



Site Investigation

1. Introduction

Site investigations or subsurface explorations are done for obtaining the information about subsurface conditions at the site of proposed construction. Site investigations in one form or the other is generally required for every big engineering project. Information about the surface and sub-surface features is essential for the design of structures and for planning construction techniques.

Site investigations consist of determining the profile of the natural soil deposits at the site, taking the soil samples and determining the engineering properties of the soils. It also includes in-situ testing of the soils.

Site investigations are generally done to obtain the information that is useful for one or more of the following purposes.

- (1) To select the type and depth of foundation for a given structure.
- (2) To determine the bearing capacity of the soil.
- (3) To estimate the probable maximum and differential settlements.
- (4) To establish the ground water level and to determine the properties of water.
- (5) To predict the lateral earth pressure against retaining walls and abutments.
- (6) To select suitable construction techniques.
- (7) To predict and to solve potential foundation problems.
- (8) To ascertain the suitability of the soil as a construction material.
- (9) To investigate the safety of the existing structures and to suggest the remedial measures.

The relevant information is obtained by drilling holes, taking the soil samples and determining the index and engineering properties of the soil. In-situ tests are also conducted to determine the properties of the soils in natural conditions.



2. Planning a Subsurface Exploration Programme

A sub-surface exploration programme depends upon the type of the structure to be built and upon the variability of the strata at the proposed site. The extent of sub-surface exploration is closely related to the relative cost of the investigations and that of the entire project for which it is undertaken. In general, the more detailed the investigations are done, the more is known about the sub-surface conditions. As a result, the greater economy can be achieved in the construction of the project because the element of uncertainty is considerably reduced. However, a limit is reached when the cost of investigations outweighs any saving in the cost of the project, and it increases the overall cost. It would not be economical to have investigations beyond that limit.

The extent of investigations would also depend upon the location of the project. A small house in an already built-up area would not require much exploration. On the other hand, if the house is to be built in a newly developed area, a detailed investigation would be required to ascertain the location of different soil strata and their physical characteristics. If a multi-storeyed building is to be constructed, extensive sub-surface explorations would be necessary. These buildings impose very heavy loads and the zone of influence is also very deep. It would, therefore, be more desirable to invest some amount on sub-surface exploration than to overdesign the building and make it costlier.

Planning of a sub-surface exploration programme is a difficult task. Besides a thorough knowledge of soil engineering, it requires experience and engineering judgment. Sometimes, the exploration programme base to be changed as the investigations progress. As the variability of the soil strata is found to increase, the extent of investigations is also increased. On the other hand, if the site is found to be underlain by uniform deposits, the extent of investigations is decreased. In general, the aim of the investigations should be to get the maximum information that is useful in the design and construction of the project at a minimum cost. The cost of site



investigations generally varies between 0.05 to 0.2% of the total cost of the entire structure. In some unusual conditions, the cost may be even up to 1%

3. Stages in Sub-Surface Explorations

Sub-surface explorations are generally carried out in three stages:

(1) Reconnaissance. 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- 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.

(2) Preliminary Exploration. The aim of a preliminary exploration is to determine the depth, thickness, extent and composition of each soil stratum at the site. The depth of the bed rock and the ground water table is also determined.

The preliminary explorations are generally in the form of a few borings or test pits. Tests are conducted with cone penetrometers and sounding rods to obtain information about the strength and compressibility of soils. Geophysical methods are also used in preliminary explorations for locating the boundaries of different strata.

(3) Detailed Explorations. The purpose of the detailed explorations is to determine the engineering properties of the soils in different strata. It includes an extensive boring programme, sampling and testing of the samples in a laboratory.

Field tests, such as vane shear tests, plate load tests and permeability tests, are conducted to determine the properties of the soils in natural state. The tests for the determination of dynamic properties are also carried out, if required.

For complex projects involving heavy structures, such as bridges, dams, multi-story buildings, it is essential to have detailed explorations. However, for small projects, especially at sites where the strata are uniform, detailed investigations may not be required. The design of such projects is generally based on the data collected during reconnaissance and preliminary explorations.



