

# TECH NOTES

## Soils & Excavation Safety



A product of

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# TECH NOTES

What the concrete contractor needs to know about soils, OSHA excavation regulations and the safe practices of excavating for concrete foundations.

Foundations walls are designed based on a constant soil condition that assumes the site is maintained to ensure their long term performance. The properties of the soil, its water content and the conditions that can affect those factors must be identified to successfully design the footings and walls

Once the foundation is designed, excavation is the first step of actual on site work. It sets the stage for the construction of the walls and must be done according to common regulations to ensure the safety of the workers and the integrity of the structure.

## SOILS

A complex matrix of inorganic and organic particles, the physical properties of soils vary by region as well as within localities. The most important properties influencing construction are texture, density, porosity and consistency. Soil texture is determined by the relative proportion of sand, silt, and clay. These three particles adhere in varying ways becoming larger, relatively stable secondary structures. Soil density is a measure of its compaction. Soil porosity is the discussion of the voids between the particles and secondary structures that become occupied by or permitting the travel of gases or water. Soil consistency, sometimes also referred to as cohesion, is the ability of soil to stick together.

The structural behavior of the soil is governed by these characteristics and the resulting water content. The most commonly used measures of soil conditions are:

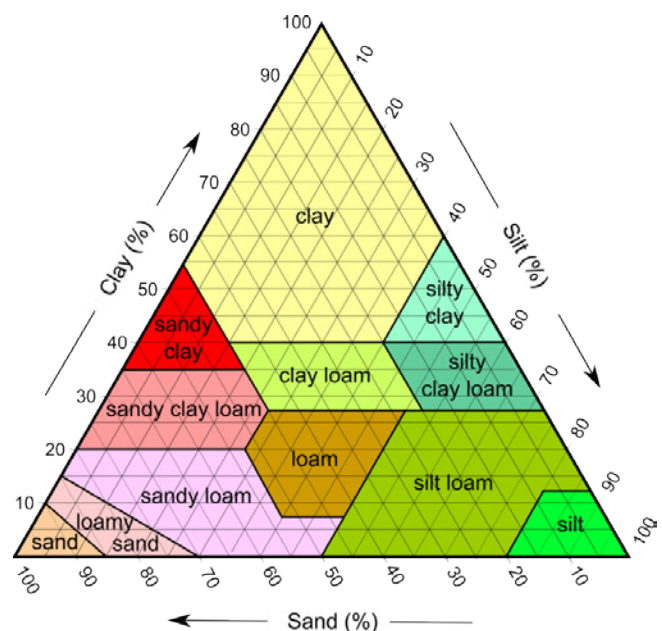
- Maximum particle size.
- Density.
- Porosity ratio.

### Maximum Particle Size

The Standard Test Method for Particle-Size Analysis of Soils of the American Society of Testing and Materials (ASTM D422-63) is the most widely recognized standard for particle size. Based on the particles passing through the decreasing screen hole diameters in sieves, soils are given designation within the following general definitions:

- Gravel - from 3 in. to 0.08 in.
- Sand – from 0.08 in. to 0.003 in.
- Silt – from 0.003 in. to 0.0002 in.
- Clay - less than 0.0002 in.

Figure 1 below demonstrates the relationship of these common general categories to the mix of soil types as defined by the United States Department of Agriculture.



**FIGURE 1: SOIL CLASSIFICATION RELATIONSHIP PYRAMID (U.S.D.A.)**

## Density

Density, defining the level of compaction for the soil, is the weight per unit volume of an object. Soil particle density is usually unchanging for a given soil, however, the resulting compaction desired or assumed for the project design, can be altered if the soil type used in the backfill is changed or if the process for compaction is not completed properly (see CFA TN-002). Soil particle density is lower for soils with high organic matter content, and is higher for soils with high iron-oxide content. The higher the organic matter content, the less compacted the soil can become.

