Subsurface Exploration

The process of determining the sequence of layers of natural soil deposits that will underlie a proposed structure and their physical properties is generally referred to as site investigation.

Significance of SI

- Prerequisite to the economical and safe design of substructure elements
- Necessary for feasibility and economic studies of a project
- To eliminate the site exploration, which usually is 0.5-1% of the total construction cost of a project, is not wise as it may lead to redesign of foundation or facing problems afterwards
- Suitable sites in urban areas are difficult to find and often sites targeted are reclaimed land and have many anomalies
- 35~40% of all delays in buildings are due to unforeseen ground problems
- 50% of insurance claims on properties are to geotechnical problems
- SI properly carried out under qualified supervision can reduce project cost, maintenance and produce safer structures no matter how large or small the project
- More important: SI data is only as good as the design and operation of the SI. GARBAGE IN = GARBAGE OUT

The purpose of a soil investigation program

1. Selection of the type and the depth of foundation suitable for a given structure.
2. Evaluation of the load-bearing capacity of the foundation.
3. Estimation of the probable settlement of a structure.
4. Determination of potential foundation problems (for example, expansive soil, collapsible soil, sanitary landfill, and so on).
4. Establishment of ground water table.
6. Prediction of lateral earth pressure for structures like retaining walls, sheet pile bulkheads, and braced cuts.
7. Identification of construction problems and their solution (sheeting, dewatering, rock excavation, etc.)
8. Identification of problems concerning adjacent existing buildings (settlement, damages)
9. Conducting field tests to measure relevant engineering properties of soils.

FACTORS AFFECTING EXPLORATION PROGRAM

Soil exploration program are influenced by a number of factors some of these are:

- **Size and type of the project;**
- **General characteristics of the soils in the work area;**
- **Time available for exploration; and**
- **Degree of risk or safety involved.**

General Considerations of SI

Mainly two requirements should always be observed in planning/conducting SI

- 1. Accuracy/reliability of work performed, carelessness or lack of experience may produce inconclusive results leading to wrong interpretations
- Timeliness of performing SI,

EXPLORATION PROGRAM

The purpose of the exploration program is to determine, within practical limits, the stratification and engineering properties of the soils underlying the site. The principal properties of interest will be the strength, deformation, and hydraulic characteristics. The program should be planned so that the maximum amount of information can be obtained at minimum cost.

Phases of SI

- Project Assessment:

  For affective planning of SI program, the geotech engineer must assess the following aspects of the proposed development.

- The type, purpose, location and appropriate dimension of the proposed facility, number of storey, type of foundation, provision basement etc.
- The type of construction, structural loads, allowable settlements etc.
- The existing topography and any proposed grading
- The presence of various developments in the site area

All the factors have an impact and thoroughness on SI program, e.g., a proposed nuclear power plant to be built on difficult ground would require an extensive SI program and characterization, while a one storey wood frame building on a good site may require only minimal effort.

Phases of SI

- Frame work/Stages of SI

SI program may consists of the following stages

1. Desk Study or Literature Search
2. Reconnaissance
3. Preliminary Investigation
4. Detailed Investigation

Phases of SI (Stage-I)

- **1. Desk Study:**

Assembly of all available information regarding the site, it may include

1. The information about the proposed development:

dimensions, column spacing, type and use of the structure, basement requirements, and any special architectural considerations of the proposed building. Foundation regulations in the local building code should be consulted for any special requirements. For bridges the soil engineer should have access to type and span lengths as well as pier loadings. This information will indicate any settlement limitations, and can be used to estimate foundation loads.

2. Site history---earlier site use—mining---industrial complexes—Ancient monuments
3. Geological maps
4. Soil survey reports
5. Geotechnical investigation report of nearby sites
6. Historic ground water
7. Remote sensing data, aerial photogramps, now a days satellite imagery maps

Phases of SI [Stage 2]

2.Reconnaissance of the area:

This may be in the form of a field trip to the site which can reveal

1. Information on the type and behavior of adjacent structures such as cracks, noticeable sags, and possibly sticking doors and windows. The type of local existing structure may influence, to a considerable extent, the exploration program and the best foundation type for the proposed adjacent structure.
2. Includes marking the location of proposed exploratory borings/trenches/test pits
3. The exposed rock and the surface soils are mapped
4. Marking of difficult areas like coverved with organic soil, sanitary fill etc
5. Approximate map of the site area showing the relative position of various existing features in the site area
6. Further focus on various aspects like:

- Any evidence of previous development on the site
- Any evidence of previous grading on site
- Any evidence of landslides or stability problem
- Performance of nearby structure
- Access to the site
- Affects of any offsite conditions e.g. flooding, mud flow or rock falls etc

Phases of SI [Stage 3]

3. Preliminary site investigation:

-In this phase a few borings are made or a test pit is opened to establish in a general manner the stratification, types of soil to be expected, and possibly the location of the groundwater table.