4. Reconnaissance

The geotechnical engineer makes a visit to the site for a careful visual inspection in reconnaissance. The information about the following features is obtained in reconnaissance.

- (1) The general topography of the site, the existence of drainage ditches and dumps of debris and sanitary fills.
- (2) Existence of settlement cracks in the structure already built near the site.
- (3) The evidence of land slides, creep of slopes and the shrinkage cracks.
- (4) The stratification of soils as observed from deep cuts near the site.
- (5) The location of high flood marks on the nearby building and bridges.
- (6) The depth of ground water table as observed in the wells.
- (7) Existence of springs, swamps, etc. at the site.
- (8) The drainage pattern existing at the site.
- (9) Type of vegetation existing at the site. The type of vegetation gives a clue to the nature of the soil.
- (10) Existence of underground water mains, power conduit, etc. at the site.

In addition to making site visits, the geotechnical engineer should study geological maps, aerial photographs, toposheet, soil maps and the blue prints of the existing buildings. Maps and publications of various agencies give a lot of information about the geologic character of the area. The geotechnical engineer should also get information about the type of structure to be built and its proposed use. In the case of a multi.storeyed building, the information about the column loads and their approximate locations should be obtained. In the case of bridges, the span length and the load carried by the piers and abutments should be ascertained. In the case of a dam, the geotechnical engineer should get information about the type or the dam, its height, base width and other salient characteristics. The information obtained during reconnaissance is helpful in evolving a suitable sub-surface investigation programme.



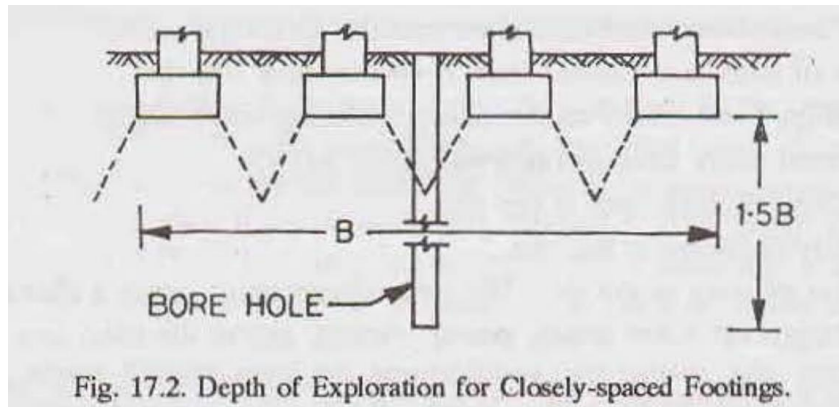
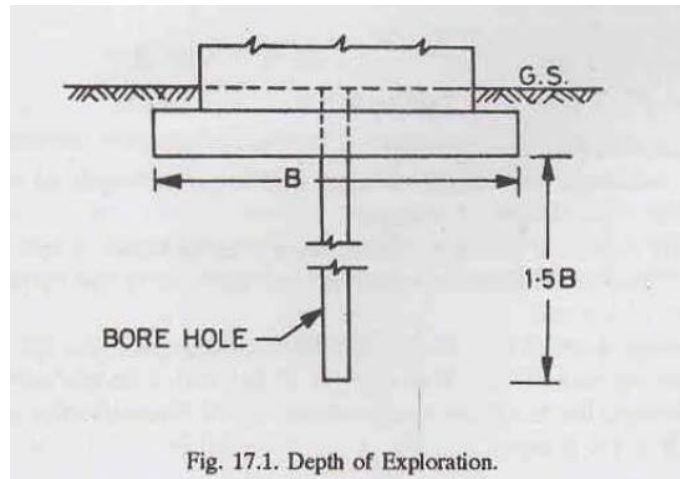
5. Depth of Exploration

The depth of exploration required at a particular site depends upon the degree of variation of the subsurface data in the horizontal and vertical directions. It is not possible to fix the number, disposition and depth of borings without making a few preliminary borings or soundings at the site. The geotechnical engineer having a long experience and good engineering judgment may give some guidelines. The depth of exploration is governed by the depth or the influence zone. The depth of the influence zone depends upon the type of the structure, intensity of loading, shape and disposition or the loaded area, the soil profile, and the physical characteristics of the soil. The depth up to which the stress increment due to superimposed loads can produce significant settlement and shear stresses is known as the *significant depth*. The depth of exploration should be at least equal to the significant depth.

