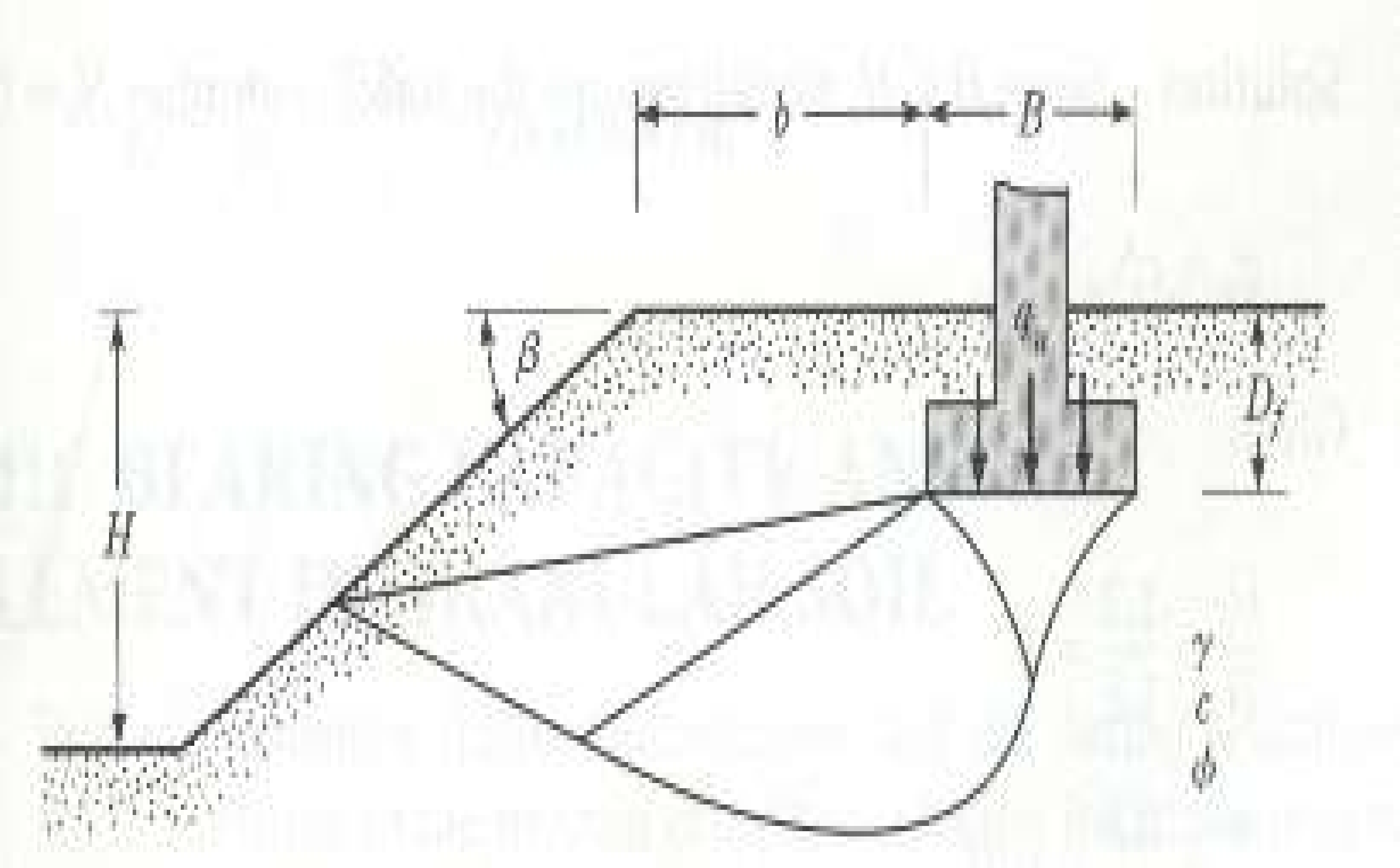
(a)

(b)

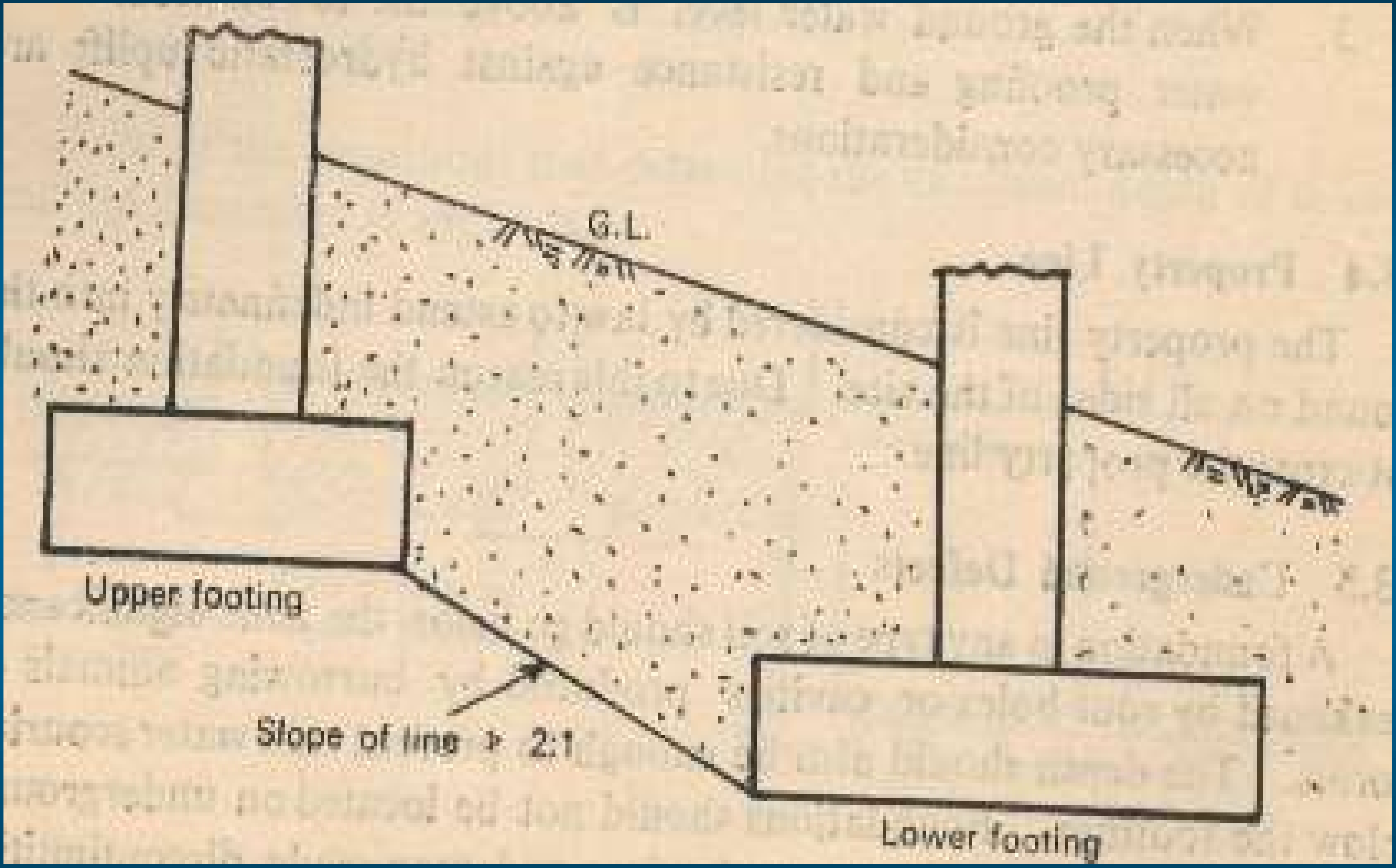
Two-Way Eccentricity



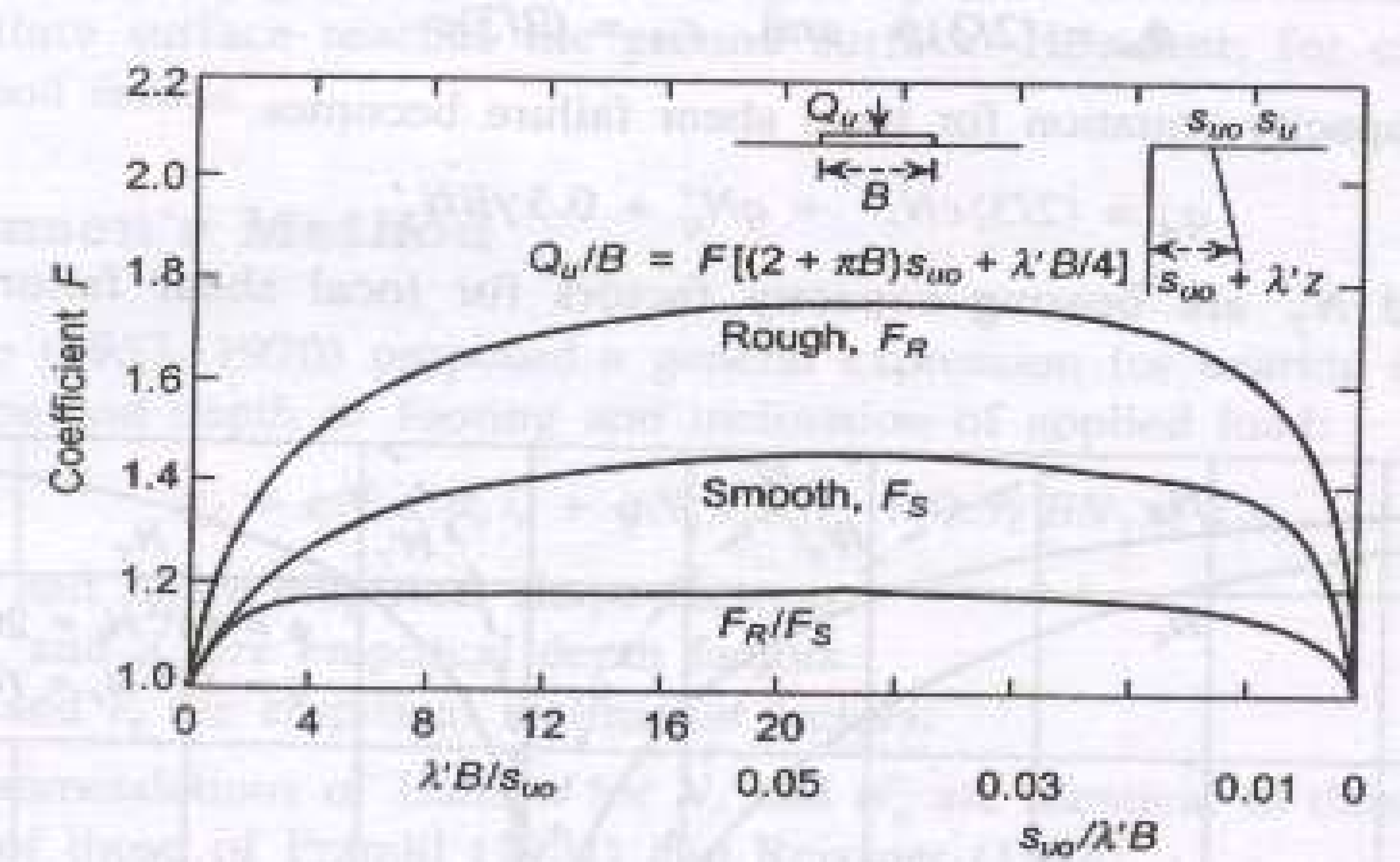
Footing on Slope



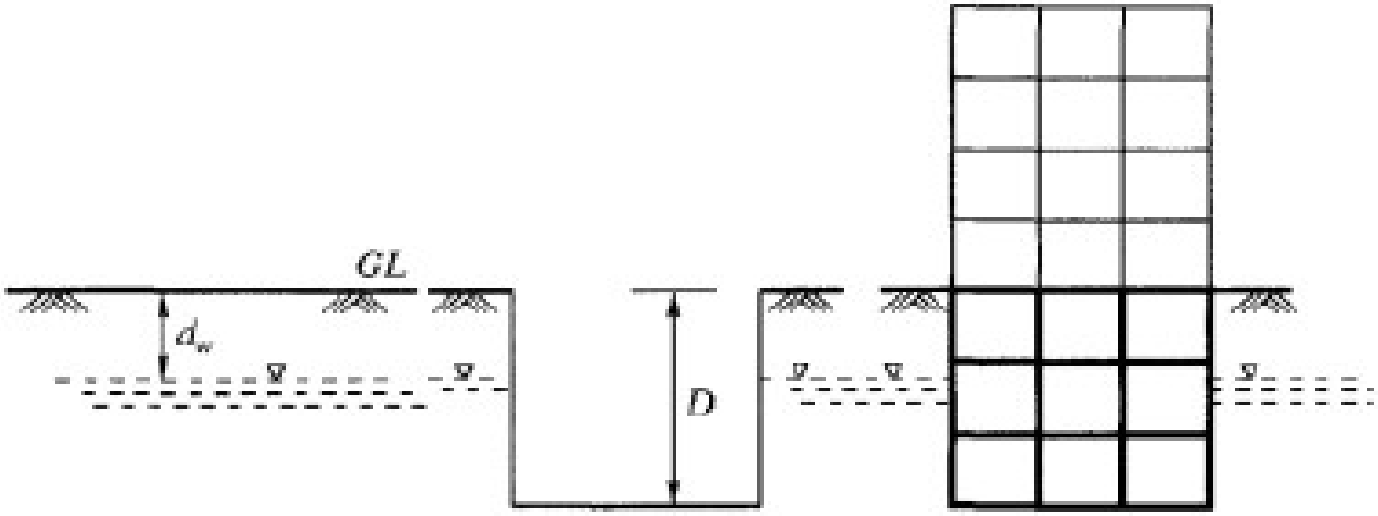
Footings at Different Levels



Bearing Capacity Factor for Non-homogeneous Soil

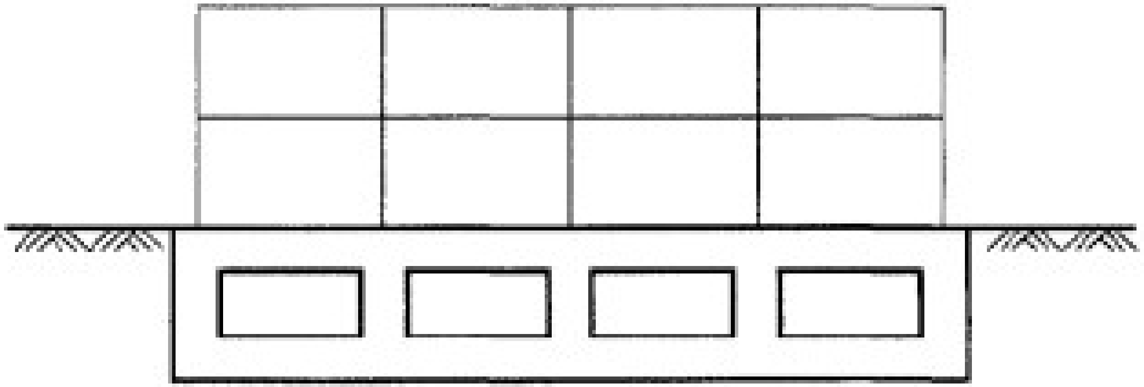


Floating Foundation



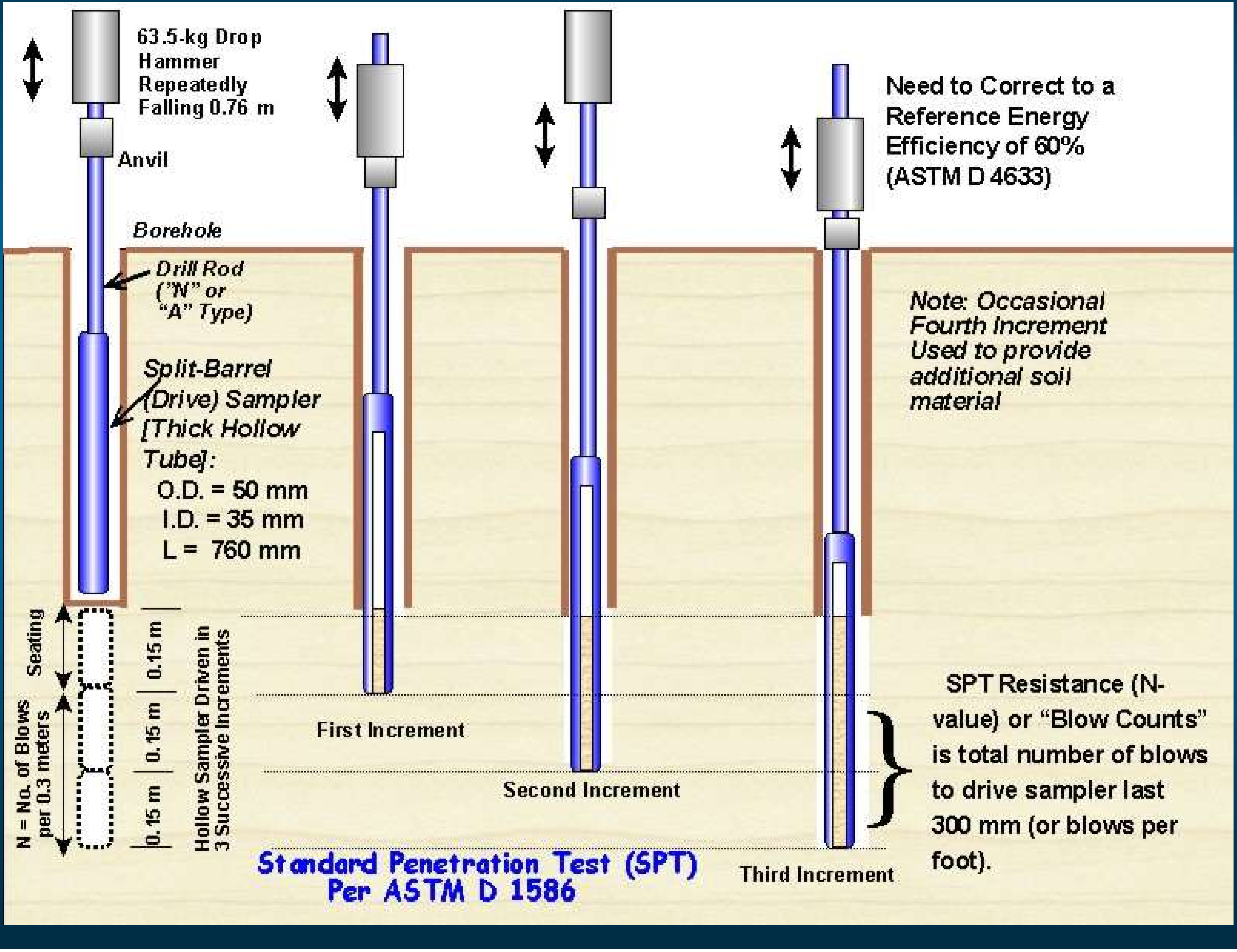
(a) (b) (c)

Balance of stresses in foundation excavation



(d) Rigid raft foundation

Standard Penetration Test (SPT)



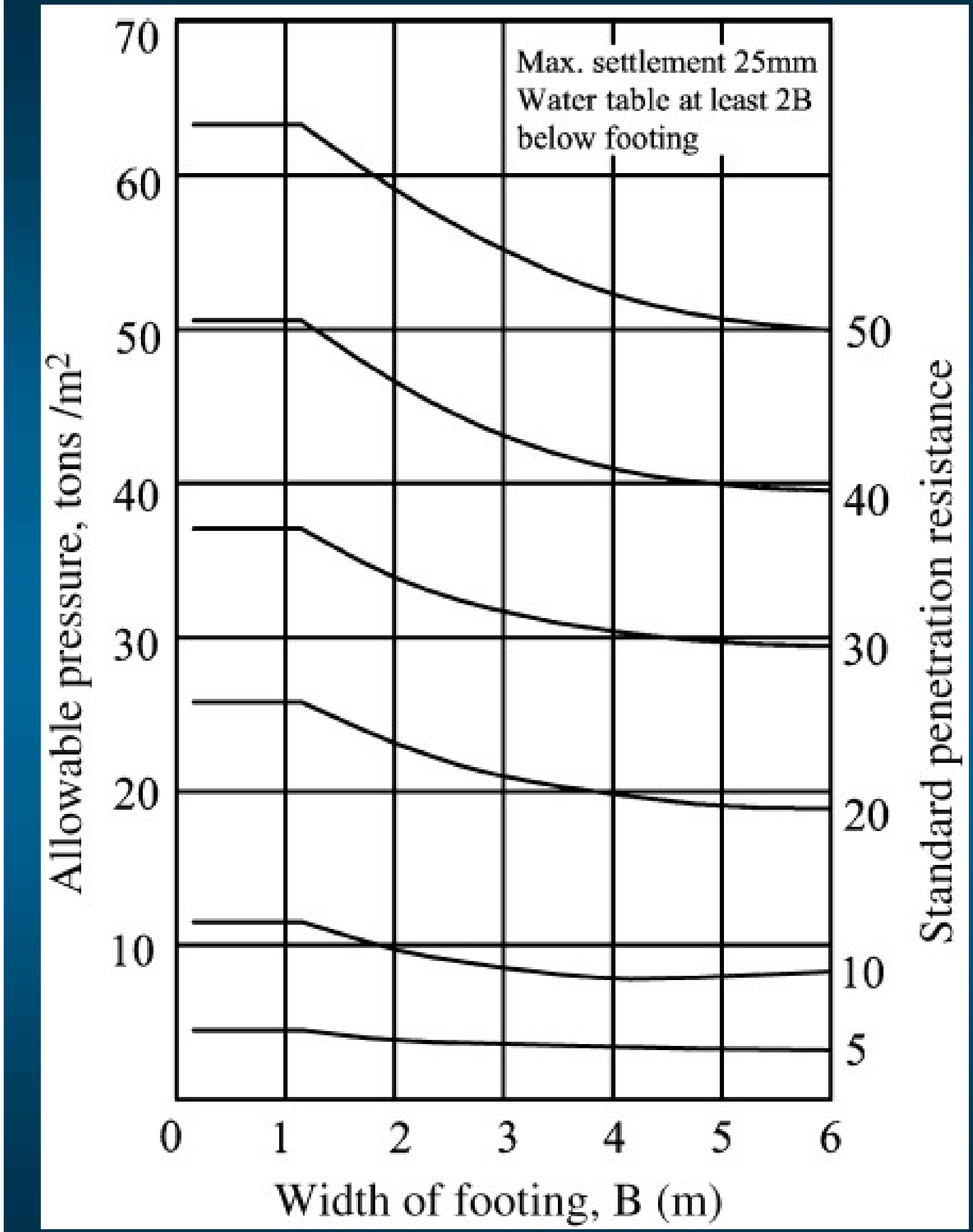
Need to Correct to a Reference Energy Efficiency of 60% (ASTM D 4633)

