Stability Problems in Geotechnical Engineering

Lectured
by
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Text books:

J.H. Atkinson, "Foundations and slopes", McGRAW-HILL Company (UK) Limited.(1981) (Mainly Chapter 4, 5 and 6)

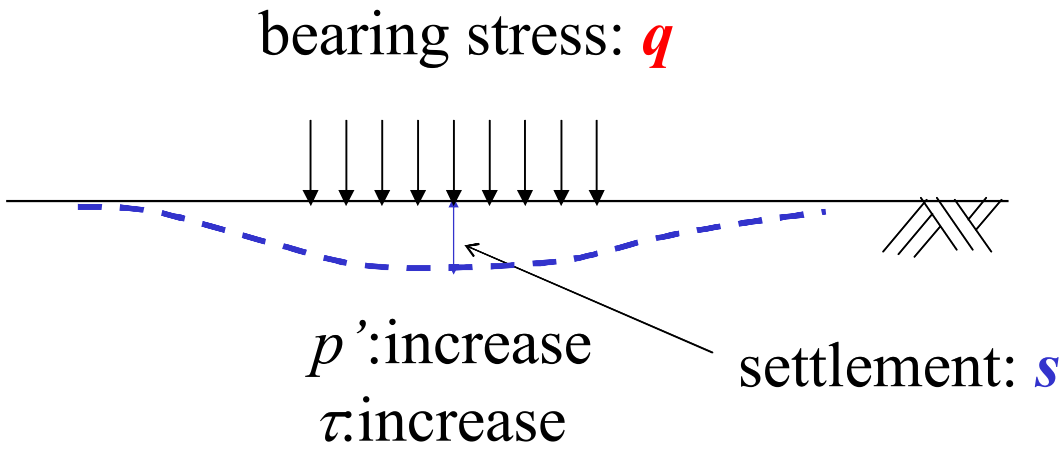
Evaluation: Attendance, Assignments, Examination (Mid & Final)

1. Introduction

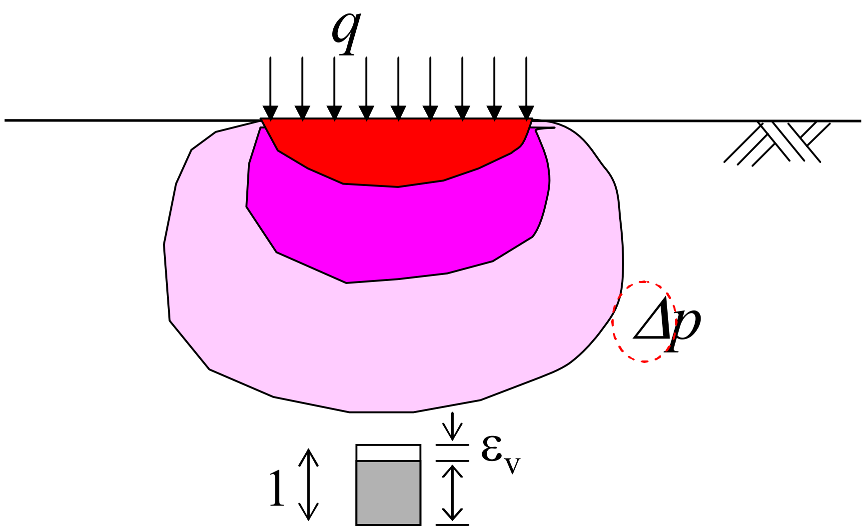
1.1 Design of foundation

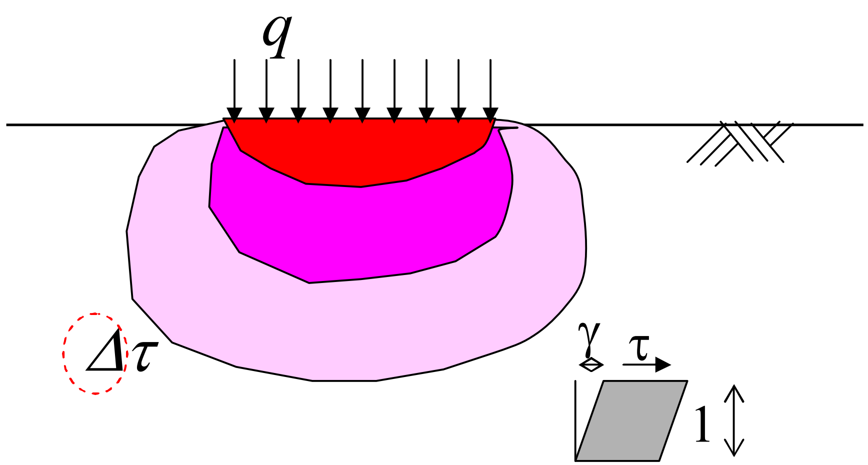
ex) Shallow Foundation:

Loads from the superstructure are transferred to the subsoil and yield increases of both mean effective stresses (p') and shear stresses (τ') beneath the foundation. The increases of p' and τ' cause volumetric strain and shear strain respectively, which both lead settlement of foundation.



Increase of mean effective stress and shear stress under loading area





$$\varepsilon_v = m_v \Delta p'$$

$$\gamma = \frac{1}{G}\Delta\tau$$

increase of *p'*
↓
volume compression

increase of *τ'*
↓
shear strain

→ **settlement** ←

load – settlement curve

<u>point A</u>: Yield (降伏) first begins.

$\tau = \tau_f$

<u>point B</u>: *q*-*s* curve steepens, where yield zone still confined in elastic zone.

(local shear failure:局所せん断)

<u>point C</u>: The yield zone extends beyond the loading area, at this point settlement increases rapidly and it is not possible to increase *q* without very large settlement.