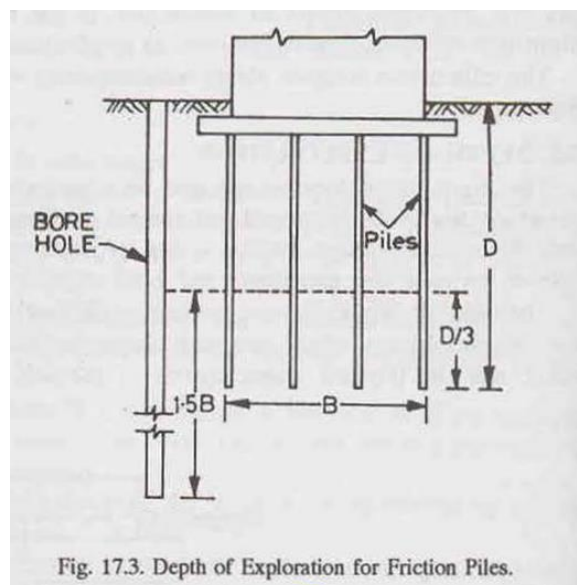
The significant depth is generally taken as the depth at which the vertical stress is 20% of the load intensity. According to the above criterion, the depth of exploration should be about 1.5 times the width of the square footing (Fig. 17. 1) and about 3.0 times the width of the strip footing. However, if the footings are closely spaced, the whole of the loaded area acts as: a raft foundation. In that case. the depth of boring should be at least 1.5 times the width of the entire loaded area (Fig. 17 .2).

Table: Suggested values of depth of borings

| Width of building in meters | Boring depth in meters | | | | | | |
|-----------------------------|------------------------|-----|------|------|------|----|------|
| | Number of storey | | | | | | |
| | 1 | 2 | 3 | 4 | 6 | 8 | 16 |
| 30 | 3.0 | 6.0 | 8.0 | 10.0 | 13.0 | 16 | 24 |
| 60 | 3.5 | 6.5 | 4.0 | 12.0 | 16.6 | 21 | 32.5 |
| 120 | 3.5 | 70 | 10.0 | 13.5 | 19.0 | 24 | 41 |



In the case of pile foundation, the depth of exploration below the tip of bearing piles is kept at least 1.5 times the width of the pile group. However, in the case of friction piles, the depth of exploration is taken 1.5 times the width of the pile group measured from the lower third point (Fig. 17.3).





It is more logical to relate the increase in stress to the in-situ stress. The depth of exploration is usually taken up to the level at which the increase in stress is 1/20th of the in-situ stress before the application of the load.

When the foundations are taken up to rock, it should be ensured that large boulders; are not mistaken as bed rock. The minimum depth of core boring into the bed rock should be 3m to establish it as a rock.

In case of multi-storeyed buildings, the depth of exploration can be taken from the following formula (Sowers and Sowers, 1970),

$$D = C(S)^{0.7}$$

where D = depth of exploration (m). C = constant, equal to 3 for light steel buildings and narrow concrete buildings. It is equal to 6 for heavy steel buildings and wide concrete buildings. S = number of stories.

If loose soil or recently deposited soil or a weak stratum is encountered, it should be explored thoroughly. Explorations should be carried to a depth at which the net increase in the vertical stress is less than the allowable bearing pressure of the soil.

