Foundation Design - Soils

from Building Structures, 2nd ed., Ambrose, 1993

CHAPTER THIRTY-NINE

General Considerations

Chapter 39 summarizes the general issues involved in foundation design, the properties and behavioral characteristics of foundation materials of significance for design work, and the problems of establishing useful design data and criteria.

39.1. BASIC PROBLEMS IN FOUNDATION DESIGN

The design of the foundation for a building cannot be separated from the overall problems of the building structure and the building and site designs in general. Nevertheless, it is useful to consider the specific aspects of the foundation design that must be dealt with.

Site Exploration

For purposes of the foundation design, as well as for the building and site development in general, it is necessary to know the actual site conditions. This investigation usually consists of two parts: determination of the ground surface conditions, and of the subsurface conditions. The surface conditions are determined by a site survey that establishes the three-dimensional geometry of the surface and the location of various objects and features on the site. Where they exist, the location of buried objects such as sewer lines, underground power and telephone lines, and so on, may also be shown on the site survey.

Unless they are known from previous explorations, the subsurface conditions must be determined by penetrating the surface to obtain samples of materials at various levels below the surface. Inspection and testing of these samples in the field, and possibly in a testing lab, is used to identify the materials and to establish a general description of the subsurface conditions.

Site Design

Site design consists of positioning the building on the site and the general development, or redevelopment, of the site contours and features. The building must be both horizontally and vertically located. Recontouring the site may involve both taking away existing materials (called *cutting*) and building up to a new surface with materials brought in or borrowed from other locations on the site (called *filling*). Development of controlled site drainage for water runoff is an important part of the site design.

Selection of Foundation Type

The first formal part of the foundation design is the determination of the type of foundation system to be used. This decision cannot normally be made until the surface and subsurface conditions are known in some detail and the general size, shape, and location of the building are determined. In some cases it may be necessary to proceed with an approximate design of several possible foundation schemes so that the results can be compared.

Design of Foundation Elements

With the building and site designs reasonably established, the site conditions known, and the type of foundation determined, work can proceed to the detailed design of individual structural elements of the foundation system.

Construction Planning

In many cases the construction of the foundation requires a lot of careful planning. Some of the possible problems include conditions requiring dewatering the site during construction, bracing the sides of the excavation, underpinning adjacent properties or buildings, excavating difficult objects such as large tree roots or existing constructions, and working with difficult soils such as wet clays, quick sands or silts, soils with many large boulders, and so on. The feasibility of dealing with these problems, primarily in terms of cost and delays, may influence the foundation design as well as the positioning of the building on the site and the general site development.

Inspection and Testing

During the design and construction of the foundation there are several times when it may be necessary to perform inspection or testing. Whether done by the designer or by others, the results of the inspections and tests will be used to influence design decisions or to verify the adequacy of the completed designs or construction. The need for this work will depend on the size of the building, the type of construction, the specific subsurface conditions, the type of foundation system, and the various problems encountered during construction. Some of the ordinary inspections or tests are as follows:

Preliminary Site Investigation. The preliminary investigation usually consists of a site survey and some minimal subsurface investigation prior to the construction and often prior to the final design of the foundation. For major projects or difficult subsurface conditions it is usually necessary to have this information even before the preliminary site design and building design can be done.

Detailed Site Design. In some cases it is necessary to have additional information prior to the final design or the construction of the foundation. In some instances it is possible to incorporate this investigation with the early stages of the foundation work, with any necessary design adjustments made as the work progresses.

Inspection and Testing during Construction. At a bare minimum the completed excavation should be visually inspected prior to any construction to verify that the actual conditions encountered are those assumed for the design. In some cases the site conditions, the type of foundation, or the nature of the building may require extensive and continuous inspection and testing throughout the foundation construction process. Inspections by both the designer and the permit-granting agency may be required.

Inspection and Testing after Construction. In some cases it may be necessary to perform inspection and testing after the foundation construction is complete. This is usually required where progressive soil deformation is anticipated over time or with seasonal changes.

Remedial Alterations

For various reasons it is often necessary to modify the foundation in some way from the original design. This is best done prior to construction, of course, but must sometimes be done as repair or renovation. The remedial measures may be obvious and simple to accomplish, or may require the best efforts of the most-qualified experts. Some of the situations that may require remedial alterations are:

Unanticipated Subsurface Conditions. Where the site conditions are very nonuniform or the preliminary investigations sketchy, or for other reasons, it may be necessary to modify the design due to actual encountered conditions.

Unanticipated Construction Problems. Weather conditions, unusual excavation problems, unavoidable delays, and a host of other possibilities may necessitate expedient change of the design.

Construction Errors. Foundation construction is usually done under the crudest and sloppiest of working conditions. Great accuracy and perfection is not to be expected. Overexcavation, mislocation of elements, errors in dimensions, omission of details, and so on, are common.

Inadequate Performance of the Foundation. During construction, or even at some time after completion of the building, there may be evidence of excessive settlement, uneven settlement, horizontal shifting, tilting, or other forms of foundation failure.

39.2. SOIL CONSIDERATIONS RELATED TO FOUNDATION DESIGN

The principal properties and behavior characteristics of soils that are of direct concern in foundation design are the following:

Strength. For bearing-type foundations the main concern is resistance to vertical compression. Resistance to horizontal pressure and to friction are of concern when foundations must resist the force of wind, earthquakes, or retained earth.

Strain Resistance. Deformation of soil under stress is of concern in designing for limitations of the movements of foundations, such as the vertical settlement of bearing foundations.

