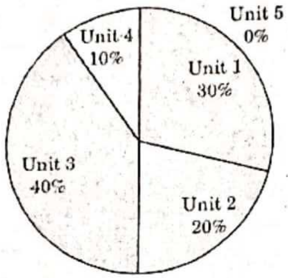
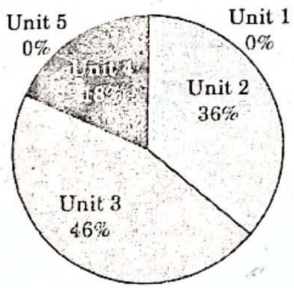
| Units | Ques. Asked (2016-17) |
|---|---|
| Unit-1 | 3 |
| Unit-2 | 2 |
| Unit-3 | 4 |
| Unit-4 | 1 |
| Unit-5 | 0 |

% Weightage of Units (2016-17)



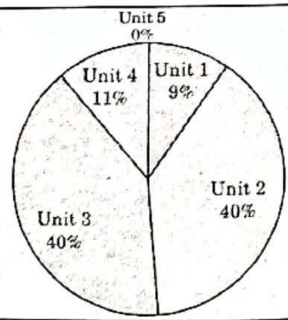

| Units | Ques. Asked (2017-18) |
|---|---|
| Unit-1 | 0 |
| Unit-2 | 4 |
| Unit-3 | 5 |
| Unit-4 | 2 |
| Unit-5 | 0 |

% Weightage of Units (2017-18)




| Units | Total Questions (2013-14 to 2017-18) |
|---|---|
| Unit-1 | 4 |
| Unit-2 | 18 |
| Unit-3 | 18 |
| Unit-4 | 5 |
| Unit-5 | 0 |

% Weightage of Units (2013-14 to 2017-18)




1
UNIT

# Soil Exploration and Geophysical Methods

## CONTENTS

PART-1

*Soil Exploration.*

## CONCEPT OUTLINE

**Types of Method for Soil Exploration :** Following are the types of method for soil exploration :

i. Direct method.

ii. Semi-direct method.

iii. Indirect method.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 1.1. Describe soil exploration ? What are the types of methods available for soil exploration ?**

**Answer**

• The object of Soil Exp. is to provide reliable, specific & detailed information about the soil.

1. **Soil Exploration :**

i. The field and the laboratory investigations required to obtain the essential information on the subsoil are known as soil exploration.

ii. Soil exploration is a must in the present age for the design of foundation of any project.

iii. The extent of the exploration depends upon the magnitude and importance of the project.

iv. The principle of soil exploration remains the same for all the projects but the program and methodology may vary from project to project.

v. The elements of soil exploration depend mostly on the importance and magnitude of the project, but generally should provide the following :

   a. Information to determine the type of foundation required such as a shallow or deep foundation.

   b. Necessary information with regards to the strength and compressibility characteristics of the subsoil to allow the design consult to make recommendations on the safe bearing pressure or pile load capacity.

2. **Types of Methods :** Following are the types of methods for soil exploration :



i. **Direct Methods :** Test pits, trial pits or trenches.

ii. **Semi-direct Methods :** Borings.

iii. **Indirect Methods :** Soundings or penetration tests and geophysical methods.

**Que 1.2. Explain the reconnaissance ? Which type of information is obtained in reconnaissance ?**

**Answer**

1. Site reconnaissance is the first step in a sub-surface exploration programme.

2. It includes a visit to the site and to study the maps and other relevant records.

3. It helps in deciding future programme of site investigations, scope of work, methods of exploration to be adopted, types of samples to be taken and the laboratory testing and in-situ testing.

4. **Following informations are obtained in reconnaissance :**

i. The general topography of the site, the existence of drainage ditches and dumps of debris and sanitary fills.

ii. Existence of settlement cracks in the structure already built near the site.

iii. The evidence of landslides, creep of slopes and the shrinkage cracks.

iv. The stratification of soils as observed from deep cuts near the site.

v. The location of high flood marks on the nearby building and bridges.

vi. The depth of ground water table as observed in the wells.

vii. Existence of springs, swamps, etc. at the site.

viii. The drainage pattern existing at the site.

ix. Type of vegetation existing at the site. The type of vegetation gives a clue to the nature of the soil.

PART-2

*Methods of Boring and Drilling.*

## CONCEPT OUTLINE

**Types of Method of Boring or Drilling :** Following are the types of methods of boring or drilling :

i. Auger boring.

ii. Wash boring.

iii. Percussion drilling.

iv. Rotary drilling.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 1.3.** **Discuss on different types of borings for soil exploration.**

**AKTU 2016-17, Marks 10**

**Answer**

Following are the different types of boring :

1. **Auger Boring :**
   • These are used for cohesive & other soft soil.
   • यह Generally 6m depth के लिए use होता है।

i. Augers are used in cohesive and other soft soils above water table.

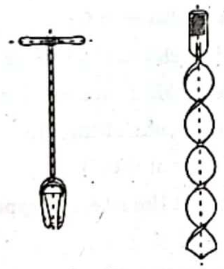
ii. Hand operated augers are used for depths upto about 6 m.

iii. Mechanically operated augers are used for greater depths and they can also be used in gravelly soils.

iv. Fig. 1.3.1, shows a post hole auger and a helical (spiral) auger.

v. Samples recovered from the soil brought up by augers are badly disturbed and are useful for identification purposes only.

vi. Auger boring is fairly satisfactory for highway explorations at shallow depth and for exploring borrow pits.



(*a*) Post hole auger. (*b*) Helical (spiral) auger.

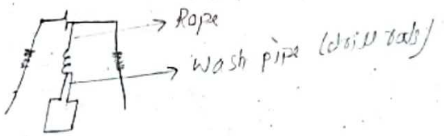
**Fig. 1.3.1.** Hand augers.

2. **Wash Boring :**

i. Wash boring is a fast and simple method for boring holes in all types of soils. But boulders and rocks cannot be penetrated by this method.

ii. Initially, in wash boring a hole is drilled for a short depth by using an auger.

iii. A casing pipe is pushed in the hole and driven with a drop weight or with the aid of power.






iv. A hollow drill bit screwed to the lower end of a hollow drill rod connected to a rope passing over a pulley and supported by a tripod is inserted into the casing pipe.

v. Water is forced under pressure through the drill rod which is alternately raised and dropped and also rotated.

vi. The resulting chopping and jetting action of the bit and water disintegrate the soil and forces the ground surface in the form of soil water slurry through the annular space between the drill rod and the casing.

vii. The change of soil stratification could be guessed from the rate of progress and the colour of the wash water.

viii. The samples recovered from the wash water are almost valueless for interpreting the correct geotechnical properties of soil.

3. **Percussion Drilling :**

i. The percussion drilling method is used for boring holes in rocks, boulders and other hard strata.

ii. In this method a heavy drill bit called 'churn bit' suspended from a drill rod or a cable is alternately lifted and dropped in the vertical hole.

iii. By the repeated blows of the drill bit the material in the hole gets pulverised.

iv. If the point where the drill bit strikes is above the ground water table, water is added to the hole to facilitate the breaking of stiff soil or rock.

v. The water forms slurry with the pulverized material which is removed by a bailer at intervals.

vi. The formation gets very much disturbed by the impact.

vii. This method cannot be used in loose sand and is slow in plastic clay.

4. **Rotary Drilling :**

i. The rotary drilling method is a fast method of boring holes in rock formations. V soil

ii. A hollow drill bit, fixed to the lower end of a hollow drill rod, is rotated by power while being kept in firm contact with the bottom of the hole.

iii. Drilling fluid, usually bentonite clay slurry is forced under pressure through the drill rod and it comes up bringing the cuttings to the surface.

iv. The drilling fluid supports the walls of the hole and hence no casing is required.

v. This method is, however, not used in porous deposits as the consumption of the drilling fluid would be prohibitively high.

vi. In this method, by using suitable diamond studded drill bits or steel bits with shots, the rock cores may be obtained. This method is also known as core boring or core drilling.

vii. In this case water is circulated down the drill rod during boring to facilitate the cutting operation and to keep the drill bit cool.

## PART-3

*Soil Sampling and Sampler.*

### CONCEPT OUTLINE

**Types of Sample :** Following are the types of sample :

i. Undisturbed sample.

ii. Disturbed sample.

**Types of Soil Sampler :** Following are the various types of sampler :

i. Open drive sampler.

ii. Thin-walled sampler.

iii. Split barrel or split-spoon sampler.

iv. Stationary piston sampler.

v. Continuous sampler.

vi. Compressed air sampler.

vii. Window sampler.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 1.4. What do you understand about disturbed and undisturbed samples ? What are the uses of them ?**

**Answer**

1. **Disturbed Samples :**

i. These are the samples in which the natural structure of the soil gets disturbed during sampling.

ii. These samples represent the composition and the mineral content of the soil.

iii. Disturbed samples can be used to determine the index properties of the soil, such as grain size, plasticity characteristics, specific gravity, etc.

2. **Undisturbed Samples :**

i. These are the samples in which the natural structure of the soil and the water content are retained.



ii. However, it may be mentioned that it is impossible to get truly undisturbed sample. Some disturbance is inevitable during sampling, even when the utmost care is taken.

iii. Even the removal of the sample from the ground produces a change in the stresses and causes disturbances.

iv. Undisturbed samples are used for determining the engineering properties of the soil, such as compressibility, shear strength, and permeability. Some index properties such as shrinkage limit can also be determined. The smaller the disturbance, the greater would be the reliability of the results.

**Que 1.5. Give the different types of samplers. Also explain split spoon samplers with the help of neat sketches.**

**Answer**

A. **Types of Samplers :** Following are the various types of samplers :

1. Split spoon sampler.
2. Scraper bucket sampler.
3. Shelby tubes and thin walled sampler.
4. Piston sampler.
5. Denison sampler.

B. **Split Spoon Sampler :**

1. The most commonly used sampler for obtaining a disturbed sample of the soil is the standard split-spoon sampler as shown in the Fig. 1.5.1.
2. It consists mainly of three parts :

i. Driving shoe, made of tool-steel, about 75 mm long.

ii. Steel tube about 450 mm long, split longitudinally in two halves.

iii. Coupling at the top of the tube about 150 mm long.

3. The inside diameter of the split tube is 38 mm and the outside diameter is 50 mm.
4. The coupling head may be provided with a check valve and 4 venting ports of 10 mm diameter to improve sample recovery.
5. After the bore hole has been made, the sampler is attached to the drilling rod and lowered into the hole.
6. The sample is collected by jacking or forcing the sampler into the soil by repeated blows of a drop hammer, the sampler is then withdrawn.

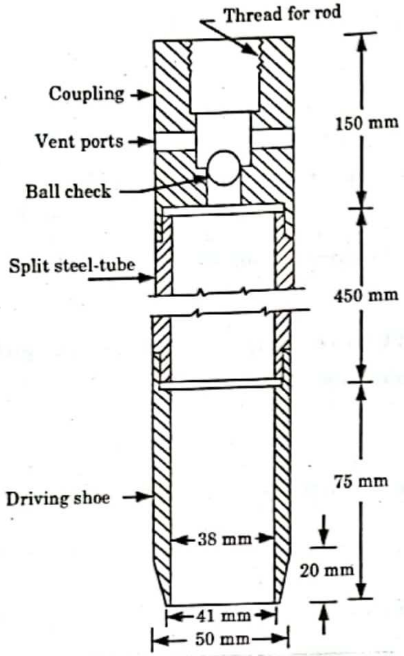



Fig. 1.5.1. Standard split spoon sampler.

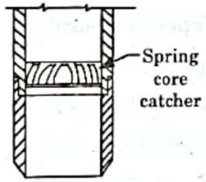



Fig. 1.5.2. Spring core catcher.

7. The split tube is separated after removing the shoe and the coupling and the sample is taken out.
8. It is then placed in a container, sealed, and transported to the laboratory.
9. This sampler is also used in conducting standard penetration test.

## PART-4

*In-situ Tests, SPT, CPT, DCPT.*

### CONCEPT OUTLINE

**Types of In-situ Tests :** Following are the types of in-situ test :

i. SPT (Standard penetration test)
ii. CPT (Cone penetration test)
iii. DCPT (Dynamic cone penetration test)

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions



**Que 1.6.** **List the field test commonly used in subsurface investigation. What are the corrections that must be applied to the field *N*-values for sand before they are used in design charts and empirical correlations ?**

**OR**

**Explain SPT test. Also, explain the corrections used for the test.**

**Answer**

A. **Field Tests :** Following are the field test used in sub surface investigation :

1. Plate load test.
2. SPT (Standard penetration test).
3. DCPT (Dynamic cone penetration test).
4. SCPT (Static cone penetration test).

B. **Standard Penetration Test :**

1. It is the most commonly used in-situ test, especially for cohesionless soils cannot be easily sampled.
2. The test is extremely useful for determining the relative density and the angle of shearing resistance of cohesionless soils.
3. It can also be used to determine the unconfined compressive strength of cohesive soils.

**Procedure :**

1. The standard penetration test is conducted in a bore hole using a standard split-spoon sampler.
2. When the bore hole has been drilled to the desired depth, the drilling tools are removed and the sampler is lowered to the bottom of the hole.
3. The sampler is driven into the soil by a drop hammer of 63.5 kg mass falling through a height of 750 mm at the rate of 30 blows per minute.
4. The number of hammer blows required to drive 150 mm of the sample is counted.
5. The sampler is further driven by 150 mm and the number of blows recorded.
6. Likewise, the sampler is once again further driven by 150 mm and the number of blows recorded.
7. The number of blows recorded for the first 150 mm is discarded.
8. The number of blows recorded for the last two 150 mm intervals are added to give the standard penetration number (*N*).
9. In other words, the standard penetration number is equal to the number of blows required for 300 mm of penetration beyond a seating drive of 150 mm.

10. If the number of blows for 150 mm drive exceeds 50, it is taken as refusal and the test is discontinued.

**Correction for *N*-Value :** The standard penetration number is corrected for dilatancy correction and overburden correction as given below :

1. **Dilatancy Correction :**

i. Silty fine sands and fine sands below the water table develop pore pressure which is not easily dissipated.

ii. The pore pressure increases the resistance of the soil and hence increase the penetration number ($N$).

iii. Terzaghi and peck recommend the following correction in the case of silty fine sands when the observed value of $N$ exceeds 15.

a. The corrected penetration number,

$$N_c = 15 + 1/2 \times (N_R - 15)$$

where, $N_R$ = Recorded value.

$N_c$ = Corrected value.

b. If $N_R \leq 15$, $N_c = N_R$

2. **Overburden Pressure Correction :**

i. In granular soils, the overburden pressure affects the penetration resistance.

ii. If the two soils having same relative density but different confining pressures are tested, the one with a higher confining pressure gives a higher penetration number.

iii. As the confining pressure in cohesionless soils increases with the depth, the penetration number for soils at shallow depths is underestimated and that at greater depths is overestimated.

iv. For uniformity, the $N$-values obtained from field tests under different effective overburden pressures are corrected to a standard effective overburden pressure.

v. Gibbs and Holtz recommend the use of the following equation for dry or moist clean sand.

$$N_c = N_R \times \frac{350}{\sigma_0 + 70}$$

where, $\sigma_0$ = Effective overburden pressure (kN/m$^2$).

**Que 1.7.** **Explain static cone penetration test (CPT) with neat sketch and also gives the limitations of CPT test.**

**OR**

**Elaborate on the standard penetration tests and static cone test in a detailed manner.**

**AKTU 2016-17, Marks 10**



**Answer**

A. **SPT :** Refer Q. 1.6, Page 1–9D, Unit-1.

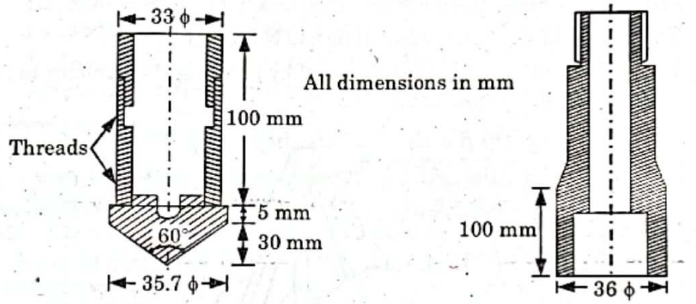
B. **Static Cone Penetration Test :**

1. In field, SCPT is widely used for recording variation in the in-situ penetration resistance of soil in cases where the in-situ density is disturbed by boring method and SPT is unreliable below water table.

2. This test is very useful for soft clays, soft silts, medium sands and fine sands.

**Procedure :**

1. By this test, the standard cone is pushed at the rate of 10 to 20 mm/sec into the soil and noting the friction, the strength is determined.




(*a*) Cone assembly (*b*) Friction jacket

**Fig. 1.7.1.** Cone assembly and friction jacket for static cone penetration test (IS).

2. After installing the equipments as per the IS : 4968 part III, sounding rod is pushed into the soil and the driving is operated at the steady rate of 10 mm/sec approximately so as to advance the cone only by external loading to the depth for which a cone assembly is available.

3. For finding combined cone friction resistance, the shear strength of the soil and the tip resistance is noted in gauge and added to get the total strength.

**Limitations :**

1. The test is unsuitable for gravelly soils and for soils with standard penetration value $N$ greater than 50.

2. Also in dense sands, the anchorage becomes too cumbersome and expensive and for such cases, dynamic cone penetration tests may be carried out.

3. It is also unsuitable for field operation since erroneous value obtained due to presence of brick bats, loose stones etc.

**Que 1.8.** **Discuss the procedure of dynamic cone penetration test (DCPT). Also gives the advantages and disadvantages of DCPT test.**

**Answer**

**Procedure of Dynamic Cone Penetration Test :**

1. The equipment consists of a cone, driving rods, driving head, hoisting equipment and a hammer.
2. The cone with threads (recoverable) shall be of steel with tip hardened.
3. The driving rods should be marked at every 100 mm.
4. The driving rod shall have a diameter of 100 mm and a length of 100 to 150 mm.
5. Any suitable hoisting equipment such as a tripod may be used.
6. The weight of the hammer shall be 640 N (65 kg).
7. The cone shall be driven into the soil by allowing the hammer to fall freely through 750 mm each time.

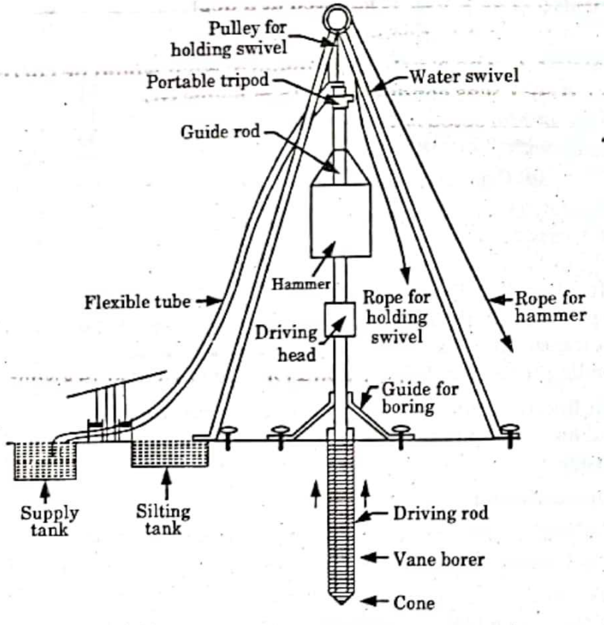



**Fig. 1.8.1.** DCPT test set-up.

8. The number of blows for every 100 mm penetration of the cone shall be recorded.



9. The process shall be repeated till the cone is driven to the required depth.
10. To save the equipment from damage, driving may be stopped when the number of blows exceeds 35 for 100 mm penetration.

**Advantages :** Following are the advantages of DCPT :

1. The test does not need a bore hole.
2. It can be done quickly to cover a large area economically.
3. It helps to identify variability of subsoil profile and to locate soft pockets such as filled up ponds.
4. When DCPT is carried out close to a few bore holes, suitable corrections may be obtained for a particular site and the number of bore holes can be reduced.

**Disadvantages :** Following are the disadvantages of DCPT :

1. Not suitable for cohesive soils or very loose cohesionless soils.
2. It is normally not possible to evaluate the mechanical properties of the soil at great depths when the friction along the extension rod is significant.

**Que 1.9.** **A SPT was conducted at a depth of 2 m in sand deposit with a unit weight of 20 kN/m³. The water table at this site was at 1 m below *GL*. The *N* value was found 5. What would be corrected *N* value ? If SPT was conducted at 15 m below *GL* the *N* obtained was 21. What is corrected *N* ?**

**Answer**

**Given :** Unit weight of soil, $\gamma = 20$ kN/m³, Depth of water table = 1 m
Depth of test = 2 m
**To Find :** Corrected *N* values

1. **For First Condition :**

i. Effective overburden pressure at 2 m depth,

$$\bar{\sigma} = 1 \times 20 + (20 - 9.81) \times 1 = 30.19 \text{ kN/m}^2$$

ii. Corrected *N* value = Combined correction is given by,

$$N_c = \frac{1}{2}\left[N_R \times 0.77 \log \frac{2000}{\bar{\sigma}} + 15\right]$$

$$= \frac{1}{2}\left[5 \times 0.77 \log_{10}\left(\frac{2000}{30.19}\right) + 15\right]$$

iii. Corrected value, $N_C = 11.$

2. **For Second Condition :**

i. Effective overburden pressure at 15 m depth,

$$\bar{\sigma} = 15 \times 20 - 14 \times 9.81 = 162.66 \text{ kN/m}^2$$

Geophysical • Without excavation हम determine कर सकते है properties of soil.
→ यह बहुत जल्दी होता है।



ii. Corrected $N$ value is given by,

$$N_c = \frac{1}{2}\left[N_R \times 0.77 \log\left(\frac{2000}{\bar{\sigma}}\right) + 15\right]$$

$$N_c = \frac{1}{2}\left[21 \times 0.77 \log_{10} \frac{2000}{162.66} + 15\right]$$

iii. Corrected value, $N_c = 16.3$ say 16.

## PART-5

*Soil Resistivity Methods.*

### CONCEPT OUTLINE

Geophysical methods can be broadly divided into the two categories :

i. Seismic method.

ii. Electrical resistivity method.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 1.10. What do you understand by geophysical methods used for the soil investigation ? Explain the soil resistivity method in detail.**

**OR**

**List various geophysical methods used for the soil investigation. Explain the soil resistivity method in detail. Write also their relative advantages and disadvantages.** **AKTU 2015-16, Marks 10**

**Answer**

**A. Geophysical Methods :**

1. Geophysical methods involve the technique of determining subsurface materials by measuring some physical property of the materials, and through correlations, using the values obtained for identifications.
2. Most geophysical methods determine conditions over large distances and can be used to obtain rapid results.
3. There are two geophysical method commonly used :

i. Seismic refraction methods.

ii. Electrical resistivity methods.



**B. Electrical Resistivity Method :** Electric resistivity methods are a form of geophysical surveying that helps in imaging the subsurface. These methods utilize differences in electric potential to identify subsurface material.

**Types :** The three main methods of electric resistivity surveys are vertical electric sounding (VES), electric profiling, and electric imaging.

1. **Vertical Electric Sounding :** → vertically check करेगा।

i. VES is one of the more commonly used and cost effective resistivity survey methods.

ii. Current is moved through the subsurface from one current electrode to the other and the potential as the current moves is recorded.

iii. From this information, resistivity values of various layers is acquired and layer thickness can be identified.

iv. The apparent resistivity values determined are plotted as a log function versus the log of the spacing between the electrodes.

v. These plotted curves identify thickness of layers. If there are multiple layers (more than 2), the acquired data is compared to a master curve to determine layer thickness.

vi. There are a few limitations with VES :

a. The depth of the survey is limited to the electrode spacing.

b. Layers may vary in resistivity horizontally.

c. Layers must have consistent thickness.

d. If there is a case where the middle layer is much thinner than the layers above and below it then the resistivity results will be inaccurate. The resistivity of the thin middle layer will affect the reading.

2. **Electric Profiling :** → Horizontal मे check करेगे।

i. Where VES focuses on determining resistivity variations on a vertical scale, electric profiling seeks to determine resistivity variations on a horizontal scale.

ii. Profiling can use the same electrode spacing configurations as VES.

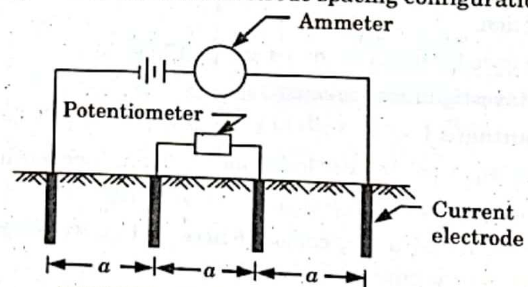



**Fig. 1.10.1.** Electrical Profiling method.

iii. Since changing the spacing between electrodes only affects the depth at which the survey can reach, the profiling method does not involve manipulating electrode spacing.

iv. Instead, the electrode spacing is kept constant and the entire survey is moved along a line or a profile to measure horizontal changes in resistivity.

**3. Electric Imaging :** → इसमें दोनों होता है।

i. In many cases resistivity can change as both depth and horizontal distance increase.

ii. Both VES and electric profiling are limited to surveying in one direction.

iii. Electric imaging is able to survey both vertical and horizontal changes in resistivity.

iv. This method essentially combines the other two methods.

v. Electrode spacing is increased and the survey is moved along a profile in order to measure both vertical and horizontal resistivity.

vi. These values are then used to create a pseudosection. The pseudosection can be used to generate an image of the subsurface. Imaging can be done in both 2D and 3D.

**C. Advantages and Disadvantages :** Refer Q. 1.11, Page 1–16D, Unit-1.

**Que 1.11.** **Write down the relative advantages and disadvantages of soil resistivity method.**

**Answer**

**A. Advantages :**

1. The equipment is light, portable and inexpensive.
2. Qualitative interpretation of the data is rapid and straightforward.
3. Field expenses are minimal.
4. It is flexible and can be used for various purposes and depths of investigation.
5. It can be used for both soundings and profiling.
6. Shallow investigations are rapid.

**B. Disadvantages :**

1. Deep investigations require long cables and consume much field time.
2. Interpretation of complex geologic structures is difficult and ambiguous.
3. Presence of metal pipes, cables, fences and electrical grounds can complicate interpretation.
4. Accuracy of depth determination is lower than with seismic techniques.



5. The results are considerably influenced by surface irregularities, wetness of the strata and electrolyte concentration of the ground water.
6. As the resistivity of different strata at the interface changes gradually and not abruptly as assumed, the interpretation becomes difficult.
7. The services of an expert in the field are needed.

## PART-6

*Seismic Refraction Methods.*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 1.12.** **Explain the seismic refraction method of soil exploration.**

**OR**

**Explain about the seismic refraction method and electrical resistivity method of soil exploration.** **AKTU 2016-17, Marks 10**

**Answer**

**A. Electrical Resistivity Method :** Refer Q. 1.10, Page 1–14D, Unit-1.

**B. Seismic Refraction Method :**

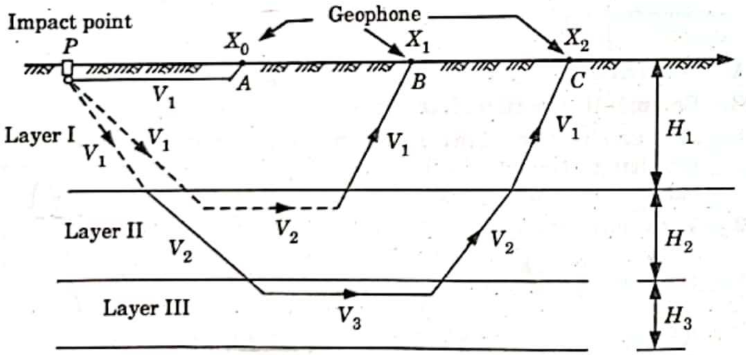
1. When a shock or impact is made at a point on or in the earth, the resulting seismic (shock or sound) waves travel through the surrounding soil at speeds related to their elastic characteristics.
2. The velocity is given by,

$$v = C\sqrt{\frac{Eg}{\gamma}}$$

where, $v$ = Velocity of the shock wave.
$E$ = Modulus of elasticity of the soil.
$g$ = Acceleration due to gravity.
$\gamma$ = Density of the soil.
$C$ = Dimensionless constant involving Poisson's ratio.

3. The magnitude of the velocity is determined and is utilized to identify the material.
4. A shock may be created with a sledge hammer hitting a strike plate placed on the ground or by detonating a small explosive charge at or below the ground surface.

5. The radiating shock waves are picked up by detectors, called geophones, placed in a line at increasing distances, $d_1$, $d_2$,... from the origin of the shock (The geophone is actually a transducer, an electromechanical device that detects vibrations and converts them into measurable electric signals).
6. The time required for the elastic wave to reach each geophone is automatically recorded by a seismograph.
7. Some of the waves, known as direct or primary waves, travel directly from the source along the ground surface or through the upper stratum and are picked up first by the geophone.
8. If the subsoil consists of two or more distinct layers, some of the primary waves travel downwards to the lower layer and get refracted as the surface. If the underlying layer is denser, the refracted waves travel much faster.
9. As the distance from the source and the geophone increases, the refracted waves reach the geophone earlier than the direct waves.
10. Fig. 1.12.1 shows the diagrammatic representation of the travel of the primary and the refracted waves.
11. The distance of the point at which the primary and refracted waves reach the geophone simultaneously is called the critical distance which is a function of the depth and the velocity ratio of the strata.




$$H_2 = 0.85\,H_1 + \frac{X_2}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}} \qquad H_1 = \frac{X_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

**Fig. 1.12.1.** Seismic method.

**Que 1.13.** **What are the limitations of seismic refraction method ?**

**Answer**

Following are the limitations of seismic refraction method :



1. The method cannot be used where a hard layer overlies a soft layer, because there will be no measurable refraction from a deeper soft layer.
2. The method cannot be used in an area covered by concrete or asphalt pavement, since these materials represent a condition of hard surface over a softer stratum.
3. A frozen surface layer also may give results similar to the situation of a hard layer over a soft layer.
4. Discontinuities such as rock faults or earth cuts, dipping or irregular underground rock surface and the existence of thin layers of varying materials may also cause misinterpretation of test data.

**Que 1.14.** **How the seismic refraction method is better than the seismic reflection method ?** **AKTU 2015-16, Marks 02**

**Answer**

| | Refraction Method | Reflection Method |
|---|---|---|
| Typical target | Near-horizontal density contrasts at depths less than 100 feet | Horizontal to dipping density contrasts, and laterally restricted targets such as cavities or tunnels at depths greater than 50 feet. |
| Required site conditions | Accessible dimensions greater than 5 times of the depth of interest; unpaved greatly preferred | None |
| Vertical resolution | 10 to 20 percent of depth | 5 to 10 percent of depth |
| Lateral resolution | 1/2 the geophone spacing | 1/2 the geophone spacing |
| Effective practical survey depth | 1/5 to 1/4 the maximum shot-geophone separation | > 50 feet |
| Relative cost | Low | High |

**2**
**UNIT**

# Shallow Foundations and its Settlement

## CONTENTS



• Numericals → Bearing capacity by terzaghi's
→ settlement analysis





### PART-1

*Bearing Capacity of Shallow Foundation, Design Criteria.*

### CONCEPT OUTLINE

Methods for calculating bearing capacity of shallow foundation :
- i. Terzaghi's theory.
- ii. Meyerhof's analysis.
- iii. Hansen's recommendations.
- iv. IS Code recommendations.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

Note

**Que 2.1.** **Describe the following terms :**

1. **Ultimate bearing capacity.**
2. **Net safe bearing capacity.**
3. **Safe bearing pressure.**
4. **Allowable bearing pressure.**
5. **Gross safe bearing capacity.**

**Answer**

1. **Ultimate Bearing Capacity :** The maximum gross intensity of loading that the soil can support before it fails in shear is called the ultimate bearing capacity, and it denoted by $q_u$.
2. **Net Safe Bearing Capacity :** Net safe bearing capacity, $q_{ns}$ is the maximum net intensity of loading that the soil can safely support without the risk of shear failure.

   It is obtained by dividing $q_{nu}$ by a factor of safety, $F$. Usually a factor of safety of 2.5 or 3 is used.

$$q_{ns} = \frac{q_{nu}}{F}$$

3. **Safe Bearing Pressure :** It is the maximum net intensity of loading that can be allowed on the soil without the settlement exceeding the permissible value. It denoted by $q_{ns}$. No factor of safety is used when dealing with settlement.
4. **Allowable Bearing Pressure :** It is the maximum net intensity of loading that can be imposed on the soil with no possibility of shear failure or the possibility of excessive settlement.

Hence, it is the smaller of the net safe bearing capacity (shear failure criterion) and safe bearing pressure (settlement criterion).

5. **Gross Safe Bearing Capacity :** Gross safe bearing capacity, $q_s$ is the maximum gross intensity of loading that the soil can carry safely without failing in shear. Thus,

$$q_s = q_{ns} + \gamma D_f$$

or

$$q_s = \frac{q_{nu}}{F} + \gamma D_f$$

**Que 2.2.** **What are the major criteria to be satisfied in the design of a foundation ?**

**Answer**

Following are the major criteria considered in the design of a foundation :

1. **Location and Depth Criterion :** A foundation must be properly located and founded at such a depth that its performance is not adversely affected by factors such as lateral expulsion of soil from beneath the foundation, seasonal volume changes causes by freezing and thawing and presence of adjoining structures.
2. **Bearing Capacity Criterion :** A foundation must be safe against shear strength failure or soil rupture. An adequate factor of safety is provided to preclude bearing capacity failure, as soil rupture is commonly referred to.
3. **Settlement Criterion :** The settlement of a foundation, especially the differential settlement, must be within the permissible limit. Excessive settlement may affect the utility of the structure, spoil the appearance of the structure and in some cases, may even cause damage to the structure.

## PART-2

*Factors Affecting Bearing Capacity, Factors Influencing Selection of Depth of Foundation.*

| Questions-Answers |
|---|
| Long Answer Type and Medium Answer Type Questions |

**Que 2.3.** **Discuss the affecting factors of bearing capacity of shallow foundation.**

**Answer**

Following are the affecting factors of bearing capacity of shallow foundation :



1. Nature of soil and its physical and engineering properties.
2. Nature of the foundation and other details such as size, shape, depth below the ground surface and rigidity of the structure.
3. Total and differential settlements that the structure can withstand without functional failure.
4. Location of ground water table relative to the level of the foundation.
5. Initial stresses, if any.