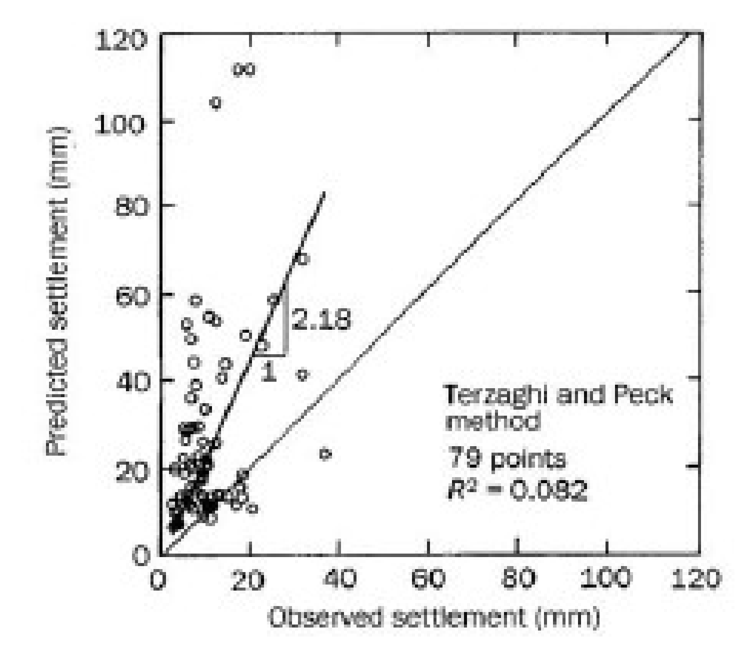
Note: Occasional Fourth Increment Used to provide additional soil material

SPT Resistance (N-value) or "Blow Counts" is total number of blows to drive sampler last 300 mm (or blows per foot).

Standard Penetration Test (SPT) Per ASTM D 1586

Terzaghi & Peck (1967)



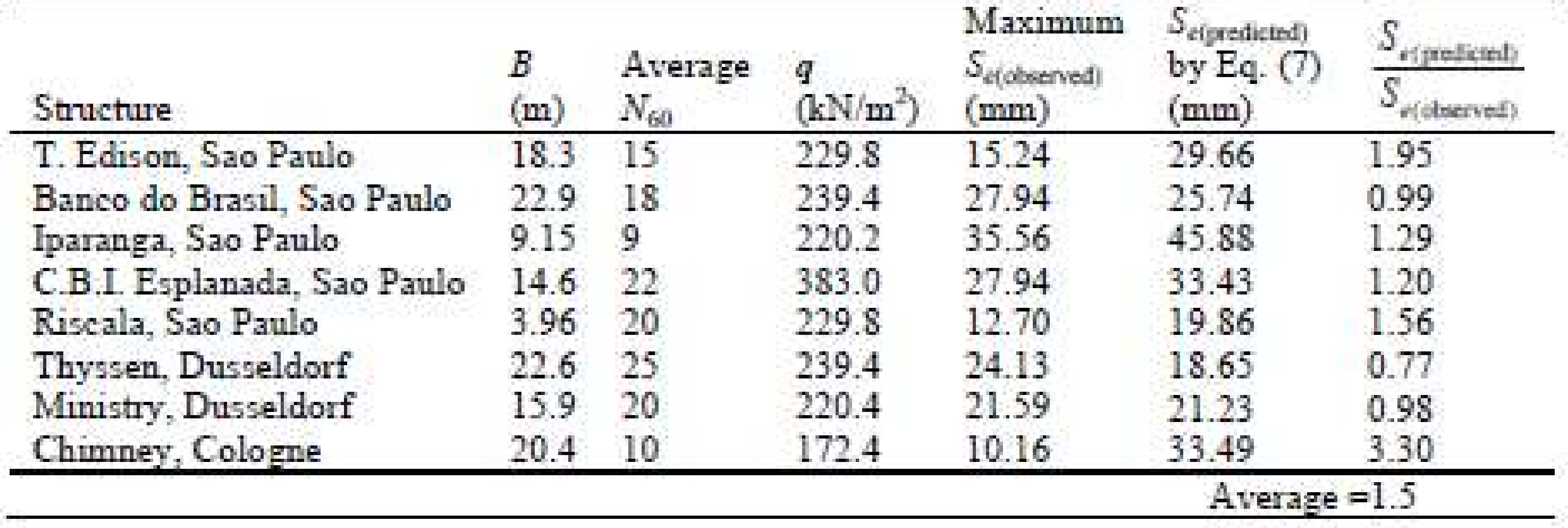


Meyerhof (1965)

$$S_e = C_W C_D \frac{1.25q}{N_{60}} \quad (\text{for } B \leq 1.22 \text{ m})$$

$$S_e = C_W C_D \frac{2q}{N_{60}} \left(\frac{B}{B+0.3}\right)^2 \quad (\text{for } B > 1.22 \text{ m})$$

$$C_D = 1.0 - \frac{D_f}{4B}$$



Structure	B (m)	Average N_{60}	q (kN/m^2)	Maximum $S_{e(\text{observed})}$ (mm)	$S_{e(\text{predicted})}$ by Eq. (7) (mm)	$\frac{S_{e(\text{predicted})}}{S_{e(\text{observed})}}$
T. Edison, Sao Paulo	18.3	15	229.8	15.24	29.66	1.95
Banco do Brasil, Sao Paulo	22.9	18	239.4	27.94	25.74	0.99
Iparanga, Sao Paulo	9.15	9	220.2	35.56	45.88	1.29
C.B.I. Esplanada, Sao Paulo	14.6	22	383.0	27.94	33.43	1.20
Riscala, Sao Paulo	3.96	20	229.8	12.70	19.86	1.56
Thyssen, Dusseldorf	22.6	25	239.4	24.13	18.65	0.77
Ministry, Dusseldorf	15.9	20	220.4	21.59	21.23	0.98
Chimney, Cologne	20.4	10	172.4	10.16	33.49	3.30
					Average =1.5	

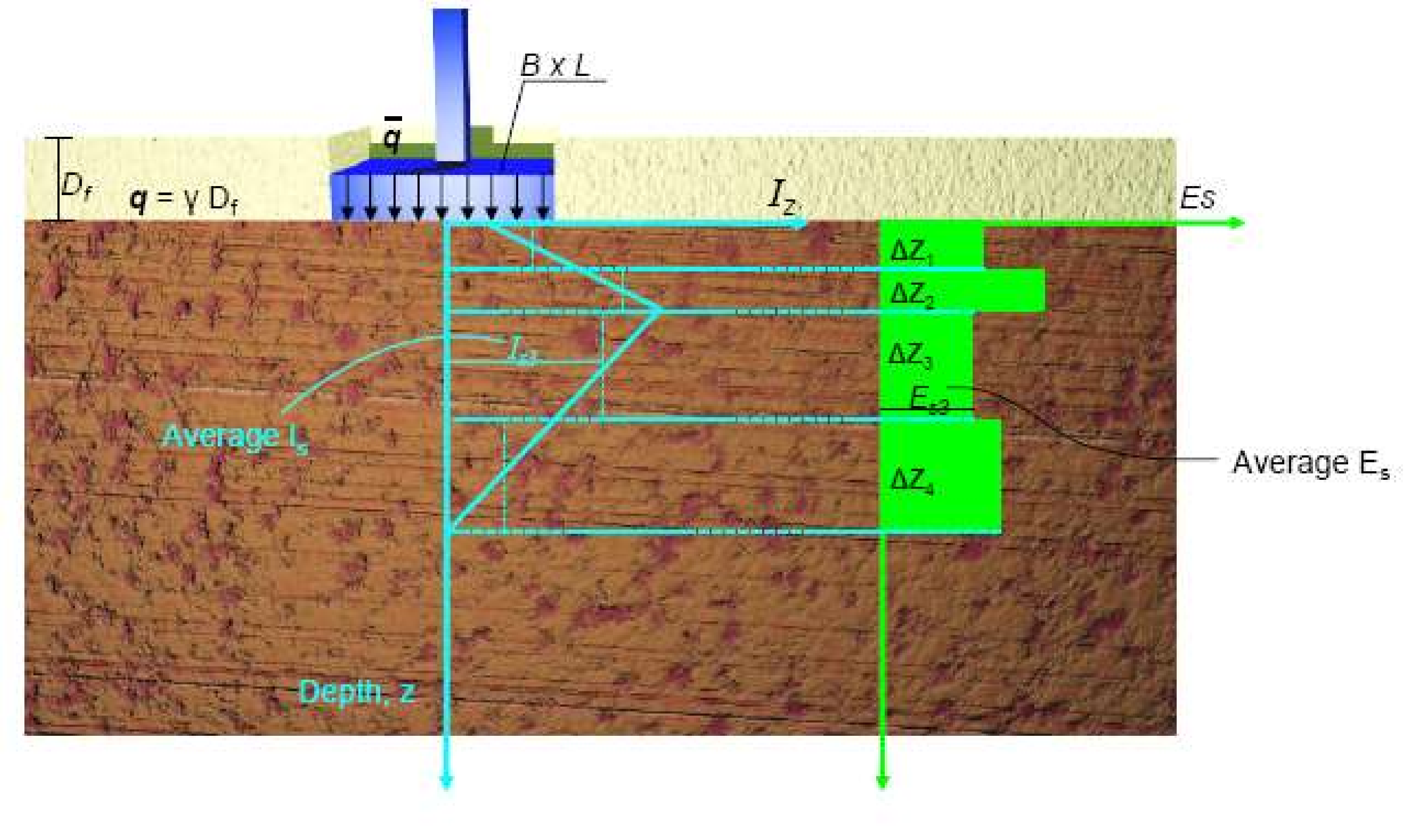
Burland and Burbridge (1985)

$$\frac{S_e}{B_R} = 0.14\alpha\left\{\frac{1.71}{\left[\overline{N}_{60} or \overline{N}_{60(a)}\right]^{1.4}}\right\}\left[\frac{1.25\left(\frac{L}{B}\right)}{0.25+\left(\frac{L}{B}\right)}\right]^{2}\left(\frac{B}{B_R}\right)^{0.7}\left(\frac{q}{p_a}\right)$$

$$\alpha = \frac{H}{z'}\left(2-\frac{H}{z'}\right) \leq 1$$

$$\frac{z'}{B_R} = 1.4\left(\frac{B}{B_R}\right)^{0.75}$$

Settlement - Strain Influence Factor Method [Schmertmann et al. (1978)]



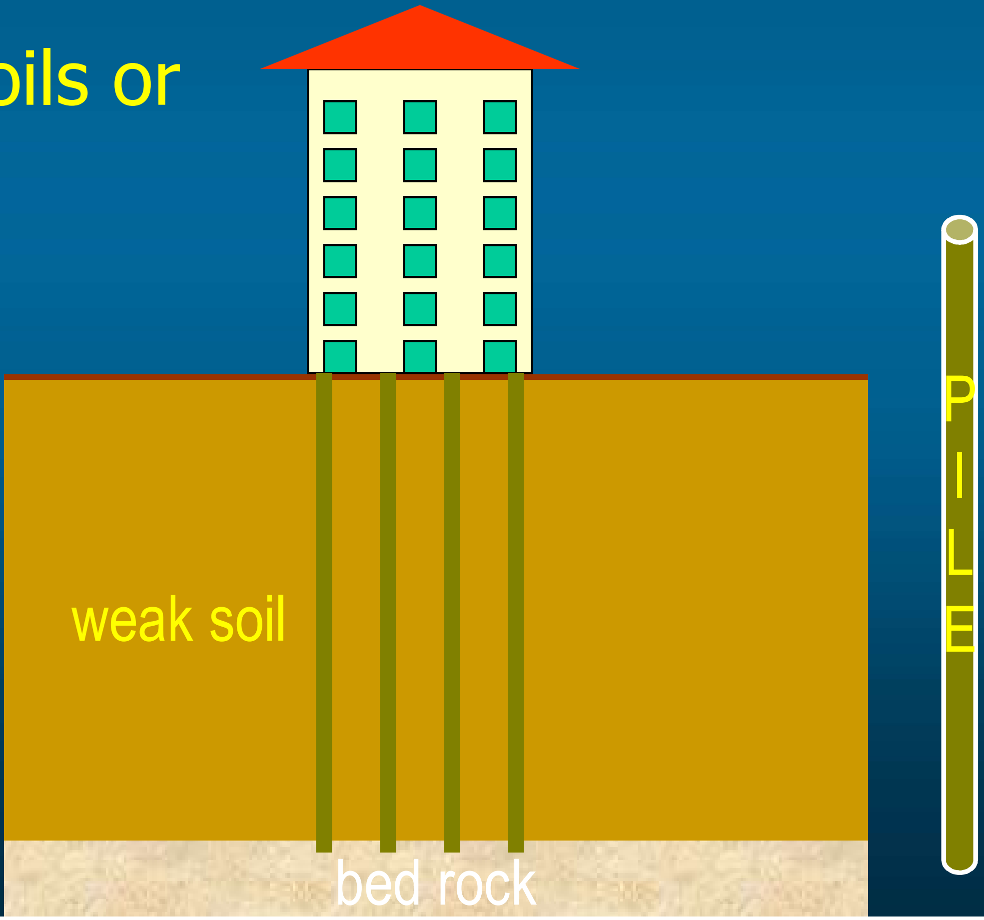
$$\rho = C_1 C_2 \Delta\sigma \sum_{i=1}^{n} \left(\frac{I_z}{E}\right)_i \Delta z_i$$

- $E_s = 2.5q_c$ Square (or circular)
- $E_s = 3.5q_c$ Strip
- C_1- Embedment Correction
- C_2- Creep Correction