Soil bulk density is equal to the dry mass of the soil divided by the entire volume of the soil including air space and organic materials. A high bulk density means either the soil compaction was great or the sand content was high whereas lower bulk density means the amount of cultivated loam is greater. The soil bulk density for a given soil is highly variable and is always less than the actual soil particle density.

## Porosity

Porosity is the opposite ratio to density as it divides the volume of the voids by the total volume of the soil sample. The voids, or pore spaces are not occupied by either mineral or organic matter and therefore are open space to be occupied by either gases or water. On average, the total pore space is 50% of the soil volume.

Soils that exhibit high water content are generally those with lower porosity but having forces of attraction that hold water in place greater than the gravitational force acting to drain the water. Having large pore spaces that allow rapid gas and water movement is superior to smaller pore space soil that has a greater percentage pore space. Soil texture determines the pore space at the smallest scale, but at a larger scale, soil structure has a strong influence on soil aeration, water infiltration and drainage. Clay soils have smaller pores, but more total pore space than sand.

## The Affects of Particle Size, Density and Porosity

Maximum particle size, density and the porosity ratio are all loosely related. Typically the larger the aggregate size the larger the porosity ratio. However soils with large aggregate sizes can be very compact and thus have low porosity ratio.

Three important soil design parameters are based on the impact of those properties and generally govern foundation wall designs. They are:

- Coefficient of permeability.
- Settlement.
- Bearing capacity

## Coefficient of Permeability

Allowing for proper drainage is the single most important thing that can be done to ensure the integrity of the foundation walls. The coefficient of permeability measures the rate at which water can travel through the soil. It shows how fast water can fill and leave the voids in the soil.

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It depends on several factors: the size of the soil grains or the maximum aggregate size as described above, the shapes and the arrangement of the soils, the properties of the water, and the porosity of the soil.

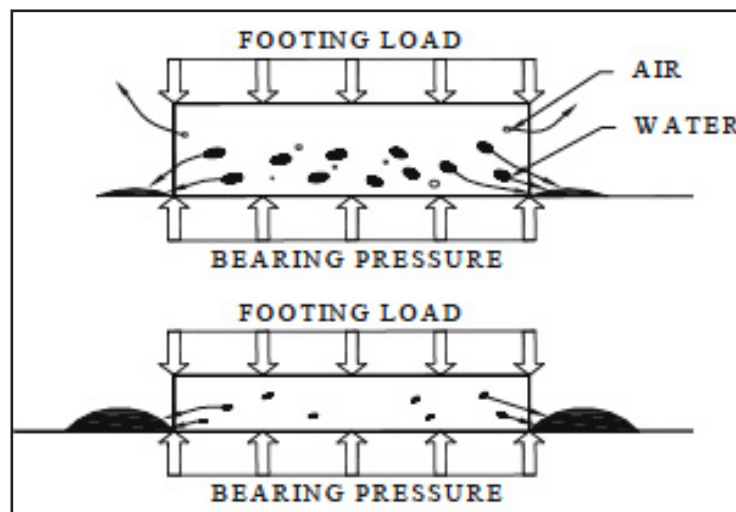
There are standard tests developed to determine this coefficient. It is measured in inches per hour and usually soils with permeability of less than 0.8 in/hr are considered moderate or slow permeability. Soils with low permeability like clay drain slower and are more likely to retain water for long periods and thus become unstable.

Permeability, or rather proper drainage is very influential on the long-term performance of foundation walls. See 'CFA TN-010' for more information on the design and construction solutions to ensure proper perimeter drainage.

## Settlement

Settlement is another soil property that affects both the short- and long- term life of the foundation. Its effects can become noticeable soon after the foundation is completed or after several years, particularly due to poor maintenance of the water drainage systems.

