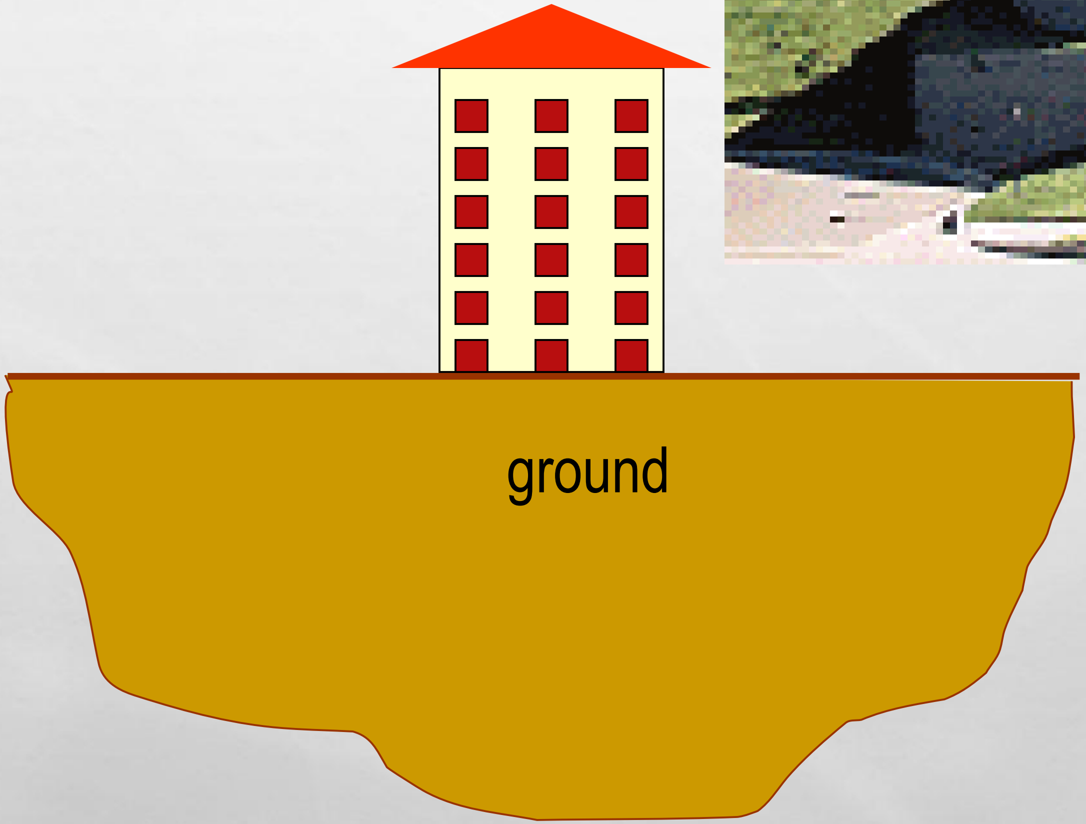
FOUNDATION ENGINEERING AND DESIGN



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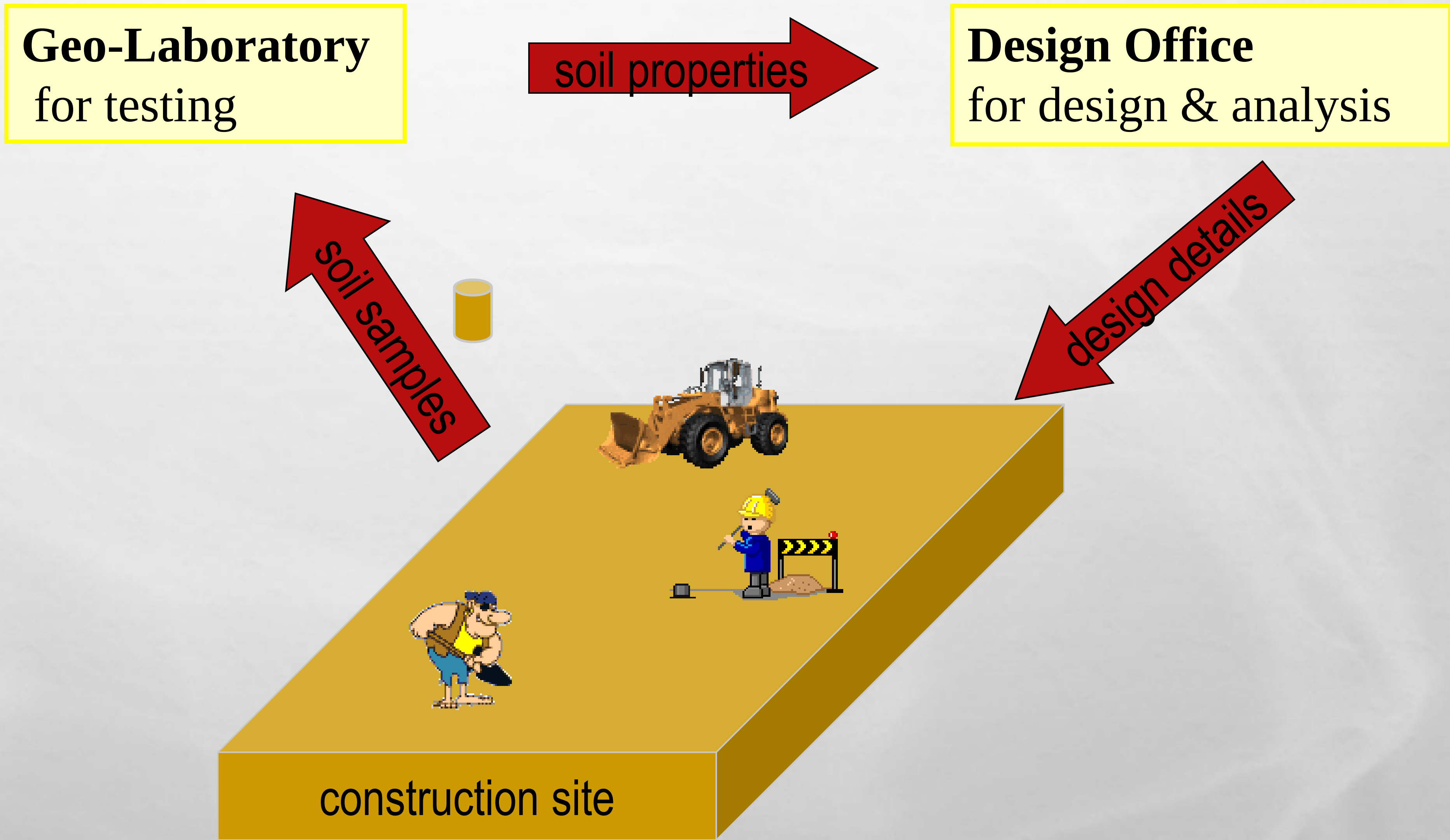
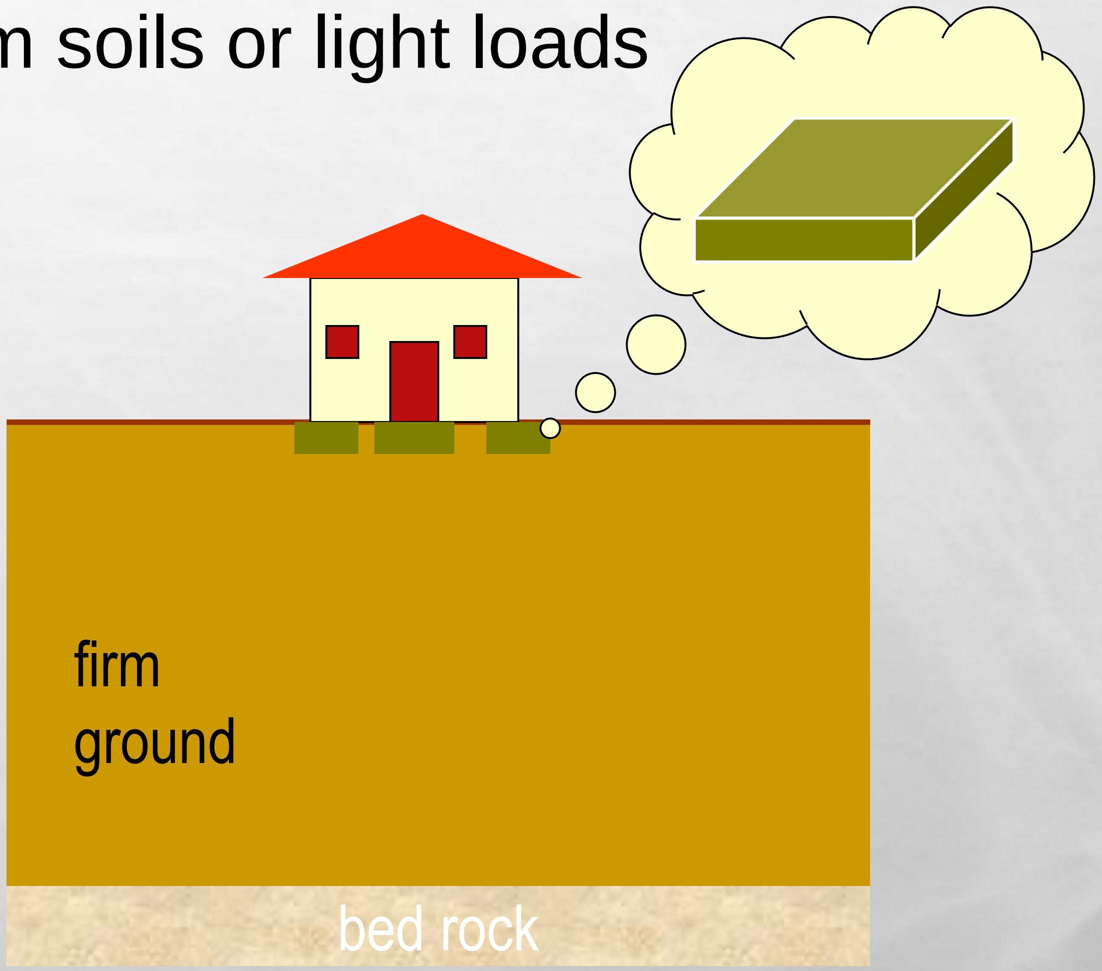
TYPICAL GEOTECHNICAL PROJECT



Geotechnical Applications

SHALLOW FOUNDATIONS

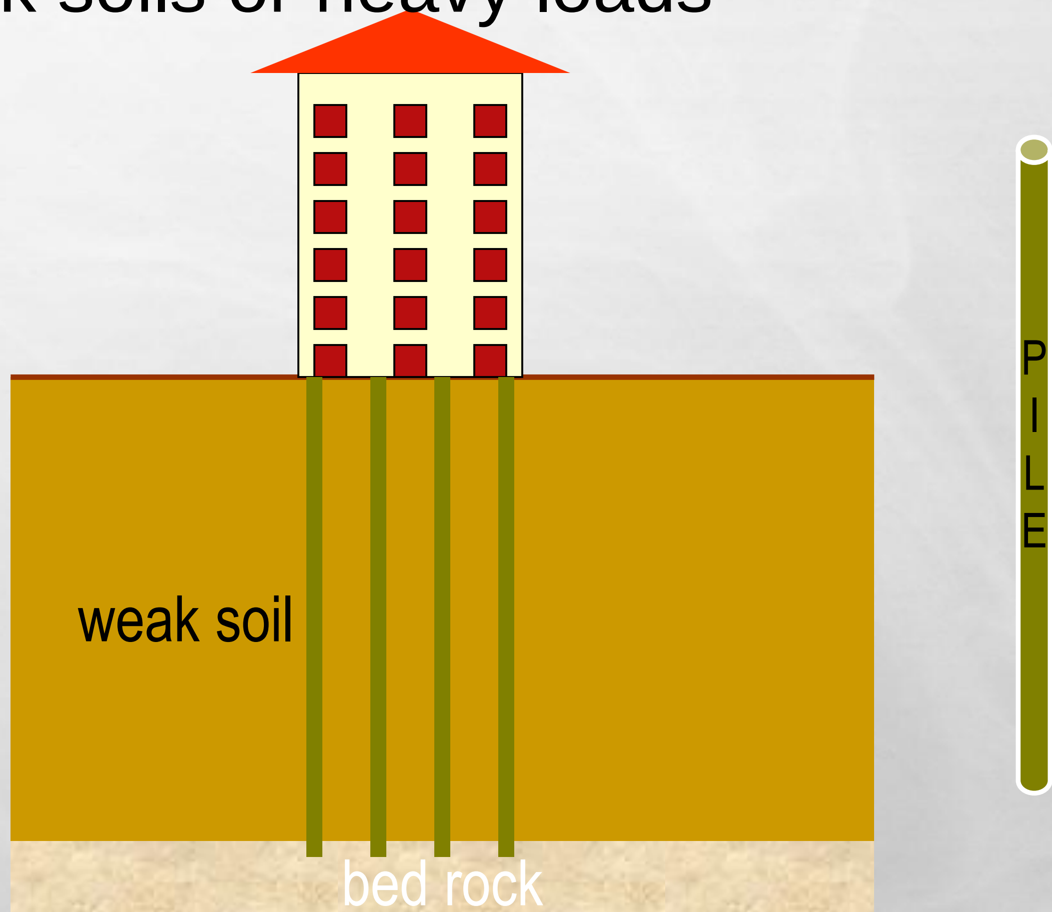
- for transferring building loads to underlying ground
- mostly for firm soils or light loads



SHALLOW FOUNDATIONS

DEEP FOUNDATIONS

- for transferring building loads to underlying ground
- mostly for weak soils or heavy loads



PILE DRIVING RIG – ROSS RIVER DAM

PILE DRIVING RIG – ROSS RIVER DAM

DEEP FOUNDATIONS

Driven timber piles, Pacific Highway

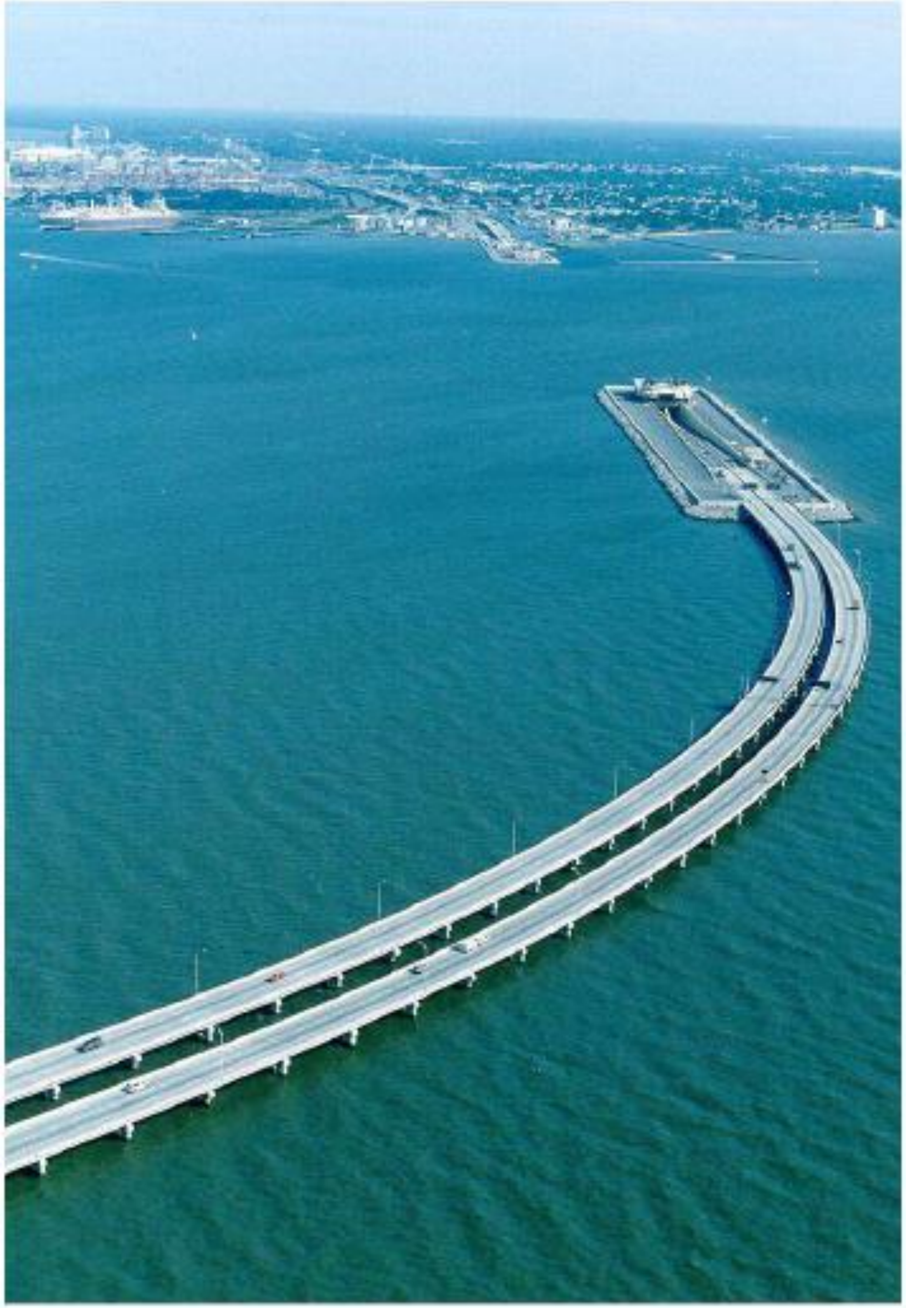
PIER FOUNDATIONS FOR BRIDGES

Millau Viaduct in France (2005)