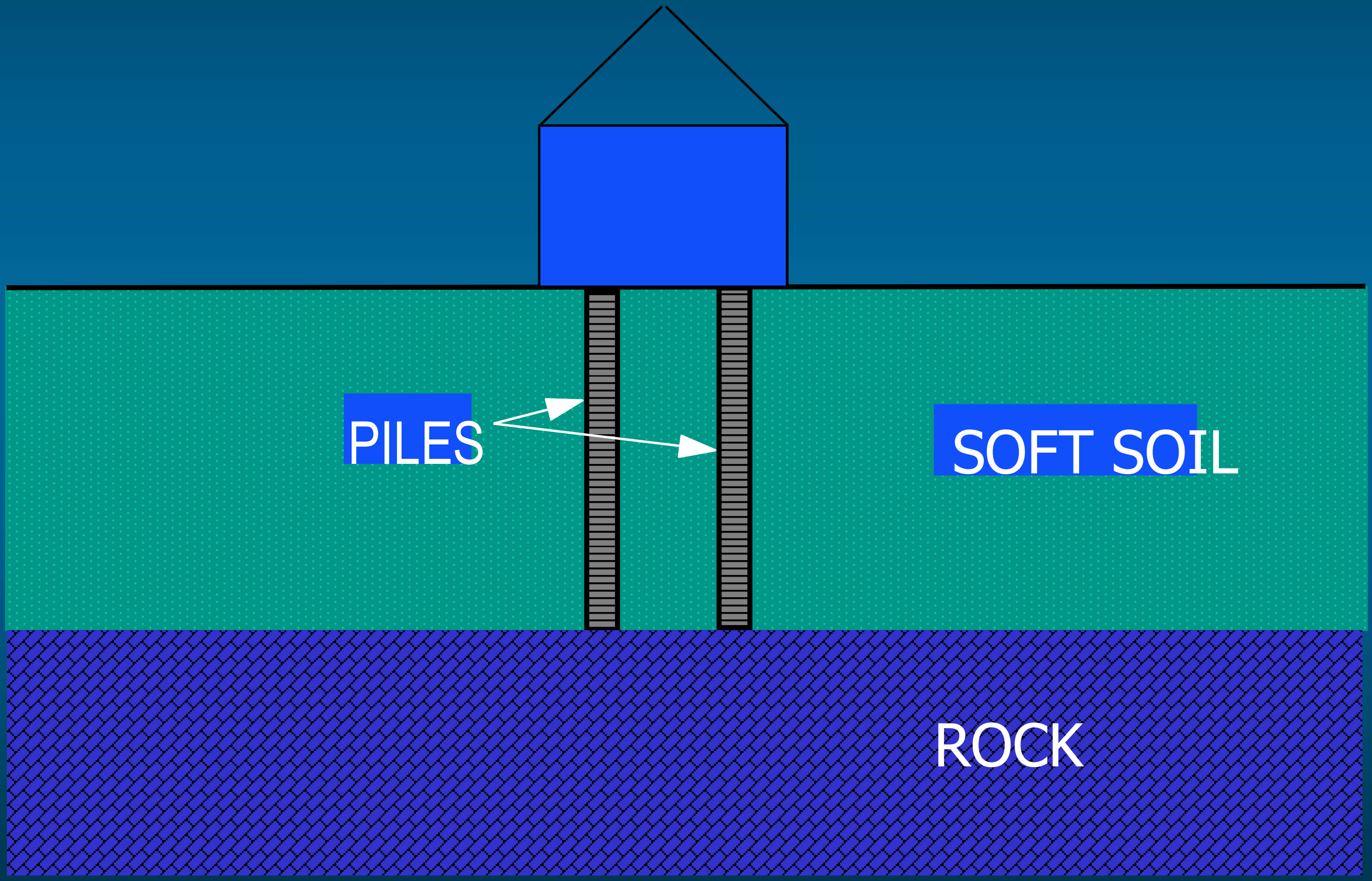
Deep Foundations

~ For transferring building loads to underlying ground

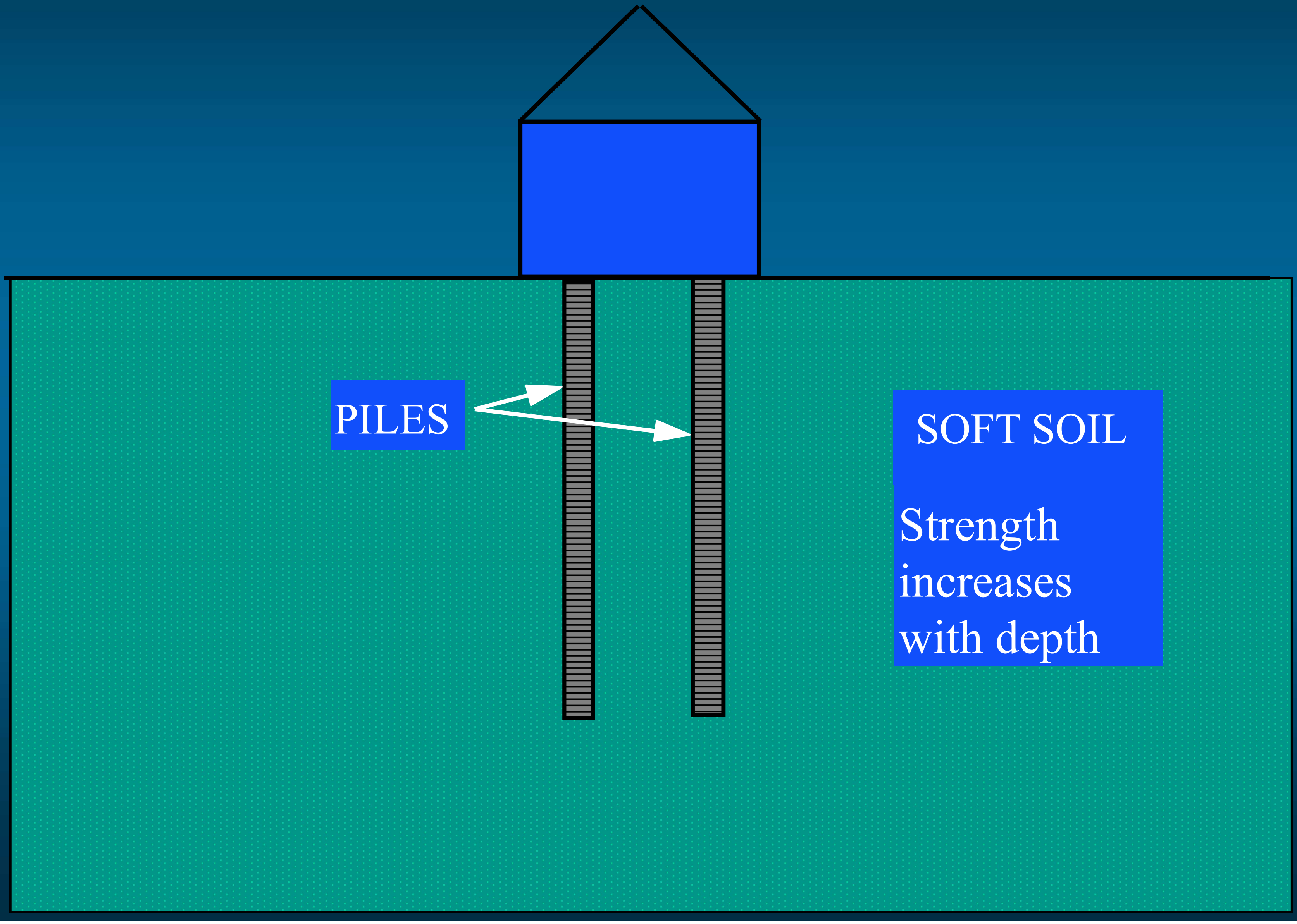
~ Mostly for weak soils or heavy loads



End Bearing Piles



Friction Piles

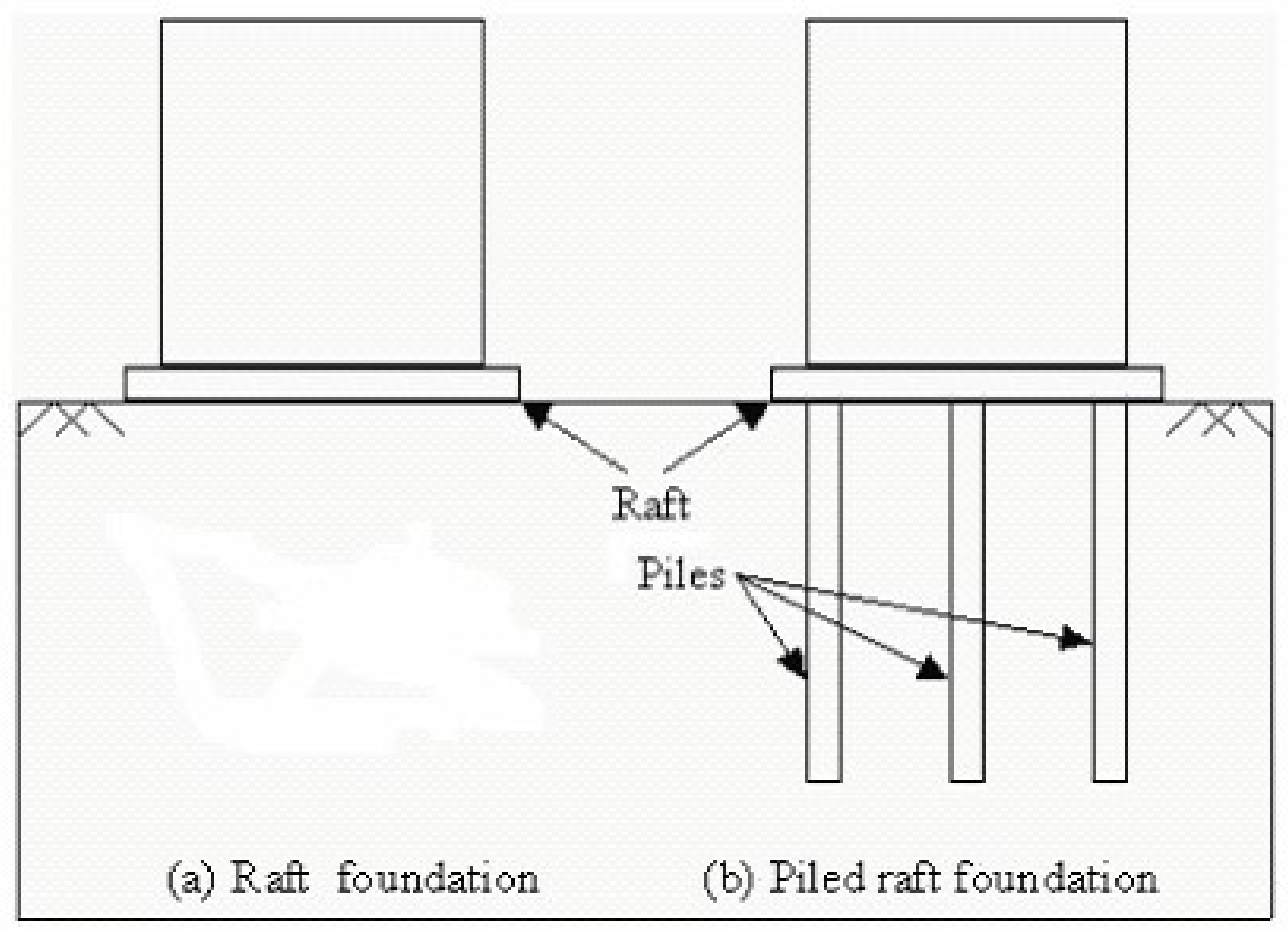


PILES

SOFT SOIL

Strength increases with depth

Raft & Piled-Raft



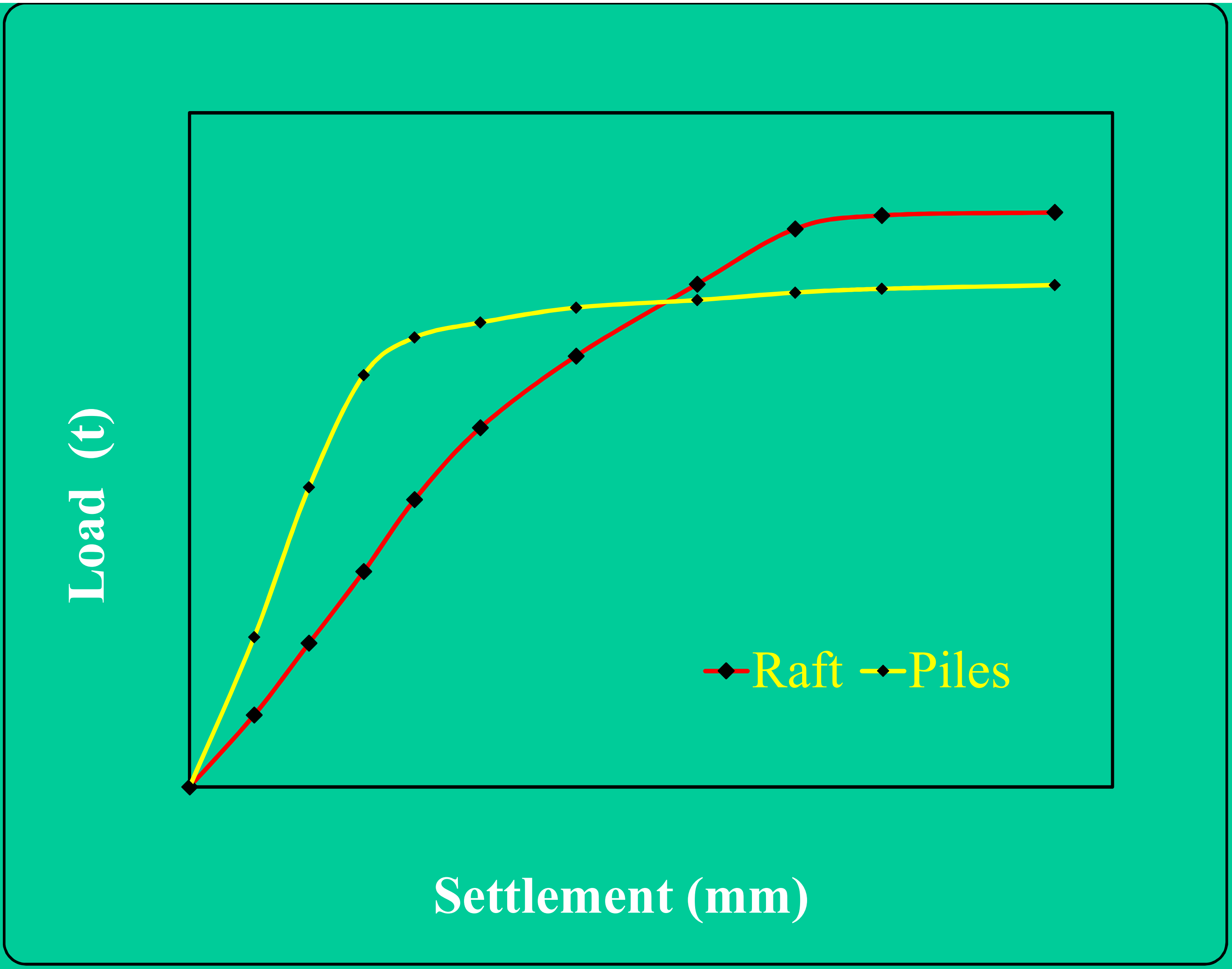
Design Philosophy of Piled Rafts

Conventional Design

- Disregards the capacity of Pile caps/Rafts
- Large number of piles or longer piles
- Very small allowable settlement
- Pile factor of safety (FS ≈ 2)

Piled Raft Design

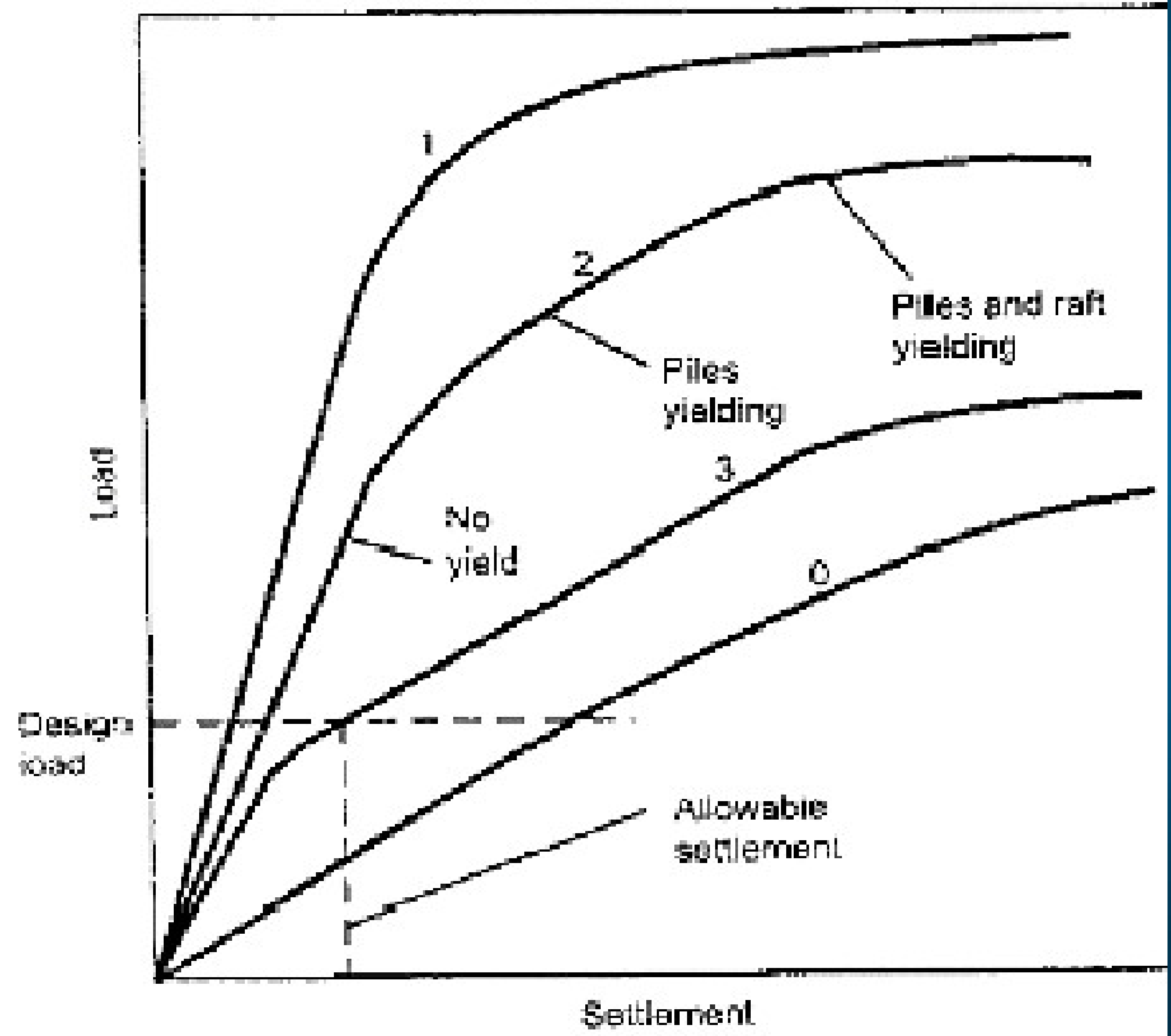
- Raft - main bearing element
- Design for full utilization of pile capacity (FS ≥1)
- Piles - Settlement reducers
- Optimal location of piles to decrease the differential settlement and bending moment of raft.



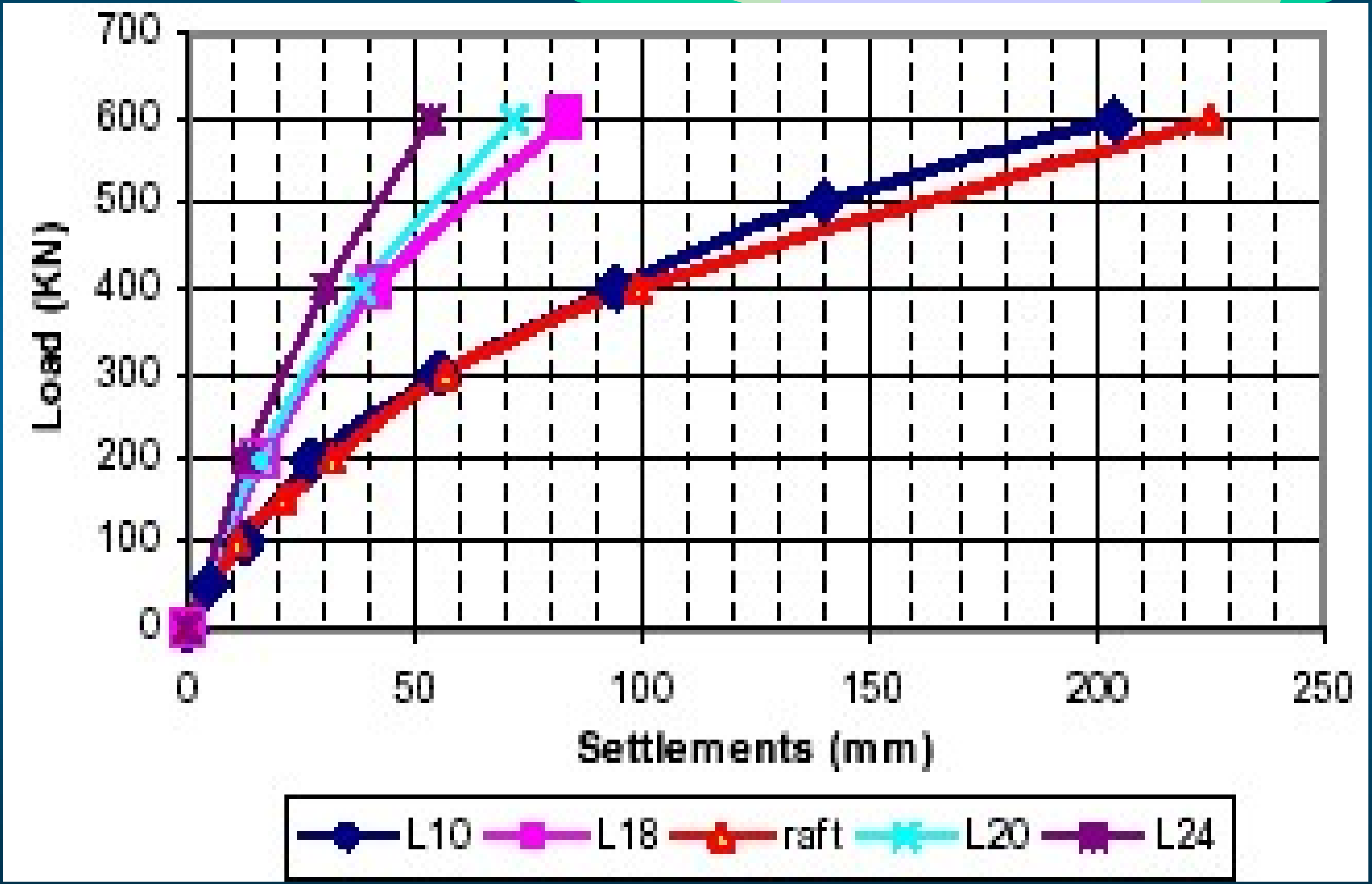
Load - settlement curves for piles and Raft

Piled Raft

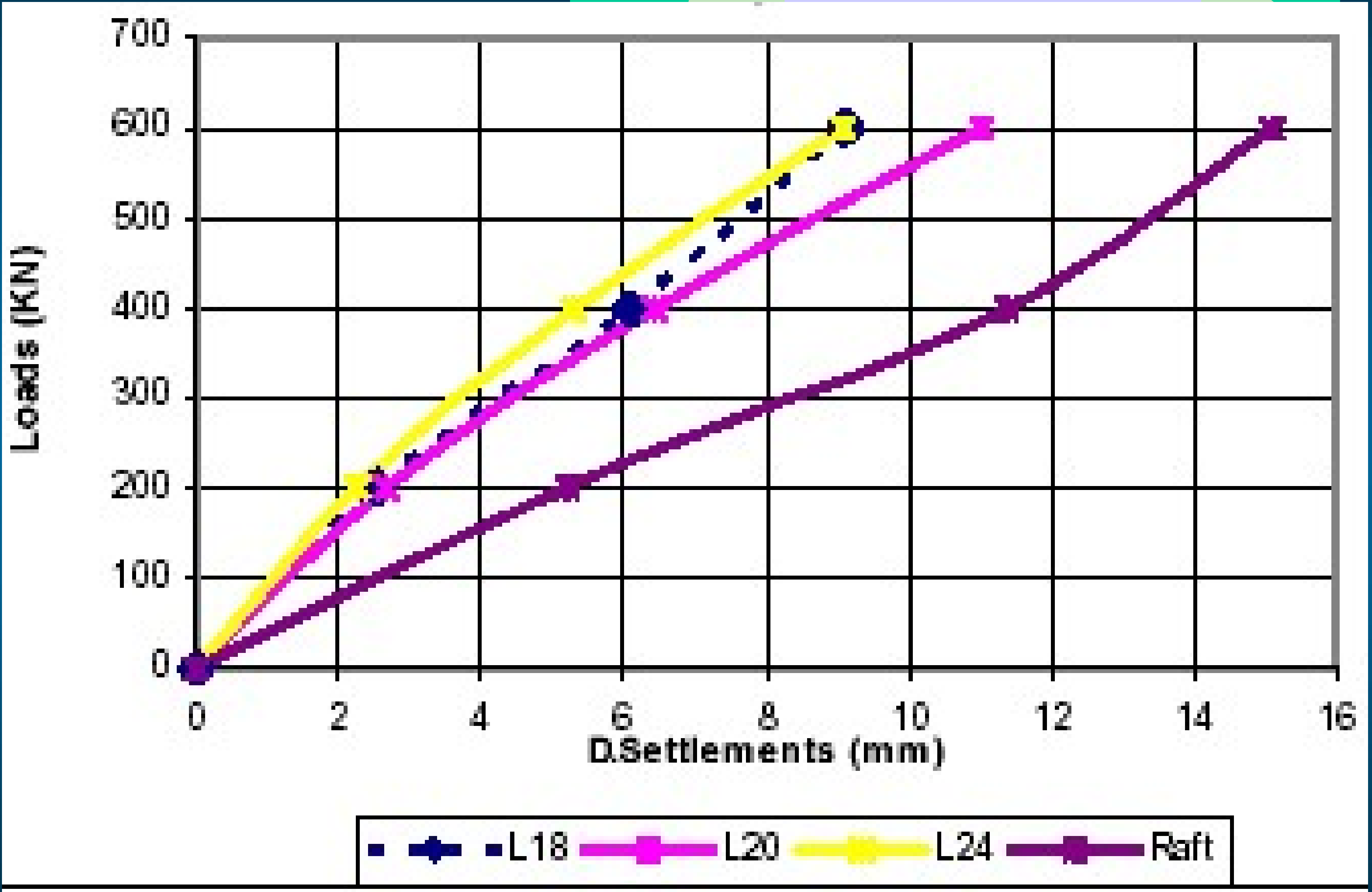
Piled Rafts: 0- Raft alone; 1, 2 and 3- Raft with piles designed with decreasing FS



