Lesson #2

Causes of Cave-ins

What is in this lesson?

1. The four things that impact soil strength
2. The five things that create downward forces that impact soil stability
3. The terminology used to identify soil types
4. The terminology used to describe water conditions
5. The responsibilities of the Competent Person regarding classifying soil types

Key Words

- Angular gravel
- Clay
- Cohesive Soils
- Fissured Soil
- Granular Soil
- Layered Soil System
- Rounded Gravel
- Silt
- Soil Type A, B or C
- Spoil Bank
- Surcharge
- Competent Person
- Cemented Soils
- Density
- Granular Cohesionless Soil
- Gravel
- Porosity
- Sand
- Sloped Layered System
- Spall
- Stable Rock
- UCS

Causes of Cave-ins

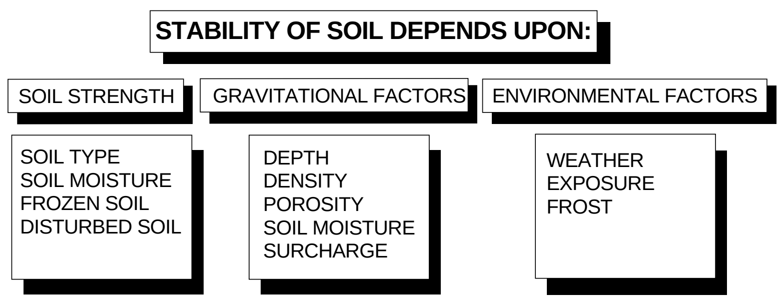
Introduction

From Lesson #1

As we learned in lesson one, cave-ins can occur when gravity overcomes the ability of the soil to support its own weight. Signs that indicate the possibility that the soil is moving are: Bulging at the bottom or walls of the trench, tension cracks parallel to the trench walls or spalls from the trench walls.

Soil Stability

In order for soil to stand when a trench is opened it must withstand the gravitational forces and the environmental factors that may be working to break down the soils natural ability to bind together. This natural ability to bind together is called the soil strength.



Soil Strength

The strength of the soil is dependent on the bonding between soil particles. This bonding is called cohesion. How cohesive[1] a soil is, is dependent upon the type of soil, the amount of moisture present in the soil and the proximity of previously disturbed soil (as in an adjacent trench).

Gravitational Factors

Factors that work against the strength of the soil include depth of the trench, the weight of the soil and the weight of the surcharge. Surcharge is the weight placed on the trench walls by the spoils pile and adjacent equipment. The weight of the soil is controlled by the density[2] of the soil, the porosity[3] of the soil and the amount of soil moisture.

Environmental Factors

Environmental factors include weather conditions and the amount of time the trench walls are exposed to the atmosphere.

This Lesson

In this lesson we will discuss each of the factors concerning soil strength and the forces working to break down the soils ability to hold together.

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1 **Cohesive Soil** - A clay (fined grained soil), or soil with a high clay content, which has cohesive strength. Cohesive soil does not crumble, can be excavated with vertical side slopes, and is plastic when molded. Cohesive soil is hard to break up when dry, and exhibits significant cohesion when submerged. Cohesive soils include clayey silt, sandy clay, silt clay, clay and organic clay.

2 **Density** - The weight per unit volume of a substance. (pounds/cubic foot).

3 **Porosity** - The ratio of pore space to total volume. That portion of a cubic foot of soil that is air space and therefore could contain moisture.

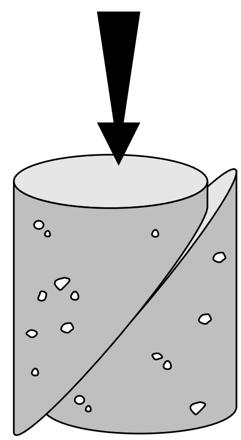
Cave-ins and Cave-in Indicators

Two Forces

There are two forces at work on the soil that form the sides of a trench. One is the vertical or downward force caused by gravity and the second in the horizontal or lateral force. Undisturbed soil is supported on all sides by adjacent soil. When soil is exposed by excavation the sides of the trench wall are no longer supported.