- **CABLE-STAYED BRIDGE**
- **SUPPORTED ON 7 PIERS, 342 M APART**
- **LONGEST PIER (336) IN THE WORLD**

PIER FOUNDATIONS FOR BRIDGES

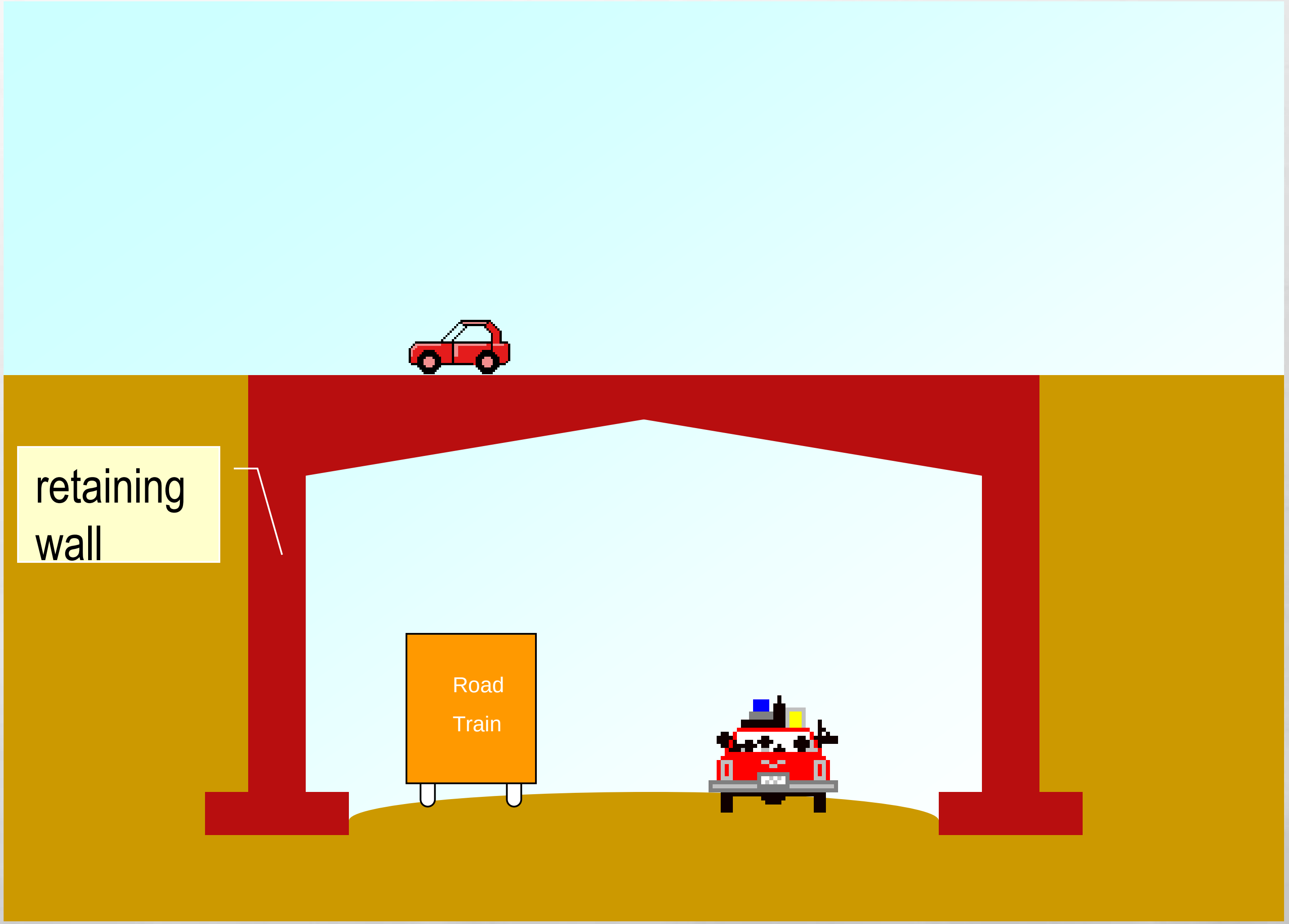
Millau Viaduct in France (2005)



The new link between Copenhagen, (Denmark) and Malmo (Sweden) includes the causeway and its tunnel seen in this photograph, plus one of the world's longest cable-stayed bridges (not seen here).

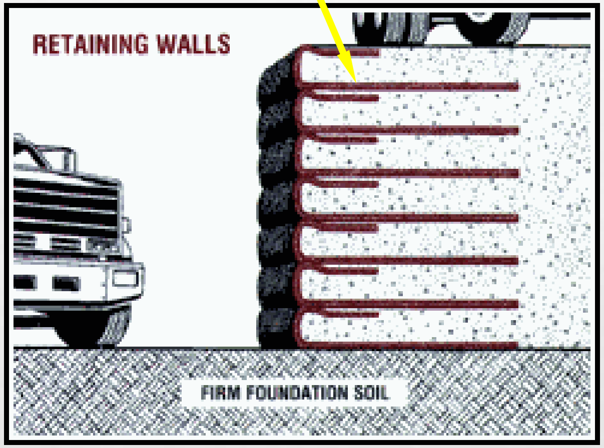
RETAINING WALLS

❖ for retaining soils from spreading laterally



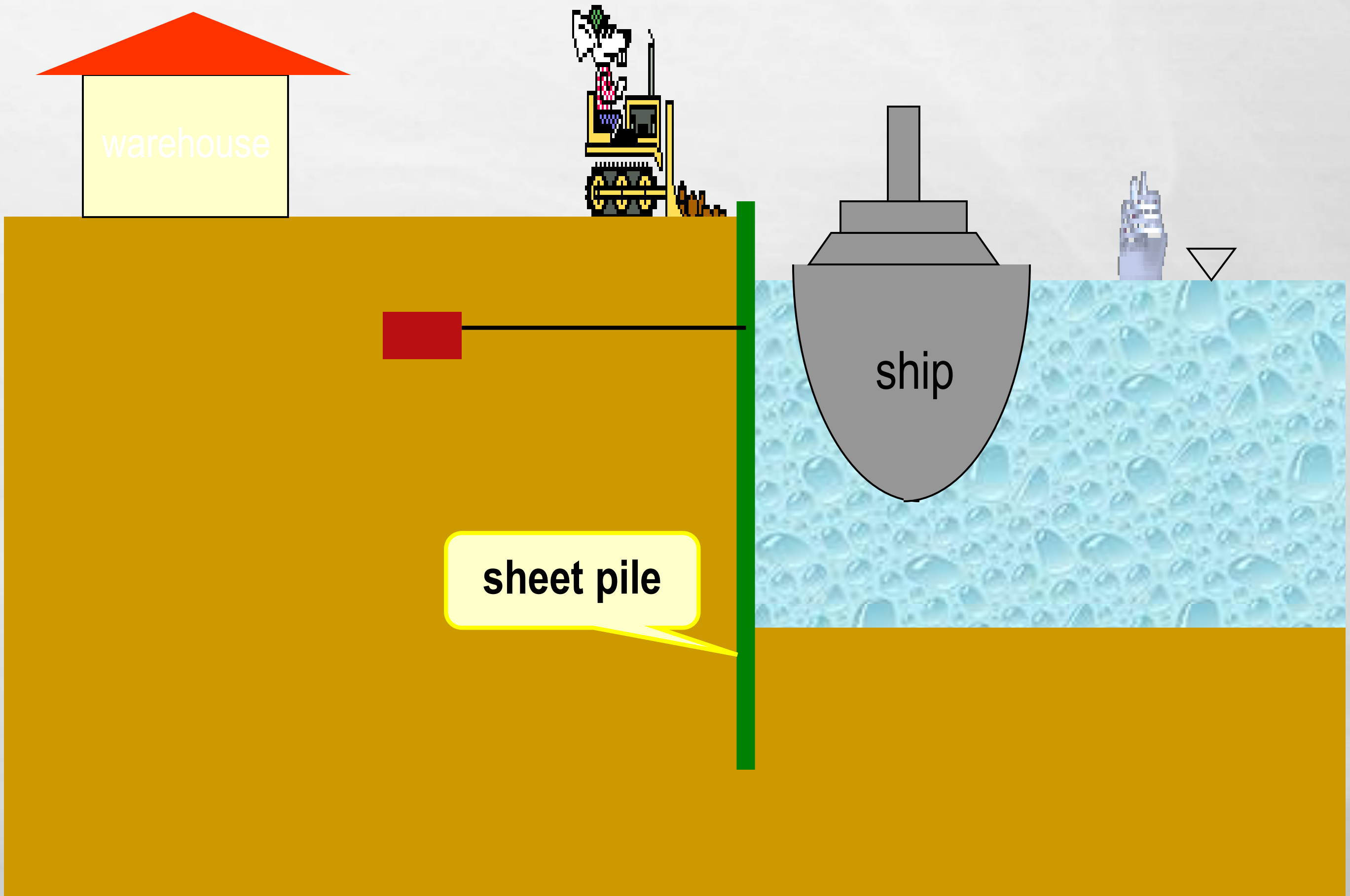
REINFORCED EARTH WALLS

~ using geofabrics to strengthen the soil



SHEET PILES

~ sheets of interlocking-steel or timber driven into the ground, forming a continuous sheet



SHEET PILES

~ resist lateral earth pressures

~ used in excavations, waterfront structures, ..

SHEET PILE AT WOOLCOCK ST

SHEET PILES

~ used in temporary works

COFFERDAM

~ sheet pile walls enclosing an area, to prevent water seeping in

COFFERDAM

~ sheet pile walls enclosing an area, to prevent water seeping in

SHORING

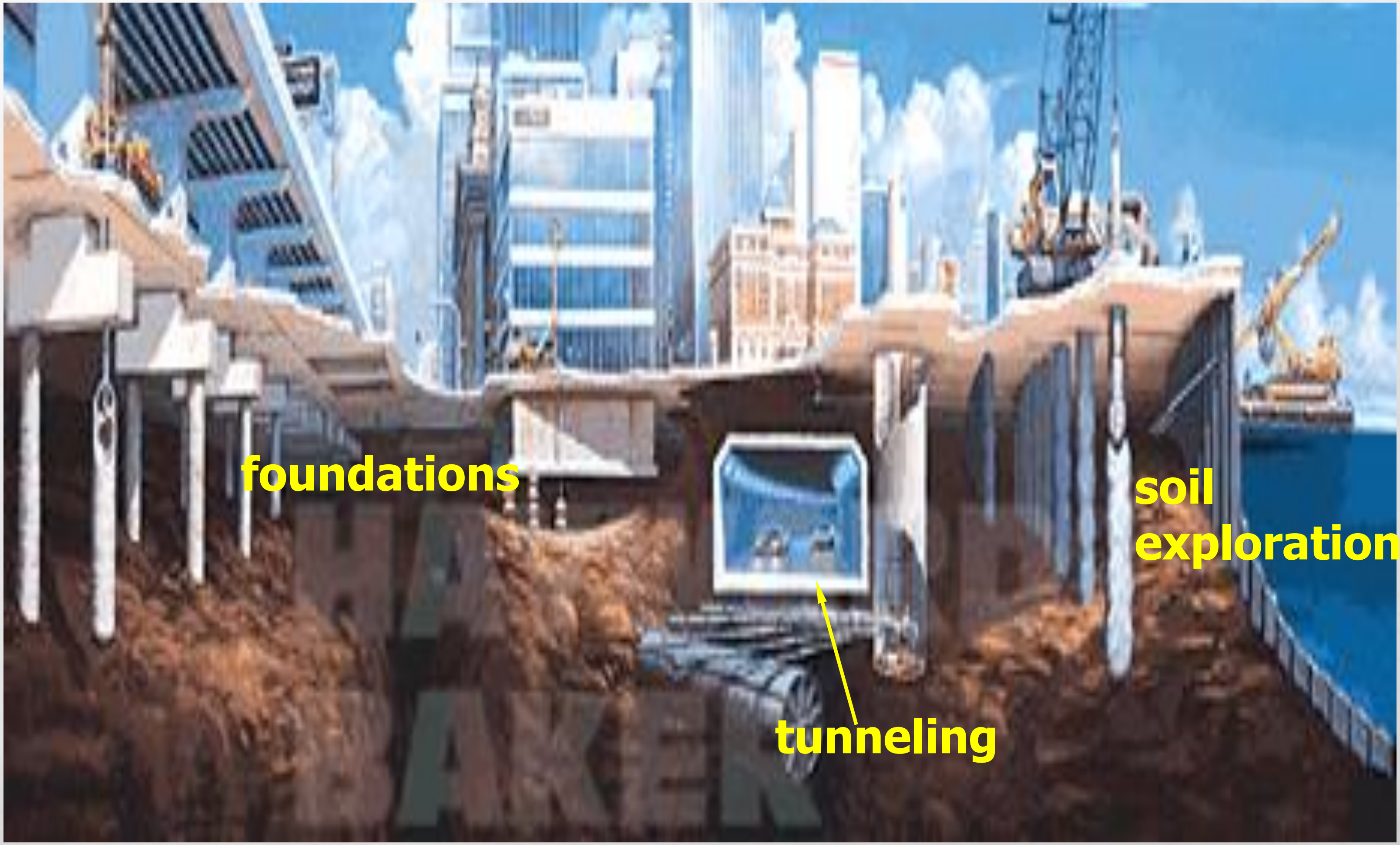
propping and supporting the exposed walls to resist lateral earth pressures

EXCAVATIONS

TYPICAL SAFETY FACTORS

Type of Design	Safety Factor	Probability of Failure
Earthworks	1.3-1.5	1/500
Retaining structures	1.5-2.0	1/1500
Foundations	2.0-3.0	1/5000

SOME CIVIL ENGINEERING MARVELS ….



… buried right under your feet.

Hall of Fame

GREAT CONTRIBUTORS TO THE DEVELOPMENTS IN GEOTECHNICAL ENGINEERING

Karl Terzaghi
1883-1963

C.A.Coulomb
1736-1806

M. Rankine
1820-1872

Challenges

GEOTECHNICAL ENGINEERING LANDMARKS

LEANING TOWER OF PISA

Our blunders become monuments!

FOUNDATION ENGINEERING

IMPORTANCE & PURPOSE

- All engineered construction resting on the earth must be carried by some kind of interfacing element called *a foundation*

- Foundation is the part of an engineered system that transmits to, and into, the underlying soil or rock the loads supported by the foundation and its self-weight

- The term *superstructure* is commonly used to describe the engineered part of the system bringing load to the foundation, or substructure. the term *superstructure* has particular significance for buildings and bridges; however, foundations also may carry only machinery, support industrial equipment (pipes, towers, tanks), act as sign bases, and the like.

- The foundation as that part of the engineered system that interfaces the load-carrying components to the ground.

    - it is evident on the basis of this definition that a foundation is the most important part of the engineering system.

MINIMUM REQUIRED FOR DESIGNING A FOUNDATION

1. Locate the site and the position of load. a rough estimate of the foundation load(s) is usually provided by the client or made in-house. depending on the site or load system complexity, a literature survey may be started to see how others have approached similar problems.

2. Physically inspect the site for any geological or other evidence that may indicate a potential design problem that will have to be taken into account when making the design or giving a design recommendation. supplement this inspection with any previously obtained soil data.

3. Establish the field exploration program and, on the basis of discovery (or what is found in the initial phase), set up the necessary supplemental field testing and any laboratory test program.

MINIMUM REQUIRED FOR DESIGNING A FOUNDATION CONT'

4. Determine the necessary soil design parameters based on integration of test data, scientific principles, and engineering judgment. simple or complex computer analyses may be involved.

5. For complex problems, compare the recommended data with published literature or engage another geotechnical consultant to give an outside perspective to the results.

6. Design the foundation using the soil parameters from step 4. the foundation should be economical and be able to be built by the available construction personnel. take into account practical construction tolerances and local construction practices. interact closely with all concerned (client, engineers, architect, contractor) so that the substructure system is not excessively overdesigned and risk is kept within acceptable levels. a computer may be used extensively (or not at all) in this step.