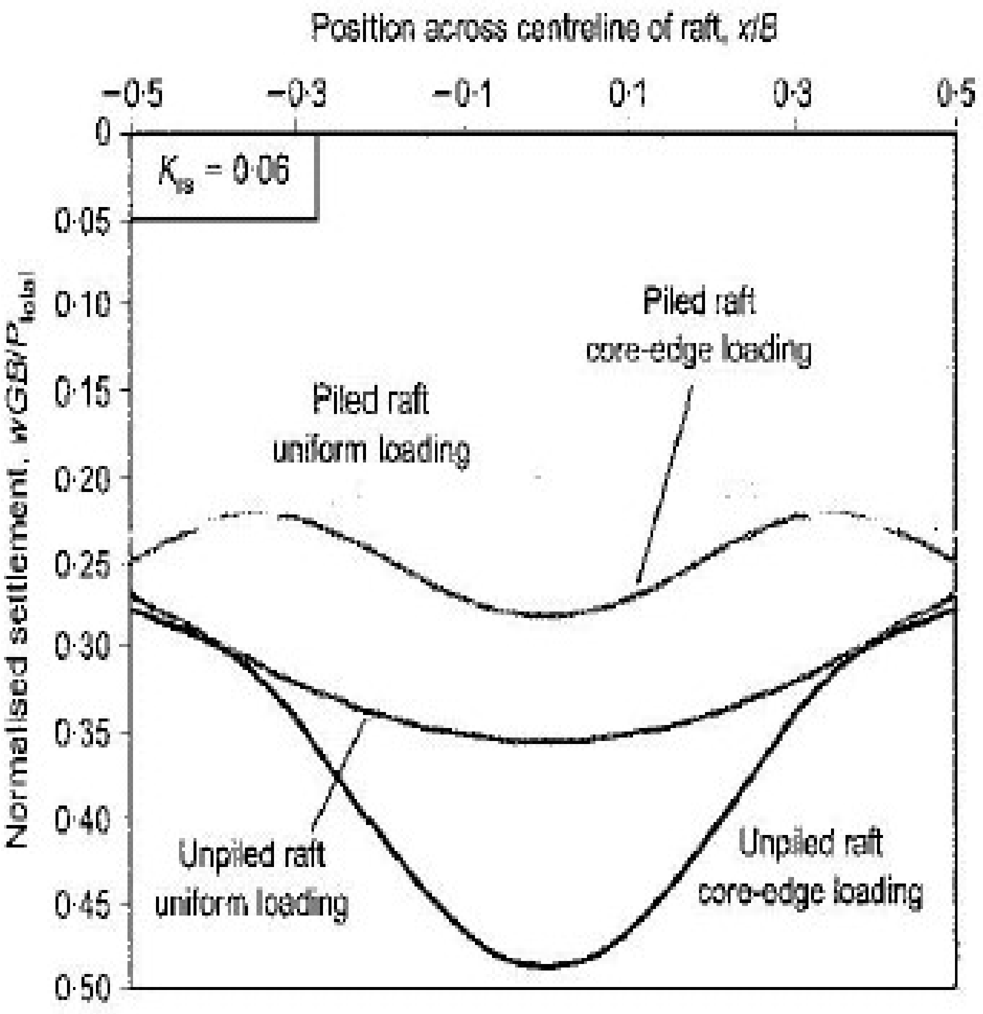
Load vs Settlement, Raft and Piled Rafts with Different Pile Lengths

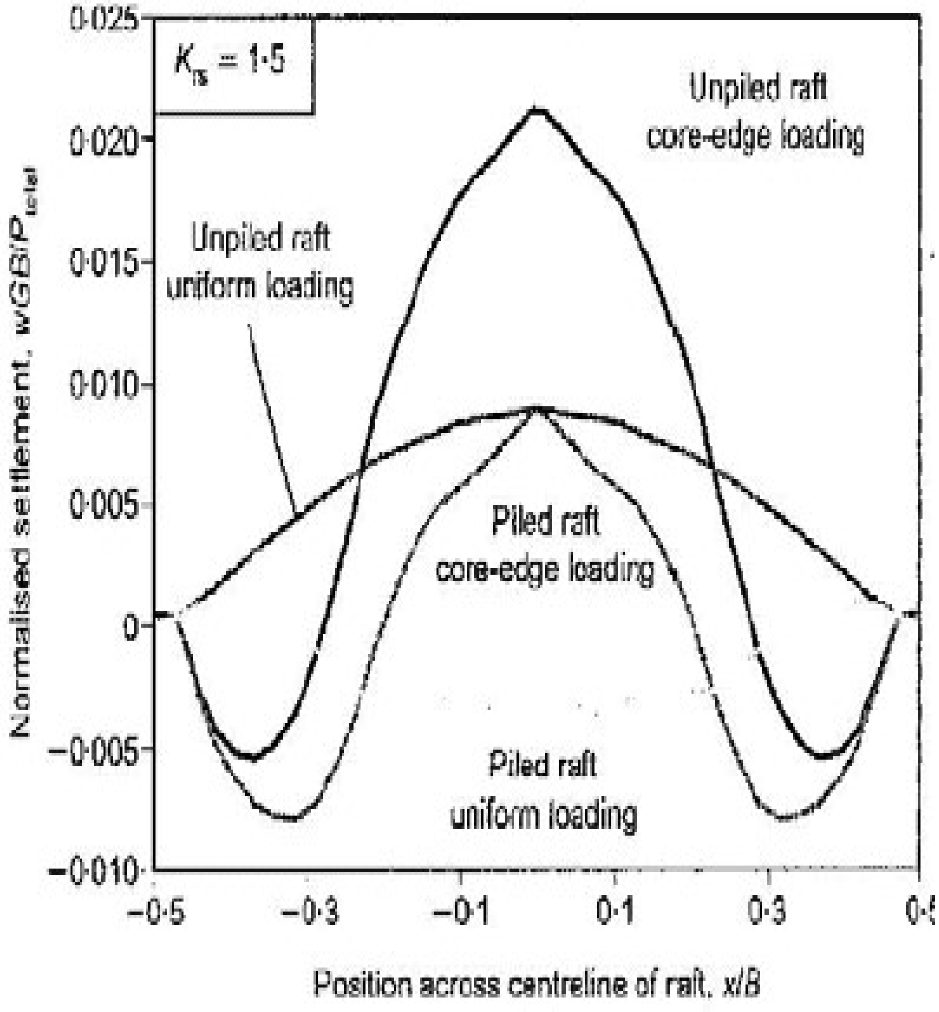


Comparison of Differential Settlements

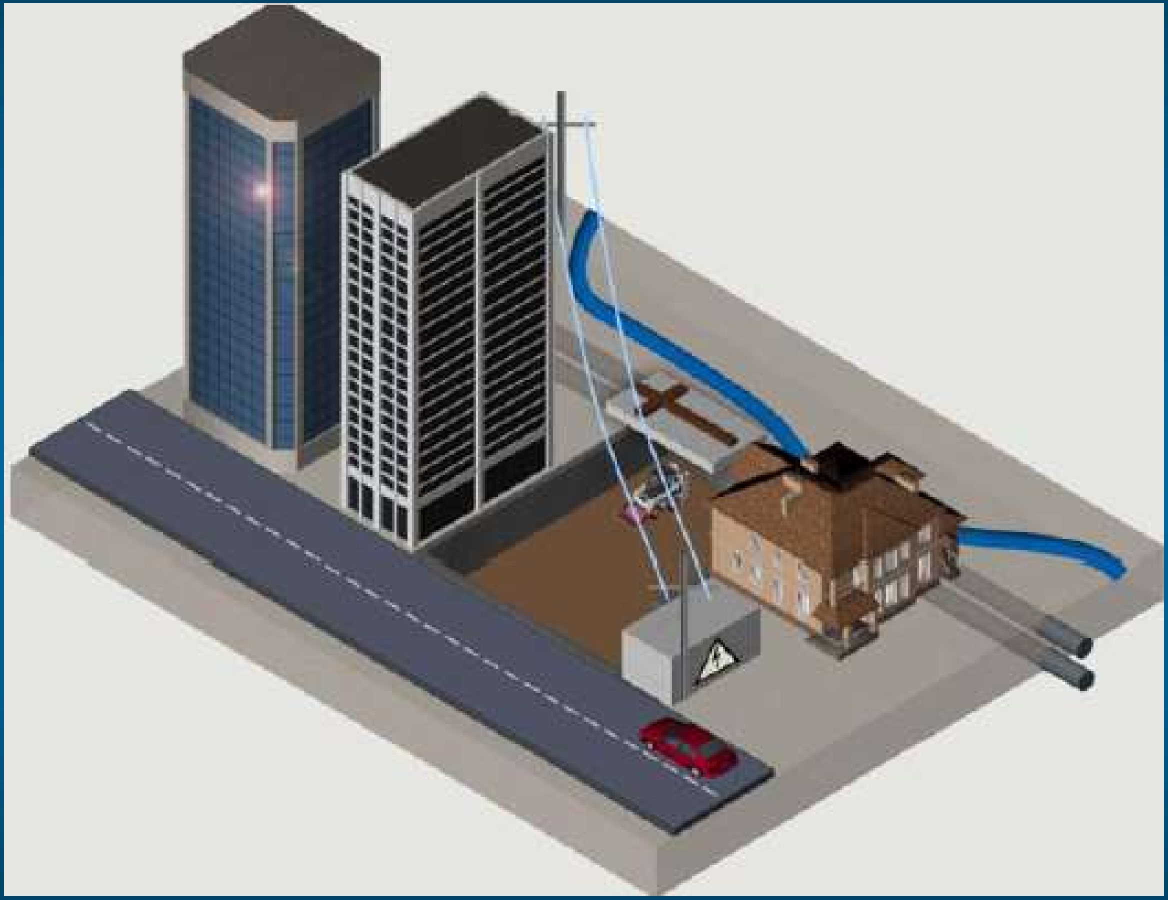


Settlements of Piled Raft vs Raft Alone





Challenges for Deep Excavation



Adjacent buildings
Limited headroom
Limited working space
Roads nearby
Existing tunnels
Installations
Groundwater
Different existing foundations
Different soil layers
…..

Options

Typical Deep Excavations


south
east


EAST


North

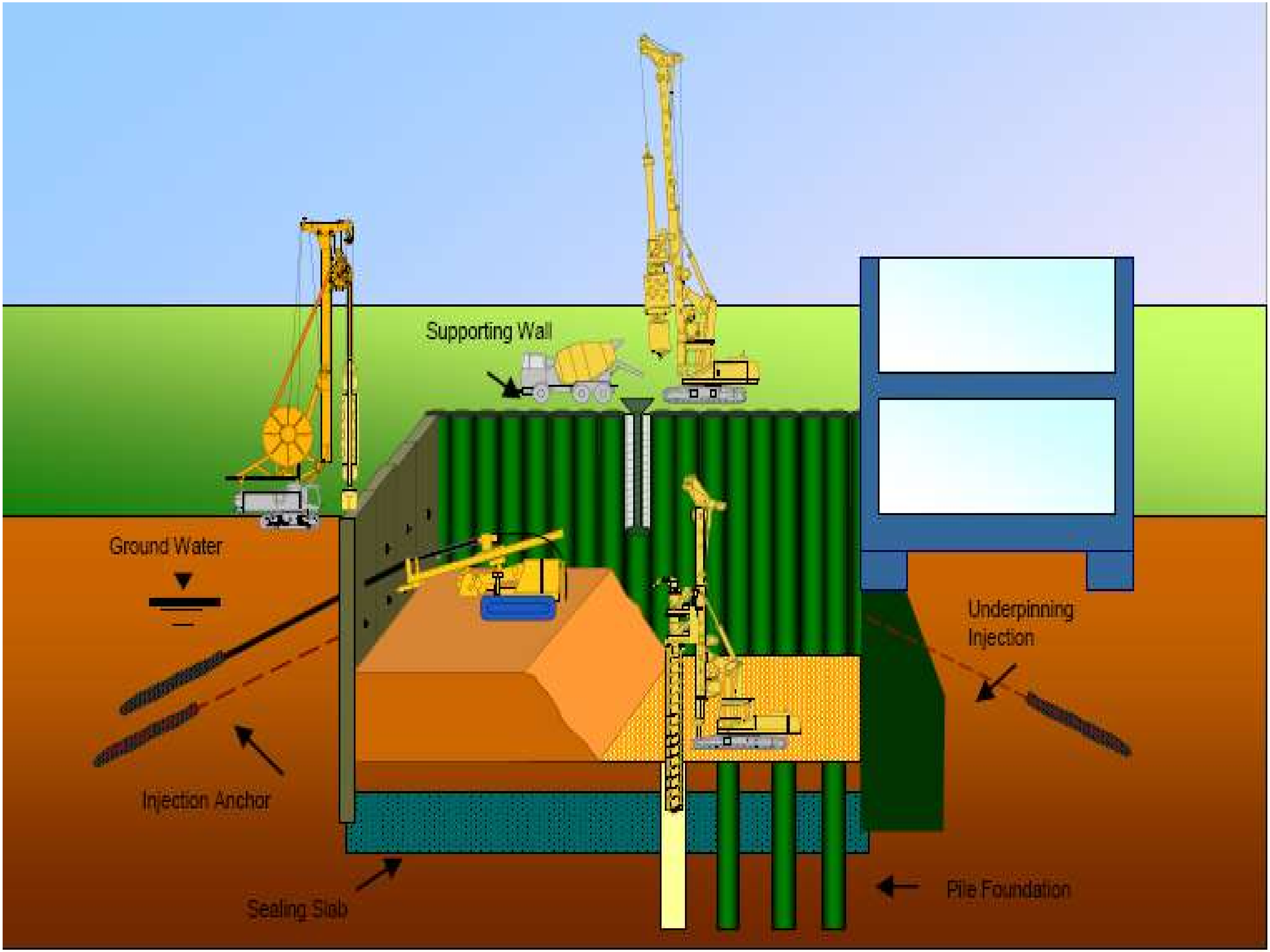

North

Price of Ignorance/Negligence

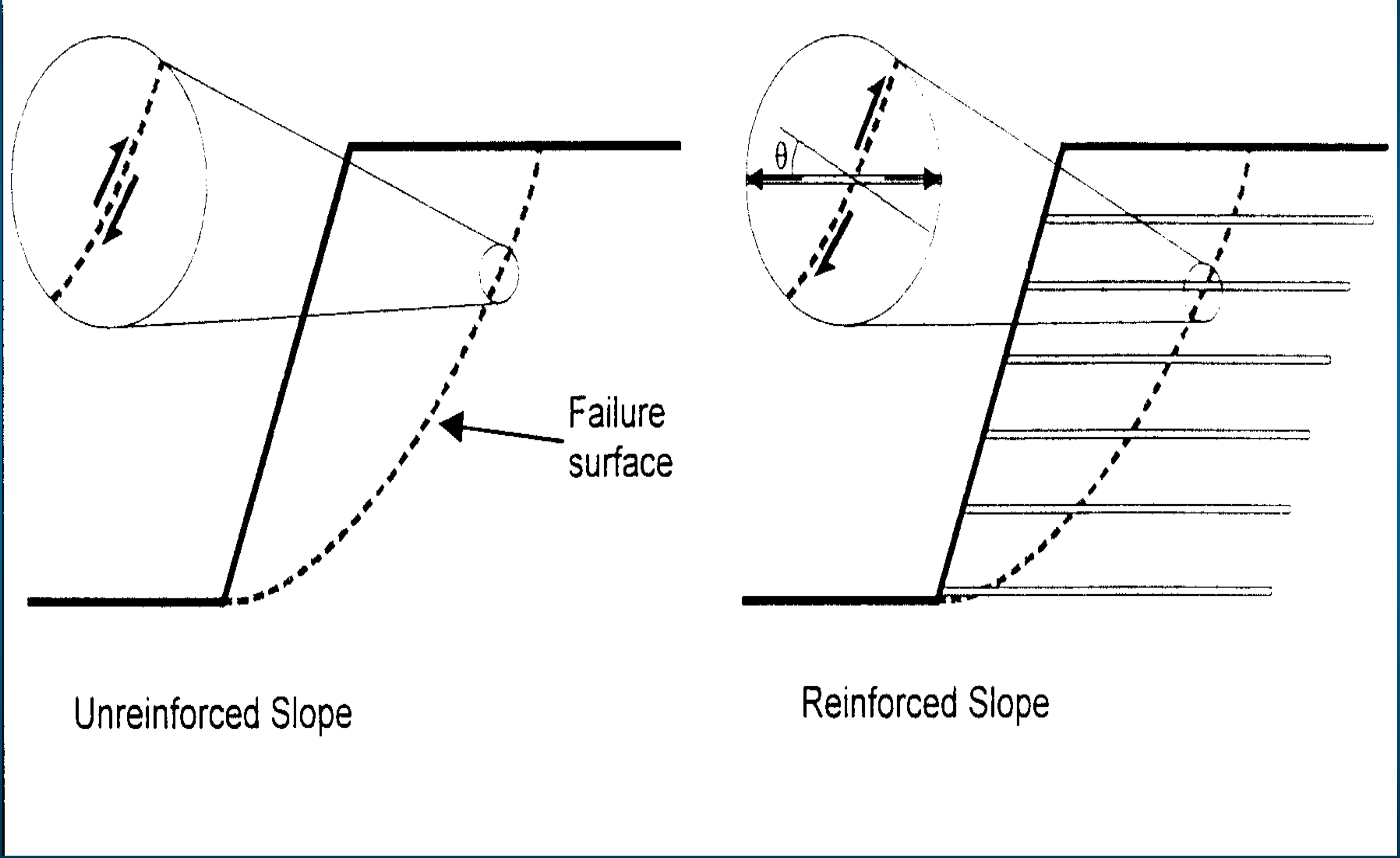

12 07 2014


12 07 2014

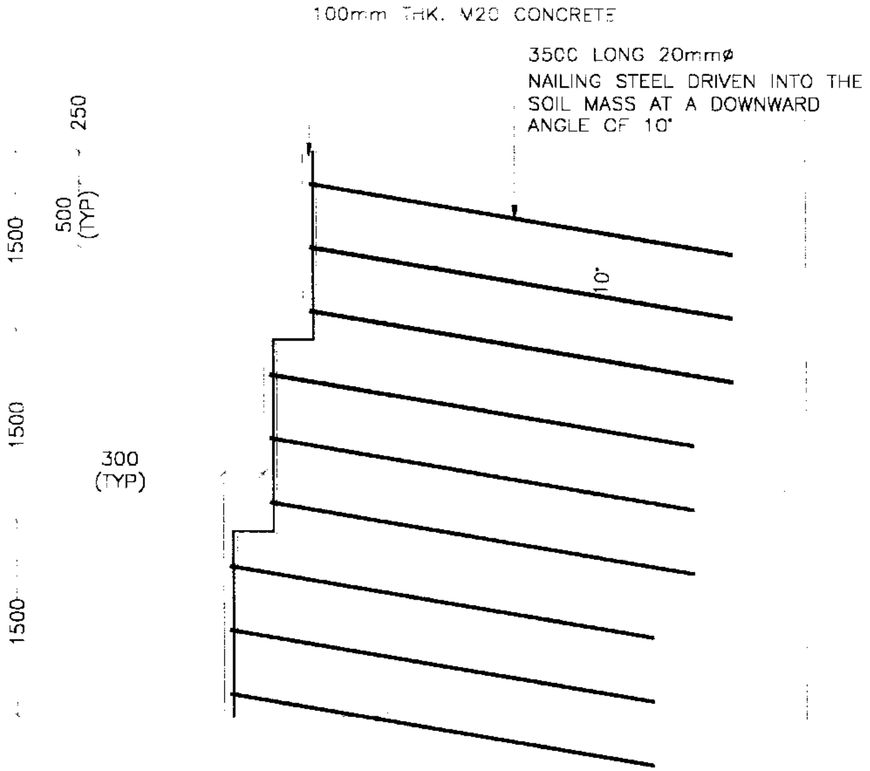

12 07 2014


Supporting Wall
Ground Water
Underpinning Injection
Injection Anchor
Sealing Slab
Pile Foundation