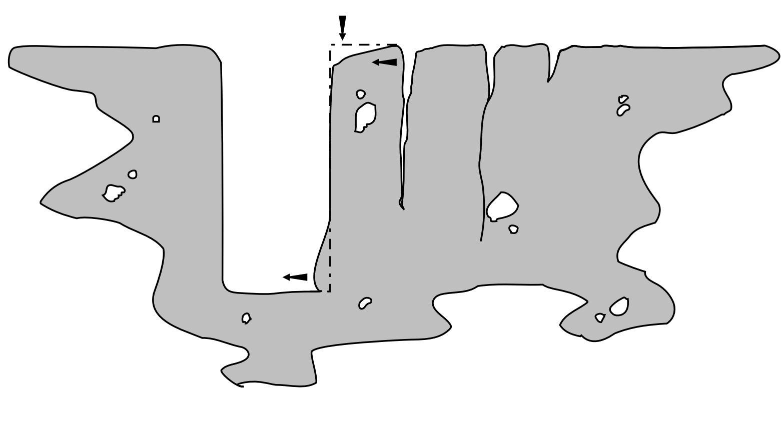
When Cave-ins Occur

A cave-in occurs anytime the strength of the soil is overcome by the weight of the soil. If a column of soil were placed under a steadily increasing pressure, at some point the column would crumble under the load. The amount of force required to cause this failure is called the unconfined compressive strength of the soil.



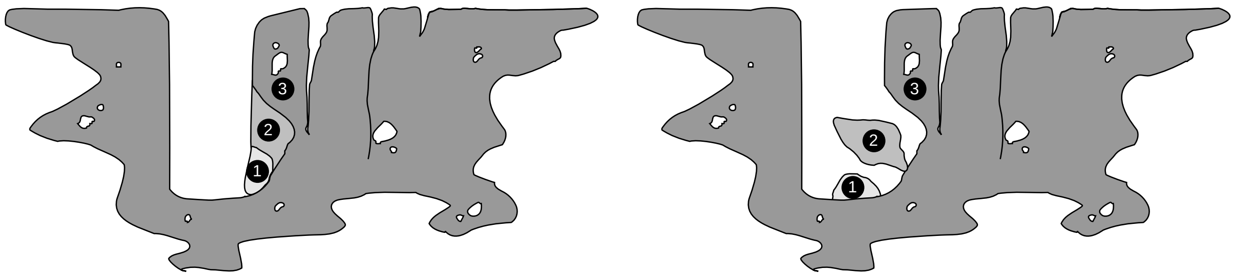
Causes of Failure

When a trench is opened, the lateral support for the wall of the trench is removed. This causes the soil near the bottom of the trench to bulge inward as a result of the weight of the soil above it. When this happens the lip of the trench wall will move downward. This downward movement causes the soil in back of the trench face to hold on to the soil at the trench face, keeping it from caving into the trench. This creates a tensile stress at right angle to the trench wall creating tension cracks parallel to the trench. The trench is now ready for failure.



The Cave-in

Under this condition, the first portion of trench to fail will be at the bottom of the trench. This will be followed by a second failure and finally a third. The most common failures of trench walls occur in three steps.



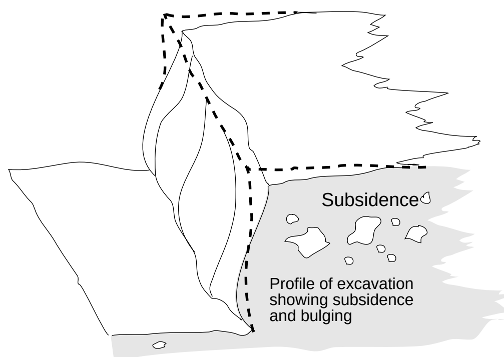
Three Types of Cave-ins and their Indicators

Introduction

There are several ways that cave-ins occur. The three primary ones are:

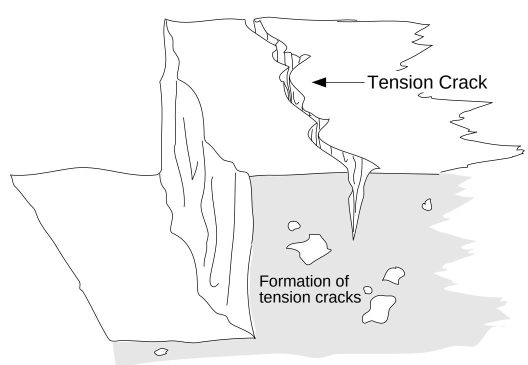
Bulging at Bottom of Trench

(1) When the soil sags and forms a bulge at the bottom, it is getting too heavy to hold itself up. This often occurs with wet soil. The weight of the added water causes the soil to exceed its holding capacity and the bulge folds into the trench.