The amount of settlement is directly attributed to the porosity of the soil, the particle size and the relationship of particle mix (Figure 1). Settlement of the foundation occurs when the weight of the building compresses the soil and either air or water has been squeezed out. It is known that all foundations settle with time. Settlement of the surrounding soils occurs when the pore spaces of the soil are filled repeatedly with water, compressing the soil under greater weight until the water is pushed out from the resulting densification. Depending on the soil type settlement can vary both in the duration over which settlement occurs and the amount as seen in Table 1. Figure 2 demonstrates the process of settlement.



**FIGURE 2: SETTLEMENT PROCESS FOR FOUNDATIONS**

**TABLE 1: TYPICAL SETTLEMENT PATTERNS FOR COMMON SOIL TYPES**

Type of Soil	Timeframe	Amount (inches)
Sands	Weeks to months	1/8 – 3/8
Silts	Months to years	1/8 – 1/2
Clays	Years to decades	3/8 – 3/4

## Bearing Capacity

Without getting too deep in the process of geotechnical engineering, the bearing capacity of the soil represents its ability to support, distribute, and transfer loads to the ground. The size of a footing in a foundation design accounts for the allowable bearing capacity or the maximum pressure the soil can be subjected to before the soil structure fails in either shear or excessive settlement. Allowable bearing capacity is generally expressed in pounds per square foot (psf) and is a criteria in most prescriptive footing design tables. Table 2 below shows soil bearing capacity ranges and the respective commonly-adopted ratings:

**TABLE 2: SOIL BEARING CLASSIFICATION**

From (pounds per square foot)	To (pounds per square foot)	Bearing Capacity
500	1,000	Poor
1,000	1,500	Marginal
1,500	2,000	Low
2,000	3,000	Medium
3,000	4,000	Good
More than 4000		Excellent

Soils with bearing capacity of above 2,500 psf are considered adequate for foundation construction. The most common soil types and average allowable bearing capacities can be found in Table 3.

**TABLE 3: PRESUMPTIVE LOAD BEARING VALUES OF FOUNDATION MATERIALS**

CLASS OF MATERIAL	LOAD-BEARING PRESSURE (pounds per square foot)
Intact Crystalline Bedrock	30,000
Fractured Crystalline Bedrock	12,000
Intact Sedimentary Rock	15,000
Fractured Sedimentary Rock	6,000
Sandy Gravel or Gravel	5,000
Sand, Silty Sand, Clayey Sand, Silty Gravel and Clayey Gravel	3,000
Clay, Sandy Clay, Silty Clay and Clayey Silt	2,000

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Table 4 presents the properties of the common soil types that impact the design and performance of foundations.

**TABLE 4 – SOIL PROPERTIES ACCORDING TO THE UNIFIED CLASSIFICATION SYSTEM**

SOIL GROUP	UNIFIED SOIL CLASSIFICATION SYSTEM SYMBOL	SOIL DESCRIPTION	DRAINAGE CHARACTERISTICS <sup>a</sup>	FROST HEAVE POTENTIAL	VOLUME CHANGE POTENTIAL EXPANSION <sup>b</sup>	DESIGN LATERAL PRESSURE (psf per ft of depth)
Group I	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Good	Low	Low	30
	GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Good	Low	Low	30
	SW	Well-graded sands, gravelly sands, little or no fines.	Good	Low	Low	30
	SP	Poorly graded sands or gravelly sands, little or no fines.	Good	Low	Low	30
	GM	Silty gravels, gravel-sand-silt mixtures.	Good	Medium	Low	41
	SM	Silty sand, sand-silt mixtures.	Good	Medium	Low	41
Group II	GC	Clayey gravels, gravel-sand-clay mixtures.	Medium	Medium	Low	46
	SC	Clayey sand, sand-clay mixtures.	Medium	Medium	Low	48
	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	Medium	High	Low	45
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium	Medium	Medium to Low	45
Group III	CH	Inorganic clays of high plasticity, fat clays.	Poor	Medium	High	Note C
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Poor	High	High	55
Group IV	OL	Organic silts and organic silty clays of low plasticity.	Poor	Medium	Medium	Note C
	OH	Organic clays of medium-to-high plasticity, organic silts.	Unsatisfactory	Medium	High	Note C
	Pt	Peat and other highly organic soils.	Unsatisfactory	Medium	High	Note C

a. The percolation rate for good drainage is over 4 inches per hour, medium drainage is 2 to 4 inches per hour, and poor is less than 2 inches per hour.