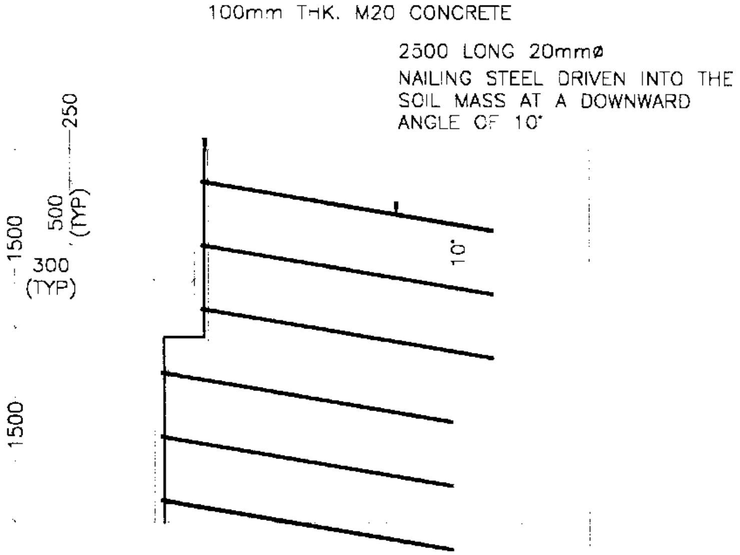
NAILING - MECHANISM



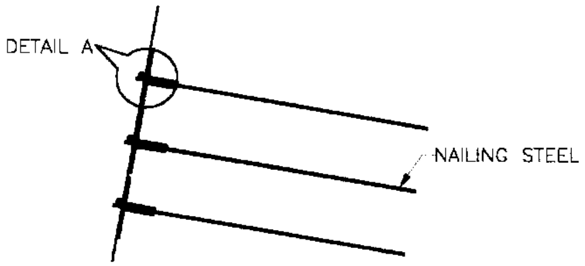
SOIL NAILING

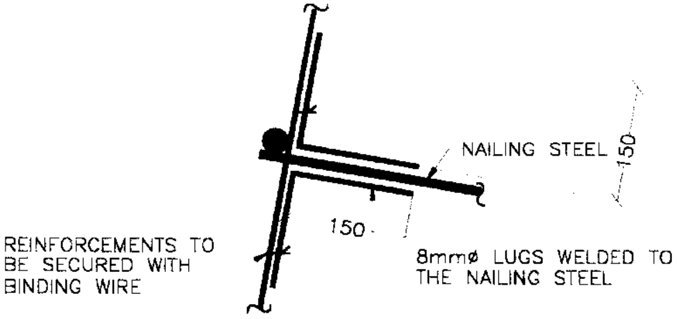


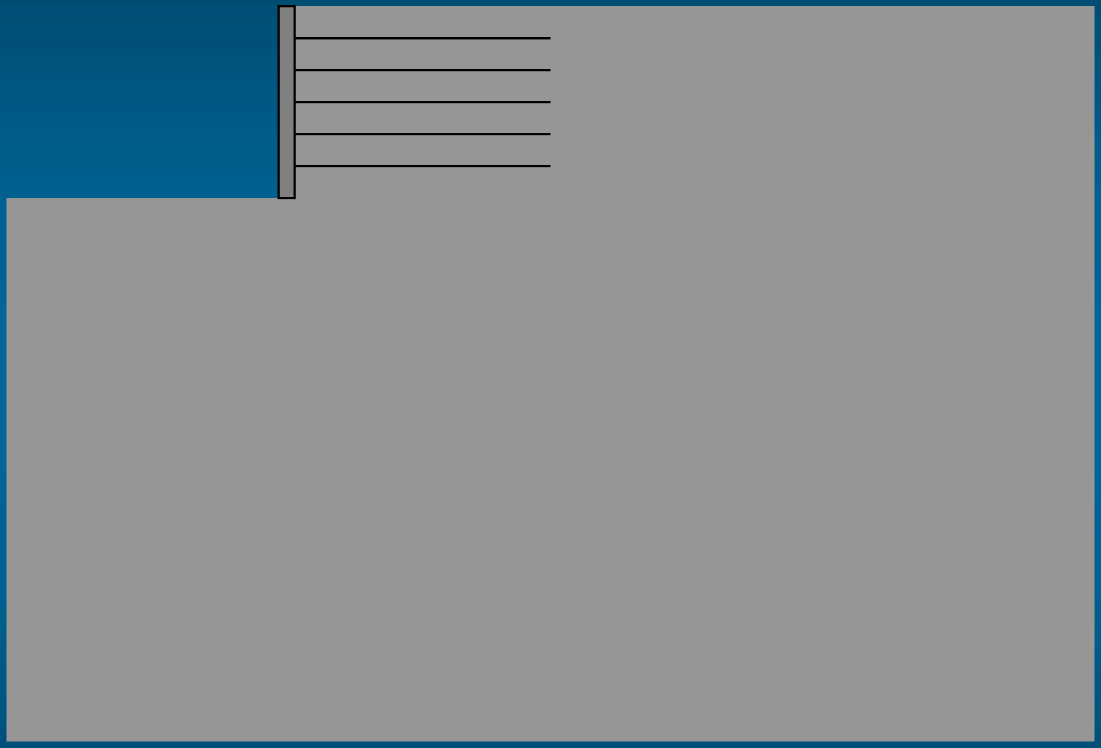
NAILING DETAILS FOR 4.5m TO 3.0m DEPTH

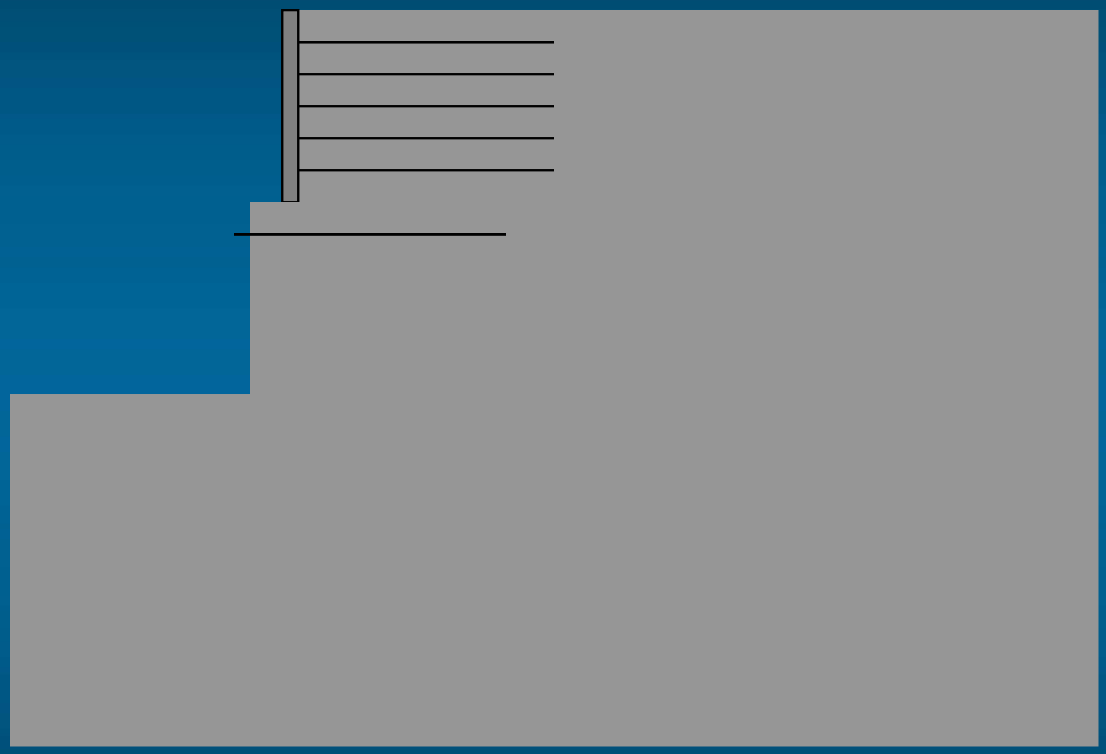


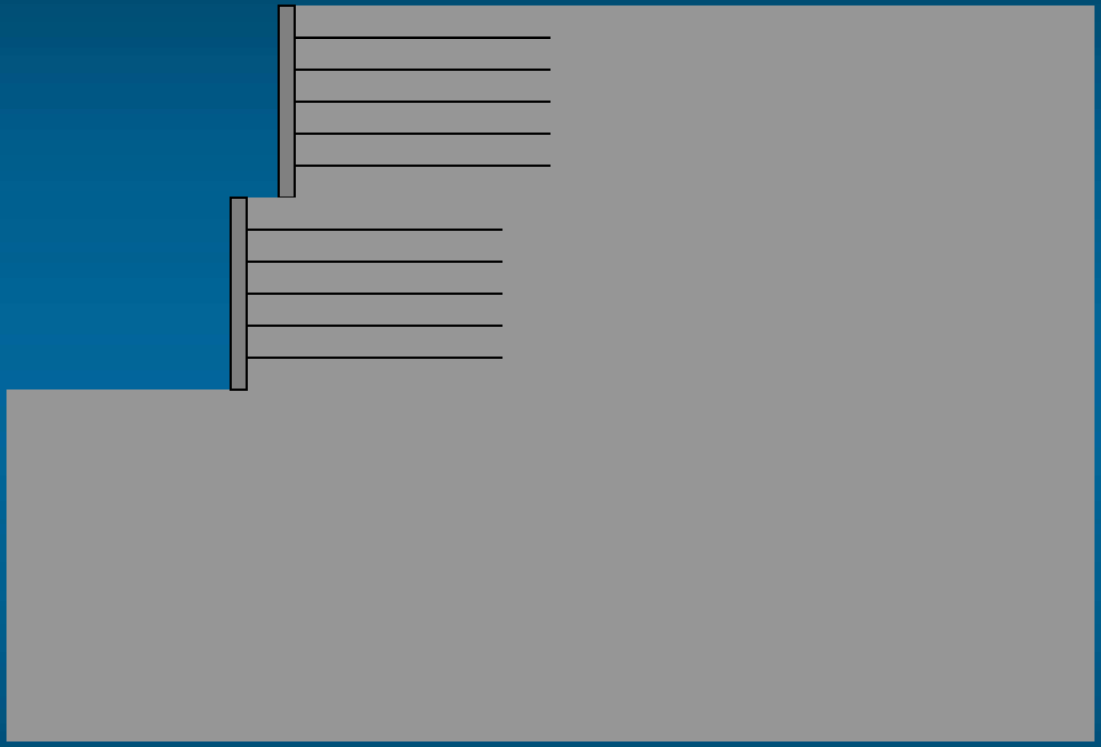
NAILING DETAILS FOR 3.0m TO 1.5m DEPTH

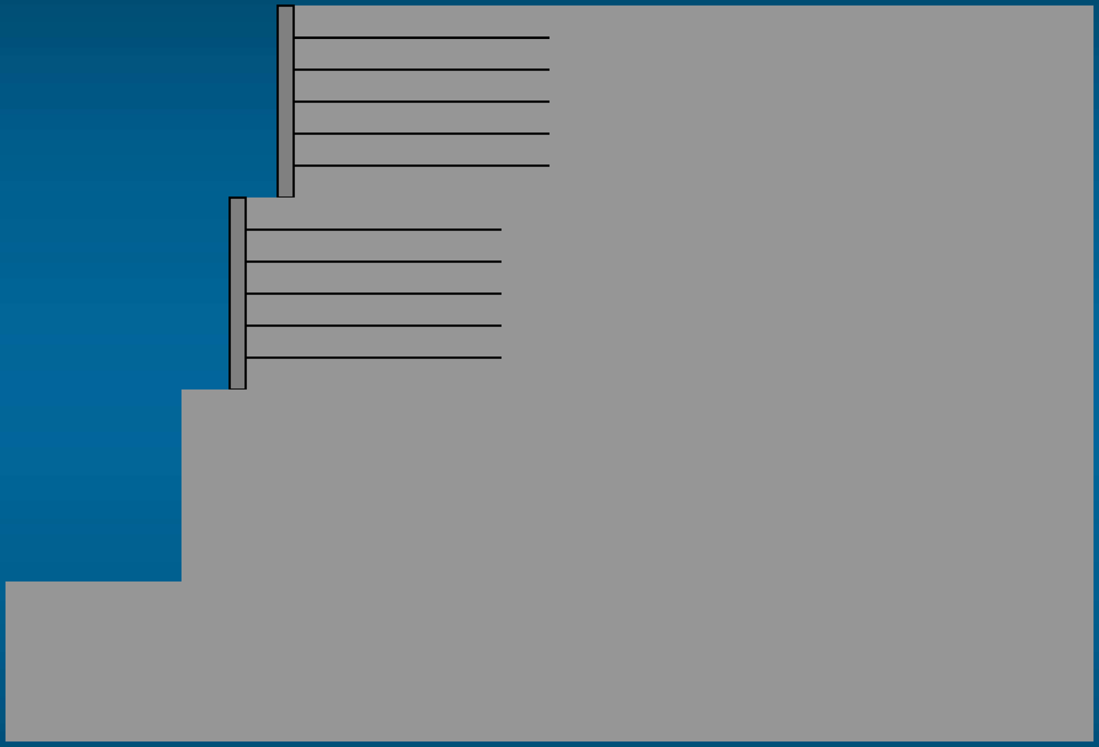


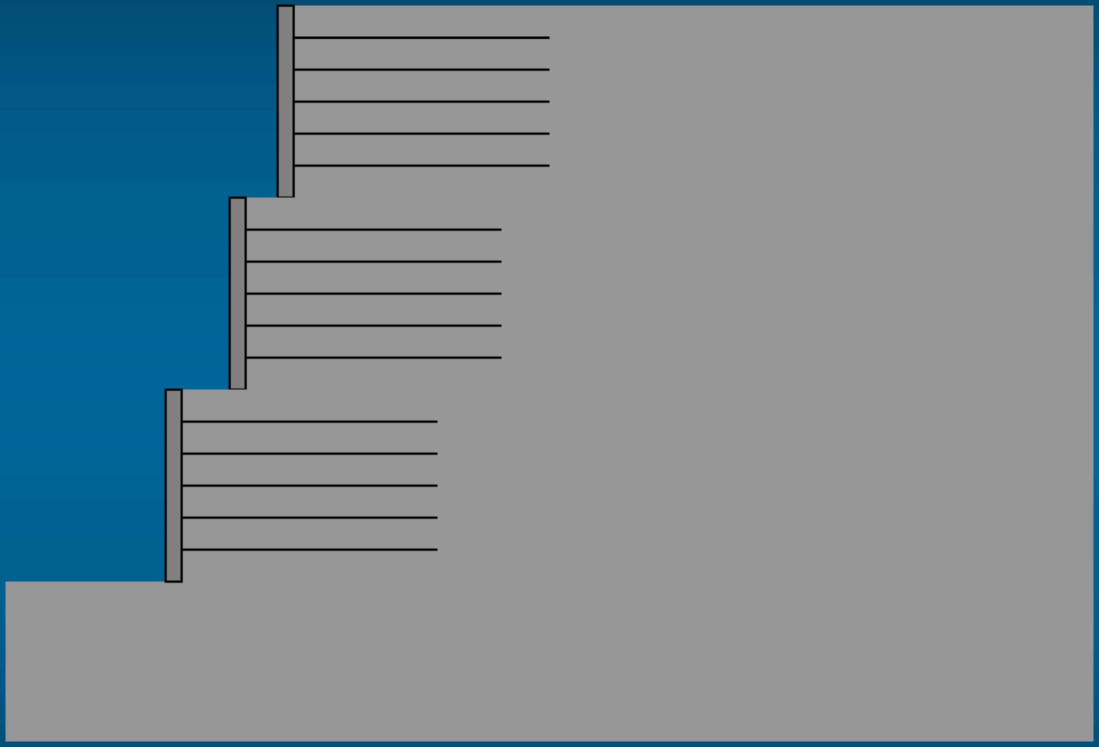


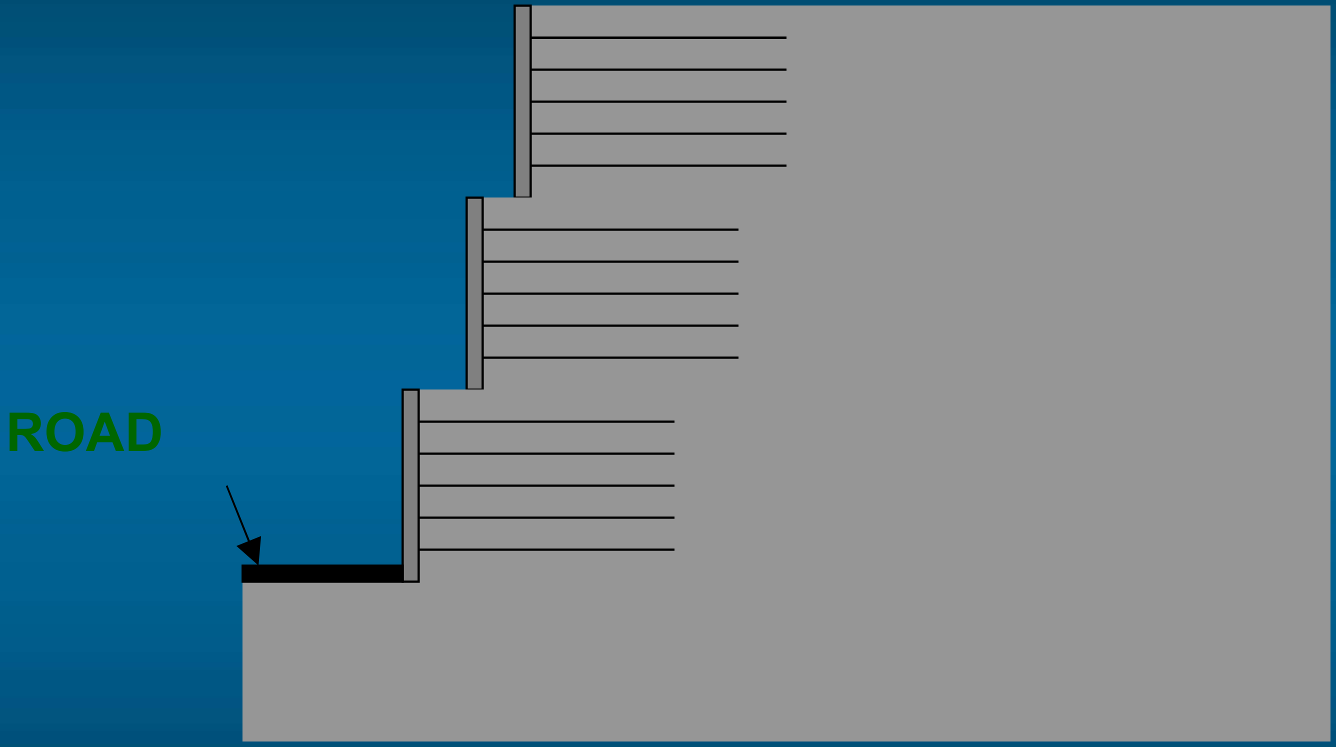


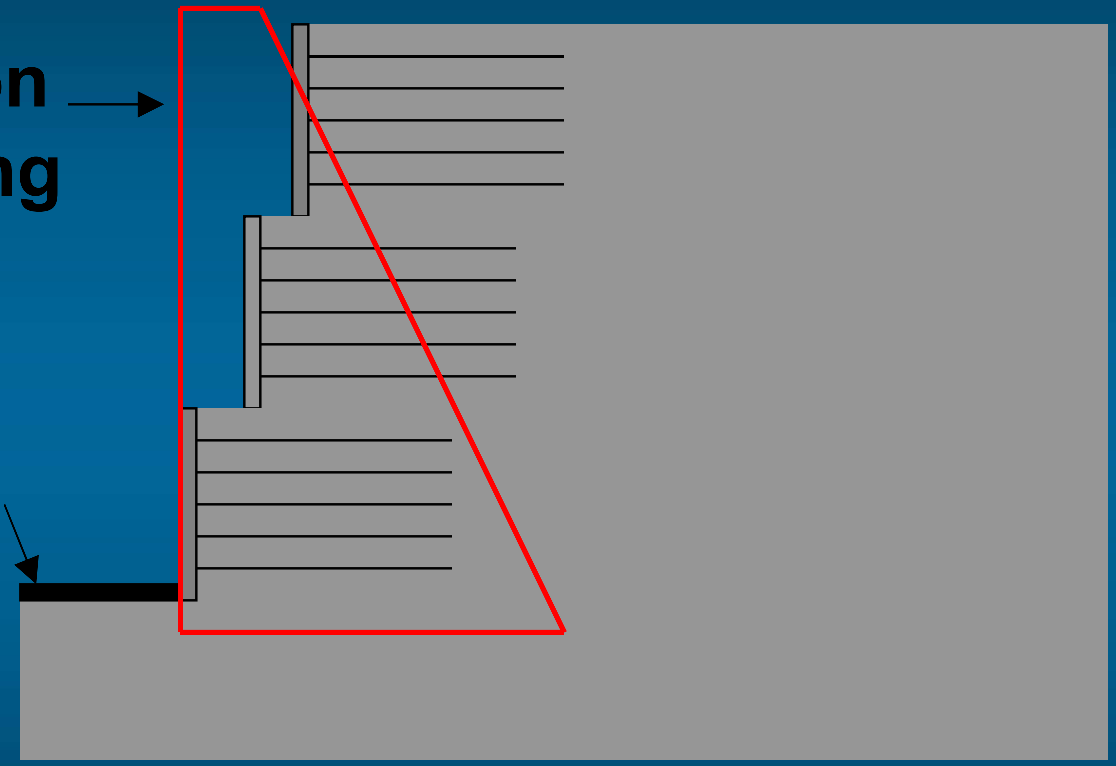








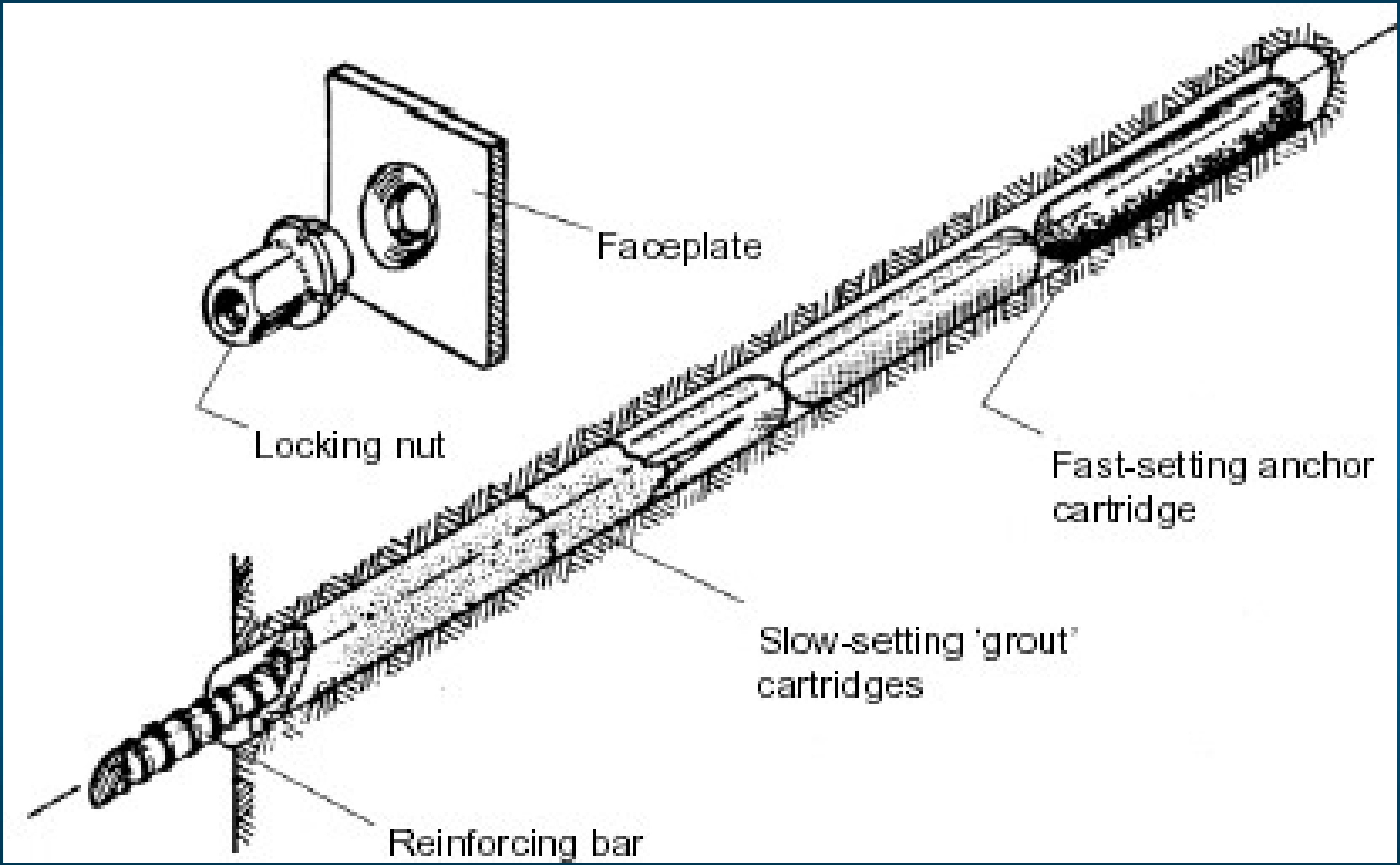

ROAD



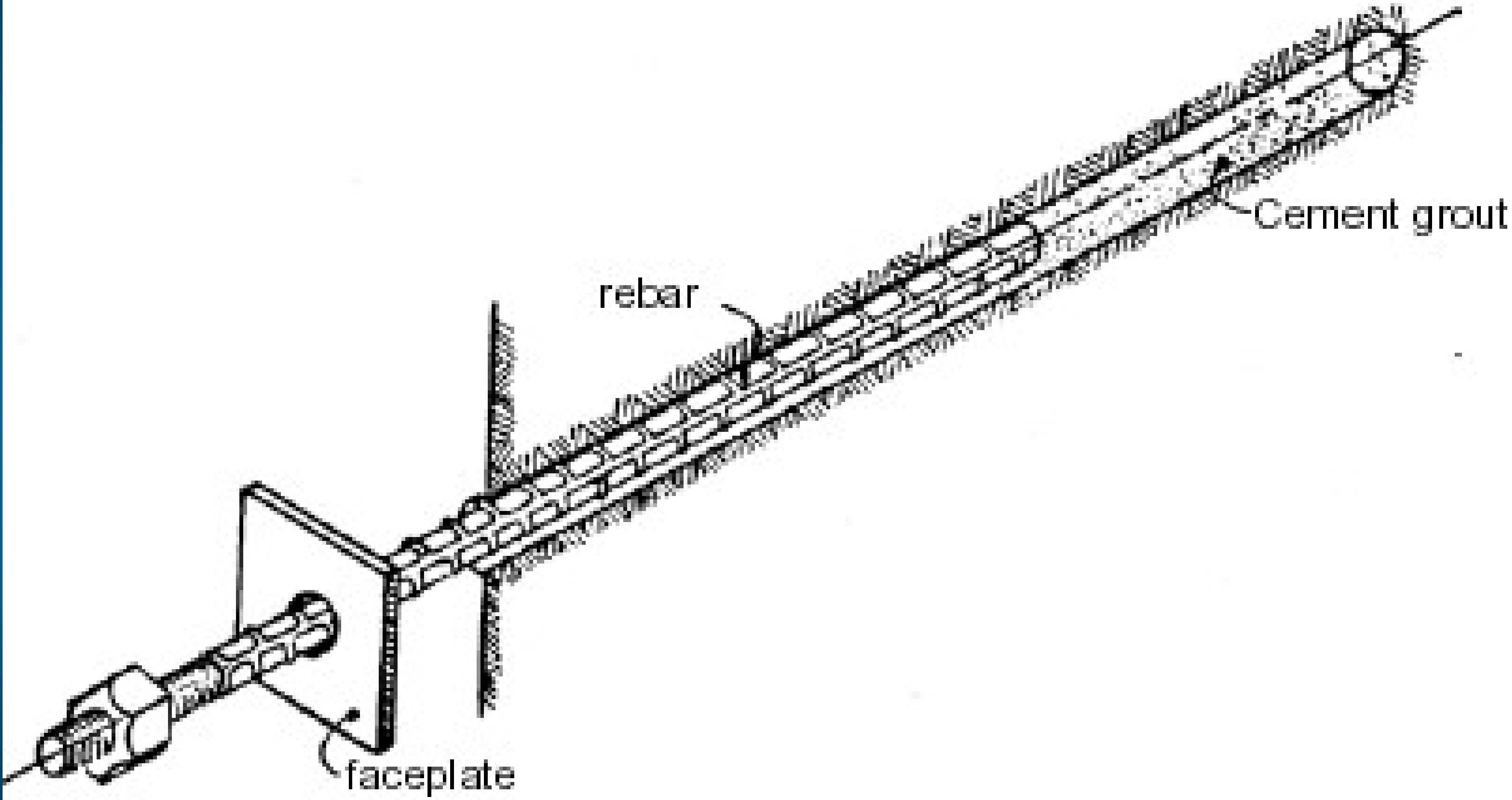