**Que 2.4.** **Explain in details, the effects of size of footing on both the ultimate bearing capacity and the settlement.**

**AKTU 2013-14, Marks 06**

**Answer**

1. Fig. 2.4.1 gives typical load-settlement relationships for footings of different widths on the surface of a homogeneous sand deposit.
2. It can be seen that the ultimate bearing capacities of the footings per unit area increase with the increase in the widths of the footings.
3. However, for a given settlement $s$, such as 25 mm, the soil pressure is greater for a footing of intermediate width $B_b$ than for a large footing with $BC$.
4. The pressures corresponding to the three widths intermediate, large and narrow, are indicated by points $b$, $c$ and $a$ respectively.
5. The same data is used to plot Fig. 2.4.1 which shows the pressure per unit area corresponding to a given settlement $s_1$, as a function of the width of the footing.
6. The soil pressure for settlement $s_i$ increases for increasing width of the footing, if the footings are relatively small, reaches a maximum at an intermediate width, and then decreases gradually with increasing width.
7. Although the relation shown in Fig. 2.4.1 is generally valid for the behavior of footings on sand, it is influenced by several factors including the relative density of sand, the depth at which the foundation is established, and the position of the water table.
8. Furthermore, the shape of the curve suggests that for narrow footings small variations in the actual pressure, Fig. 2.4.1 may lead to large variation in settlement and in some instances to settlements so large that the movement would be considered a bearing capacity failure.
9. On the other hand, a small change in pressure on a wide footing has little influence on settlements as small as $s_1$, and besides, the value of $q_i$ corresponding to $s_1$ is far below that which produces a bearing capacity failure of the wide footing.
10. For all practical purposes, the actual curve given in Fig. 2.4.1 can be replaced by an equivalent curve $omn$ where $om$ is the inclined part and $mn$ the horizontal part.

11. The horizontal portion of the curve indicates that the soil pressure corresponding to a settlement $s_1$ is independent of the size of the footing.
12. The inclined portion $om$ indicates the pressure increasing with width for the same given settlement $s_1$ up to the point $m$ on the curve which is the limit for a bearing capacity failure.
13. This means that the footings up to size $B$ in Fig. 2.4.1 should be checked for bearing capacity failure also while selecting a safe bearing pressure by settlement consideration.

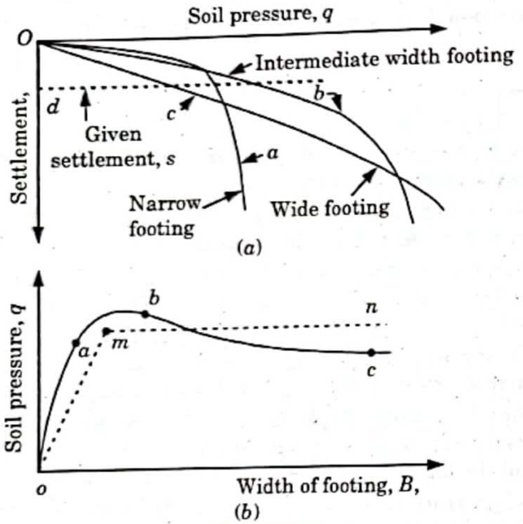



Fig. 2.4.1.

14. The position of the broken lines $omn$ differs for different sand densities or in other words for different SPT $N$ values.
15. The soil pressure that produces a given settlement $s_i$ on loose sand is obviously smaller than the soil pressure that produces the same settlement on a dense sand.
16. Since $N$-value increases with density of sand, $q_a$ therefore increases with an increase in the value of $N$.

**PART-3**

*Modes of Shear failure.*



**CONCEPT OUTLINE**

**Modes of Shear Failure :** Following are the modes of shear failure :
i. General shear failure.
ii. Local shear failure.
iii. Punching shear failure.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 2.5.** **Discuss the various types of bearing capacity failure occur in soil.**

**AKTU 2015-16, Marks 03**

**Answer**

Dense sand → stiff clay

**Types of Shear Failure :** Basic classified the bearing capacity failures into three categories : • ये Low compressibility soil से ही होता है।

**A. General Shear Failure :**

1. When the sudden failure in the dense sand or stiff cohesive soil supporting the foundation takes place and the failure surface extends to the ground surface, the failure will be the general shear failure.
2. If a load is gradually applied to the foundation, settlement will increase.

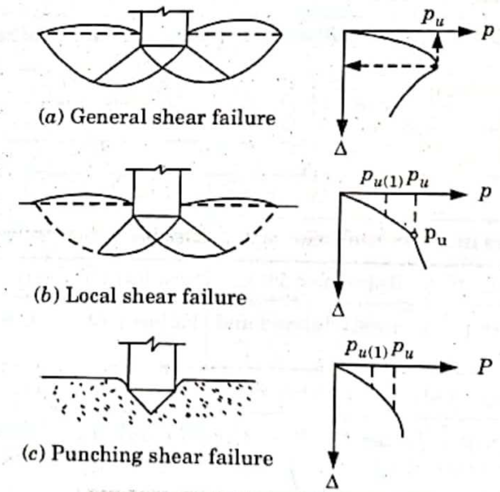



Fig. 2.5.1. Types of shear failure.

3. At a certain point when the load per unit area equals to the ultimate bearing capacity of the foundation, a sudden failure in the soil supporting the foundation will take place.

**B. Local Shear Failure :** • ये Intermediate compression soil में ही मिलता है। (loose sand & soft clays)

1. When the failure in the sand or clayey soil of medium supporting the foundation takes place and the failure surface in the soil will gradually extend outward from the foundation, the failure is called as local shear failure.
2. When the load per unit area on the foundation equals first failure load, movement of the foundation accompanied by sudden jerks.
3. A considerable movement of the foundation is then required for the failure surface to extend to the ground surface as shown by the broken lines in the Fig. 2.5.1(*b*).
4. Beyond that point an increase in load will cause large increase in foundation settlement.

**C. Punching Shear Failure :** • High compressive soil (loose soil & deep footing)

1. If the soil is so loose that it cannot sustain the shearing forces developed on the failure surface, the soil underneath will collapse, causing the shear zone to progress downward, more or less vertically.
2. If the foundation is supported by fairly loose soil, the failure surface will not extend to the ground surface.
3. Beyond the ultimate failure load, the load settlement plot will be steep and practically linear.
4. This type of failure is called punching shear failure.

**Que 2.6.** **Differentiate between the general shear failure and the local shear failure.**

**AKTU 2017-18, Marks 05**

**Answer**

| S. No. | General Shear Failure | Local Shear Failure |
|---|---|---|
| 1. | Occurs in dense/stiff soil. | Occurs in loose/soft soil. |
| 2. | Results in small strain (< 5 %). | Results in large strain (> 20 %). |
| 3. | Failure pattern well defined and clear. | Failure pattern not well defined. |
| 4. | Well defined peak in P-Δ curve. | No peak in P-Δ curve. |
| 5. | Bulging formed in the neighborhood of footing at the surface. | No Bulging observed in the neighborhood of footing. |
| 6. | Extent of horizontal spread of disturbance at the surface large. | Extent of horizontal spread of disturbance at the surface very small. |
| 7. | Observed in shallow foundations. | Observed in deep foundations. |
| 8. | Failure is sudden and catastrophic. | Failure is gradual. |
| 9. | Less settlement, but tilting failure observed. | Large settlement of footing observed. |



## PART-4

*Types of Shallow Foundation, Contact Pressure Under rigid and flexible footing.*

### CONCEPT OUTLINE

**Types of Shallow Foundation :** Following are the types of shallow foundation :

i. Strip footing.
ii. Spread or isolated footing.
iii. Combined footing.
iv. Strap or cantilever footing.
v. Mat or raft foundations.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 2.7.** **What are different types of shallow foundation? Explain with the help of sketches.**

**Answer**

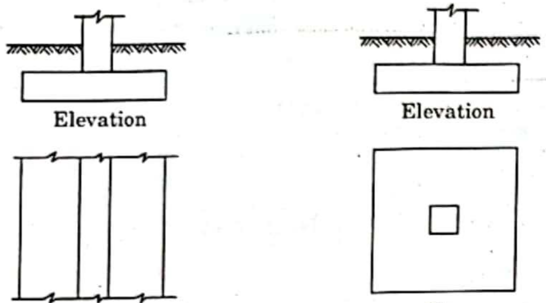
Following are the different types of shallow foundations :

1. **Strip Footing :**

i. A strip footing is provided for a load-bearing wall as shown in Fig. 2.7.1(*a*).
ii. A strip footing is also provided for a row of columns which are so closely spaced that their spread footings overlap or nearly touch each other.
iii. In such a case, it is more economical to provide a strip footing than to provide a number of spread footings in one line. A strip footing is also known as continuous footing.

It is used to support a

single column **2. Spread or Isolated Footing :** A spread (or isolated or pad) footing is provided to support an individual column as shown in Fig. 2.7.1(b). A spread footing is circular, square or rectangular slab of uniform thickness.




(a) Strip footing **Fig. 2.7.1.** (b) Spread footing

**3. Combined Footing :**

i. A combined footing supports two columns as shown in Fig. 2.7.2. It is used when the two columns are so close to each other that their individual footings would overlap.

ii. A combined footing is also provided when the property line is so close to one column that a spread footing would be eccentrically loaded when kept entirely within the property line.

iii. A combined footing may be rectangular or trapezoidal in plan.

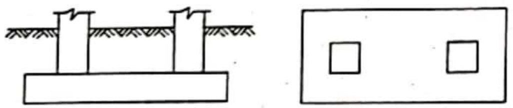



**Fig. 2.7.2.** Combined footing.

**4. Strap or Cantilever Footing :**

i. A strap (or cantilever) footing consists of two isolated footings connected with a structural strap or a lever, as shown in Fig. 2.7.3.

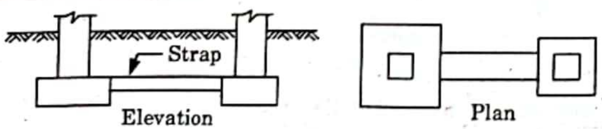



**Fig. 2.7.3.** Strap footing.

ii. The strap connects the two footings such that they behave as one unit.

iii. The strap simply acts as a connecting beam and does not take any soil reaction. The strap is designed as a rigid beam.



**5. Mat or Raft Foundations :**

i. A mat or raft foundation is a large slab supporting a number of columns and walls under the entire structure or a large part of the structure.

ii. A mat is required when the allowable soil pressure is low or where the columns and walls are so close that individual footings would overlap or nearly touch each other.

**Que 2.8.** **What do you understand by contact pressure ? What are the factors that affect the contact pressure distributions ? Draw the contact pressure distribution diagram for flexible and rigid footings on sand and clayey soils.**

**Answer**

नीचला Part

**A. Contact pressure :** The upward pressure due to soil on the underside of the footing is termed as contact pressure.

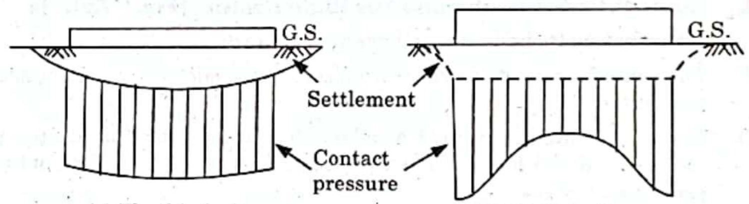
**B. Factors :** Following are the factors affect the contact pressure :

i. Nature of soil (*i.e.*, cohesive on non cohesive soil).

ii. Types of footing (*i.e.*, flexible or rigid footing).

**C. Contact Pressure Distribution Diagrams :**

**1. Contact Pressure on Saturated Clay for Flexible Footing :**




(*a*) Flexible footing (*b*) Rigid footing

**Fig. 2.8.1.** Contact pressure on saturated clay.

i. Fig. 2.8.1 shows the qualitative contact pressure distribution under flexible and rigid footings resting on a saturated clay and subjected to a uniformly distributed load *q*.

ii. When the footing is flexible, it deforms into the shape of a bowel, with the maximum deflection at the centre.

iii. The contact pressure distribution is uniform.

**2. Contact Pressure on Saturated Clay For Rigid Footing [Fig. 2.8.1(b)] :**

i. If the footing is rigid, the settlement is uniform.

ii. The contact pressure distribution is minimum at the centre and the maximum at the edges.

iii. The stresses at the edges in real soils cannot be infinite as theoretically determined for an elastic mass.

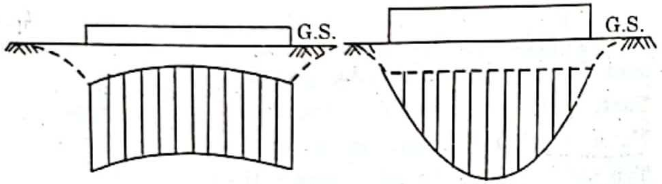
iv. In real soils, beyond a certain limiting value of stress, the plastic flow occurs and the pressure becomes finite.

**3. Contact Pressure on Sand For Flexible Footing :**

i. Fig. 2.8.2 shows the qualitative contact pressure distribution under flexible and rigid footing resting on a sandy soil and subjected to a uniformly distributed load $q$.

ii. In this case, the edges of the flexible footing undergo a large settlement than at the centre.

iii. The contact pressure is uniform.




(*a*) Flexible footing (*b*) Rigid footing

**Fig. 2.8.2.** Contact pressure on sand.

**4. Contact Pressure on Sand For Rigid Footing [Fig. 2.8.2(b)] :**

i. If the footing is rigid, the settlement is uniform.

ii. The contact pressure increase from zero at the edges to a maximum at the centre.

iii. The soil, being unconfined at edges, has low modulus of elasticity. However, if the footing is embedded, there would be finite contact pressure at edges.

## PART-5

*Terzaghi's Bearing Capacity Theory.*

### CONCEPT OUTLINE

Terzaghi's general bearing capacity equation for continuous footing.

$$q_u = CN_c + \bar{\sigma} N_q + 0.5\,\gamma B N_\gamma$$

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**



Notes

**Que 2.9. What are the assumptions made in Terzaghi's analysis of bearing capacity of continuous footing ?**

**AKTU 2015-16, Marks 02**

**OR**

**Show and explain Terzaghi's bearing capacity failure, in soil with the help of their neat sketches. Give $\phi$ values for different types of failure.**

**AKTU 2014-15, Marks 03**

**OR**

**How the ultimate bearing in load shear is determined ?**

**AKTU 2017-18, Marks 05**

**Answer**

**A. Assumptions of Terzaghi's Theory :**

• He ignore side resistance. He considered only base resistance.

1. The base of footing is rough.
2. The footing is laid at a shallow depth, *i.e.*, $D_f \le B$. • footing is continuous
3. The shear strength of the soil above the base of the footing is neglected. The soil above the base is replaced by a uniform surcharge $\gamma D_f$.
4. The load on the footing is vertical and is uniformly distributed.
5. The footing is long *i.e.*, $L/B$ ratio is infinite, where $B$ is the width and $L$ is the length of the footing.
6. The shear strength of the soil is governed by the Mohr-Coulomb equation.

**B. Failure Zones :**

According to Terzaghi the loaded soil fails along the composite surface *FGCDE* as shown in Fig. 2.9.1. Terzaghi divided the stresses below the foundation in 3 zones

**1. Zone-I :** (Central zone or direct shear zone)

i. Zone I-*ABC* is wedge shaped located immediately beneath the footing.

ii. It is assumed that its boundaries *AC* and *BC* are plane surfaces and the angle *CAB* and *CBA* are equal to the angle of shearing resistance $\phi$ of the soil.

iii. The soil in Zone I is prevented from undergoing any lateral yield by the friction and adhesion between the soil and the base of the footing.

iv. Thus the soil in Zone I remain in a state of elastic equilibrium, and it behaves as it were a part of the footing.

**2. Zone-II :** (Radial shear zone)

i. Zone II-*BCD* and *ACG* are called the radial shear zones, because the lines that constitute one set of shear pattern are straight radial lines, while the lines of the other set are logarithmic spirals.

ii. Thus boundaries *AC*, *AG* and *BC*, *BD* of these zones are the plane surfaces while the boundaries *CG* and *CD* are the arcs of a logarithmic spiral.

3. **Zone-III :** (Rankin passive zone)

i. Zones III-$AGF$ and $BDE$ called zones of linear shear are triangular in shape.

ii. These are passive Rankine zones with their boundaries making angles $\left(45° - \frac{\phi}{2}\right)$ with the horizontal.

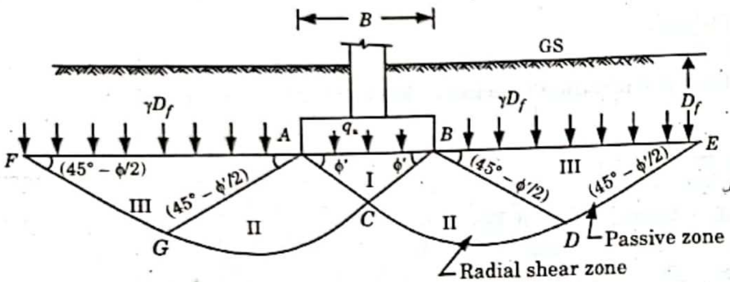



**Fig. 2.9.1.** Terzaghi's analysis.

**C. Terzaghi's Bearing Capacity Equation :**

i. Ultimate bearing capacity is given by,

$$q_u = CN_c + \gamma D_f N_q + 0.5\,\gamma B N_\gamma$$

where, $\sigma = \gamma D_f$ = Overburden pressure.
$B$ = Width of footing.
$\gamma$ = Unit weight of soil.
$C$ = Cohesion of soil.

ii. The bearing capacity factors $N_c$, $N_q$ and $N_\gamma$ are the dimensionless numbers depending upon the angle of shearing resistance ($\phi'$) of the soil.

**D. Determination of Ultimate Bearing Capacity in Local Shear Failure :**

i. Terzaghi proposed empirical adjustments to the shear strength parameters $C$ and $\phi$ to cover the case of local shear failure.

ii. Shear strength parameters $C_m$ and $\phi_m$ should be used in the bearing capacity equation and the bearing capacity factors are determined on the basis of $\phi_m$ instead of $\phi$, where

$$C_m = (2/3)C$$
$$\tan\phi_m = (2/3)\tan\phi$$

iii. The bearing capacity factors corresponding to local shear failure are indicated as $N_c'$, $N_q'$ and $N_\gamma'$.

iv. The ultimate bearing capacity of strip footing for local shear failure is given by,

$$q_u = (2/3)CN_c' + \sigma N_q' + 0.5\gamma B N_\gamma'$$

**E. ϕ Values :**

i. For a sand soil $\phi \geq 36°$ indicates a dense sand and general shear failure.

ii. $\phi' \leq 29°$ indicates a loose sand and local shear failure.



**Que 2.10.** **Write the short note on effect of water table on bearing capacity.**

**OR**

**How will you modify the bearing capacity equations for the different cases of water table location ?** **AKTU 2014-15, Marks 03**

**Answer**

**Effect of Water Table on Bearing Capacity :**

1. Bearing capacity is the maximum stress at which a particular soil can withstand without failing.
2. The position of ground water has a significant effect on the bearing capacity of soil. Following are two cases w.r.t the position of water table :

**i. When Water Table is Located above the Base of Footing (Fig. 2.10.1) :**

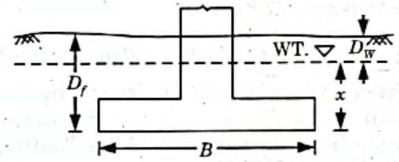



**Fig. 2.10.1.**

a. The effective surcharge is reduced as the effective weight below water table is equal to submerged unit weight.

$$q = D_w\gamma + x\,\gamma_{sub}$$

where, $D_w$ = Depth of water table below the ground surface.
$x$ = Height of water table above the base of footing.

b. Put
$$x = D_f - D_w$$
$$q = \gamma_{sub} D_f + (\gamma - \gamma_{sub}) D_w$$

c. Thus,
$$q_u = C' N_c + [\gamma_{sub} D_f + (\gamma - \gamma_{sub}) D_w] N_q + 0.5\,\gamma_{sub} B N_\gamma \quad ...(2.10.1)$$

d. When, $D_w = 0$
$$q_u = C' N_c + \gamma_{sub} D_f N_q + 0.5\,\gamma_{sub} B N_\gamma \quad ...(2.10.2)$$

f. When, $x = 0$
$$q_u = C' N_c + \gamma D_f N_q + 0.5\,\gamma_{sub} B N_\gamma \quad ...(2.10.3)$$

**ii. When Water Table is Located at a Depth y below Base (Fig. 2.10.2) :**

a. If the water table is located at the level of the base of footing or below it, the surcharge term is not affected.

b. Unit weight in term in bearing capacity equation is modified as :
$$\gamma = \gamma_{sub} + y(\gamma - \gamma_{sub})/B$$

c. Thus, $q_u = C' N_c + \gamma D_f N_q + 0.5B \gamma N_\gamma$

d. When $y = 0$, *i.e.*, water table at the base

$$q_u = C' N_c + \gamma D_f N_q + 0.5B\gamma' N_\gamma$$

e. When $y = B$ *i.e.*, water table at depth $B$ below the base of footing.

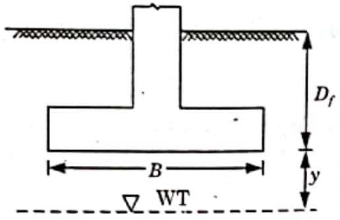



Fig. 2.10.2.

$$q_u = C' N_c + \gamma D_f N_q + 0.5 B\gamma N_\gamma$$

f. Hence, when ground water table is at a depth $y \geq B$, then ultimate bearing capacity is not affected.

**Que 2.11.** **A square footing of 3.0 m × 3.0 m size has been founded at 1.2 m below the ground level in a cohesive soil having a bulk density of 1.8 t/m³ and an unconfined compressive strength of 5.5 t/m². Determine the safe bearing capacity of the footing for a factor of safety of 2.5 by Skempton's method.**

**AKTU 2015-16, Marks 05**

**Answer**

**Given :** Size of footing = 3 m × 3 m, Depth of footing, $D_f$ = 1.2 m
Density of clay, $\rho$ = 1.8 t/m³, Unconfined compressive strength, $q_u$ = 5.5 t/m², Factor of safety = 2.5
**To Find :** Capacity of footing by Skempton's method.

1. Cohesion, $C_u = \dfrac{q_u}{2} = \dfrac{5.5}{2} \times 10 = 27.5 \text{ kN/m}^2$

For $\dfrac{D_f}{B} = \dfrac{1.2}{3} = 0.4 < 2.5$

2. Bearing capacity factor,

$$N_c = 6\left[1 + 0.2 \times \frac{D_f}{B}\right] = 6\left[1 + 0.2 \times \frac{1.2}{3}\right] = 6.48$$

3. Net bearing capacity,

$$q_{nu} = C_u N_c = 27.5 \times 6.48 = 178.2 \text{ kN/m}^2$$

4. Safe bearing capacity,

$$q_{ns} = \frac{178.2}{2.5} = 71.28 \text{ kN/m}^2$$



**Que 2.12.** **A foundation in sand will be 5 metres wide and 1.5 meters deep. Adopting a factor of safety of 2.5, what will be safe bearing capacity if the unit weight of the sand is 1.9 gm/cc and angle of internal friction is 35°. How does it compare with safe bearing capacity for surface loading ?**

**$N_c = 57$, $N_q = 44$, $N_y = 42$.** **AKTU 2013-14, Marks 06**

**Answer**

**Given :** Angle of internal friction, $\phi = 35°$, Unit weight of sand, = 19 kN/m³, Width of footing, $B$ = 5 m, Depth of footing, $D_f$ = 1.5 m, Factor of safety, $F_s$ = 2.5, For sand (non-cohesive soil), $C = 0$,
For $\phi = 35°$, $N_c = 57$, $N_q = 44$, $N_\gamma = 42$
**To Find :** Safe bearing capacity.

1. Safe bearing capacity ($q_s$) for ~~rectangular~~ square footing,
Ultimate bearing capacity,

$$q_u = \bar{\sigma} N_q + 0.4\gamma B N_\gamma = \gamma D N_q + 0.4\gamma B N_\gamma$$
$$= (19 \times 1.5 \times 44) + (0.4 \times 19 \times 5 \times 42)$$
$$= 1254 + 1596 = 2850 \text{ kN/m}^2$$

2. Net bearing capacity, $q_{nu} = q_u - \gamma D$
$$= 2850 - 19 \times 1.5 = 2821.5 \text{ kN/m}^2$$

3. Safe bearing capacity, $q_s = \dfrac{q_{nu}}{F_s} + \gamma D = \dfrac{2821.5}{2.5} + (19 \times 1.5)$
$$q_s = 1128.6 + 28.5 = 1157.1 \text{ kN/m}^2$$

**Que 2.13.** **Determine the ultimate bearing capacity of the footing, 1.5 m wide and its base at a depth of 1 m, if the ground water table is located :**

**i. At a depth of 0.5 m below the ground surface.**

**ii. At a depth of 0.5 m below the base of the footing.**

**$\gamma_{sat}$ = 20 kN/m³.**
**$\gamma_d$ = 17 kN/m³, $\phi$ = 38° and $C$ = 0. Use Terzaghi's theory.**
**$N_q$ = 60 and $N_\gamma$ = 75.**

**AKTU 2013-14, Marks 06**

**Answer**

**Given :** Width of footing, $B$ = 1.5 m, Depth of footing, $D$ = 1.0 m
Unit weight of saturated soil, $\gamma_{sat}$ = 20 kN/m³, Unit weight of dry soil, $\gamma_d$ = 17 kN/m³, Angle of internal friction, $\phi = 38°$, $N_q = 60$, $N_\gamma = 75$
**To Find :** Ultimate bearing capacity.

1. **When Water Table is above Footing :**

i. Correction factor, $R_w = 0.5$

ii. Ultimate bearing capacity is given by,

$$q_u = \bar{\sigma} N_q + \frac{1}{2} B \gamma N_\gamma R_w$$

Net stress, $\bar{\sigma} = 0.5 \times 17 + 0.5 \times (20 - 9.81) = 13.595 \text{ kN/m}^2$

$$q_u = 13.595 \times 60 + (1/2) \times 1.5 \times 20 \times 75 \times 0.5$$
$$= 1378.2 \text{ kN/m}^2$$

2. **When Water Table in below the Footing Base :**

i. $z_w = 1.5 - 1 = 0.5$

ii. Correction factor, $R_w = 0.5\left[1 + \frac{z_w}{B}\right]$

$$R_w = 0.5\left[1 + \frac{0.5}{1.5}\right] = 0.667$$

iii. Average density, $\gamma_{av} = \frac{0.5 \times 17 + 0.5 \times 20}{0.5 + 0.5} = 18.5 \text{ kN/m}^3$

iv. Ultimate bearing capacity,

$$q_u = \gamma_d D N_q + \frac{1}{2} B \gamma_{av} N_\gamma R_w$$
$$q_u = 17 \times 1 \times 60 + (1/2) \times 1.5 \times 18.5 \times 75 \times 0.667$$
$$= 1714 \text{ kN/m}^2$$

## PART-6

*Meyerhof's Bearing Capacity Theory.*

### CONCEPT OUTLINE

**Meyerhof's Analysis :** Meyerhof has presented a simple general bearing capacity equation for the bearing capacity of shallow foundation.

$$q_u = CN_c s_c d_c i_c + \sigma N_q s_q d_q i_q + 0.5 \gamma B N_\gamma s_\gamma d_\gamma i_\gamma$$

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 2.14.** **Discuss the Meyerhof's analysis of bearing capacity for shallow foundations.**



**Answer**

1. Meyerhof gave a comprehensive analysis for the bearing capacity of a strip footing at any depth.
2. The failure mechanism that he envisaged was similar to Terzaghi's, but Meyerhof considered failure surfaces that extended above the foundation level.
3. Hence, the shearing resistance of the soil above the base of the foundation is also taken into account in Meyerhof's analysis.
4. Meyerhof has presented a simple general bearing capacity equation for the bearing capacity of shallow foundations in the form.

$$q_u = CN_c s_c d_c i_c + \sigma N_q s_q d_q i_q + 0.5 \gamma B N_\gamma s_\gamma d_\gamma i_\gamma$$

i. Symbols $s$, $d$ and $i$ stand for empirical correction factors called the shape factor, depth factor and inclination factor, respectively.

ii. Bearing capacity factors $N_c$ and $N_q$ are the same as proposed by Prandtl and Reissner,

$$N_c = (N_q - 1) \cot \phi$$
$$N_q = e^{(\pi \tan \phi)} \tan^2 (45 + \phi/2)$$

iii. $N_\gamma$ was approximately established by Meyerhof as,

$$N_\gamma = (N_q - 1) \tan (1.4 \phi)$$

5. **Table : 2.14.2.** Meyerhof's correction factors.

| S. No. | Factors | Expression |
|---|---|---|
| i. | $s_c, s_q, s_\gamma$ | 1 for strip footings |
| ii. | $s_c$ | $1 + 0.2 \frac{B}{L} \tan^2\left(45° + \frac{\phi}{2}\right)$ |
| iii. | $s_q, s_\gamma$ | $1 + 0.1 \frac{B}{L} \tan^2\left(45° + \frac{\phi}{2}\right)$ for $\phi > 10°$<br>1 for $\phi = 0$ |
| iv. | $d_c$ | $1 + 0.2 \frac{D}{B} \tan\left(45° + \frac{\phi}{2}\right)$ |
| v. | $d_q, d_\gamma$ | $1 + 0.1 \frac{D}{B} \tan\left(45° + \frac{\phi}{2}\right)$ for $\phi > 10°$<br>1 for $\phi = 0$. |
| vi. | $i_c, i_q$ | $\left(1 - \frac{\alpha}{90}\right)^2$ $\alpha$ in degree |
| vii. | $i_\gamma$ | $\left(1 - \frac{\alpha}{\phi}\right)^2$ |

**Que 2.15.** **A chimney, with a rigid base 2.5 m square, is placed at a depth of 1 m below the ground surface. The soil is clay with an unconfined compressive strength of 60 kN/m² and unit weight of 20 kN/m³. The weight of the chimney is 60 kN. The chimney has a resultant wind load of 19.5 kN/m² acting parallel to one of the sides of the chimney base at a height of 1.5 m above the ground surface. Determine the factor of safety with respect to bearing capacity. Use Meyerhof's recommendations.**

**Answer**

**Given :** Width of footing = 2.5 m

Unconfined strength of clay = 60 kN/m²

Unit weight of soil = 20 kN/m³, Weight of chimney = 60 kN

Wind load = 19.5 kN.

**To Find :** Factor of safety.

1. The horizontal wind load will have the effect of introducing both inclination and eccentricity of loading.
2. The resultant of the wind load and weight force will be inclined at an angle α to the vertical.

$$\tan\alpha = \frac{\text{Horizontal wind force}}{\text{Vertical weight force}} = \frac{19.5}{60} = 0.325$$

$$\alpha = 18°$$

3. Height of horizontal load above the base = 1.5 + 1 = 2.5 m. Eccentricity of the resultant load, $e$ can be calculated from,

$$\frac{e}{2.5} = \tan\alpha = 0.325$$

$$e = 2.5 \times 0.325 = 0.81 \text{ m}$$

4. Reduced dimension $B'$ on account of eccentricity of loading is given by,

$$B' = B - 2e = 2.5 - 2 \times 0.81 = 0.88 \text{ m}$$

5. Area, $A' = B'L = 0.88 \times 2.5 = 2.2 \text{ m}^2$
6. For $\phi = 0°, N_c = 5.14, N_q = 1,$ $N_\gamma = 0, \tan(45° + \phi/2) = 1$
7. Correction factors :

i. $$s_c = 1 + 0.2\frac{B'}{L}\tan^2(45° + \phi/2) = 1 + 0.2 \times \frac{0.88}{2.5} = 1.07$$

ii. $s_q = 1,$

iii. $$d_c = 1 + 0.2 \times \frac{D}{B'}\tan(45° + \phi/2)$$

$$= 1 + 0.2 \times \frac{1}{0.88} = 1.23$$



iv. $d_q = 1$

v. $$i_c = i_q = \left(1 - \frac{\alpha}{90}\right)^2 = \left(1 - \frac{18°}{90°}\right)^2 = 0.64$$

8. Ultimate bearing capacity,

$$q_u = CN_c s_c d_c i_c + \sigma N_q s_q d_q i_q \text{ (since } N_\gamma = 0)$$

$$C_u = \frac{60}{2} = 30 \text{ kN/m}^2$$

$$q_u = (30 \times 5.14 \times 1.07 \times 1.23 \times 0.64) + (20 \times 1 \times 1 \times 1 \times 0.64)$$

$$= 129.9 + 12.8 = 142.7 \text{ kN/m}^2$$

9. Ultimate load, $Q_u = q_u A' = 142.7 \times 2.2 = 314$ kN
10. Factor of safety $= \frac{314}{60} = 5.23.$

## PART-7

*Hansen's Bearing Capacity Theory.*

### CONCEPT OUTLINE

**Hansen's Recommendation :** Hansen proposed a bearing capacity equation in the form of,

$$q_u = CN_c s_c d_c i_c + \sigma N_q s_q d_q i_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma$$

For $\phi = 0$, Hansen recommends the equations,

$$q_u = CN_c(1 + s_c + d_c - i_c) + \sigma$$

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 2.16.** **Write the Hansen's bearing capacity equation along with the detailed equation of their correction factors.**

**Answer**

1. Hansen has proposed a general bearing capacity equation similar to Meyerhof's simplified recommendations.
2. For cohesive soils, Hansen's theory gives better correlations than the Terzaghi equations.
3. Hansen proposed a bearing capacity equation in the form of,

$$q_u = CN_c s_c d_c i_c + \sigma N_q s_q d_q i_q + 0.5\gamma BN\gamma s_\gamma d_\gamma i_\gamma$$

where $s$, $d$ and $i$ are respectively Hansen's shape, depth and inclination factors.

4. The above equation is applicable only for $\phi > 0$. For $\phi = 0$, Hansen recommends the equation,

$$q_u = CN_c(1 + s_c + d_c - i_c) + \sigma$$

5. $N_c$, $N_q$ and $N_\gamma$ are Hansen's bearing capacity factors. The recommendations of Hansen for $N_c$ and $N_q$ are identical to those of Meyerhof and are due to Prandtl and Reissner.

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

$$N_q = (\exp.\pi\tan\phi)\tan^2(45° + \phi/2)$$

$$N_\gamma = 1.5\,(N_q - 1)\tan\phi$$

6. Hansen's shape, depth and inclination factors are given in Table 2.16.1.

For a circular foundation, $B$ is the diameter of the footing. $V$ and $H$ are the vertical and horizontal components of the inclined load. When eccentric loads are acting, $B$ and $L$ have to be substituted by modified dimensions $B'$ and $L'$.

