ENCE 4610
Foundation Analysis and Design

University of Tennessee at Chattanooga

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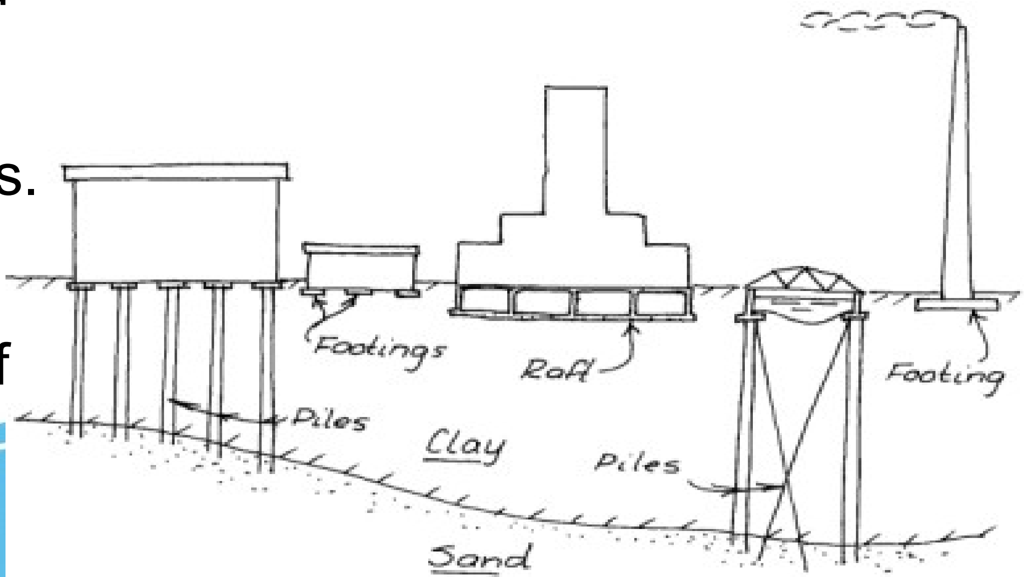
Introduction

Credits for Text and Graphics

- Textbooks
  - Verruijt, A., *Soil Mechanics*. Delft, The Netherlands: VSSD, 2012.
  - Naresh C. Samtani and Edward A. Nowatzki, *Soils and Foundations Reference Manual*, Vols. 1 and 2. Washington, DC: National Highway Institute, Department of Transportation, 2006.

- Line Drawings, Videos and other Graphics
  - Dr. Bengt Broms
  - GRL/Pile Dynamics Inc.
  - Jonathan Tremmier, Pile Hammer Equipment



What We Need From Soil Mechanics

- Phase Relationships
  - The single most important topic of the course
- Total Stresses, Effective Stresses, and Pore Water Pressure
  - Important with all foundations, but especially with deep foundations
- Consolidation and Volume Change Due to Particle Rearrangement and Pore Water Squeeze
  - Cohesive soils method is standard
  - New Method for cohesionless Soils
- Lateral Earth Pressures

General Approach to Foundation Design

The duty of the foundation design specialist is to establish the most economical design that safely conforms to prescribed structural criteria and properly accounts for the intended function of the structure. Essential to the foundation engineer's study is a rational method of design, whereby various foundation types are systematically evaluated and the optimum alternative selected. The following foundation design approach is recommended:

1. Determine the direction, type and magnitude of foundation loads to be supported, tolerable deformations and special constraints such as:

    a. Underclearance requirements that limit allowable total settlement.
    b. Structure type and span length that limits allowable deformations and angular distortions.
    c. Time constraints on construction.
    d. Extreme event loading and construction load requirements.

    In general, a discussion with the structural engineer about a preliminary design will provide this information and an indication of the flexibility of the constraints.

2. Evaluate the subsurface investigation and laboratory testing data with regard to reliability and completeness. The design method chosen should be commensurate with the quality and quantity of available geotechnical data, i.e., **don't use state-of-the-art computerized analyses if you have not performed a comprehensive subsurface investigation to obtain reliable values of the required input parameters.**

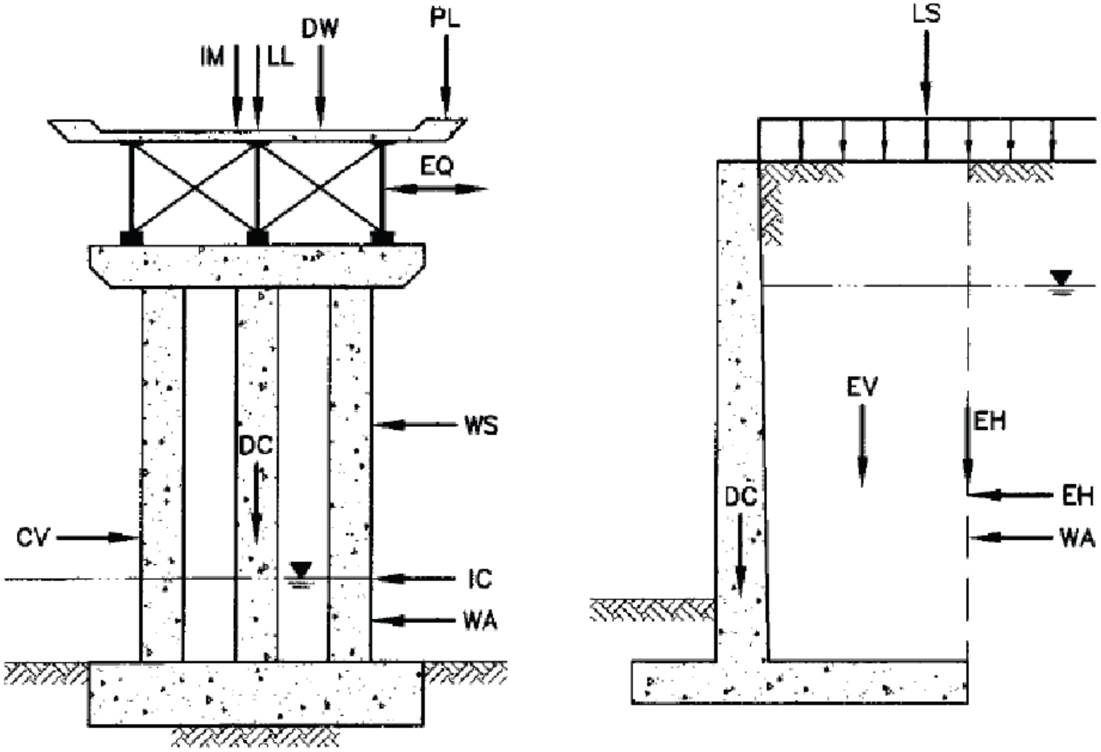
3. Consider alternate foundation types where applicable as discussed below.

Requirements for Foundation Design

- Basic Requirements
  - Strength Requirements
  - Serviceability Requirements
  - Constructibility Requirements
  - Economic Requirements
- Foundation Loading
  - Types of Loads
  - Sources of Loads

- Questions to consider
  - How to we deal with uncertainty in loading?
  - How do we deal with combined loads?
  - What is the code environment?
  - How do different foundations respond to different loading?

Sources of Loading



LEGEND:

DC = DEAD LOAD OF STRUCTURAL COMPONENTS AND NONSTRUCTURAL ATTACHMENTS
DW = DEAD LOAD OF WEARING SURFACES AND UTILITIES
EH = HORIZONTAL EARTH PRESSURE LOAD
ES = EARTH SURCHARGE LOAD
EV = VERTICAL PRESSURE FROM DEAD LOAD OF EARTH FILL
CV = VESSEL COLLISION FORCE

EQ = EARTHQUAKE
IC = ICE LOAD
IM = VEHICULAR DYNAMIC LOAD ALLOWANCE
LL = VEHICULAR LIVE LOAD
LS = LIVE LOAD SURCHARGE
PL = PEDESTRIAN LIVE LOAD
WA = WATER LOAD AND STREAM PRESSURE
WS = WIND LOAD ON STRUCTURE