FOUNDATIONS: CLASSIFICATIONS

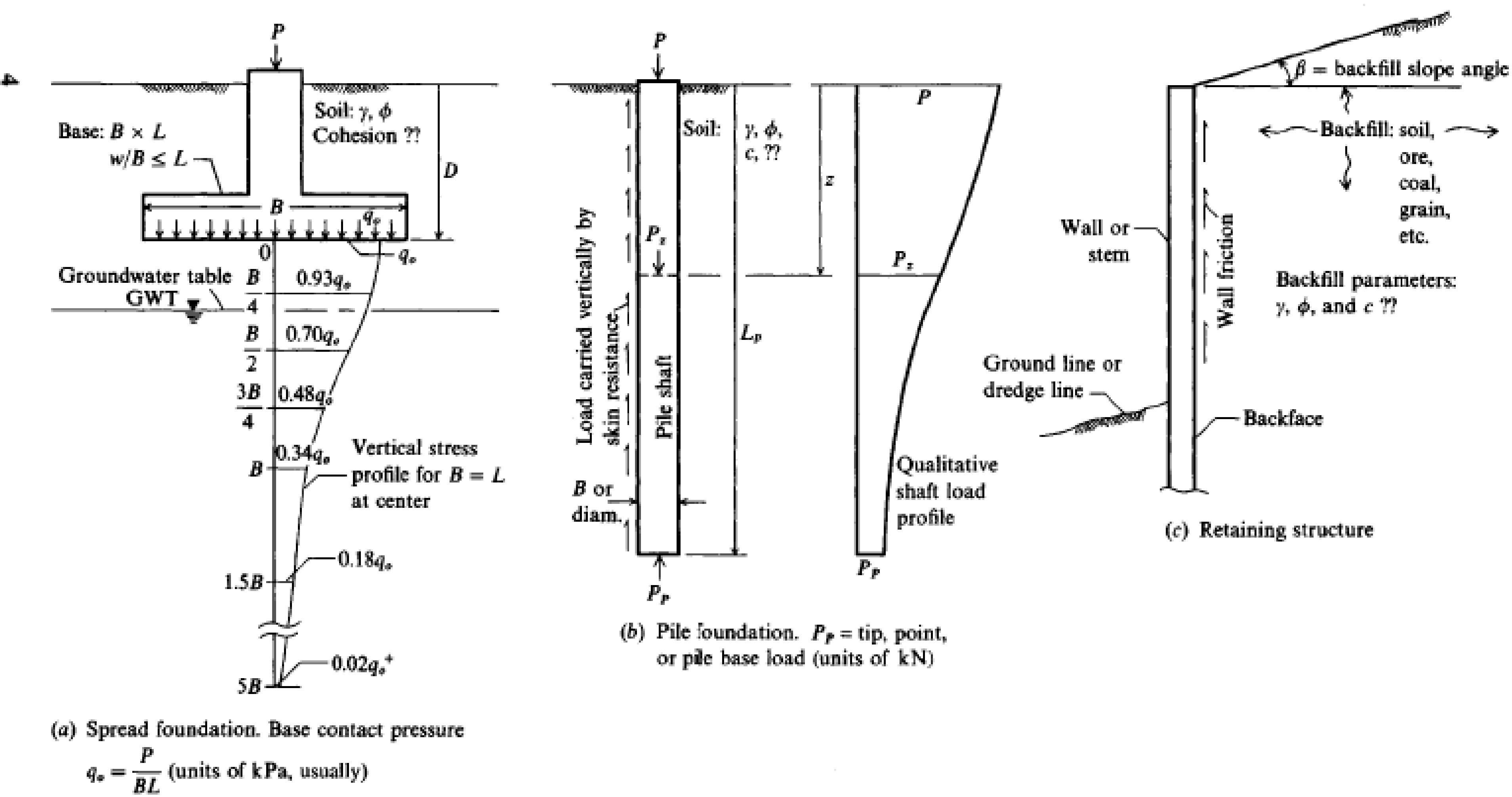
- Foundations may be classified based on where the load is carried by the ground, producing:

  - ***Shallow foundations*—termed bases, footings, spread footings, or mats. the depth is generally**

$D/B < 1$ but may be somewhat more.

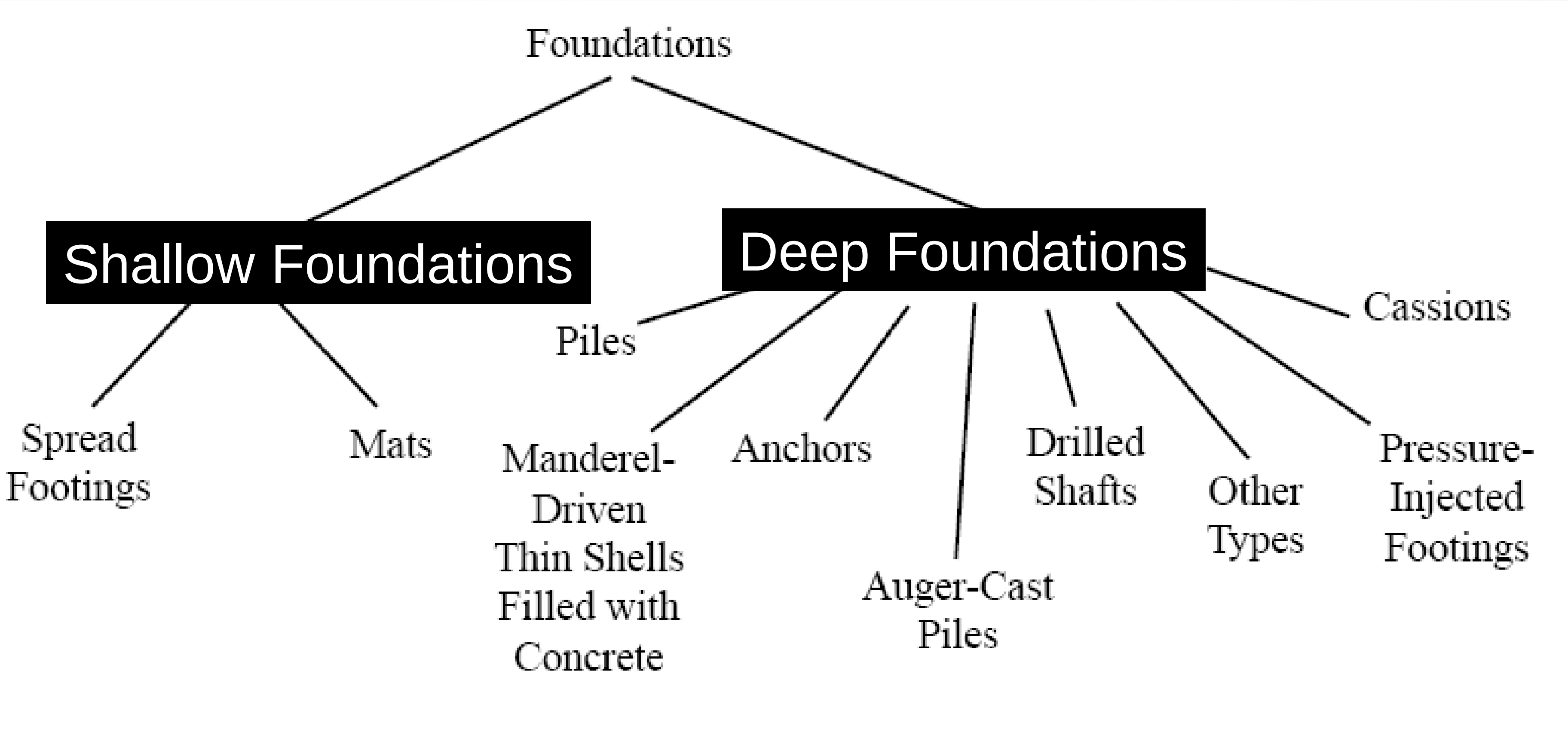
  - ***Deep foundations*—piles, drilled piers, or drilled caissons. $L_P/B > 4+$**

FOUNDATIONS: CLASSIFICATIONS



Definition of select terms used in foundation engineering

OTHER FOUNDATIONS TYPE



GENERAL REQUIREMENTS

- Foundation elements must be proportioned both to interface with the soil at a safe stress level and to limit settlements to an acceptable amount
- Excessive settlement problems are fairly common and somewhat concealed
- In summary, a proper design requires the following:
    1. Determining the building purpose, probable service-life loading, type of framing, soil profile, construction methods, and construction costs
    2. Determining the client/owner's needs
    3. Making the design, but ensuring that it does not excessively degrade the environment, and provides a margin of safety that produces a tolerable risk level to all parties: the public, the owner, and the engineer

ADDITIONAL CONSIDERATIONS
THAT MAY HAVE TO BE TAKEN INTO ACCOUNT AT SPECIFIC SITES

1. Depth must be adequate to avoid lateral squeezing of material from beneath the foundation for footings and mats. Similarly, excavation for the foundation must take into account that this can happen to existing building footings on adjacent sites and requires that suitable precautions be taken. The number of settlement cracks that are found by owners of existing buildings when excavations for adjacent structures begin is truly amazing.

2. Depth of foundation must be below the zone of seasonal volume changes caused by freezing, thawing, and plant growth. Most local building codes will contain minimum depth requirements.

3. The foundation scheme may have to consider expansive soil conditions. Here the building tends to capture upward-migrating soil water vapor, which condenses and saturates the soil in the interior zone, even as normal perimeter evaporation takes place. The soil in a distressingly large number of geographic areas tends to swell in the presence of substantial moisture and carry the foundation up with it.

ADDITIONAL CONSIDERATIONS THAT MAY HAVE TO BE TAKEN INTO ACCOUNT AT SPECIFIC SITES CONT'

4. In addition to compressive strength considerations, the foundation system must be safe against overturning, sliding, and any uplift (flotation).

5. System must be protected against corrosion or deterioration due to harmful materials present in the soil. safety is a particular concern in reclaiming sanitary landfills but has application for marine and other situations where chemical agents that are present can corrode metal pilings, destroy wood sheeting/piling, cause adverse reactions with portland cement in concrete footings or piles, and so forth.

6. Foundation system should be adequate to sustain some later changes in site or construction geometry and be easily modified should changes in the superstructure and loading become necessary.

ADDITIONAL CONSIDERATIONS
THAT MAY HAVE TO BE TAKEN INTO ACCOUNT AT SPECIFIC SITES CONT'

5. The foundation should be buildable with available construction personnel. For one-of-akind projects there may be no previous experience. In this case, it is necessary that all concerned parties carefully work together to achieve the desired result.

6. The foundation and site development must meet local environmental standards, including determining if the building is or has the potential for being contaminated with hazardous materials from ground contact (for example, radon or methane gas). Adequate air circulation and ventilation within the building are the responsibility of the mechanical engineering group of the design team.

SELECTION OF TYPE

Foundation type	Use	Applicable soil conditions
	Shallow foundations (generally $D/B \leq 1$)	
Spread footings, wall footings	Individual columns, walls	Any conditions where bearing capacity is adequate for applied load. May use on a single stratum; firm layer over soft layer or soft layer over firm layer. Check settlements from any source.
Combined footings	Two to four columns on footing and/or space is limited	Same as for spread footings above.
Mat foundations	Several rows of parallel columns; heavy column loads; use to reduce differential settlements	Soil bearing capacity is generally less than for spread footings, and over half the plan area would be covered by spread footings. Check settlements from any source.

SELECTION OF TYPE

Deep foundations (generally $L_p/B \geq 4^+$)		
Floating pile	In groups of 2^+ supporting a cap that interfaces with column(s)	Surface and near-surface soils have low bearing capacity and competent soil is at great depth. Sufficient skin resistance can be developed by soil-to-pile perimeter to carry anticipated loads.
Bearing pile	Same as for floating pile	Surface and near-surface soils not relied on for skin resistance; competent soil for point load is at a practical depth (8–20 m).
Drilled piers or caissons	Same as for piles; use fewer; For large column loads	Same as for piles. May be floating or point-bearing (or combination). Depends on depth to competent bearing stratum.

SELECTION OF TYPE

Retaining structures		
Retaining walls, bridge abutments	Permanent material retention	Any type of soil but a specified zone (Chaps. 11, 12) in backfill is usually of controlled fill.
Sheeting structures (sheet pile, wood sheeting, etc.)	Temporary or permanent for excavations, marine cofferdams for river work	Retain any soil or water. Back-fill for waterfront and cofferdam systems is usually granular for greater drainage.

- Where the groundwater table (GWT) is present, it is common to lower it below the construction zone either permanently or for the duration of the construction work.

- If the GWT later rises above the footing level, the footing will be subject to uplift or flotation, which would have to be taken into account.

Exploration, Sampling, and In Situ Soil Measurements

FOUNDATION ENGINEERING

Purpose of Soil Exploration

- Information to determine the type of foundation required (shallow or deep).
- Information to allow the geotechnical consultant to make a recommendation on the allowable load capacity of the foundation.
- Sufficient data/laboratory tests to make settlement predictions.
- Location of the groundwater table (or determination of whether it is in the construction zone). For certain projects, groundwater table fluctuations may be required. These can require installation of piezometers and monitoring of the water level in them over a period of time.

Purpose of Soil Exploration Cont'

- Information to the identification and solution of construction problems (sheeting and dewatering or rock excavation) can be made.
- Identification of potential problems (settlements, existing damage, etc.) concerning adjacent property.
- Identification of environmental problems and their solution.

Planning The Exploration Program

- The subsurface exploration program in general comprises of three steps
  - Collection of primary data
  - Reconnaissance
  - Site Investigation

Collection of primary data

- *Assembly of all available information* on:
  - dimensions,
  - column spacing,
  - type and use of the structure,
  - basement requirements,
  - any special architectural considerations of the proposed building,
  - and tentative location on the proposed site.
- Foundation regulations in the local building code should be consulted for any special requirements.

Reconnaissance of the area

- This may be in the form of:
  - a field trip to the site, which can reveal information
    - on the type and behavior of adjacent structures such
      - as cracks,
      - noticeable sags,
      - and possibly sticking doors and windows.
- The type of local existing structures may influence to a considerable extent the exploration program and the best type of foundation for the proposed adjacent structure.
- Since nearby existing structures must be maintained in their "as is" condition,
  - excavations or construction vibrations will have to be carefully controlled, and this can have considerable influence on the "type" of foundation that can be used.

Reconnaissance of the area Cont'

- Study of the various sources of information available, some of which include the following:
  - *Geological maps.*
  - *Agronomy maps.*
  - *Aerial photographs.* Investigator may require special training to interpret soil data, but the nonspecialist cannot easily recognize terrain features. *Water and/or oil well logs.*
  - *Hydrological data.* Data collected on streamflow data, tide elevations, and flood levels.
  - *Soil manuals by state departments of transportation.*
  - *State (or local) university publications.* These are usually engineering experiment station publications.

Site Investigation

- *A preliminary site investigation.* In this phase a few borings (one to about four) are made or a test pit is opened to establish in a general manner the stratification, types of soil to be expected, and possibly the location of the groundwater table. If the initial borings indicate that the upper soil is loose or highly compressible, one or more borings should be taken to rock or competent strata. This amount of exploration is usually the extent of the site investigation for small structures.

- *A detailed site investigation.* Where the preliminary site investigation has established the feasibility and overall project economics, a more detailed exploration program is undertaken. The preliminary borings and data are used as a basis for locating additional borings, which should be confirmatory in nature, and determining the additional samples required.

Methods Of Exploration

- The most widely used method of subsurface investigation for compact sites as well as formost extended sites is boring holes into the ground, from which samples may be collected for either visual inspection or laboratory testing.
- **The several exploration methods for sample recovery**
  - **Disturbed samples taken**
  - **Undisturbed samples taken**

Disturbed samples taken

Disturbed samples taken		
Method	**Depths**	**Applicability**
Auger boring†	Depends on equipment and time available, practical depths being up to about 35 m	All soils. Some difficulty may be encountered in gravelly soils. Rock requires special bits, and wash boring is not applicable. *Penetration testing* is used in conjunction with these methods, and disturbed samples are recovered in the split spoon. Penetration counts are usually taken at 1- to 1.5 m increments of depth
Rotary drilling Wash boring Percussion drilling	Depends on equipment, most equipment can drill to depths of 70 m or more	
Test pits and open cuts	As required, usually less than 6 m; use power equipment	All soils

† Most common method currently used.

Undisturbed samples taken

Undisturbed samples taken

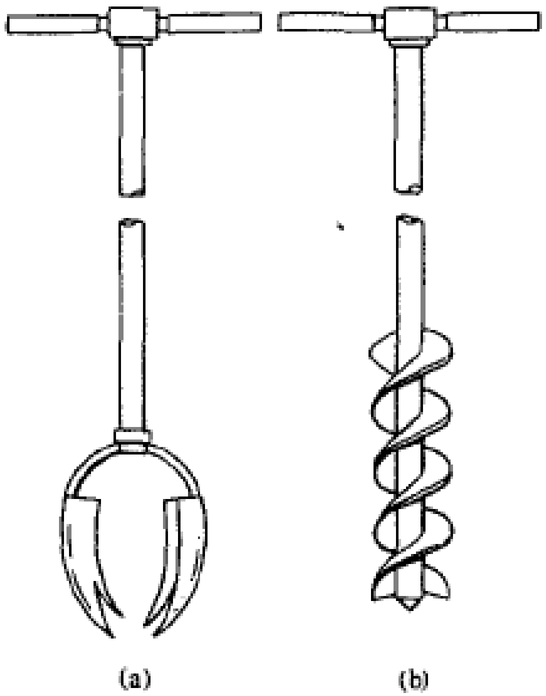
Auger drilling, rotary drilling, percussion drilling, wash boring	Depends on equipment, as for disturbed sample recovery	Thin-walled tube samplers and various piston samplers are used to recover samples from holes advanced by these methods. Commonly, samples of 50- to 100-mm diameter can be recovered
Test pits	Same as for disturbed samples	Hand-trimmed samples. Careful trimming of sample should yield the least sample disturbance of any method

Soil Boring

- Exploratory holes into the soil may be made by
  - hand tools,
  - but more commonly truck- or trailer-mounted power tools are used

Hand Tools For Soil Exploration,

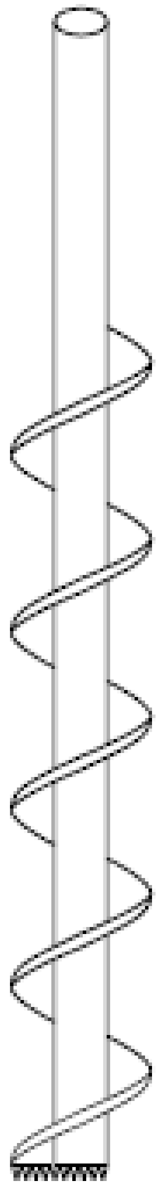
- Hand augers



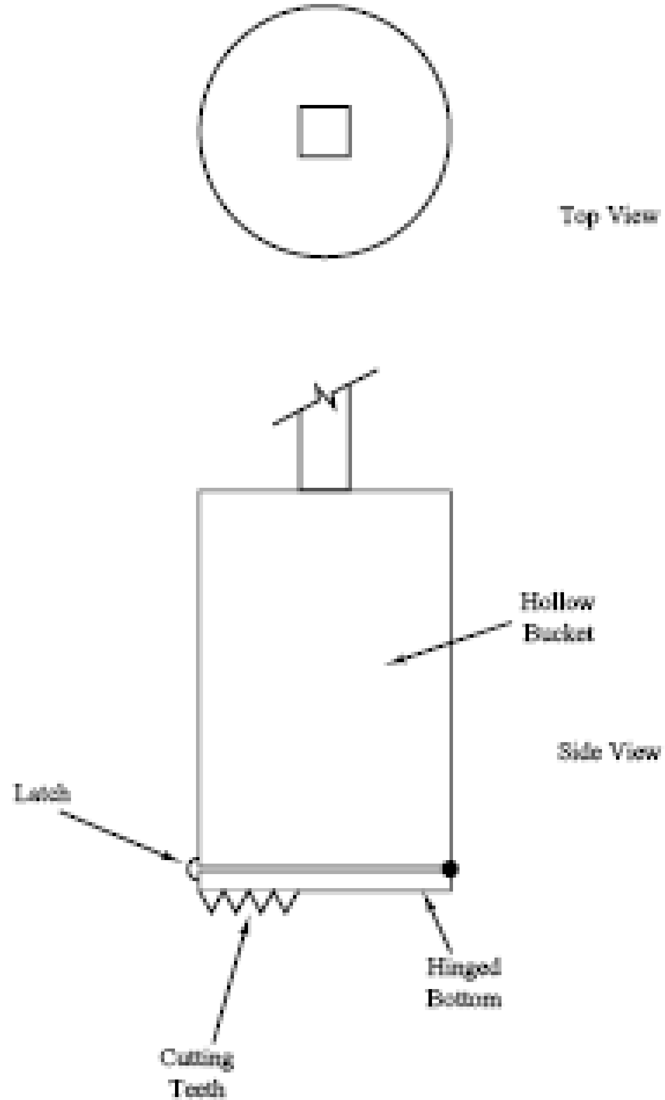
Hand tools:
(a) posthole auger;
(b) helical auger

Gasoline-engine-powered Hand Auger

gasoline-engine-powered hand auger with additional auger flights in the foreground together with hand-driven sample tube.