(general shear failure:全般せん断, ultimate bearing capacity: q_u)

bearing capacity: q_b

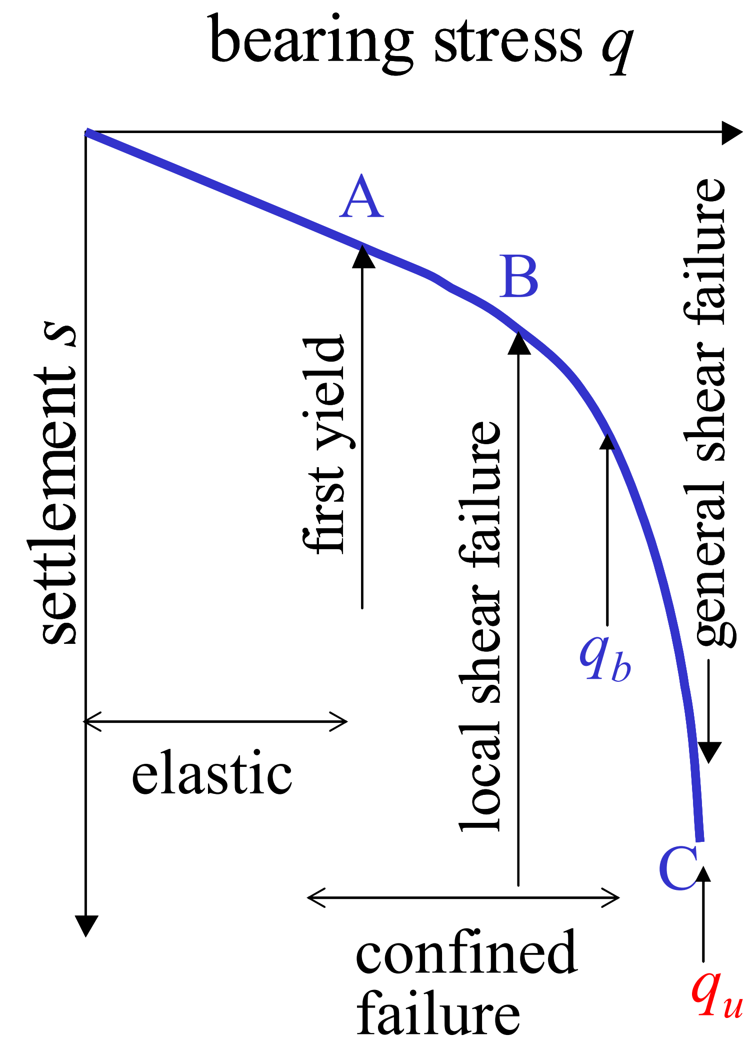


Fig. 1.1

Expanding yield zone in ground

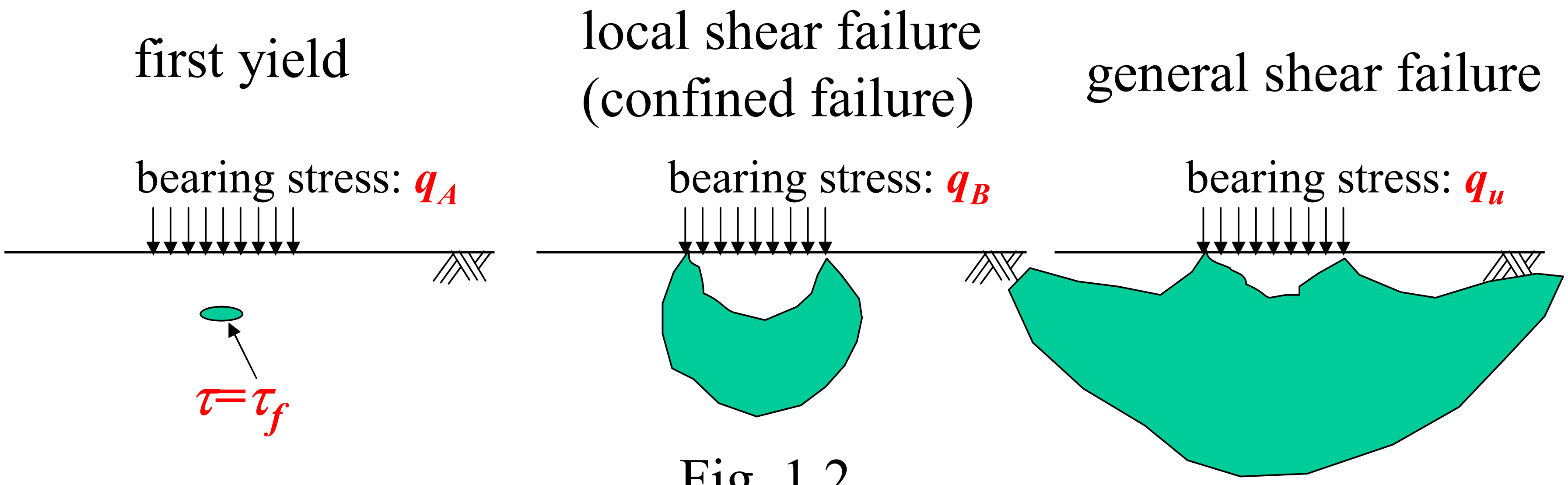


Fig. 1.2

bearing capacity (q_b): bearing stress at which settlements begin to become very large and very difficult to be predicted, because of strong non-linear behavior.

$$q_b <= q_u$$

1.2 Design criteria

Basic criterion governing the design of foundations supporting the superstructure is that settlement or deformation must not exceed some permissible value(許容値). The permissible value depends on type of structure.

In order to ensure the criterion is met,

1. Foundation should be safe enough against the design load, in other words, the design bearing stress is less than the bearing capacity, with an appropriate margin of safety to cover the **uncertainties** in the estimate of both the bearing stress (design load) and the bearing capacity .
2. The settlement or displacement caused by the design load should be tolerable in the operation of the superstructure, i.e., expected settlement is less than the permissible value.

from where??