- One or more borings should be taken to rock, or competent strata, if the initial borings indicate the upper soil is loose or highly compressible.

- Geophysical methods may be used to establish the tentative boundary between the strata, especially the location of bed rock.

- Laboratory testing on limited soil samples to evaluate the soil parameters

This amount of exploration is usually the extent of the site investigation for small structures and help formulating the scope of SI for large project at detailed SI stage.

Phases of SI [Stage 4]

4. Detailed site investigation:

Where the preliminary site investigation has established the feasibility of the project, a more detailed exploration program is undertaken. The preliminary borings and data are used as a basis for locating additional borings, which should be confirmatory in nature, and it may also include:

- In-situ testing
- Procuring soil samples and comprehensive lab testing
- Comprehensive analyses and reporting.

5. During Construction Soil Investigation

If during excavations, the geotechnical condition may change from the established condition, more soil investigation may be required to explore the extent of the changed conditions.

Planning/Scope of SI

The SI comprises field testing and Lab testing.

The field work includes execution of test pits, borings and field testing in test pits and borings.

The Lab testing includes all relevant tests to fully characterize the subsoil encountered.

Planning/Scope of SI

While deciding field work of SI, three aspects are important

1. Locations 2. Spacing 3. depth of investigation/boring

- **Location:** The boring should be placed at points of strategic importance
- At points where heavy loads are anticipated
- At abutments and at points where intermediate piers will come in case of bridges
- For dams, usually along the centre line but some lateral boring should be placed on both sides of C/L
- For building units, at corners and at centre of the plan

Planning/Scope of SI

Spacing:

- No hard and fast rule
- For structures usually 10-30 m
- For small structures, min of 3 borings
- Structures consisting of separate units, one boring for each unit
- For Dams, tunnels and other excavations may be closely spaced to get better geology.

Planning/Scope of SI

Depth:

- Up to depths which are affected by loadings, up to influence zone
- Exploration should be extended below all deposits unsuitable for foundation purposes, e.g. made ground, compressible soils etc
- Up to hard stratum, min 3 m in rocks

More specifically: As per BS-5930-1981

For Shallow Foundations:

To a depth at least 1.5 times the loaded area, and the loaded area may be:

A. the area of the individual footings if footing widely spaced

B. where spacing between the individual footing is less than 3 times footing width or where floor loading is significant, the loaded area should be the plan area

C. The area of a foundation raft

For Piles

- Up to hard stratum
- Up to atleast 4-5 times of the pile diameter below the intended pile length

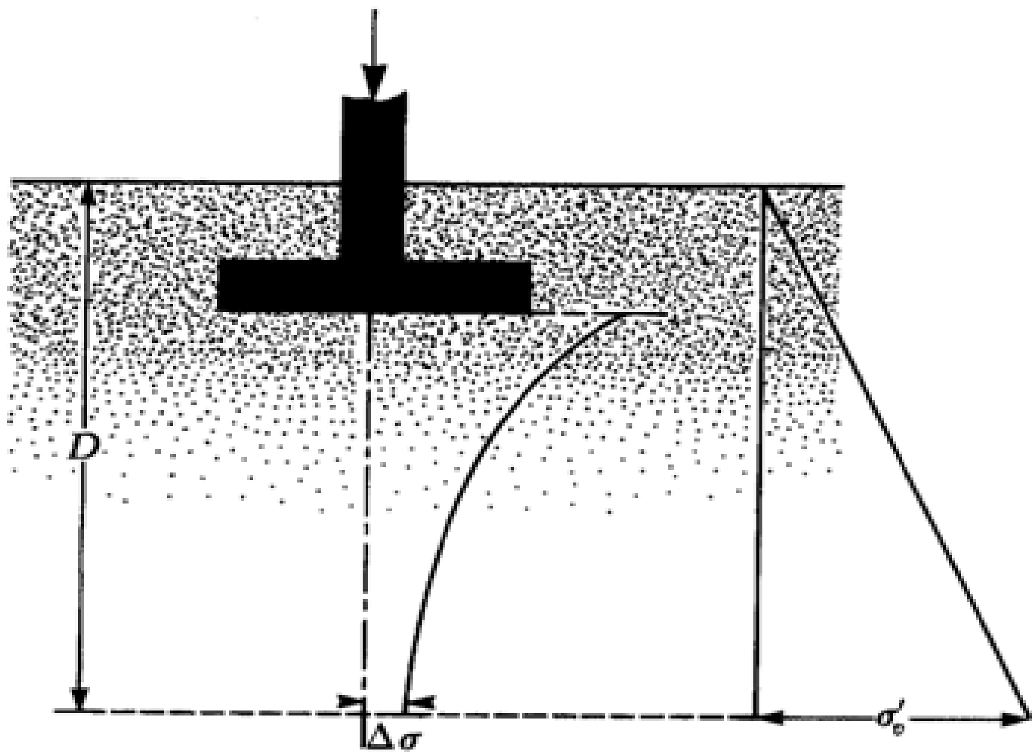
Planning/Scope of SI

Depth of Boring as Per ASCE (1972)