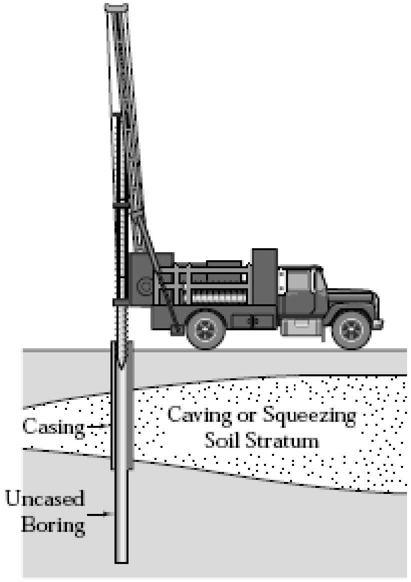


Flight Auger

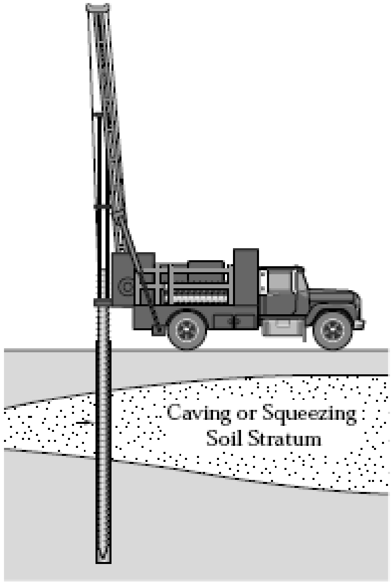


Bucket Auger.

Mounted Power Drills



(a)



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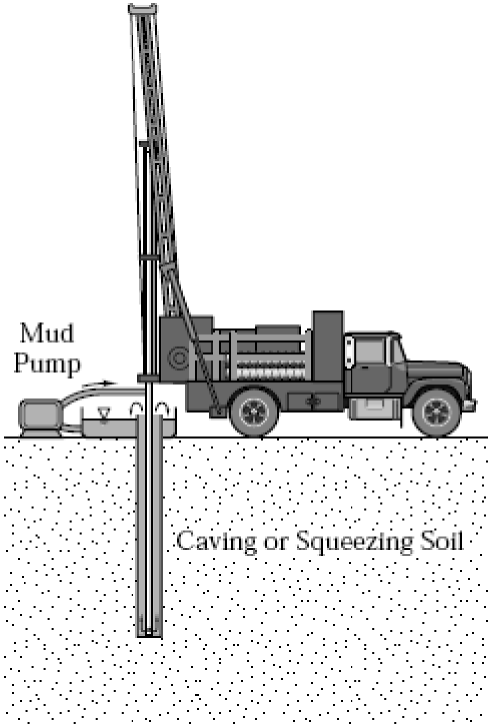


Go To Movie For Better Quality

Soil Sampling

- The most important engineering properties for foundation design are strength, compressibility, and permeability.
  - Needs undisturbed sample
    1) The sample is always unloaded from the in situ confining pressures, with some unknown resulting expansion. Lateral expansion occurs into the sides of the borehole, so in situ tests using the hole diameter as a reference are "disturbed" an unknown amount. This is the reason K_0 field tests are so difficult.
    2) Samples collected from other than test pits are disturbed by volume displacement of the tube or other collection device. The presence of gravel greatly aggravates sample disturbance.
    3) Sample friction on the sides of the collection device tends to compress the sample during recovery. Most sample tubes are (or should be) swaged so that the cutting edge is slightly smaller than the inside tube diameter to reduce the side friction.

Soil Sampling Continued

4. There are unknown changes in water content depending on recovery method and the presence or absence of water in the ground or borehole.
5. Loss of hydrostatic pressure may cause gas bubble voids to form in the sample.
6. Handling and transporting a sample from the site to the laboratory and transferring the sample from sampler to testing machine disturb the sample more or less by definition.
7. The quality or attitude of drilling crew, laboratory technicians, and the supervising engineer may be poor.
8. On very hot or cold days, samples may dehydrate or freeze if not protected on-site. Furthermore, worker attitudes may deteriorate in temperature extremes.

sample disturbance

- Sample disturbance depends on factors such as
  - rate of penetration,
  - whether the cutting force is obtained by pushing or driving,
  - and presence of gravel,
  - it also depends on the ratio of the volume of soil displaced to the volume of collected sample, expressed as an *area ratio*

$$\boxed{A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100}$$

where D_0 *— outside diameter of tube*

D_i *= inside diameter of cutting edge of tube*

Well-designed sample tubes should have an area ratio of less than about 10 percent.

sample disturbance

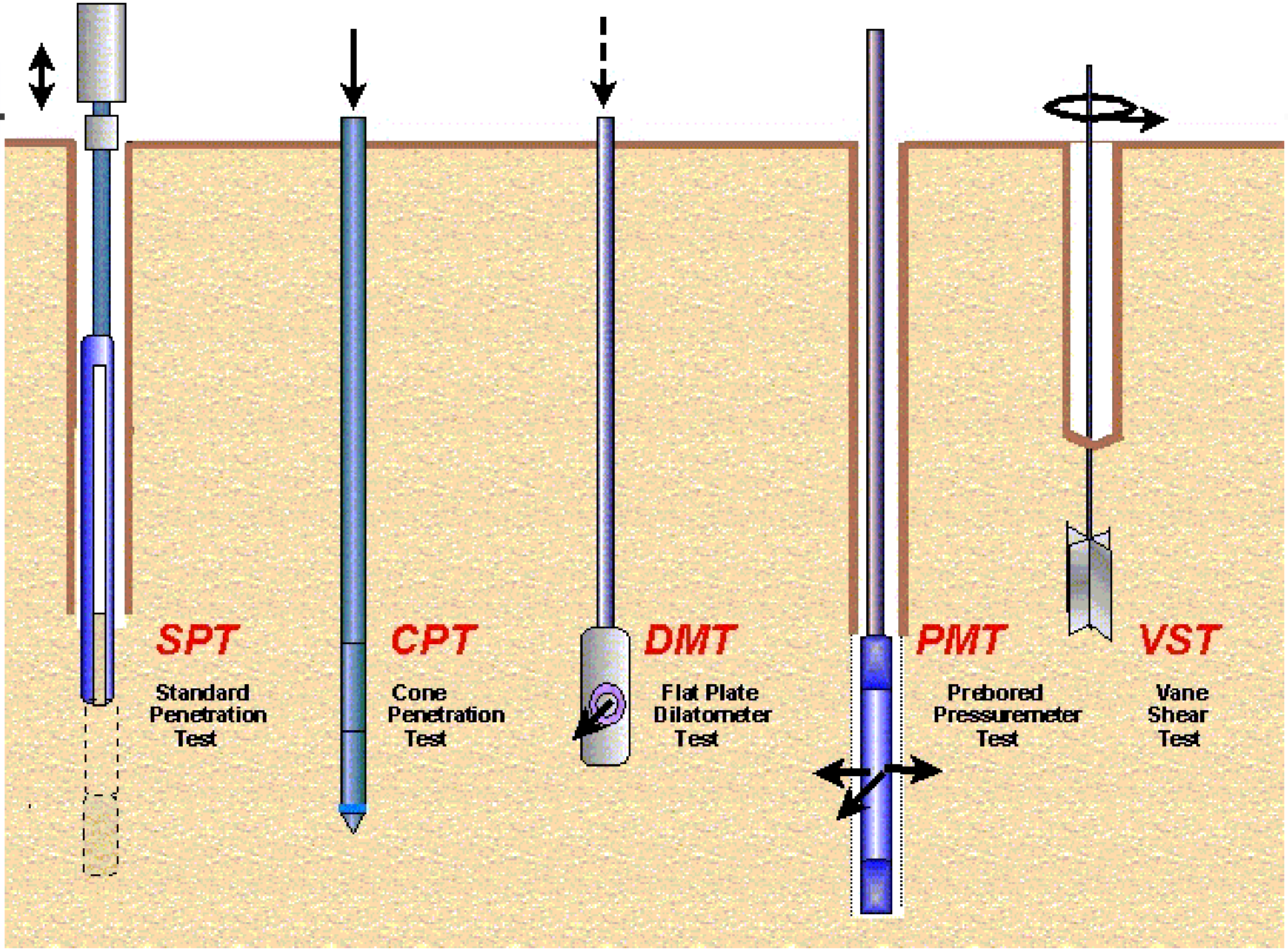
- Another term used in estimating the degree of disturbance of a cohesive or rock core sample is the recovery ratio L_r

$$L_r = \frac{\text{Actual length of recovered sample}}{\text{Theoretical length of recovered sample}}$$

A recovery ratio of 1 (recovered length of the sample = the length sampler was forced into the stratum) indicates that, theoretically, the sample did not become compressed from friction on the tube. A recovery ratio greater than 1.0 would indicate a loosening of the sample from rearrangement of stones, roots, removal of preload, or other factors.

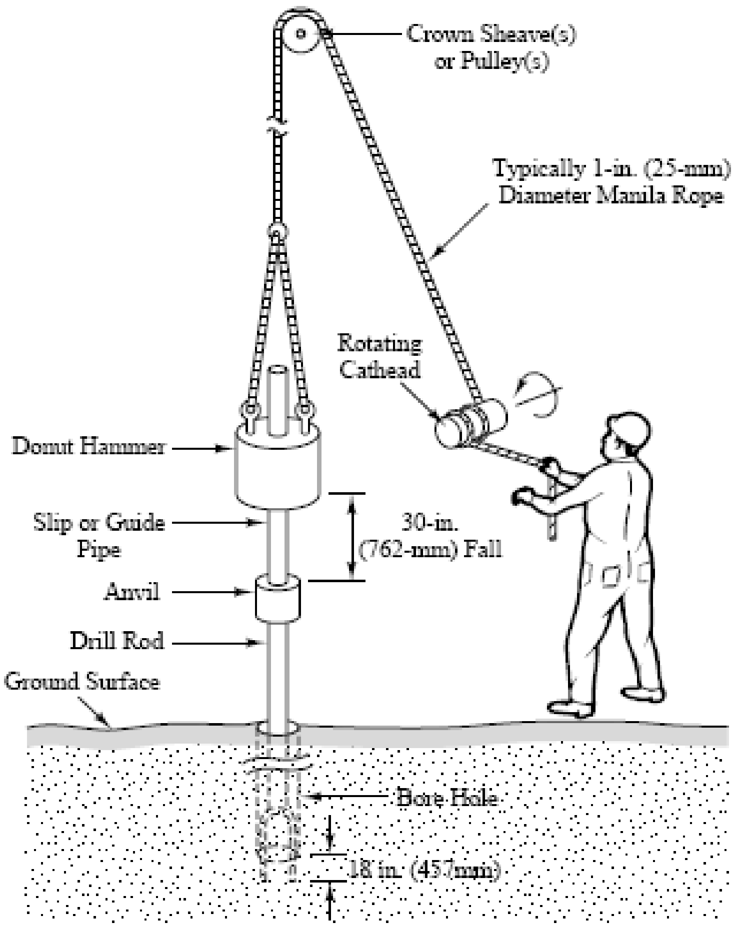
Go To Movie For Better Quality

Soil Testing



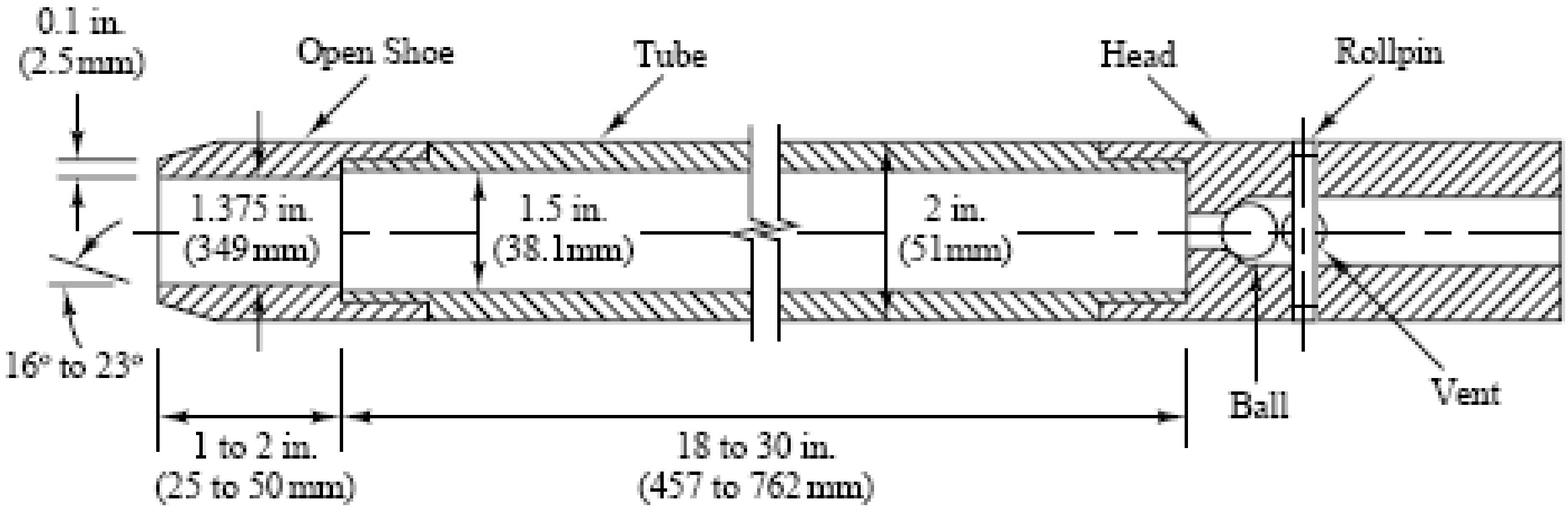
Variety of Field Testing Devices

Standard Penetration Test

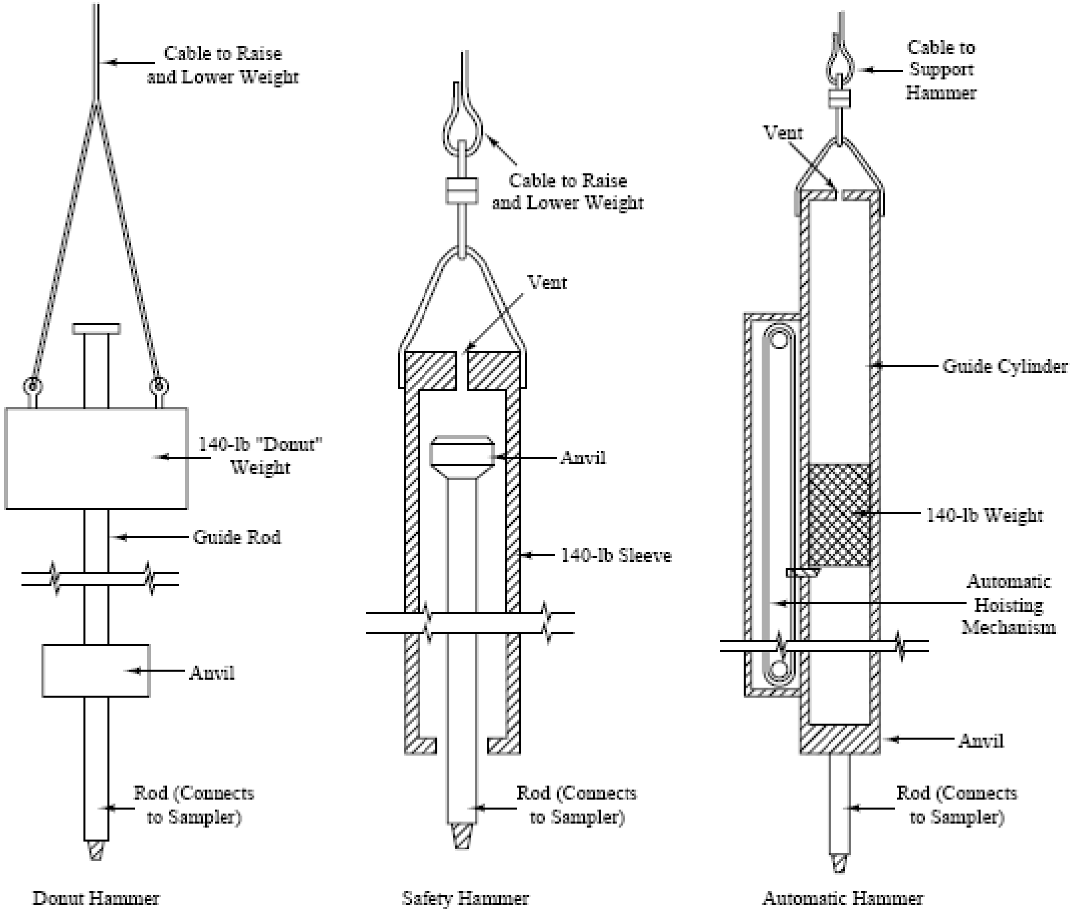


Standard Penetration Test

SPT sampler
(Adapted from ASTM D1586)



Types of SPT hammers



SPT discrepancies (correction)

- Equipment from different manufacturers. A large variety of drilling rigs are in current use; however, the rotary auger with the safety hammer of is the most common in North American practice (**type of hammer**).
- **Drive hammer configurations**. The anvil also seems to have some influence on the amount of energy input to the sampler.
- Whether a liner is used inside the split barrel sampler. Side friction increases the driving resistance (and AO and is less without the liner. It is common practice not to use a liner. Also it would appear that *N* values should be larger for soils with OCR > 1 (and larger relative density *Dr)* than for normally consolidated soils. borehole size)
- **Overburden pressure**. Soils of the same density will give smaller TV values if *p'o* is smaller (as near the ground surface). Oversize boreholes on the order of 150 to 200 mm will also reduce N unless a rotary hollow-stem auger is used with the auger left in close contact with the soil in the hole bottom. Degree of cementation may also be significant in giving higher N counts in cemented zones that may have little overburden pressure.
- **Length of drill rod**.