1.3 Three key steps in foundation design

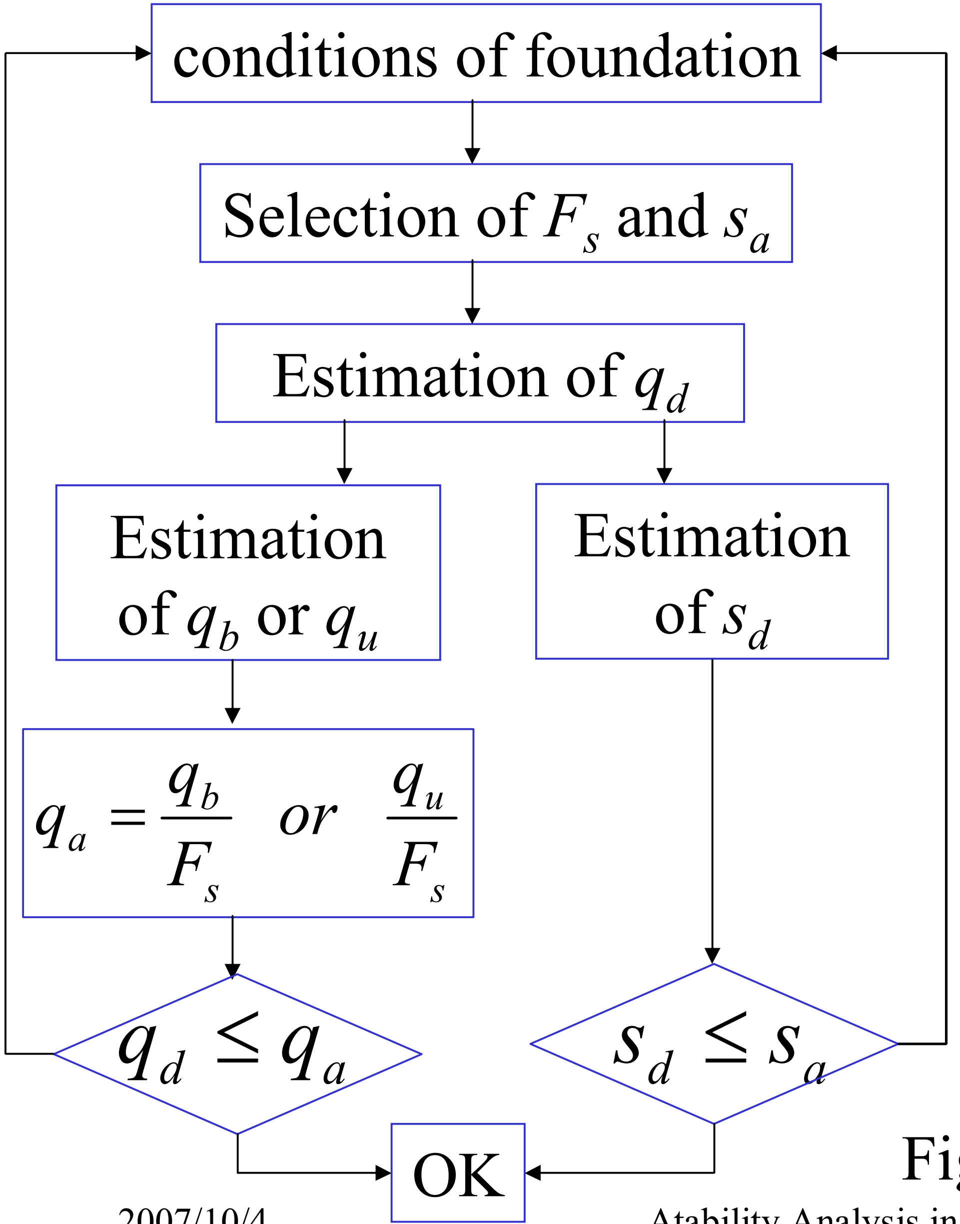
1. Selection of the required factor of safety (F_s) against a shear failure and the permissible settlement (s_a) .

   (allowable stress design) ⬄ *(limit state design)*
   許容応力度法 限界状態設計法

2. Determination of the bearing capacity and the actual factor of safety under the expected load.
   stability analysis based on plasticity theory

3. Estimation of the settlement (s_d) and comparison with the permissible settlement.
   settlement analysis (elastic model, elasto-plastic model, consolidation theory)