Conventional Retaining Wall

Raft

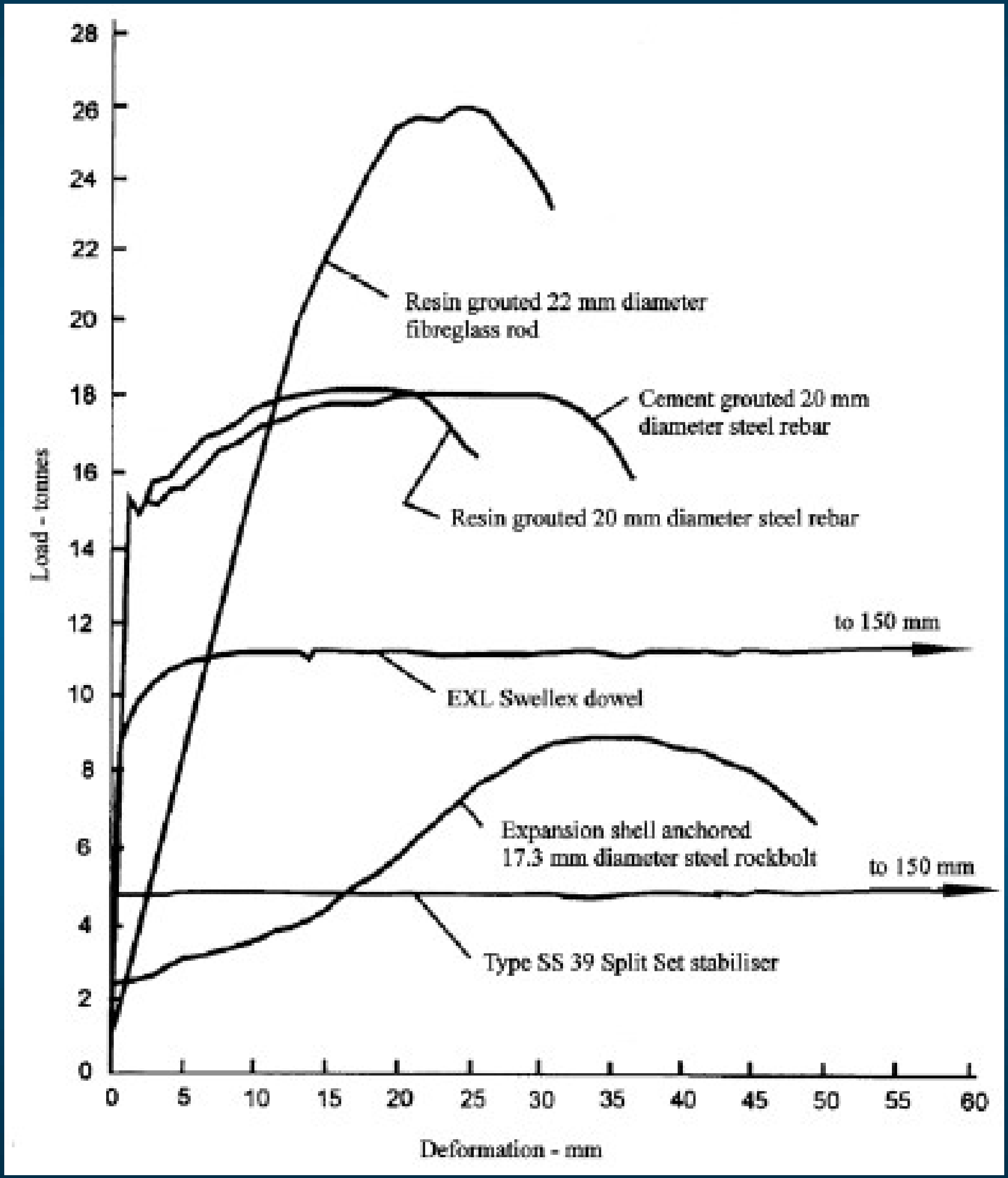
Resin Grouted Anchor Bolt



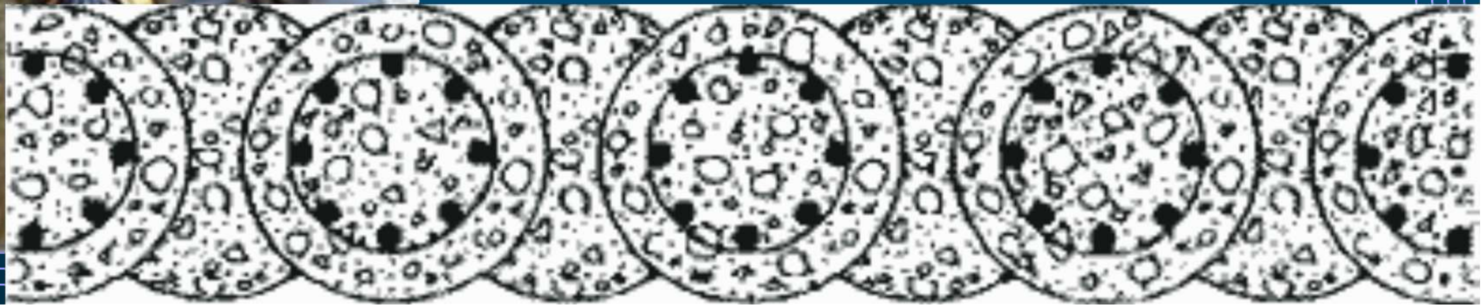
Grouted Dowel/Rock Bolt



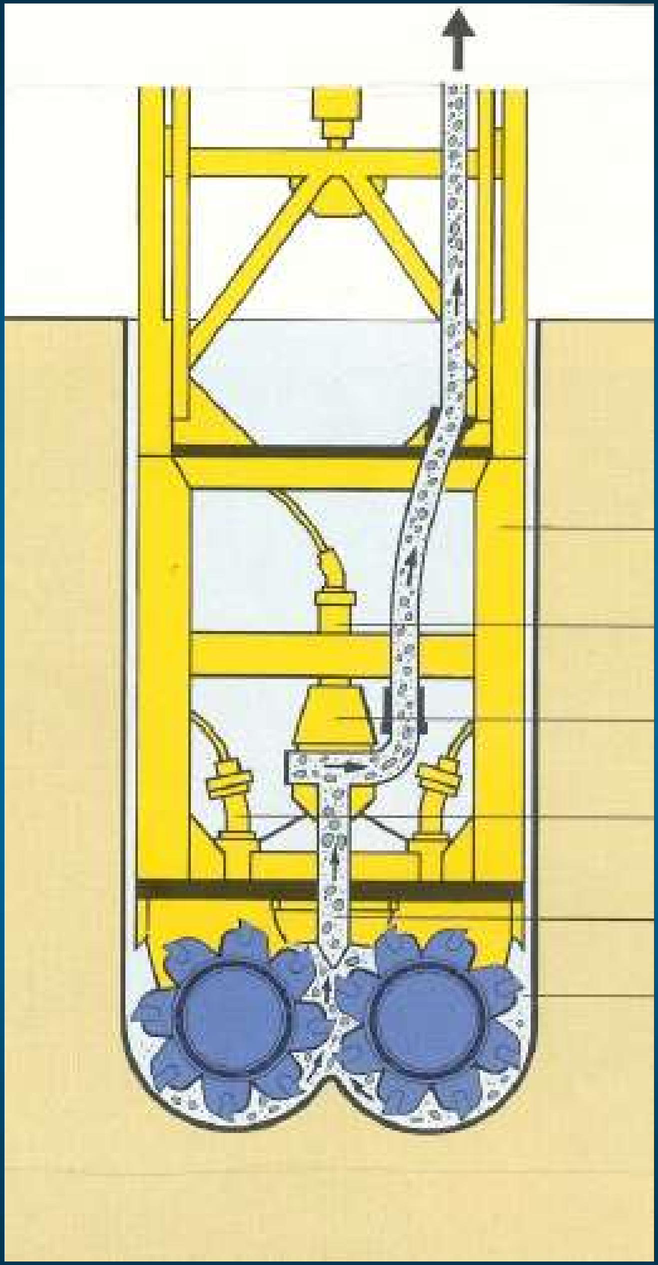
Typical Load – Deformation Responses

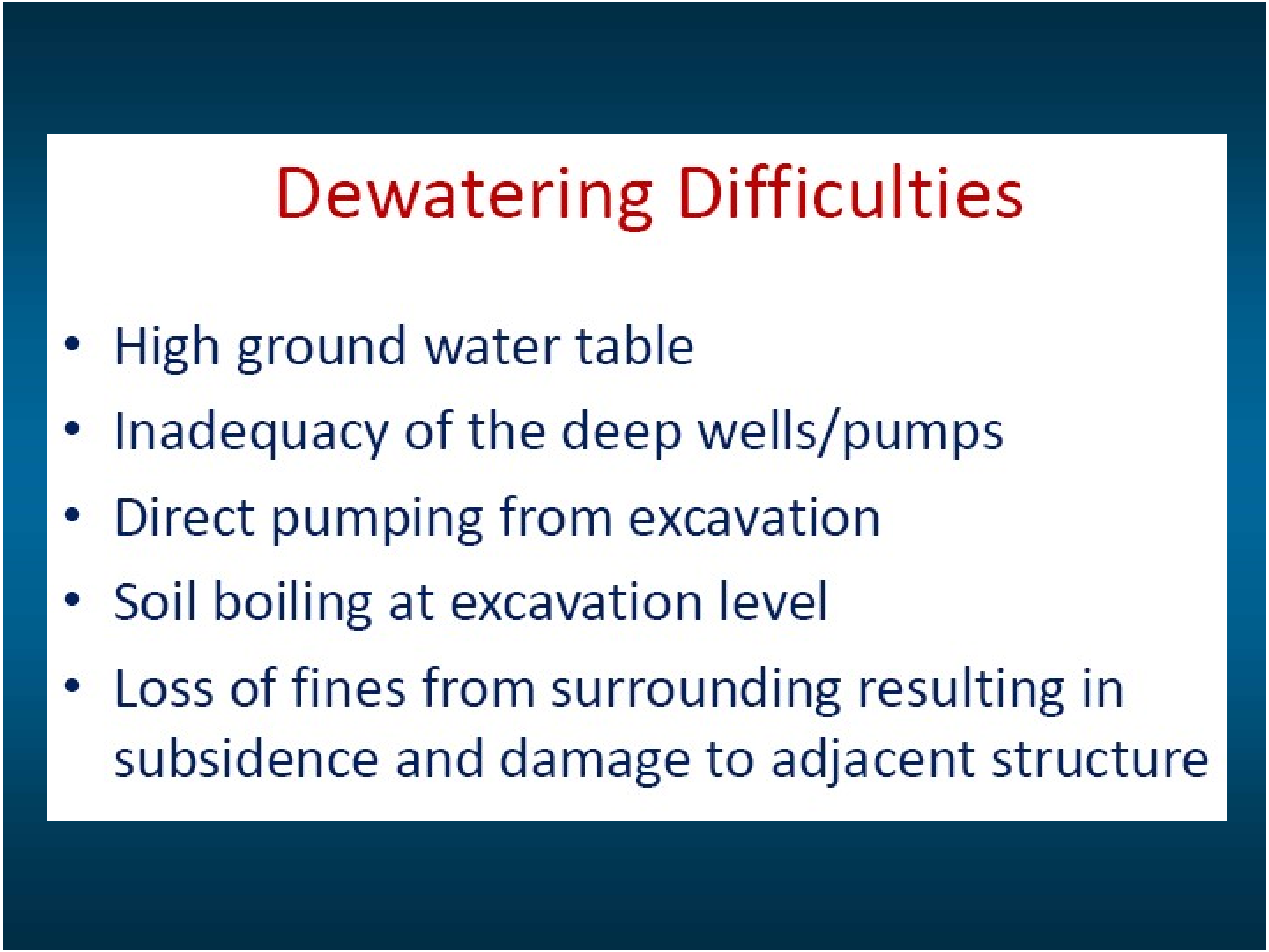


Bored Secant Pile Wall



Diaphragm Walls

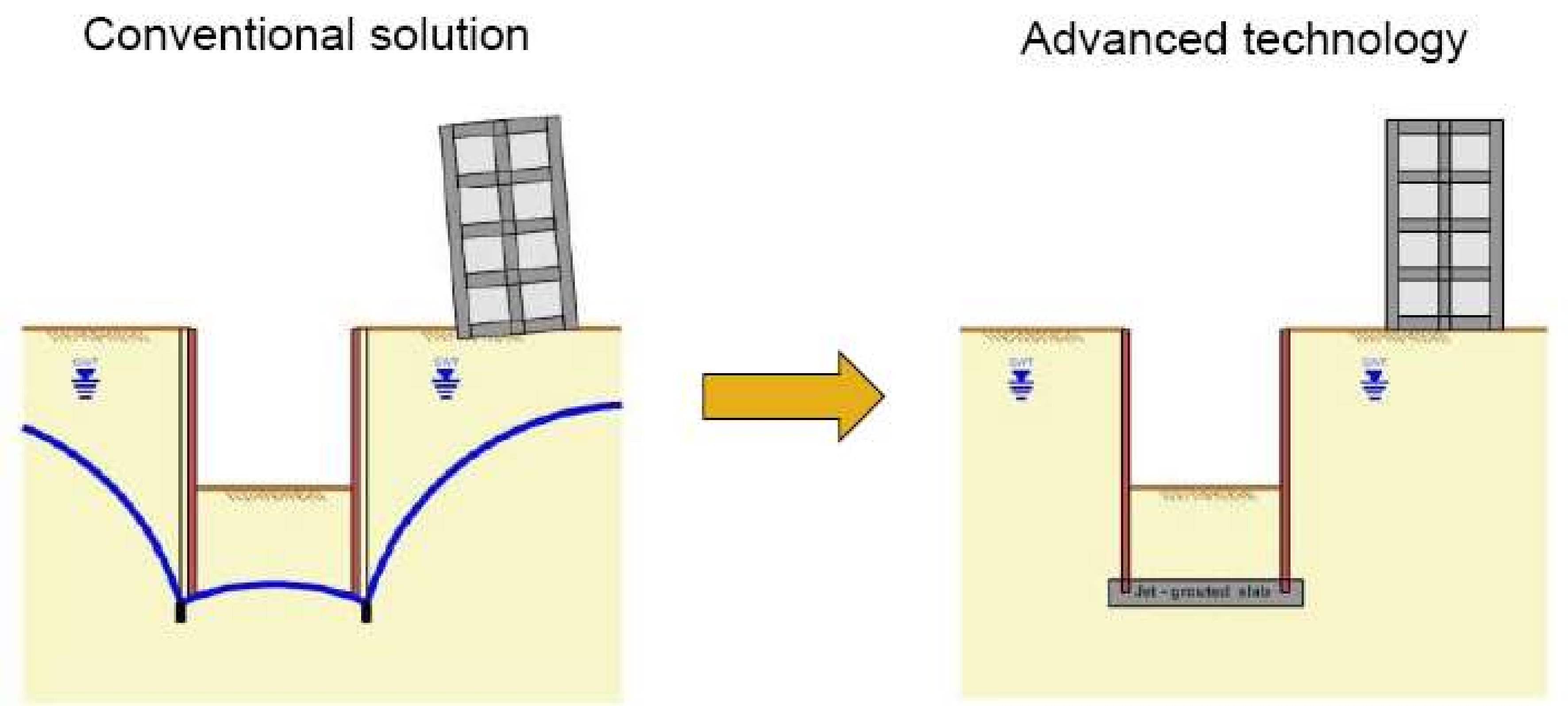




Dewatering Difficulties

- High ground water table
- Inadequacy of the deep wells/pumps
- Direct pumping from excavation
- Soil boiling at excavation level
- Loss of fines from surrounding resulting in subsidence and damage to adjacent structure