Correction SPT, N_{60}

$$N_{60} = \frac{N\eta_H \eta_B \eta_S \eta_R}{60}$$

N60= SPT values corrected for field procedure

η_H= hammer efficiency (table 2.3 Das)

η_B= borehole diameter correction (table 2.3 Das)

η_S= Sampler correction (table 2.3 Das)

η_R= Rod length correction (table 2.3 Das)

N= Measured SPT N values (table 2.3 Das)

Correction Tables

Table 2.3 Variations of η_H, η_B, η_S, and η_R [Eq. (2.8)]

1. Variation of η_H

Country	Hammer type	Hammer release	η_H (%)
Japan	Donut	Free fall	78
	Donut	Rope and pulley	67
United States	Safety	Rope and pulley	60
	Donut	Rope and pulley	45
Argentina	Donut	Rope and pulley	45
China	Donut	Free fall	60
	Donut	Rope and pulley	50

2. Variation of η_B

Diameter		
mm	in.	η_B
60–120	2.4–4.7	1
150	6	1.05
200	8	1.15

3. Variation of η_S

Variable	η_S
Standard sampler	1.0
With liner for dense sand and clay	0.8
With liner for loose sand	0.9

4. Variation of η_R

Rod length		
m	ft	η_R
>10	>30	1.0
6–10	20–30	0.95
4–6	12–20	0.85
0–4	0–12	0.75

Correction SPT, $(N_1)_{60}$

$$(N_1)_{60} = N_{60}\sqrt{\frac{2000\,\text{lb/ft}^2}{\sigma'_o}}$$

$$(N_1)_{60} = C_N N_{60} = \left[\frac{1}{\frac{\sigma'_o}{P_o}}\right]^{0.5} = N_{60}\sqrt{\frac{100\text{kPa}}{\sigma'o}}$$

N_{60}: N corrected for field procedure

$(N_1)_{60}$: N corrected for field procedure and overburden pressure

CN: correction factor

Consistency of clay

Table 2.4 Approximate Correlation between CI, N_{60}, and q_u

Standard penetration number, N_{60}	Consistency	CI	Unconfined compression strength, q_u (kN/m²)	(lb/ft²)
<2	Very soft	<0.5	<25	500
2–8	Soft to medium	0.5–0.75	25–80	500–1700
8–15	Stiff	0.75–1.0	80–150	1700–3100
15–30	Very stiff	1.0–1.5	150–400	3100–8400
>30	Hard	>1.5	>400	8400

$$\mathrm{CI} = \frac{\mathrm{LL} - w}{\mathrm{LL} - \mathrm{PL}}$$

the consistency index (CI)

w = natural moisture content

LL = liquid limit

PL = plastic limit

Consistency of saturated cohesive soils

$$C_u = KN_{60}$$

K= (3.5-6.5 kN/m²)

Consistency of saturated cohesive soils*

Consistency		(N_{60})	q_u, kPa	Remarks
Very soft	NC / Young clay	0–2	< 25	Squishes between fingers when squeezed
Soft		3–5	25 – 50	Very easily deformed by squeezing
Medium		6–9	50 – 100	? ?
Stiff	Increasing OCR / Aged/cemented	10–16	100 – 200	Hard to deform by hand squeezing
Very stiff		17–30	200 – 400	Very hard to deform by hand squeezing
Hard		>30	> 400	Nearly impossible to deform by hand

* Blow counts and OCR division are for a guide—in clay "exceptions to the rule" are very common.

Water Table correction (drained vs undrained)

$$N' = N + \tfrac{1}{2}(N - 15) \text{ for } N > 15;\; N' = N \text{ for } N \leq 15.$$

SPT Correlations

Relative Density and Internal Friction Angle

$$Dr(\%) = \left[(N_1)_{60} \frac{(0.23 + \frac{0.06}{D_{50}})^{1.7}}{9} \left(\frac{1}{\frac{\sigma'_o}{Pa}} \right) \right]^{0.5} (100)$$

$$\phi = \tan^{-1} \left[\frac{(N_{60})}{12.2 + 20.3(\frac{\sigma'_o}{pa})} \right]^{0.34}$$

$$\phi' = \sqrt{20(N_1)_{60}} + 20$$

Table 2.5 Relation between the Corrected $(N_1)_{60}$ Values and the Relative Density in Sands

Standard penetration number, $(N_1)_{60}$	**Approximate relative density, D_r, (%)**
0–5	0–5
5–10	5–30
10–30	30–60
30–50	60–95

SPT Correlations

Empirical values for ϕ, *Dr* and unit weight of granular soils based on the SPT at about 6 m depth and normally consolidated

$\phi = 28° + 15° D_r\ (\pm 2°)]$

Description	Very loose	Loose	Medium	Dense	Very dense
Relative density D_r	0	0.15	0.35	0.65	0.85
SPT $(N_1)_{60}$: fine	1–2	3–6	7–15	16–30	?
medium	2–3	4–7	8–20	21–40	> 40
coarse	3–6	5–9	10–25	26–45	> 45
ϕ: fine	26–28	28–30	30–34	33–38	
medium	27–28	30–32	32–36	36–42	< 50
coarse	28–30	30–34	33–40	40–50	
γ_{wet}, kN/m^3	11–16*	14–18	17–20	17–22	20–23

* Excavated soil or material dumped from a truck has a unit weight of 11 to 14 kN/m^3 and must be quite dense to weigh much over 21 kN/m^3. No existing soil has a $D_r = 0.00$ nor a value of 1.00. Common ranges are from 0.3 to 0.7.

The modulus of elasticity of granular soils (Es)

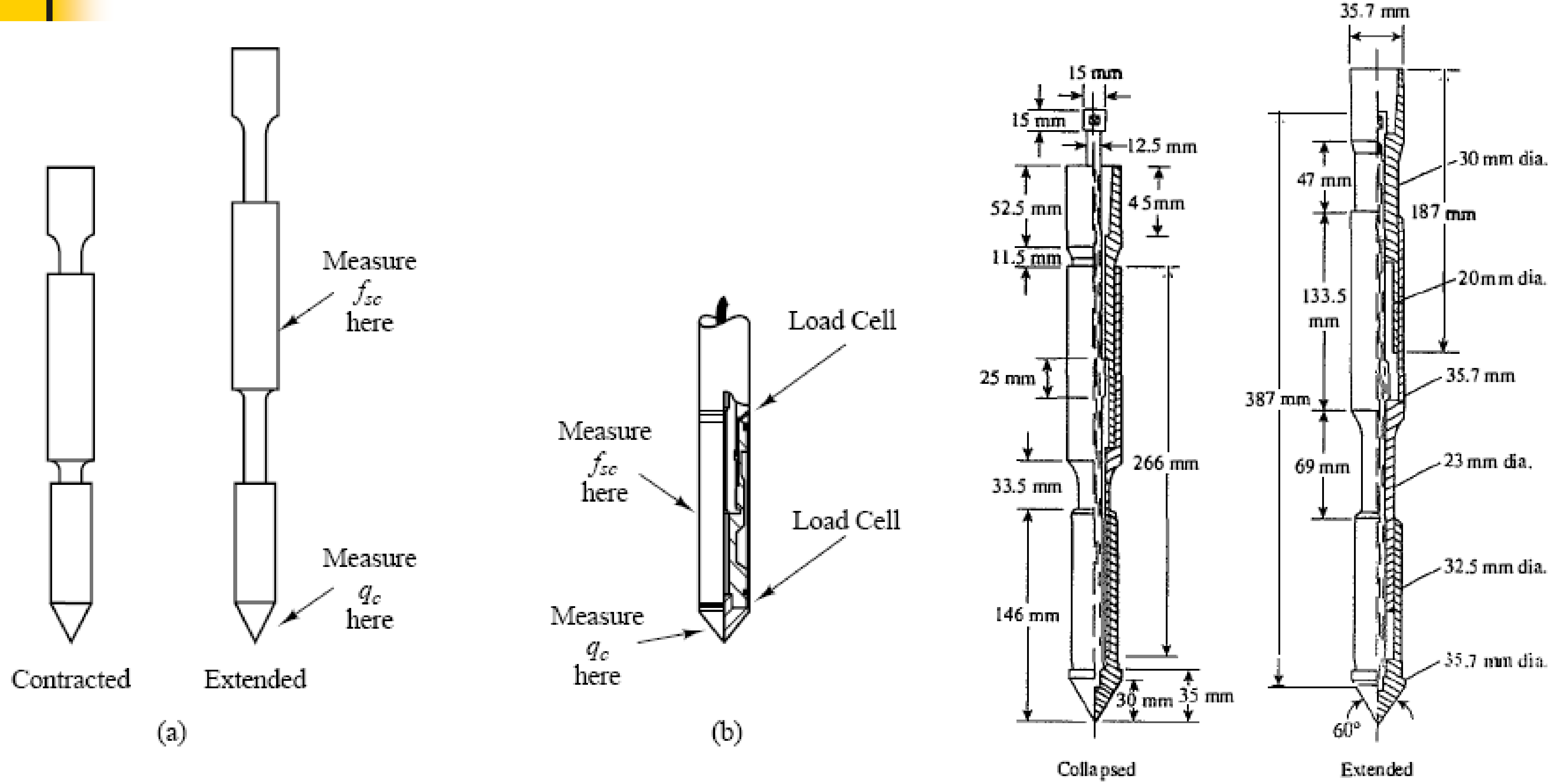
$$\frac{E_s}{p_a} = \alpha N_{60}$$

where

$p_a =$ atmospheric pressure (same unit as E_s)

$$\alpha = \begin{cases} 5 \text{ for sands with fines} \\ 10 \text{ for clean normally consolidated sand} \\ 15 \text{ for clean overconsolidated sand} \end{cases}$$

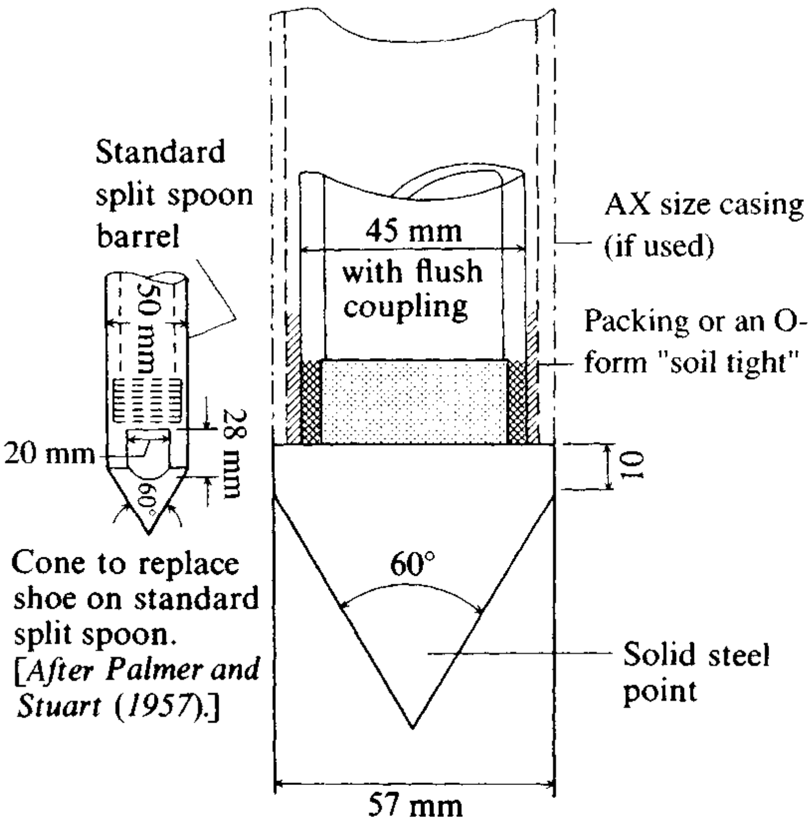
Cone Penetration Test



Types of cones (Most common): (a) A mechanical cone (also known as a Begemann Cone); and (b) An electric cone

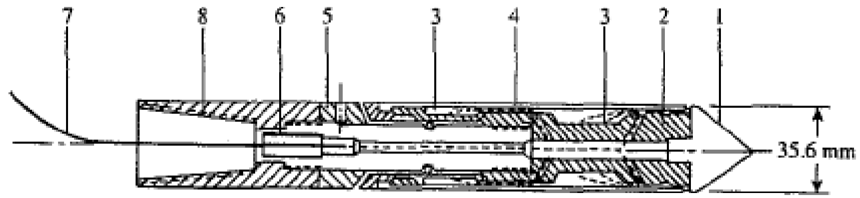
[see Figure 2.12 & 2.13 page 69 Das]

CPT



(a) Cone to replace shoe on standard split spoon. [*After Palmer and Stuart (1957).*]

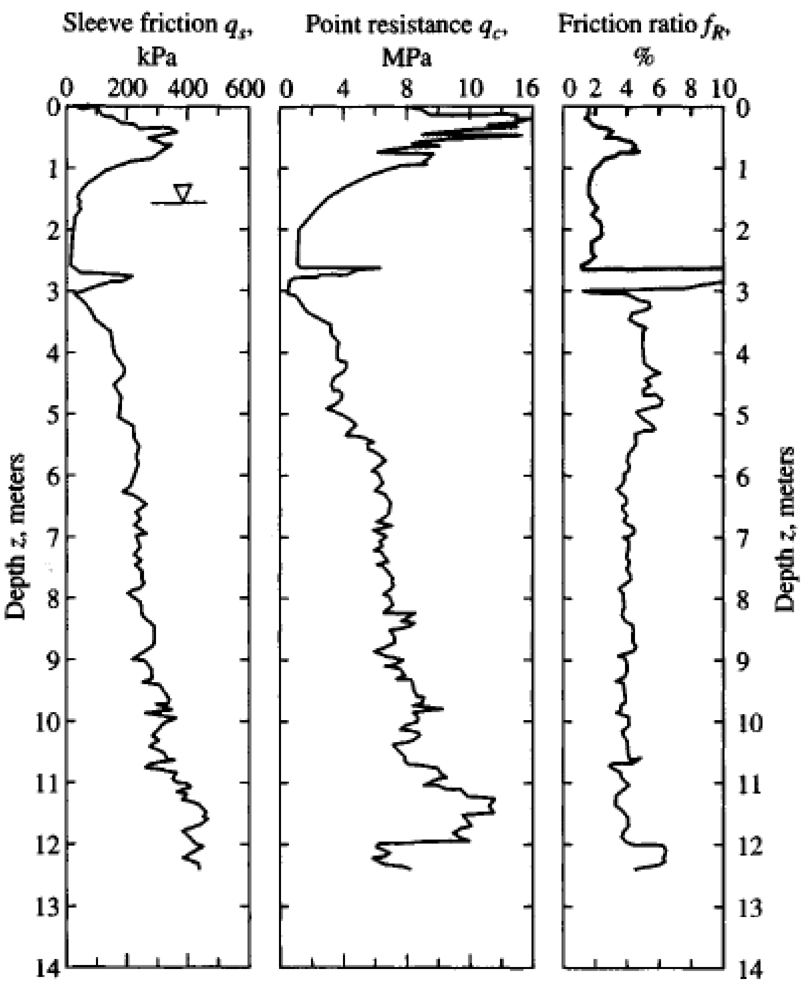
(b) Cone attached to drill rods.