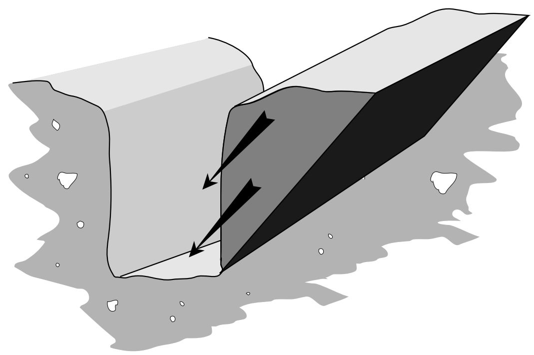
Tension Cracks

(2) Soil will develop tension cracks at the top that allow the top to lean toward the center of the excavation. When this happens, the wall can tumble down into the trench. When you see these conditions, even in shallow excavations, you should stop work and install some form of protection.



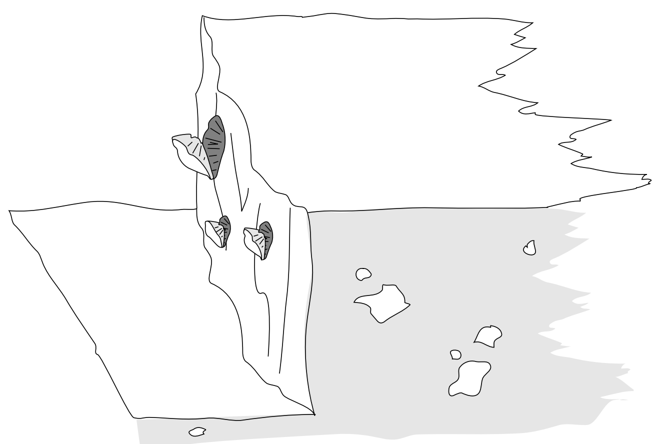
Classic Failure

(3) The wedge described earlier in this lesson is considered the classic failure. This failure occurs when a wedge of the soil slides into the trench. This type of failure supports the reasoning behind the use of sloping as a means of controlling cave-ins.



Other Signs

Other signs of impending trench failure are; spalling[4] of materials from the sides of the trench, the sliding of portions of layered soils, and the falling of fractured sections of rock. All of these signs are described in greater detail in the next lesson.



4 **Spall** - Chips of soil that break off the walls of a trench.

Responsibility of Competent Person

Classifying Soil

The Competent Person[5] must be able to classify each soil and rock deposit associated with the trench as to Stable Rock[6], Type A[7], Type B [8]or Type C[9] soil.

Basis of Classification

The classification of soil type must include at least one visual and one manual test. While several tests are available it is recommended that the Competent Person primarily rely on those tests described in the regulations. This testing must be done by the Competent Person and performed prior to and during the job.

Reclassification

If after the soil has been classified conditions change, the Competent Person must reevaluate the situation and if necessary change the soil classification.

Dynamic Situation

As you can see the classification of soil is a dynamic situation. For this reason the Competent Person must be on or near the job at all times and be systematically evaluating the soil conditions as well as other hazards that may be encountered by the crew or public. In some cases one Competent Person may be able to evaluate the conditions at two or more locations if they are close together.

5 **Competent Person** - one who is capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.

6 **Stable Rock** - Natural solid mineral material that can be excavated with vertical sides and will remain intact while exposed. Unstable rock is considered to be stable when the rock material on the side or sides of the excavation is secured against caving-in or movement by rock bolts or by another protective system that has been designed by a registered professional engineer.

7 **Type A Soils** - cohesive soils with an unconfined compressive strength of 1.5 tons per square foot (tsf) or greater. Examples of cohesive soils are: clay, silty clay, sandy clay, clay loam and in some cases, silty clay loam and sandy clay loam. Cemented soils such as caliche and hardpan are also considered Type A.

8 **Type B Soils** - cohesive soils with an unconfined compressive strength greater than 0.5 tsf but less than 1.5 tsf or, granular cohesionless soils including; angular gravel (similar to crushed rock), silt, silt loam, sandy loam and, in some cases, silty clay loam and sandy clay loam. Previously disturbed soils except those which would otherwise be classed as Type C soil. Soil that meets the unconfined compressive strength or cementation requirements for Type A, but is fissured or subject to vibration or; dry rock that is not stable. Material that is part of a sloped, layered system where the layers dip into the excavation on a slope less steep than 4H:1V, but only if the material would otherwise be classified was Type B.

9 **Type C Soi**l - cohesive soil with an unconfined compressive strength of 0.5 tsf or less, or granular soils including gravel, sand and loamy sand, or submerged soil or soil from which water is freely seeping, or submerged rock that is not stable, or material in a sloped, layered system where the layers dip into the excavation or slope of 4H:1V or steeper.

Soil Strength Factors

Introduction

Terms Used to Describe Soil Texture

One of the functions of the Competent Person is to identify soil type by observation. This requires an understanding of how soil is typed and classified. One of the common methods of typing soil is by texture. Texture is the basis for the OSHA soil classification system. Texture is based on the size of the particles.