(a) Bridge Pier (b) Cantilever Retaining Wall

Uplift and Lateral Loading

- Lateral Loading

- Uplift Loading

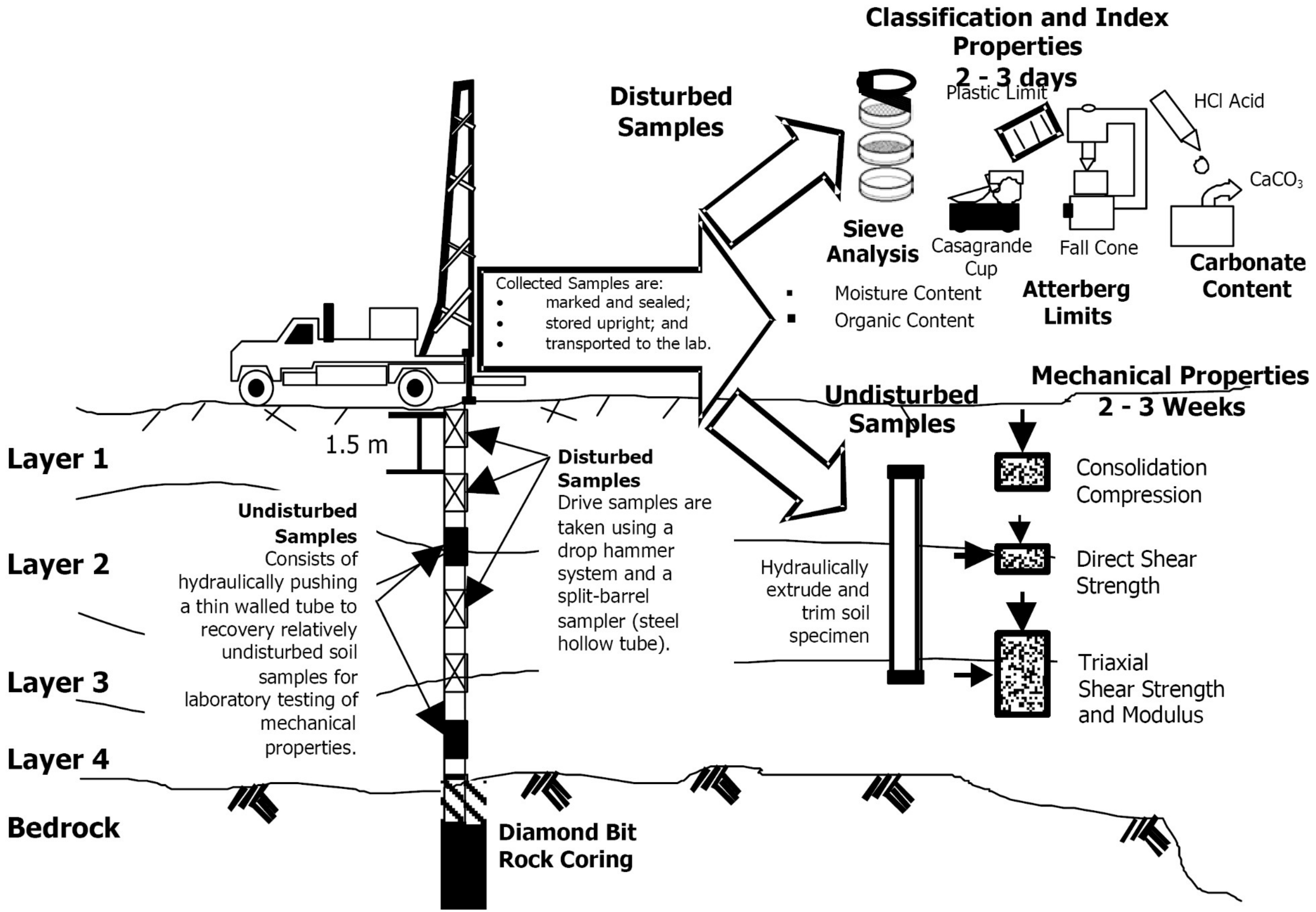
Sources of Information and Considerations for Foundation Design

- Sources of Information
  - Experience obtained by trial and error in the past; this developed into the empirical or "rule of thumb" procedures for today.
    - The weakness of this approach is not recognizing differences in the engineering properties of soils. What works well at one location may not succeed with the same type of soil at another location.
  - Information on the properties of soils; generally obtained by field explorations and laboratory tests. Subsequent, theoretical analysis results will only be as good as the soils data used as input.
  - Scientific principles from various fields of engineering and science; used to explain or predict the behavior of soils under various conditions.

- Considerations for Foundation Design

1. Economical
2. Edequate safety (F_s)
   (Bearing capacity, sliding, overturning etc)
3. Small settlements
   (Total and differential settlements)
4. Small seasonal changes
   (drying, frost, heave)
5. Construction problems (stability of excavation, bottom heave, ground water problems, vibrations, noise etc)
6. Environmental effects
   (E.g. permanent lowering of the ground water level)

Field and Lab Testing of Soils



Typical Properties for Cohesionless Soils

a. Relative Density and Gradation
(Data from Schmertmann 1978)

Relative Density D_r, Percent	Fine Grained: Uniform	Fine Grained: Well-graded	Medium Grained: Uniform	Medium Grained: Well-graded	Coarse Grained: Uniform	Coarse Grained: Well-graded
40	34	36	36	38	38	41
60	36	38	38	41	41	43
80	39	41	41	43	43	44
100	42	43	43	44	44	46

b. Relative Density and In Situ Soil Tests

Soil Type	Relative Density D_r, Percent	Standard Penetration Resistance N_{60} (Terzaghi and Peck 1967)	Cone Penetration Resistance q_c, ksf (Meyerhof 1974)	Friction Angle ϕ', deg: Meyerhof (1974)	Friction Angle ϕ', deg: Peck, Hanson and Thornburn (1974)	Friction Angle ϕ', deg: Meyerhof (1974)
Very Loose	< 20	< 4	----	< 30	< 29	< 30
Loose	20 - 40	4 - 10	0 - 100	30 - 35	29 - 30	30 - 35
Medium	40 - 60	10 - 30	100 - 300	35 - 38	30 - 36	35 - 40
Dense	60 - 80	30 - 50	300 - 500	38 - 41	36 - 41	40 - 45
Very Dense	> 80	> 50	500 - 800	41 - 44	> 41	> 45