**Table 2.16.1.** Hansen's correction factors.

| S.No. | Shape Factors | Depth Factors | Inclination Factors |
|---|---|---|---|
| 1. | $s_c = 0.2\,i_c \frac{B}{L}$<br>for $\phi = 0$<br>$s_c = 0.2(1 - 2i_c)\frac{B}{L}$<br>for $\phi > 0$ | $d_c = 0.4\frac{D}{B}$<br>for $D \le B$ and $\phi = 0$<br>$d_c = 0.4\tan^{-1}\frac{D}{B}$<br>for $D > B$ and $\phi = 0$<br>$d_c = 1 + 0.4\frac{D}{B}$<br>for $D \le B$ and $\phi > 0$<br>$d_c = 1 + 0.4\tan^{-1}\frac{D}{B}$<br>for $D > B$ and $\phi > 0$ | $i_c = 1 - \left[\frac{H}{2BLC}\right]$<br>for $\phi = 0$<br>$i_c = 0.5\left[1 + \left\{\frac{1-H}{BLS_u}\right\}^{1/2}\right]$<br>for $\phi > 0$ |
| 2. | $s_q = 1 + i_q\left(\frac{B}{L}\right)\sin\phi$ | $d_q = 1 + 2\tan\phi \times$<br>$(1 - \sin\phi)^2\left(\frac{D}{B}\right)$ for $D \le B$<br>$d_q = 1 + 2\tan\phi(1 - \sin\phi)^2$<br>$\times \tan^{-1}\left(\frac{D}{B}\right)$ for $D > B$ | $i_q = \left[1 - \left\{\frac{0.5H}{V + BLc\cot\phi}\right\}\right]^5$ |
| 3. | $s_\gamma = 1 - 0.4\,i_\gamma\left(\frac{B}{L}\right)$ | $d_\gamma = 1$ | $i_\gamma = \left[1 - \left\{\frac{0.7H}{V + BLc\cot\phi}\right\}\right]^5$ |



**Que 2.17.** **A square footing 1.5 m × 1.5 m is located at a depth of 1 m. The soil has the following properties, $\gamma = 17.5$ kN/m³, $C = 0$ and $\phi = 35°$. Use Hansen's method to compute the ultimate bearing capacity of the soil. The footing base and ground are horizontal.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given:** Size of footing, $L \times B = 1.5 \times 1.5$ m
Depth of footing, $D_f = 1$ m, Unit weight of soil, $\gamma = 17.5$ kN/m³
Cohesion of soil, $C = 0$, Angle of internal friction, $\phi = 35°$
**To Find :** Ultimate bearing capacity.

1. For $\phi = 35°$, bearing capacity factor is calculated as :

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

$$N_q = e^{(\pi\tan 35°)}\tan^2\left(45° + \frac{35°}{2}\right) = 33.296$$

ii. $$N_c = (N_q - 1)\cot\phi = (33.296 - 1)\cot 35° = 46.12$$

iii. $$N_\gamma = 1.8\,(N_q - 1)\tan\phi$$

$$= 1.8 \times (33.296 - 1)\tan 35° = 40.7$$

2. Bearing capacity equation is given by,

$$q_u = CN_c s_c d_c i_c + qN_q s_q d_q i_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma$$

3. Bearing capacity correction factors :

i. $$d_q = 1 + 2 \times \tan\phi \times (1 - \sin\phi)^2\,\frac{D_f}{B}$$

$$= 1 + 2 \times \tan 35° \times (1 - \sin 35°)^2 \times \frac{1}{1.5} = 1.17$$

ii. $d_\gamma = 1$ (for square footing)

iii. $$i_q = \left[1 - \left\{\frac{0.5H}{V + BLC\cot\phi}\right\}\right]^5 = \left[1 - \frac{0.5H}{H + 0}\right]^5 \quad [\because C = 0]$$

$$= 0.03125 \quad [\because H = V]$$

iv. $$i_\gamma = \left[1 - \left\{\frac{0.7H}{V + BLC\cot\phi}\right\}\right]^5 = [1 - 0.7]^5 = 0.00243$$

v. $$s_q = 1 + i_q\left(\frac{B}{L}\right)\sin\phi = 1 + 0.03125 \times \left(\frac{1.5}{1.5}\right)\sin 35° = 1.018$$

vi. $$s_\gamma = 1 - 0.4\,i_\gamma\left(\frac{B}{L}\right) = 1 - 0.4 \times 0.00243 \times \frac{1.5}{1.5} = 0.999$$

4. $$q_u = \gamma D_f N_q s_q d_q i_q + 0.5\,B\gamma N_\gamma s_\gamma d_\gamma i_\gamma \quad [\because C = 0]$$

$= 17.5 \times 1 \times 33.296 \times 1.018 \times 1.17 \times 0.03125 + 0.5 \times 1.5 \times 17.5 \times 40.7 \times 0.999 \times 1 \times 0.00243 = 22.98\ kN/m^2$

## PART-8

*IS Code Method.*

### CONCEPT OUTLINE

**IS Code Recommendations for Bearing Capacity :** IS Code : 6403-1981 recommends that for the computation of the net ultimate bearing capacity of a shallow foundation in general shear failure.

$$q_{nu} = CN_c s_c d_c i_c + \sigma(N_q - 1)s_q d_q i_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma W'$$

$W'$ is a factor which takes into account the effect of water table.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 2.18.** **Discuss the BIS method of bearing capacity of shallow foundation.**

**Answer**

1. IS : 6403-1981 recommends that for the computation of the net ultimate bearing capacity of a shallow foundation in general shear failure, equation may be used.

$$q_{nu} = CN_c s_c d_c i_c + \sigma(N_q - 1)s_q d_q i_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma W'$$

where, $q_{nu}$ = Net ultimate bearing capacity.

$N_c$, $N_q$ and $N_\gamma$ = Bearing capacity factors.

$W'$ = Factor which takes into account the effect of water table.

i. $W' = 1$, if the water table is likely to remain permanently at or below a depth $(D_f + B)$ below ground level or for $D_w' \geq B$ where $D_w'$ is the depth of water table measured from the base of the foundation.

ii. For $D_w' = 0, W' = 0.5$.

iii. $W'$ can be linearly interpolated between 0 and 1 if $0 < D_w' < B$.

iv. Equivalent value of $\gamma$ as given in equation, $\gamma = \gamma' + \dfrac{D_w'}{B}(\gamma_t - \gamma')$.

v. In the second term of IS code equation, the influence of water table is taken care of by taking $\sigma$ as the effective surcharge at the level of the base of the footing.



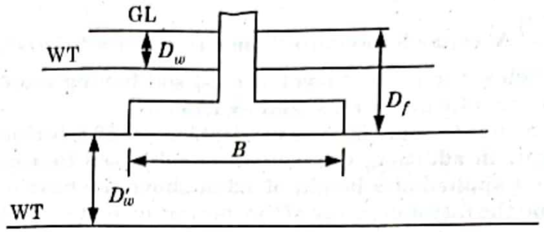



**Fig. 2.18.1.**

2. For local shear failure, the recommendations of IS : 6403-1981 are given below :

$$C' = (2/3)C$$
$$\tan\phi' = (2/3)\phi$$

3. For a cohesive soil, the net ultimate bearing capacity of a footing immediately upon construction ($\phi_u = 0$ condition) is given by the equation,

$$q_{nu} = C_u N_c s_c d_c i_c$$

where, $N_c = 5.14$ and $s_c$, $d_c$, $i_c$ are the shape, depth and inclination factors given by table 2.18.1.

**Table 2.18.1.** Shape, depth and inclination factors as per IS : 6403-1981.

| S.No. | Factors | Value |
|---|---|---|
| i. | $s_c$ | $1+0.2\dfrac{B}{L}$ for rectangle<br>1.3 for square and circle |
| ii. | $s_q$ | $1+0.2\dfrac{B}{L}$ for rectangle<br>1.2 for square and circle |
| iii. | $s_\gamma$ | $1-0.4\dfrac{B}{L}$ for rectangle<br>0.8 for square and 0.6 for circle |
| iv. | $d_c$ | $1+0.2\dfrac{D_f}{B}\tan\left(45° + \dfrac{\phi}{2}\right)$ |
| v. | $d_q = d_\gamma$ | $1+0.1\dfrac{D_f}{B}\tan\left(45° + \dfrac{\phi}{2}\right)$ for $\phi > 10°$<br>1 for $\phi < 10°$ |
| vi. | $i_c = i_q$ | $\left(1-\dfrac{\alpha}{90}\right)^2$ |
| vii. | $i_\gamma$ | $\left(1-\dfrac{\alpha}{\phi}\right)^2$ $\alpha$ in degrees |

**Que 2.19.** **A rectangle footing of 2.5 m × 4.0 m size is to be constructed at 1.8 m below the ground level in a c-$\phi$ soil having the following properties : $c = 1.0$ t/m², $\phi = 20°$ and $\gamma = 1.75$ t/m³. The footing has to carry a gross vertical load of 80 t, inclusive of its self-weight. In addition, the column is subjected to a horizontal load of 10 t applied at a height of 3.3 m above the base of footing. Determine the factor of safety of the footing against shear failure as per IS : 6403-1981.**

**AKTU 2015-16, Marks 15**

**Answer**

**Given :** Height of horizontal load above the base = 3.3 m
Length of footing, $L = 4$ m, Width of footing, $B = 2.5$ m,
For $\phi = 20°$, $N_c = 14.8$, $N_q = 6.4$, $N_\gamma = 5.4$
**To Find :** Factor of safety.

Assume water table is situated at well below the base of footing ($\because W' = 1$)

1. $$\tan\alpha = \frac{\text{Horizontal force}}{\text{Vertical force}}$$
$$\tan\alpha = \frac{10}{80} = 0.125$$
$$\alpha = 7.12° \approx 7°$$
2. Eccentricity ($e$) of the resultant load can be calculated as,
$$e/3.3 = \tan\alpha = 0.125$$
3. Eccentricity, $e = 3.3 \times 0.125 = 0.41$ m
4. Reduced dimension $B'$ an account of eccentricity of loading is given by,
$$B' = B - 2e = 2.5 - 2 \times 0.41 = 1.68 \text{ m}$$
5. Corrected Area,
$$A' = B'L = 1.68 \times 4 = 6.72 \text{ m}^2$$
6. Shape factors : $$s_c = 1 + 0.2\frac{B'}{L} = 1 + 0.2\left(\frac{1.68}{4}\right) = 1.084$$
$$s_q = 1 + 0.2\frac{B'}{L} = 1 + 0.2\left(\frac{1.68}{4}\right) = 1.084$$
$$s_\gamma = 1 - 0.4\frac{B'}{L} = 1 - 0.4\left(\frac{1.68}{4}\right) = 0.832$$
7. Depth factors : $$d_q = d_\gamma = 1 + 0.1\frac{D_f}{B'}\tan\left(45 + \frac{\phi}{2}\right)$$
$$= 1 + 0.1 \times \frac{1.8}{1.68}\tan\left(45 + \frac{20}{2}\right) = 1.153$$



$$d_c = 1 + 0.2 \times \frac{D_f}{B}\tan\left(45 + \frac{\phi}{2}\right)$$
$$= 1 + 0.2 \times \frac{1.8}{1.68}\tan\left(45 + \frac{20}{2}\right) = 1.30$$

8. Inclination factors :
$$i_c = i_q = \left(1 - \frac{\alpha}{90}\right)^2 = \left(1 - \frac{7°}{90°}\right)^2 = 0.85$$
$$i_\gamma = \left(1 - \frac{\alpha}{\phi}\right)^2 = \left(1 - \frac{7°}{20°}\right)^2 = 0.4225$$
9. Bearing capacity of rectangular footing,
$$q_{nu} = CN_c s_c d_c i_c + \sigma(N_q - 1)s_q d_q i_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma W'$$
Cohesion of soil, $C = 10$ kN/m²
10. Unit weight of soil, $\gamma = 17.5$ kN/m³
$$\sigma = \gamma D_f = 17.5 \times 1.8 = 31.5 \text{ kN/m}^2$$
$$q_{nu} = 10 \times 14.8 \times 1.084 \times 1.30 \times 0.85 + 31.5\,(6.4 - 1) \times 1.084 \times 1.153 \times 0.85 + 0.5 \times 17.5 \times 1.68 \times 5.4 \times 0.832 \times 1.153 \times 0.4225 \times 1$$
$$q_{nu} = 390.16 \text{ kN/m}^2$$
$$Q_u = q_{nu}A' = 390.16 \times 6.72 = 2621.88 \text{ kN}$$
11. $$\text{Factor of safety} = \frac{2621.88}{800} = 3.28$$

**Que 2.20.** **A rectangular footing has a size of 1.8 m × 3 m has to transmit the load of a column at a depth of 1.5 m. Calculate the safe load which the footing can carry at a factor of safety of 3 against shear failure. Use IS code method. The soil has following properties : Porosity, $n$ = 40 %, Specific gravity, $G$ = 2.67, Water content, $w$ = 15%, Cohesion, $c$ = 8 kN/m², Angle of shearing resistance, $\phi = 32°$. For $\phi = 32°$, $N_c = 36$, $N_q = 23$ and $N_\gamma = 30$.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Size of footing, = 1.8 m × 3 m, Depth, $D = 1.5$ m,
FOS = 3, Porosity, $n$ = 40 %, Specific gravity, $G = 2.67$,
Water content, $w$ = 15 %, Cohesion, $C = 8$ kN/m²,
Angle of shearing resistance, $\phi = 32°$, $N_c = 36$, $N_q = 23$ and $N_\gamma = 30$.
**To Find :** Safe load by IS method.

Assume water table is situated at well below the base of footing ($\because W' = 1$)

1. Ultimate bearing capacity,
$$q_{nu} = CN_c s_c d_c i_c + \sigma(N_q - 1)\, s_q d_q i_q + 0.5\, B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'$$
2. For vertical load, inclination factors :

$$i_c = i_q = i_\gamma = 1$$

3. Shape factors : $s_c = 1 + 0.2\, B/L = 1 + 0.2 \times \dfrac{1.8}{3} = 1.12$

$$s_q = 1 + 0.2 \times B/L = 1 + 0.2 \times \frac{1.8}{3} = 1.12$$

$$s_\gamma = 1 - 0.4 \times B/L = 1 - 0.4 \times \frac{1.8}{3} = 0.76$$

4. Depth factors : $d_c = 1 + 0.2\,(D/B) \tan(45° + \phi/2)$

$$= 1 + 0.2 \times \frac{1.5}{1.8} \times \tan\left(45° + \frac{32°}{2}\right) = 1.3$$

$$d_q = d_\gamma = 1 + 0.1\,(D/B) \tan(45° + \phi/2)$$

$$= 1 + 0.1 \times \left(\frac{1.5}{1.8}\right) \tan\left(45° + \frac{32°}{2}\right) = 1.15$$

5. Saturated weight,

$$\gamma_{sat} = \frac{(1+w)\,G\,\gamma_w}{1+wG} = \frac{(1+0.15) \times 2.67 \times 10}{1 + 0.15 \times 2.67}$$

$$\gamma_{sat} = 21.92 \text{ kN/m}^3$$

6. $q_{nu} = 8 \times 36 \times 1.12 \times 1.3 \times 1 + (21.92 \times 1.5) \times (23 - 1) \times 1.12 \times 1.15 \times 1 + 0.5 \times 1.8 \times 21.92 \times 30 \times 0.76 \times 1.15 \times 1 \times 1$

$$q_{nu} = 1868.3 \text{ kN/m}^2$$

7. Safe load bearing capacity $= \dfrac{1868.3}{3} = 622.77 \text{ kN/m}^2$

8. Safe load $= 622.77 \times (1.8 \times 3) = 3362.958 \text{ kN} \approx 3363 \text{ kN}$

Note

**PART-9**

*Components of Settlements.*

**CONCEPT OUTLINE**

**Settlement of Foundation :** Foundation settlement under loads can be classified into three types :

i. Immediate or elastic settlement ($S_i$),
ii. Consolidation settlement ($S_c$), and
iii. Secondary consolidation settlement ($S_s$).

**Total settlement :** Total settlement is given by,

$$S = S_i + S_c + S_s$$

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**



**Que 2.21.** **Write short notes on :**

**i. Immediate or elastic settlement ($S_i$)**
**ii. Consolidation settlement ($S_c$)**
**iii. Secondary consolidation settlement ($S_s$)**

**Answer**

**Settlement under Loads :** Foundation settlement under loads can be classified into three types :

1. **Immediate or Elastic Settlement ($S_i$) :**

i. Immediate or elastic settlement takes place during or immediately after the construction of the structure.

ii. It is also known as the distortion settlement as it is due to distortions (and not the volume change) within the foundation soil.

iii. Although the settlement is not truly elastic, it is computed using elastic theory, especially for cohesive soils.

2. **Consolidation Settlement ($S_c$) :** Consolidation settlement occurs due to gradual expulsion of water from the voids of the soil. This component is determined using Terzaghi's theory of consolidation.

3. **Secondary Consolidation Settlement ($S_s$) :**

i. This component of the settlement is due to secondary consolidation.

ii. This settlement occurs after completion of the primary consolidation.

iii. It can be determined from the coefficient of secondary consolidation.

iv. The secondary consolidation is not significant for inorganic clays and silty soils.

4. The total settlement (S) is given by,

$$S = S_i + S_c + S_s$$

**Que 2.22.** **Give all steps to calculate the elastic settlement of sandy soil by using strain influence factor. Also show the variation of the strain influence factor with Z.** **AKTU 2014-15, Marks 06**

**OR**

**Discuss the Schmertmann's method by determining settlement of footing in cohesionless soils.** **AKTU 2016-17, Marks 05**

**Answer**

**Immediate Settlement of Cohesionless Soils :**

1. As cohesionless soils do not follow Hooke's law, immediate settlements are computed using a semi-empirical approach proposed by Schmertmann and Hartman.

$$S_i = C_1C_2(\bar{\sigma}-\sigma)\sum_{z=0}^{2B}\frac{I_z}{E_s}\Delta z$$

where, $C_1$ = Correction factor for the depth of foundation embedment $= 1 - 0.5\,\{\sigma/(\bar{\sigma} - \sigma)\}$

$C_2$ = Correction factor for creep in soils [$= 1 + 0.2 \log_{10}$ (time in years/0.1)].

$\bar{\sigma}$ = Pressure at the level of the foundation.

$\sigma$ = Surcharge ( $= \gamma D_f$).

$E_s$ = Modulus of elasticity.

$I_z$ = Strain influence factor.

2. The value of the strain-influence factor $I_z$ varies linearly for a square or circular foundation as shown in Fig. 2.22.1.
3. The value of $I_z$ at depth $z = 0, 0.5\,B$ and $2B$ are respectively equal to 0.1, 0.5 and 0.0.
4. For rectangular foundations, with $L/B$ ratio equal to or greater than 10.0, the values at depth $z = 0.0$, $B$, and $4B$ are, respectively, 0.2, 0.5 and 0.0. For intermediate values of $L/B$ ratio, between 1.0 and 10.0, interpolation can be made.
5. The value of $E_s$ can be determined from the standard penetration number ($N$) using the following equations given by Schmertmann :

$$E_s = 766\,N\ (\text{kN/m}^2)$$

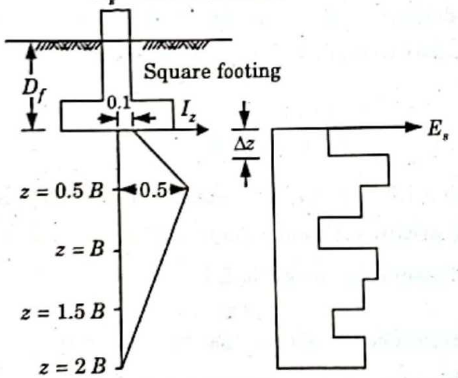



**Fig. 2.22.1.**

6. Alternatively, it can be estimated from the static cone penetration resistance ($q_c$) as,

$$E_s = 2q_c$$

**Procedure :**

i. For computation of the immediate settlement, the soil layer is divided into several layers of thickness $\Delta z$, upto a depth $z = 2B$, in case of square footings and $z = 4B$, in case of rectangular footings.



ii. The immediate settlement of each layer is computed using equation, taking corresponding values of $E_s$ and $I_z$.

iii. The required immediate settlement is equal to the sum of the settlements of all individual small layers.

**Semi-empirical Methods (De Beer and Martens) :**

1. In this method, the sand layer is divided into small layers such that each small layer has approximately constant value of the cone resistance.
2. The average value of the cone resistance of each small layer is determined.
3. The settlement of each small layer is estimated using the following equation.

$$S = \frac{H}{C}\log_e\frac{\bar{\sigma}_0 + \Delta\sigma}{\bar{\sigma}_0}$$

$$C = 1.5\,q_c / \bar{\sigma}_0$$

where, $q_c$ = Static cone resistance.

$\bar{\sigma}_0$ = Mean effective overburden pressure.

$\Delta\sigma$ = Increase in pressure at the centre of the layer due to the net foundation pressure.

$H$ = Thickness of layer..

4. The total settlement of the entire layer is equal to the sum of settlements of individual layers.

**Que 2.23.** **For $L/B$ = 6.0'; Explain all the steps, which will you follow for determining the settlement in the cohesionless soil by using the Schmertmann approach.**

**AKTU 2014-15, Marks 06**

**AKTU 2015-16, Marks 10**

**Answer**

1. As cohesionless soils do not follow Hook's law, immediate settlements are computed using a semi-empirical approach proposed by Schmertmann and Hartman.

$$S_i = C_1\,C_2\,(\bar{q} - q)\sum_{z=0}^{2B}\frac{I_z}{E_s}\Delta z \qquad ...(2.23.1)$$

2. For $L/B = 6$, values obtained for $z = 0, 0.8B, 3.2B$ are obtained 0.16, 0.5 and 0 respectively by interpolation.
3. The value of $E_s$ can be determined from the standard penetration number ($N$) using the following equations given by Schmertmann :

$$E_s = 766\,N\ (\text{kN/m}^2)$$

4. Alternatively, it can be estimated from the static cone penetration resistance ($q_c$) as,

$$E_s = 2\,q_c$$

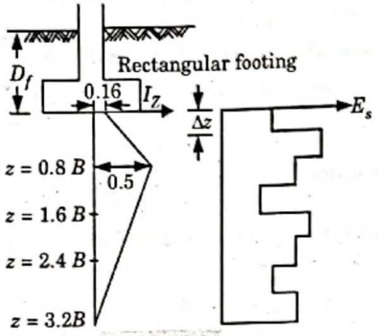



**Fig. 2.23.1.**

**Procedure :**

i. For computation of the immediate settlement, soil layer is divided into several layers of thickness $\Delta z$, upto a depth $z = 3.2\,B$.

ii. The immediate settlement of each layer is computed using equation (2.23.1), taking corresponding values of $E_s$ and $I_z$.

iii. The required immediate settlement is equal to the sum of the settlements of all individual small layers.

**Que 2.24. A 30 cm square bearing plate settles by 8 mm in the plate load test on cohesionless soil, when the intensity of loading is 180 kN/m². Estimate the settlement of shallow foundation of 1.6 m square under the same intensity of loading.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Size of bearing plate = 30 cm × 30 cm,
Settlement of plate, $S_p$ = 8 mm, Intensity of loading = 180 kN/m²,
Size of foundation = 1.6 m × 1.6 m.
**To Find :** Settlement of shallow foundation.

1. Settlement of foundation,

$$S_f = S_p\left[\frac{B_f(B_p+0.3)}{B_p(B_f+0.3)}\right]^2 = 8\left[\frac{1.6\times10^3\,(300+0.3)}{300\,(1.6\times10^3+0.3}\right]^2$$

2. Settlement of foundation, $S_f$ = 8.013 mm.



**Que 2.25. Fig. 2.25.1 shows a 2.5 m square footing resting on a sand deposit. The total pressure at foundation level is 200 kN/m². The variation of cone penetration resistance with depth is simplified as shown in Fig. 2.25.1. Determine the settlement of the foundation 6 years after construction. Use the Schmertmann approach. The ground water table is deep.**

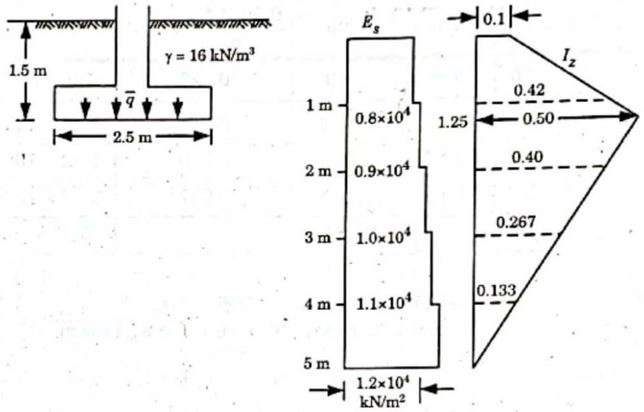



**Fig. 2.25.1.**

**Answer**

**Given :** Size of square footing = 2.5 m, Total pressure = 200 kN/m²
**To Find :** Settlement of foundation.

1. Stress at 1.5 m depth, $\sigma = 16 \times 1.5 = 24$ kN/m²
2. Net stress $= \bar{\sigma} - \sigma = 200 - 24 = 176$ kN/m².
3. Settlement correction factors :

i. $$C_1 = 1 - 0.5\left(\frac{\sigma}{\bar{\sigma}-\sigma}\right) = 1 - 0.5(24/176) = 0.932$$

ii. $$C_2 = 1 + 0.2\log_{10}(t/0.1) = 1 + 0.2\times\log_{10}(6/0.1) = 1.356$$

4. Settlement is given by,

$$S_i = C_1 C_2(\bar{\sigma}-\sigma)\sum_0^{2B}\frac{I_z}{E_s}\Delta z$$

$$S_i = 0.932\times1.356\times176\sum_0^{2B}\frac{I_z}{E_s}\Delta z$$

$$= 222.43\sum_0^{2B}\frac{I_z}{E_s}\Delta z$$

6. The value of $\sum_{0}^{2B} (I_z/E_s)\Delta z$ is determined as shown in the table 2.25.1. It is equal to $13.99 \times 10^{-5}$.

**Table 2.25.1.**

| $z$ | $\Delta z$ | $E_s$ (kN/m²) | $I_z$ | $(I_z/E_s)\Delta z$ |
|---|---|---|---|---|
| 0 – 1.0 | 1.0 m | 8000 | $\frac{0.1+0.42}{2} = 0.26$ | $3.25\times10^{-5}$ |
| 1.0 – 2.0 | 1.0 m | 9000 | 0.453 | $5.03\times10^{-5}$ |
| 2.0 – 3.0 | 1.0 m | 10000 | 0.333 | $3.33 \times 10^{-5}$ |
| 3.0 – 4.0 | 1.0 m | 11000 | 0.200 | $1.82 \times 10^{-5}$ |
| 4.0 – 5.0 | 1.0 m | 12000 | 0.067 | $0.56 \times 10^{-5}$ |
| | | | | $\Sigma\ 13.99 \times 10^{-5}$ |

7. Therefore, settlement of foundation after 6 years,

$$S_i = 222.43 \times 13.99 \times 10^{-5}\ \text{m} = 31.12\ \text{mm}$$

☺☺☺

# 3 UNIT

# Design of Shallow Foundation and Deep Foundation

## CONTENTS



• Numericals → Group efficiency, safe load .... Underreamed piles, pile capacity....

## PART-1

*Principles of Design of Footing.*

### CONCEPT OUTLINE

**Foundation Design Principles :** The main objectives of foundation design are to ensure that the structural loads are transmitted to the subsoil safely, economically and without any unacceptable movement during the construction period and throughout the anticipated life of the building or structure.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 3.1. Describe the principles of design of footing.**

**Answer**

**Principles of Design of Footings :**

1. Before actual design, it is essential to estimate the dead load, live load other loads. The frequency and duration of various loads also be available. The bending moment at the base of column (or wall) should also be ascertained if it is subjected to an eccentric load or moment.
2. As the bearing capacity of the soil depends upon the depth of footing and its length and width, an estimate about these dimensions is required before the actual design.
3. For members carrying axial load combined with bending moments that do not change direction, a rectangular footing is more suitable than a square footing.
4. The investigation of the site should be first carried out.
5. The samples should be taken to determine the engineering properties of the soil. The safe bearing capacity should be calculated on the basis of soil data obtained from the tests using.
6. For cohesionless soils, as it is difficult to obtain undisturbed samples, the bearing capacity is determined from the standard penetration test number ($N$) or from the plate load test.
7. The value of N to be used is the average of the N values from the base of footings to a depth equal to width of the footing.



## PART-2

*Design of Isolated Footing.*

### CONCEPT OUTLINE

**Isolated Footing :** It is used to support a single column. Isolated footings are independent footings which are provided for each column.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 3.2. Write down the procedure of design of footing.**

**Answer**

Following are the steps of design of footing :

**Step 1 :** The safe bearing capacity is determined. For small, unimportant structures, these values can be taken as presumptive values.

**Step 2 :** The footing is proportioned making use of the safe bearing capacity determined in Step (1).

**Step 3 :** The maximum settlement of the footing is determined. An estimate of the differential settlement between various footings is made.

**Step 4 :** Angular distortion is determined between various parts of the structure.

**Step 5 :** The maximum settlement, the differential settlement and the angular distortion obtained in the step (3) and (4) are compared with the given allowable values.

**Step 6 :** If the values are not within the allowable limits, the safe bearing capacity is revised and the procedure repeated.

**Step 7 :** The stability of the footing is checked against sliding and overturning.

i. The factor of safety against sliding should not be less than 1.5 when dead load, live load and earth pressure and wind pressure (or seismic forces) are considered.

ii. However, if only dead load, live load and earth pressure are considered, it should not be less than 1.75. The corresponding factors of safety against overturning are 1.50 and 2.00, respectively.

0

## PART-3

*Design of Strip Footing.*

### CONCEPT OUTLINE

**Strip Footing :** A wall footing or strip footing is a continuous strip of concrete that serves to spread the weight of a load-bearing wall across an area of soil.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.3. Explain the design procedure of strip footings in detail.**

**Answer**

**Design of Strip Footings :**

i. Plain cement concrete strip footings are provided when the loads are light and the soil is good.

ii. If the loads are heavy and the soil conditions are not favourable, plain cement concrete footings are not economical. Reinforced cement concrete footings are more suitable. Design procedure of strip footing in such cases is given below :

**1. Plain Concrete Footings :**

i. The footing is designed so that the contact pressure on the soil does not exceed the allowable bearing pressure.

ii. The width ($B$) of the footing is given by

$$B = \frac{Q}{q_{na}} \quad \text{...(3.3.1)}$$

where, $Q$ = Load per m run.

$q_{na}$ = Allowable soil pressure.

iii. If the actual width provided is different from the theoretical width, the actual pressure is given by,

$$q_0 = \frac{Q}{\text{Actual width}}$$

iv. The thickness at the edge of the footing should be at least 15 cm. On cohesive soils, generally a minimum thickness of 30 cm is specified in order to resist swelling pressure.

Deep foundation → Df 777 width



v. The thickness of the footing should be adequate to minimise the development of tension on the underside of the projection acting as a cantilever.

vi. The thickness of the projection is generally kept twice the length of the projection from the wall face.

vii. A 45° load distribution is also commonly used which gives a small tension on the underside.

viii. For wide and thick footings, sloping of the upper surface is done to effect economy in the quantity of concrete. However, the cost of form work will add to the total cost.

**2. Reinforced Concrete Footings.**

i. Footings carrying heavy loads on weak soils are reinforced in the transverse direction.

ii. The width of the footing is determined using eq. (3.3.1).

iii. For computing the bending moment for which the footing is to be designed, the critical section is taken as follows (IS 456 - 1978).

a. At the face of the monolithic wall.

b. Half-way between the centre line and the edge of the wall for footings under masonry walls.

iv. For monolithic walls the maximum bending moment is given by,

$$M = [q_0 (B - b)^2]/8$$

## PART-4

*Introduction, Necessity of Deep Foundation.*

### CONCEPT OUTLINE

**Deep Foundation :** It is a type of foundation that transfers building loads to the earth farther down from the surface than a shallow foundation does to a subsurface layer or a range of depths.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.4. Discuss the various types of piles which are used in the construction work on the basis of their structural characteristics with their advantage and disadvantages.**

**AKTU 2014-15, Marks 07**

**Answer**

A. **Classification According to Material Used :** There are four types of piles according to materials used :

1. **Steel Piles :**

i. Steel piles are generally either in the form of thick pipes or rolled steel H-sections.

ii. Steel piles are driven into the ground with their ends open or closed.

iii. Piles are provided with a driving point or shoe at the lower end.

**Advantages :**

i. It can penetrate hard layers such as dense gravel, soft rock.

ii. High load carrying capacity.

**Disadvantages :**

i. Relatively costly material.

ii. Subject to corrosion.

2. **Concrete Piles :**

i. Concrete piles are either precast or cast-in-situ. Precast concrete piles are prepared in a factory or a casting yard.

ii. A cast-in situ pile is constructed by making a hole in the ground and then filling it with concrete.

iii. The reinforcement is provided to resist handling and driving stresses.

**Advantages :**

i. Corrosion resistant.

ii. Easy to extend.

iii. Initially economical.

**Disadvantages :**

i. Voids may be created if concrete is placed rapidly.

ii. Difficult to achieve proper cutoff.

iii. Difficult to transport.

3. **Timber Piles :** Timber piles are made from tree trunks after proper trimming. The timber used should be straight, sound and free from defects.

**Advantages :**

i. Economical.

ii. Easy to handle.

iii. Permanently submerged piles are fairly resistant to decay.

**Disadvantages :**

i. Decay above water table.



ii. Can be damaged in hard driving.

iii. Low load bearing capacity.

4. **Composite Piles :**

i. A composite pile is made of two materials. A composite pile may consist of steel and concrete or timber and concrete.

ii. As it is difficult to provide a proper joint between two dissimilar materials, composite piles are rarely used in practice.

**Advantages :**

i. Reduces cross sectional area of pile.

ii. High load carrying capacity.

**Disadvantage :**

i. Difficult in joining two different materials.

B. **Classification Based on Mode of Transfer of Loads :**

1. **End-Bearing Piles :** End-bearing piles transmit the loads through their bottom tips. Such piles act as columns and transmit the load through a weak material to a firm stratum below.

2. **Friction Piles :**

i. Friction piles are used when a hard stratum does not exist at a reasonable depth.

ii. These piles transfer the load through skin friction between the embedded surface of the pile and the surrounding soil.

3. **Combined End Bearing and Friction Piles :** These piles transfer loads by a combination of end bearing at the bottom of the pile and friction along the surface of the pile shaft.

C. **Classification Based on Method of Installation :** Based on the method of installation, the piles may be classified into the following categories :

1. **Driven Piles :** These piles are driven into the soil by applying blows of a heavy hammer on their tops.

2. **Driven and Cast-in-situ Piles :** These piles are formed by driving a casing with a closed bottom end into the soil. The casing is later filled with concrete. The casing may or may not be withdrawn.

D. **Classification Based on Use :** The piles can be classified into the following categories, depending upon their uses.

1. **Load Bearing Piles :** These piles are used to transfer the load of the structure to a suitable stratum by end bearing, by friction or by both.

2. **Compaction Piles :** These piles are driven into loose granular soils to increase the relative density. The bearing capacity of the soil is increased due to densification caused by vibrations.

3. **Tension Piles :** These piles are in tension. These piles are used to anchor down structures subjected to hydrostatic uplift forces or overturning forces.

**Que 3.5.** **What is the necessity of pile foundation ?**

**OR**

**What are the conditions where the pile foundation is more suitable than a shallow foundation ?** **AKTU 2017-18, Marks 05**

**Answer**

**Suitability of Pile Foundation over than Shallow Foundation :**

1. When the strata at or just below the ground surface is highly compressible and very weak to support the load transmitted by the structure.
2. When the plan of the structure is irregular relative to its outline and load distribution. It would cause non-uniform settlement if a shallow foundation is constructed. A pile foundation is required to reduce differential settlement.
3. Pile foundations are required for the transmission of structural loads through deep water to a firm stratum.
4. Pile foundations are used to resist horizontal forces in addition to support the vertical loads in earth-retaining structures and tall structures that are subjected to horizontal forces due to wind and earthquake.
5. Piles are required when the soil conditions are such that a wash out, erosion or scour of soil may occur from underneath a shallow foundation.
6. Piles are used for the foundations of some structures, such as transmission towers, off-shore platforms, which are subjected to uplift.
7. In case of expansive soils, such as black cotton soil, which swell or shrink as the water content changes, piles are used to transfer the load below the active zone.