1. Determine the net increase of stress, $\Delta\sigma$ under a foundation with depth as shown in the Figure.
2. Estimate the variation of the vertical effective stress, σ'_{υ}, with depth.
3. Determine the depth, $D = D_1$, at which the stress increase $\Delta\sigma$ is equal to (1/10) q_o (q_o = estimated net contact stress on the foundation).
4. Determine the depth, $D = D_2$, at which $\Delta\sigma/\sigma'_{\upsilon} = 0.05$.

5. Unless bedrock is encountered, the smaller of the two depths, D_1 and D_2, just determined is the approximate minimum depth of boring required.

Depth of Boring



Determination of the minimum depth of boring

Sowers Methods for number and depth of Borings

Number of Borings

TABLE 3.1 ROUGH GUIDELINES FOR SPACING EXPLORATORY BORINGS FOR PROPOSED MEDIUM TO HEAVY WEIGHT BUILDINGS, TANKS, AND OTHER SIMILAR STRUCTURES.

Subsurface Conditions	Structure Footprint Area for Each Exploratory Boring	
	(m^2)	(ft^2)
Poor quality and/or erratic	100–300	1,000–3,000
Average	200–400	2,000–4,000
High quality and uniform	300–1,000	3,000–10,000

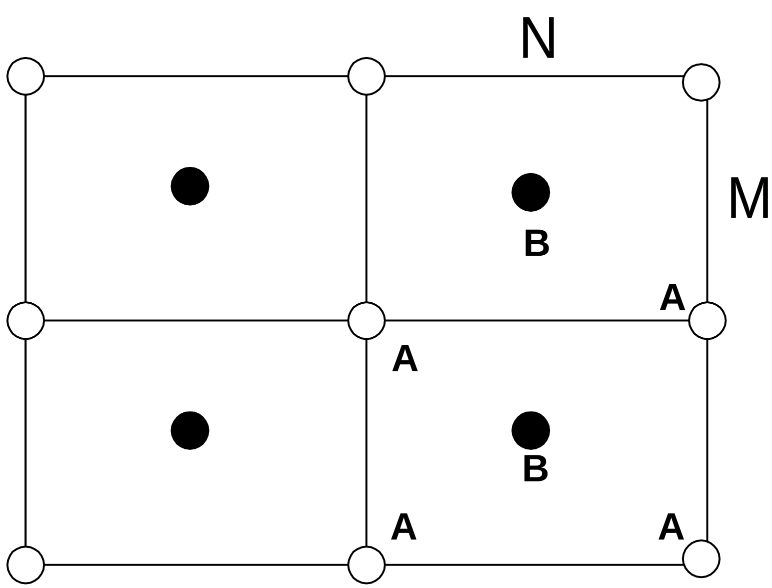
Depth of Borings

TABLE 3.2 ROUGH GUIDELINES FOR DEPTHS OF EXPLORATORY BORINGS FOR BUILDINGS ON SHALLOW FOUNDATIONS (Adapted from Sowers, 1979)

Subsurface Conditions	Minimum Depth of Borings (S = number of stories; D = anticipated depth of foundation)	
	(m)	(ft)
Poor	$6\,S^{0.7} + D$	$20\,S^{0.7} + D$
Average	$5\,S^{0.7} + D$	$15\,S^{0.7} + D$
Good	$3\,S^{0.7} + D$	$10\,S^{0.7} + D$

Method Proposed by Cernica

Divide the proposed area in rectangular sub-division and mark boring A & B as shown below. The depth and spacing is indicated in the Table below:



Description	Depth		Spacing	
	A (ft)	B (ft)	M (ft)	N (ft)
Light (1-2 S)	10 --20	20 -- 25	100	100
Medium (3-4 S)	20 --25	30 -- 40	80 -- 100	80 -- 100
Heavy (5-8 S)	30 -- 40	50 -- 80	50 -- 80	50 -- 80

Planning/Scope of SI

Embankments: ASCE recommends

- 1.5 to 2 times the height of embankments
- Depth should be sufficient to possible shear failure and probable settlement

Dams, depth should be such to explore all stata through which piping and seepage may occur and some borings up to rock bed (min 3 m into the rock)

Roads: Exploration up to 2-3 m below the formation level

Runways: 5-6 m below the formation level

Pipe Lines: Depth below invert level of the order of 1.5-2 m may be sufficient

Tunnels: Relatively to deeper depth as the level of the tunnel may be lowered.