For two adjacent footings, each of size B x L, spaced at a clear spacing A, IS: 1892-1972 suggests that the minimum depth of boring should be 1.5 B when $A \geq 4B$; and it should be 1.5L when $A < 2B$. For adjacent rows of such footings, the minimum recommended depth of exploration is 4.5B when $A < 2B$; it is 3.5 B when $A > 2B$ and it is 1.5 B when $A \geq 4B$.

For explorations of deep excavations, the depth of exploration below the proposed excavation level should be at least 1.5 times the depth of excavation. In case of road cuts, it is taken at least equal to the width of the cut.

In case of road fills, the minimum depth of boring is 2m below the ground surface or equal to the height of the fill, whichever is greater .

In case of gravity dams, the minimum depth of boring is twice the height of the dam.

American Society of Civil Engineers (1972) suggests that the boreholes be extended to the lesser of the following two.



- a. The depth where the net vertical stress increase $\Delta\sigma'$ is equal to 10% of the vertical stress applied by the structures
- b. The depth where the net vertical stress increase $\Delta\sigma'$ is equal to 5% of the effective vertical overburden stress

More detailed guidelines specific to different structures are given in Table1, where B and L are the breadth and length of the structure.

Table 1: Minimum Depths of Boreholes (Adopted from Mayne et al., 2001)

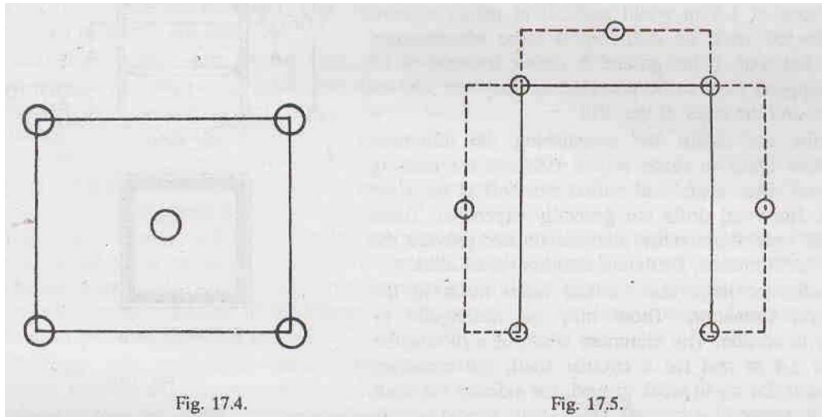
| Structure | Minimum depth |
|-------------------------------------|---|
| Spread footings: | |
| $L < 2B$ | 2B below the foundation level |
| $L > 5B$ | 4B below the foundation level |
| Deep foundations: | |
| Piles in soils | 6 m below the expected pile tip level |
| Pile groups in soils | Twice the maximum pile group length |
| Piles supported on rock | 3 m into the rock to ensure it is not a boulder |
| Drilled shafts extending into rocks | 3 m or 2D below the tip ($D = \text{diameter}$) |
| Drill shaft group | Twice the group length below the tip |
| Raft foundations | 1.5 times B (the smaller dimension) |
| Retaining walls | 0.75–1.5 times the wall height below the ground level. If deep instability or high settlements expected, extend to the hard stratum |
| Roads | 2 m below the proposed subgrade level |
| Excavations | 5 m below the excavation level |
| Embankments | Twice the embankment heights if no hard stratum encountered before. |
| Culverts | Similar to embankments |

6. Lateral Extent of Explorations

The lateral extent of exploration and the spacing of bore holes depend mainly on the variation of the strata in the horizontal direction. The exploration should be extensive so as to reveal major changes in the properties of the sub-surface strata.



For small and less important buildings, even one bore hole or a trial pit in the center may suffice. But for compact buildings, covering an area of about 0.4 hectares, there should be at least 5 bore holes, one at the centre and four near the corners (Fig. 17 .4).