Key steps of foundation design



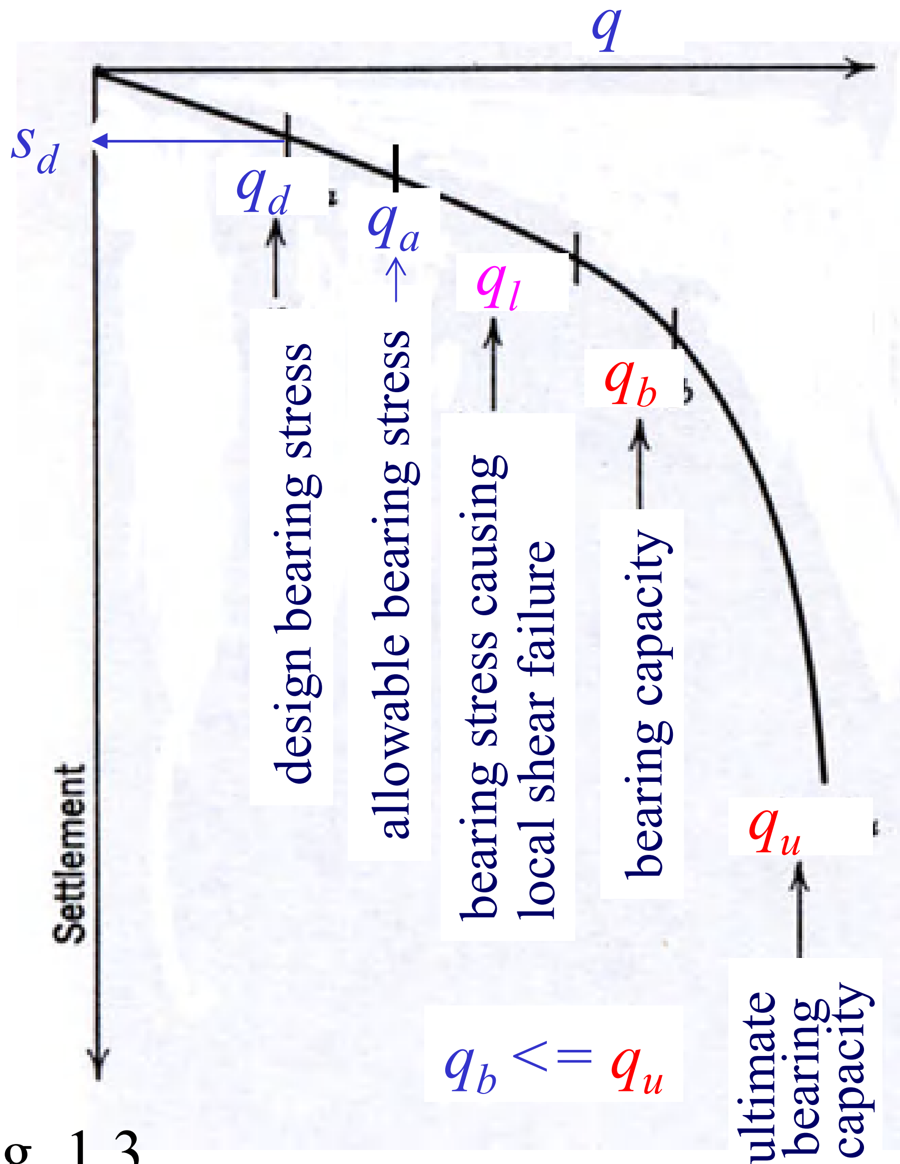


Fig. 1.3

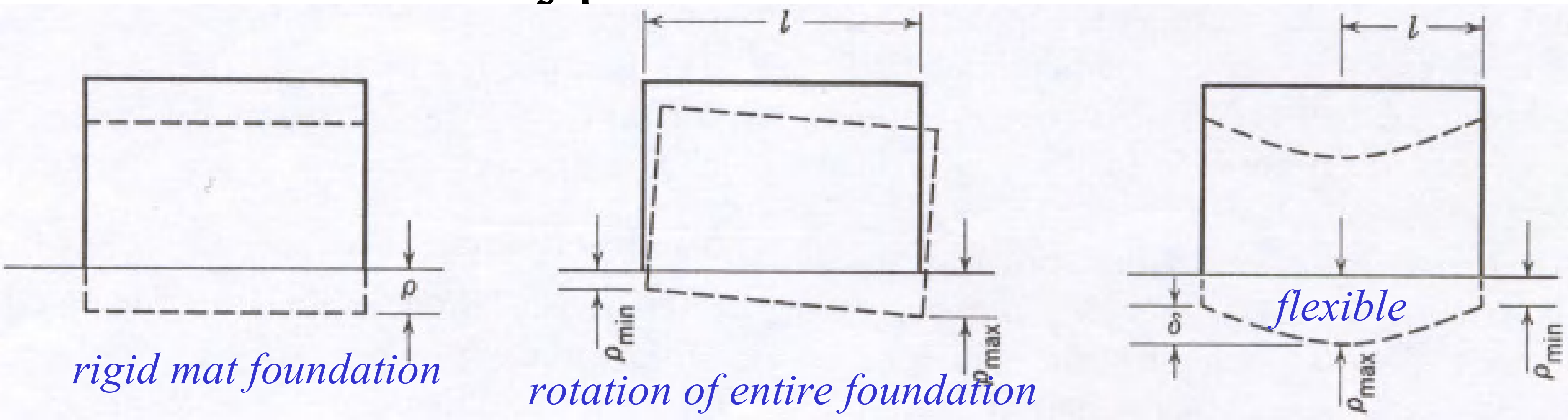
1.4 Allowable settlement s_a

Settlement is important, even though no rupture is imminent in the foundation for mainly three reasons:

- appearance of structure:
  cracks in exterior and interior walls;
  tilting enough to be detected by human eye.
- utility or function of structure:
  cranes and the other such equipment may not operate correctly;
  pumps, compressors, etc, may be out of line;
  tracking units such as radar become inaccurate.
- damage to the structure:
  settlement can cause a structure to fail structurally and collapse even though the factor of safety against the shear failure in the foundation is high.

Allowable settlement (s_a) is determined considering these reasons.

Types of settlement



(a) Uniform settlement （等沈下） (b) Tilt （傾斜） (c) Non-uniform settlement （不等沈下）

Fig. 1.4 Lambe & Whitman, "Soil Mechanics SI Version", John Wiley & Sons. (1979)

Maximum settlement: ρ_{max}

Differential settlement: $\Delta\rho_{max}=\rho_{max}-\rho_{min}$,

Angular distortion= $\dfrac{\Delta\rho}{l}=\dfrac{\delta}{l}$

The most common situation caused by
-uniform stress acting upon a homogeneous soil;
-non-uniform bearing stress;
-non-homogenous subsoil conditions

The ρ_a depends on many factors:

type, size, location, and intended use of the structure;

pattern, rate, cause and source of settlement.

examples

Table 1.1 Allowable settlement from Sowers (1962)

Type of Movement	Limiting Factor	Maximum Settlement
Total settlement	Drainage	150-300mm
	Access	300-600mm
	Probability of nonuniform settlement:	
	Masonry walled structure	25-50mm
	Framed structures	50-100mm
	Smokestacks, silos, mats	75-300mm
Titling	Stability against overturning	Depending on height and width
	Tilting of smokestacks, towers	0.004*l*
	Rolling of trucks, etc.	0.01*l*
	Stacking of goods	0.01*l*
	Machine operation-cotton loom	0.003*l*
	Machine operation-turbogenerator	0.0002*l*
	Crane rails	0.003*l*
	Drainage of floors	0.01-0.02*l*

Table 1.1 Allowable settlement from Sowers (1962) cont'd

Lambe & Whitman, "Soil Mechanics SI Version", John Wiley & Sons. (1979)