More Typical Properties of Cohesionless Soils

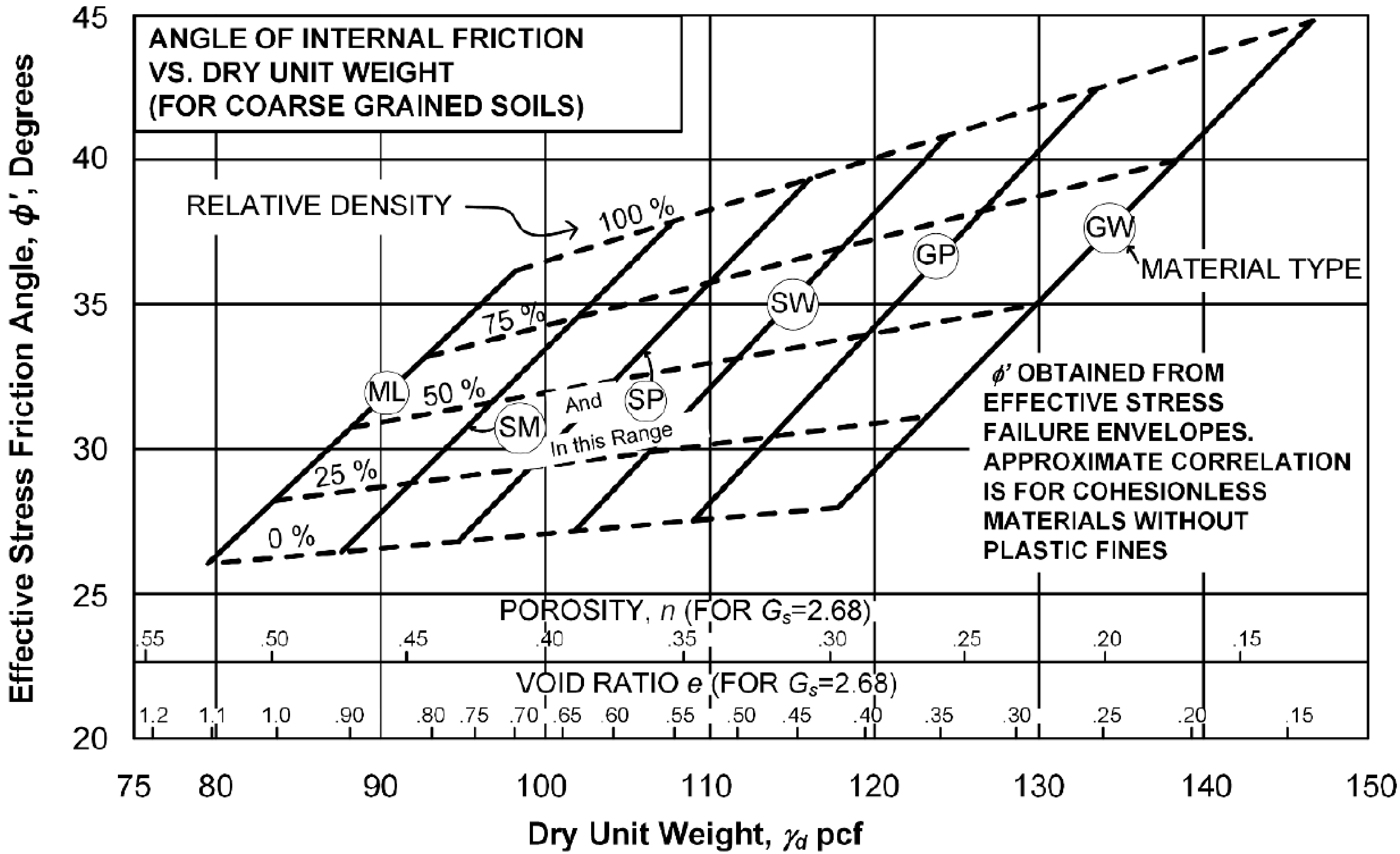


Figure 8-1 Approximate Relationship between the Effective Stress Friction Angle and Dry Unit Weight for Various Relative Densities and Types of Soil

Typical Properties of Cohesive Soils

Consistency	*Very Soft*	*Soft*	*Medium*	*Stiff*	*Very Stiff*	*Hard*
q_u = unconfined compression strength, tons per square ft	0–0.25	0.25–0.50	0.50–1.00	1.00–2.00	2.00–4.00	4.00
Standard penetration resistance, N = no. of blows per ft	0–2	2–4	4–8	8–16	16–32	32
Unit weight, pcf (saturated)	100-120	100-120	110-130	120-140	120-140	130+
Identification characteristics	Exudes from between fingers when squeezed in hand	Molded by light finger pressure	Molded by strong finger pressure	Indented by thumb	Indented by thumb nail	Difficult to indent by thumb nail

Very approximate; for preliminary purposes only

Remember that $c = q_u/2$

Cost of Site Investigation and Analysis vs. Foundation Cost

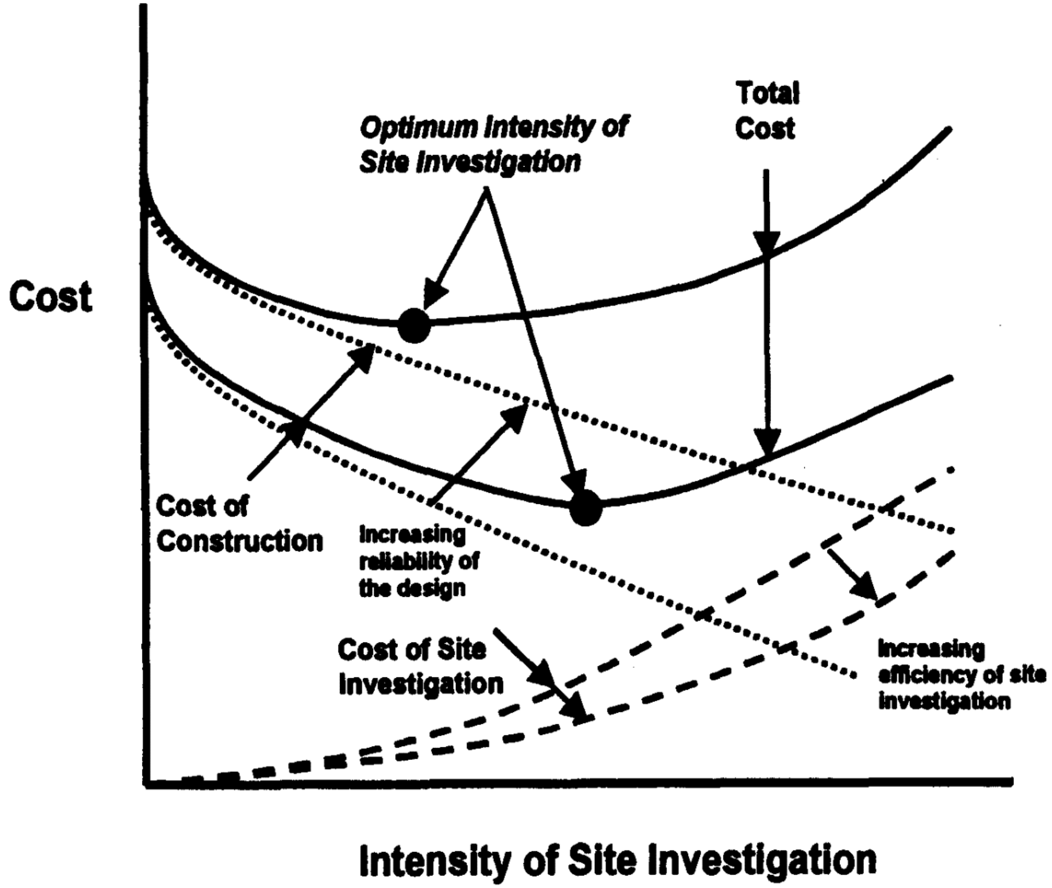
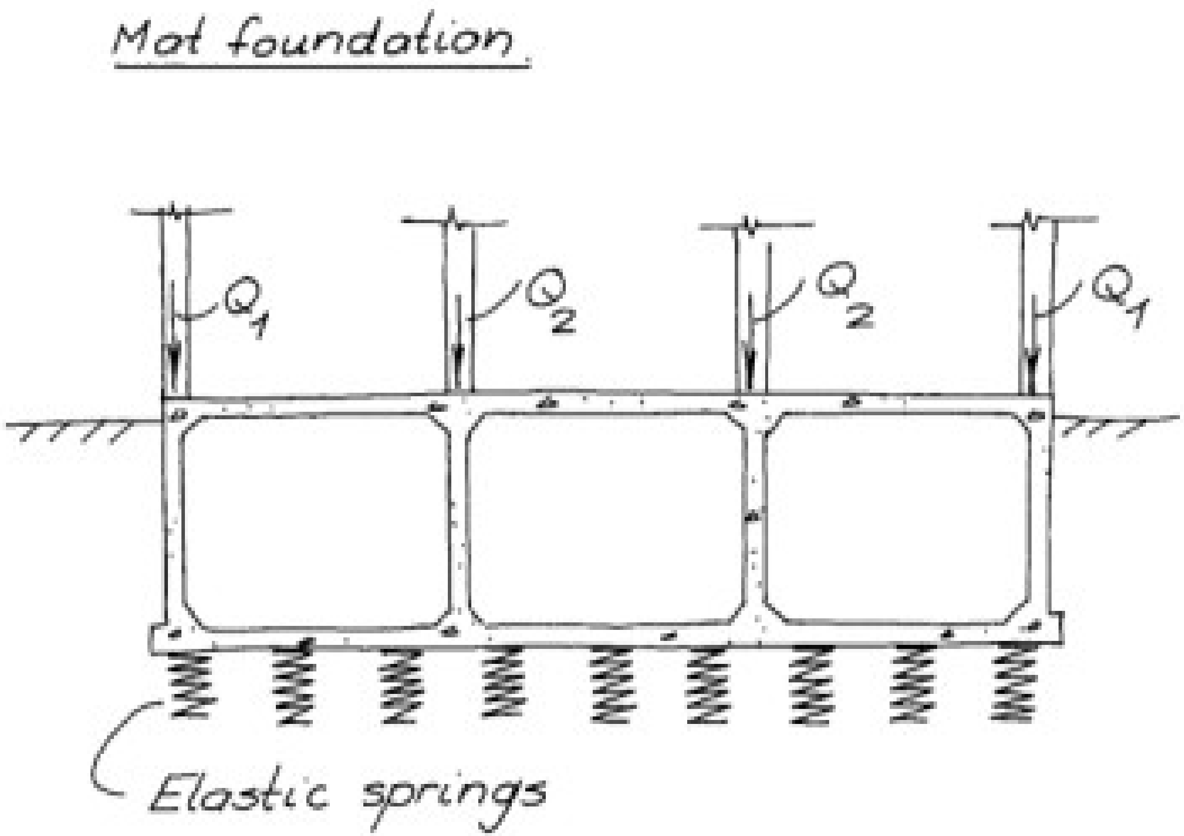