b. Soils with a low potential expansion have a plasticity index (PI) of 0 to 15, soils with a medium potential expansion have a PI of 10 to 35 and soils with a high potential expansion have a PI greater than 20.

c. Excavation shall be backfilled with engineered fill.

# FROST

One of the factors affecting the long-term performance of sub-grade and on-grade concrete is frost. Frost is the crystallization of water vapor within the pore spaces or on the surface of soils. It is usually formed when there are long periods of temperature of less than 32 °F, there is water present, and the soil has fine grains, which allow capillary action. Since frost is a product of the phase change of water from liquid to solid, the volume of the soils must change and expansion can occur if there is not sufficient pore space within the particles to accommodate the change.

## Effect

In its solid state water occupies about 10% more volume than in liquid so it forces the soil to expand. Since bearing capacity is based on the soil having a consistent volume and cohesion, the presence of frost can alter the bearing capacity and influence settlement.

Therefore, if a footing or a slab is poured on ground that is frozen or has enough frost in it, a non-uniform settling might occur as the soil defrosts or thaws naturally that might cause the concrete to crack. See 'CFA TN-003' for more information on the effects of cold weather on foundation construction and ACI 332 for the minimum requirements for placing concrete during cold weather.

# EXCAVATION SAFETY

The cohesion of the soils and allowable bearing capacity is affected when loads are applied adjacent to an open excavation without sufficient design. When a hole is dug to prepare for a foundation, the soil capacity is altered by exposure to the elements. Additionally, the wall resulting from the removal of soils no longer has lateral support for the transfer of vertical forces including gravity. The results of not attending to proper excavation design can be catastrophic.

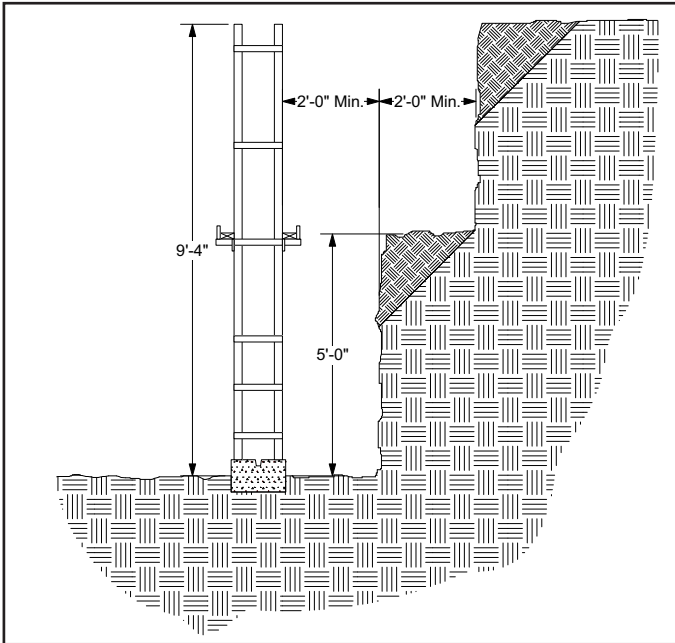
## Requirements

Contractors must comply with the Occupational Safety and Health Administration (OSHA 1926.652) requirements. This standard provides regulations on excavation and backfilling safety.

