1

Introduction

1.1 Foundations, Soils and Superstructures

Foundations are essential to transfer the loads coming from the superstructures such as buildings, bridges, dams, highways, walls, tunnels, towers and for that matter every engineering structure. Generally that part of the structure above the foundation and extending above the ground level is referred to as the superstructure. The foundations in turn are supported by soil medium below. Thus, soil is also the foundation for the structure and bears the entire load coming from above. Hence, the structural foundation and the soil together are also referred to as the substructure. The substructure is generally below the superstructure and refers to that part of the system that is below ground level. Thus, the structural foundation interfaces the superstructure and the soil below as shown in Figures 1.1 and 1.2. The soil supporting the entire structure above is also referred to as subsoil and/or subgrade. For a satisfactory performance of the superstructure, a proper foundation is essential.

The manmade superstructures or facilities/utilities are expected to become very intricate and complex depending on creativity, architecture and infinite scope in modern times. However, the soil medium is mother earth which is a natural element and very little can be manipulated to achieve the desirable engineering properties to carry the large loads transmitted by the superstructure through the interfacing structural foundation (which is usually referred to as the foundation). Further, almost all problems involving soils are statically indeterminate (Lambe and Whitman, 1998) and soils have a very complex behavior, as follows:

1. Natural soil media are usually not linear and do not have a unique constitutive (stress–strain) relationship.
2. Soil is generally nonhomogeneous, anisotropic and location dependent.
3. Soil behavior is influenced by environment, pressure, time and several other parameters.
4. Because the soil is below ground, its prototype behavior cannot be seen in its entirety and has to be estimated on the basis of small samples taken from random locations (as per provisions and guidelines).
5. Most soils are very sensitive to disturbances due to sampling. Accordingly, their predicted behavior as per laboratory samples could be very much different from the in situ soil.
Thus, foundation design becomes a challenging task to provide a safe interface between the manmade superstructure and the natural soil media whose characteristics have limited scope for manipulation. Hence, the above factors make every foundation or soil problem very unique which may not have an exact solution.

Figure 1.1  Building with spread foundations.

Figure 1.2  Superstructure with pile foundations.
The generally insufficient and conflicting soil data, selection of proper design parameters for design, the anticipated mode for design, the perception of a proper solution and so on require a high degree of intuition – that is, engineering judgment. Thus, foundation engineering is a complex blend of soil mechanics as a science and its practice through foundation engineering as an art. This may be also referred to as geotechnique or geotechnical engineering.

1.2 Classification of Foundations

Foundations are classified as shallow and deep foundations based on the depth at which the load is transmitted to the underlying and/or surrounding soil by the foundation as follows.

1.2.1 Shallow Foundation

A typical shallow foundation is shown in Figure 1.3(a). If $D_f/B \leq 1$, the foundations are called shallow foundations, where $D_f =$ depth of foundation below ground level, and $B =$ width of foundation (least dimension). Common types of shallow foundations are continuous wall footing, spread footing, combined footing, strap footing, grillage foundation, raft or mat foundation and so on. These are shown in Figure 4.2.

![Figure 1.3 Shallow and deep foundations.](image)

All design and analysis considerations of shallow foundations are discussed in Chapters 4–8 and 12. The shallow foundations are thus used to spread the load/pressure coming from the column or superstructure (which is several times the safe bearing pressure of supporting soil) horizontally, so that it is transmitted at a level that the soil can safely support. These are used when the natural soil at the site has a reasonable safe bearing capacity, acceptable compressibility and the column loads are not very high.
1.2.2 Deep Foundations

A typical deep foundation is shown in Figure 1.3(b). If $D_y/B \geq 1$, the foundations are called deep foundations such as piles, drilled piers/caissons, well foundations, large diameter piers, pile raft systems. The details of analysis and design of such foundations are discussed in Chapters 9 and 10.

Deep foundations are similar to shallow foundations except that the load coming from columns or superstructure is transferred to the soil vertically. These are used when column loads are very large, the top soils are weak and the soils with a good strength and compressibility characteristics are at a reasonable depth below ground level. Further, earth retaining structures are also classified under deep foundations.

Foundations can be classified in terms of the materials used for their construction and/or fabrication. Usually reinforced concrete (RCC) is used for the construction of foundations. Plain concrete, stone and brick pieces are also used for wall footings when the loads transmitted to the soil are relatively small. Engineers also use other materials such as steel beams and sections (such as in grillage foundations and pile foundations), wood as piles (for temporary structures), steel sheets (for temporary retaining structures and cofferdams) and other composite materials.

Sometimes, these are also encased in concrete depending on the load and strength requirements (Bowles, 1996; Tomlinson, 2001).

1.3 Selection of Type of Foundation

While engineering judgment and cost play a very important role in selecting a proper foundation for design, the guidelines given in Table 1.1 can be helpful (please see also Chapters 4–12).

1.4 General Guidelines for Design

Following broad guidelines may be useful for foundation design and construction, depending on site.