Figure 10.2. Total cost vs. intensity of exploration (after Kulhawy et al., 1983)

Types of Foundations

- ## Shallow Foundations
- Spread Footings
- Mat or Raft Foundations
- Suitable when soil has sufficient bearing capacity at or near grade, either naturally or by soil improvement
- ## Deep Foundations
- Driven Piles
- Drilled Shafts
- Caissons
- Required when shallow foundations will not carry the load
- ## Floating Foundations
- Used when displaced soil and groundwater weight is sufficiently large to « float » the foundation on the surface
- ## Lateral Earth Retaining Structures
- Gravity Walls
- Gabion Walls
- Sheet Piling Walls
- Reinforced Earth Walls
- Slopes (supported and unsupported)
- Used for necessary elevation changes of structure(s)

Mat Foundations: Elasticity of Soil and Foundation

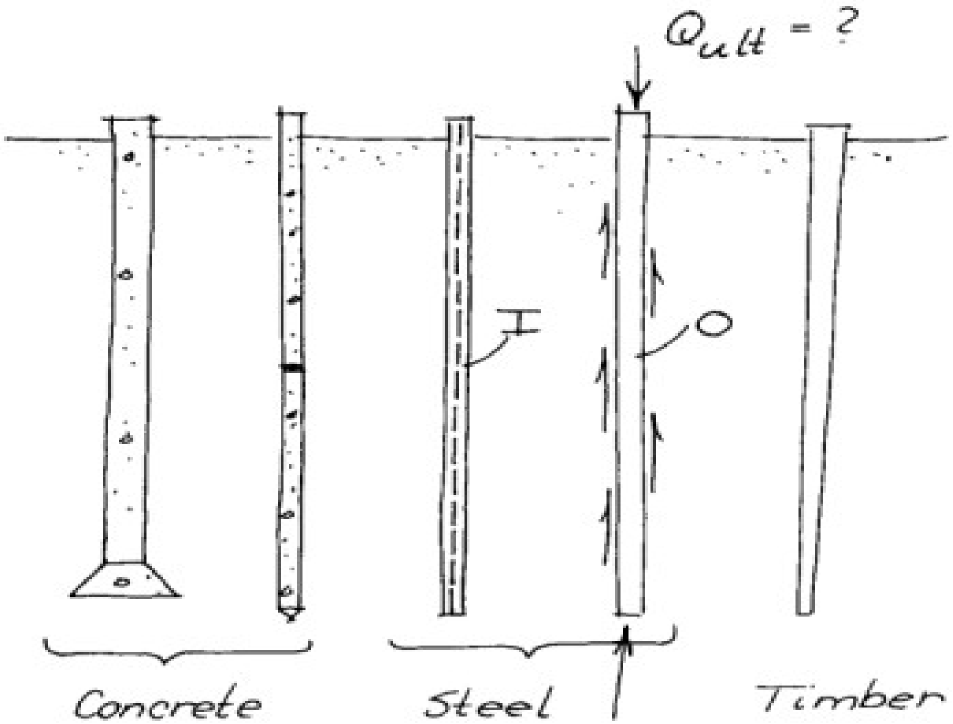


Deep Foundations