1 Conical point (10 cm²)
2 Load cell
3 Strain gauges
4 Friction sleeve (150 cm²)
5 Adjustment ring
6 Waterproof bushing
7 Cable
8 Connection with rods

- Driving rate 10 to 20 mm/s
- The tip (or cone) usually has a projected cross-sectional area of 10 cm^2,
- Friction sleeve area 150 cm^2

Typical measurements



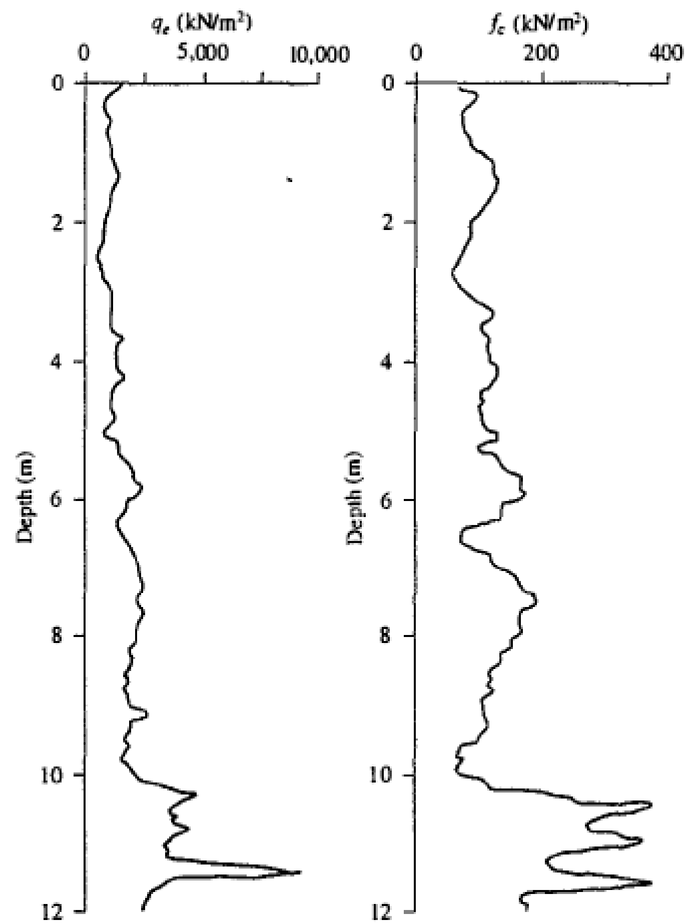


Figure 2.20 Cone penetrometer test with friction measurement

Correlation

- **With Relative density as**

$$Dr = \sqrt{\left[\frac{1}{305Q_c OCR^{1.8}}\right]\frac{\frac{q_c}{P_a}}{(\frac{\sigma'_o}{P_a})^{0.5}}}$$

Qc : compressibility factor **ranges between 0.91 for High compressible sand (loose) to 1.09 law compressible sand (dense to very dense)**

- **Internal Friction angle**

$$\phi' = \tan^{-1}\left[0.1 + 0.38\log(\frac{qc}{\sigma'_o})\right]$$

- **Undrained Shear Strength, Cu ;**

$$\frac{C_u}{\sigma'_o} = \left(\frac{q_c - \sigma_o}{\sigma'_o}\right)\frac{1}{N_K}$$

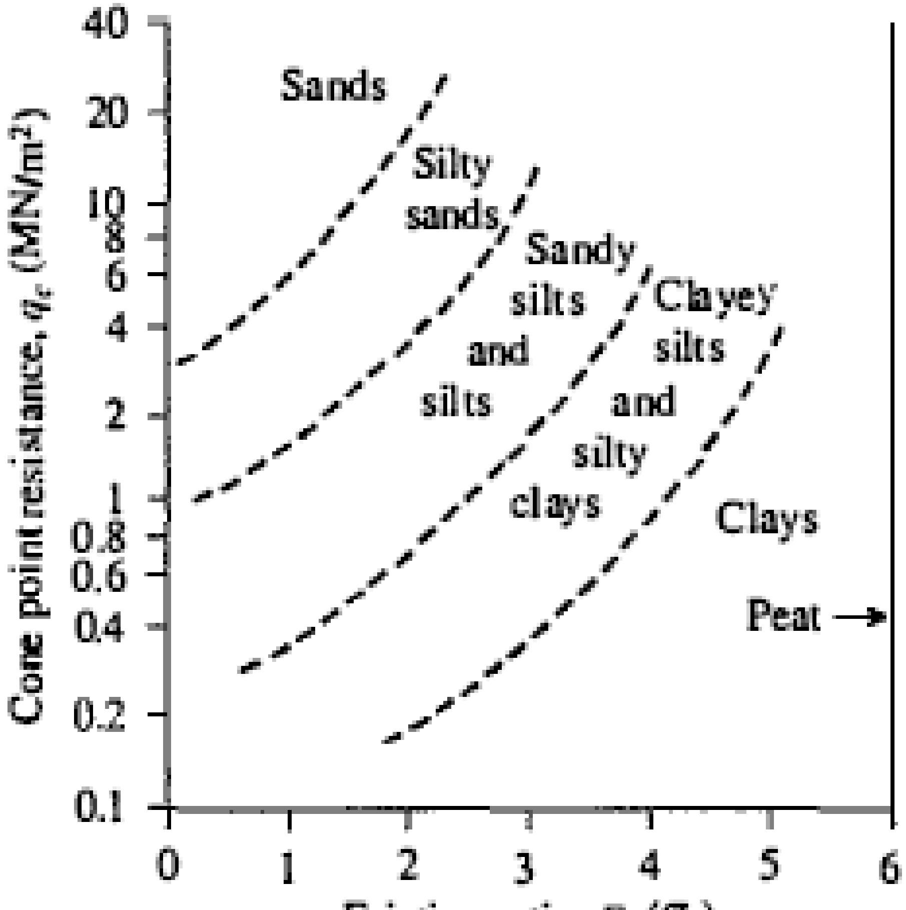
N_K Bearing capacity factor 15 for mechanical and 20 for electrical

- **Maximum past pressure and OCR as**

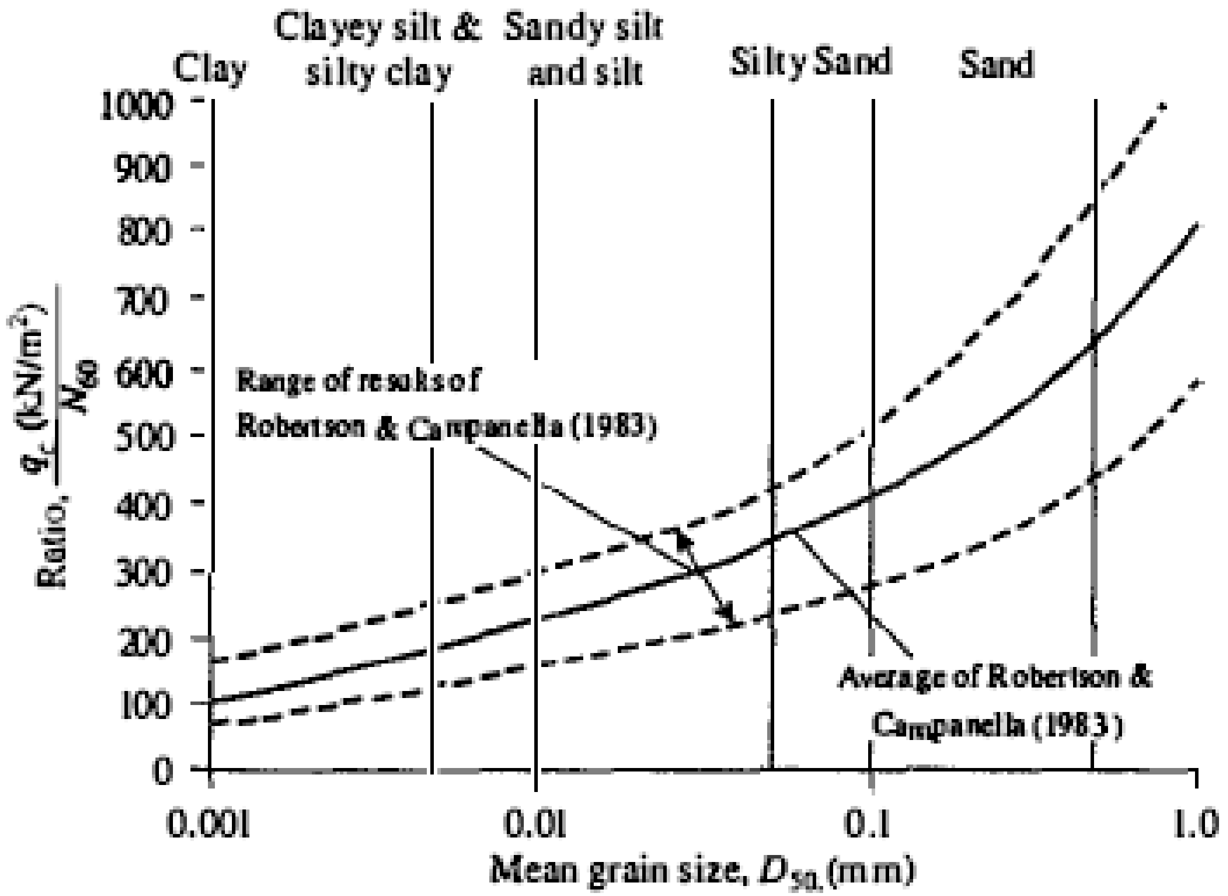
$$OCR = 0.37\left(\frac{q_c - \sigma_o}{\sigma'_o}\right)^{1.01}$$

$$\sigma'_c = 0.243(q_c)^{0.96} \quad (MN/m^2)$$

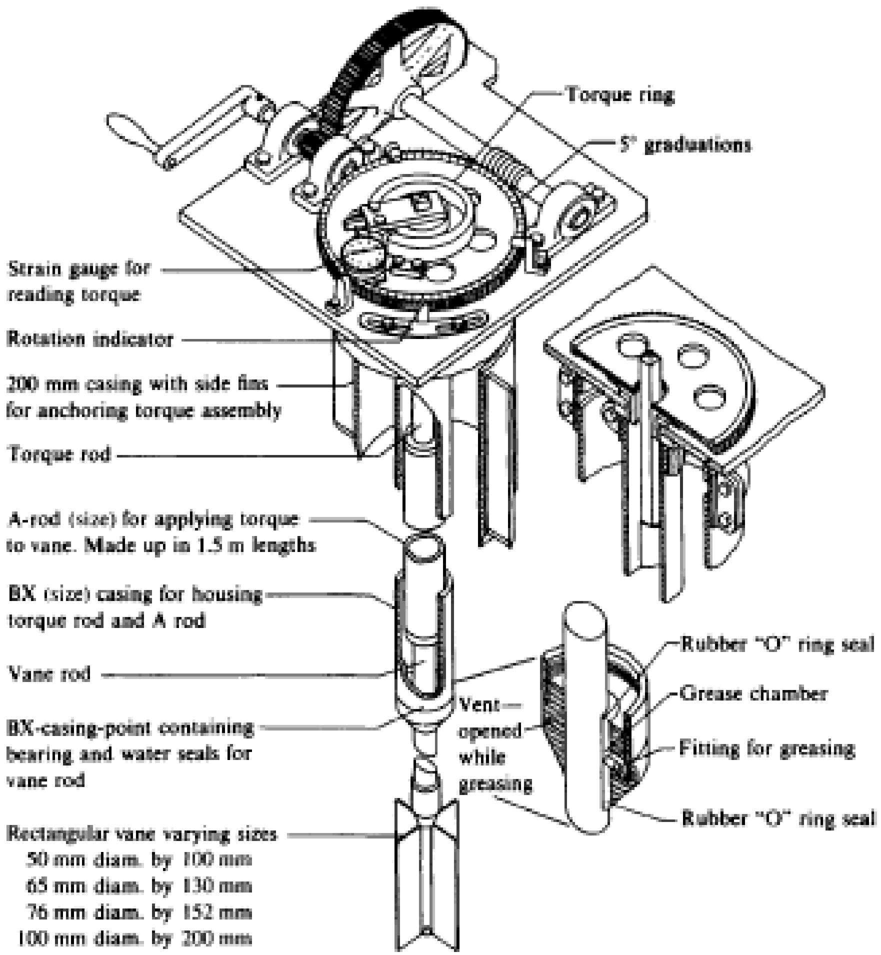
Classification of soil based on CPT test results



Correlation between q_c/N_{60} and the mean grain size, D50.



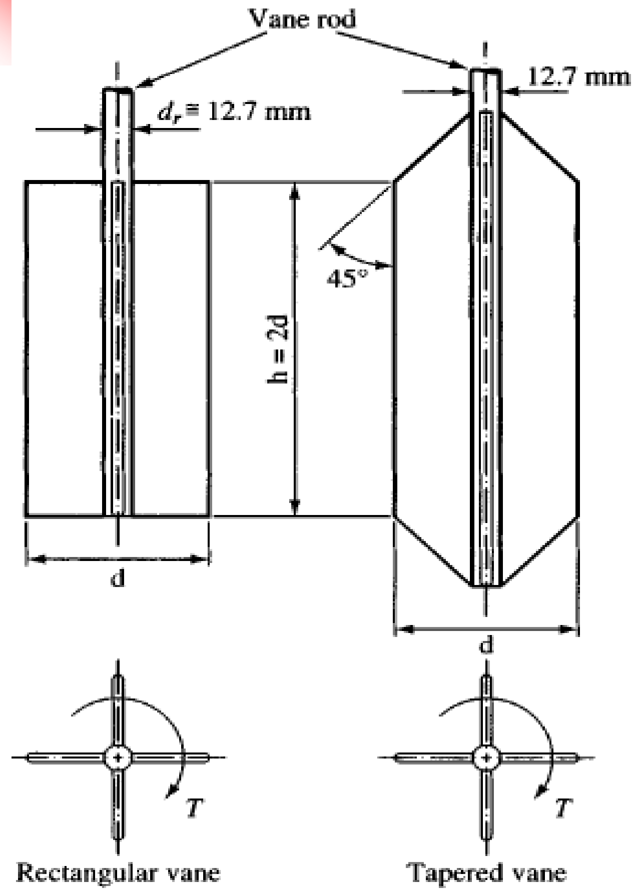
FIELD VANE SHEAR TESTING (FVST)



(a) The Bureau of Reclamation vane shear test apparatus. *Gibbs et al. (1960), courtesy of Gibbs and Holtz of the USBR.*]

Vane Shear Test

Data Reduction
undrained shear strength



(a) usual shapes

$$T = f(c_u, H, \text{and } D)$$

$$Cu = T/K$$

$$K = \left(\frac{\pi}{10^6}\right)\left(\frac{D^2H}{2}\right)\left(1 + \frac{D}{3H}\right)$$

$K = 366 \times 10^{-8} D^3$; D(cm) if H/D=2.0

$$Cu = \lambda C_{u(VST)}$$

$\lambda = 1.7 - 0.54\log(PI\%)$

or use Figure 2.11 in text page 67

GROUNDWATER TABLE (GWT) LOCATION

- The GWT is generally determined by directly measuring to the stabilized water level in the borehole after a suitable time lapse, often 24 to 48 hr later. **This measurement is done by lowering a weighted tape down the hole until water contact is made**. In soils with a high permeability, such as sands and gravels, 24 hr is usually a sufficient time for the water level to stabilize unless the hole wall has been somewhat sealed with drilling mud.

NUMBER AND DEPTH OF BORINGS

- Depth of Boring for a building of 30.5 m wide
  - $D_b = 3S^{0.7}$ **for light steel and narrow concrete building**
  - $D_b = 6S^{0.7}$ **for heavy steel or wide concrete structure**
- **For deep excavation at least 1.5 timers of the depth of excavation**
- **In bed rock at least 3m**
- **Approximate spacing of Boreholes (Number)**

Approximate spacing of Boreholes (number)

Type of Project	Spacing (m)
Multistory building	10-30
One store industrial plants	20-60
Highways	250-500
Dams and Dukes	40-80

Minimum Depths Requirements For Boring for Shallow Foundation

AASHTO Standard Specifications for Design of Highway Bridges

- For isolated footings of breadth Lf and width Bf, where Lf < 2Bf, borings shall extend a minimum of two footing widths below the bearing level.

- For isolated footings where Lf >5Bf, borings shall extend a minimum of four footing widths below the bearing level.

- For 2Bf < Lf < 5Bf, minimum boring length shall be determined by linear interpolation between depths of 2Bf and 5Bf below the bearing level.

Minimum Depths Requirements For Boring for Deep Foundation

AASHTO Standard Specifications for Design of Highway Bridges

- In soil, borings shall extend below the anticipated pile or shaft tip elevation a minimum of 6 m, or a minimum of two times the maximum pile group dimension, whichever is deeper.
- For piles bearing on rock, a minimum of 3 m of rock core shall be obtained at each boring location to verify that the boring has not terminated on a boulder.
- For shafts supported on or extending into rock, a minimum of 3 m of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.

Minimum Depths Requirements For Boring for Retaining Walls AASHTO Standard Specifications for Design of Highway Bridges

- Extend borings to depth below final ground line between 0.75 and 1.5 times the height of the wall. Where stratification indicates possible deep stability or settlement problem, borings should extend to hard stratum.

Minimum Depths Requirements For Boring for Roadways AASHTO Standard Specifications for Design of Highway Bridges

- Extend borings a minimum of 2 m below the proposed subgrade level.

Guidelines For Boring Layout

FHWA Geotechnical Checklist and Guidelines; FHWA-ED-88-053

Bridge Foundations	▪For piers or abutments over 30 m wide, provide a minimum of two borings. ▪For piers or abutments less than 30 m wide, provide a minimum of one boring. ▪Additional borings should be provided in areas of erratic subsurface conditions.
Retaining Walls	▪A minimum of one boring should be performed for each retaining wall. ▪For retaining walls more than 30 m in length, the spacing between borings should be no greater than 60 m. ▪Additional borings inboard and outboard of the wall line to define conditions at the toe of the wall and in the zone behind the wall to estimate lateral loads and anchorage capacities should be considered.