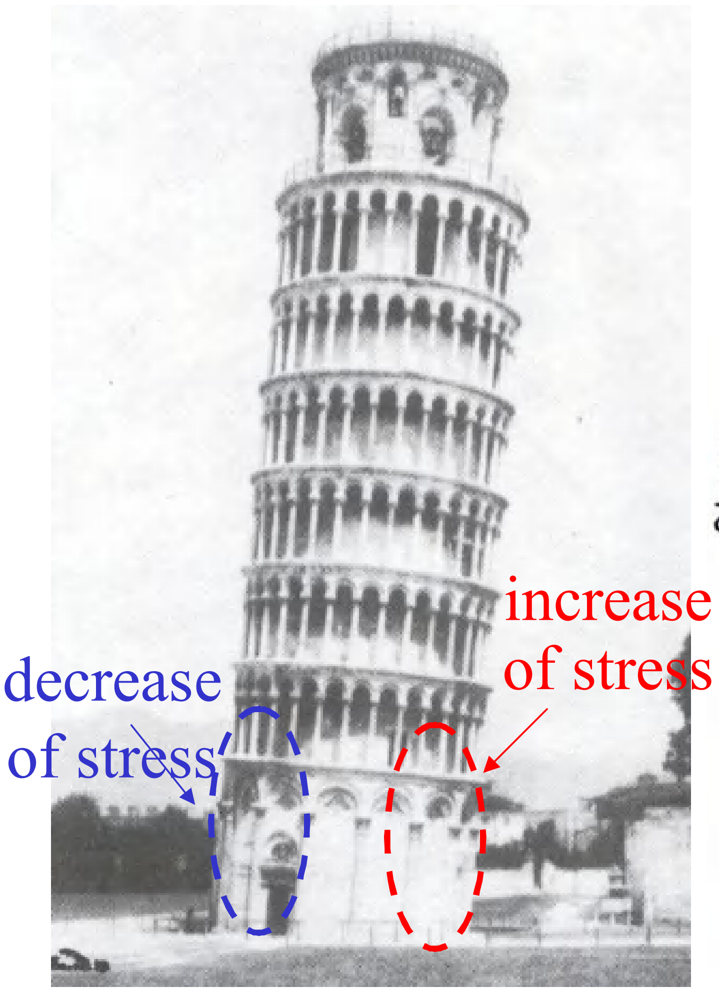
Type of Movement	Limiting Factor	Maximum Settlement
Differential movement	High continuous brick walls	0.0005-0.001*l*
	One-story brick mill building, wall cracking	0.001-0.002*l*
	Plaster cracking (gypsum)	0.001*l*
	Reinforced-concrete building frame	0.0025-0.004*l*
	Reinforced-concrete building curtain wall	0.003*l*
	Steel frame, continuous	0.002*l*
	Simple steel frame	0.005*l*

note. *l*= distance between adjacent columns that settle different amounts, or between any two points that settle differently. Higher values are for regular settlements and more tolerant structures. Lower values are for irregular settlements and critical structures.

Tilt

Tiling increase the possibility not only ***overturning of tower*** but also ***overstressing of the structural member***

north ⇔ south



Leaning Tower of Pisa

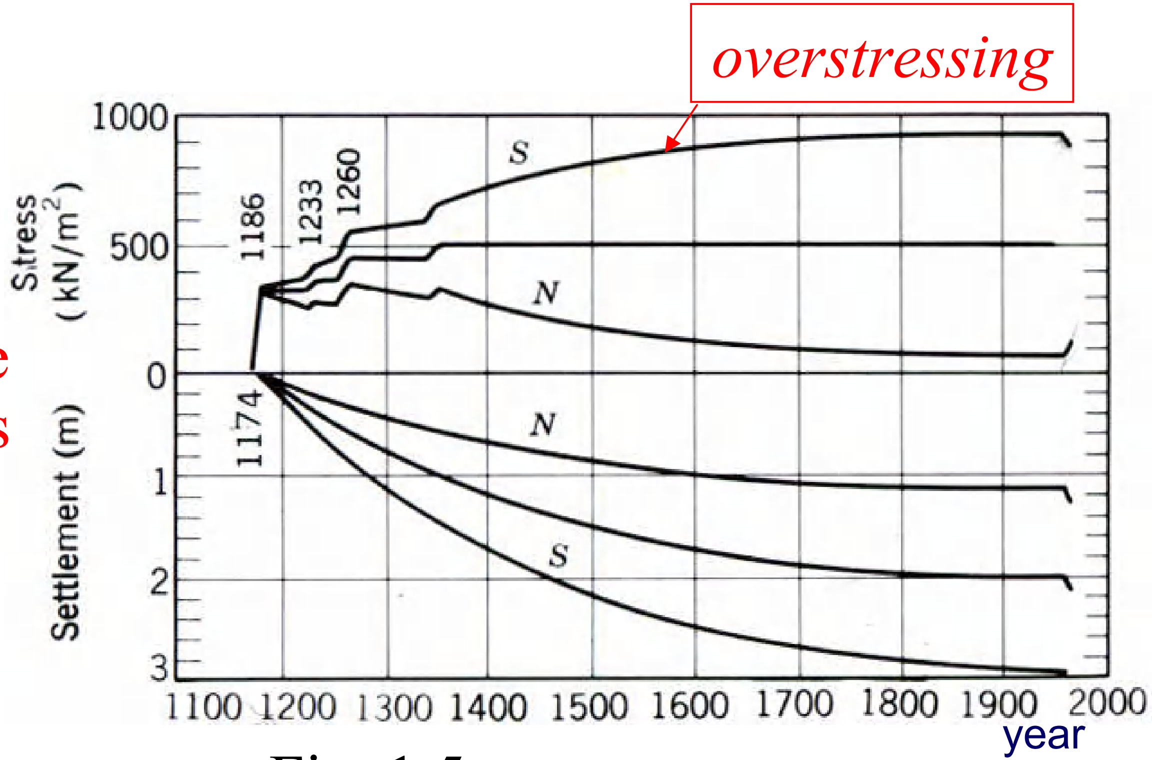
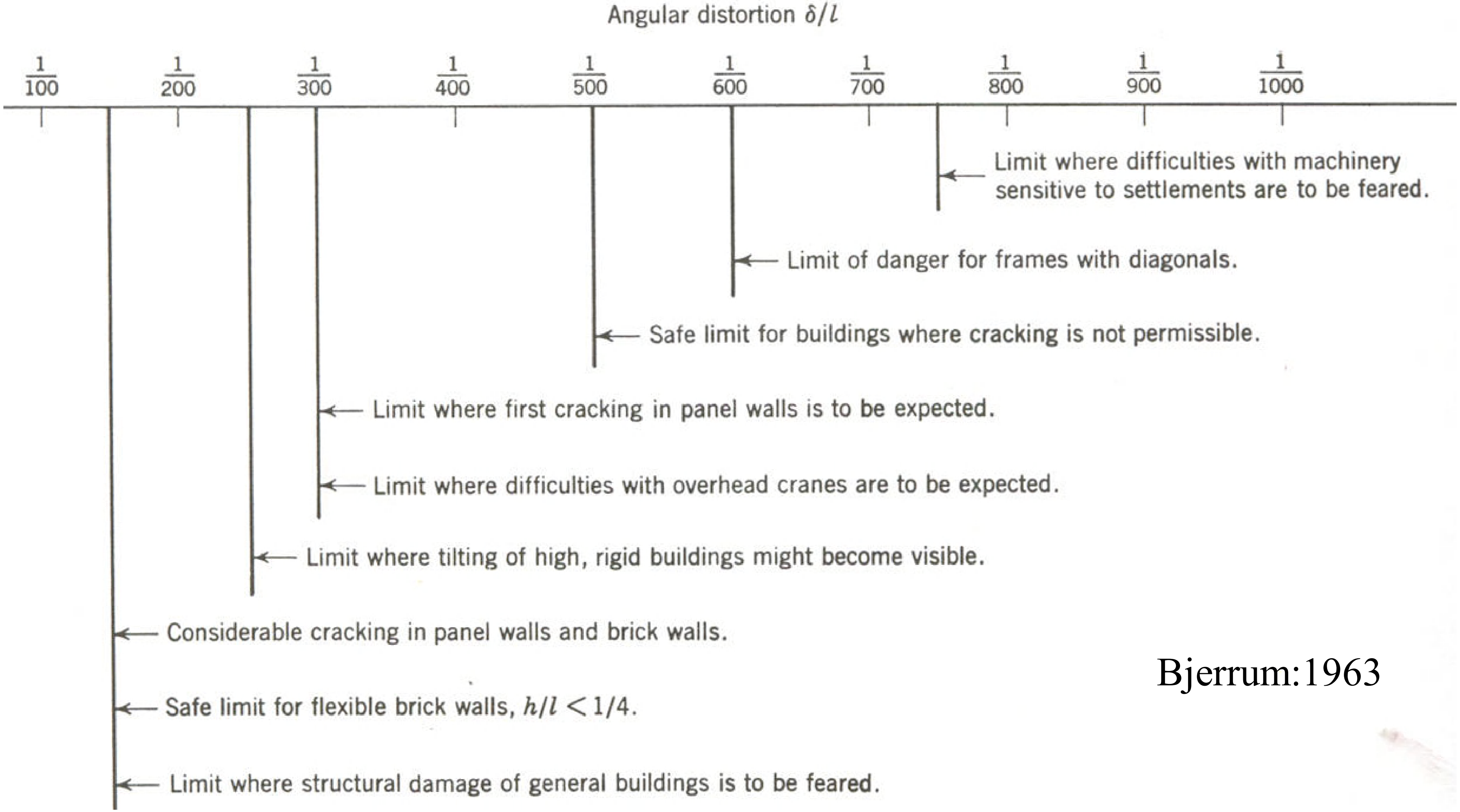