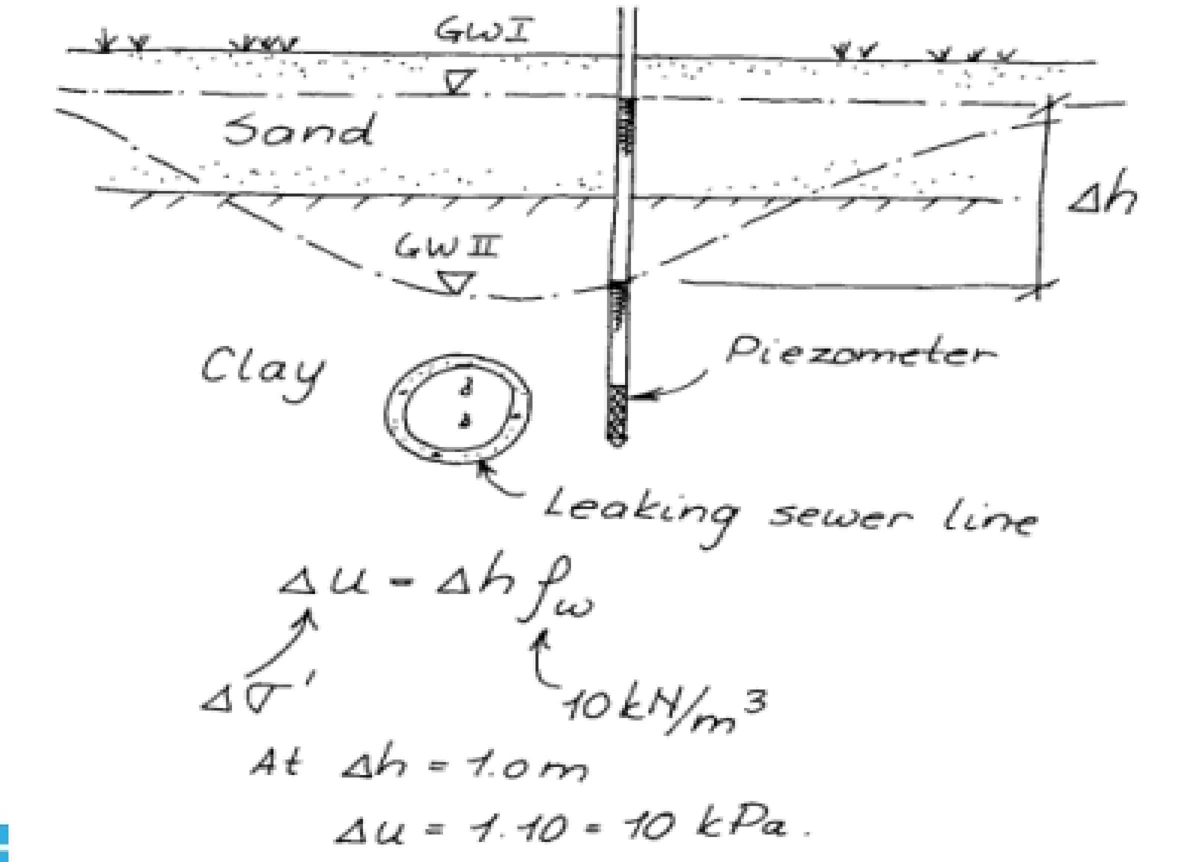
- Driven Piles

- Drilled Shafts

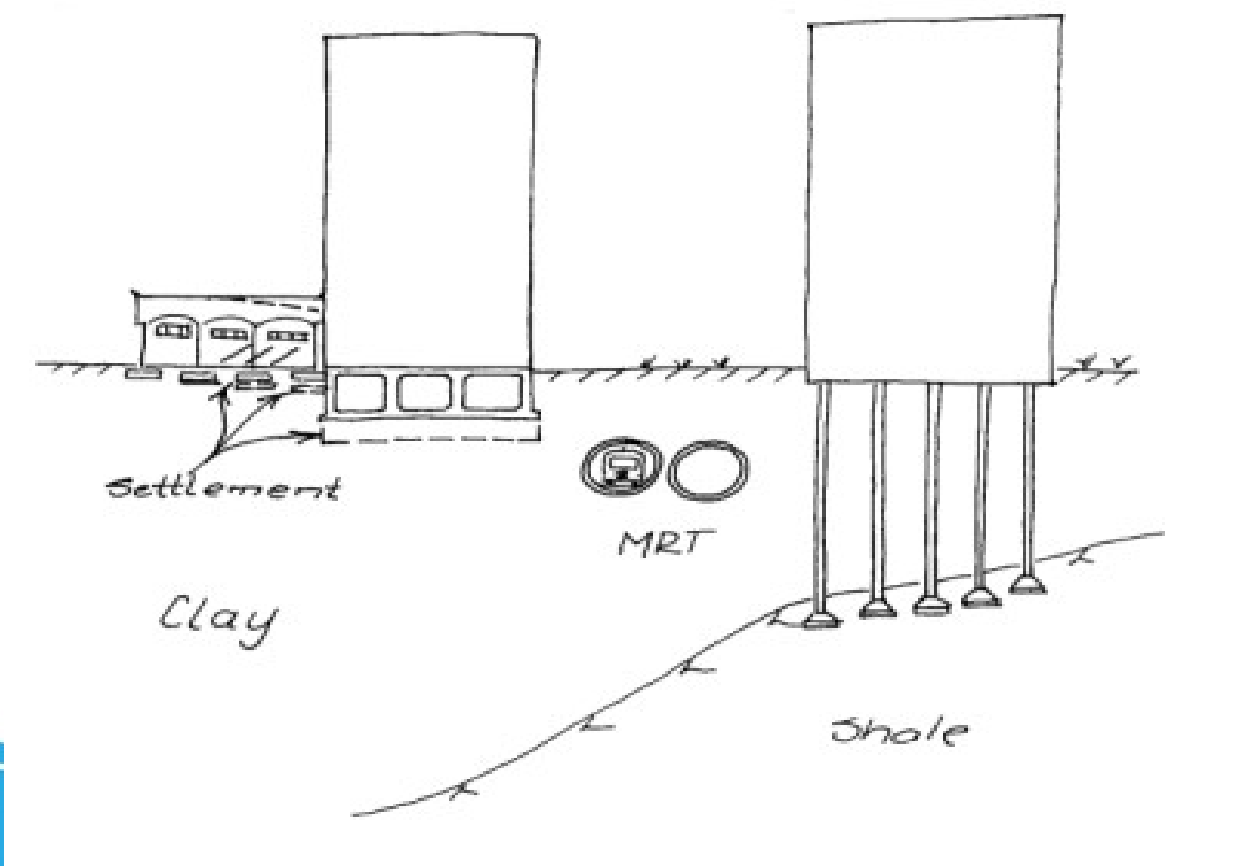
- Load Transfer



Groundwater Effects



Consideration of Neighboring Underground Structures



Definition of Failure

- "...an unacceptable difference between expected and observed performance." (G.A. Leonards)
- Foundations are not typically perfectly rigid or unyielding
- They can fail in one of two ways:
  - Catastrophically (bearing or shear failure);
  - Excessive settlement (consolidation, differential settlement, etc.)
- Failure is also dependent on other factors not directly related to the foundation and soil interaction (type of structure, etc.)

Shallow Foundations: Failure by Shear or Excessive Settlement?

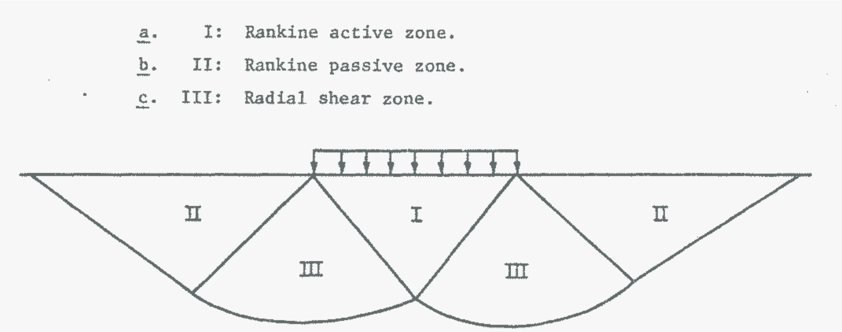
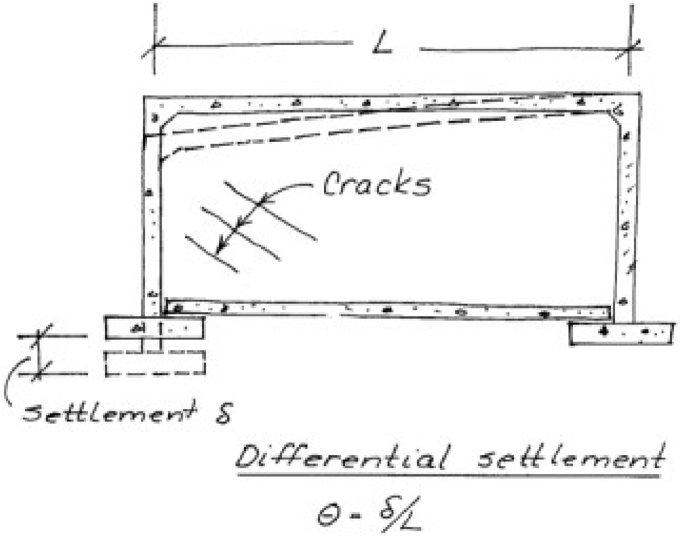
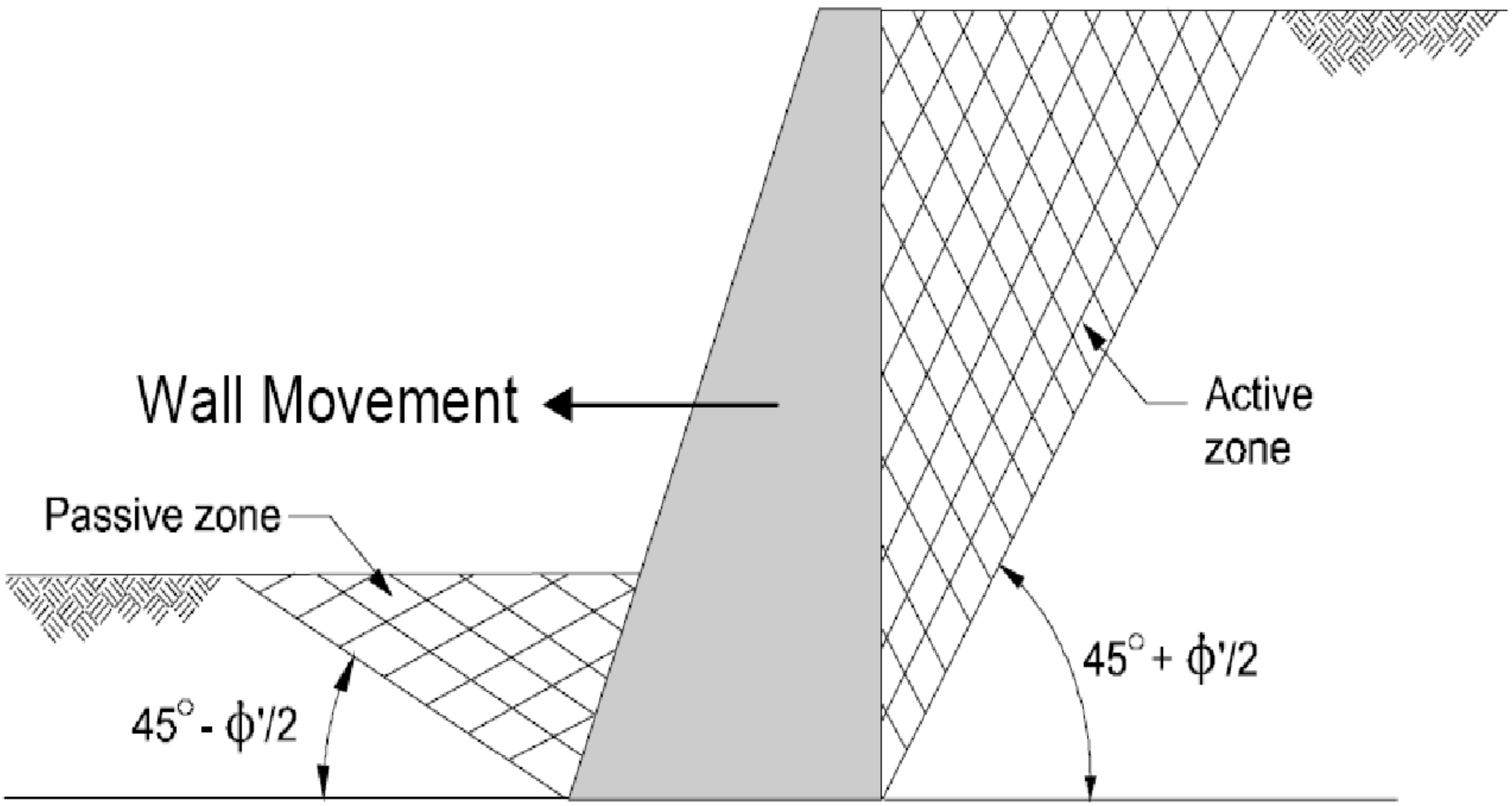