**Que 3.6.** **What do you meant by laterally loaded piles ? Why batter piles are more effective than vertical piles in resisting the horizontal loads ? Give all the basic steps to find the forces in pile by Culmann's method.** **AKTU 2014-15, Marks 06**

**Answer**

**Laterally Loaded Piles :**

1. Piles are sometimes subjected to lateral loads due to wind pressure, water pressure, earth pressure, earthquakes, etc.



2. When the horizontal component of the load is small in comparison with the vertical load (say, less than 20 %), it is generally assumed to be carried by vertical piles and no special provision for lateral load is made.

**Reason :** In case of batter piles, additional resistance is provided by the skin friction and the end bearing. Therefore, batter piles are more effective than vertical piles in resisting horizontal loads.

**Culmann's Method :**

1. When piles are oriented in two or three directions Culmann's method is used.
2. As the axis of the batter pile is inclined, it can resist the horizontal load equal to $Q \cos \theta$, where $Q$ is the axial load capacity and $\theta$ is the angle which the pile makes with the horizontal.

**Steps :**

i. Group the piles according to their slopes [in Fig. 3.6.1($a$), the piles are grouped in 3 directions].

ii. Draw the geometry of the pile group to some scale, and mark the directions of the inclined load $Q_g$ and the centre line of each pile group ($R_1$, $R_2$ and $R_3$).

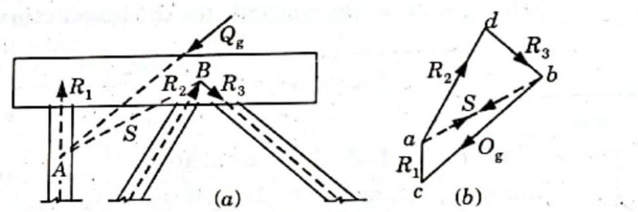



**Fig. 3.6.1.**

iii. Determine the location of point $A$ which is at the intersection of $R_1$ and $Q_g$.

iv. Join $A$ to the point $B$ which is at the intersection of $R_2$ and $R_3$.

v. Draw the force triangle, as shown in Fig. 3.6.1($b$).

Select the line $ab$ parallel to $AB$. From b draw a line $bc$ parallel to $Q_g$ to some scale. Draw a vertical at $c$ to determine $ca$ which is equal to $R_1$.

From $b$ draw a line parallel to $R_3$, and from a, line parallel to $R_2$, to complete the triangle $abd$.

vi. Determine forces in piles as follows :

The magnitudes of $R_2$ and $R_3$ are, respectively, given by $ad$ and $bd$. However, $R_2$ is compressive and $R_3$ is tensile.
The magnitude of $R_1$ is given by $ca$ which is compressive.

## PART-5

*Pile Installation.*

### CONCEPT OUTLINE

**Displacement Piling Installation :** It refers to the method of driving piles into the ground without first removing any of the soil or other material.

**Replacement Piling Installation :** It refers to the method of first digging out a hole, into which the pile is then manoeuvered.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.7. Discuss different methods for the installation of piles.**

**AKTU 2017-18, Marks 05**

**Answer**

Following are the methods of pile installation :

**A. Drop Hammer Method of Pile Driving :**

1. A hammer with approximately the weight of the pile is raised a suitable height in a guide and released to strike the pile head.
2. This is a simple form of hammer used in conjunction with light frames and test piling, where it may be uneconomical to bring a steam boiler or compressor on to a site to drive very limited number of piles.
3. **There are two main types of drop hammers :**

i. **Single-Acting Steam or Compressed-Air Hammers :**

a. Single-acting steam or compressed-air comprises a massive weight in the form of a cylinder.

b. Steam or compressed air admitted to the cylinder raises it up the fixed piston rod.

c. At the top of the stroke, or at a lesser height which can be controlled by the operator, the steam is cut off and the cylinder falls freely on the pile helmet.



ii. **Double-Acting pile Hammers :**

a. Double-acting pile hammers can be driven by steam or compressed air.

b. A piling frame is not required with this type of hammer which can be attached to the top of the pile by leg-guides, the pile being guided by a timber framework.

**B. Pile Driving by Vibrating :**

1. Vibratory hammers are usually electrically powered or hydraulically powered and consists of contra-rotating eccentric masses within a housing attaching to the pile head.
2. The amplitude of the vibration is sufficient to break down the skin friction on the sides of the pile.
3. Vibratory methods are best suited to sandy or gravelly soil.
4. Jetting to aid the penetration of piles in to sand or sandy gravel, water jetting may be employed. However, the method has very limited effect in firm to stiff clays or any soil containing much coarse gravel, cobbles, or boulders.

**C. Continuous Flight Auger (CFA) :**

1. Equipment comprises of a mobile base carrier fitted with a hollow-stemmed flight auger which is rotated into the ground to required depth of pilling.
2. To form the pile, concrete is placed through the flight auger as it is withdrawn from the ground.
3. The auger is fitted with protective cap on the outlet at the base of the central tube and is rotated into the ground by the top mounted rotary hydraulic motor which runs on a carrier attached to the mast.
4. On reaching the required depth, highly workable concrete is pumped through the hollow stem of the auger, and under the pressure of the concrete the protective cap is detached.
5. While rotating the auger in the same direction as during the boring stage, the spoil is expelled vertically as the auger is withdrawn and the pile is formed by filling with concrete.
6. In this process, it is important that rotation of the auger and flow of concrete is matched that collapse of sides of the hole above concrete on lower flight of auger is avoided. This may lead to voids in filled with soil in concrete.

## PART-6

*Pile Group, Group Action of Piles in Sand and Clay.*

## CONCEPT OUTLINE

**Pile Group :** A pile group is a set of piles that have a pile cap that means that they act together to carry the load. The pile cap would normally be in contact with the ground.

Group action of piles is evaluated by considering the piles to fail as a unit around the perimeter of the group. Both end bearing and friction piles are considered in evaluating the group capacity.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 3.8.** **What are the factors governing load carrying capacity of pile ?**

**AKTU 2013-14, Marks 03**

**Answer**

Following are the factors influencing pile capacities :

1. The surrounding soil.
2. Installation technique like driven or bored.
3. Method of construction (precast or cast in situ).
4. Spacing of piles in a group.
5. Symmetry of the group.
6. Location of pile cap *i.e.,* above or below soil.
7. Shape of the pile cap.
8. Location of pile in the group.
9. Drainage conditions in soil.

**Que 3.9.** **Discuss the capacity of pile group. How can be calculated the pile group capacity ?**

**Answer**

1. **Capacity of Pile Group :**

i. Capacity of pile group is the sum of the individual capacities of piles.

ii. Capacity of group of pile is influenced by the spacing between the piles.

iii. Piles are driven generally in groups in regular pattern to support the structural loads.

iv. The structural load is applied to the pile cap that distributes the load to individual piles.



v. If piles are spaced sufficient distance apart, then the capacity of pile group is the sum of the individual capacities of piles.

vi. However, if the spacing between piles is too close, the zones of stress around the pile will overlap and the ultimate load of the group is less than the sum of the individual pile capacities specially in the case of friction piles, where the efficiency of pile group is much less.

vii. Group action of piles is evaluated by considering the piles to fail as a unit around the perimeter of the group.

viii. Both end bearing and friction piles are considered in evaluating the group capacity.

2. **Calculate the Pile Group Capacity :**

i. End bearing pile is evaluated by considering the area enclosed by the perimeter of piles as the area of footing located at a depth corresponding to the elevation of pile tips.

ii. The friction component of pile support is evaluated by considering the friction that can be mobilized around the perimeter of the pile group over the length of the piles as shown in Fig. 3.9.1.

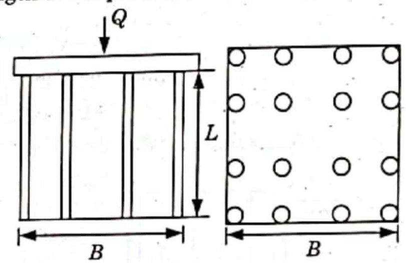



Fig. 3.9.1.

The ultimate load capacity of the pile group by block failure, $Q_{ug}$ is given by

$$Q_{ug} = C_{ub} N_c A_b + P_b L C'_u$$

where,
$C_{ub}$ = Undrained strength of clay at the base of the pile group.
$C'_u$ = Average undrained strength of clay along the length of the block.
$N_c$ = Bearing capacity factor, taken as 9.
$A_b$ = Cross-sectional area of the block.
$P_b$ = Perimeter of the block.
$L$ = Embedded length of the pile.

Notes

**Que 3.10.** **Discuss the group action of piles.**

**Answer**

1. A pile is not used singularly beneath a column or a wall, because it is extremely difficult to drive the pile absolutely vertical and to place the foundation exactly over its centre line.
2. If eccentric loading results, the connection between the pile and the column may break or the pile may fail structurally because of bending stresses.
3. In actual practice, structural loads are supported by several piles acting as a group.
4. For columns, a minimum of three piles in a triangular pattern are used. For walls, piles are installed in a staggered arrangement on both sides of its centre line.
5. The loads are usually transferred to the pile group through a reinforced concrete slab, structurally tied to the pile tops such that the piles act as one unit.
6. The slab is known as a pile cap. The load acts on the pile cap which distributes the load to the piles Fig. 3.10.1.

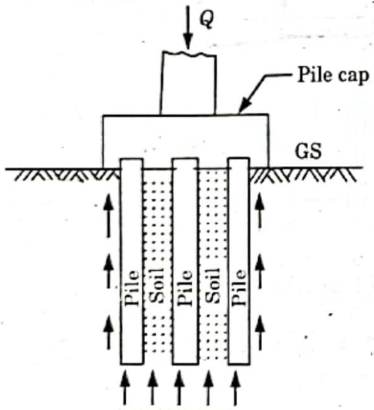



**Fig. 3.10.1.**

7. The load carrying capacity of a pile group is not necessarily equal to the sum of the capacity of the individual piles.
8. The efficiency ($\eta_g$) of a group of piles is defined as the ratio of the ultimate load of the group to the sum of individual ultimate loads.

Thus $$\eta_g = \frac{Q_{g(u)}}{NQ_u} \times 100$$

where, $Q_{g(u)}$ = Ultimate load of the group.
$Q_u$ = Ultimate load of the individual pile.
$N$ = Number of piles in the group.



9. Thus the group efficiency is equal to the ratio of the average load per pile in the group at which the failure occurs to the ultimate load of a comparable single pile.
10. The group efficiency depends upon the spacing of the piles. Ideally, the spacing should be such that the efficiency is 100 %. Generally, the centre to centre spacing is kept between 2.5 $B$ and 3.5 $B$, where $B$ is the diameter of the pile.

## PART-7

*Group Efficiency of Pile.*

**CONCEPT OUTLINE**

**Group Efficiency :** The efficiency of the pile group is equal to 1 or 100 %. For piles in sand, the efficiency of the pile group may be more than 100 %.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

Noty

**Que 3.11.** **How will you determine the efficiency of pile group ?**

**AKTU 2016-17, Marks 05**

**Answer**

A. **Pile Groups in Sand and Gravel :**
1. For piles driven in loose and medium dense cohesion less soils, the group efficiency is high.
2. The piles and the soil between them move together as a unit when subjected to loads.
3. The group acts as a pier foundation having a base equal to the gross plan area contained between the piles.

i. **End-Bearing Piles :**
  a. For driven piles bearing on dense, compact sand with spacing equal to or greater than 3$d$, the group capacity is generally taken equal to the sum of individual capacity. Thus,
  $$Q_g = NQ_u$$
  b. In this case, the load taken by the group is much greater ($\eta_g > 100$ %) than the sum of the individual capacities.
  c. For spacing less than 3$d$, the group capacity is found for the block of piles group.

**ii. Friction Piles :**

a. The group efficiency of friction piles in sand is obtained from the following expression :

$$\eta_g = \frac{Q_{g(u)}}{NQ_u} \times 100 = \frac{f_s(P_g L)}{Nf_s(pL)} \times 100$$

where, $P_g$ = Perimeter of the block.
$p$ = Perimeter of the individual pile.
$L$ = Length of pile.
$f_s$ = Unit friction resistance.

b. If the centre-to-centre spacing is large, the group efficiency ($\eta_g$) may be more than 100 %.

c. The piles will behave as individual piles, and the group capacity is obtained as :

If $\eta_g$ is less than 100 %,

$$Q_{g(u)} = \eta_g \frac{(NQ_u)}{100}$$

d. The group efficiency can also be obtained from the Converse-Labarre equation given below,

$$\eta_g = 1 - \left[\frac{(n-1)m + (m-1)n}{mn}\right]\frac{\theta}{90}$$

where, $m$ = Number of rows of piles.
$n$ = Number of piles in a row.
$\theta = \tan^{-1}(d/S)$.
$d$ = Diameter of pile.
$S$ = Spacing of pile, centre-to-centre.
$\eta_g$ = Group efficiency (expressed as a ratio).

**iii. Bored Piles :**

a. For bored piles in sand at conventional spacing of $3d$, the group capacity is taken as 2/3 to 3/4 times the sum of individual capacities for both the end-bearing and the friction piles. Thus,

$$Q_{g(u)} = (2/3 \text{ to } 3/4)\,(NQ_u)$$

b. In bored piles, there is limited densification of the sand surrounding the pile group. Consequently, the efficiency is lower.

**B. Pile Groups in Clay :**

1. As the pile group acts as a block, its ultimate capacity is determined by adding the base resistance and the shaft resistance of the block.
2. The capacity of the block having closely spaced piles ($S \le 3d$) is often limited by the behavior of the group acting as a block.



3. The group capacity of the block is given by,

$$Q_{g(u)} = q_p\,(A_g) + \alpha\,\bar{c}\,(P_g L) \quad ...(3.11.1)$$

where, $q_p$ = Unit point resistance ($N_c$ = 9.0).
$A_g$ = Base area of the block.
$P_g$ = Perimeter of the block.
$L$ = Depth of the block.
$\alpha$ = Adhesion factor ( = 1.0 for soft clays).
$c$ = Undrained cohesion.

4. The individual pile capacity is given by,

$$Q_u = q_p A_p + \alpha\, c(p \times L)$$

5. The group capacity considering the piles as individual piles is given by,

$$Q_{g(u)} = NQ_u \quad ...(3.11.2)$$

6. The lower of the two values, given by eq. (3.11.1) and eq. (3.11.2), is the actual capacity.

**Que 3.12.** **A 30 cm diameter concrete pile is driven in a normally consolidated clay deposit 15 m thick. Estimate the safe load. Take $C_u$ = 70 KN/m², $\alpha$ = 0.9 and $F.S$ = 2.5.**

**AKTU 2013-14, Marks 03**

**Answer**

**Given :** Diameter of pile, $d$ = 30 cm, Thickness of clay = 15 m
Undrained cohesion value, $c_u$ = 70 kN/m², Adhesion factor, $\alpha$ = 0.9, Factor of safety = 2.5
**To Find :** Safe load.

1. Ultimate load capacity of pile, $Q_u = C_{ub} N_c A_b + \alpha C_u A_s \quad (\because \; C_{ub} = C_u)$

$$= 70 \times 9 \times \frac{\pi}{4} \times 0.30^2 + 0.9 \times 70 \times \pi \times 0.30 \times 15$$
$$= 935.17 \text{ kN}$$

2. Safe load, $$Q_a = \frac{Q_u}{F_s} = \frac{935.17}{2.5} = 374 \text{ kN}$$

**Que 3.13.** **A group of 20 piles, each having a diameter of 600 mm and 12 m long are arranged in 4 rows at a spacing 1.2 m centre to centre. The capacity of each pile is 380 kN. Determine the group efficiency of pile.**

**AKTU 2014-15, Marks 06**

**Answer**

**Given :** Number of pile, $N = 20$, Diameter of pile, $d = 600$ mm

Length of pile, $L = 12$ m, Spacing of pile, $S = 1.2$ m

Capacity of one pile, $Q_u = 380$ kN

**To Find :** Group efficiency of pile.

1. Ultimate load capacity of a pile group of 20 piles on the basis of individual action = 20 × 380 kN = 7600 kN
2. Length of pile group = 4 × 1.2 + 0.6 = 5.4 m
3. Width of pile group = 3 × 1.2 + 0.6 = 4.2 m
4. Ultimate load capacity of the pile group by block failure is given by,

$$Q_{g(u)} = C_{ub} N_c A_b + P_b L C_u \quad ...(3.13.1)$$

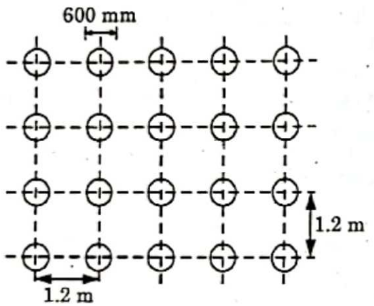



**Fig. 3.13.1.**

5. We known that, $Q_u = C_{ub} N_c A_p + \alpha C_u A_s$

$$380 = C_u \times 9 \times \frac{\pi}{4} \times 0.6^2 + 0.9 \times C_u \times \pi \times 0.6 \times 12$$

$$C_u = 16.6 \text{ kN/m}^2 \quad (\because \; C_u = C_{ub})$$

6. From eq. (3.13.1),

$$Q_{g(u)} = 16.6 \times 9 \times 5.4 \times 4.2 + 2(5.4 + 4.2) \times 12 \times 16.6$$
$$= 7213.032 \text{ kN/m}^2$$

7. Group efficiency of pile,

$$\eta_g = \frac{Q_{g(u)}}{NQ_u} \times 100 = \frac{7213.032}{20 \times 380} \times 100 = 94.9\ \%$$

**Que 3.14.** **A group of 16 piles, each having a diameter of 350 mm and 10 m long, are arranged in 4 rows at a spacing 1.0 m centre to centre. The capacity of each pile is 360 kN. Determine the group capacity of the piles.**

**AKTU 2015-16, Marks 10**



**Answer**

**Given :** Number of piles, $N = 16$, Diameter of pile, $d = 350$ mm

Length of pile, $L = 10$ m, Spacing of pile, $S = 1$ m,

Capacity of one pile, $Q_u = 360$ kN

**To Find :** Group capacity of piles.

1. Ultimate load capacity of a pile group of 16 piles on the basis of individual action

$$= 16 \times 360 \text{ kN} = 5760 \text{ kN}$$

Length of pile group = 3 × 1 + 0.35 = 3.35 m

Width of pile group = 3 × 1 + 0.35 = 3.35 m

2. Ultimate load capacity of the pile group by block failure is given by,

$$Q_{g(u)} = C_{ub} N_c A_b + P_b L C_u$$

3. We know that, capacity of one pile

$$Q_u = C_{ub} N_c A_p + \alpha C_u A_s$$

$$360 = C_u \times 9 \times \frac{\pi}{4} \times 0.35^2 + 0.9 \times C_u \times \pi \times 0.35 \times 10$$

$$C_u = 33.46 \text{ kN/m}^2 \quad (\because \; C_u = C_{ub})$$

4. Ultimate bearing capacity of group piles,

$$Q_{g(u)} = 33.46 \times 9 \times 3.35 \times 3.35 + 2\,(3.35 + 3.35) \times 10 \times 33.46$$
$$= 7863.18 \text{ kN}$$

5. Arrangement of pile group.

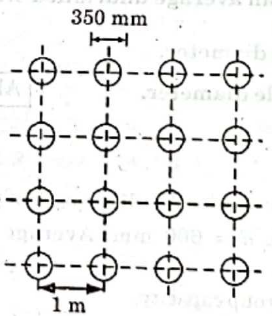



**Fig. 3.14.1.**

**Que 3.15.** **It is proposed to provide pile foundation for a heavy column the pile group consisting of 4 piles, placed at 2 m center to center, forming a square pattern. The underground soil is clay,**

**having $C_u$ at surface as 60 kN/m² and at depth 10 m as 100 kN/m². Compute the allowable column load on the pile cap, if the piles are circular having diameter 0.5 m each and depth as 10 m.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Number of pile = 4, Spaced between column = 2 m c/c, $C_u$ at surface = 60 kN/m² and at 10 m depth = 100 kN/m², Diameter of pile = 0.5 m, Length of pile = 10 m.
**To Find :** Allowable column load on pile cap.

1. Average unconfined compressive strength,

$$= \frac{60 + 100}{2} = 80 \text{ kN/m}^2$$

2. Ultimate bearing capacity of a single pile is given by,

$$Q_u = C_u N_c A_p + \alpha C_u A_s$$

$$= 80 \times 9 \times \frac{\pi}{4} (0.5)^2 + 0.9 \times 80 \times \pi \times 0.5 \times 10$$

$$= 1272.345 \text{ kN.}$$

3. Ultimate load capacity of the pile group of 4 piles on the basis of individual action.
4. Ultimate load capacity of pile group, $Q_{g(u)} = 4 \times 1272.345 = 5089.38$ kN.

**Que 3.16.** **Compute the pile group capacity of 16 pile group in square arrangement made up of 15 m long piles of 600 mm diameter in soft clay having an average undrained strength of 50 kN/m² if the c/c pile spacing is :**

1. **Two times pile diameter.**
2. **Three times pile diameter.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Number of pile, $N = 16$, Length of pile, $L = 15$ m
Diameter of pile, $d$ = 600 mm, Average undrained strength, $q_u = 50$ kN/m²
**To Find :** Pile group capacity.

1. **When Spacing is Two Times of Pile Diameter :**

i. Spacing, $S = 2 \times d = 2 \times 600 = 1200$ mm

ii. Undrained cohesion, $C_{ub} = C_u = \frac{50}{2} = 25$ kN/m²

Assume adhesion factor, $\alpha = 0.80$



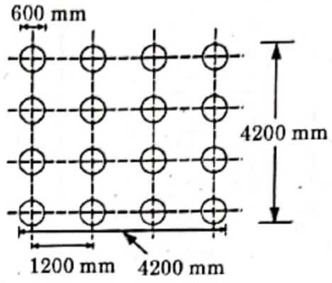



**Fig. 3.16.1.**

iii. Ultimate load capacity of a single pile is given by, [$\because N_c = 9$]

$$Q_u = C_{ub} N_c A_b + \alpha C_u A_s$$

$$= 25 \times 9 \times \frac{\pi}{4} \times 0.6^2 + 0.8 \times 25 \times (0.6 \times \pi) \times 15$$

$$Q_u = 629.1 \text{ kN/m}^2$$

iv. Ultimate load capacity of the pile group of 16 piles on the individual action

$$= 16 \times 629.1 = 10065.66 \text{ kN} \quad ...(3.16.1)$$

v. Width of pile group = 3 × 1.2 + 0.6 = 4.2 m

vi. Length of pile group = 3 × 1.2 + 0.6 = 4.2 m

vii. Ultimate load capacity of the pile group by block failure is given by,

$$Q_{g(u)} = C_{ub} N_c A_b + P_b L C_u$$

$$= 25 \times 9 \times 4.2 \times 4.2 + 4 \times 4.2 \times 15 \times 25 = 10269 \text{ kN} \quad ...(3.16.2)$$

viii. Hence, ultimate load capacity of pile group is a minimum value of eq. (3.16.1) and eq. (3.16.2) = 10065.66 kN

2. **When Spacing is Three Times of Pile Diameter :**

Spacing, $S = 3 \times d = 3 \times 600 = 1800$ mm

i. Width of pile group = 3 × 1.8 + 0.6 = 6 m

ii. Length of pile group = 3 × 1.8 + 0.6 = 6 m

iii. Ultimate load capacity of the pile group by block failure

$$= C_{ub} N_c A_b + P_b L C_u$$

$$Q_{g(u)} = 25 \times 9 \times 6 \times 6 + 4 \times 6 \times 15 \times 25 = 17100 \text{ kN} \quad ...(3.16.3)$$

iv. Ultimate load capacity of pile group is a minimum value of eq. (3.16.1) and eq. (3.16.3) = 10065.66 kN

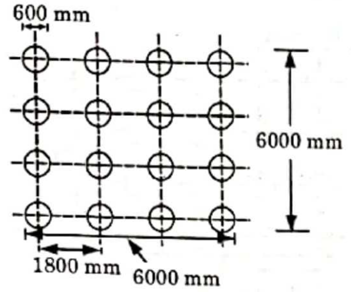



Fig. 3.16.2.

## PART-8

*Settlement of Piles.*

### CONCEPT OUTLINE

**Settlement of Piles :** The overall observed settlement of the pile is a combination of the settlement of the soil mass as a whole, axial compression of pile and slip between soil-pile interfaces due to loss of shaft resistance owing to liquefaction.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.17. Describe the methods of settlement of pile groups.**

**Answer**

**Settlement of Pile Groups :**

1. The settlement of a pile group is due to elastic shortening of piles and due to the settlement of the soil supporting the piles.
2. It is assumed that the pile group acts as a single large deep foundation, such as a pier or a mat.
3. The total load is assumed to act at a depth equal to two-thirds the pile length in the case of frictional piles, as shown in Fig. 3.17.1(*a*).
4. In the case of end-bearing piles, the total load is assumed to act at the pile tips, as shown in Fig. 3.17.1(*b*).
5. In the case of combined action, the frictional component is assumed to act at 2/3 *D* and the bearing component at the tip.



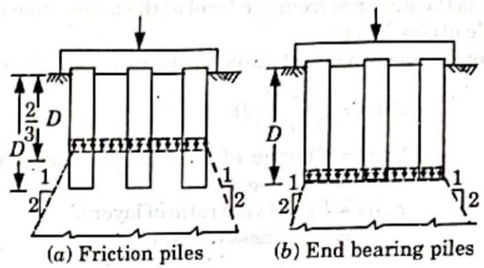



Fig. 3.17.1.

**A. Calculate the Settlement in Cohesionless Soils :**

i. Meyerhof suggests the following empirical relation for the elastic settlement of a pile group in sands and gravels.

$$S_g = \frac{9.4q\sqrt{B_g I}}{N} \quad ...(3.17.1)$$

where, $S_g$ = Settlement of group (mm).

$q$ = Load intensity (= $Q_g/A_g$).

$B_g$ = Width of the group.

$I$ = Influence factor [= $1 - D/(8\,B_g) \geq 0.5$].

$D$ = Length of pile.

$N$ = Corrected standard penetration number within the seat of settlement (approximately equal to $B_g$ below the tip).

ii. If static cone results are available, the settlement of the group can be obtained from the relation,

$$S_g = \frac{qB_g I}{2q_c} \quad ...(3.17.2)$$

where, $q_c$ = Average cone penetration resistance within the seat of settlement.

**B. Calculate the Settlement in Clayey Soils :** The consolidation settlement of a pile group in clay can be determined using the following procedure discussed in below.

i. Generally, a 2 : 1 load distribution is assumed from the level at which the load acts.

ii. Sometimes, the load is assumed to spread outwards from the edge of the block at an angle of 30° to the vertical.

iii. For 2 : 1 distribution, the stress increase at the middle of each layer is calculated as,

$$q_i = \frac{Q_g}{(B_g + Z_i)(L_z + Z_i)} \quad ...(3.17.3)$$

where, $Z_i$ is the distance from the level of the application of the load to the middle of clay layer $i$.

iv. The settlement of each layer caused by the increased stress is given by,

$$\Delta s(i) = \frac{\Delta e(i)}{1+e_0(i)} H_i \qquad ...(3.17.4)$$

where, $\Delta e(i)$ = Change of void ratio caused by the stress increase.

$e_0(i)$ = Initial void ratio of layer $i$.

$H_i$ = Thickness of layer $i$.

$$\text{Alternatively, } \Delta s(i) = C_c \frac{H_i}{1+e_0(i)} \log\left(\frac{\bar{\sigma}_o + \Delta\sigma_i}{\bar{\sigma}_o}\right) \qquad ...(3.17.5)$$

v. The total consolidation settlement is equal to the sum of the settlement of all layers.

$$S_g = \Sigma \Delta s(i)$$

**Que 3.18.** **A group of friction piles of 30 cm diameter is subjected to a net load of 2000 kN, as shown in Fig. 3.18.1. Estimate the consolidation settlement.**

**Answer**

**Given :** Data shown in Fig. 3.18.1.
**To Find :** Consolidation settlement.

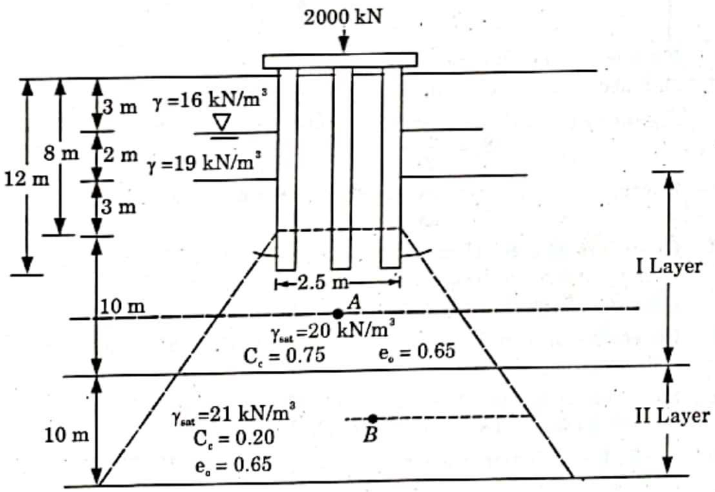



**Fig. 3.18.1.**



1. $\sigma_0$ at point $A$, middle of layer I
$= 3 \times 16 + 2 \times (19 - 10) + 8 \times 10.0 = 146 \text{ kN/m}^2$

2. $\sigma_0$ at point $B$, middle of II layer
$= 3 \times 16 + 2 \times 9.0 + 13 \times 10.0 + 5 \times 11 = 251 \text{ kN/m}^2$

3. Cross-sectional area at $A = \left(2.5 + 2 \times 5 \times \frac{1}{2}\right) = 7.5 \text{ m}^2$

4. $$\Delta\sigma = \frac{2000}{7.5 \times 7.5} = 35.56 \text{ kN/ m}^2$$

5. Cross-sectional area at $B = \left(2.5 + 15 \times 2 \times \frac{1}{2}\right) = 17.5 \text{ m}^2$

6. $$\Delta\sigma = \frac{2000}{17.5 \times 17.5} = 6.53 \text{ kN/ m}^2$$

7. Settlement of I layer $= C_c \left(\frac{H}{1+e_0}\right) \log \frac{\sigma_0 + \Delta\sigma}{\sigma_0}$
$$= 0.25 \times \frac{10}{1+0.75} \log \frac{146 + 35.56}{146} = 0.135 \text{ m}$$

8. Settlement of II layer $= 0.20 \times \frac{10}{1+0.65} \log \frac{251 + 6.53}{251} = 0.014$

9. Total settlement $= 0.135 + 0.014 = 0.149$ m

## PART-9

*Negative Skin Friction.*

### CONCEPT OUTLINE

**Negative Skin Friction :** It occurs when concrete piles are situated in soft soils, consolidating soil-mass, etc., resulting in a downward force that increases loading on shaft piles and reduces the bearing capacity of the pile.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

Q+ Note

**Que 3.19.** **What is the negative skin friction ? What is its effect on the pile ?** **AKTU 2013-14, Marks 03**

**Answer**

**A. Negative Skin Friction :**

1. Negative skin friction or downdrag is a phenomenon which occurs when a soil layer surrounding a portion of the pile shaft settles more than the pile.
2. This condition can develop where a soft or loose soil stratum located anywhere above the pile tip is subjected to new compressive loading.
3. If a soft or loose layer settles after the pile has been installed, the skin friction-adhesion developing in this zone is in the direction of the soil movement, pulling the pile downward, as shown in Fig. 3.19.1. Extra loading is thus imposed on the pile.
4. Negative skin friction may also occur by the lowering of ground water which increases the effective stress inducing consolidation and consequent settlement of the soil surrounding the pile.

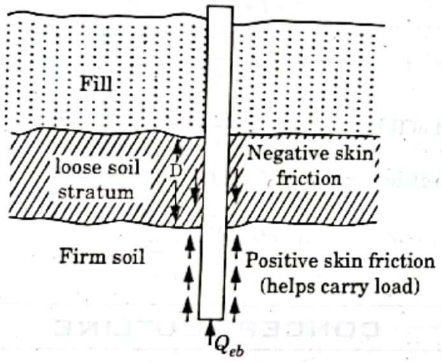



**Fig. 3.19.1.** Negative skin friction on a pile.

**B. Effect of Negative Skin Friction on Pile :** Following are the effect of negative skin friction on pile :

1. Negative skin friction contributes to the uneven settlement of piles or pile group.
2. For piles in compressible soils where pile capacity is contributed by both point resistance and shaft adhesion, the problem of negative skin friction should be considered a settlement problem.
3. In bearing piles where the settlement of the pile is negligible, negative skin friction becomes a pile capacity problem.

**PART-10**

*Single and Double Underreamed Piles.*



**CONCEPT OUTLINE**

**Underreamed Piles :** It is of bored cast in situ and bored compaction concrete types having one or more bulbs formed by suitable enlarging the borehole for pile stem. With provision of bulbs, substantial anchorage or bearing is available.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.20.** **Elaborate with a neat sketch the type of foundation used in case of expansive soils.** **AKTU 2016-17, Marks 05**

**Answer**

**Type of Foundation :** Following are the various type of foundation used in expansive soils :

**1. Spread Footings and Wall Footings on Black Cotton Soil :**

i. Spread footings and wall footings are used where a layer of good soil is within 2 m to 3m (6 to 10 feet) from the natural ground surface.

ii. Spread footings and wall footings should not be used where the high flow of the groundwater is found within the depth of foundation as it may result in scouring.

**2. Mat Foundation on Black Cotton Soil :**

i. The mat foundation is suitable for black cotton/expansive soils whose bearing capacity is less for suitability of spread footings and wall footings.

ii. It is also recommended and or economical when the area of footings becomes greater than 50 percent area of the building.

iii. This is generally recommended for high rise buildings.

**3. Pile Foundation in Black Cotton Soil :**

i. The pile foundation is used to transfer the heavy loads from the structure to hard rock strata which is much deep below the ground level and where shallow foundations or mat foundation is not feasible due to weak or expansive soil in upper layer.