Fig. 1.5 Lambe & Whitman, "Soil Mechanics SI Version", John Wiley & Sons. (1979)

Limiting angular distortion



Bjerrum:1963

Fig. 1.6 Lambe & Whitman, "Soil Mechanics SI Version", John Wiley & Sons. (1979)

Relationship between maximum and differential settlement

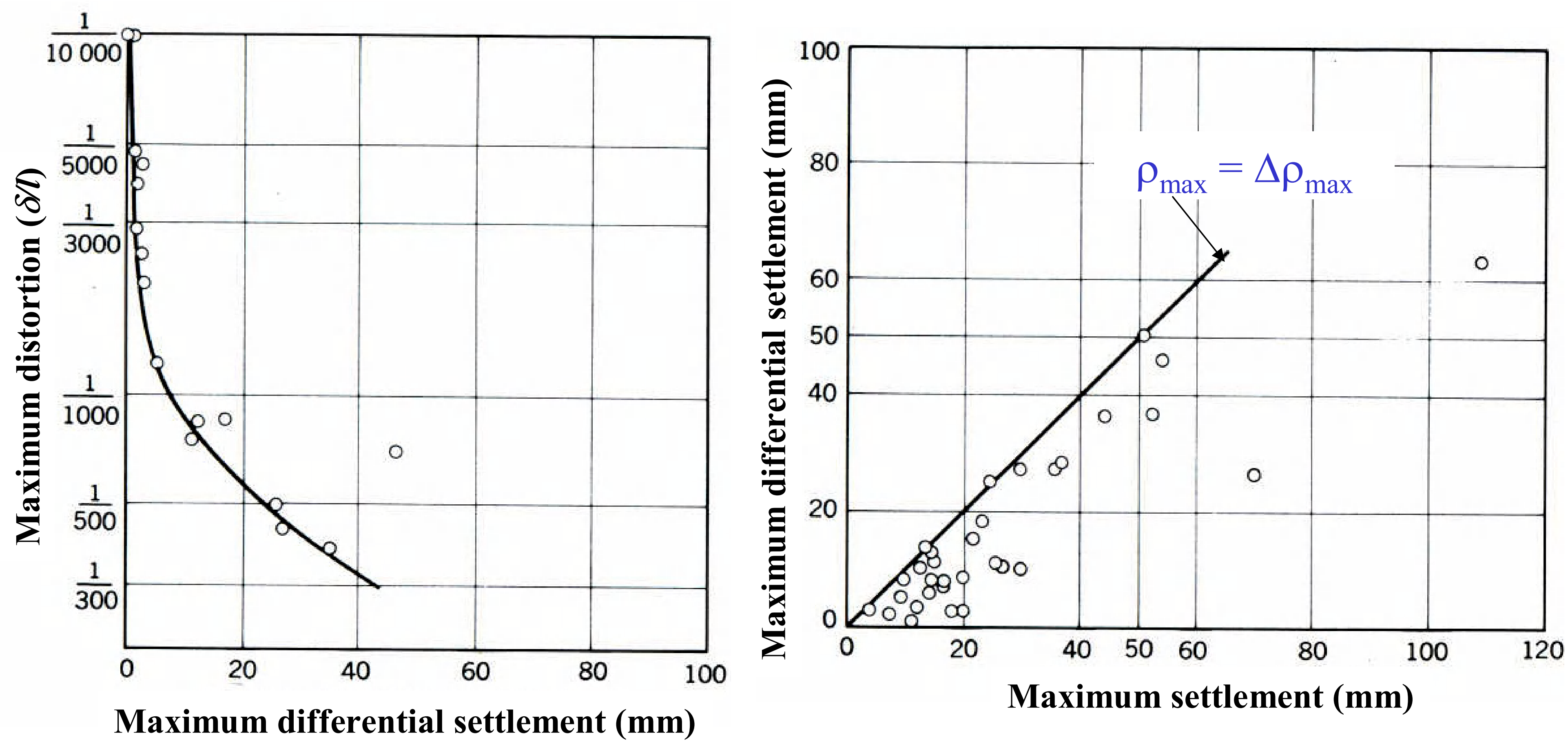
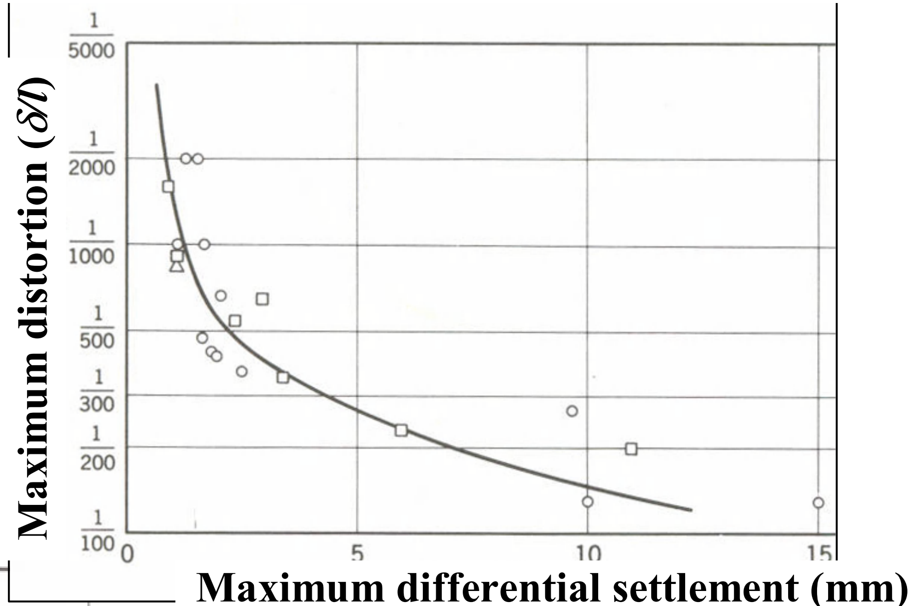