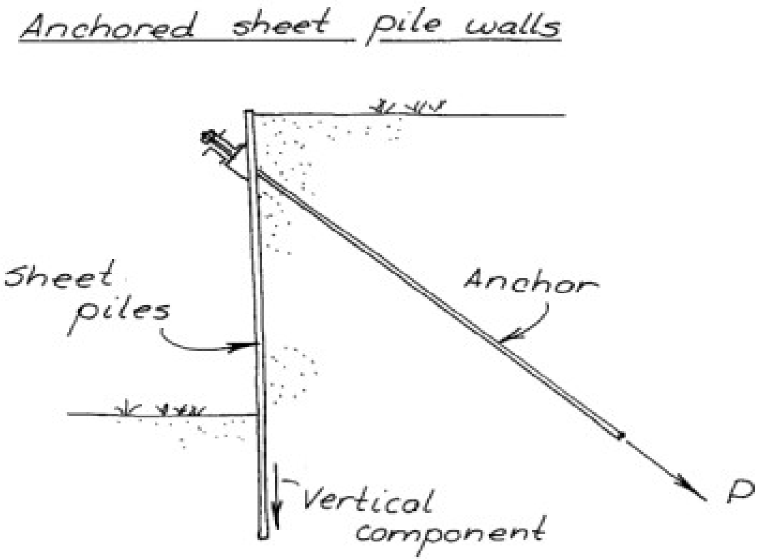
Figure 2. Shear zone at failure of an earth supported strip footing