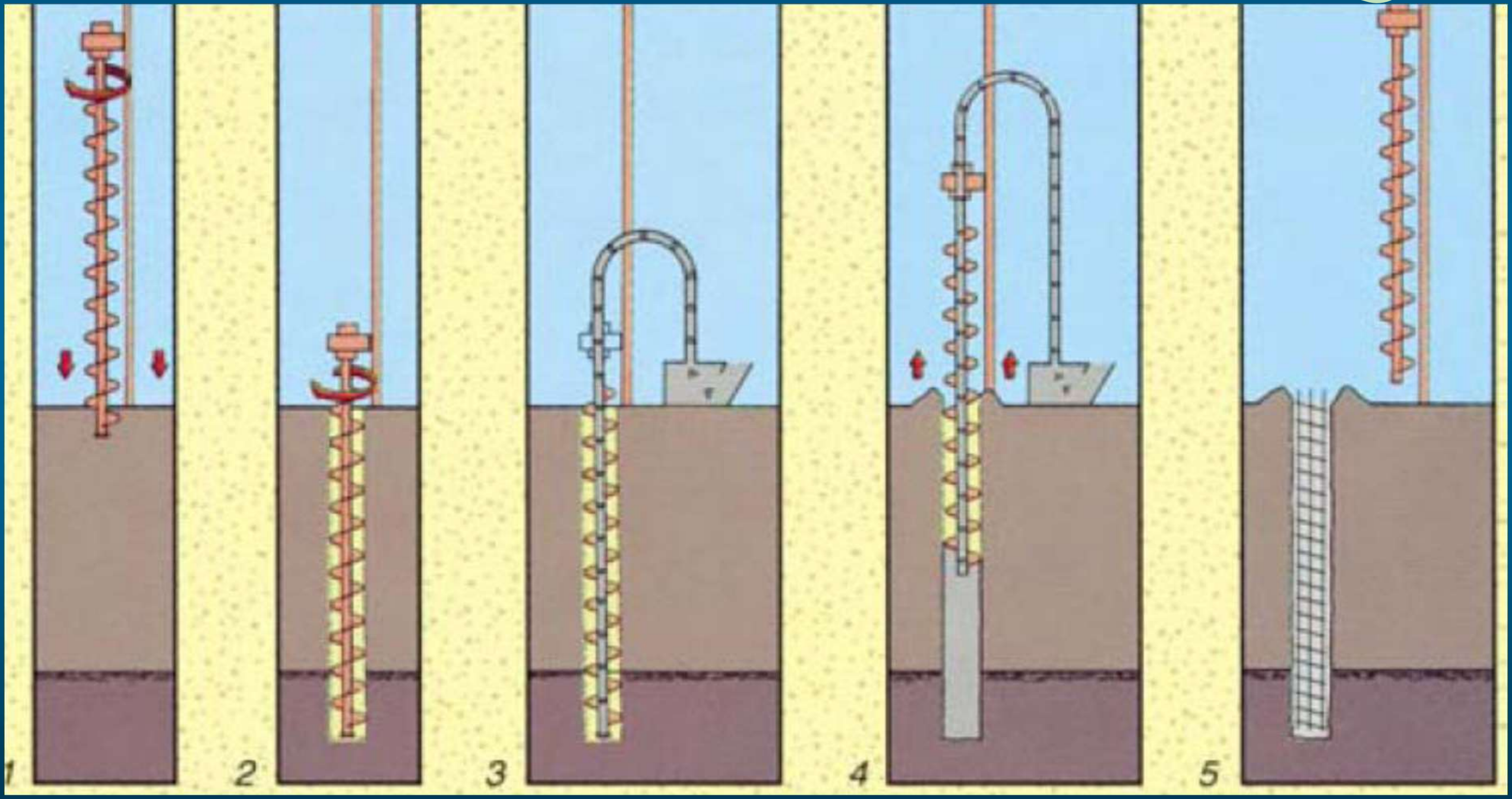
Sealing Slab

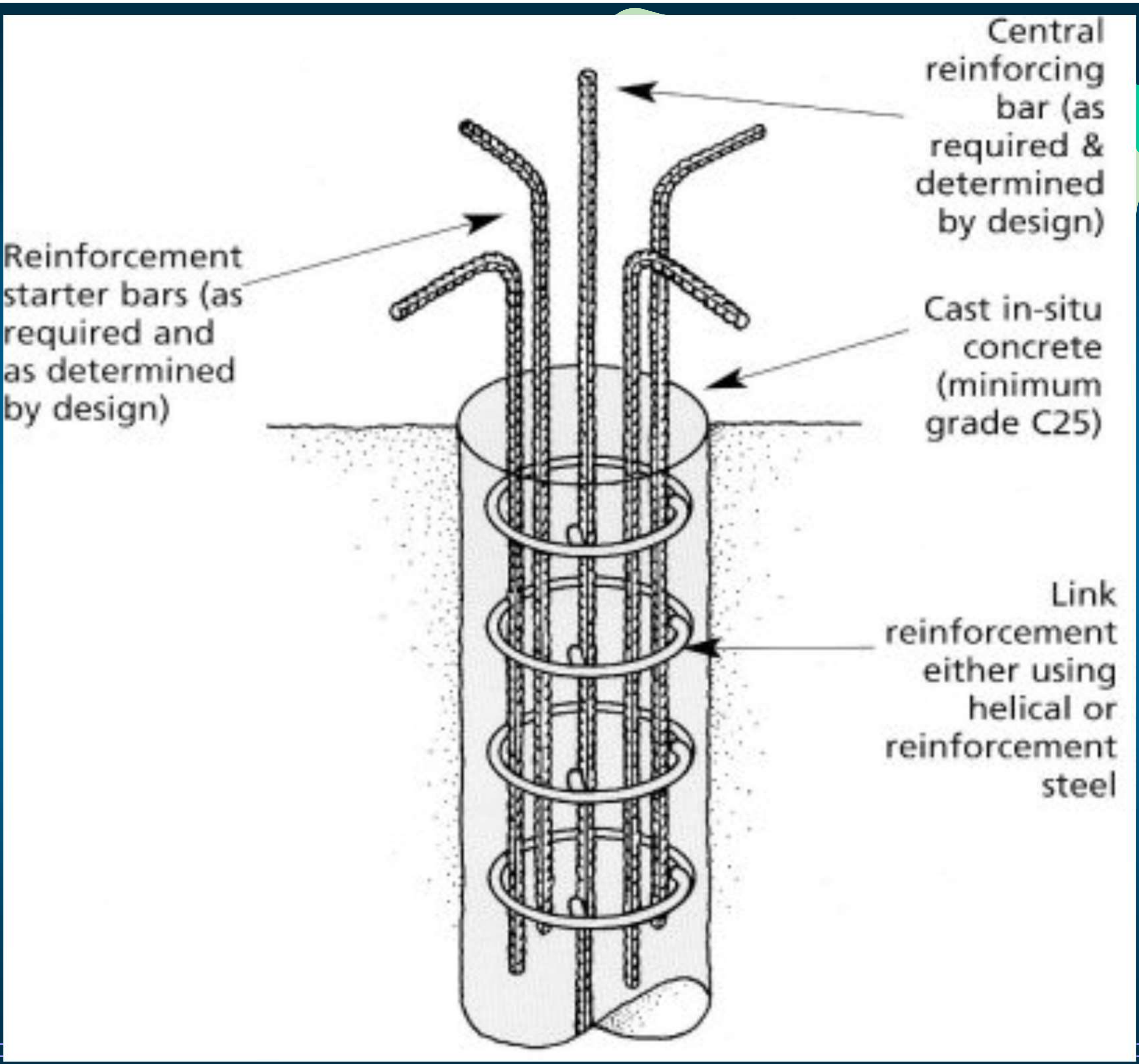


Top Down Construction

New Piling Techniques

Continuous Flight Auger Pile Installation




Central reinforcing bar (as required & determined by design)
Reinforcement starter bars (as required and as determined by design)
Cast in-situ concrete (minimum grade C25)
Link reinforcement either using helical or reinforcement steel

Multi-Helix Screw Pile

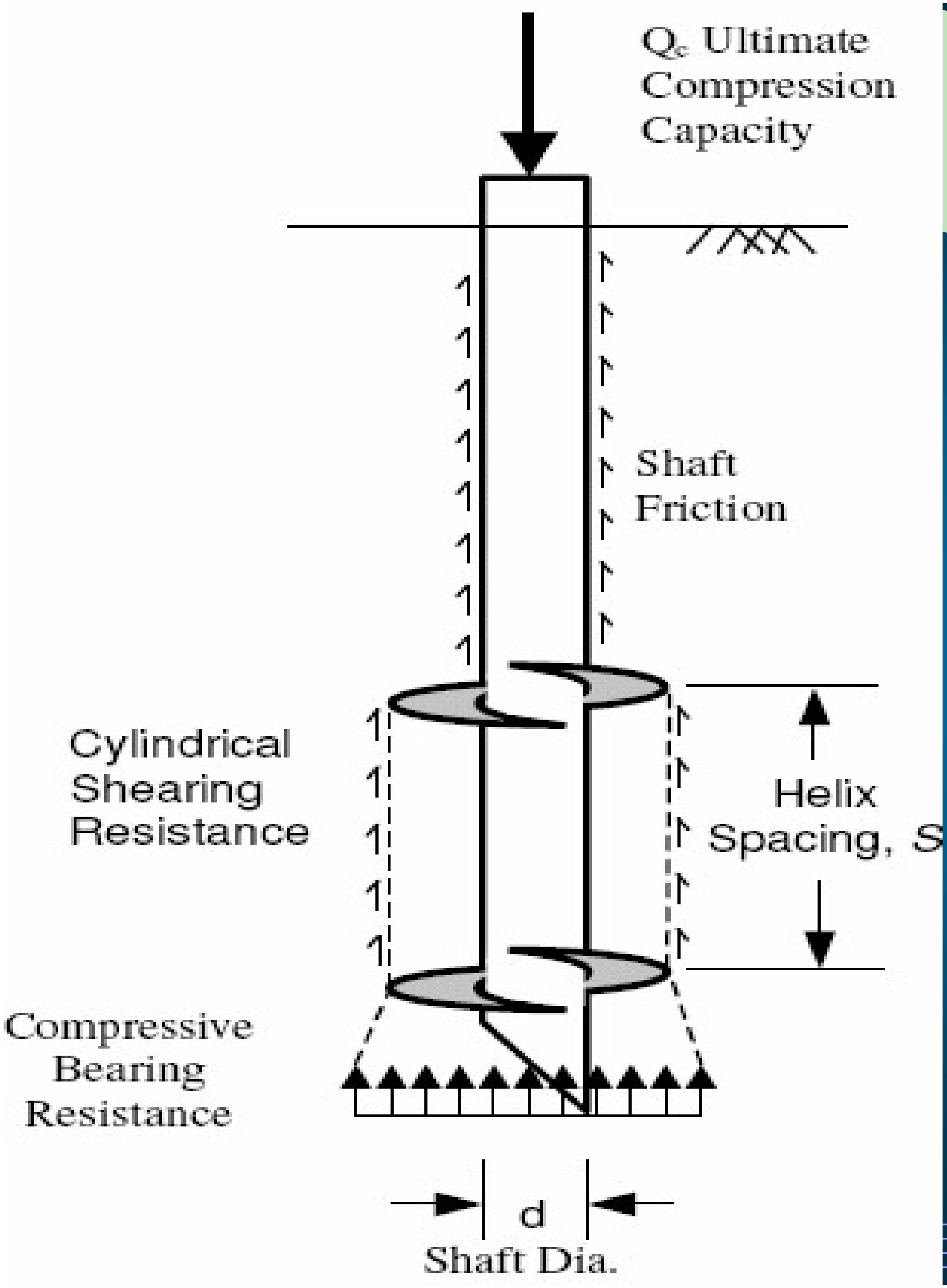
SHAFT - HOLLOW
ROUND STRUCTURAL
STEEL PIPE.
2 7/8" DIA. TO 36" DIA.

PILE MAY CONSIST
OF ONE OR MORE
HELIXES DEPENDING
ON DESIGN

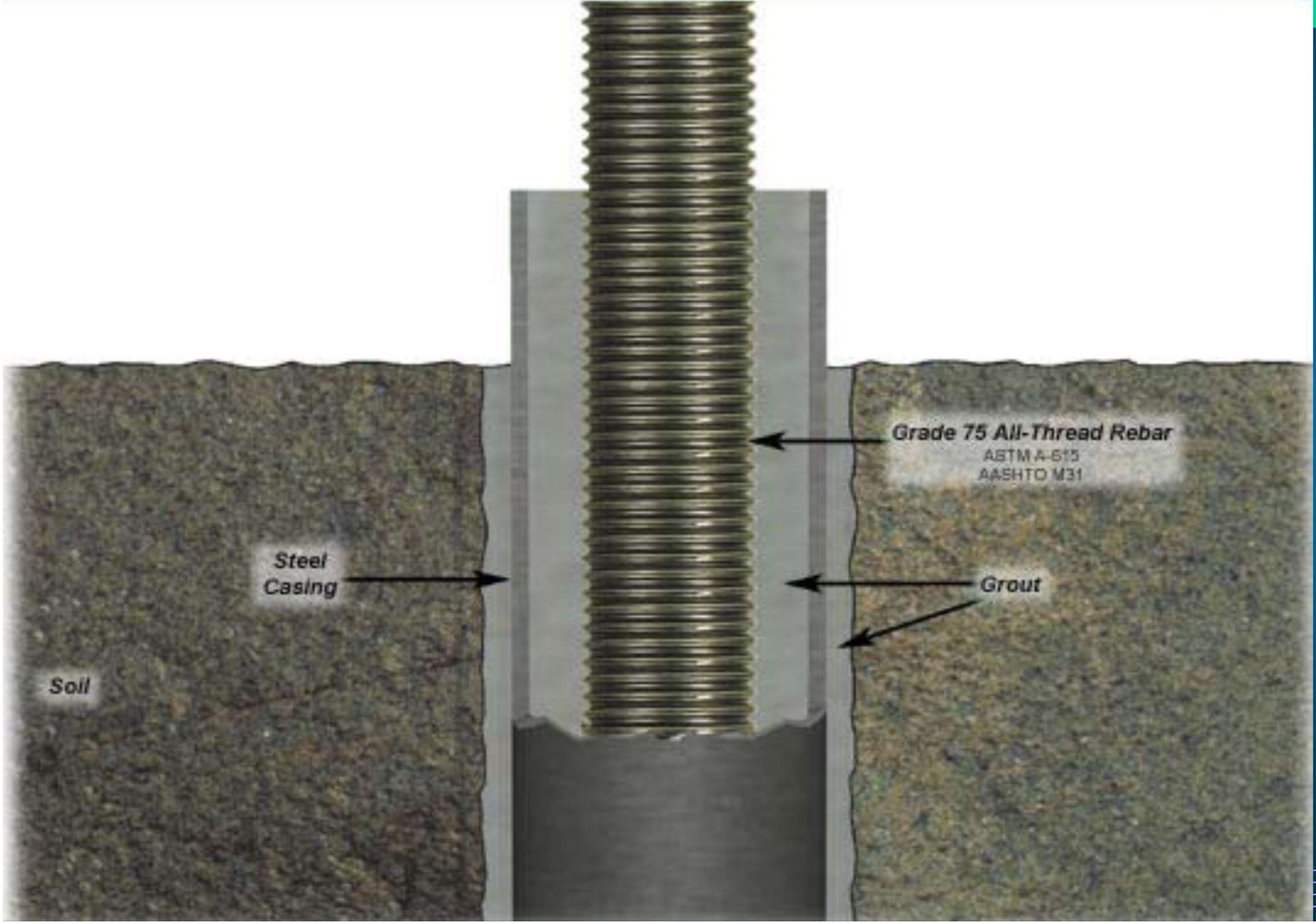
HELIX
VARIOUS PLATE
THICKNESS AND
DIAMETERS

45 DEGREE END
CUT TO ASSIST
INSTALLATION

Forces on Screw Pile



Micro-pile


Grade 75 All-Thread Rebar
ASTM A-615
AASHTO M31
Steel Casing
Grout
Soil

Preventive Measures - Concepts

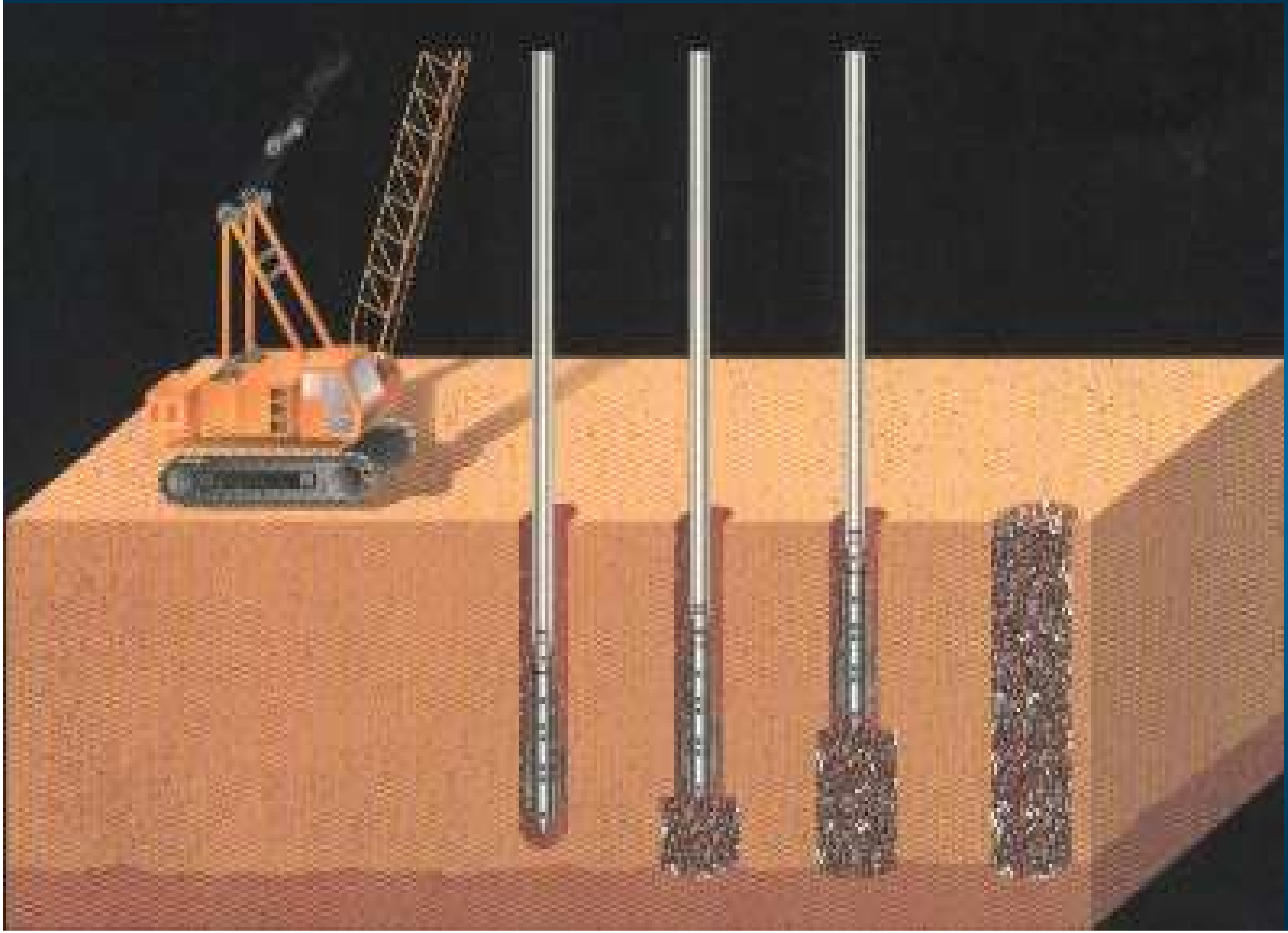
A. Ground Characteristics:

Methods
1. Densification
2. Solidification
3. Replacement
4. Lower GWL

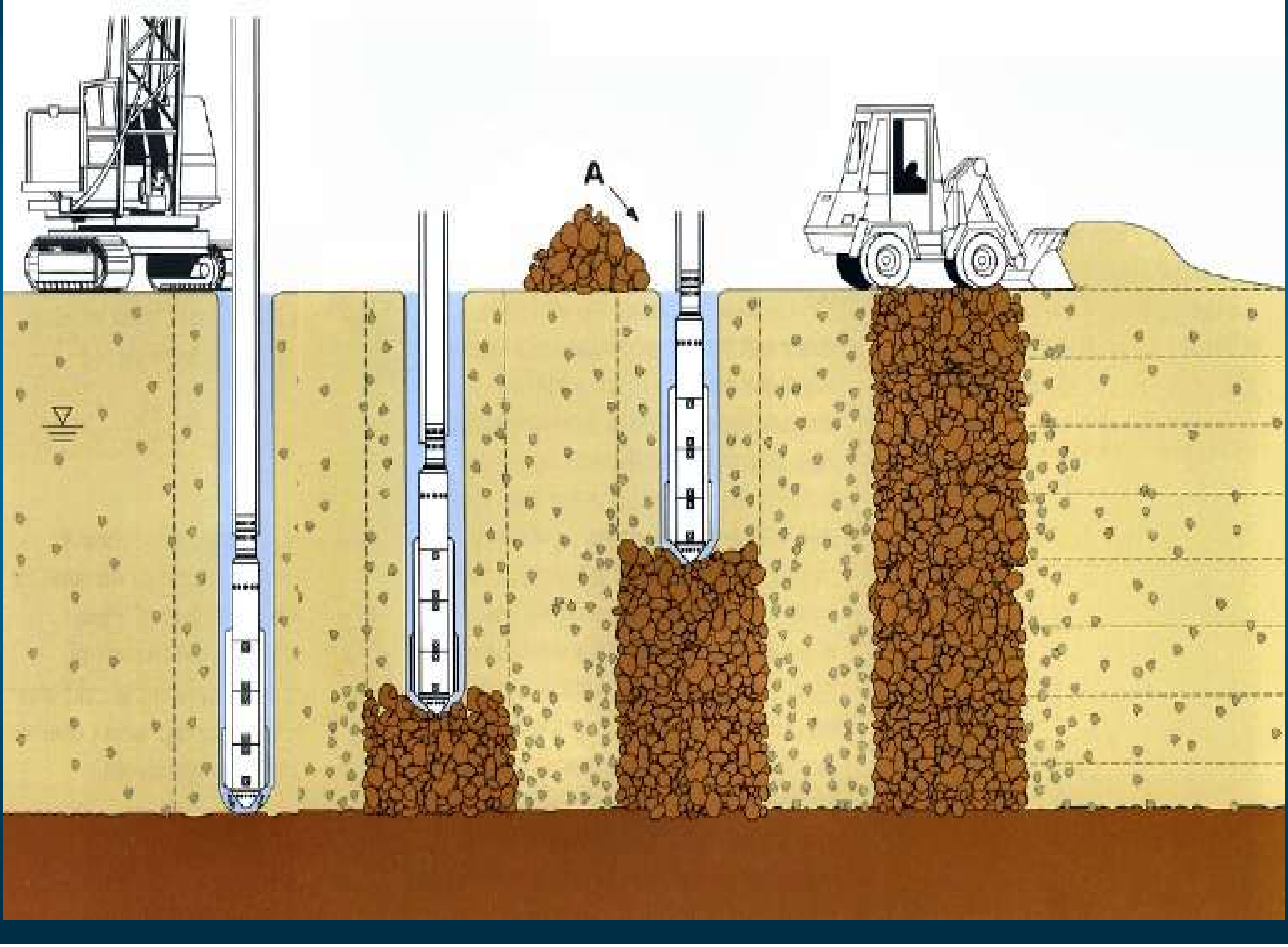
B. Stress, Deformation & Pore Pr.

Methods
1. Increase Eff. Stress
2. Dissipate Pore Pr.
3. Restrict Shear Def.

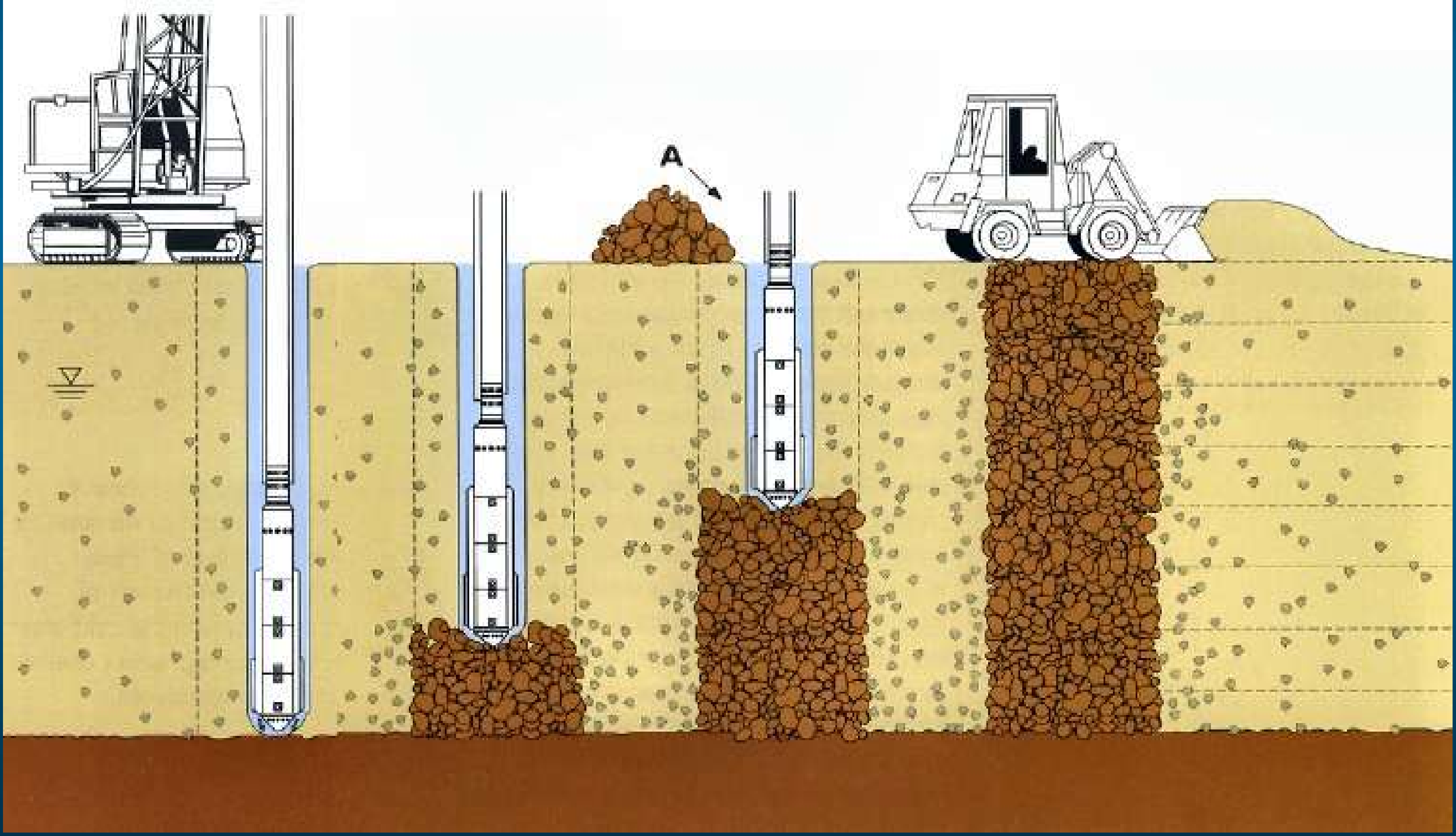
Concept	Methods
Densification	Sand Compaction Piles
	Vibratory Probes
	Vibro-Compaction
	Heavy Tamping
	Resonant Compaction
	Displacement Piles
Solidification	Deep mixing
	Injection
	Quick Lime Plies
	Pre-Mixing
Replacement	Replace with Suitable Soils
Lower GWL	Deep Wells & Trenches
Dissipate Excess Pore pressure	Gravel Drains
	Geosynthetic Drains
Control Shear Deformations	Diaphram Walls



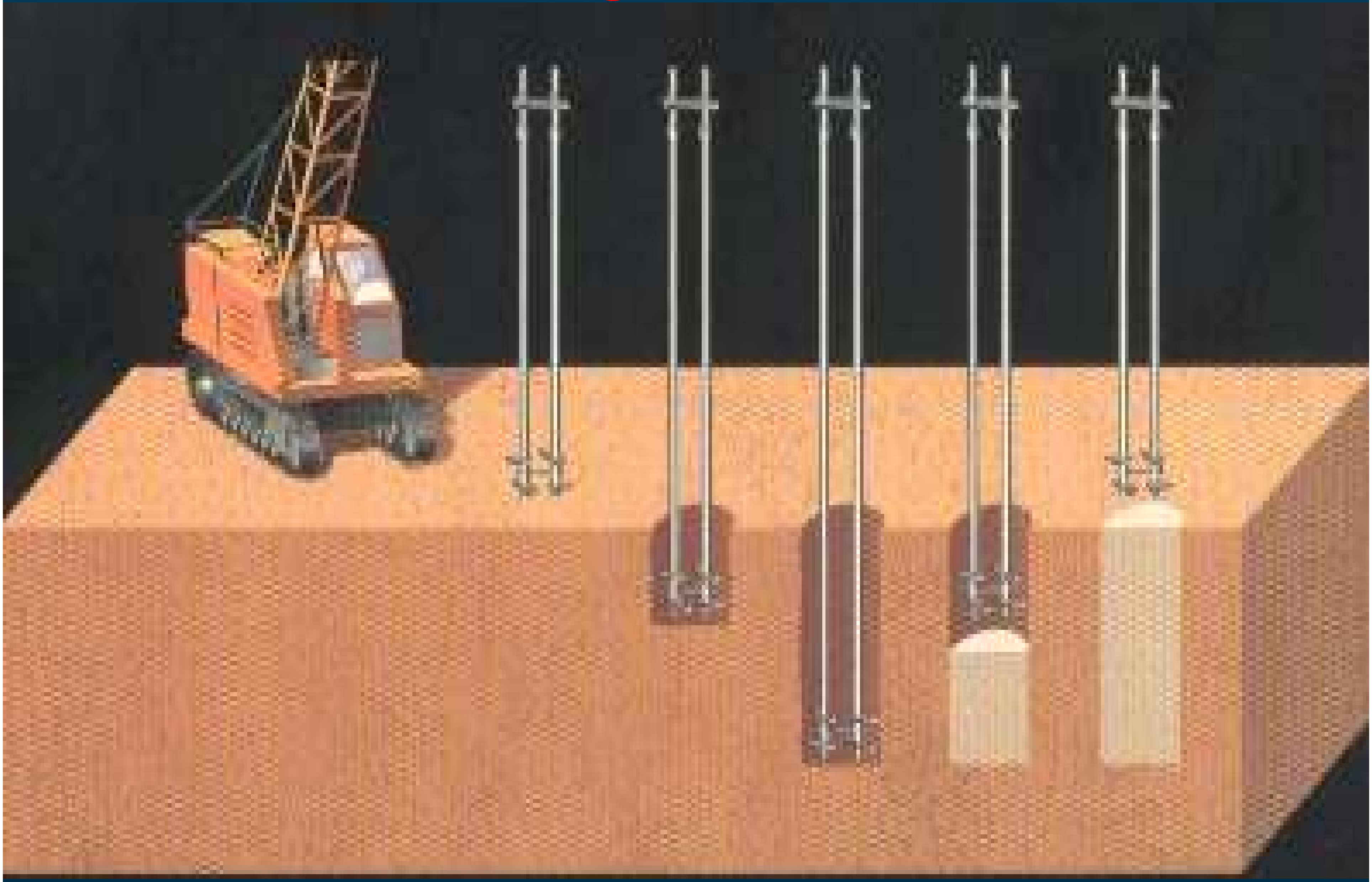
Vibro-Replacement



Vibro-Compaction

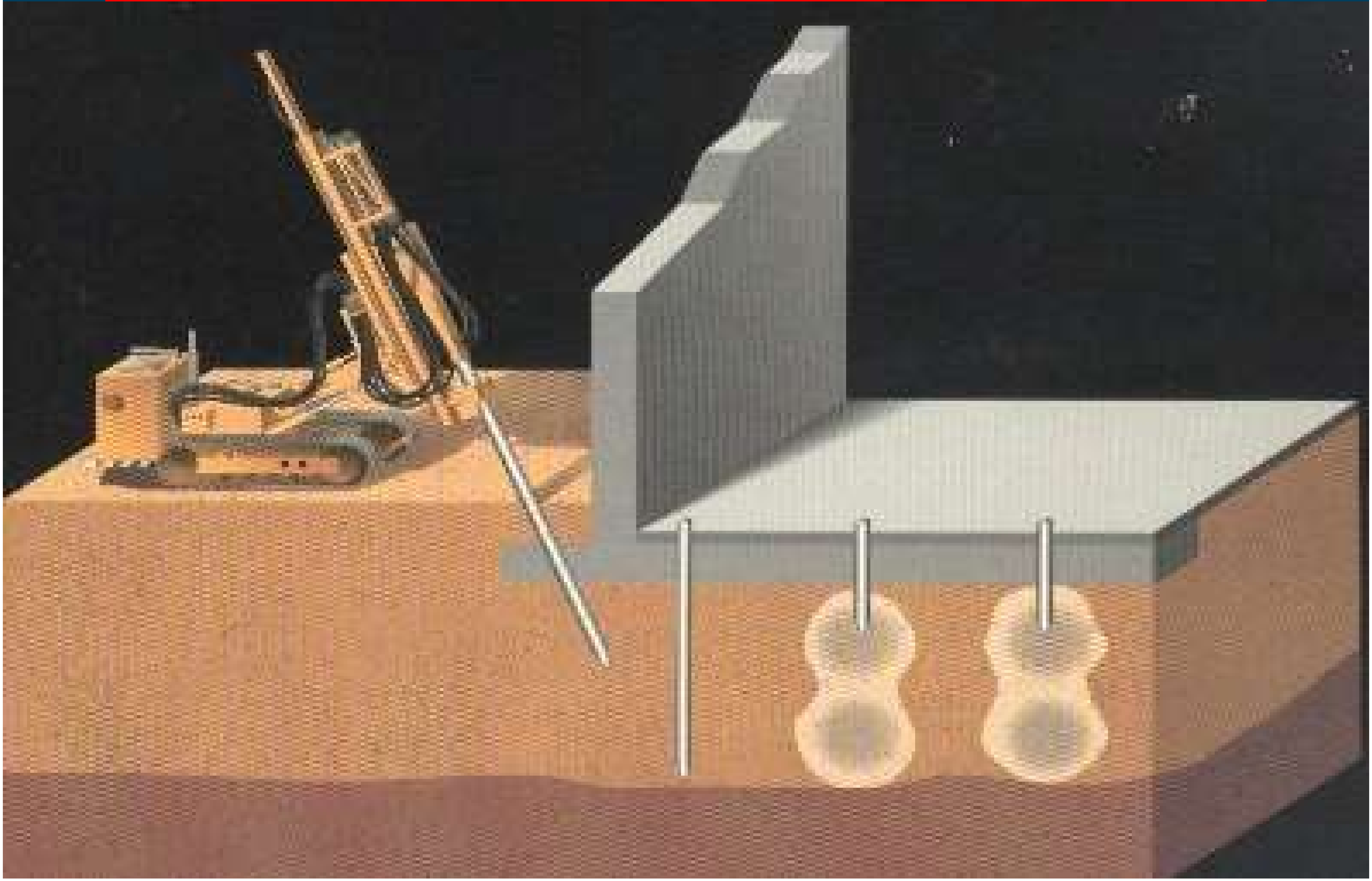


Soil Mixing – Cement/Lime

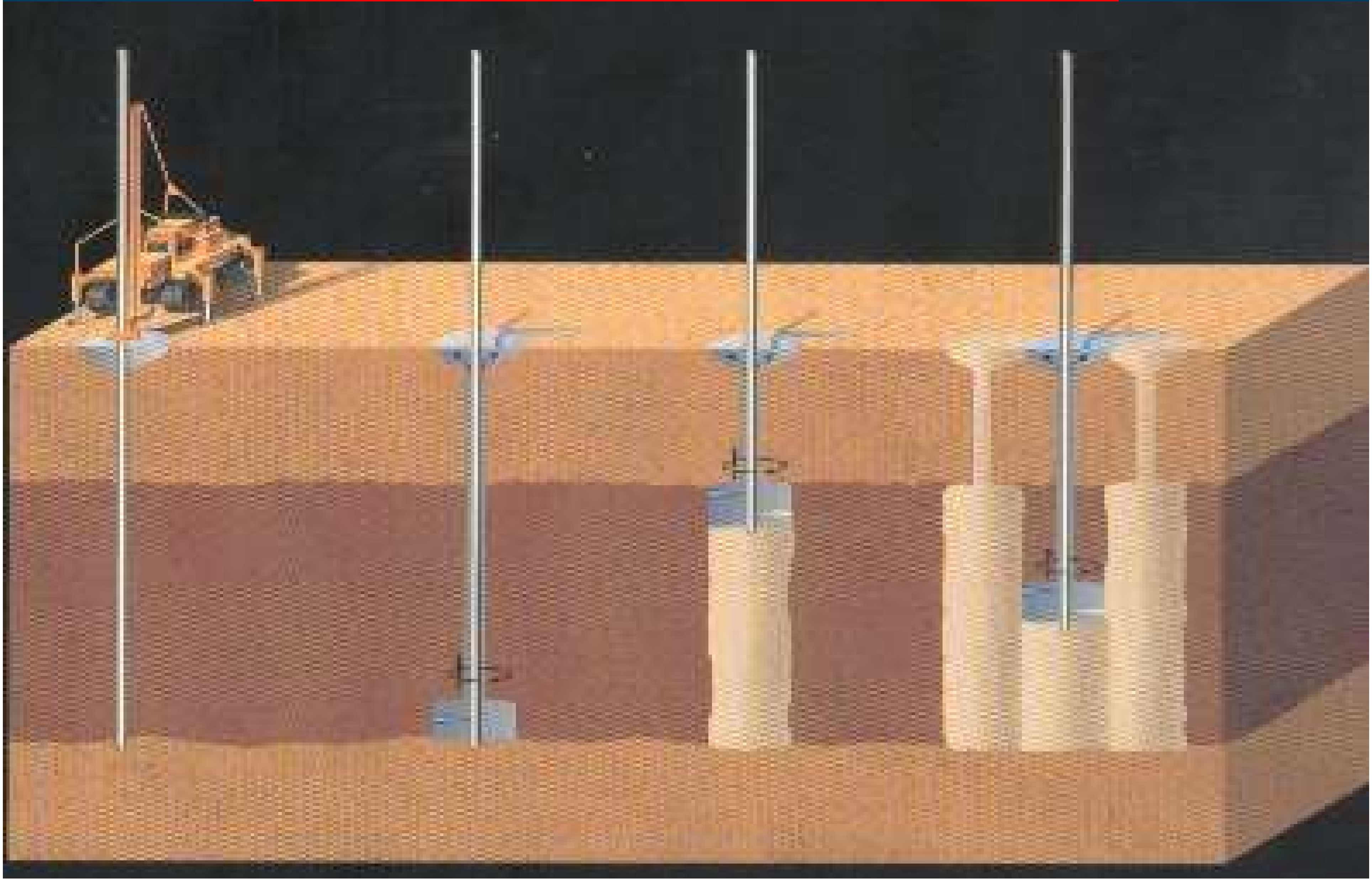


Injection Grouting

Compaction Grouting



Jet Grouting

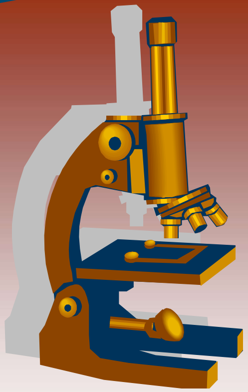


finally found the square root!

There is Life in the Ground:
it goes into the seed and
it also, when stirred up,
goes into the man who stirs it.

C. D. Warner

GEOTECHNICAL ENGINEERING



IS A SCIENCE

BUT ITS PRACTICE

AN ART