Fig. 1.7 Settlement of structures on **sand** (Bjerrum, 1963)

Lambe & Whitman, "Soil Mechanics SI Version", John Wiley & Sons. (1979)

Relationship between maximum and differential settlement



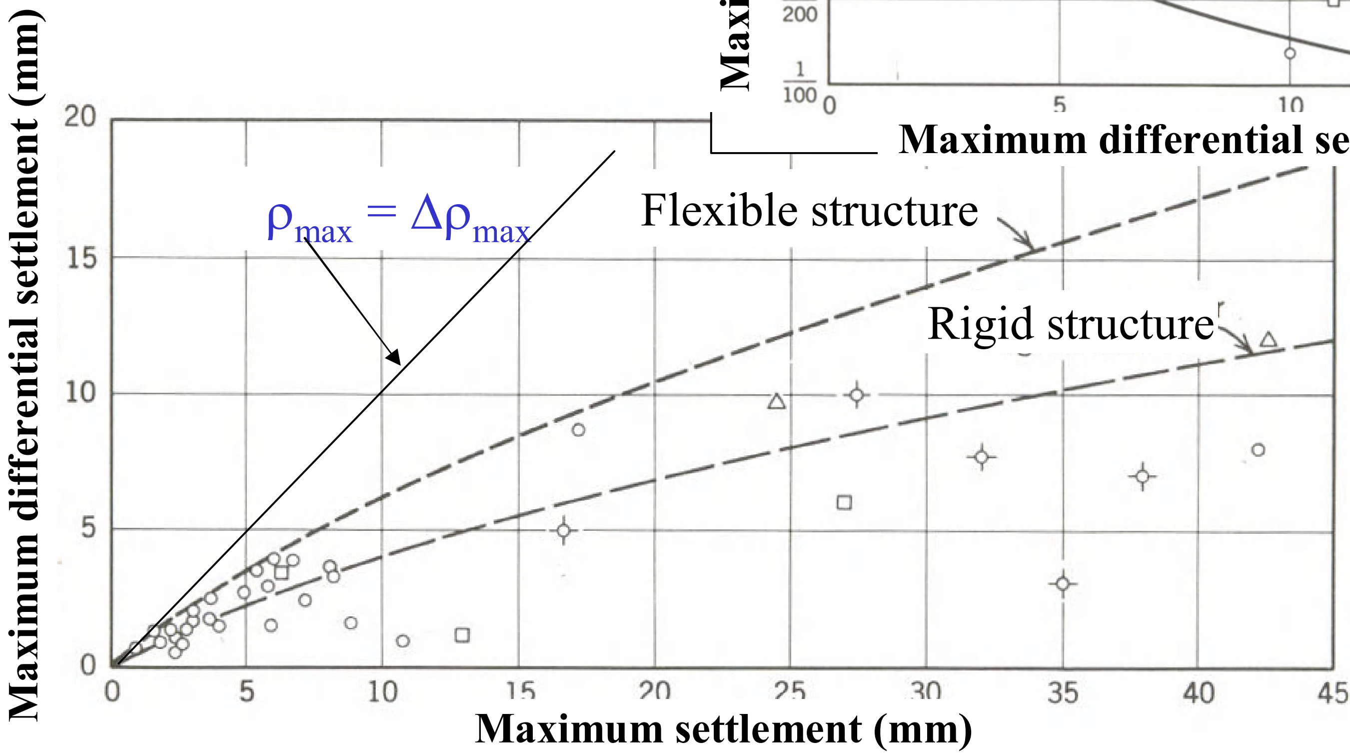


Fig. 1.8 Settlement of structures on **clay** (Bjerrum, 1963)

Lambe & Whitman, "Soil Mechanics SI Version", John Wiley & Sons. (1979)

Comparison of sand and clay as Foundation material

Table 1.2

item	sand	clay (normally consolidated or lightly overconsolidated)
Factor controlling footing design	$\Delta\rho$, especially under cycles of load or dynamic load	ρ_{max} and $\Delta\rho$
Settlement magnitude	Small	Large
Settlement rate	Fast	Slow
Settlement pattern	Irregular; larger ρ at edge of footing	Dished shape
Relation betw. ρ_{max} and $\Delta\rho$	$\Delta\rho_{max}$ often close to ρ_{max}	$\Delta\rho_{max}$ usually much less than ρ_{max}
Effect of given $\Delta\rho$ on structure	Relatively large because ρ is irregular and occurs fast	Relatively small because ρ is regular and occurs slowly

Lambe and Whitman, 1979

1.5 Safety factor

The selection of safety factors for design cannot be made properly without assessing **the degree of reliability** of all other parameters that enter into design, such as ***design loads, strength and deformation characteristics of the soil mass***, etc. **In view of this, each case is to be considered separately by the designer**.