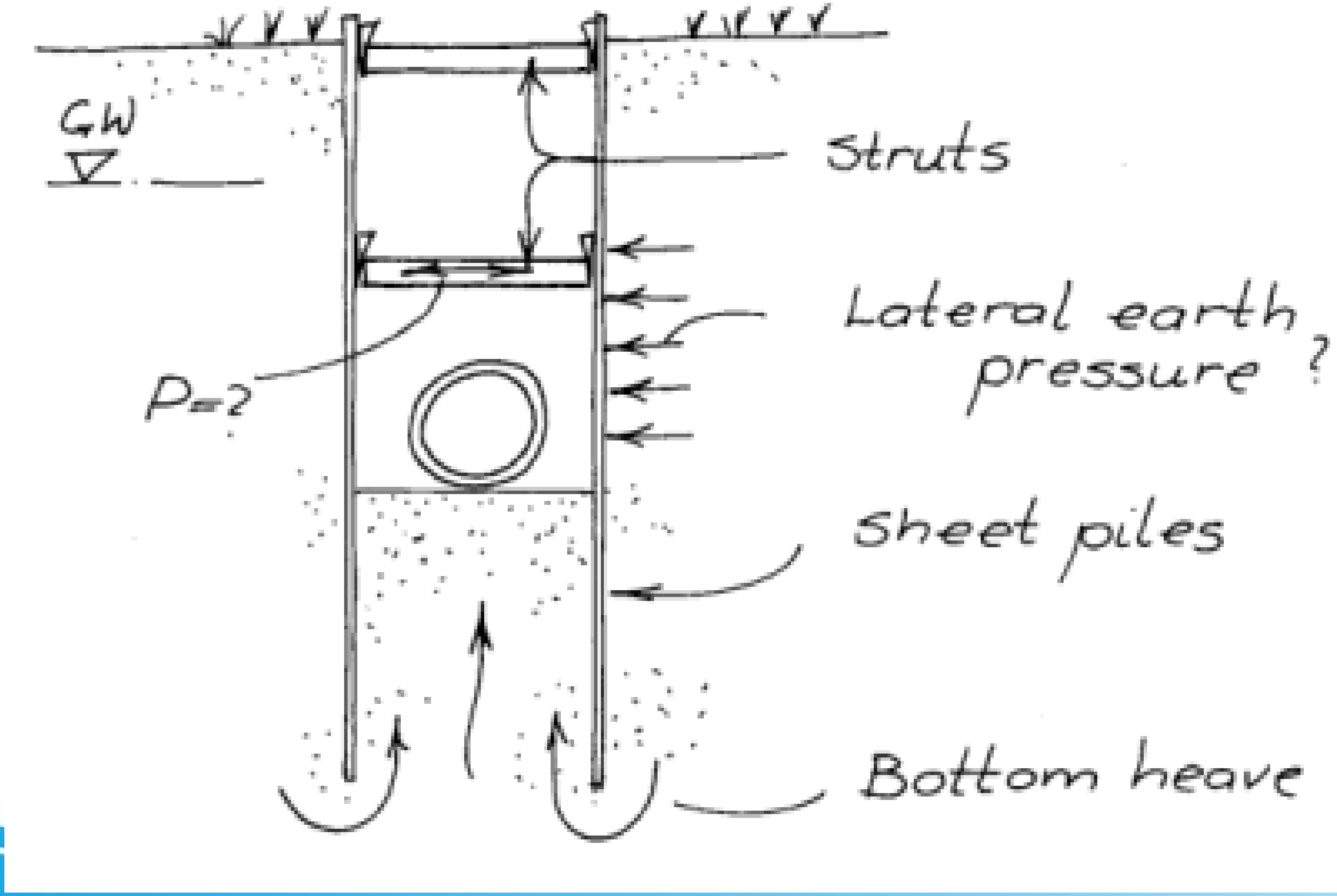
Retaining Walls



Anchored Sheet Piling Wall

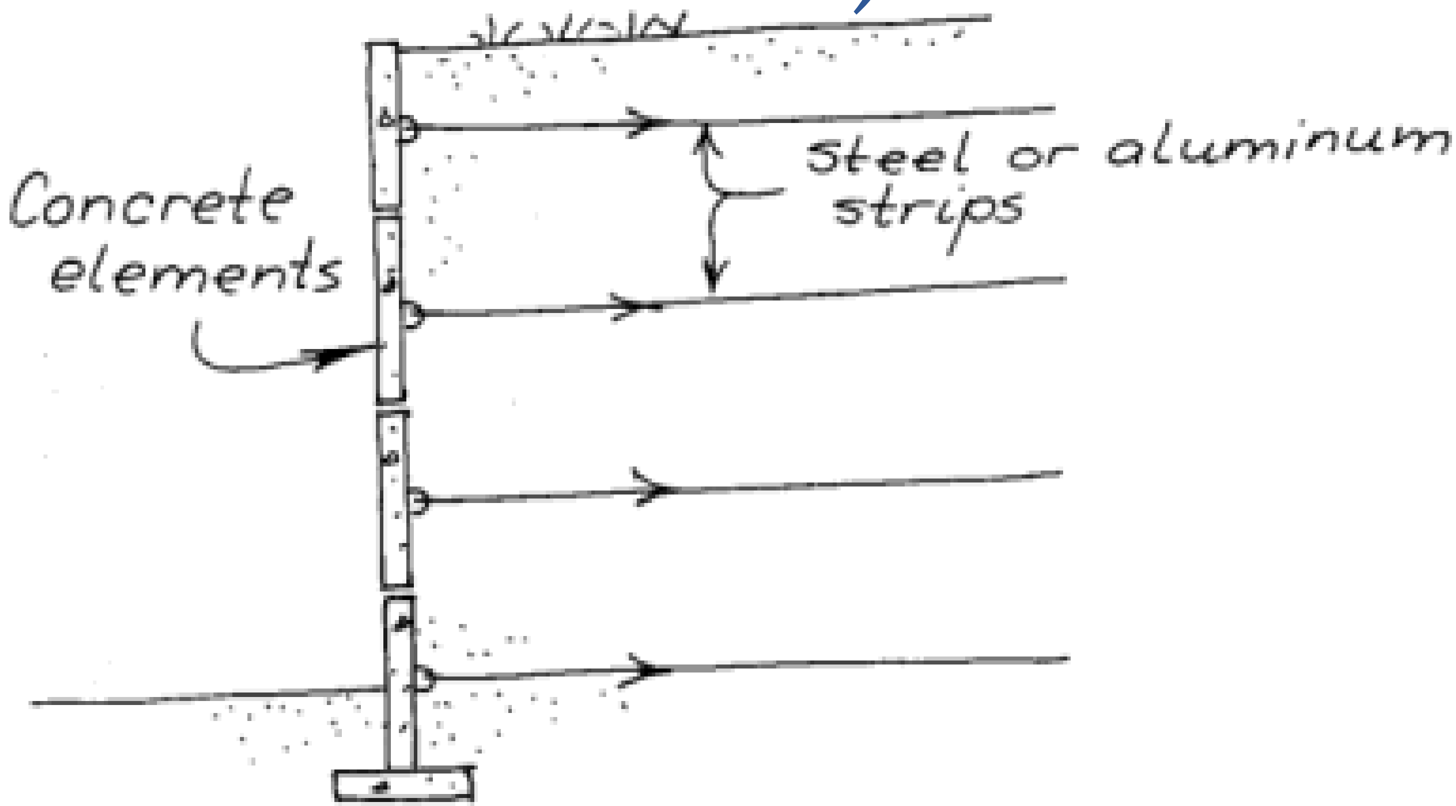


Braced Cuts

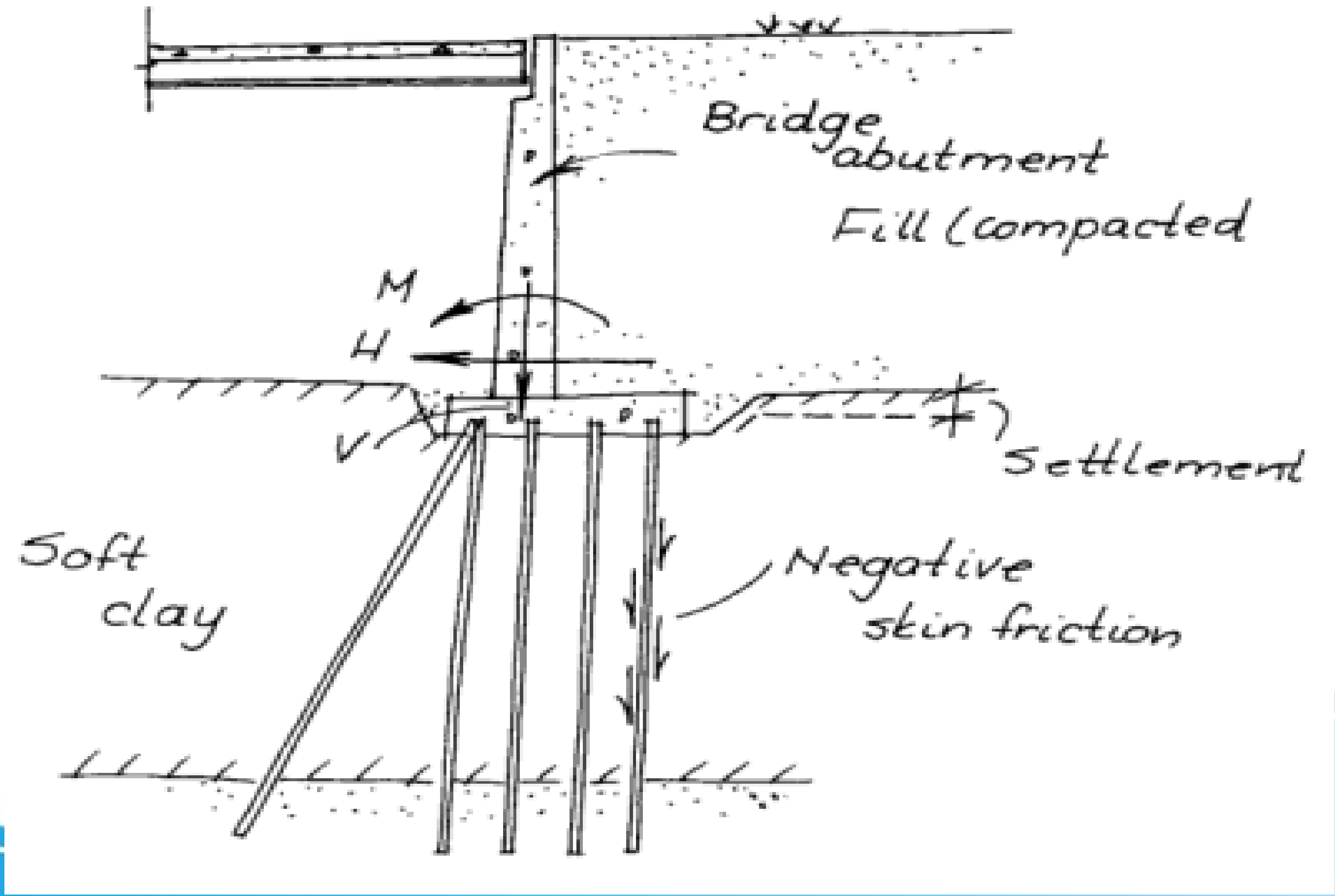


GW
Struts
Lateral earth pressure ?
P=?
Sheet piles
Bottom heave

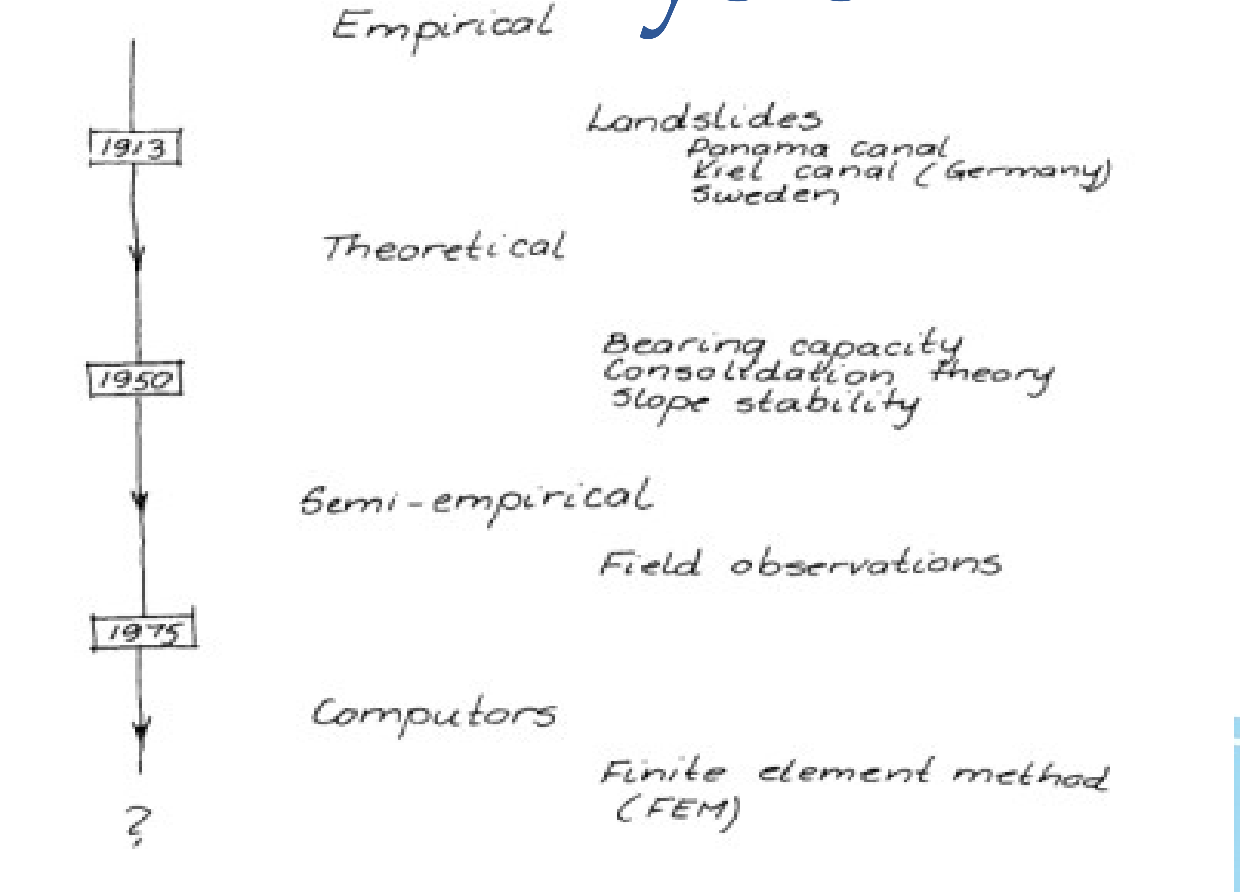
Other Methods of Reinforcement (MSE Wall)



Combination of Foundation Types



Methods of Foundation Analysis



Method of Expression of Design Load

- **Allowable Stress Design (ASD)**
  - Deals with uncertainty by applying a global "factor of safety" to reduce the design resistance of the foundation
  - Design load is the most critical combination of the various load sources, as defined by the applicable code
  - The traditional method of geotechnical design
  - Load combinations computed with ASD are referred to as *unfactored loads*
- **Load and Resistance Factor Design (LRFD)**
  - Applies separate load and resistance factors
    - Load factor usually > 1
    - Resistance Factor usually < 1
  - For loads, the result is referred to as a *factored load*
  - Factored load is then compared to a resistance factored by its own resistance factor
  - Becoming more important in foundation design