Stability. Frost action, fluctuations in water content, seismic shock, organic decomposition, and disturbance during construction are some of the things that may produce changes in physical properties of soils. The degree of sensitivity of the soil to these actions is called its *relative stability*.

Properties Affecting Construction Activity

A number of possible factors may affect construction activity, including the following:

The relative ease of excavation.

Ease of and possible effects of site dewatering during construction.

Feasibility of using excavated materials as fill material.

Ability of the soil to stand on a vertical side of an excavation.

Effects of construction activity—notably the movement of workers and equipment—on unstable soils.

Miscellaneous Conditions

In specific situations various factors may affect the foundation design or the problems to be dealt with during construction. Some examples are the following:

Location of the water table, affecting soil strength or stability, need for waterproofing basements, requirement for dewatering during construction, and so on.

Nonuniform soil conditions on the site, such as soil strata that are not horizontal, strips or pockets of poor soil, and so on.

Local frost conditions, affecting the depth required for bearing foundations and possible heave and settlement of exterior pavements.

Deep excavation or dewatering operations, possibly affecting the stability of adjacent properties, buildings, streets, and so on.

All of these concerns must be anticipated and dealt with in designing buildings and in planning and estimating construction costs. Persons charged with responsibility for design and planning foundation construction must have some understanding of the characteristics of ordinary soils so that they can translate information about site conditions into usable data. The discussions that follow deal with the basic nature of soils of various types, the behavior and design considerations of various foundation elements and systems, and the means for obtaining and using information about specific site conditions.

39.3. FOUNDATION DESIGN CRITERIA

For the design of ordinary bearing-type foundations several structural properties of a soil must be established. The principal values are the following:

Allowable Bearing Pressure. This is the maximum permissible value for vertical compression stress at the contact surface of bearing elements. It is typically quoted in units of pounds or kips per square foot of contact surface.

Compressibility. This is the predicted amount of volumetric consolidation that determines the amount of settlement of the foundation. Quantification is usually done in terms of the actual dimension of vertical settlement predicted for the foundation.

Active Lateral Pressure. This is the horizontal pressure exerted against retaining structures, visualized in its simplest form as an equivalent fluid pressure. Quantification is in terms of a density for the equivalent fluid given in actual unit weight value or as a percentage of the soil unit weight.

Passive Lateral Pressure. This is the horizontal resistance offered by the soil to forces against the soil mass. It is also visualized as varying linearly with depth in the manner of a fluid pressure. Quantification is usually in terms of a specific pressure increase per unit of depth.

Friction Resistance. This is the resistance to sliding along the contact bearing face of a footing. For cohesionless soils it is usually given as a friction coefficient to be multiplied by the compression force. For clays it is given as a specific value in pounds per square foot to be multiplied by the contact area.

Whenever possible, stress limits should be established as the result of a thorough investigation and the recommendations of a qualified soils engineer. Most building codes allow for the use of *presumptive* values for design. These are average values, on the conservative side usually, that may be used for soils identified by groupings used by the codes. Reprints of portions of the *UBC*, 1991 edition, and the *Building Code of the City of Los Angeles*, 1976 edition, are given in Appendix D; both contain presumptive values for design. Soil types are identified only rather broadly in the *UBC*, whereas the Los Angeles code uses what is essentially the unified system in establishing allowable bearing pressures.

from Foundation Analysis and Design, 5th ed., Bowles, 1996

4-14 BEARING CAPACITY BASED ON BUILDING CODES (PRESUMPTIVE PRESSURE)

In many cities the local building code stipulates values of allowable soil pressure to use when designing foundations. These values are usually based on years of experience, although in some cases they are simply used from the building code of another city. Values such as these are also found in engineering and building-construction handbooks. These arbitrary values of soil pressure are often termed *presumptive* pressures. Most building codes now stipulate that other soil pressures may be acceptable if laboratory testing and engineering considerations can justify the use of alternative values. Presumptive pressures are based on a visual soil classification.

Table 4-8 indicates representative values of building code pressures. These values are primarily for illustrative purposes, since it is generally conceded that in all but minor construction projects some soil exploration should be undertaken. Major drawbacks to the use of presumptive soil pressures are that they do not reflect the depth of footing, size of footing, location of water table, or potential settlements.

TABLE 4-8
Presumptive bearing capacities from indicated building codes, kPa
Soil descriptions vary widely between codes. The following represents author's interpretations.

Soil description	Chicago, 1995	Natl. Board of Fire Underwriters, 1976	BOCA,* 1993	Uniform Bldg. Code, 1991†
Clay, very soft	25			
Clay, soft	75	100	100	100
Clay, ordinary	125			
Clay, medium stiff	175	100		100
Clay, stiff	210		140	
Clay, hard	300			
Sand, compact and clean	240		140	200
Sand, compact and silty	100			
Inorganic silt, compact	125			
Sand, loose and fine			140	210
Sand, loose and coarse, or sand-gravel mixture, or compact and fine		140 to 400	240	300
Gravel, loose and compact coarse sand	300		240	300
Sand-gravel, compact			240	300
Hardpan, cemented sand, cemented gravel	600	950	340	
Soft rock				
Sedimentary layered rock (hard shale, sandstone, siltstone)			6000	1400
Bedrock	9600	9600	6000	9600

Note: Values converted from psf to kPa and rounded.
*Building Officials and Code Administrators International, Inc.
†Author interpretation.