Vesic(1975) has suggested the **total factor of safety** (F_s) on the basis of classification of structures, knowledge of foundation conditions, and the consequence failure.

Home works for Japanese: translation into Japanese p18 -20.

Minimum safety factor for design of shallow foundation

Vesic (1975)

Table 1.3

Cate gory	Typical structures	Characteristics of the Category	Soil Exploration	
			Complete	Limited
A	Railway bridge Warehouses blast furnaces Hydraulic retaining walls Silos	Maximum design load likely to occur often; Consequence of failure disastrous	3.0	4.0
B	Highway bridge Light industrial and public building	Maximum design load may occur occasionally; Consequence of failure serious	2.5	3.5
C	Apartment and office building	Maximum design load unlikely to occur	2.0	3.0

Remarks on the table: next page

Total factor of safety: F_s

Remarks on the table

1. For temporary structure, these factors can be reduced to 75% of the above values. However, in no case should safety factors lower than 2.0 be used.
2. For exceptionally tall buildings, such as chimneys and towers, or generally whenever progressive bearing capacity failure may be feared, these factors should be increased by 20-50%.
3. The probability of flooding of foundation soil and/or removal of existing overburden by scour or excavation should be given adequate consideration.
4. It is advisable to check both the short term (end-of construction) and long term stability, unless one of the two conditions is clearly less favorable.
5. It is understood that all foundations will be analyzed also with respect to maximum tolerable total and differential settlement. If settlement governs the design, higher safety factor must be used.

load factor and resistance factors -partial factor (部分安定係数)-

Meyerhof(197, 1984) discussed the total factors of safety F_s given in Table 1.4 below and the use of the load and resistance factors (partial factors) in Table 1.5.

Table 1.4 Values of minimum total safety factors (Meyerhof, 1984)

Failure type	Item	Safety Factor, F_s
Shearing	Earthworks	1.3 - 1.5
	Earth-retaining structure, excavation	1.5- 2
	Foundations	2- 3
Seepage	Uplift, heave	1.5 - 2
	Exit gradient, piping	2 - 3

The higher value are applied to the normal loads and service condition. The lower values are applied to the maximum and worst environmental conditions

load factor(荷重係数) and resistance factors(抵抗係数)

Value of minimum partial factors (Meyerhof,1984)

Category	Item	Load Factor	Resistance Factor
Loads	Dead loads	(f_d) 1.25(0.85)	
	Live loads, wind or earthquake	(f_l) 1.5	
	Water pressure	(f_u) 1.25(0.85)	
Shear strength	Cohesion (c) (stability; earth pressure)		(f_c) 0.65
	Cohesion(c) (foundations)		(f_c) 0.5
	Friction (tanϕ)		(f_ϕ)0.8

note: Load factors given in parentheses apply to dead loads and water pressures when their effects are beneficial, as for dead loads resisting instability by sliding, overturning or uplift.

Total factor of safety vs. partial factor

Basic philosophy using total factor of safety:

Foundation should be capable of resisting a load F_s times greater than the design load. F_s covers both uncertainties in load and resistance.

Load and resistance factor design (LRFD) method applies separate or partial factors to load and resistance. ⇔ **Limit state design concept**

The **load factors** are provided mainly for the variability and pattern of loading, which differ for dead loads, live loads, environmental loads, and water pressures.

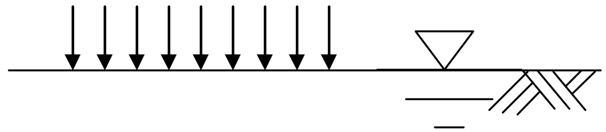
The **resistance factors** consider the variability and uncertainty of the assessment of soil resistance, which differ for the cohesion and friction components. The factored shear strength at ultimate state (τ_{ff}) may be expressed as for Coulomb criterion.

$$\tau_{ff} = f_c c + \sigma f_\phi \tan\phi$$

The factors f_c and f_ϕ are the resistance factors for the cohesive and friction components, respectively. The total factor of safety obtained will depend on the relative contribution of the cohesive and friction components.

Short test about basics of soil mechanics (15min.)

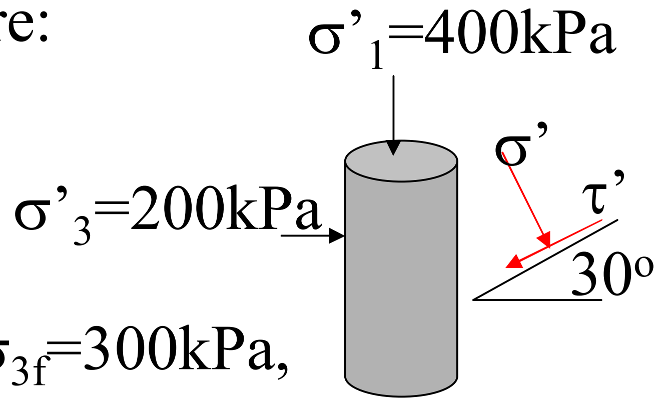
1. Basic properties of soil shown in the right figure.
   (1)Void ratio (e) of the soil?
   (2)Water content (w)?
   (3) Total overburden stress (σ_v) at z=10m?
   (4) Effective overburden stress (σ'_v) at z=10m?



γ_{sat}=20kN/m^3
γ_w=10kN/m^3
G_s=2.7
S_r=100%

2. Volumetric strain of soil (ε_v) when the initial void ratio e_i=0.7 and decrement of void ratio Δe=0.07?

3.Stresses of the soil element in the right figure:
   (1) Draw Mohr stress circle?
   (2) Normal stress (σ') and shear stress (τ') in the plane 30^o from the horizon ?



4. Strength of saturated soil for σ_{1f}=500kPa, σ_{3f}=300kPa,
   (1) Undrained strength (c_u)?
   (2) Effective friction angle (ϕ') with c'=0, u=200kPa?

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