1. Footings should be constructed at an adequate depth below ground level to avoid passive failure of the adjacent soil by heaving.
2. The footing depth should be preferably below the zone of seasonal volume changes due to freezing, thawing, frost action, ground water and so on.
3. Adequate precautions have to be taken to cater for expansive soils causing swelling pressure (upward pressure on the footing).
4. The stability of the footing has to be ensured against overturning, sliding, uplift (floatation), tension at the contact surface (base of the footing), excessive settlement and bearing capacity of soil.
5. The foundation needs to be protected against corrosion and other harmful materials that may be present in the soil at site.
6. The design should have enough flexibility to take care of modifications of the superstructure at a later stage or unanticipated site conditions.
Table 1.1  Foundation types.

<table>
<thead>
<tr>
<th>Types of foundation</th>
<th>Use</th>
<th>Condition of soil at site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow foundations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Spread footing or wall footings</td>
<td>Isolated/individual columns, and continuous walls</td>
<td>Bearing capacity is reasonably adequate for applied load.</td>
</tr>
<tr>
<td>2. Combined footings</td>
<td>Two to four columns on footing and/or space is limited</td>
<td>Compressibility of soil is acceptable.</td>
</tr>
<tr>
<td>3. Raft/mat foundations</td>
<td>Several rows of parallel columns; heavy column loads; used to reduce differential settlements</td>
<td>Soil bearing capacity is generally less than for spread footings and over half the plan area would be covered if spread footings are used. Settlement has to be acceptable.</td>
</tr>
<tr>
<td>4. Grillage foundation</td>
<td>Very large column loads from superstructure</td>
<td>Reasonable soil bearing capacity, necessary to restrict the depth of foundation to enable it to be above the ground water table.</td>
</tr>
<tr>
<td>Deep foundations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Floating pile</td>
<td>In groups of two supporting a cap which is connected to column(s)</td>
<td>Surface and near surface soils have low bearing capacity and good soil is at a reasonable depth.</td>
</tr>
<tr>
<td>2. Bearing pile</td>
<td>Same as above</td>
<td>Surface and near surface soils are very weak. Good soil is at reasonable depth. Same as for piles.</td>
</tr>
<tr>
<td>3. Drilled piers or caissons</td>
<td>For large column loads</td>
<td></td>
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<tr>
<td>Earth-retaining structures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Retaining walls, bridge abutments</td>
<td>Permanent soil retention</td>
<td>Any type of soil but a specified zone in backfill is usually of controlled fill.</td>
</tr>
<tr>
<td>2. Sheetung structures</td>
<td>Temporary or permanent for excavations; marine cofferdams for underwater construction</td>
<td>Retain any type of soil or water.</td>
</tr>
</tbody>
</table>

- 69x79 Table 1.1
- 86x109 Foundation types.
- 103x79 Types of foundation
- 103x62 Use
- 103x446 Condition of soil at site
- 125x62 Bearing capacity is reasonably adequate for applied load.
- 125x446 Compressibility of soil is acceptable.
- 147x63 Soil bearing capacity is generally less than for spread footings and over half the plan area would be covered if spread footings are used. Settlement has to be acceptable.
- 169x40 Reasonable soil bearing capacity, necessary to restrict the depth of foundation to enable it to be above the ground water table.
- 207x40 Surface and near surface soils have low bearing capacity and good soil is at a reasonable depth.
- 257x436 Surface and near surface soils are very weak. Good soil is at reasonable depth. Same as for piles.
1.5 Modeling, Parameters, Analysis and Design Criteria

All practical problems need to be reduced to physical models and behavior represented by corresponding analytical equations. The physical parameters of the system form the inputs in the mathematical equations for computing the responses. The models used should be simple enough that the physical parameters needed for computations are accurately and reliably determined using inexpensive test procedures. For example, in a foundation–soil system, the foundation can be modeled as rigid, while the soil may be assumed to be elastic. The physical parameters needed in such a model are the elasticity parameters of the soil, that is. Young’s modulus of elasticity, $E$, and Poisson’s ratio, $v$, of the soil. Naturally $E$ and $v$ have to be

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**Figure 1.4** Soils of India. (Adapted from B.K. Ramiah and L.S. Chickanagappa, *Soil Mechanics and Foundation Engineering* p. 3 (Figure 1.1), Oxford and IBH Publishing Co., New Delhi, India. © 1981.)
accurately determined for the soil under consideration as they will be needed for the computation of the responses of the system. Thus modeling, evaluation of parameters and analysis are closely linked and the solutions obtained are highly dependent on all these aspects.

The responses thus obtained have to be judged using appropriate design criteria specified either by codes or evolved from practice and/or experience.

The design process necessarily has two vital components, namely the methods of analysis and experimental data which have to be integrated with them to yield accurate results. However, both the methods and data depend entirely on the mechanism chosen for mathematical idealization of the system components. At this juncture, engineering judgment and experience is very useful. It may be noted that optimum accuracy in analysis and design can be achieved only by properly matching the data and analytical methods used. It is also obvious that any improvement in the data alone or any sophistication in the analytical methods alone can even reduce the accuracy of the results/predictions (Lambe, 1973).

1.6 Soil Maps

Most countries have prepared maps of soil deposits, based on the geological and geotechnical data available. These are very useful for a quick assessment of the project and its requirements. A map of soil deposits in India is given in Figure 1.4 (Ramiah and Chickanagappa, 1981).