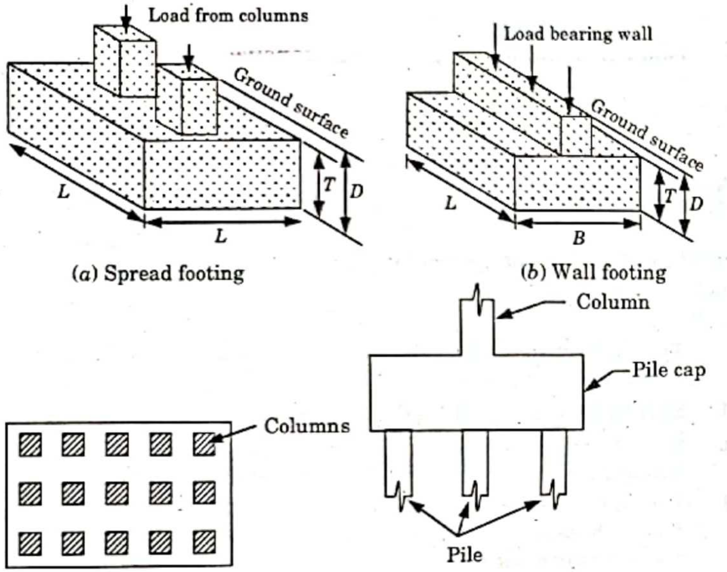
ii. The pile foundation also prevents uplift of building due to lateral loads such as earthquake and wind forces.

iii. The pile foundations resist the loads from structure by skin friction and by end bearing. Uses of pile foundations also prevent settlements of foundations.

**4. Drilled Shafts Piles in Black Cotton Soil :**

i. Drilled shafts can be used for the deep foundation of high rise building where the depth of hard firm strata below the ground is 10 m or up to 100 m.

ii. Drilled shafts foundations are not suitable when deep deposits of soft clays and loose water bearing granular soils exists.




(*a*) Spread footing (*b*) Wall footing

(*c*) Mat foundation (*d*) Pile foundation

**Fig. 3.20.1.**

**Que 3.21.** **Which type of pile foundation you will use for the expansive soil ? Explain the particular types with a neat sketch. Also give the expression for finding the capacity of pile for single bulb under reamed piles.**

AKTU 2014-15, Marks 07

**OR**

**Discuss on underreamed pile foundation. Also give the expression for load carrying capacity for clayey soil and sandy soil.**

AKTU 2016-17, Marks 10

**OR**

**Explain with a neat sketch which type of foundation you will use for the case of expansive soils ? Write also expressions for finding the capacity of piles for single bulb and double bulb underreamed piles.**

AKTU 2015-16, Marks 10

bulb get compacted due to introduction of bulb. this compacted soil behaves as a pile.

इसमें bulb use होता तो वह single bulb है x when 2 bulb use होता then Double bulb.



**OR**

**Discuss about the underreamed piles, and where these piles are to be used ? Which method will you use for the design of shallow and deep foundations for the expansive soils ?**

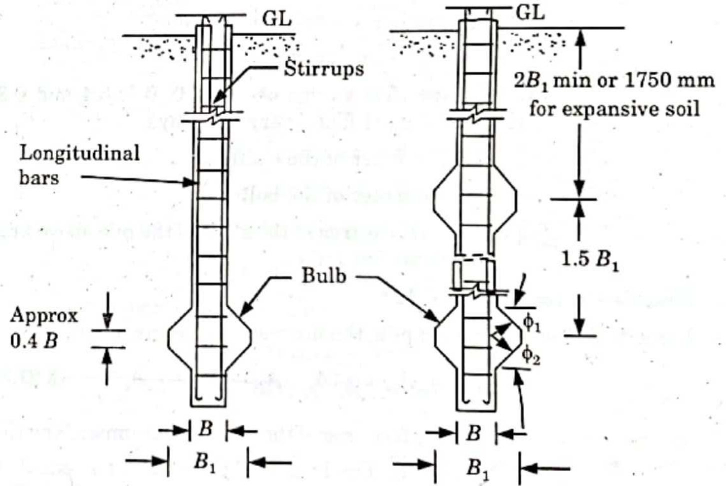
AKTU 2017-18, Marks 10

**Answer**

A. **Types of Foundation used in Expansive Soils :** Refer Q. 3.20, Page 3–27D, Unit-3.

B. **Underreamed Piles :**

1. The underreamed piles developed by the CBRI, Roorkee, are commonly used in India for foundations in expansive soils.
2. The underreamed pile foundations are quite suitable for expansive soils. The underreamed piles anchor the structure to a stable soil mass well below the unstable soil which is subjected to ground movement because of seasonal changes.
3. The depth of the active zone is normally 3 to 4 m at most places in India. The piles are thus seated up in good bearing strata.
4. The underreamed piles are bored, cast-in situ concrete piles with a bulb or underream at its bottom. In a double underreamed pile, there are two bulbs. IS : 2911-Part 3 (1980) recommends a maximum of two bulbs.
5. Fig. 3.21.1 shows the details of a single under-reamed and a double underreamed pile.




$\phi_1$ = 45° Approx $\phi_2$ = 30°– 45° Approx $B_1$ = 2.5 *B* (Normally)

**Fig. 3.21.1.** (*a*) Single underreamed pile and (*b*) Double underreamed pile.

6. The bulbs provide adequate bearing and anchorage to the pile.
7. The underreamed pile should satisfy the bearing capacity and settlement criteria like all other piles.

**i. Load Carrying Capacity for Single Blub Underreamed Pile :**
The ultimate load for a single bulb, underreamed pile is given by,

$$Q_u = Q_p + Q_s$$

$$Q_u = q_{sh}A_{sh} + q_b(A_b - A_{sh}) + fA_{sh} \quad ...(3.21.1)$$

where, $q_{sh}$ = Bearing capacity of the soil at the bulb.

$A_b$ = Cross-sectional area of the bulb ($= \pi/4\ B_1^2$).

$A_{sh}$ = Cross-sectional area of the shaft ($= \pi/4\ B^2$).

$f$ = Unit skin friction (adhesion) on the shaft above and below the bulb.

$q_b$ = Bearing capacity of the soil at the underream section.

Taking $q_b = 9C$, *i.e.*, $N_c = 9.0$,

$$Q_u = \left[\frac{\pi}{4}B^2(9C) + \frac{\pi}{4}(B_1^2 - B^2)(9C')\right] + \alpha C_a A_s$$

$$Q_{up} = 9c\left[\frac{\pi}{4} bu^2\right] + \alpha\bar{c}\,[\pi \cdot b \cdot L] \quad ...(3.21.2)$$

where, $C$ = Unit cohesion at the base.

$C'$ = Unit cohesion at the bulb.

$C_a$ = Average cohesion on the shaft.

$\alpha$ = Adhesion factor.

IS: 2911-Part 1, 1972 specifies values of $\alpha$ = 1.0, 0.7, 0.4 and 0.3 respectively for soft, medium, stiff and very stiff clays.

$B$ = Diameter of the shaft.

$B_1$ = Diameter of the bulb.

$A_s$ = Surface area of the shaft of the pile above and below the bulb.

**B. Double Underreamed Pile :**

1. For a double underreamed pile, the ultimate load is given by,

$$Q_u = q_{sh}A_{sh} + q_b(A_b - A_{sh}) + fA_s + \bar{f}\,\bar{A}_{sb} \quad ...(3.21.3)$$

where, $\bar{A}_{sb}$ = Surface area of the cylinder circumscribing the bulbs. The length of the cylinder is equal to the distance between the centres of the bulbs.

$$Q_{up} = 9c\left[\frac{\pi}{4} bu^2\right] + \alpha_1\bar{c}\,[\pi b L_1] + \alpha_2\bar{c}\,[\pi bu L_2]$$



$\bar{f}$ = Unit skin friction between soil to soil along the cylindrical surface $A_{sb}$.

2. Other notations are the same as explained earlier. Eq. (3.21.3) can be written as :

$$Q_u = \frac{\pi}{4}B^2(9C) + \frac{\pi}{4}(B_1^2 - B^2)(9C') + \alpha C_a A_s + C_a'\,\bar{A}_{sb} \quad ...(3.21.4)$$

where, $C'_a$ = Average unit cohesion on area $A_{sb}$.

**Que 3.22.** **A drilled pier length 5 m is constructed in an expansive soil having the depth of active zone as 3 m. If the shaft diameter is 1 m and the bulb diameter is 1.25 m. Calculate the factor of safety :**
**A. Without considering dead load.**
**B. With considering dead load of 300 kN on the pier.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Length of pile = 5 m, Depth of active zone = 3 m,
Shaft diameter, $d_s$ = 1 m, Bulb diameter = 1.25 m,
Dead load = 300 kN

**To Find :** A. Factor of safety without considering dead load
B. Factor of safety with considering dead load.

1. Assume undrained cohesion of soil as 75 kN/m², $\alpha$ = 0.5, $\gamma$ = 18 kN/m³, $N_c$ = 6

2. Uplift pressure, $U = \pi d_s L_1 C_u \alpha_s$

where, $d_s$ = Diameter of shaft = 1m

$L_1$ = Depth of active zone = 3 m

$C_u$ = Undrained cohesion of soil.

$U = \pi \times 1 \times 3 \times 75 \times 0.5 = 353.5$ kN

3. Resisting force, $Q_R = Q_{R1} + Q_{R2}$

$Q_{R1} = \pi d_s L_2 \alpha C_u = \pi \times 1 \times (5 - 3) \times 0.5 \times 75$
$= 235.62$ kN

$$Q_{R2} = \frac{\pi}{4}(D_b^2 - D_s^2)(C_u N_c + \gamma L_2)$$

$$= \frac{\pi}{4}(1.5^2 - 1^2)(75 \times 6 + 18 \times 2) = 477.2 \text{ kN}$$

$$Q_R = Q_{R1} + Q_{R2} = 235.62 + 477.2 = 712.82 \text{ kN}$$

4. Factor of safety without dead load,

$$\text{FOS} = \frac{Q_R}{U} = \frac{712.82}{353.5} \geq 1.2$$

$$= 2.016 \geq 1.2 \text{ (Safe)}$$

5. Factor of safety with dead load,

$$\text{FOS} = \frac{Q_R}{U - Q_b} = \frac{712.82}{353.5 - 300} \geq 2 = 13.3 \geq 2 \text{ (Safe)}$$

☺☺☺

# 4 UNIT

# Well Foundations and Retaining Structures

## CONTENTS

PART-1

*Well Foundation, Shape of Well.*

## CONCEPT OUTLINE

**Well Foundation :** Well foundation is also, like the pile foundation, deep foundation. Well foundation provide a solid and massive foundation for heavy loads and are useful in situations where the loads have to be transferred to a soil stratum deep below.

**Shape of Well :** Different shapes of wells that are commonly used are :

i. Circular shape.
ii. Double-D well.
iii. Double-octagonal wells.
iv. Twin circular wells.
v. Rectangular wells.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 4.1.** **What do you mean by well foundation ? What are the advantages of well foundation over other types of foundations ?**

**Answer**

**A. Well Foundation :**

1. Well foundations are one of the types of deep foundations that provide a solid and massive foundation typically for bridges and heavy structures.
2. Well foundations are also useful for transmission line towers, where uplift loads are large.
3. In earlier practice, well foundations were constructed with stone or brick, but today they are mostly of reinforced concrete.
4. The advantages of well foundations are that they are monolithic and rigid, being a massive substructure.
5. They have better lateral load resistance than pile foundations.
6. Well foundations can also be conveniently installed in a boulder stratum as well.



**Advantages of Well Foundations :** The following are the advantages of well foundations over other types of deep foundations such as pile foundations :

1. It is easily adaptable to varying site conditions.
2. High axial and lateral load capacity for these foundations. The weight of the structure can be easily held by the piers and is very sturdy.
3. The are very economical. The cost to drill and install the caissons is minimal when compared to the cost to lay a traditional foundation.
4. Piers minimize the need for pile caps. Because the piers are filled with concrete, pile caps are really not necessary.
5. The effect of scour can be better withstood by a well foundation because of its large cross-sectional area and rigidity.
6. A well foundation can withstand large lateral loads and moments that occur in the case of bridge piers, abutments, tall chimneys, and towers, hence it is preferred to support such structures.
7. There is no danger of damage to adjacent structures since sinking of a well does not cause any vibrations.
8. Well foundations have been found to be economical for large structures when a suitable bearing stratum is available only at large depths.

**Que 4.2.** **What are the different shapes of wells ? Explain them.**

**Answer**

**Different Shapes of Wells :** Following are the different shapes of wells :

**1. Circular Wells :**

i. The most commonly used shape is circular Fig. 4.2.1 (*a*), as it has high structural strength and is convenient in sinking.
ii. The chances of tilting are also minimum in this shape.
iii. The shape is quite suitable for piers of the single-line railway bridges and the double-lane road bridges.
iv. However, when the piers are excessively long, the circular shape becomes uneconomical.
v. The maximum diameter of circular wells is generally limited to 9 m.

**2. Double-*D* Wells :**

i. These are generally used for the piers and abutments of bridges which are too long to be accommodated on a circular well of 9 m diameter.
ii. The wells of this shape can also be sunk easily.
iii. However, considerable bending moments are caused in the steining due to the difference in pressure between the outside and the inside of the well.

iv. Further, the square corners at the partition wall offer greater resistance to sinking.

3. **Double-Octagonal Wells :**

i. These are better than the double-*D* wells in many respects.

ii. The square corners are eliminated and bending stresses are considerably reduced.

iii. However, they offer greater resistance than double-*D* wells against sinking on account of increased surface area.

iv. Moreover, the construction is more difficult.

4. **Twin-Circular Wells :**

i. These are two independent wells placed very close to each other and having a common well cap.

ii. The wells are sunk simultaneously.

iii. These wells are suitable where the length of the pier is considerable, which cannot be accommodated on a double-*D* or double-octagonal well.

iv. Twin circular wells are advantageous when the depth of sinking is small and the bearing capacity of the soil is high.

v. The disadvantage of twin circular wells is that there is a possibility of the relative settlement of the two wells even if a heavy RCC top cap is provided unless the wells are founded on an incompressible soil.

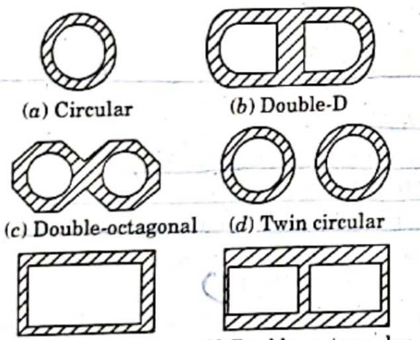



**Fig. 4.2.1.** Different shapes of wells.

5. **Rectangular Wells :**

i. These are generally used for bridge foundation having depths upto 7-8 m.

ii. For large foundations, double-rectangular wells are used.

iii. For piers and abutments of very large size, rectangular wells with multiple dredge holes are used. Bending stresses in the steining are very high in rectangular wells.



**Que 4.3.** **Explain the various types of well foundation with its advantages and disadvantages.**

**Answer**

Following are the types of well foundation :

1. **Open Caisson :** The top and bottom of the caisson is open during construction. It may have any shape in plan e.g., circular, rectangular, oblong etc.

**Advantages :**

i. The caisson can be constructed to large depths.

ii. The cost of construction is relatively less than other types of caissons.

**Disadvantages :**

i. Progress of construction in boulder deposits is very slow.

ii. The concrete sealed under water is not very effective.

iii. Inspection of the bottom of the well is not possible.

2. **Box Caisson :**

i. A box caisson is open at the top but is closed at the bottom.

ii. This type of caisson is first cast on land and then towed to the site where it is sunk onto a previously levelled foundation base. It is also called as floating caisson.

**Advantages :**

i. The cost of construction of box caissons is low.

ii. It can be used where other types of caissons cannot be constructed.

**Disadvantages :**

i. It is difficult to provide the foundation base below the water level, especially for deep excavations.

ii. Bearing capacity of the foundation base has to be properly assessed. Care has to be taken to protect the foundation base from scour.

3. **Pneumatic Caisson :** A pneumatic caisson has a working chamber at the caisson which is kept dry by forcing out water under pressure, thus permitting excavation under dry condition. Air locks are provided at the top.

**Advantages :**

i. There is a complete control over the sinking of the caisson, so that tilts and shifts can be detected immediately.

ii. The bottom of the chamber can be sealed effectively as it is maintained under dry conditions.

iii. Obstructions to sinking, such as boulders, can be removed easily.

**Disadvantages :**

i. Pneumatic caissons are costlier than other types of caissons.

## PART-2

*Components of Well Foundation.*

### CONCEPT OUTLINE

**Components of a Well Foundation :** The various components of a well foundation are :

| | |
|---|---|
| i. Well cap. | ii. Steining. |
| iii. Curb. | iv. Cutting edge. |
| v. Bottom plug. | vi. Dredge hole. |
| vii. Top plug. | |

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 4.4. Discuss the components of well foundation and draw the neat sketch of a well foundation. Explain all the terms in brief.**

**AKTU 2013-14, Marks 06**

**OR**

**Explain the term used in well foundation : well curb, cutting edge and bottom plug.**

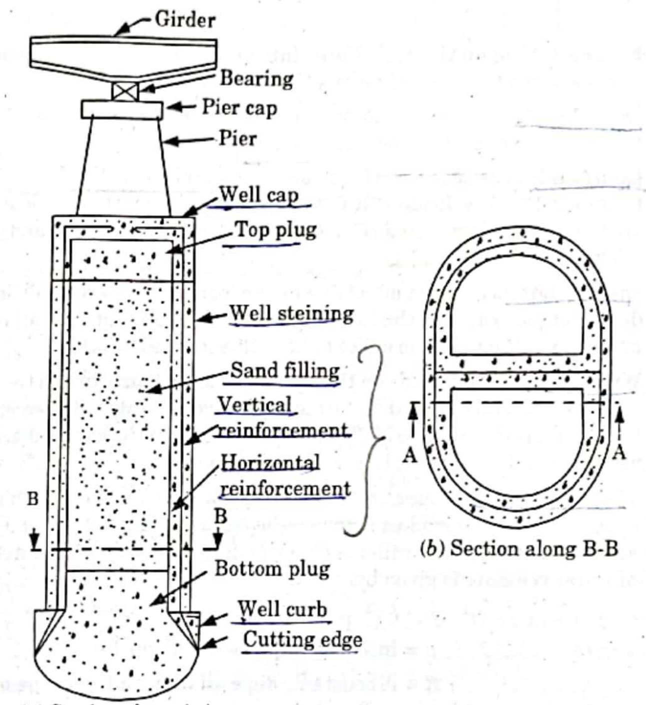
**AKTU 2017-18, Marks 05**

**Answer**

**Components of a Well Foundation :** Following are the various components of a well foundation :

1. **Well-Cap :** The well cap is a RCC slab laid at the top of the well steining and is usually cast monolithically with the steining. It transmits the load of the superstructure to the steining.
2. **Steining :** The well steining is the main body of the well which transfer load to the subsoil. It also acts as a coffer dam during sinking and provides the weight for sinking.
3. **Curb :** The lower wedge shaped portion of the well steining is called the well curb. The curb facilitates the process of sinking.






(a) Section along A-A

(b) Section along B-B

**Fig. 4.4.1.** Various components of a well foundation.

4. **Cutting Edge :** The lowermost portion of the well curb is the cutting edge. It cuts into the soil during sinking.
5. **Bottom Plug :** After the well is sunk to the required depth, the base of the well is plugged with concrete. This is called bottom plug. It transmits the load to the subsoil.
6. **Dredge Hole :** The well is sunk by excavating soil from within the well. The hole formed due to the excavating of soil is called dredge hole. The dredge hole is later filled with sand. The sand filling helps in distributing the load of the superstructure to the bottom plug.
7. **Top Plug :** A concrete plug covering the sand filling is usually constructed at the top. It is called the top plug. The top plug provides contact between the well cap and sand filling and helps in transferring the load through the sand filling.

**Que 4.5. Discuss the various forces acting on a well foundation.**

**Answer**

**Forces Acting on the Well Foundation :** The following forces should be considered in the design of a well foundation :

1. **Dead Loads :** The dead loads carried by the well include the weight of the superstructure and the self weight.
2. **Live Loads :** The design live loads for railway bridges are taken according to Indian Railway Bridges Rules. For road bridges, the live loads as specified by the Indian Road Congress Standard Specifications and Code of Practice for Road Bridges.
3. **Impact Loads :** Impact effect due to live load is considered only in the design of pier cap and the bridge seat on the abutment. For all other members of the well, the effect of impact is ignored.
4. **Wind Loads :** Wind loads on the live load, superstructure and the part of the substructure located above the water level are calculated according to the provisions of IS : 875. The wind load acts on the exposed area in elevation and thus it acts laterally on the bridge.
5. **Water Pressure :** Water pressure due to water current acts on the part of substructure which lies between the water level and the maximum scour level. On piers parallel to the direction of the water, the intensity of water pressure is given by,

$$p = Kv^2$$

where, $p$ = Intensity of pressure (kN/m$^2$).

$K$ = A constant, depending upon the shape of the well.

v = Velocity of current (m/sec).

6. **Longitudinal Forces :** Longitudinal forces occur due to tractive and braking forces. These forces depend upon the type of vehicles and bearings. These forces are transmitted to substructure mainly through fixed bearings and through friction in movable bearings.
7. **Centrifugal Force :** A centrifugal force is transmitted through bearings if the bridge is curved in plan.
8. **Buoyant Forces :** Buoyancy reduces the effective weight of the well. In masonry or concrete steining, 15 % buoyancy is considered to account for the porousness.
9. **Earth Pressure :** The earth pressure is calculated according to Rankine's theory or Coulomb's theory. For the stability of foundations below the scour level, the passive earth pressure of the soil is considered.
10. **Temperature Stresses :** Longitudinal forces are induced due to temperature changes. The movements due to temperature changes are partially restrained in girder bridges because of friction at the movable end.



11. **Seismic Forces :** For the wells constructed in the seismic zone, seismic forces should be considered. The forces act on all components of the structure. The force is usually specified as $\alpha W$, where $W$ is the weight of the component and $\alpha$ is the seismic coefficient.

**PART-3**

*Sinking of Well.*

**CONCEPT OUTLINE**

**Sinking of Well :** Following are the steps in sinking of well :

i. Constructing of the well curb.
ii. Construction of well steining.
iii. Sinking process.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 4.6.** **Describe about well sinking. What are the measures employed in controlling well sinking ?** **AKTU 2016-17, Marks 10**

**Answer**

**Sinking of Wells :** The operation sinking of a well consists of the following steps :

1. **Construction of the Well Curb :**

i. In dry ground excavate up to 15 cm in river bed and place the cutting edge at the required position.
ii. If the curb is to be laid under water and depth of water is greater than 5 m. prepare Sand Island and lay the curb.
iii. If depth of water exceeds 5 in built curb in dry ground and float it to the site.
iv. Concreting of the curb is done in continuous operation.
v. After the curb is cured and allowed to cure for at least seven days, the shuttering may be removed as also the sleepers.

**Answer**

**Forces Acting on the Well Foundation :** The following forces should be considered in the design of a well foundation :

1. **Dead Loads :** The dead loads carried by the well include the weight of the superstructure and the self weight.
2. **Live Loads :** The design live loads for railway bridges are taken according to Indian Railway Bridges Rules. For road bridges, the live loads as specified by the Indian Road Congress Standard Specifications and Code of Practice for Road Bridges.
3. **Impact Loads :** Impact effect due to live load is considered only in the design of pier cap and the bridge seat on the abutment. For all other members of the well, the effect of impact is ignored.
4. **Wind Loads :** Wind loads on the live load, superstructure and the part of the substructure located above the water level are calculated according to the provisions of IS : 875. The wind load acts on the exposed area in elevation and thus it acts laterally on the bridge.
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$$p = Kv^2$$

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## PART-3

*Sinking of Well.*

### CONCEPT OUTLINE

**Sinking of Well :** Following are the steps in sinking of well :

i. Constructing of the well curb.

ii. Construction of well steining.

iii. Sinking process.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 4.6.** **Describe about well sinking. What are the measures employed in controlling well sinking ?** **AKTU 2016-17, Marks 10**

**Answer**

**Sinking of Wells :** The operation sinking of a well consists of the following steps :

1. **Construction of the Well Curb :**

i. In dry ground excavate up to 15 cm in river bed and place the cutting edge at the required position.

ii. If the curb is to be laid under water and depth of water is greater than 5 m. prepare Sand Island and lay the curb.

iii. If depth of water exceeds 5 in built curb in dry ground and float it to the site.

iv. Concreting of the curb is done in continuous operation.

v. After the curb is cured and allowed to cure for at least seven days, the shuttering may be removed as also the sleepers.

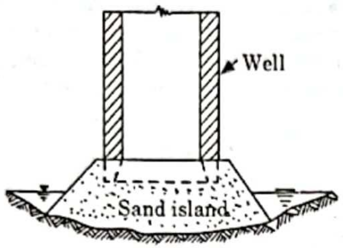



Fig. 4.6.1. Sand island for sinking a well.

**2. Construction of Well Steining :**

i. The steining should be built in short height of 1.5 m initially and 3 m after a 6 m grip length is achieved.

ii. The vertically should he maintained.

iii. The aim of the well sinking is to sink the well vertically and at the correct position.

**3. Sinking Process :**

i. Excavate material under the inside of well curb mechanically or manually.

ii. Allow the well to remain vertical.

iii. Up to a depth of 1 m, excavation underwater can be made manually. When the depth of water exceeds 1 m excavate by Jhams or grabs.

iv. When well goes on sinking skin friction increases and weight of well decreases due to buoyancy.

v. When the well does not sink, by applying kentledge. If this operation is not sufficient jet outside the well or grease the outside.

vi. Go on adding sections of steining (2 to 5 m in length) up to the required founding strata.

**Que 4.7. Write about the various types of shifts takes place in the well foundation. How these shifts can prevent ?**

AKTU 2015-16, Marks 10

**Answer**

**Types of Shifts :** There are three stages in the construction of well foundation :

i. Constructing of the well curb.

ii. Construction of well steining.

iii. Sinking process.

In each of above stages shifts & tilts take place in the well foundation.

**Precautions :** The following precautions may be taken to avoid tilts and shifts :

i. The outer surface of the well curb and steining should be smooth.



ii. The curb diameter should be kept 40 to 80 mm larger than the outer diameter of the steining, and the well should be symmetrically placed.

iii. The cutting edge should be uniformly thick and sharp.

iv. Dredging should be done uniformly on all sides and in all the pockets.

v. IS : 3955-1967 recommends that tilt should be generally limited to 1 in 60. The shift should be restricted to one percent of the depth sunk. In case these limits are exceeded, suitable remedial measures are to be taken for rectification.

**Que 4.8. Discuss the various methods for rectification of tilts and shifts in the well foundation.**

AKTU 2017-18, Marks 05

**Answer**

purification झुकाव बदलाव

**Remedial Measures for Rectification of Tilts and Shifts :** The following remedial measures may be taken to rectify tilts and shifts :

**1. Regulation of Excavation :**

i. The higher side is grabbed more be regulating the dredging. In the initial stages this may be all right.

ii. Otherwise, the well may be dewatered if possible and open excavation may be carried out on the higher side, as shown in Fig. 4.8.1.

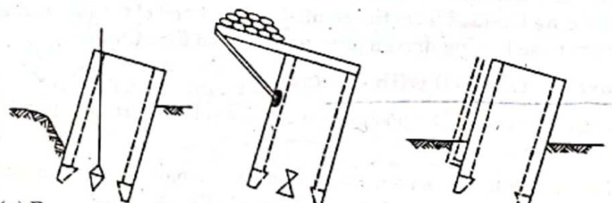
**2. Eccentric Loading :**

i. Eccentric placing of the kentledge may be resorted to provide greater sinking effort on the higher side.

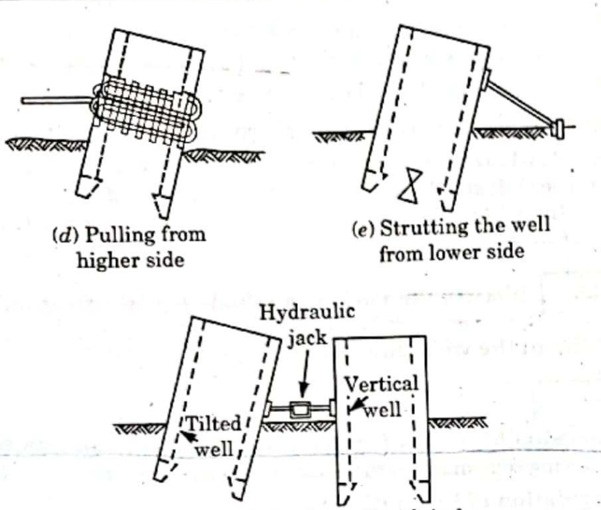
ii. If necessary a platform with greater projection on the higher side may be constructed and used for this purpose.

iii. As the depth of sinking increases, heavier kentledge with greater eccentricity would be required to rectify tilt, as shown in Fig. 4.8.1 (*b*).

**3. Water Jetting :** If water jets are applied on the outer face of the well on the higher side, the friction is reduced on that side, and the tilt may get rectified, as shown in Fig. 4.8.1 (*c*).



(*a*) Excavation on higher side (*b*) Using eccentric kentledge (*c*) Water or air jetting on higher side




(*d*) Pulling from higher side

(*e*) Strutting the well from lower side

(*f*) Pushing the well with jacks

**Fig. 4.8.1.** Remedial measures for correction of tilt of wells.

4. **Excavation under the Cutting Edge :** If hard clay is encountered, open excavation is done under the cutting edge, if dewatering is possible, if not, divers may be employed to loosen the strata.

5. **Insertion of Wood Sleeper under the Cutting Edge :** Wood sleepers may be inserted temporarily below the cutting edge on the lower side to avoid further tilt.

6. **Pulling the Well :** In the early stages of sinking, pulling the well to the higher side by placing one or more steel ropes round the well, with vertical sleepers packed in between to distribute the pressure over larger areas of well steining, is quite effective, as shown in Fig. 4.8.1(*d*).

7. **Strutting the Well :**

   The well is strutted on its tilted side with suitable logs of wood to prevent further tilt. The well steining is provided with sleepers to distribute the load from the strut. The other end of the logs rest against a firm base having driven piles as shown in Fig. 4.8.1(*e*).

8. **Pushing the Well with Jacks :**

   i. Tilt can be rectified by pushing the well by suitably arranging mechanical or hydraulic jacks.

   ii. In actual practice, a combination of two or more of these approaches may be applied successfully, as shown in Fig. 4.8.1(*f*).



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## PART-4

*Retaining Walls, Types of Retaining Structures.*

### CONCEPT OUTLINE

**Retaining Walls :** Retaining walls are relatively rigid walls used for supporting the soil mass laterally so that the soil can be retained at different levels on the two sides.

**Types of Retaining Walls :** Following are the types of retaining walls :

i. Gravity retaining walls.

ii. Semi-gravity retaining walls.

iii. Cantilever retaining wall.

iv. Counterfort retaining wall.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 4.9.** What are the different types of retaining walls ?

**Answer**

Following are the different types of retaining walls :

1. **Gravity Retaining Walls :**

   i. These walls depend upon their weight for stability.

   ii. The walls are usually constructed of plain concrete or masonry.

   iii. Such walls are not economical for large heights.

   • G.R.W. can be constructed from concrete, stone or even brick masonry

   • G.R.W are much thicker in section.

2. **Semi-Gravity Retaining Walls :** The size of the section of a gravity retaining wall may be reduced if a small amount of reinforcement is provided near the back face. Such walls are known as semi-gravity walls.

3. **Cantilever Retaining Walls :**

   i. Cantilever retaining walls are made of reinforced cement concrete.

   ii. The wall consists of a thin stem and a base slab cast monolithically.

   iii. This type of wall is found to be economical upto a height of 6 to 8 m.

   • Can C.R.W are most commonly and widely used type of retaining wall.

**4. Counterfort Retaining Walls :**

i. Counterfort retaining walls have thin vertical slabs, known as counterforts, spaced across the vertical stem at regular intervals.

ii. The counterforts tie the vertical stem with the base slab.

iii. Thus the vertical stem and the base slab span between the counterforts.

iv. The purpose of providing the counterforts is to reduce the shear force and bending moments in the vertical stem and the base slab.

vi. The counterfort retaining walls are economical for a height more than 6 to 8 m. • C.R.W is adopted for large heights.

**Que 4.10.** **What are the various types of retaining structure ?**

**Answer**

Following are the various types of retaining structure :

**1. Cellular Confinement :**

i. Cellular confinement systems have become increasingly popular for earth retention applications.

ii. They can be constructed as a gravity wall or a "geogrid" wall which consists of vertical layers of geocells with geogrid reinforcement installed behind the face of the wall every few layers of the geocell depending on design.

iii. Cellular confinement systems (geocells) are also used for steep earth stabilization in gravity and reinforced retaining walls with geogrids.

iv. Geocell retaining walls are structurally stable under self- weight and externally imposed loads, while the flexibility of the structure offers very high seismic resistance.

v. The outer fascia cells of the wall can be planted with vegetation to create a green wall.

**2. Soil Nailing :**

i. Soil nailing is a technique in which soil slopes, excavations or retaining walls are reinforced by the insertion of relatively slender elements - normally steel reinforcing bars.

ii. The bars are usually installed into a pre-drilled hole and then grouted into place or drilled and grouted simultaneously.

iii. They are usually installed untensioned at a slight downward inclination.

iv. A rigid or flexible facing (often sprayed concrete) or isolated soil nail heads may be used at the surface.



**3. Gabion Meshes :**

i. This type of soil strengthening, often also used without an outside wall, consists of wire mesh boxes, which are filled with roughly cut stone or other material.

ii. The mesh cages reduce some internal movement and forces, and also reduce erosive forces.

iii. Gabion walls are free draining retaining structures and as such are often built in locations where ground water is present.

**4. Buttress Wall :**

i. It is similar to counterfort wall, except that the transverse stem supports, called buttress, are located in the front side, interconnecting the stem with the toe slab (and not with heel slab, as with counterforts).

ii. Although the buttresses are structurally more efficient (and more economical) counterforts, the counterfort wall is generally preferred to the buttress wall as it provides free usable space (and better aesthetics) in front of the wall.

**Que 4.11.** **Explain the various types of failure of cantilever retaining walls.**

**Answer**

Following are the various types of failures occur in retaining walls :

**1. Sliding Failure :**

i. Sliding failure is nothing but sliding of wall away from backfill when there is shearing failure at the base of wall.

ii. The Factor of safety against sliding is

$$F_s = \frac{\mu R_V}{R_H} < 1.5$$

where, $\mu$ = Coefficient of friction = tan δ

$R_V$ and $R_H$ = Vertical and horizontal components of resultant $R$ of weight of wall and earth pressure.

**2. Overturning Failure :**

i. Overturning failure is rotation of wall about its toe due to exceeding of moment caused due to overturning forces to resisting forces.

ii. The Factor of safety against overturning is given by,

$$F_O = \frac{\Sigma M_R}{\Sigma M_O} < 1.5 - 2.0$$

where, $\Sigma M_R$ = Sum of resisting moment about toe.

$\Sigma M_O$ = Sum of overturning moment about toe.

3. **Bearing Capacity Failure :**

i. The pressure exerted by resultant vertical force at toe of wall must not exceed the allowable bearing capacity of the soil.

ii. The pressure distribution is assumed to be linear.

iii. The maximum pressure is given by.

$$P_{max} = \frac{R_V}{b}\left(1 + \frac{6e}{b}\right)$$

iv. The Factor of safety against bearing failure is.

$$F_b = \frac{q_{na}}{P_{max}} < 3.0$$

where, $q_{na}$ = Allowable bearing pressure.