Shallow Foundations:
Ultimate Bearing Capacity

Chapter 3

Foundation Engineering

The building began tilting after high winds buffeted the giant signs, which were connected to columns (and foundations), for several days.

Types of Foundations

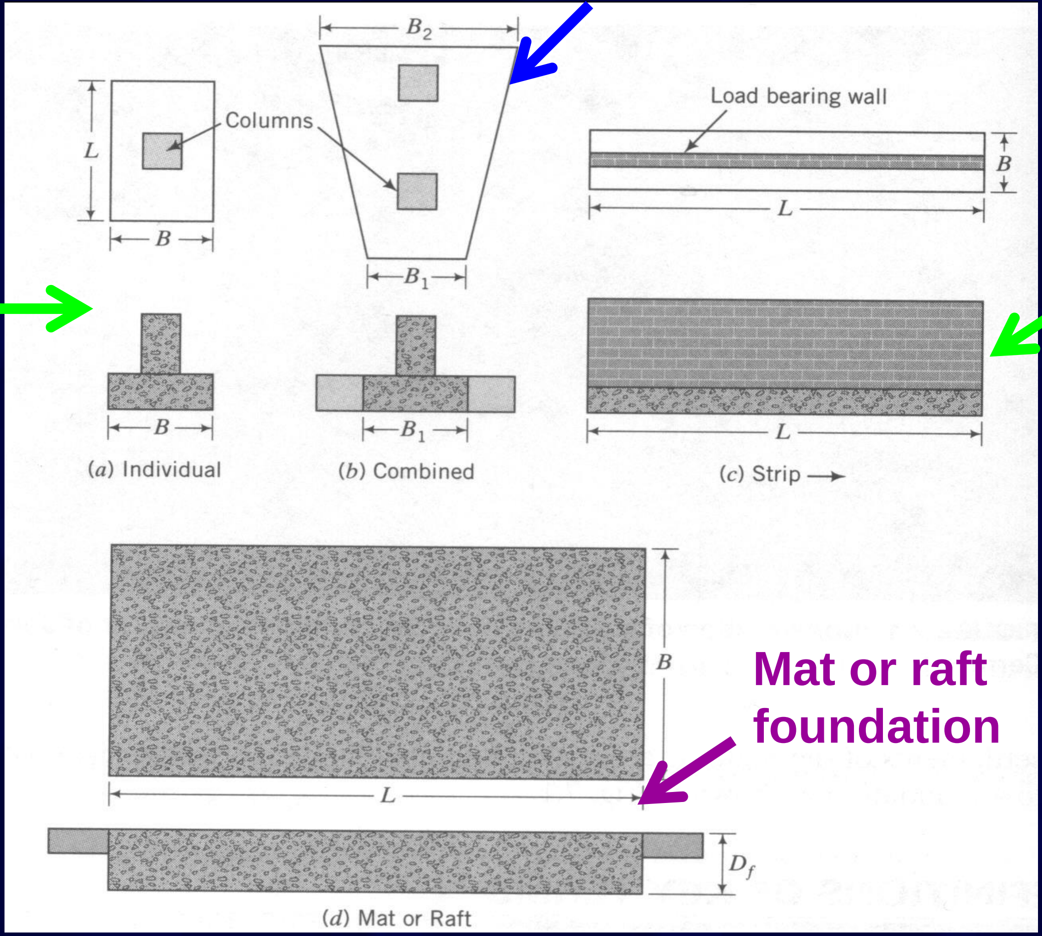
- **Shallow Foundations ($D_f \leq B$)**
- **Deep Foundations**

Combined foundation

Individual or isolated footing

Continuous or strip footing

Mat or raft foundation



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B
L

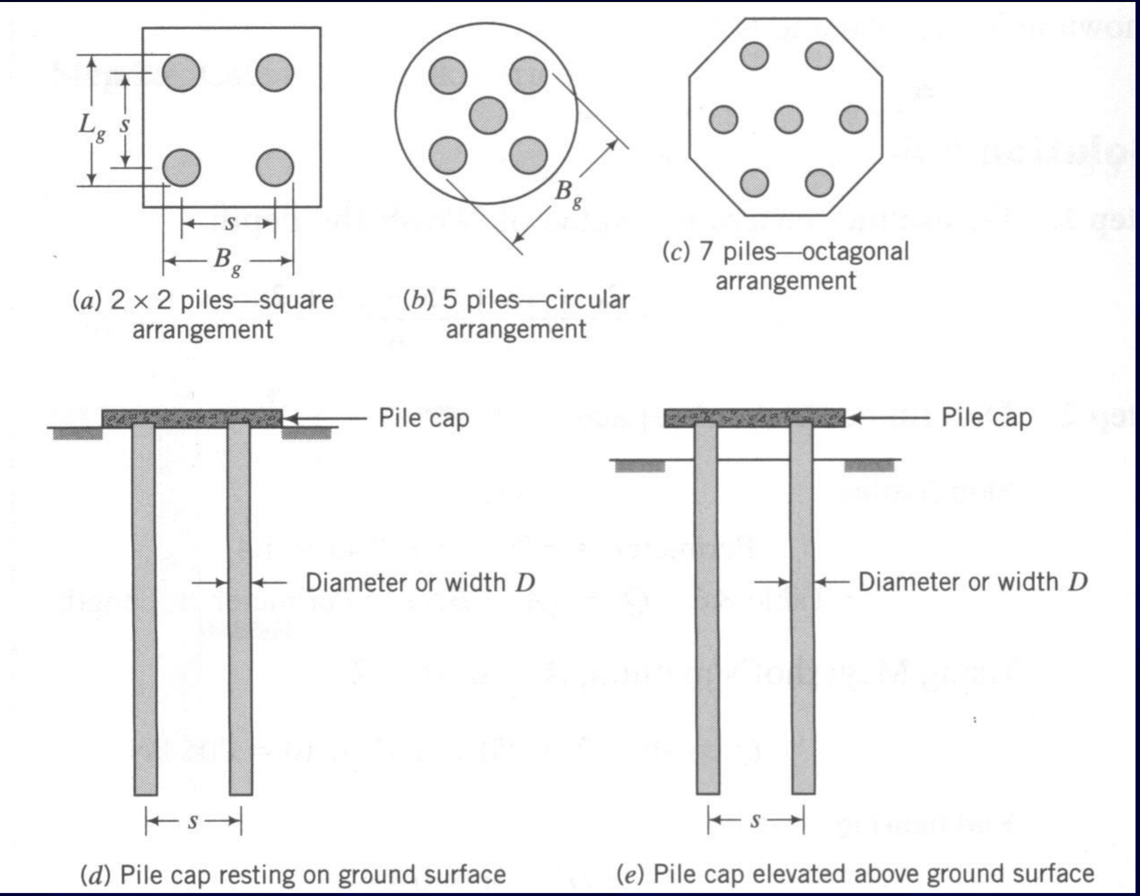

L
B = L

Types of Foundations

- **Deep Foundations:** - single pile
  - pile group
  - drilled shafts & piers (large diameter)

Plan view

Cross sections



Ultimate Bearing Capacity

q_u (also q_{ult})

Ultimate bearing capacity is the ***contact load per unit area*** at the foundation base that causes the ***shear failure*** in the soil due to the loads from an engineering structure located above.

Key words:

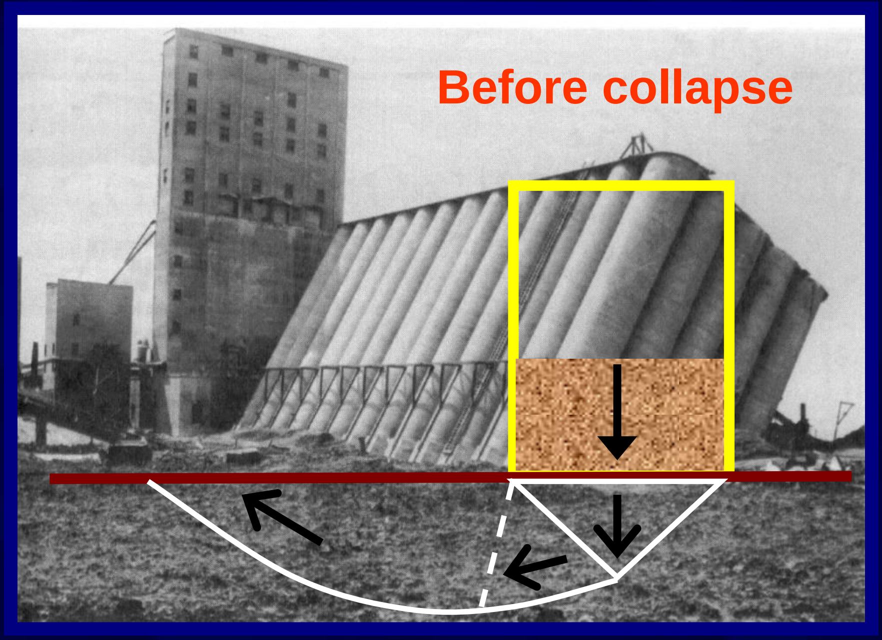
- ***Stress***
- ***Shear failure***
- ***Due to structural loads***

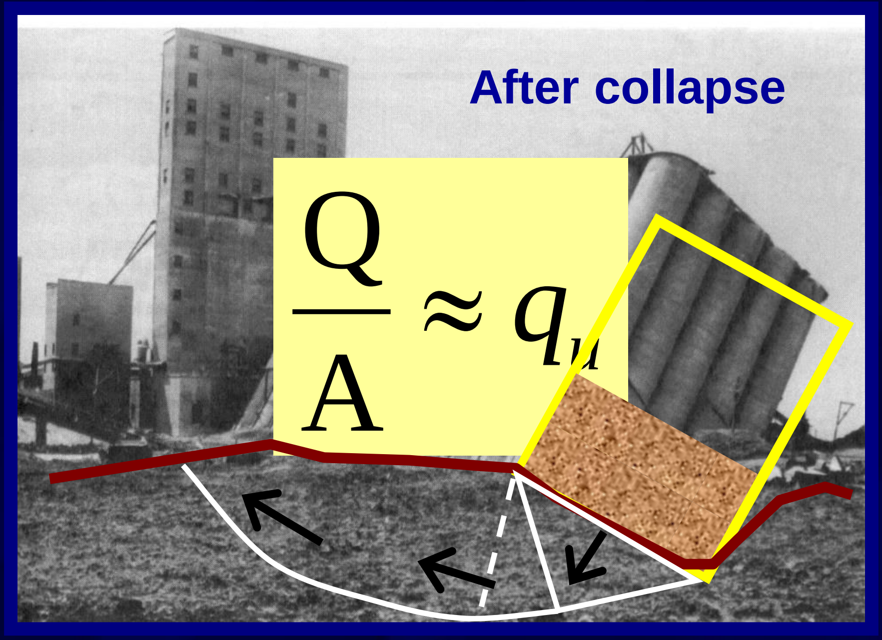
Failure of the Transcona Grain Elevator

(1913)

Lessons learned from the Transcona Grain Elevator Failure

- *Importance of soil exploration*
- *Failure in the soil*
- *Proof of bearing capacity theory*