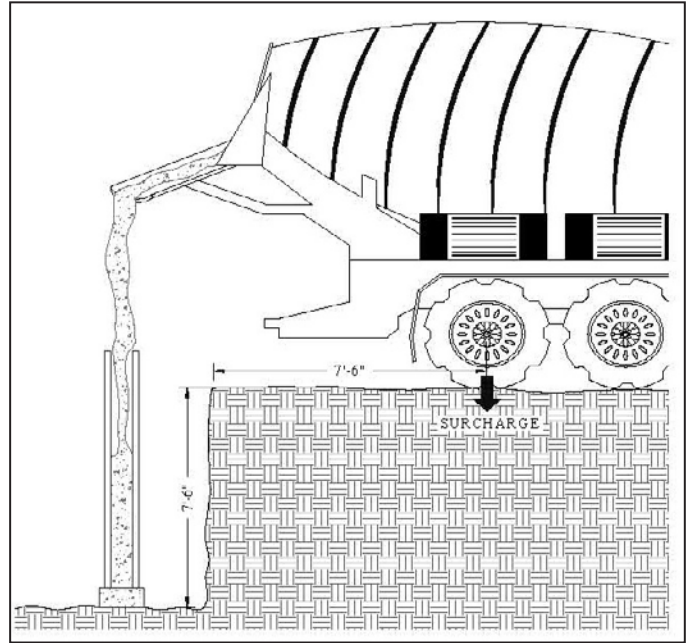
Some of the basic requirements are:

- The minimum distance between the excavation and the foundation wall forming system should be 2 ft (see Fig. 3).
- If the wall is more than 7-1/2 ft deep the excavation should be benched 2 ft horizontally for every 5 ft of vertical depth (see Fig. 3).
- All heavy equipment should not operate at a distance to the top edge of the excavation, (see Fig. 4). Organizing the site to permit the perpendicular approach of heavy equipment will minimize the potential for collapse of the excavation walls (see Fig. 5) or the use of placement equipment such as concrete pumps and conveyors is recommended.
- All excavations must provide workers a method of egress within 20 ft.
- The work in the excavation should be planned such that it requires a minimum number of workers and minimum amount of time.

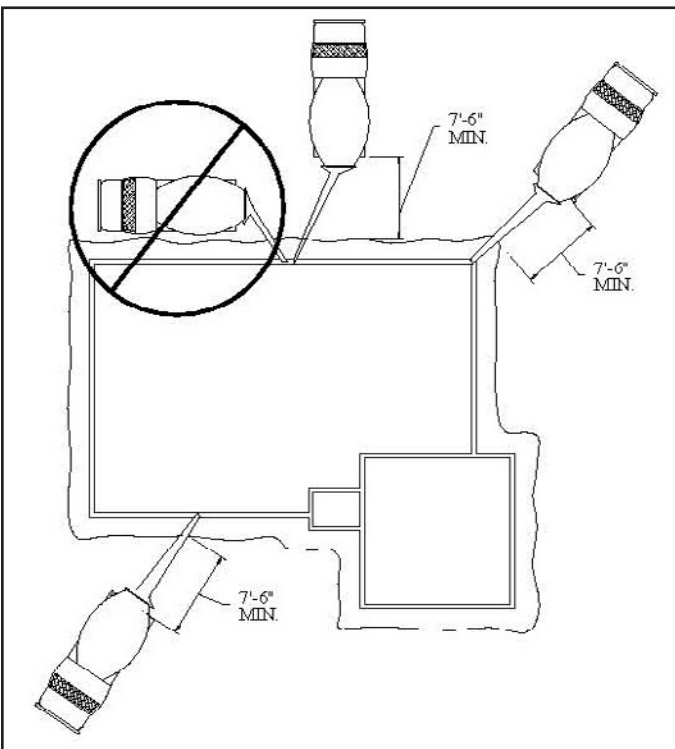
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**FIGURE 3 - BENCHING REQUIREMENTS PER OSHA 1926.652**



**FIGURE 4 - MINIMUM DISTANCE FROM EXCAVATION FOR LOAD SURCHARGE**



**FIGURE 5 - TYPICAL DELIVERY LOCATIONS FOR FOUNDATIONS AT EXCAVATIONS**



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