4. **Shallow Shear Failure :**

i. This type of failure occurs along a cylindrical surface ABC passing through the heel of retaining wall as shown in the Fig. 4.11.1.(iv).

ii. The failure takes place because of excessive shear stresses along the cylindrical surface within the soil mass.

iii. The FOS against horizontal sliding is lower than that for shallow shear failure.

iv. However, FOS against sliding is greater than 1.5 shallow shear failures is not likely to occur.

5. **Deep Shear Failure :**

i. This type of slope failure occurs along a cylindrical surface ABC as shown in above Fig. 4.11.1.(v), when there is a weak layer of soil under the wall at a depth of about 1.5 times height of wall.

ii. The critical failure surface is found by trial and error method.



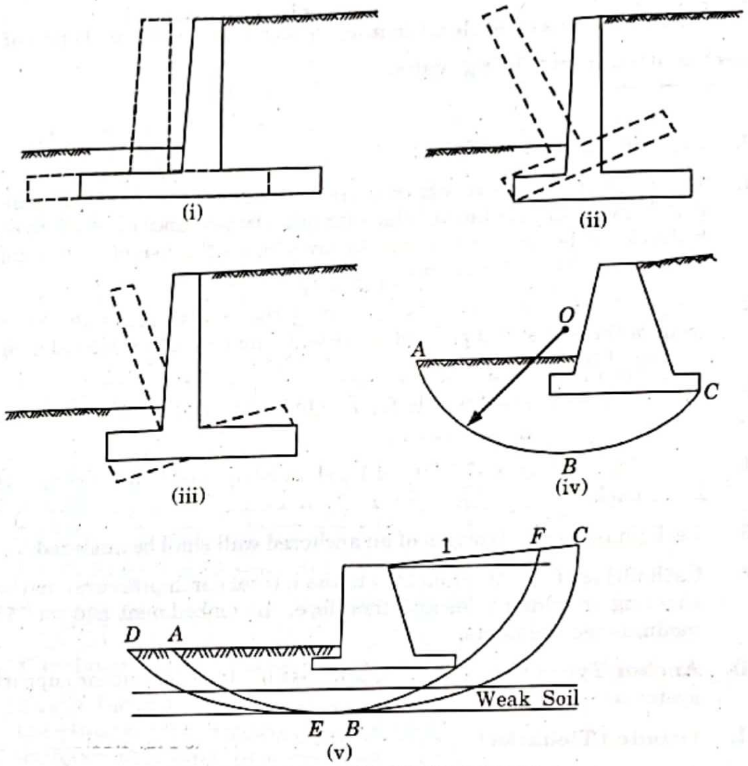


**Fig. 4.11.1.** Failure of retaining walls.

iii. For the backfills having slope $i$ less than 10°, it has been seen that critical failure surface DEF passes through the edge of heel slab as shown in above Fig. 4.11.1.(v).

iv. In this condition possibility of excessive settlement should also be checked.

**PART-5**

*Support System for Flexible Retaining Wall (Struts, Anchoring).*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 4.12.** **Discuss the flexible anchor walls and various types of anchor used in retaining walls.**

**Answer**

**A. Flexible Anchored Walls :**

1. When the height of excavation increases over 15 ft. (4.6 m), or if the embedment depth is limited (for example, the presence of boulders or bedrock), it becomes necessary to investigate the use of additional support for the wall system.
2. An anchored wall derives its support by the passive pressure on the front of the embedded portion of the wall and the anchor tie rod near the top of the wall.
3. Anchored walls are suitable for heights up to approximately 35 ft. (10.5 m).
4. An additional factor of safety of 1.5 shall be applied to all anchor and brace loads.
5. Each phase of construction of an anchored wall shall be analyzed.
6. Each phase of construction affects the lateral earth pressures on the sheeting or soldier piles and therefore, the embedment and section modulus requirements.

**B. Anchor Types :** The following are possible types of anchor support systems :

1. **Grouted Tiebacks :**

i. A grouted tieback is a system used to transfer tensile loads from the flexible wall to soil or rock.

ii. It consists of all prestressing steel, or tendons, the anchorage, grout, coatings, sheathings, couplers and encapsulation (if applicable).

2. **Deadman :**

i. A deadman may consist of large masses of precast or cast-in-place concrete, driven soldier piles or a continuous sheeting wall.

ii. The required depth of the deadman shall be analyzed based on the active and passive earth pressures exerted on the deadman.

iii. Deadman anchors must be located a distance from the anchored wall such that they can fully mobilize their passive pressure resistance outside of the anchored wall's active zone.



3. **Struts or Braces / Rakers :**

i. Struts or braces are structural members designed to resist pressure in the direction of their length.

ii. Struts are usually installed to extend from the flexible wall to an adjacent parallel structure.

iii. Rakers are struts that are positioned at an angle extending from the flexible wall to a foundation block or supporting substructure.

## PART-6

*Construction Method of Retaining Walls.*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 4.13.** **Explain the construction method of retaining walls.**

**Answer**

**Construction Procedure of Retaining Walls :**

1. Firstly, the area will be surveyed in order to know the elevation and the proper section or shape, construction joints and the straightness of the line with respect to the gridlines.
2. As the surveying is done, the installation of vertical rebars takes place. The rebar installation includes the vertical main bars, filler bars, ties, inner ties and tie wires. The alternate hook-squala should be implemented in this procedure. Proper splicing of the rebars should be strictly observed. The placing of spacer between the rebars and the formworks is included.
3. As the rebar installation is done, cleaning before concrete pouring takes place. The vacuum cleaner, air compressor and pressure washer is being used. And inspection of the construction quality control and the inspector of the owner's consultant take place.
4. If the approval of the inspector got, closure for the column takes place. Then, the formwork is being installed, if the column is greater than 3m, there should be 1st lift, 2nd lift and so on.
5. After the formworks is done, concrete pouring takes place. While the concrete is being poured, the concrete vibrator is being used.

6. As the concrete pouring is done, checking of elevation: surveying takes place.
7. As the concrete hardens, the removing of the formworks takes place.
8. As the formworks were removed, they put burlap over the hardened concrete.
9. Lastly, curing takes place.

## PART-7

*Introduction and Uses of Sheet Pile.*

| Questions-Answers |
|---|
| Long Answer Type and Medium Answer Type Questions |

• Sheets of steel driven into the ground.
eg. Roadside है।

**Que 4.14. Discuss sheet piles and its various types.**

**Answer**

**A. Sheet Pile Wall :**

1. It consists of a series of sheet piles driven side by side into ground thus forming a continuous wall for the purpose of retaining an earth bank.
2. Sheet piling is an earth retention and excavation support technique that retains soil, using sheet sections with interlocking edges.
3. Sheet piles are installed in sequence to design depth along the planned excavation perimeter or seawall alignment.
4. Sheet pile is act as a temporary supportive wall that been driven into a slope or excavation to support the soft soils collapse from higher ground to lower ground.

**B. Types of Sheet Piles :** Following are the various types of sheet piles :

**1. Wooden Sheet Piles :**

i. Wooden sheet piles are made in various sizes and forms.

ii. The nature of site conditions determine, the choice of a particular type,

iii. In places where excavation is small and the ground water problem is not serious, 5 cm × 30 cm to 10 cm × 30 cm wooden planks arranged in a simple row will serve the purpose.



**2. Precast Concrete Piles :**

i. Precast concrete piles are made in square or rectangular cross-section and are driven similar to wooden piles to form a continuous wall.

ii. The interlock between two piles is normally provided with the help of tongue and groove joint.

iii. The tongue and groove extends to the full length of the piles in most of the cases.

**3. Prestressed Concrete Piles :**

i. Similar to concrete sheet piles, they are reinforced on both the faces so that they could be handled from either side.

ii. They are comparatively lighter in weight, more durable and economical in the long run.

**4. Steel Sheet Piles :**

i. Steel sheet pile is a rolled steel section consisting of a plate called the web with integral interlocks on each edge.

ii. The interlocks consist of a groove, one of whose legs has been suitably flattened.

iii. This flattening forms the tongue which fits into the groove of the second sheet.

**Que 4.15. Explain the general guidelines for construction of sheet pile walls.**

**Answer**

**Guidelines for Construction of Sheet Pile Walls :**

1. In the construction of sheet-pile walls, the sheet pile may be driven into the ground and then the backfill placed on the land side, or the sheet pile may first be driven into the ground and the soil in front of the sheet pile dredged.
2. In either case, the soil used for backfill behind the sheet-pile wall is usually granular.
3. The soil below the dredge line may be sandy or clayey. The surface of soil on the water side is referred to as the mud line or dredge line.
4. Thus, construction methods generally can be divided into two categories (sheet pile wall types) :

i. Backfilled structure.

ii. Dredged structure.

i. The sequence of construction for a backfilled structure is as follows :

   a. Dredge the in situ soil in front and back of the proposed structure

   b. Drive the sheet piles.

   c. Backfill up to the level of the anchor, and place the anchor system.

   d. Backfill up to the top of the wall.

   e. For a cantilever type of wall, only Steps a, b, and d apply.

ii. The sequence of construction for a dredged structure is as follows :

   a. Drive the sheet piles.

   b. Backfill up to the anchor level, and place the anchor system.

   c. Backfill up to the top of the wall.

   d. Dredge the front side of the wall.

   e. With cantilever sheet-pile walls, Step b is not required.

**Que 4.16.** **What are the advantages and disadvantages of sheet pile walls.**

**Answer**

**Advantage of Sheet Pile Walls :**

1. Provides high resistance to driving stresses.
2. Light weight.
3. Can be reused on several projects.
4. Long service life above or below water with modest protection.
5. Easy to adapt the pile length by either welding or bolting.
6. Joints are less apt to deform during driving.

**Disadvantages of Sheet Pile Walls :**

1. Sections can rarely be used as part of the permanent structure.
2. Installation of sheet piles is difficult in soils with boulders or cobbles. In such cases, the desired wall depths may not be reached.



3. Excavation shapes are dictated by the sheet pile section and interlocking elements.
4. Sheet pile driving may cause neighborhood disturbance.
5. Settlements in adjacent properties may take place due to installation vibrations.

**Que 4.17.** **Give the uses of sheet pile walls.**

**Answer**

**Uses of Sheet Pile Wall :** Following are the uses of sheet pile walls :

1. Sheet pile walls have been used to support excavations for below-grade parking structures, basements, pump houses, and foundations, to construct cofferdams, and to construct seawalls and bulkheads.
2. Sheet piling is also used for beach erosion protection; for stabilizing ground slopes, particularly for roads; for shoring walls of trenches and other excavations.
3. Create barriers to groundwater flow.

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5

UNIT

# Reinforced Soil

## CONTENTS







## PART-1

*Geotechnical Properties of Reinforced Soil.*

### CONCEPT OUTLINE

In soil reinforcement, different engineering material are used to enhance the soil strength :
1. Geogrids.
2. Geotextiles.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 5.1.** **What do you mean by reinforcement soil ? What are the effects of reinforcement on soil properties ?**

**Answer**

**A. Soil Reinforcement :**

i. Soil reinforcement is a technique used to improve the stiffness and strength of soil using geo-engineering methods.

**B. Effect of Reinforcement on Properties :** Following are the effect of reinforcement on soil properties :

1. The compaction behavior is affected by fibre inclusion, and the maximum dry density is found to reduce slightly with an increase of fibre content and marginal increase in OMC is noted.
2. It is noticed that the stress-strain behaviour has changed from brittle to ductile with inclusion of basalt fibre.
3. The percentage increase in shear strength of soil is about 17 % for basalt fibre and about 25 % for polypropylene fibre.
4. It is also found that at large fibre content (> 1 %). the strength also reduces, as the whole matrix become highly compressible at same load.
5. It is noticed that the inclusion of basalt fibres does not affect the compressibility characteristics of soil significantly, which is due to fact that basalt fibre consists of natural minerals having specific gravity similar to soil.

**Que 5.2.** **Write the short note on following :**

**A. Strips reinforcement.**
**B. Grids reinforcement.**
**C. Sheet reinforcement.**

**Answer**

**A. Strips Reinforcement :**

1. These are flexible linear elements having their breadth greater than their thickness.
2. The thickness usually ranges between 3 mm and 9 mm, while the breadth between 40 mm and 120 mm.
3. The most common strips are metals (galvanized steel, Aluminium-Magnesium alloy, 17 % chrome stainless steel).
4. The strip may either be plain or having several protrusions such as ribs or grooves to increase the friction between the reinforcement and soil.
5. Metal strips are used as reinforcement, provision should be made for loss of thickness due to corrosion.
6. Maximum rate of corrosion of the same metals with other soils is 15 to 20 times less.
7. Strips can also be formed from bamboo, polymers and glass fibre reinforced plastics.

**B. Grids Reinforcement :**

1. Grids can be made from steel (in the form of plain or galvanized weld mesh) or from expanded metal.
2. Grids formed from polymers are known as geogrids, and are normally in the form of an expanded proprietary plastic product.
3. The raw materials are polypropylene or high density polyethylene.
4. The polymer sheets are first perforated, the form, size and distribution of holes being determined by the end product.
5. The perforated sheets are then stretched in one direction while it is gently heated.
6. The action of stretching the sheet aligns the polymer's long chain molecules in the direction of stretch, giving the grid a high tensile stiffness in this direction.

**C. Sheet Reinforcement :**

1. Sheet reinforcement may be formed from metal such as galvanized steel, fabric (textile) or expanded metal not meeting the criteria for the grid.
2. Geofabrics are very common sheet type reinforcement.
3. These are porous fabrics manufactured from synthetic materials such as polypropylene, polyester, polyethylene, polyamide and glass fibres.
4. They come in thicknesses ranging from 0.125 mm to 7.5 mm with permeability comparable in range from coarse gravel to fine sand.
5. They can be constructed in a variety of ways, the most common methods being;
   i. Woven, made from continuous monofilament fibres, and



   ii. Non-woven, made from continuous or staple fibres laid down in a random pattern and then mechanically entangled into a relatively thick, felt-like fabric by means of punching with barbed needles.
6. A wide variety of both woven and non-woven fabrics are available where the fibres are either bonded or interlocked.

**Que 5.3.** **Write down the different engineering techniques are used to enhance the soil strength of soil reinforcement.**

**Answer**

Following different engineering techniques are used to enhance the soil strength :

1. The geogrids are most commonly used in soil reinforcement as they are engineered to be extremely durable and resistant.
2. There are 3 different types of Geogrids available,
   i. Extruded Geogrids are flat structures in polymer (usually high density polyethylene or polypropylene) that are extruded and then pulled: this may be done in one direction (mono-oriented geogrids), or in the two main directions (bi-oriented geogrids). They are used in soil and road paving reinforcement.
   ii. Bonded Geogrids are flat structures, where two or more series of strip elements made of polyester coated with polyethylene, are linked at regular intervals by means of bonding.
   iii. Woven Geogrids are flat structures in the shape of a net made of high module synthetic fibres, which may also be coated with a further protection layer, using synthetic material (usually PVC or other polymer).
3. Geotextiles are another popular option as they are cost-effective, more profitable and highly adaptable. This serves to maximise the reproducibility of soil and thickens the soil volume for increased strength.

**PART-2**

*Use of Soil Reinforcement.*

| Questions-Answers |
| --- |
| Long Answer Type and Medium Answer Type Questions |

**Que 5.4.** **What factors govern the effectiveness of a reinforcing element in soil ? Explain each in detail. Give some application areas of reinforced soil.**

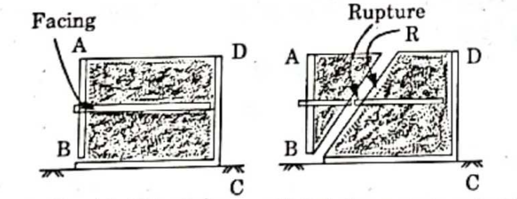
**Answer**

A. **Factors :** The effectiveness of a reinforcing element embedded in soil is governed by the following factors :

1. The capacity of the element to withstand tensile stresses, *i.e.* its tensile strength,
2. The amount of extension exhibited by the element under tensile stress.
3. The shearing resistance (adherence) between the reinforcement and the surrounding soil *i.e.* the maximum stress that can be resisted by the soil-reinforcement interface before the reinforcement slips away from the soil.

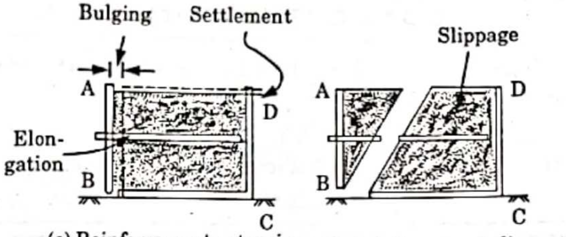
B. **Explanation :**

1. When the tensile strength of an element is low, it can break or yield and become ineffective.
2. If the tensile strength is adequate but its extension under stress is high, then the soil may show large movement (settlement or lateral bulging) because of the inadequate stiffness of the soil-reinforcement system.
3. If the reinforcement is sufficiently strong and rigid but there is inadequate adherence between the soil and the reinforcement, then relative movement can occur, making the reinforcement ineffective.
4. To better understand the above mechanisms let us look at Fig. 5.4.1. It shows the tank ABCD filled with dry sand.
5. Side AB of the tank has been replaced by a wooden board, called facing, which is attached to a reinforcing element buried in the sand.
6. When the soil-reinforcement interaction is satisfactory, the board remains held in position as depicted in Fig. 5.4.1(a).




(a) Sand held back by reinforcement and facing (b) Reinforcement rupture causes failure






(c) Reinforcement extension cause bulging and settlement (d) Reinforcement slippage cause failure

**Fig. 5.4.1.** Reinforcement failure mechanisms.

7. When the tensile strength of the reinforcement is low, failure occurs due to rupture of the reinforcement at point *R* [Fig. 5.4.1(b)].
9. When tensile strength is adequate but the reinforcement shows large extension, then lateral and vertical movement of soil occurs as shown in Fig. 5.4.1(c).
10. When tensile strength is enough and extension is low but the soil-reinforcement adherence is inadequate, failure occurs due to slippage of the reinforcement from the stable soil as shown in Fig. 5.4.1(d).
11. It is important to note that amongst metal strips, geogrids and geotextiles, metal reinforcements exhibit the highest tensile strength and the least extensibility, whereas geogrids offer the highest soil-reinforcement shearing resistance per unit surface area.

C. **Applications :** Following are the application of reinforcement soil :

1. The largest application of soil reinforcement is for the construction of earth structures with steep or vertical sides in lieu of rigid retaining walls.
2. In particular when approach roads have to be made for flyovers in urban areas, a structure of reinforced soil with vertical sides is observed to be more economical than backfilling behind cantilever or gravity retaining walls.
3. Other applications of reinforced soil are in construction of bridge abutments, highway embankments in hilly regions, steep or vertical cuts in open excavations, stabilizations of unstable slopes, unpaved roads on soft soils and embankment on soft soils.

**PART-3**

*Shollow Foundation on Soil with Reinforcement.*

## CONCEPT OUTLINE

Ultimate bearing capacity of reinforced soil ($q_{ur}$) has been found to be equal to :

$$q_{ur} = q_r + \gamma D_R N_q$$

Where $D_R$ = Depth of lowermost layer of reinforcement.

$N_q$ = Terzaghi's bearing capacity factor.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 5.5. Write down the assumption used for the analysis of strip footing on reinforced soil bed.**

**Answer**

Following are the assumption used for the analysis of strip footing on reinforced soil bed :

1. The central zone of soil moves down with respect to outer zones. The boundary between the downward moving and outward moving zones has been assumed as locus of points of maximum shear stress at every depth $Z$.
2. At the plane separating the downward and lateral movements, the ties are assumed to undergo two right-angled bends around two frictionless rollers and $T_D$ is a vertically acting tensile force.
3. The tie-soil friction coefficient has been assumed to vary with depth as per following equation

$$f_e = mf$$

where, $m$ = Mobilization factor.

4. The forces evaluated in the analysis are for the same size of footing and same settlement for a footing on reinforced and unreinforced soil.
5. Elastic theory is applied to estimate the stress distribution inside the soil mass.

**Que 5.6. Give the expression for computation of the tie-pull-out frictional resistance ($T_f$) for strip footing.**

**Answer**

**Computation of the Tie-Pull-Out Frictional Resistance ($T_f$) :**

1. The tie-pull-out frictional resistance shall be due to the normal force on the length of the tie which is outside the assumed plane separating downward and outward flow $a$-$c$ as shown in Fig. 5.6.1.



2. The normal force is consisting of two components. One is due to the applied bearing pressure and the other is due to the normal overburden pressure of soil.
3. The force due to applied pressure $q$ is given by,

$$F_{V1}(q, Z) = L_{DR}\int_{X_0}^{L_0} \sigma_z(q,x,z)\,dx \qquad \text{...(5.6.1)}$$

where, $L_0 = 0.5B + L_x = L_r/2$

$L_x$ = Extension of reinforcement on either side of footing beyond the edge of footing.

$L_r$ = Length of the reinforcement.

$L_{DR}$ = Linear density of reinforcement.

$$= \frac{\text{Length of footing covered with reinforcement}}{\text{Length of footing}}$$

(1, for geogrids/mats/sheets).

4. Equation (5.6.1) may be written in dimensionless form as

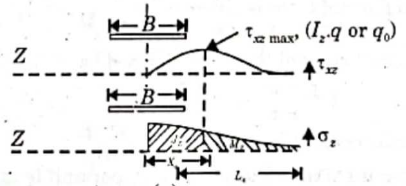
$$F_{V1}(q, Z) = L_{DR} B M_z q \qquad \text{...(5.6.2)}$$

In Which,

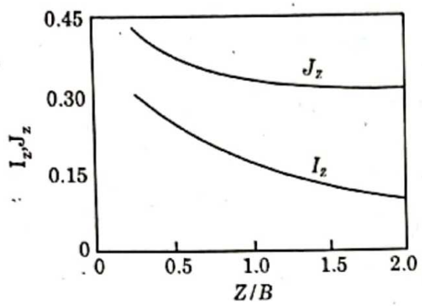
$$M_z = \frac{\int_{x_0}^{L_0} \sigma_z dx}{qB} \qquad \text{...(5.6.3)}$$

$M_z$ is the area shown in Fig. 5.6.1(a).

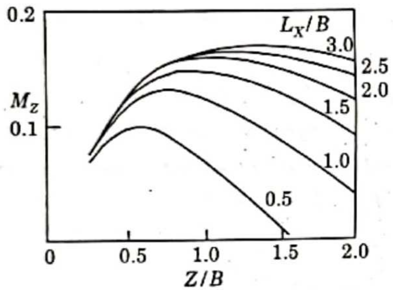
5. The values of $M_z$ corresponding to different $Z/B$ values are presented in the form of curves in Fig. 5.6.1(c) for $L_x/B$ equal to 0.5, 1.0, 1.5 and 2.0 covering the range commonly adopted in practice.




(a)




(b)




(c)

**Fig. 5.6.1.** Non-dimensional force components for pressure ratio calculation of isolated strip footing on reinforced soil.

6. The force due to overburden pressure on the ties at depth $Z$ is given by
$$F_{V2} = L_{DR}\gamma\,(L_0 - X_0)\,(Z) \quad ...(5.6.4)$$
where,
$\gamma$ = Unit weight of the overburden soil.
7. The vertical normal force is given by
$$F_{VT} = F_{V1} + F_{V2} \quad ...(5.6.5)$$
8. The soil tie coefficient of friction is defined by,
$$f_e = mf \quad ...(5.6.6)$$
where $$f = \tan\phi_f \quad ...(5.6.7)$$
$\phi_f$ = Soil-reinforcement friction angle.
9. The tie-pull-out frictional resistance, $T_f$, per unit length of strip footing at depth $Z$ in terms of pressure ratio may be written by combining eq. (5.6.2), (5.6.4), (5.6.5), (5.6.6) and (5.6.7).
$$T_f = 2f_eL_{DR}\,[M_zBq_0p_r + \gamma\,(L_0 - x_0)\,(Z)]$$
10. For footing at depth $D_f$
$$T_f = 2f_eL_{DR}\,[M_zBq_0p_r + \gamma\,(L_0 - x_0)\,(Z + D_f)]$$



**Que 5.7.** **Deduce the expression for computation of Tie-pull-out frictional resistance for rectangular footing on reinforced soil bed.**

**Answer**

1. Tie-pull-out frictional resistance shall be due to normal force on plane area of reinforcement which is outside the assumed plan separating the downward and outward flow as shown in Fig. 5.7.1.
2. The normal force is consisting of two components, on due to applied bearing pressure and the other due to the normal overburden pressure of soil.
3. Considering both the components over whole of the area outside the separating plane, we get the tie-pull-out frictional resistance in $x$-direction at depth $Z$, for a footing placed at depth $D_f$ as
$$T_{fx} = 2f_eL_{DR}\,[M_{xz}BLq_0\,(p_r) + \gamma A_{xz}\,(Z + D_f)\,BL] \quad ...(5.7.1)$$
4. $$M_{xz} = \frac{\int_{-Ly_0}^{+Ly_0}\int_{x_0}^{+Lx_0} \sigma_z\,dx\,dy}{qBL} \quad ...(5.7.2)$$
$$A_{xz} = \frac{\int_{-Ly_0}^{+Ly_0} (Lx_0 - x_0)\,dy}{BL} \quad ...(5.7.3)$$
$$L_{DR} = \frac{\text{Total area of reinforcement}}{\text{Total area of reinforcement soil layer}}$$
$= 1$, for geogrids/mats/sheets.
5. Similarly, $$T_{fy} = 2f_eL_{DR}\,[M_{yz}BLq_0\,(p_r) + \gamma A_{yz}\,(Z + D_f)\,BL] \quad ...(5.7.4)$$
$$M_{yz} = \frac{\int_{-Lx_0}^{+Lx_0}\int_{y_0}^{Ly_0} \sigma_z\,dx\,dy}{qBL} \quad ...(5.7.5)$$
$$A_{yz} = \frac{\int_{-Lx_0}^{+Lx_0} (L_{y0} - y_0)\,dx}{BL} \quad ...(5.7.6)$$
$$T_f = T_{fx} + T_{fy} \quad ...(5.7.7)$$
or $$T_f = 2f_eL_{DR}\,[(M_{xz} + M_{yz})\,BLq_0p_r + \gamma\,(Z + D_f)\,BL\,(A_{xz} + A_{yz})] \quad ...(5.7.8)$$
where, $f_e$ is mobilized friction coefficient.
6. Non-dimensional charts are used to determine the value $x$ for $M_{xz}$, $M_{yz}$, $A_{xz}$ and $A_{yz}$ corresponding to $Z/B$ values.

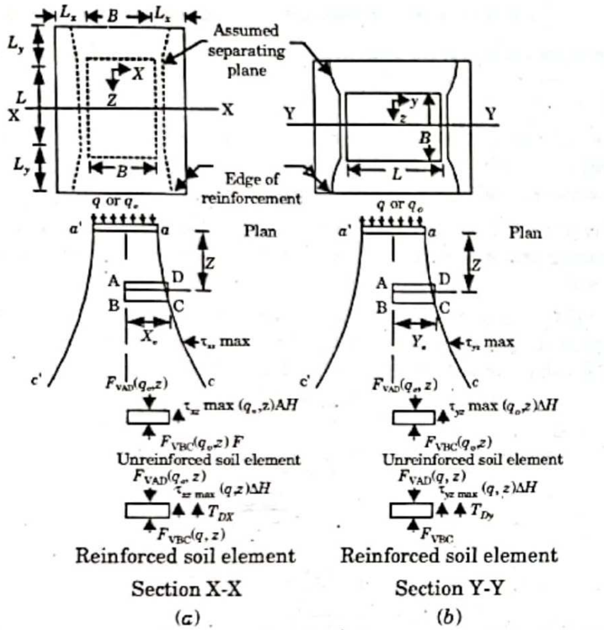



**Fig. 5.7.1.** Assumed separating plane (plane and section) and components of forces for pressure ratio calculation of isolated rectangular footing resting on reinforced soil.

**Que 5.8.** **Discuss the method to obtain ultimate bearing capacity of a footing resting on reinforced earth slab. Show the pattern of pressure-settlement curves for unreinforced and reinforced sand supporting a footing.**

**Answer**

1. The pressure intensity of footing can be calculated on reinforced soil at a settlement Δ, corresponding to the given pressure intensity of same footing on unreinforced soil for the same settlement Δ.
2. Therefore, the pressure-settlement values of reinforced soil can be computed only upto the ultimate bearing capacity of unreinforced soil.
3. The experimental results show that this does not give the ultimate bearing capacity of reinforced soil.
4. It is observed that the footing size reinforcement layers beneath the footing upto depth $D_R$ increase the bearing capacity and effect is very similar to unreinforced sand loaded with rigid deep footing having same depth, *i.e.* $D_f = D_R$ and it is applicable for $D_f = D_R$ upto 1.0*B*.



5. Now, if $q_r$ is the pressure intensity of reinforced soil at settlement corresponding to ultimate bearing capacity of unreinforced soil $q_u$ as shown in Fig. 5.8.1 then ultimate bearing capacity of reinforced soil ($q_{ur}$) has been found to be equal to :

$$q_{ur} = q_r + \gamma D_R N_q \quad \text{...(5.8.1)}$$

where,

$D_R$ = Depth of lowermost layer of reinforcement.

$N_q$ = Terzaghi's bearing capacity factor.

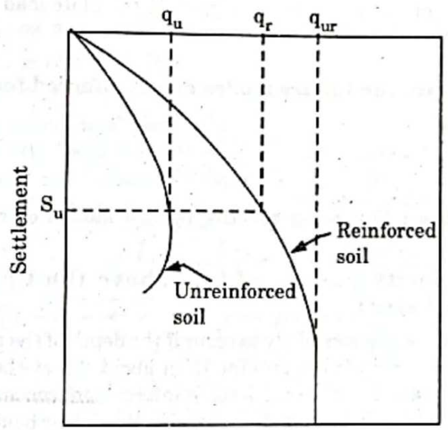



**Fig. 5.8.1.** General nature of pressure-settlement curves for unreinforced and reinforced sand supporting a footing.

6. Value of $q_r$ can be obtained by obtaining the pressure ratio corresponding to the ultimate pressure of the actual footing, *i.e.*, $q_u$. Let this pressure ratio is $p_{ru}$.

   Then, $q_r = q_u p_{ru}$

**Que 5.9.** **Write a short note on pressure ratio.**

**Answer**

**Pressure Ratio :**

1. The aim of the analysis is to obtain the pressure that can be imposed on the footing resting on reinforced earth slab corresponding to a given settlement of the same footing resting on unreinforced soil.
2. Pressure ratio is defined as the ratio of average contact pressure of footing on unreinforced soil to the average contact pressure of footing on reinforced soil.
3. The pressure ratio is given by,

$$P_r = \frac{q}{q_0}$$

Where, $q_0$ = Average contact pressure of footing on unreinforced soil at settlement

$q$ = Average contact pressure of footing on reinforced soil at the same settlement *i.e.*, $\Delta$.

4. The prerequisite of the analysis is to have the pressure settlement characteristics of the actual footing resting on unreinforced soil bed. This can be obtained by suitably interpreting the plate load test data/ standard penetration test data.

**Que 5.10.** **What are the failure modes of a reinforced foundation soil ?**

**Answer**

**Failure Modes :** Following are the failure modes of reinforced foundation soil :

1. **Bearing Capacity Failure of Soil above the Uppermost Geosynthetic Layer :**
   i. This type of failure appears likely to occur if the depth of the uppermost layer of reinforcement ($u$) is greater than about 2/3 of the width of footing ($B$), that is, $u/B > 0.67$, and if the reinforcement concentration in this layer is sufficiently large to form an effective lower boundary into which the shear zone will not penetrate.
   ii. This class of bearing capacity problems corresponds to the bearing capacity of a footing on the shallow soil bed overlying a strong rigid boundary.

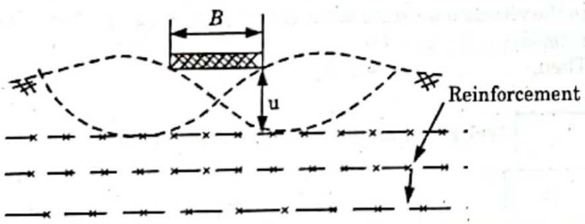



**Fig. 5.10.1.** Bearing capacity failure above upper reinforcement layer.

2. **Pullout of Geosynthetic Layer :**
   i. This type of failure is likely to occur with long, shallow, and heavy reinforcement ($u/B < 0.67$ and number of reinforcement layer, $N < 3$).



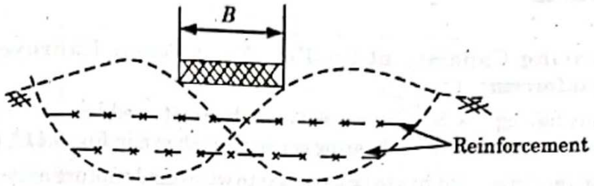



**Fig. 5.10.2.** Pullout of reinforcement due to insufficient embedment length.

3. **Breaking of Geosynthetic Layer :**
   i. This type of failure is likely to occur with long, shallow, and heavy reinforcement ($u/B < 0.67$, $N > 3$ or 4).
   ii. The reinforcement layers always break approximately under the edge or towards the centre of the footing. The uppermost layer is most likely to break first, followed by the next deep layer and so forth.

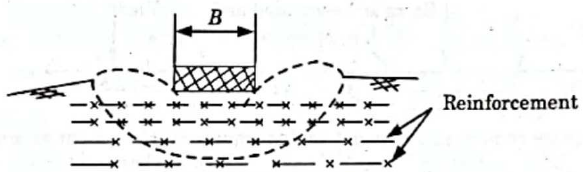



**Fig. 5.10.3.** Tensile failure (breaking) of reinforcement due to over stressing.

4. **Creep Failure of Geosynthetic Layer :** This failure may occur due to long-term settlement caused by sustained surface load and subsequent geosynthetic stress relaxation.

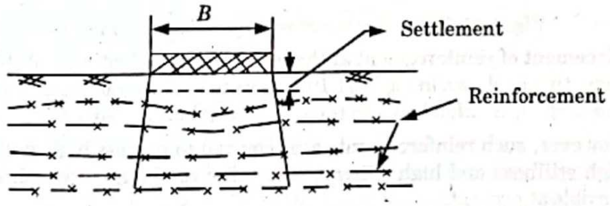



**Fig. 5.10.4.** Excessive long-term deformation (creep).

**Que 5.11.** **Discuss how the bearing capacity of shallow foundations can be improved by reinforcing the foundation soil. Compare load-settlement behaviour of a reinforced soil with that for an unreinforced soil.**

**Answer**

**A. Bearing Capacity of Shallow Foundation Improved by Reinforcement :**

1. Soils having low bearing capacity can be reinforced beneath shallow footings to increase the bearing capacity as shown in Fig. 5.11.1 (a).
2. The reinforcement has to be designed to withstand rupture as depicted in Fig. 5.11.1 (c) and slippage-as shown in Fig. 5.11.1 (d).
3. Placement of reinforcement beneath footings requires excavation of the soil and backfilling in layers with careful placement of reinforcement and proper compaction of soil.
4. Since the excavation of soil is necessary in all such cases, the economics of backfilling with reinforced soil has to be compared with that of backfilling with a better soil or with stabilized soil.