For large, multi-storeyed buildings, the bore holes should be drilled at all the corners and also at important locations. The spacing between the bore holes is generally kept between 10 to 30 m, depending upon the variation in the subsurface conditions and loading (Fig. I 7 .5.). For highways, subsurface explorations are usually carried out along the proposed center line or along the propose ditch line. The spacing of bore holes usually varies between 150 and 300 m. If the sub~strata is erratic, the spacing may be reduced to even 30m. In case of concrete dams, the spacing of bore holes generally varies between 40 and 80 m.

While there is no hard and fast rule for deciding on the number of boreholes, some guidelines given are as follows.

- 15 m to 40 m grid spacing for industrial and high-rise buildings.
- Grid with less than 60 m spacing for structures with very large footprints.
- 20 m to 200 m spacing for linear structures (e.g., roads, railways, channels, pipelines, retaining walls, tunnels, and dikes).
- Two to six locations for special structures such as bridges, stacks, machine foundations, etc.
- 25 m to 75 m spacing along the vertical section for dams and weirs.



Laboratory versus In Situ Tests

While triaxial and consolidation tests require the best possible quality undisturbed samples, highly disturbed samples and trimmings can be used for the determination of index properties such as moisture content, Atterberg limits, and specific gravity of the soil grains, and visual classification.

It is possible to determine some of the design parameters from either in situ tests or laboratory tests. It is the responsibility of the geotechnical engineer to strike the right balance between the two. They both have their advantages and disadvantages, as summarized in Table 2. Laboratory and in situ tests should complement each other; one should not be at the expense of the other.

Table 2: Advantages and Disadvantages of Laboratory and In Situ Tests

| Laboratory tests on specimens | In situ tests |
|--|---|
| Test results are not available immediately after the field work. | Test results are available immediately. |
| More rational interpretation. | Empirical and semiempirical interpretation. |
| Smaller volumes tested. | Larger volumes tested in relatively shorter period. More representative of the soil mass. |
| Well-defined boundary conditions. | Poorly defined boundary conditions. |
| Better control of the boundary conditions. | Little control of the boundary conditions. |
| Stress relief and mechanical disturbance in sampling. | Testing in situ; no stress relief and limited sample disturbance. |
| Better control of strain rate and stress path. | Difficult to control strain rate or stress path. |
| Very few points tested along the depth. | Continuous profiling possible. |



ADVANCED LABORATORY AND FIELD SOIL TESTING 2024-2025

The ASTM standards covering the major in situ tests and sampling procedures are listed in Table 3

Table 3: ASTM Standards Relevant to Site Investigations

| Standard | Purpose |
|----------|--|
| D 1195 | Repetitive static plate load tests of soils and flexible pavement components, for airport and highway pavements |
| D 1196 | Nonrepetitive static plate load tests of soils and flexible pavement components, for use in evaluation and design of airport and highway pavements |
| D 1452 | Soil exploration and sampling by auger borings |
| D 1586 | Standard penetration test and split-barrel sampling of soils |
| D 1587 | Thin-walled tube sampling of fine-grained soils |
| D 2113 | Rock core drilling and sampling of rock for site exploration |
| D 2487 | Classification of soils for engineering purposes—USCS |
| D 2488 | Description and identification of soils (Visual-manual procedure) |
| D 2573 | Field vane shear test in saturated fine-grained soil |
| D 3441 | Mechanical cone penetration testing of soils |
| D 3550 | Thick wall ring-lined split barrel drive sampling of soils |
| D 4220 | Preserving and transporting soil samples |
| D 4428 | Crosshole seismic test |
| D 4429 | In situ CBR |
| D 4633 | Energy measurements for dynamic penetrometers |
| D 4700 | Soil sampling |
| D 5092 | Design and installation of ground water monitoring wells |
| D 5777 | Guide for seismic refraction method for subsurface investigation |
| D 5778 | Electronic friction cone and piezocone penetration testing of soils |
| D 6429 | Selecting surface geophysical methods |
| D 6431 | Resistivity method for subsurface exploration |
| D 6635 | Flat plate dilatometer testing |
| D 7128 | Seismic reflection method for shallow subsurface investigation |
| G 57 | Field measurement of soil resistivity using Wenner array |