Example of Planning SI program

A three-story steel frame office building is to be built on a site where the soils are expected to be of average quality and average uniformity. The building will have a 30 m × 40 m footprint and is expected to be supported on spread footing foundations located about 1 m below the ground surface. The site appears to be in its natural condition, with no evidence of previous grading. Bedrock is several hundred feet below the ground surface. Determine the required number and depth of the borings.

Economics of SI

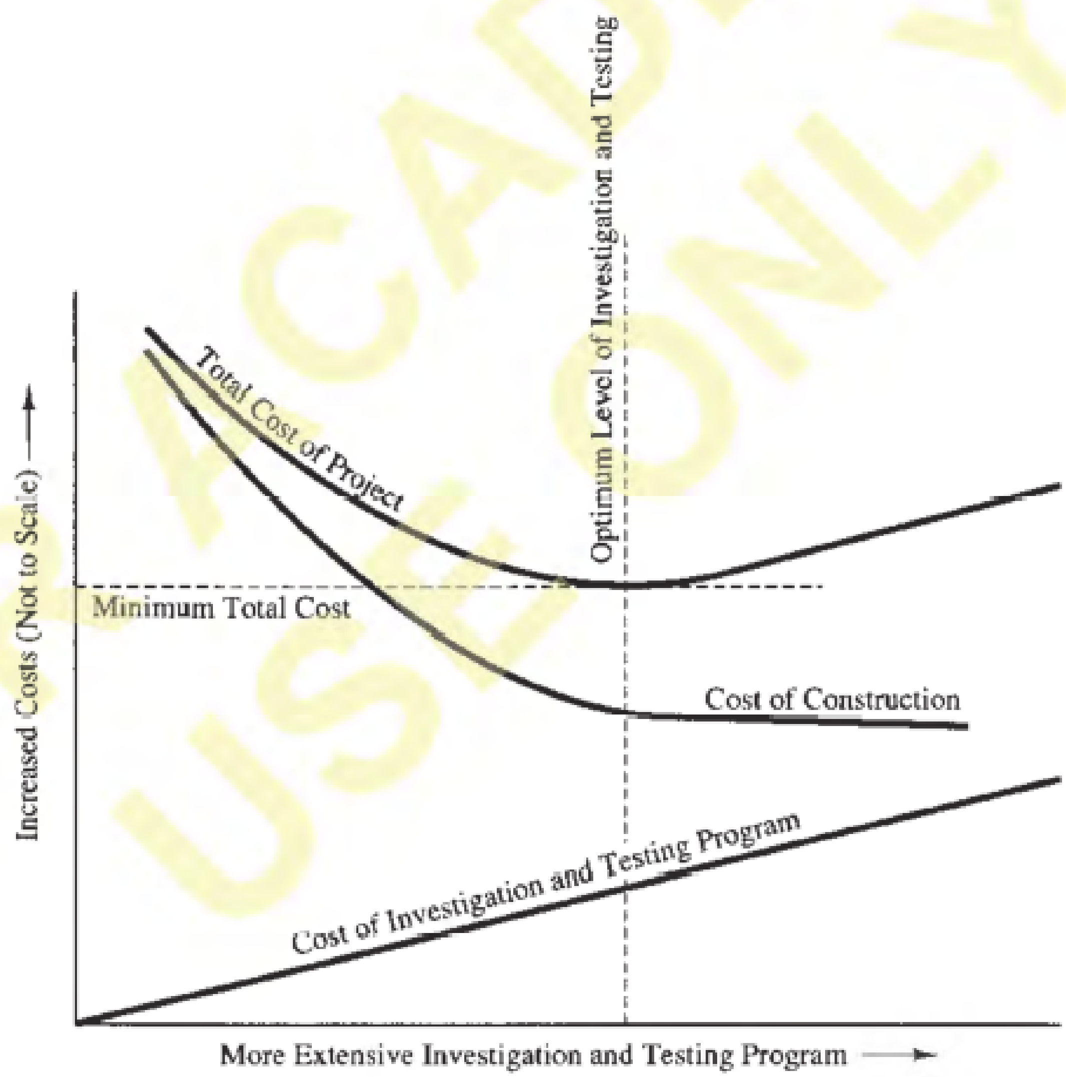


Figure 3.39 Cost-effectiveness of more extensive site characterization programs.