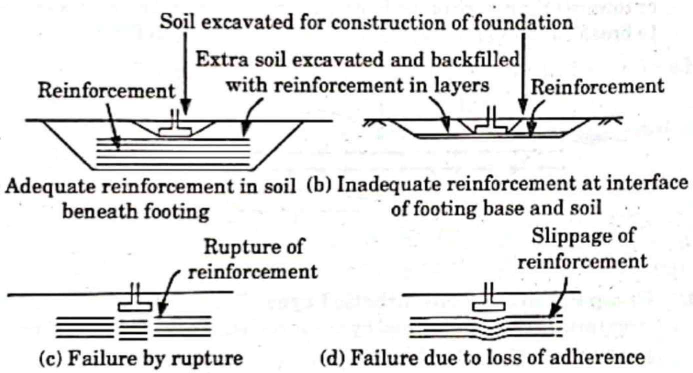


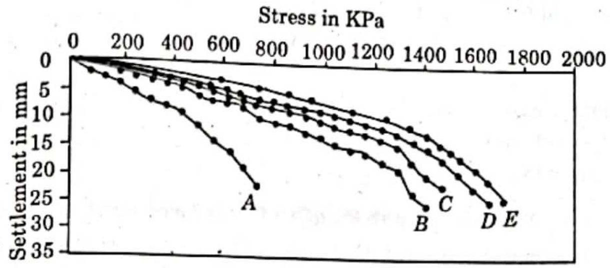

**Fig. 5.11.1.** Reinforcement of soil beneath footing.

5. Placement of reinforcement at the interface of the footing and the soil beneath it as shown in Fig. 5.11.1(b) seems to be an attractive alternative in which excavation beneath the footing can be avoided.
6. However, such reinforcements are required to possess high strength, high stiffness and high adherence to soil-a combination which is not feasible at present.

**B. Comparison :**

1. Stress *vs.* Settlement curves are shown in the Fig. 5.11.2. The settlement is plotted along the Y-axis and the stress is plotted along X-axis.
2. It is clearly observed that the inclusion of reinforcement improves the load carrying capacity of the soil. The settlement of soil is also significantly reduced.






*A* 1- layer of geotextiles
*B* 2- layer of geotextiles
*C* 3- layer of geotextiles
*D* 4- layer of geotextiles
*E* Unreinforced foundation soil.

**Fig. 5.11.2.** Stress versus settlement curves for reinforced soil for different layers.

## PART-4

*Design Considerations.*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 5.12. Give design criterion and factor to be considered in foundation on reinforced soil bed.**

**Answer**

**A. Design Criterion :** Following are the design criterion of reinforcement soil foundation :

1. Depth of the first layer of the reinforcemert, *u*, is in the range 0.25 *B* to 0.5 *B*, where *B* is the width of the footing.
2. Number of layers of reinforcement is preferably about 3 to 6.
3. Length of reinforcement layer is ideally about 7*B*, more than 7*B* is not economical.
4. Generally, uniform vertical spacing varies from 0.1*B* to 0.4*B*, depending on the number of layers. Reinforcement should have sufficient tensile strength.

**B. Factors to be Considered :** Following are the factors considered in reinforcement soil bed :

1. Depth of first layer of reinforcement.
2. Number of layers of reinforcement.
3. Length of reinforcement.
4. Vertical and horizontal spacing between the layers.
5. Type and material of reinforcement.
6. Shape and size of footing.

**Que 5.13.** **Why sufficient length of reinforcement is required beyond the loaded region of the footing or beyond the failure surface ? Also explain why the bearing capacity of foundation increases due to application of geosynthetic reinforcement below foundation.**

**Answer**

1. The sufficient length of reinforcement is required for the effective application of soil reinforced structure.
2. If we do not provide a sufficient anchorage length then the total reinforcement system is slide along this surface as and hence the structure may be fail.
3. It reduces the chances of failure due to external stability and internal stability failure.

**Reasons to Improve Bearing Capacity :**

1. Geosynthetics reduce the outward shear stresses transmitted from the overlying soil/fill to the top of the underlying foundation soil. This action of geosynthetics is known as the shear stress reduction effect.
2. This effect results in a general-shear stresses rather than a local-shear failure thereby causing an increase in the load-bearing capacity of the foundation soil.
3. Geosynthetics redistribute the applied surface load by providing restraint of the granular fill if embedded in it, or by providing restraint of the granular fill and the soft foundation soil if placed at their interface, resulting in reduction of applied stress.
4. The friction mobilized between the soil and the geosynthetic layer plays as important role in confining the soil.
5. The deformed geosynthetic, sustaining normal and shear stresses, has a membrane force with a vertical component that resists applied loads, *i.e.* deformed geosynthetics provide a vertical support to the overlying soil mass subjected to loading.
6. Edges of the geosynthetic layer need to be anchored in order to develop the membrane support contribution that results from normal stresses, whereas the membrane support contribution resulting from mobilized interfacial membrane shear stresses does not require any anchorage.
7. The membrane effect of geosynthetics causes an increase in the load-bearing capacity of the foundation soil below the loaded area, with a downward loading on its surface either side of the loaded area, thus reducing its heave potential.



8. It is to be noted that both the geotextile and geogrid can be effective in membrane action in case of high deformation of the reinforced foundation soils.
9. The use of geogrids has another benefit due to the interlocking of the soil through the apertures of the grid, which is known as the anchoring effect.

## PART-5

*Idealized Soil.*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 5.14.** **Describe the idealized soil behavior.**

**Answer**

1. The natural complexity in the behavior of in-situ soils has led to the development of many idealized models of soil behavior based on the classical theories of elasticity and plasticity for the analysis of soil-foundation interaction problems.
2. Although, the generalized stress-strain relations for soils, does not represent even the gross physical properties of a soil mass, the idealized models are observed to provide a useful description of certain features of soil media under limited boundary conditions.
3. The idealized soil behavior particularly reduces the analytical rigor spent in the solution of complex problems in geotechnical engineering.
4. The idealization will depend on a variety of factors such as :
   i. Type of soil.
   ii. Soil conditions.
   iii. Type of foundation.
   iv. Nature of external loading.
   v. Method of construction.
   vi. Purpose and life span of the structure.
   vii. Economical considerations.
5. The character of each model is classified by the surface deflection it experiences under the action of a system of forces, and these surface deflection in-general represent the displacement characteristics of the soil-foundation interface, and forms a significant part of the soil foundation interaction analysis.

PART-6

*Foundation and Interface Behaviour.*

| Questions-Answers |
|---|
| Long Answer Type and Medium Answer Type Questions |

**Que 5.15.** **Write a short note on behavior of foundation on reinforced soil.**

**Answer**

1. In many cases, constructing foundations on natural or artificial soil slopes to develop the infra-structures is controversial.
2. The construction of foundations on slopes can significantly affect the bearing capacity and slope stability.
3. Soil stabilisation by polymer reinforcements is a modern method employed in various projects to prevent the failure of soil slopes and to improve the bearing capacity of foundations, subsequently.
4. The effects of geometrical and resistivity parameters of reinforcements layers was investigated for determining the optimal values to achieve maximum bearing capacity.
5. The effects of strength properties of sand embankment, foundation position and slope angle on the behaviour of strip foundation rested on reinforced soil slope were investigated.
6. The results indicated that the bearing capacity of shallow foundations remarkably increased using geosynthetic reinforcement layers.

**Que 5.16.** **Explain the interface behavior of soil reinforcement.**

**Answer**

1. The interface conditions associated with the elastic continuum behavior of the soil medium are assumed to range from the completely smooth to the completely frictional interfaces.
2. The factors which are expected to significantly influence the conditions at the soil foundation interface are :

i. The presence of pore water which can alter the magnitude and distribution of the frictional forces throughout the consolidation process.



ii. The distribution and character of the external loads on the foundation.

iii. The relative flexibility of the foundation.

iv. The time dependant effects.

3. Frictional effects at the interface are expected to acquire importance when dealing with the interaction of highly flexible foundations resting on compressible soil media.
4. It is suggested that proper interface conditions be formulated only after obtaining adequate data from field observations.
5. In the absence of such data interface may be assumed as smooth and such assumption can serve as a usual first approximation.
6. The assumption of the smooth contact considerably simplifies the analysis of the interaction by retaining only the normal component of the contact stress.

**Que 5.17.** **What are the methods available for obtaining the reinforcement soil interface friction ?**

**Answer**

Following are the two methods for obtaining the reinforcement soil interface friction :

**A. Sliding Sheet Test :**

1. Sliding shear tests are used to determine the coefficient of sliding friction $\mu$ (= tan $\delta$), $\delta$ being the angle of sliding friction between soil and the reinforcing material.
2. Tests may be carried out in a standard direct shear box (60 mm × 60 mm) or in a box of larger size.
3. The reinforcing material is pasted on a wooden block of the size of the box and is flexed in the lower half of the shear box such that the reinforcing material lies along the failure plane.
4. The upper half of the box is filled in with soil at desired density.
5. A typical test set up is shown in Fig. 5.17.1. A normal load ($N$) is applied to the sample and is held constant during the test.
6. A gradually increasing horizontal load ($F$) at constant rate of strain is then applied to the upper part of the box.
7. The horizontal displacement ($H_D$) of the sample is noted at regular interval of the application of horizontal-shear load.
8. A plot is made between shear stress (F/A) and shear strain ($H_D/B$), $A$ and $B$ are respectively the area of cross-section and width of the sample. From this plot, shear stress at failure is obtained.

9. The test is repeated for varying levels of normal stress ($\sigma_n = N/A$) and in each case the corresponding shear stress at failure ($\tau_f$) is obtained.
10. The results are plotted with normal stress $\sigma_n$ along the X-axis and shear stress $\tau_f$ along the Y-axis.
11. Typical data thus obtained using 60 mm × 60 mm box. Slopes of the lines on $\sigma_n - \tau_f$ plot gives the values of coefficient of sliding friction, μ. Thus,

$$\mu = \frac{\tau_f}{\sigma_n} = \tan\delta$$

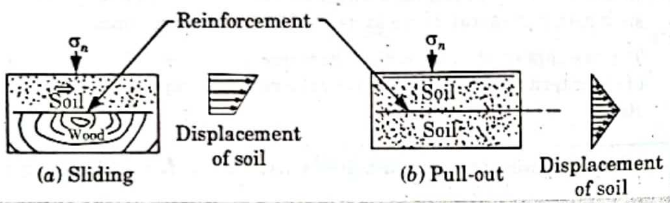



**Fig. 5.17.1.** Soil movement in mobilization of interfacial frictional resistance.

**B. Pull-Out Test :**

1. Pull-out test are performed to obtain the value of coefficient of apparent friction, $f$.
2. These tests may be performed in a model, prototype or full scale reinforced soil wall.
3. In these tests, reinforcing strips are pulled out from the wall, and for each strip a plot is made between pull-out load and corresponding displacement. From this plot, maximum pull-out load is obtained.
4. The coefficient of apparent friction, $f$ is given by :

$$f = \frac{T}{2\sigma_v LW} \quad ...(5.17.1)$$

where, $T$ = Maximum pull-out load.

$\sigma_v$ = Normal pressure intensity at the reinforcing strip level = $\gamma Z + q$

$\gamma$ = Unit weight of soil.

$Z$ = Depth of the reinforcing strip below soil surface.

$q$ = Intensity of uniformly distributed surcharge on the soil surface.



$L$ = Length of reinforcing strip.

$W$ = Width of reinforcing strip.

5. The coefficient $f$ given by eq. (5.17.1) does not take into account the actual distribution of normal stress exerted on the reinforcement, but the mean value of overburden stress *i.e.*, ($\gamma Z + q$).
6. The coefficient $f$ is a complex function of number of parameters, e.g., height of soil above the reinforcement, length and width of the reinforcing elements, the surface condition of the reinforcement and density of soil.

## PART-7

### *Elastic Models of Soil Behaviour.*

**CONCEPT OUTLINE**

Following elastic models of soil behavior :
i. The Winkler's Model.
ii. Elastic Half-Space (Elastic continuum) Models.
iii. Two Parameter Elastic Models.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 5.18. Write the different types of elastic models of soil behaviour and describe in detail any one of them.**

**OR**

**Explain the Winkler's model of elastic models of soil behavior.**

**Answer**

**A. Elastic Models of Soil Behaviour :**

1. The simplest type of idealized soil response is to assume the behavior of supporting soil medium as a linear elastic continuum.
2. The deformations are thus assumed as linear and reversible.
3. Applications of these models to soil-foundation interaction have been subject of extensive research and significant developments have been made in obtaining exact and approximate solutions.

4. Following are the three elastic models of soil behavior :

i. The Winkler's Model.

ii. Elastic Half-Space (Elastic continuum) Models.

iii. Two Parameter Elastic Models.

**The Winkler's Model :**

1. Winkler assumed that the surface displacement of the soil medium at every point is directly proportional to the stress applied to it at that point and completely independent of stresses or displacements at other, even immediately neighboring, point of the soil foundation interface.

2. Fig. 5.18.1. Surface displacements of the Winkler model due to

i. Non-uniform load.

ii. A concentrated load.

iii. A rigid load.

iv. A uniform flexible load.

3. Winkler's idealization of the soil medium can be physically represent as a system of closely spaced spring elements (Fig. 5.18.1) each of all will be deformed by the stress applied directly to it while the neighboring elements remains unaffected.

4. The characteristic feature of this representation of the soil medium is discontinuous behavior of the surface displacement.

5. The deflection $y$ of the soil medium at any point on the surface is directly proportional to the stress, $q$, applied at that point and is independent of stresses applied at other locations, *i.e.*,

$$q(x, y) = k\, y(x, y) \qquad ...(5.18.1)$$

Where '$k$' is termed as the modulus of subgrade reaction with units of stress per unit length.

6. Physically, Winkler's idealization of the soil medium consists of a system of mutually independent spring elements with spring constant '$k$'.

7. One important feature of this soil model is that the displacements occur immediately under the loaded area and outside the region the displacements are zero.

8. The displacements of a loaded region will be constant whether the soil is subjected to an infinitely rigid load or a uniform flexible load.



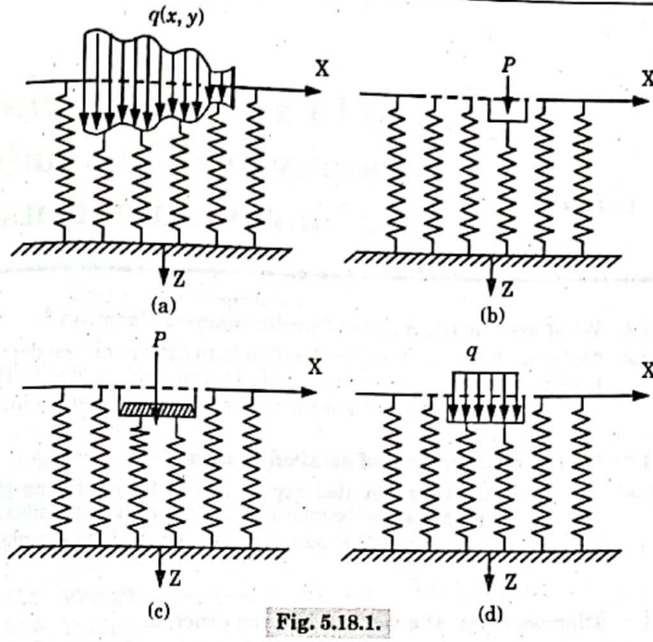



Fig. 5.18.1.

9. There are many engineering problems (excluding soil-foundation interaction) for which Winkler's Model represents a very accurate idealization of actual operating conditions.

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# 1 UNIT Soil Exploration and Geophysical Methods (2 Marks Questions)

**1.1. What are the objectives of preliminary exploration ?**

**Ans.** The aim of a preliminary exploration is to determine the depth, thickness, extent and composition of each soil stratum at site. The depth of bed rock and the ground- water table is also determined.

**1.2. Explain the purpose of detailed exploration.**

**Ans.** The purpose of the detailed exploration is to determine the engineering properties of the soils in different strata. It includes an extensive boring programme, sampling and testing of the sample in a laboratory.

**1.3. Discuss about the reconnaissance process.**

**Ans.** Site reconnaissance is the first step in a sub-surface exploration programme. It includes a visit to the site and to study the maps and other relevant records. It helps in deciding the future programme of site investigations, scope of work, methods of exploration to be adopted, types of samples to be taken and the laboratory testing and in-situ testing.

**1.4. Explain the stages in sub-surface exploration.**

**Ans.** Sub-surface explorations are generally carried out in three stages :

i. Reconnaissance.
ii. Preliminary exploration.
iii. Detailed exploration.

**1.5. What is area ratio ?**

**Ans.** It is defined as the ratio of maximum cross-sectional area of the cutting edge to the area of soil sample.

$$A_r = \frac{\text{Maximum cross-sectional area of the cutting edge}}{\text{Area of the soil sample}} \times 100$$

**1.6. What do you mean by soil sampling ?**

**Ans.** Soil sampling is the process of obtaining samples of soil from the desired depth at the desired location in a natural soil deposit. Sampling is done with the help of soil samplers.



**1.7. What are the types of soil samples used in soil exploration ?**

**AKTU 2016-17, Marks 02**

**Ans.** Following are two types of soil samples used in soil exploration :

**Disturbed Samples :**

i. These are the samples in which the natural structure of the soil gets disturbed during sampling.
ii. Disturbed samples can be used to determine the index properties of the soil, such as grain size, plasticity characteristics, specific gravity, etc.

**Undisturbed Samples :**

i. These are the samples in which the natural structure of the soil and the water content are retained.
ii. Some disturbance is inevitable during sampling, even when the utmost care is taken.

**1.8. What are the uses of undisturbed sample ?**

**Ans.** Undisturbed samples are used for determining the engineering properties of the soil, such as compressibility, shear strength, and permeability.

**1.9. For what purposes disturbed samples of soils are used ?**

**Ans.** Disturbed samples of soils can be used to determine the index properties of the soil, such as grain size, plasticity characteristics, specific gravity, etc.

**1.10. For which type of soils, auger boring is required ?**

**Ans.** Auger boring is generally used in soils which can stay open without casing or drilling mud, e.g., clays, silts and partially saturated sands. It is useful for subsurface investigations of highways, railways and air fields.

**1.11. Discuss the locations where rotary drilling is preferred.**

**Ans.** Rotary drilling can be used in clay, sand and rocks.

**1.12. Enumerate the various in-situ tests.**

**Ans.** Following are the various in-situ tests.

i. Standard penetration test (SPT).
ii. Cone penetration test (CPT).
   a. Static cone penetration test.
   b. Dynamic cone penetration test.
iii. In-situ vane shear test.

**1.13. What are the types of soil sampler.**

**Ans.** Following are the various types of soil sampler :

i. Open drive sampler.
ii. Thin-walled sampler.

iii. Split barrel or split-spoon sampler.
iv. Stationary piston sampler.
v. Continuous sampler.
vi. Compressed air sampler.
vii. Window sampler.

**1.14. Give the expression for inside clearance of soil sample.**

**Ans.** Inside clearance of soil is given by,

$$C_i = \frac{D_3 - D_1}{D_1} \times 100$$

where, $D_1$ = Inner diameter of the cutting edge.
$D_3$ = Inner diameter of the sampling tube.

**1.15. Write the equation for outside clearance of soil sample.**

**Ans.** Outside clearance of soil sample is given by,

$$C_o = \frac{D_2 - D_4}{D_4} \times 100$$

where, $D_2$ = Outer diameter of the cutting edge.
$D_4$ = Outer diameter of the sampling tube.

**1.16. What are the objectives of soil exploration ?**

**Ans.** Following are the objectives of soil exploration :
i. Determination of the nature of the deposit soil.
ii. To determine the location of groundwater and fluctuations in ground water table.
iii. Obtaining soil and rock samples from the various strata.

**1.17. What do you mean by geophysical methods ?**

**Ans.** Geophysical methods involve the technique of determining sub surface material by measuring some physical property of the materials, and through correlations using the values obtained for identifications.

**1.18. Give the limitations of the seismic refraction method of soil exploration.**

**Ans.** Following are the limitations of seismic refraction method :
i. This method cannot be used where a hard layer overlies a soft layer.
ii. This method cannot be used in an area covered by concrete or asphalt pavement.

**1.19. What are the limitations of the electrical resistivity method ?**

**Ans.** Following are the limitations of electrical resistivity method :
i. The services of an expert in the field are needed.
ii. The methods are capable of detecting only the strata having different electrical resistivity.



**1.20. What is the principle of seismic method ?**

**Ans.** The seismic method is based on the principle that the elastic shock waves have different velocities in different materials. At the interface of two different materials, the waves get partly reflected and partly refracted.

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# UNIT 2

# Shallow Foundations and its Settlement (2 Marks Questions)

**2.1. What do you infer by the term ultimate bearing capacity ?**

AKTU 2016-17, Marks 02

**Ans.** The ultimate bearing capacity is the gross pressure at the base of the foundation at which the soil fails in shear.

**2.2. Define gross safe bearing capacity.**

**Ans.** It is the maximum gross intensity of loading that the soil can carry safely without failing in shear. Thus,

$$q_s = \frac{q_u}{f} + \gamma D_f$$

**2.3. Define net safe bearing capacity.**

AKTU 2017-18, Marks 02

**Ans.** Maximum net intensity of loading that the soil can safely support without the risk of shear failure.

$$q_{ns} = q_{nu}/\text{FOS}$$

**2.4. What are the assumptions of the Terzaghi's theory ?**

**Ans.** Following are the assumptions of Terzaghi's theory :

i. The base of footing is rough.
ii. The shear strength of the soil is governed by the Mohr-Coulomb equation.
iii. The footing is laid at a shallow depth *i.e.*, $D_f \leq B$.
iv. The load on the footing is vertical and is uniformly distributed.

**2.5. Classify the shear failure.**

**Ans.** Following are the three types of shear failure :

i. General shear failure.
ii. Local shear failure.
iii. Punching shear failure.

**2.6. Define general shear failure.**

**Ans.** A shear failure occurs in the soil at that load where settlement increases suddenly and the failure surfaces extended to the ground surface. This type of failure is known as general shear failure.



**2.7. What do you mean by punching shear failure ?**

**Ans.** The footing fails at a load of $q_u$ at which stage the load-settlement curve becomes steep and practically linear. This type of failure is called the punching shear failure.

**2.8. What is local shear failure ?**

**Ans.** The failure surfaces gradually extend outwards from the foundation. However, a considerable movement of the foundation is required for the failure surfaces to extend to the ground surface. The load at which this happens is $q_u$, beyond this point, an increase of load is accompanied by a large increase in settlement. This type of failure is known as local shear failure.

**2.9. Write down the expression for Terzaghi's bearing capacity equation.**

**Ans.** Terzaghi's bearing capacity equation is given by,

$$q_u = cN_c + \gamma D_f N_q + 0.5\,\gamma B N_\gamma$$

where,

$N_q, N_c, N_\gamma$ = Bearing capacity factors.
$B$ = Width of footing.
$D_f$ = Depth of footing.
$\gamma$ = Unit weight of soil.
$c$ = Cohesion strength of soil.

**2.10. Write the effect of water table on the bearing capacity of the soil.**

AKTU 2017-18, Marks 02

**Ans.** The position of ground water has a significant effect on the bearing capacity of soil. Presence of water table at a depth less than the width of the foundation from the foundation bottom will reduce the bearing capacity of the soil.

**2.11. What are the limitations of Terzaghi's theory ?**

**Ans.** Following are the Limitations of Terzaghi's theory :

i. The relationship between the void ratio and effective stress is not independent of time.
ii. Terzaghi's theory is good only for the estimation of the rate of primary consolidation.

**2.12. Write the expression for bearing capacity of shallow foundation given by Meyerhof or Hansen's.**

**OR**

**Write the Hansen's bearing capacity equation along with their correction factors.**

AKTU 2015-16, Marks 02

**Ans.** Meyerhof or Hansen's formula for bearing capacity of shallow foundation is given by,

$$q_u = cN_c s_c d_c i_c + \sigma N_q s_q d_q i_q + 0.5\gamma BN\gamma s_\gamma d_\gamma i_\gamma$$

where, $s$, $d$, and $i$ stand for empirical correction factors called the shape factor, depth factor and inclination factor, respectively.

**Correction Factors :** Refer Q. 2.16 (Table 2.16.1), Page 2–20D, Unit-2.

**2.13. What is the equation suggest by IS code for bearing capacity of shallow foundation ?**

**Ans.** IS code formula is given by,

$$q_{nu} = cN_c s_c d_c i_c + \sigma(N_q - 1)s_q d_q i_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma W'$$

where, $W'$ = Factor which taken into account the effect of water table.

**2.14. Discuss in brief, the different types of shallow foundation settlements.** AKTU 2015-16, Marks 02

OR

**Name the different types of settlements.** AKTU 2016-17, Marks 02

**Ans.** Foundation settlement under loads can be classified into three types :

i. Immediate or elastic settlement.
ii. Consolidation settlement.
iii. Secondary consolidation settlement.

**2.15. Define significant depth.** AKTU 2016-17, Marks 02

**Ans.** The depth upto which the stress increment due to super imposed loads can produce significant settlement and shear stresses is known as significant depth.

**2.16. Give the expression for the immediate settlement of cohesive soil.**

**Ans.** Schleicher gave the following formula for the vertical settlement under a uniformly distributed flexible area.

$$S_i = qB\left(\frac{1-\mu^2}{E_s}\right)I$$

where, $\mu$ = Poisson ratio ($\mu$ = 0.5 for saturated clay).
$B$ = Characteristic length of the loaded area.
$q$ = Uniformly distributed load.
$I$ = Influence factor.

**2.17. Explain the De-Beer formula for computing the settlement of foundation.**

**Ans.** The settlement of each small layer is estimated using the following equation,



$$S = \frac{H}{C}\log_e\frac{\bar{\sigma}_o + \Delta\sigma}{\bar{\sigma}_o}$$

$$C = 1.5\, q_c/\bar{\sigma}_o$$

where, $H$ = Thickness of layer.
$q_c$ = Static cone resistance.
$\bar{\sigma}_o$ = Mean effective overburden pressure.
$\Delta\sigma$ = Increase in pressure at the centre of layer due to the net foundation pressure.

**2.18. What is contact pressure ?** AKTU 2017-18, Marks 02

**Ans.** Contact pressures are the reactive pressures offered by the soil on the foundation, at the interface between the foundation and the soil, against the loads transmitted to the soil through the foundation.

**2.19. What are the difficulties occur in computing the settlement of foundation ?**

**Ans.** Following are the difficulties occur in computing the settlement of foundation :

i. For computation of immediate settlement, it is not possible to estimate the correct value of the modulus of elasticity.
ii. For estimation of the settlement due to consolidation, it is not possible to locate exactly the drainage faces.
iii. Settlement may occur due to the causes other than that due to loads. It is not possible to estimate these settlements accurately.

**2.20. What are the factors which affects the bearing capacity ?**

**Ans.** Following are the factors which affects the bearing capacity of soil foundation :

i. Nature of soil and its physical and engineering properties.
ii. Nature of the foundation and other details such as the size, shape, depth below the ground surface and rigidity of the structure.
iii. Total and differential settlements that the structure can withstand without functional failure.

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# 3 UNIT Design of Shallow Foundation and Deep Foundation (2 Marks Questions)

**3.1. What do you mean by isolated footing ?**

**Ans.** Isolated footings are provided to support the columns of a building frame individually. Such footings behave independently of each other without being influenced by adjacent footings in any way.

**3.2. What do you understand by strip footing ?**

**Ans.** Strip footings support a load bearing wall or a number of closely spaced columns in a row. They form a long, narrow continuous foundation, with the width small compared to the length.

**3.3. Define the term deep foundation.**

**Ans.** In situations where the soil at shallow depths is poor in order to transmit the load safely, the depth of foundation has to be increase till a suitable soil stratum is met. In view of increased depth, such foundation is called deep foundation.

**3.4. Give some examples of deep foundation.**

**Ans.** Pile, pier and well foundation are the examples of deep foundation.

**3.5. What do you mean by piles ?**

**Ans.** A pile is a relatively small diameter shaft, which is driven or installed into the ground by suitable means. The piles are usually driven in groups to provide foundation for structure. These are subjected to vertical, horizontal, or combination of both loads.

**3.6. Briefly classify the pile according to their method of installation.** AKTU 2015-16, Marks 02

**Ans.** Following the pile according to their method of installation :

i. Driven piles.
ii. Board and Cast-in-situ piles.
iii. Bored and Cast-in-situ piles.
iv. Screw piles.
v. Jacked piles.



**3.7. Write down the situations where pile foundation is required.**

**Ans.** Pile foundations are used in the following conditions :

i. Pile foundations are required for the transmission structural loads through deep water to a firm stratum.
ii. In case of expansive soils, such as black cotton soil which swell or shrink as the water content changes. Piles are used to transfer the load below the active zone.
iii. Piles are used for the foundations of some structures such as transmission tower, off shore platforms which are subjected to uplift.

**3.8. Define negative skin friction ?** AKTU 2015-16, Marks 02

**OR**

**Discuss about negative skin friction.**

AKTU 2016-17, Marks 02

**Ans.** Negative skin friction or down drag is a phenomenon which occurs when a soil layer surrounding the pile settles more than the pile.

**3.9. Where negative skin friction condition occurs ?**

**Ans.** The condition can develop where a soft or loose soil stratum located anywhere above the pile tip is subjected to new compressive loading.

**3.10. Define the 'group efficiency factor' of a pile group and list the factors influencing the efficiency of pile group.**

AKTU 2017-18, Marks 02

**Ans.** **Group Efficiency Factor :** It is the ratio of uplift resistance of group of piles to the uplift resistance of single pile.

$$\eta_g = \frac{Q_{g(u)}}{NQ_u} \times 100$$

**Factors :** Following are the factors influencing the efficiency of pile group :

i. Spacing of piles.
ii. Total number of piles in a row and number of rows in a group.
iii. Characteristics of pile (material, diameter and length).

**3.11. How many ways, a group of piles may fail ?**

**Ans.** A group of piles may fail in one of the following two ways :

i. By block failure.
ii. By individual pile failure.

**3.12. Write down the expression for ultimate load capacity of the pile group by block failure.**

**Ans.** The ultimate load capacity of the pile group by block failure $Q_{ug}$ is given by,

$$Q_{ug} = c_{ub} N_c A_b + P_b L c'_u$$

where,
$c_{ub}$ = Undrained strength of clay at the base of the pile group.
$c'_u$ = Average undrained strength of clay along the length of the block.
$A_b$ = Cross-sectional area of the block.
$P_b$ = Perimeter of the block.
$L$ = Embedded length of the pile.

**3.13. How can we estimate the settlement of cohesionless soil ?**

**Ans.** Meyerhof suggests the following empirical relation for the elastic settlement of a pile group in sands and gravels.

$$S_g = \frac{9.4q\sqrt{B_g}I}{N}$$

where,
$q = Q_g/A_g$ = Load intensity.
$B_g$ = Width of group.
$N$ = Corrected standard penetration number within the seat of settlement.
$I$ = Influence factor.

**3.14. What is expansive soil ?**

**Ans.** Expansive soils are the soils which expand when the moisture content of the soils increases. The clay mineral montmorillonite is mainly responsible for expansive characteristics of the soil. Expansive soils are also called swelling soils or black cotton soils.

**3.15. What is swell pressure ?** AKTU 2017-18, Marks 02

**Ans.** Swelling pressure ($P_s$) is defined as the pressure required to be applied over a swelling soil specimen to prevent its expansion when it is in contact with water.

**3.16. What are the difficulties faced with soft clay ?**

AKTU 2015-16, Marks 02

**Ans.** The soft soil is so poor, it is very difficult to construct anything, because the bearing capacity is very low, shear strength is low, consolidation settlements are going to be very high and permeability is very low.

**3.17. Which types of structure are constructed on the expansive soil ?**

**Ans.** Following types of structures are commonly constructed on the expansive soil :



i. Strong and rigid structures.
ii. Flexible structures.
iii. Isolating foundation. (Example : Pier and underreamed pile.)

**3.18. What do you understand by term underreamed pile ?**

**Ans.** The underreamed piles are bored, cast-in-situ concrete piles with a bulb or underream at its bottom.

**3.19. Give the expression for load carrying capacity of the underreamed pile.**

**Ans.** The load carrying capacity of the underreamed pile with single bulb is given by,

$$Q_u = \left[\frac{\pi}{4}B^2 9c + \frac{\pi}{4}(B_1^2 - B^2)Ac'\right] + \alpha c_a A_s$$

where,
$c$ = Unit cohesion at the base.
$c'$ = Unit cohesion at the bulb.
$c_a$ = Average cohesion on the shaft.
$\alpha$ = Adhesion factor.
$B$ = Diameter of the shaft.
$B_1$ = Diameter of the bulb.

**3.20. Write down the expression for load bearing capacity of double underreamed pile.**

**Ans.** For a double underreamed pile, the ultimate load is given by,

$$Q_u = \frac{\pi}{4}B^2 9c + \frac{\pi}{4}(B_1^2 - B^2)9c' + \alpha c_a A_s + c'_a \overline{A}_{sb}$$

where, $\overline{A}_{sb}$ = Surface area of the cylinder circumscribing the bulbs.

**3.21. Which type of foundation is suitable for structure in expansive soil ?**

**Ans.** Underreamed pile foundations are suitable for structure in expansive soils.

**3.22. Mention the functions of pile foundations.**

AKTU 2016-17, Marks 02

**Ans.** Following are the functions of pile foundations :
i. To transmit the buildings loads to the foundations and the ground soil layers whether these loads verticals or inclined.
ii. To carry vertical compression loads.
iii. To resist uplift or tensile forces.
iv. To resist horizontal or inclined loads.

**3.23. If an expansive soil is susceptible to wetting, what preventive measures would you take ?**

AKTU 2017-18, Marks 02

**Ans.** Following three preventive measures are taken :

i. Replacement of the expansive soil.
ii. Modification of the expansive soil.
iii. Design of foundation to withstand swelling.

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4 UNIT

# Well Foundations and Retaining Structures (2 Marks Questions)

**4.1. Discuss the term well foundations.**

**Ans.** Well foundations are also, like the pile foundations, deep foundations. Well foundations, provide a solid and massive foundations for heavy loads and can useful in situations where the loads have to be transferred to a soil stratum deep below in bridge foundations.

**4.2. Where well foundation is widely used ?**

**Ans.** Well foundation is widely used in foundations for bridge, piers and abutments. Well foundation is also useful as foundations in situations where the uplift loads are large as in the case of transmission line towers.