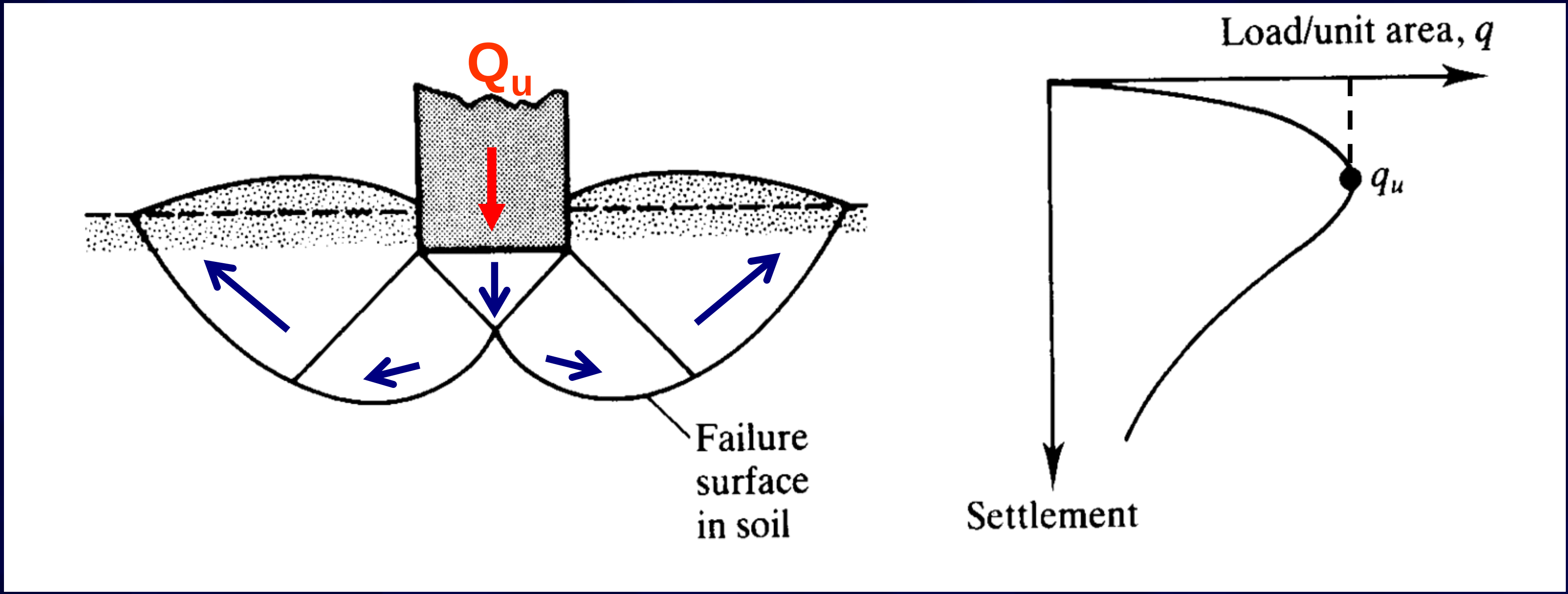




Bearing Capacity Failure - Types

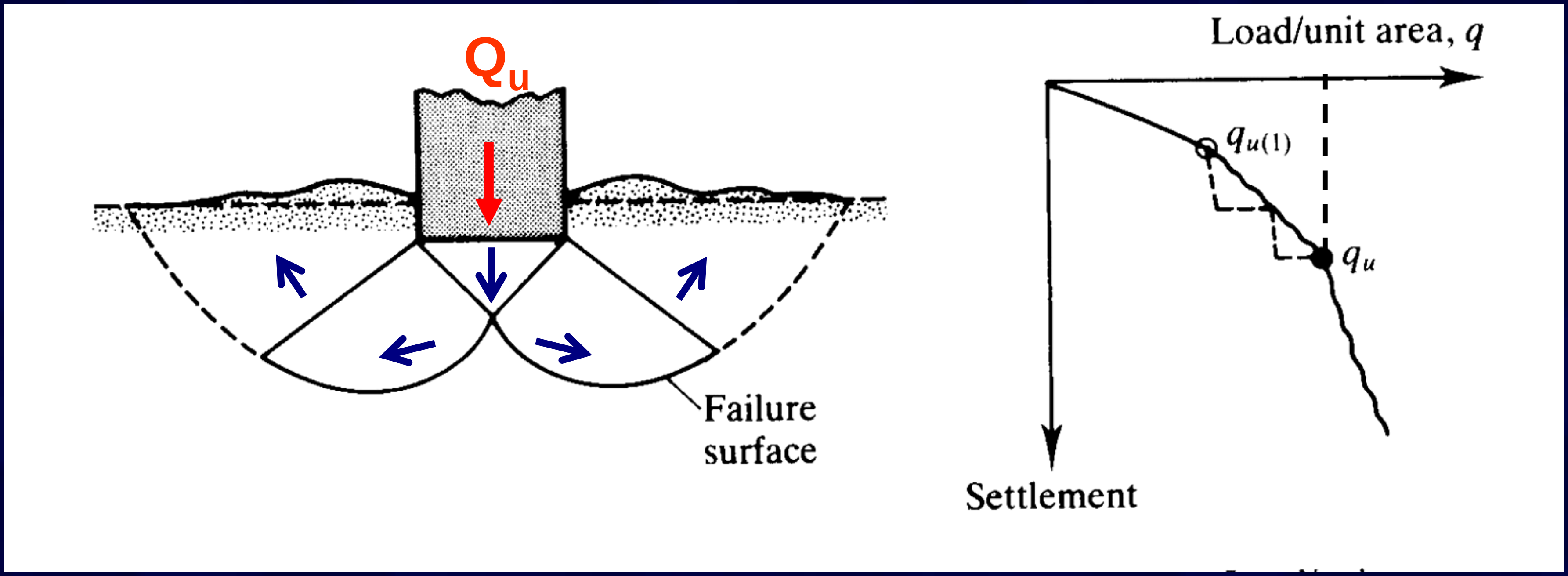
1.- General shear failure

Dense sand or stiff clay



2.- Local shear failure

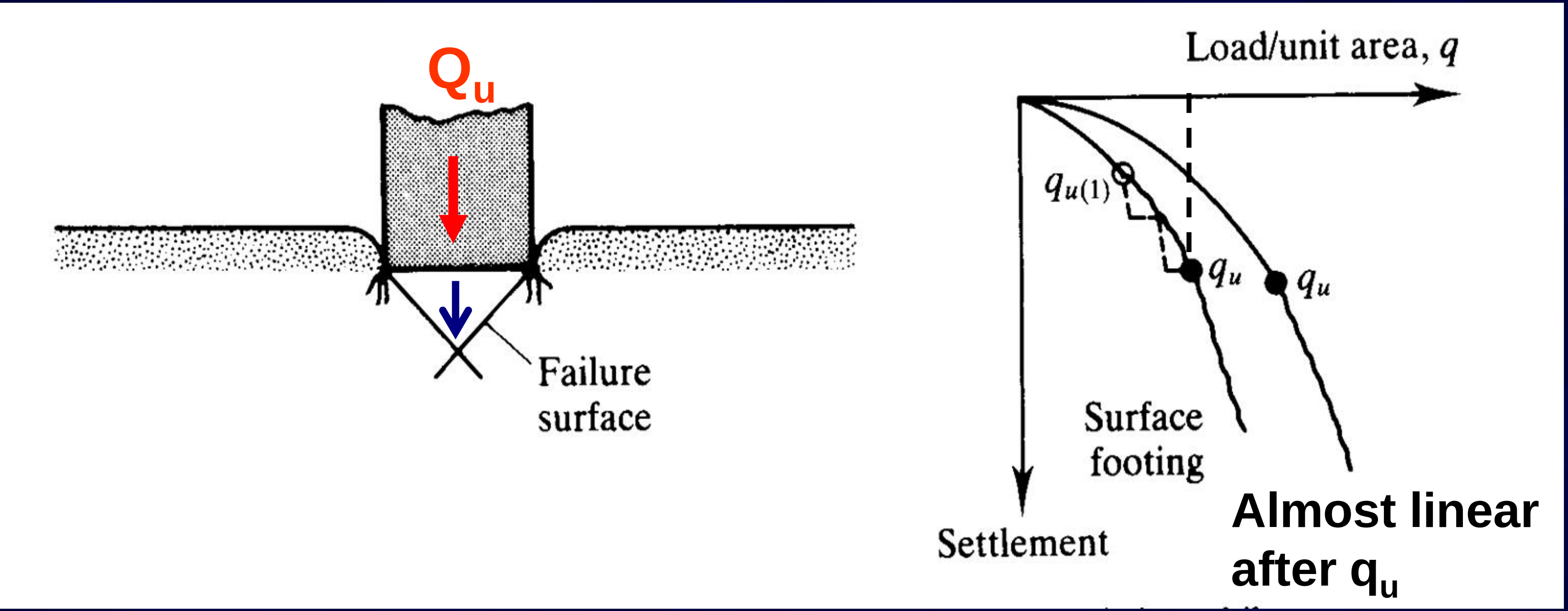
Medium dense sand or medium stiff clay



Not a peak in q_u

3.- Punching shear failure

Loose sand or soft clay

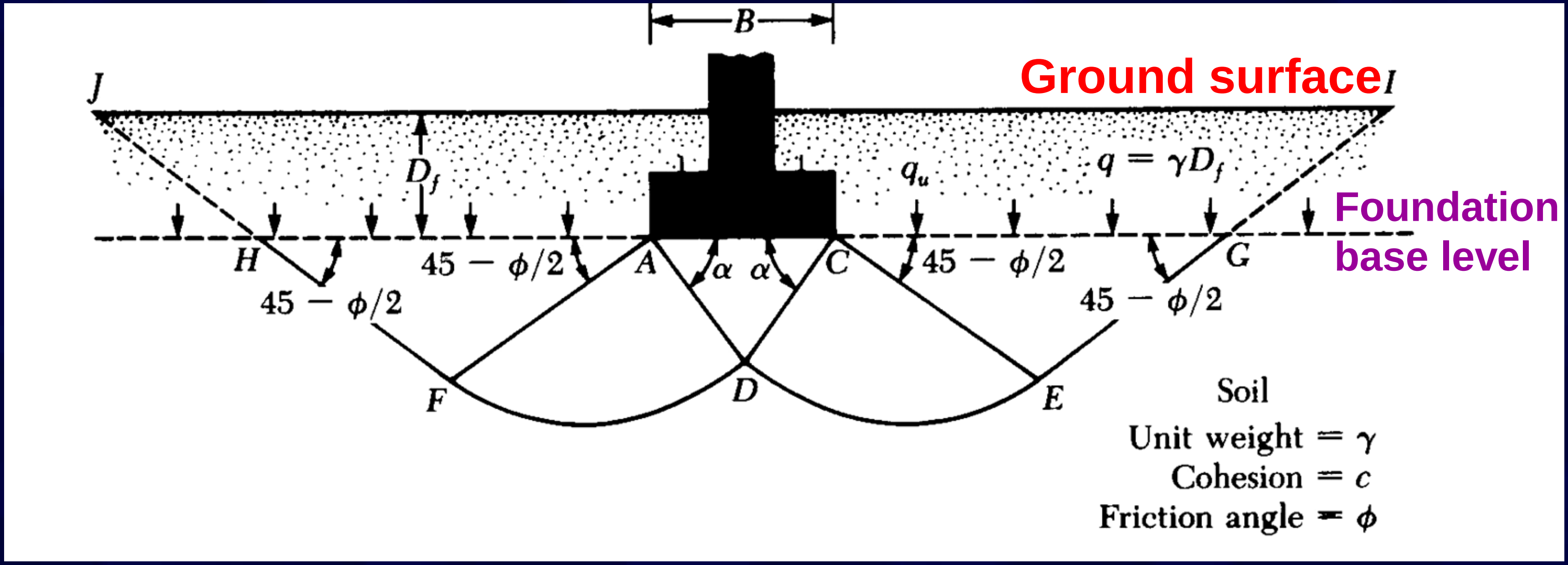


Terzaghi's Bearing Capacity Theory

General Shear Failure

$$q_u = c' N_c + qN_q + 0.5\gamma BN_\gamma$$

Continuous or strip foundation (*L* >> *B*)



Terzaghi's Bearing Capacity Equation

For continuous or <u>strip</u> foundation

$$q = \gamma \cdot D_f$$

$$q_u = c' N_c + q N_q + 0.5 \gamma B N_\gamma$$

Cohesion term

Surcharge term

Unit weight term

Friction angle??

Meyerhof's Bearing Capacity Equation

- Applies to General Shear Failure:

$$q_u = (c' N_c) F_{cs} F_{cd} F_{ci} + (q N_q) F_{qs} F_{qd} F_{qi} + (0.5 \gamma B N_\gamma) F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

For clays ($\phi = 0$): Use c_u (undrained shear strength)

$$N_c = 5.14 \quad N_q = 1 \quad N_\gamma = 0$$

Bearing Capacity Factors

$$q_u = (c' N_c) F_{cs} F_{cd} F_{ci} + (q N_q) F_{qs} F_{qd} F_{qi} + (0.5 \gamma B N_\gamma) F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

$$N_q = \tan^2\left(45 + \frac{\phi'}{2}\right) e^{\pi \tan \phi'}$$

Reissner (1924)
Meyerhof (1963)

$$N_c = (N_q - 1)\cot \phi'$$

Prandtl (1921)

$$N_\gamma = 2(N_q + 1)\tan \phi'$$

Vesić (1973, 1975)

Correction Factors

$$q_u = (c' N_c) F_{cs} F_{cd} F_{ci} + (q N_q) F_{qs} F_{qd} F_{qi} + (0.5 \gamma B N_\gamma) F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

Shape (*s*)

Depth (*d*)

Inclination (*i*)

Net and Gross Bearing Capacity

- **NET BEARING CAPACITY:** is the contact load per unit area of the foundation in excess of the pressure due to the weight of the soil and concrete above the foundation base ($q = \gamma D_f$)

$$q_{net}$$

- **GROSS BEARING CAPACITY:** *includes* the weight of the soil and concrete above the footing base

$$q_{gross} = q_{net} + (\gamma D_f)$$

Allowable Bearing Capacity

- **ALLOWABLE BEARING CAPACITY:** minimum of the following two amounts:

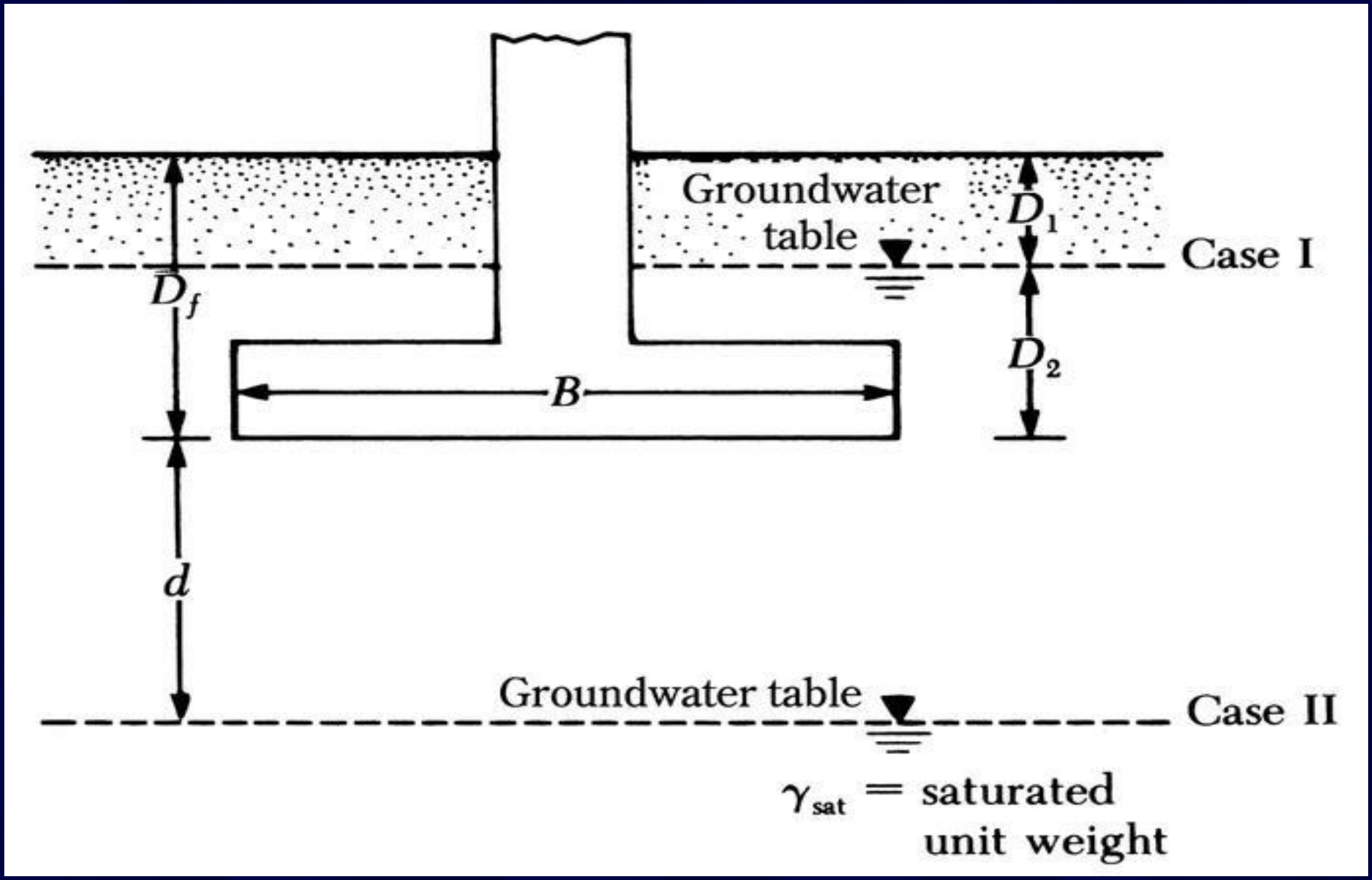
  1.- Ultimate bearing capacity (q_u) reduced by a factor of safety, or

  2.- Bearing capacity that limits the settlement (deformations) to a tolerable amount

$$q_{all} = \frac{q_u}{FS}$$

FS = **factor of safety (2 to 3); depends on *risk* and *uncertainties***

Cases with water table (WT)
Section 3.5

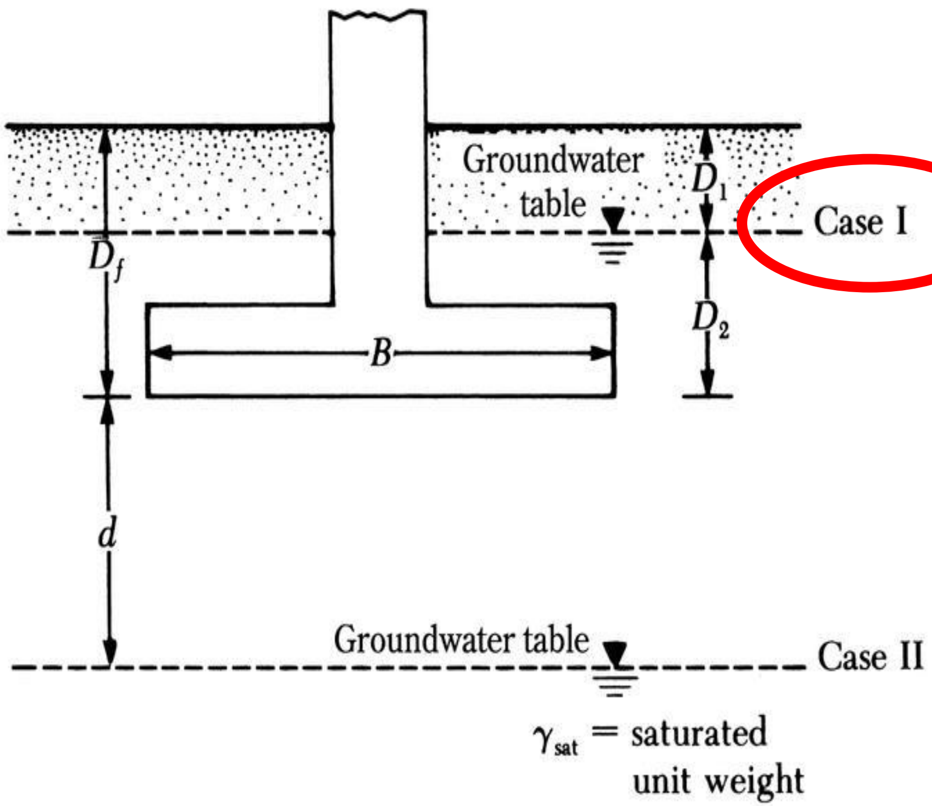


Cases with water table (WT)

CASE *I*: WT above footing base

Include correction factors!

$$q_u = c' N_c + qN_q + 0.5\gamma B N_\gamma$$



$$\gamma' = \gamma_{sat} - \gamma_w$$

$$q = D_1\gamma + D_2\gamma'$$

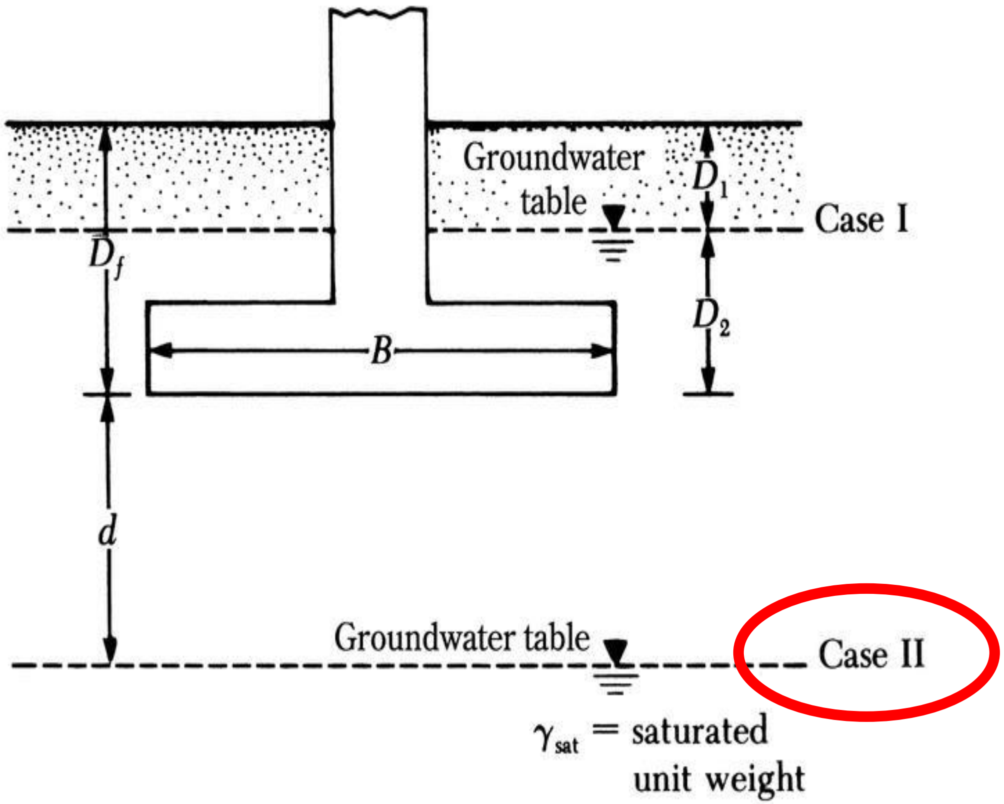
Cases with water table (WT)

CASE *II*: 0 ≤ *d* ≤ *B*

$$q_u = c' N_c + qN_q + 0.5\gamma BN_\gamma$$

$$q = \gamma D_f$$

$$\bar{\gamma} = \gamma' + \frac{d}{B}(\gamma - \gamma')$$



Cases with water table

CASE *III*: *d ≥B* ***NO EFFECT ON BEARING CAPACITY***

Use total (or moist) unit weight of the soil for the surcharge and the unit weight terms

$$q_u = c' N_c + qN_q + 0.5\gamma BN_\gamma$$

$q = \gamma D_f$

γ or γ_{sat}