ASD Factors of Safety

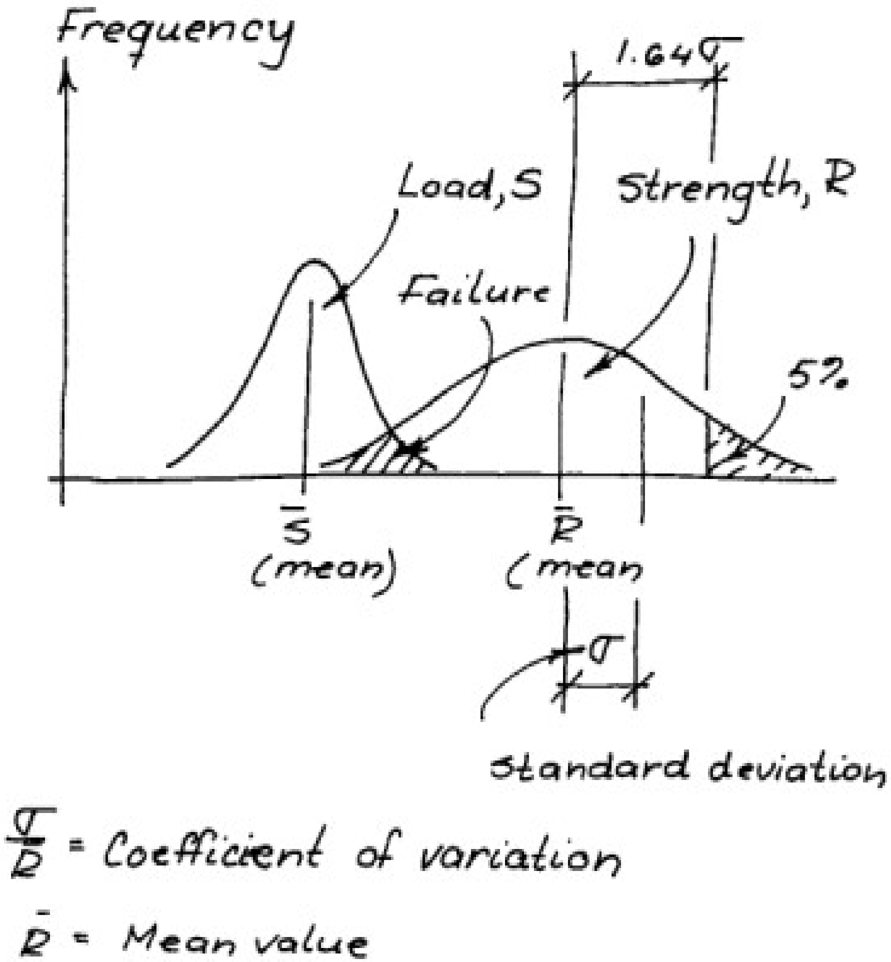
Factor of safety, F

$$F = \frac{\Sigma \text{ Forces preventing failure}}{\Sigma \text{ Forces initiating failure}}$$

$$F = \frac{\Sigma \text{ Moments preventing failure}}{\Sigma \text{ Moments initiating failure}}$$

Type	F
Dams, fills	1.2 – 1.6
Retaining walls	1.5 - 2.0
Sheet pile walls and coffer dams	1.2 – 1.6
Braced excavations	1.2 - 1.5
Footings	2 - 3
Mats, rafts	1.7 - 2.5
Uplift, heave	1.5 - 2.5
Piping	3 - 5

Load and Resistance Factor Design (LRFD)



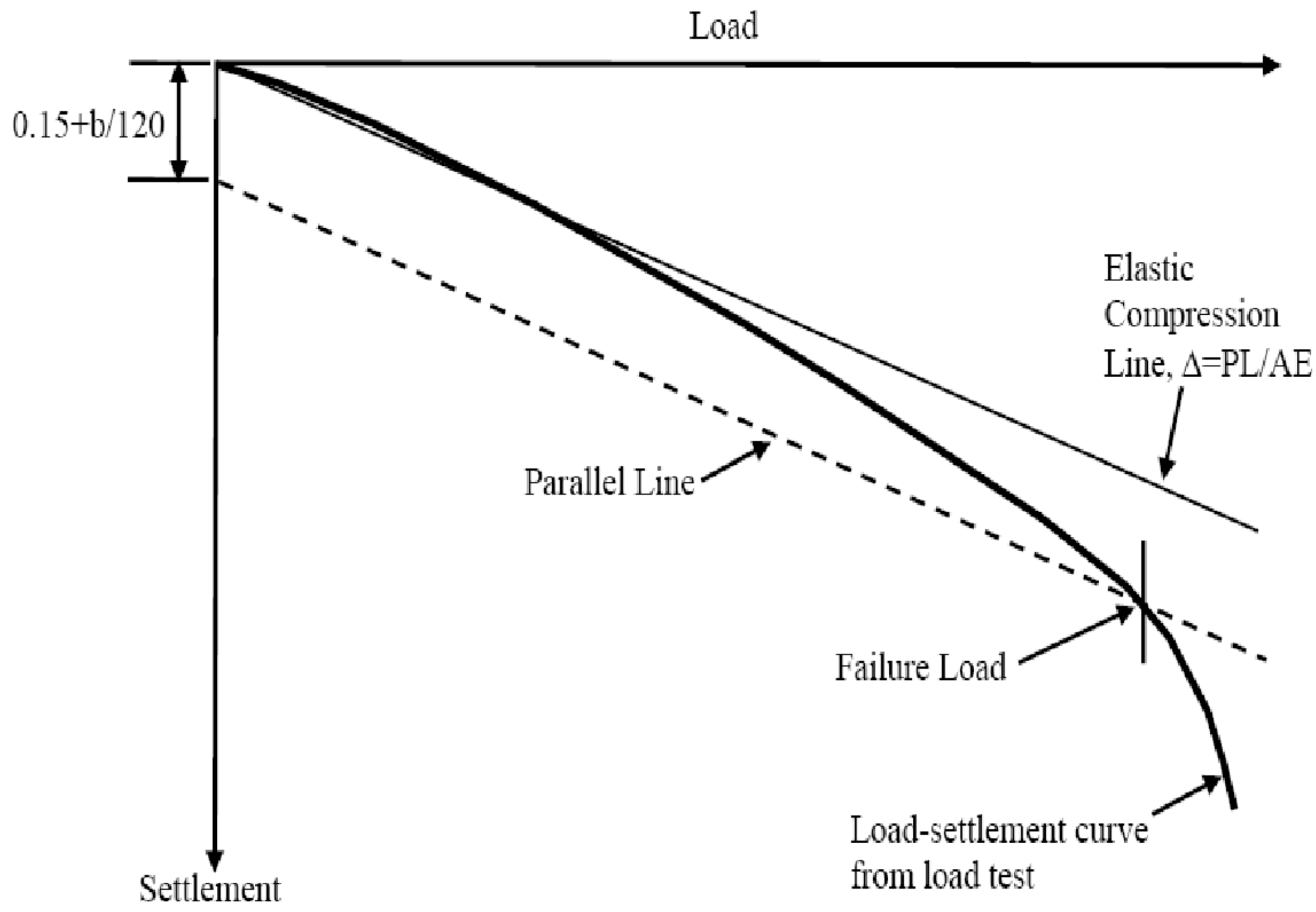
$$\varphi P_n \geq \sum_{i=1}^{m} \gamma_m P_m$$

- φ = resistance factor
- P_n = nominal normal load capacity
- γ_m = load factor for load "type" m
- P_m = load for load "type" m
- m = load "type": dead (D), live (L), etc.

Dead loads
Live loads
Wind loads
Earth quake loads

Load factors

Performance Requirements for Foundations



Notes on Design Codes

- Codes chosen in this course are primarily for example purposes
- The applicability of any given code will vary from project to project, so make sure you are referring to the correct code when designing
- Adherence to a building or design code is NOT a guarantee that your design is correct, safe, or constructible.
- ***Adherence to a code is NEVER a substitute for proper engineering judgment***

The Problem of Constructibility

« The successful transfer of design objectives into construction is accomplished by consideration of construction operations during the design phase. In recent years the amount of coordination between design and construction has steadily decreased; primarily due to graduate engineers who specialize in design and who are never exposed to construction operations. In past years, engineers either began their careers in construction and advanced into design, or were assigned the design and construction responsibilities for projects. **Present lack of coordination stemming from inexperience with field operations can result in a technically superior set of construction plans and specifications which cannot be built.** Rational construction control is vital to assure a safe, cost-effective foundation and to avoid unnecessary court of claims actions.»

(Chaney & Chassie, *Soils and Foundations Workshop Manual* FHWA HI-88-009)

Questions