**4.3. Draw a neat sketch of well foundation and mention its components.**

AKTU 2016-17, Marks 02

**OR**

**Draw neat sketch of well foundation.**

AKTU 2015-16, Marks 02

**Ans.**

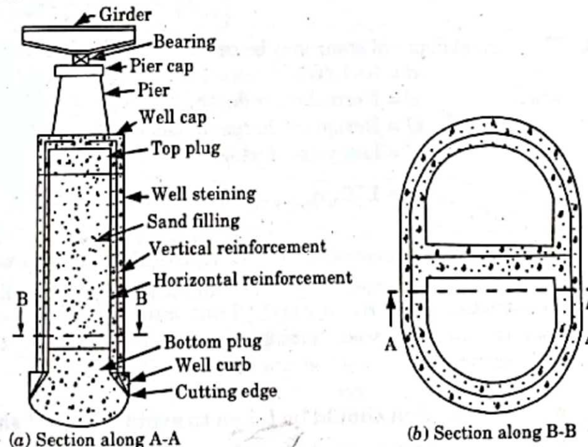


**Fig. 1.** Various components of a well foundation.

**4.4. What are the advantages of well foundation ?**

**Ans.** Following are the advantages of well foundation :

i. The effect of scour can be better withstood by a well foundation because of its large cross-sectional area and rigidity.

ii. There is no danger of damage to adjacent structures, since sinking of a well does not cause any vibration.

**4.5. What are the different shapes of well ?**

**AKTU 2017-18, Marks 02**

**Ans.** Following are the different shapes of well which are commonly used :

i. Circular wells.
ii. Double-D wells.
iii. Double-octagonal wells.
iv. Twin-circular wells.
v. Rectangular wells.

**4.6. Define grip length.**

**Ans.** The depth of the bottom of the well below the maximum scour level is known as grip length.

**4.7. Give the approaches from ascertained the scour depth.**

**Ans.** Following are the approaches from ascertained the scour depth :

i. Actual sounding at or near the proposed site immediately after a flood at any rate before there is any time for silting up appreciably.

ii. Theoretical methods taking into account the characteristics of flow like the direction, depth, and velocity and those of the river bed material.

**4.8. On what basis will you select the depth of well foundation ?**

**AKTU 2016-17, Marks 02**

**Ans.** The normal depth of scour may be calculated by Lacey's formula :

$$d = 0.473(Q/f)^{1/3}.$$

where,
$d$ = Normal scour depth.
$Q$ = Design discharge (m$^3$/sec).
$f$ = Lacey's silt factor.

$$f = 1.76\sqrt{d_m}$$

**4.9. What are the operations involve in the sinking of a well ?**

**Ans.** Following are the operations involve in the sinking of a well :

i. Construction of the well curb.
ii. Construction of the well steining.
iii. Sinking process.

**4.10. What precaution should be taken to avoid tilts and shifts ?**

**Ans.** Following are precautions taken to avoid tilts and shifts :



i. The outer surface of the well curb and steining should be smooth.
ii. The cutting edge should be uniformly thick and sharp.
iii. Dredging should be done uniformly on all sides and in all the pockets.

**4.11. Give the remedial measures of rectification of tilts and shifts.**

**Ans.** Following are the remedial measures taken to rectify tilts and shifts :

i. Eccentric loading.
ii. Water jetting.
iii. Excavation under the cutting edge.
iv. Pulling the well.
v. Strutting the well.
vi. Pushing the well with jacks, etc.

**4.12. Enlist the forces which are acting on a well foundation.**

**Ans.** Following are the forces which act on a well foundation :

i. Dead load.
ii. Live load.
iii. Wind load.
iv. Forces due to water currents.
v. Centrifugal forces.
vi. Buoyancy.
vii. Earth pressure, etc.

**4.13. What are the requirements for the horizontal cross-section of the well, according to IS : 3955 (1967) ?**

**Ans.** The following requirements for the horizontal cross-section of the well :

i. The dredge hole should be large enough to permit dredging.
ii. It should accommodate the base of structure and not cause undue obstruction to the flow of water.
iii. The overall size should be sufficient to transmit the loads to the soil.
iv. It should allow for the permissible tilt and shift of the well.

**4.14. Classify the wells.**

**Ans.** Following are the three types of wells :

i. Open wells.
ii. Box wells.
iii. Pneumatic wells.

**4.15. Define open caisson or well.**

**Ans.** The top and bottom of the caisson is open during construction. It may have any shape in plan e.g., circular, rectangular, oblong etc.

**4.16. What do you mean by box caisson ?**

**Ans.** A box caisson is open at the top but is closed at the bottom. This type of caisson is first cast on land and then towed to the site where it is sunk onto a previously levelled foundation base. It is also called as floating caisson.

**4.17. What do you understand by pneumatic caisson ?**

**Ans.** A pneumatic caisson has a working chamber at the caisson which is kept dry by forcing out water under pressure, thus permitting excavation under dry condition. Air locks are provided at the top.

**4.18. What is retaining walls and classified them ?**

**Ans.** A retaining wall is a structure that holds or retains soil behind it.

**Types :** Following are the types of retaining walls :

i. Gravity retaining walls.
ii. Semi gravity retaining walls.
iii. Cantilevered retaining walls.
iv. Counterfort retaining walls.

**4.19. Discuss the term sheet piling.**

**Ans.** It is an earth retention are excavation support technique that retains soil, using sheet sections with interlocking edges sheet piles are installed in sequence to design depth along the planned excavation perimeter or seawall alignment.

**4.20. Enumerates the uses of sheet piles.**

**Ans.** Following are the uses of sheet piles :

i. Retaining walls.
ii. Bridge abutments.
iii. Barrier for ground water.
iv. Flood protection.
v. Coastal protection.
vi. Treatment system bulkheads and seawalls.

**4.21. Give the advantages and disadvantages of sheet piles.**

**Ans. Advantages :**

i. Can be reused on several projects.
ii. Long service life above or below water with modest protection.

**Disadvantages :**

i. Installation of sheet piles is difficult in soils with boulders and cobbles.
ii. Sheet piles during may cause neighbourhood disturbance.

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# 5 UNIT

# Reinforced Soil (2 Marks Questions)

**5.1. What is the reinforced soil ?**

**Ans.** Reinforced soil is a combination of soil and linear reinforcing strips that are capable of bearing large tensile stresses.

**5.2. What are the advantages of reinforcing of soil ?**

**Ans.** Following are the advantages of reinforcing of soil :

i. Wire mesh/geotextile fabric construction materials are light, easy to transport, and quick to construct.
ii. The only machinery required is a backhoe/excavator and a compactor.
iii. Differential settlement is eliminated and bearing capacity increased.
iv. Rapid construction is reported.
v. This technique can result in saving the area of land.

**5.3. What are the reinforcing materials used in soil reinforcement ?**

**Ans.** Following are reinforcing material used in soil reinforcement :

i. Steel.
ii. Concrete.
iii. Glass fiber.
iv. Reinforcement may take the form of strips, grids, anchors and sheet material, chains, planks, rope, vegetation and combinations of these or other material forms.

**5.4. Write down the load transfer mechanism of reinforced soil.**

**Ans. Load Transfer Mechanism :**

i. The flexible reinforcement interacts frictionally with the soil resisting the shear stresses in the soil mass.
ii. The shear stress at the interface of the soil and the reinforcement generates strains in the reinforcement and a tensile force is mobilised in the reinforcement.

**5.5. What is tensile failure ?**

**Ans.** If tensile force exceeds the tensile capacity of the reinforcement, the failure occurs, is known as tensile failure.

**5.6 What is pullout failure ?**

**Ans.** If deformations are high or if the interface is smooth, it is likely that a slip occurs between the soil and reinforcement, this failure is known as pullout failure.

**5.7 Write down the different application of soil reinforcement.**

**Ans.** Following are the applications of soil reinforcement :
i. Roads.
ii. Airfields.
iii. Railroads.
iv. Embankments.
v. Retaining structures.

**5.8 What are the advantages of reinforcement soil ?**

**Ans.** Following are the advantages of reinforcement soil :
i. Lateral thrust on the wall is almost eliminated due to the development of soil-reinforcement interface friction.
ii. Thin wall element known as skin is found adequate to retain the backfill resulting in considerable economic savings.
iii. Simple construction.
iv. Faster construction than traditional concrete walls.

**5.9. What is the bearing capacity ratio ?**

**Ans.** It is defined as the average contact pressure of footing on unreinforced soil to the average contact pressure of footing on reinforced soil.

**5.10. What are the objectives of foundation ?**

**Ans.** Following are the objectives of foundation :
i. To distribute the total load coming on the structure on a larger area.
ii. To support the structures.
iii. To give enough stability to the structures against various disturbing forces, such as wind and rain.
iv. To prepare a level surface for concreting and masonry work.

**5.11. Write down the basic components of the reinforced soil structure.**

**Ans.** Following are the basic components of reinforced soil :
i. Soil or fill matrix.
ii. Reinforcement.
iii. A facing if necessary.

**5.12. What are the important points considered during the soil or fill matrix ?**

**Ans.** Following are the important points considered during the soil or fill matrix :



i. Type of structure.
ii. Long term stability of completed structure.
iii. Short term (or construction phase) stability.
iv. Physicochemical properties of materials.
v. Economy.

**5.13. List the most common types of reinforcement used in reinforced soil structures.**

**Ans.** Following are the common types of reinforcement used in reinforced soil structure :
i. Strips. ii. Grids. iii. Sheet.

**5.14. Enlist the different tests to determine the coefficient of soil reinforcement interface friction.**

**Ans.** Following two tests is performed :
i. Sliding shear test.
ii. Pull-out tests.

**5.15. Name any four applications of soil reinforcement for ground improvement.**

**Ans.** Following are the four application of soil reinforcement of ground improvement :
i. In highway embankment on hill slope.
ii. In bridge abutment.
iii. In stabilization of slope.
iv. In unpaved road on soft soil.

**5.16. What are the factors which affect the soil foundation interface ?**

**Ans.** The factors which are expected to significantly influence the conditions at the soil foundation interface are :
i. The presence of pore water which can alter the magnitude and distribution of the frictional forces throughout the consolidation process.
ii. The distribution and character of the external loads on the foundation.
iii. The relative flexibility of the foundation.
iv. The time dependant effects.

**5.17. Write down different types of elastic models of soil behavior.**

**Ans.** Following are the three elastic models of soil behavior :
i. The Winkler's model.
ii. Elastic half-space (Elastic continuum) models.
iii. Two parameter elastic models.

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# B. Tech.

## (SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2013-14

## ADVANCED FOUNDATION DESIGN

**Time : 3 Hours** **Max. Marks : 100**

**Note :** Attempt all questions.

1. Attempt any **four** parts of the following : (4 × 3.5 = 14)

**a. Discuss the equivalent point load method based on approximate stress distribution.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**b. State Boussinesq's equation for determining the vertical pressure under a superimposed load. Discuss the limitations of the equation.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**c. Explain how will you modify the Newmark's equation based on Boussinesq's analysis for vertical pressure below a corner of uniformly loaded rectangular area when the point at which vertical pressure is required is not located below a corner but below some other point of the rectangle.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**d. Determine the vertical stress at a point *P* which is located 3 m below and at a radial distance of 3 m from the vertical load of 100 kN. Use Westergaard's solution ($\mu$ = 0.0).**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**e. A concentrated load of 40 kN acts on the surface of a soil. Determine the vertical stress increament at points directly beneath the load upto a depth of 5 m.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**f. A water tower is supported only on three pillars forming an equilateral triangle with 10 m side. The total weight of the tower is 120 tonnes. Calculate vertical stress 10 m below the ground level under any one of the legs.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

2. Attempt any **two** parts of the following : (2 × 6 = 12)



**a. A foundation in sand will be 5 metres wide and 1.5 meters deep. Adopting a factor of safety of 2.5, what will be safe bearing capacity if the unit weight of the sand is 1.9 gm/c.c. and angle of internal friction is 35°. How does it compare with safe bearing capacity for surface loading ? $N_c = 57, N_q = 44, N_\gamma = 42$.**

**Ans.** Refer Q. 2.12, Page 2–16D, Unit-2.

**b. Determine the ultimate bearing capacity of the footing, 1.5 m wide and its base at a depth of 1 m, if the ground water table is located :**

**i. At a depth of 0.5 m below the ground surface.**

**ii. At a depth of 0.5 m below the base of the footing.**

**$\gamma_{sat}$ = 20 kN/m³.**

**$\gamma_d$ = 17 kN/m³, $\phi$ = 38° & $c$ = 0. Use Terzaghi's theory. $N_q$ = 60 and $N_\gamma$ = 75.**

**Ans.** Refer Q. 2.13, Page 2–16D, Unit-2.

**c. Explain in details, the effects of size of footing on both the ultimate bearing capacity & the settlement.**

**Ans.** Refer Q. 2.4, Page 2–4D, Unit-2.

3. Attempt any **two** parts of the following : (2 × 6 = 12)

**a. What are the factors governing load carrying capacity of pile ? What is the objective of pile load test ? Write steps to determine safe load from pile load test.**

**Ans.** **Factors :** Refer Q. 3.8, Page 3–12D, Unit-3.

**Pile Load Test :** This Question is Out of Syllabus From Session 2018-19.

**b. What is negative skin friction ? What is its effect on the pile ? A 30 cm diameter concrete pile is driven in a normally consolidated clay deposit 15 m thick. Estimate the safe load. Take $C_u$ = 70 KN/m², $\alpha$ = 0.9 and *F.S* = 2.5.**

**Ans.** **Negative Skin Friction and Effect :** Refer Q. 3.19, Page 3–25D, Unit-3.

**Numerical :** Refer Q. 3.12, Page 3–17D, Unit-3.

**c. Discuss the components of well foundation and draw the neat sketch of a well foundation. Explain all the terms in brief.**

**Ans.** Refer Q. 4.4, Page 4–6D, Unit-4.

4. Attempt any **two** parts of the following : (2 × 6 = 12)

**a. Derive an expression for the factor of safety of an infinite slope in a cohesionless soil. What is the effect of steady seepage parallel to the slope on the stability ?**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**b. A 10 m high cutting has a slope of 40° to horizontal, the soil was tested and its cohesion, void ratio and angle $\phi$ were found to be 2.5 t/m², 0.81 and 14° respectively. Determine the FOS with respect to cohesion against failure of the slope. When water level rises upto the full height :**
**Given : $G$ = 2.7 & for 40° slope values of stability number for different values of $\phi$**

| $\phi$ | $N$ |
|---|---|
| 6° | 0.122 |
| 7° | 0.116 |
| 14° | 0.074 |

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**c. What are the design criteria for foundations of reciprocating machines based on IS : 2874 (I) - 1982 ? Discuss criteria for the design of foundation in case of vibration without damping.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

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# B. Tech.

## (SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2014-15

## ADVANCED FOUNDATION DESIGN

**Time : 3 Hours** **Max. Marks : 100**

Answer all the questions :

1. Attempt any two parts of the following : (2 × 6 = 12)

**a. Show the expression for the Westergaard's solution for the vertical stress due to (i) point load, (ii) line load of finite length (iii) due to rectangular loaded area (iv) circular loaded area.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**b. Write the assumptions for the Boussinesq's method for determination of the stress increment due to an external load. Show all the expressions for the normal and tangential stresses with neat sketch. For a rectangular distributed load of 200 kN/m². Show the distribution of vertical stress intensity on a horizontal plane at a depth of 3 m below the base of footing by 2 : 1 dispersion method.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**c. A long flexible strip footing of 2.5 m width having a smooth base is subjected to uniformly distributed load of 80 kN/m run. Determine the vertical stress intensity at a depth of 2 m below a line parallel to the centre line of footing at a distance of 3 m from it.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

2. Attempt any two parts of the following : (2 × 6 = 12)

**a. Show and explain Terzaghi's bearing capacity failure, in soil with the help of their neat sketches. How will you modify the bearing capacity equations for the different cases of water table location ? Give $\phi$ values for different types of failures.**

**Ans. Terzaghi's Bearing Capacity Failure and $\phi$ Values :** Refer Q. 2.9, Page 2–12D, Unit-2.
**Effect of Water Table :** Refer Q. 2.10, Page 2–14D, Unit-2.

**b. Give all steps to calculate the elastic settlement of sandy soil by using strain influence factor. Also show the variation of the strain influence factor with Z.**

**Ans.** Refer Q. 2.22, Page 2–28D, Unit-2.

c. **For $L/B$ = 6.0; Explain all the steps, which will you follow for determining the settlement in the cohesionless soil by using the Schmertmann approach.**

**Ans.** Refer Q. 2.23, Page 2–30D, Unit-2.

3. Attempt any **two** parts of the following : (2 × 6 = 12)

a. **A group of 20 piles, each having a diameter of 600 mm and 12 m long are arranged in 4 rows at a spacing 1.2 m centre to centre. The capacity of each pile is 380 kN. Determine the group efficiency of pile.**

**Ans.** Refer Q. 3.13, Page 3–17D, Unit-3.

b. **What do you meant by laterally loaded piles ? Why batter piles are more effective than vertical piles in resisting the horizontal loads ? Give all the basic steps to find the forces in pile by Culmann's method.**

**Ans.** Refer Q. 3.6, Page 3–8D, Unit-3.

c. **What are the various laboratory method used to determine the dynamic properties of soil ? Explain them briefly. What is forced damping ?**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

4. Attempt any **two** parts of the following : (2 × 7 = 14)

a. **What are the various method for analyzing the stability analysis of finite slopes ? Write all the steps with their neat sketch; involve in the Bishops simplified method of slices for analyzing the stability of slopes.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

b. **Discuss the various types of piles which are used in the construction work on the basis of their structural characteristics with their advantage and disadvantages.**

**Ans.** Refer Q. 3.4, Page 3–5D, Unit-3.

c. **Which type of pile foundation you will use for the expansive soil ? Explain the particular types with a neat sketch. Also give the expression for finding the capacity of pile for single bulb under reamed piles.**

**Ans.** Refer Q. 3.21, Page 3–28D, Unit-3.

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# B. Tech.

# (SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2015-16

# ADVANCED FOUNDATION OF DESIGN

**Time : 3 Hours** **Max. Marks : 100**

## Section - A

1. Attempt **all** parts. All parts carry equal marks. Write answer of each part in short. (10 × 2 = 20)

a. **How the seismic refraction method is better than the seismic reflection method ?**

**Ans.** Refer Q. 1.14, Page 1–19D, Unit-1.

b. **Describe briefly the Newmark's influence chart.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

c. **Write the Hansen's bearing capacity equation along with their correction factors.**

**Ans.** Refer Q. 2.12, 2 Marks Questions, Page SQ–6D, Unit-2.

d. **Discuss in brief, the different types of shallow foundation settlements.**

**Ans.** Refer Q. 2.14, 2 Marks Questions, Page SQ–7D, Unit-2.

e. **Briefly classify the pile according to their method of installation.**

**Ans.** Refer Q. 3.6, 2 Marks Questions, Page SQ–9D, Unit-3.

f. **Define negative skin friction.**

**Ans.** Refer Q. 3.8, 2 Marks Questions, Page SQ–10D, Unit-3.

g. **What are the difficulties faced with soft clay ?**

**Ans.** Refer Q. 3.16, 2 Marks Questions, Page SQ–11D, Unit-3.

h. **Draw neat sketch of well foundation.**

**Ans.** Refer Q. 4.3, 2 Marks Questions, Page SQ–14D, Unit-4.

i. **What is stability number ? What are the uses of stability charts ?**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**j. Discuss the main criteria for design of rotary type of machines.**

**Ans:** This Question is Out of Syllabus From Session 2018-19.

## Section - B

2. Attempt any five questions from this section. (5 × 10 = 50)

**a. List various geophysical methods used for the soil investigation. Explain the soil resistivity method in detail. Write also their relative advantages and disadvantages.**

**Ans:** **Soil Resistivity Method :** Refer Q. 1.10, Page 1–14D, Unit-1.
**Advantages and Disadvantages :** Refer Q. 1.11, Page 1–16D, Unit-1.

**b. Discuss the various types of bearing capacity failure occurs in soil. What are the assumptions made in Terzaghi's analysis of bearing capacity of a continuous footing ? Write in brief.**
**A square footing of 3.0 m × 3.0 m size has been founded at 1.2 m below the ground level in a cohesive soil having a bulk density of 1.8 t/m³ and an unconfined compressive strength of 5.5 t/m². Determine the safe bearing capacity of the footing for a factor of safety of 2.5 by Skempton's method.**

**Ans:** **Types of Failure :** Refer Q. 2.5, Page 2–6D, Unit-2.
**Assumption :** Refer Q. 2.9, Page 2–12D, Unit-2.
**Numerical :** Refer Q. 2.11, Page 2–15D, Unit-2.

**c. For $L/B$ = 6.0; Explain all the steps, which will you follow for determining the settlement in the cohesion less soil by using the Schmertmann approach.**

**Ans:** Refer Q. 2.23, Page 2–30D, Unit-2.

**d. A group of 16 piles, each having a diameter of 350 mm and 10 m long, are arranged in 4 rows at a spacing 1.0 m centre to centre. The capacity of each pile is 360 kN. Determine the group capacity of the piles.**

**Ans:** Refer Q. 3.14, Page 3–18D, Unit-3.

**e. Explain with a neat sketch ; which type of foundation you will use for the case of expansive soils ? Write also expressions for finding the capacity of piles for single bulb and double bulb underreamed piles.**

**Ans:** Refer Q. 3.21, Page 3–28D, Unit-3.

**f. Write about the various types of shifts takes place in the well foundation. How these shifts can prevent ?**

**Ans:** Refer Q. 4.7, Page 4–10D, Unit-4.



**g. Enumerate the step by step method for design of foundation for impact type machine as per Indian standard code of practice IS : 2974 (Part II).**

**Ans:** This Question is Out of Syllabus From Session 2018-19.

**h. Discuss different types of slope failures. Stability analysis by Swedish method of slices following values per running metre for a 10 m high embankment.**
**Total shearing force = 480 kN**
**Total normal force = 1950 kN**
**Total neutral force = 250 kN**
**Length of arc = 22 m**
**If the properties of soil are, c = 24 kN/m² and $\phi$ = 6°, calculate the factor of safety with respect of shear strength.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

Note : Attempt any two questions from this section. (2 × 15 = 30)

**3. How will you determine the vertical stress intensity at any depth by using the Newmark influence chart method ? Draw a Newmark's influence chart on the basis of Boussinesq's equation, for a influence factor of 0.005. While drawing the chart, take arbitrarily the value of 'z' is 2.5 cm.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**4. A rectangle footing of 2.5 m × 4.0 m size is to be constructed at 1.8 m below the ground level in a c-$\phi$ soil having the following properties : $c$ = 1.0 t/m², $\phi$ = 20° and $\gamma$ = 1.75 t/m³.**
**The footing has to carry a gross vertical load of 80 t, inclusive of its self-weight. In addition, the column is subjected to a horizontal load of 10 t applied at a height of 3.3 m above the base of footing. Determine the factor of safety of the footing against shear failure as per IS : 6403-1981.**

**Ans.** Refer Q. 2.19, Page 2–25D, Unit-2.

**5. A machine weighing 15 kN is provided with a foundation block with a base area of 2.5 m² and a weight of 25 kN. The coefficient of elastic uniform compression for the subsoil and damping ratio are respectively 2.5 kg/cm³ and 0.15. Determine,**
**i. The natural frequency of the system.**
**ii. The maximum amplitude of the system.**
**iii. The maximum force transmitted to the soil if the force of excitation is vertical and given by,**

$$F = 0.006\,\omega^2 \sin \omega t \text{ (kgf)}$$

**Ans:** This Question is Out of Syllabus From Session 2018-19.

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# B. Tech.

# (SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2016-17

# ADVANCED FOUNDATION DESIGN

**Time : 3 Hours** **Max. Marks : 100**

**Note :** Be precise in your answer. In case of numerical problem assume data wherever not provided.

## SECTION-A

1. Attempt the following : **(10 × 2 = 20)**

**a. What are the types of soil samples used in soil exploration ?**

**Ans.** Refer Q. 1.7, 2 Marks Questions, Page SQ–2D, Unit-1.

**b. Define significant depth.**

**Ans.** Refer Q. 2.15, 2 Marks Questions, Page SQ–7D, Unit-2.

**c. What do you infer by the term ultimate bearing capacity ?**

**Ans.** Refer Q. 2.1, 2 Marks Questions, Page SQ–5D, Unit-2.

**d. Name the different types of settlements.**

**Ans.** Refer Q. 2.14, 2 Marks Questions, Page SQ–7D, Unit-2.

**e. Mention the functions of pile foundations.**

**Ans.** Refer Q. 3.22, 2 Marks Questions, Page SQ–12D, Unit-3.

**f. Discuss about negative skin friction.**

**Ans.** Refer Q. 3.8, 2 Marks Questions, Page SQ–10D, Unit-3.

**g. Draw a neat sketch of well foundation and mention its components.**

**Ans.** Refer Q. 4.3, 2 Marks Questions, Page SQ–14D, Unit-4.

**h. On what basis will you select the depth of well foundation ?**

**Ans.** Refer Q. 4.8, 2 Marks Questions, Page SQ–15D, Unit-4.

**i. List out the types of failure of a finite slope.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**j. Give the basic data required for design of reciprocating type machine.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.



## SECTION-B

2. Attempt any **five** of the following questions : **(5 × 10 = 50)**

**a. Discuss on different types of borings for soil exploration.**

**Ans.** Refer Q. 1.3, Page 1–4D, Unit-1.

**b. Elaborate on the standard penetration tests and static cone test in a detailed manner.**

**Ans.** **SPT :** Refer Q. 1.6, Page 1–9D, Unit-1.
**SCPT :** Refer Q. 1.7, Page 1–10D, Unit-1.

**c. Briefly explain about the settlement analysis of shallow foundations by Meyerhof method.**

**Ans.** This Question is Wrong but Meyerhof Method is used for Settlement Analysis for Pile Foundation : Refer Q. 3.17, Page 3–22D, Unit-3.

**d. A square footing 1.5 m × 1.5 m is located at a depth of 1 m. The soil has the following properties, $\gamma$ = 17.5 kN/m$^3$, $C$ = 0 and $\phi$ = 35°. Using Hansen's method to compute the ultimate bearing capacity of the soil. The footing base and ground are horizontal.**

**Ans.** Refer Q. 2.17, Page 2–22D, Unit-2.

**e. i. A wooden pile is being driven with a drop hammer weighing 20 kN and having a free fall of 1 m. The penetration in the last blow is 5 mm. Find the safe load carrying capacity of the pile using the Engineering New's formula.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**ii. How will you determine the efficiency of pile group ?**

**Ans.** Refer Q. 3.11, Page 3–15D, Unit-3.

**f. Describe about well sinking. What are the measures employed in controlling well sinking ?**

**Ans.** Refer Q. 4.6, Page 4–9D, Unit-4.

**g. Discuss on underreamed pile foundation. Also give the expression for load carrying capacity for clayey soil and sandy soil.**

**Ans.** Refer Q. 3.21, Page 3–28D, Unit-3.

**h. Write the procedure to calculate the factor of safety of a finite slope using method of slices.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

## SECTION-C

Attempt any two of the following questions : (2 × 15 = 30)

**3. a. Explain about the seismic refraction method and electrical resistivity method of soil exploration.**

**Ans.** **Electrical Resistivity Method :** Refer Q. 1.10, Page 1–14D, Unit-1.

**Seismic Refraction Method :** Refer Q. 1.12, Page 1–17D, Unit-1.

**b. Discuss the Schmertmann's method of determining settlement of footings in cohesionless soils.**

**Ans.** Refer Q. 2.22, Page 2–28D, Unit-2.

**4. a. Compute the pile group capacity of 16 pile group in square arrangement made up of 15 m long piles of 600 mm diameter in soft clay having an average undrained strength of 50 kN/m$^2$ if the c/c pile spacing is :**

**1. Two times pile diameter.**

**2. Three times pile diameter.**

**Ans.** Refer Q. 3.16, Page 3–20D, Unit-3.

**b. Elaborate with a neat sketch the type of foundation used in case of expansive soils.**

**Ans.** Refer Q. 3.20, Page 3–27D, Unit-3.

**5. Outline the methods available for the analysis of finite slopes. Explain with neat sketches the steps involved in the Bishop's simplified method for analyzing the stability of slopes.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

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# B. Tech.

# (SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2017-18

# ADVANCED FOUNDATION DESIGN

**Time : 3 Hours** **Max. Marks : 100**

**Note :** Be precise in your answer. In case of numerical problem assume data wherever not provided.

## SECTION-A

**1. Attempt all questions in brief :** **(10 × 2 = 20)**

**a. What is contact pressure ?**

**Ans.** Refer Q. 2.18, 2 Marks Questions, Page SQ–8D, Unit-2.

**b. What do you understand by geostatic stresses ?**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**c. Define net safe bearing capacity.**

**Ans.** Refer Q. 2.3, 2 Marks Questions, Page SQ–5D, Unit-2.

**d. Write the effect of water table on the bearing capacity of the soil.**

**Ans.** Refer Q. 2.10, 2 Marks Questions, Page SQ–6D, Unit-2.

**e. Define the 'group efficiency factor' of a pile group and list the factors influencing the efficiency of pile group.**

**Ans.** Refer Q. 3.10, 2 Marks Questions, Page SQ–10D, Unit-3.

**f. What are the different shapes of wells ?**

**Ans.** Refer Q. 4.5, 2 Marks Questions, Page SQ–15D, Unit-4.

**g. If an expansive soil is susceptible to wetting, what preventive measures would you take ?**

**Ans.** Refer Q. 3.23, 2 Marks Questions, Page SQ–13D, Unit-3.

**h. What is swell pressure ?**

**Ans.** Refer Q. 3.15, 2 Marks Questions, Page SQ–11D, Unit-3.

**i. What is meant by vibration isolation ?**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**j. What are the assumptions that are generally made in the analysis of stability of slope ?**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

## SECTION-B

2. Attempt any three part of following : (3 × 10 = 30)

**a. A long flexible strip footing of 2.5 m width having a smooth base is subjected to uniformly distributed load of 80 kN/m run. Determine the vertical stress intensity at a depth of 2 m below a line parallel to the centre line of footing at a distance of 3 m from it. Also draw the Newmark's influence chart as on the basis of Boussinesq's equation, for an influence factor of 0.005.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**b. Differentiate between the general shear failure and the local shear failure. How the ultimate bearing capacity in local shear is determined ?**

**Ans.** **Difference :** Refer Q. 2.6, Page 2–7D, Unit-2.
**Equation :** Refer Q. 2.9, Page 2–12D, Unit-2.

**c. A precast concrete pile (35 cm × 35 cm) is driven by a single-acting steam hammer. Estimate the allowable load using (*a*) Engineering News Record Formulas ($F_s$ = 6). (*b*) Hiley Formula ($F_s$ = 4) and (*c*) Danish Formula ($F_s$ = 4)**
**Use the following data :**

| | | |
|---|---|---|
| i. | Maximum rated energy, | $Wh$ = 3500 kN-cm |
| ii. | Weight of hammer, | $W$ = 35 kN |
| iii. | Length of pile, | $D$ = 15 m |
| iv. | Efficiency of hammer, | $\eta_h$ = 0.8 |
| v. | Coefficient of resistitution, | $e$ = 0.5 |
| vi. | Weight of pile cap | = 3 kN |
| vii. | Number of blows for last 2.54 mm, | $S$ = 6 |
| viii. | Modulus of elasticity of concrete, | $E = 2 \times 10^7$ kN/m² |

**Assume any other data, if required. Take the weight of pile as 73.5 kN.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**d. Explain the terms used in well foundation : well curb, cutting edge and bottom plug. Also discuss the various methods for rectification of tilts in the well foundation.**

**Ans.** **Terms :** Refer Q. 4.4, Page 4–6D, Unit-4.
**Methods :** Refer Q. 4.8, Page 4–11D, Unit-4.

**e. What is stability number ? What is its utility in the analysis of stability of slopes ? Discuss the uses of stability charts.**



**Ans.** This Question is Out of Syllabus From Session 2018-19.

## SECTION-C

3. Attempt any one part of following : (1 × 10 = 10)

**a. Explain how will you modify, the Newmark's equation based on Boussinesq analysis for vertical pressure below a corner of uniformly loaded rectangular area when point at which vertical pressure is required is not located below, a vertical but below some other point of the rectangle.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**b. Show the expressions for the Westergaard's solution for the vertical stress due to point load of finite length, due to a rectangularly loaded area and due to a circularly loaded area.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

4. Attempt any one part of following : (1 × 10 = 10)

**a. A rectangular footing has a size of 1.8 m × 3 m has to transmit the load of a column at a depth of 1.5 m. Calculate the safe load which the footing can carry at a factor of safety of 3 against shear failure. Use IS code method. The soil has following properties : Porosity, $n$ = 40 % ,Specific gravity, $G$ = 2.67, Water content, $w$ = 15 %, Cohesion, $c$ = 8 kN/m², Angle of shearing resistance, $\phi$ = 32°. For $\phi$ = 32°, $N_c$ = 36, $N_q$ = 23 and $N_\gamma$ = 30.**

**Ans.** Refer Q. 2.20, Page 2–26D, Unit-2.

**b. A 30 cm square bearing plate settles by 8 mm in the plate load test on cohesionless soil, when the intensity of loading is 180 kN/m². Estimate the settlement of shallow foundation of 1.6 m square under the same intensity of loading.**

**Ans.** Refer Q. 2.24, Page 2–31D, Unit-2.

5. Attempt any one part of following : (1 × 10 = 10)

**a. It is proposed to provide pile foundation for a heavy column the pile group consisting of 4 piles, placed at 2 m center to center, forming a square pattern. The underground soil is clay, having $C_u$ at surface as 60 kN/m² and at depth 10 m as 100 kN/m². Compute the allowable column load on the pile cap, if the piles are circular having diameter 0.5 m each and depth as 10 m.**

**Ans.** Refer Q. 3.15, Page 3–19D, Unit-3.

**b. What are the conditions where the pile foundation is more suitable than a shallow foundation ? Discuss different methods for the installation of piles.**

**Ans.** **Conditions :** Refer Q. 3.5, Page 3–8D, Unit-3.
**Installation Methods :** Refer Q. 3.7, Page 3–10D, Unit-3.

6. Attempt any one part of following : (1 × 10 = 10)

**a. Discuss about the underreamed piles, and where these piles are to be used ? Which method will you use for the design of shallow and deep foundations for the expansive soils ?**

**Ans.** Refer Q. 3.21, Page 3–28D, Unit-3.

**b. A drilled pier length 5 m is constructed in an expansive soil having the depth of active zone as 3 m. If the shaft diameter is 1 m and the bulb diameter is 1.25 m. Calculate the factor of safety :**

**A. Without considering dead load.**

**B. With considering dead load of 300 kN on the pier.**

**Ans.** Refer Q. 3.22, Page 3–31D, Unit-3.

7. Attempt any one part of following : (1 × 10 = 10)

**a. Derive an expression for the factor of safety of an infinite slope in a cohesionless soil. What is the effect of steady seepage parallel to the slope on the stability ?**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

**b. In a test block of a size 1.5 m × 1.0 m × 0.75 m, resonance occurs at a frequency of 20 cycles per second in the vertical vibration. Determine the coefficient of elastic uniform compression ($C_u$). If the mass of oscillator is 70 kg and the force produced by it at 15 cycles per second is 1000 kN. Also compute the maximum amplitude at 15 cycles per second.**

**Ans.** This Question is Out of Syllabus From Session 2018-19.

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