Soil Particle Size

There are three common soil particle size groupings. They are:

Clay

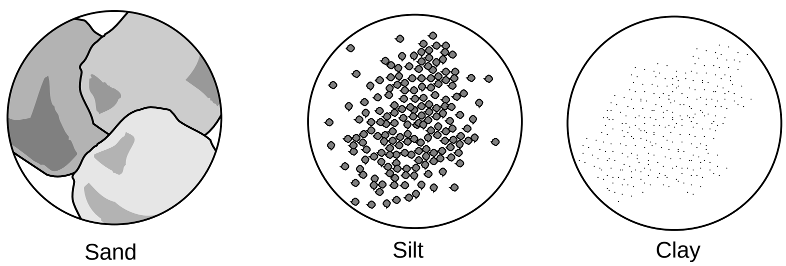
Clay is composed of mineral particles less than 0.002 mm in diameter

Silt

Silt is composed of individual mineral fragments that range from 0.002 to 0.05 mm in diameter.

Sand

Sand is individual rock or mineral fragments that range in diameter from 0.05 to 2.0 mm in diameter.



Combining the Particle Sizes

These three particle size groupings are used to define four textures, Clay, Sand, Silt and Loam and combination classes such as clayey silt, sandy clay, etc (see Lesson 3 for more details). We realize that the use of clay, sand and silt to describe particle size and texture appears to be in conflict. However, we are not responsible for the methods used over the years to describe soils. The use of the terms to describe both conditions is common and true, even if it does lead to a level of confusion. For that reason OSHA has devised its own texture system, the Type A, B and C soils. OSHA also refers to soil texture as either fine grained or coarse grained. OSHA soil classification system is based on visual observation and performance information gained by performing manual testing. While knowledge of texture is important, Type A, B, and C classifications are related to performance and observation.

Clarification

In the next lesson on Soil Classification we will go into more depth about these four textures and how they are used to determine the three OSHA soil classifications.

Other Terms

Besides these basic terms, the excavation regulations describe the following terms and conditions in classifying soils.

Four Soil Classifications

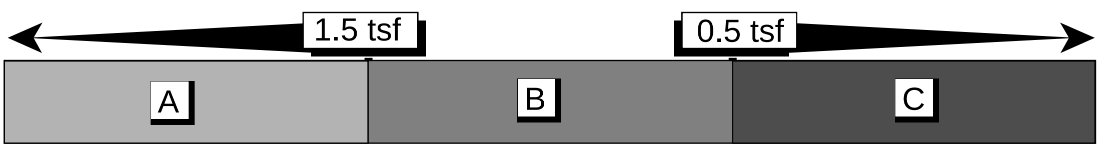
The OSHA excavation rules categorize soil as stable rock, or Types: A, B and C soil. These classifications are based on the Unconfined Compressive Strength[10] (UCS) of the soil. (The amount of pressure in tons per square foot required to cause the soil to fail.) Even though it primarily is the responsibility of the Competent Person, each person on the job should be able to identify soil in these three categories.

Unconfined Compressive Strength

The load that a soil will handle before failure is dependent upon the combination of gravitational forces, environmental conditions and soil strength. The ability of the soil to support a load can be estimated by determining the tons per square foot required to cause the soil to fail. The UCS of the soil can be estimated in the field accurately by one of two common test instruments. In the lesson on soil testing and visual observation, use of the test instruments will be discussed in length.

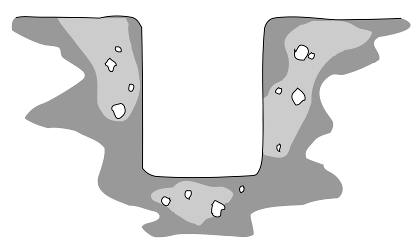
Comparing UCS to Soil Classification

Type A soil is the strongest with an UCS of 1.5 tsf or greater. Type B soil ranges between 1.5 tsf and 0.5 tsf. Type C soil is any soil that has a UCS of less than 0.5 tsf.



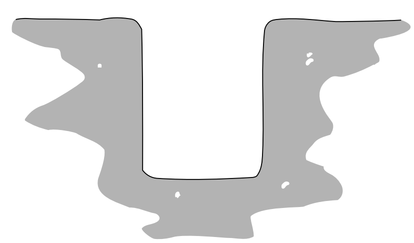
Soil Types

Cemented Soils



Cemented soil is soil in which the particles are held together by a chemical agent, such as calcium carbonate. Finger pressure cannot crush hand-size sample of cemented soils into powder or individual soil particles.

Cohesive Soils



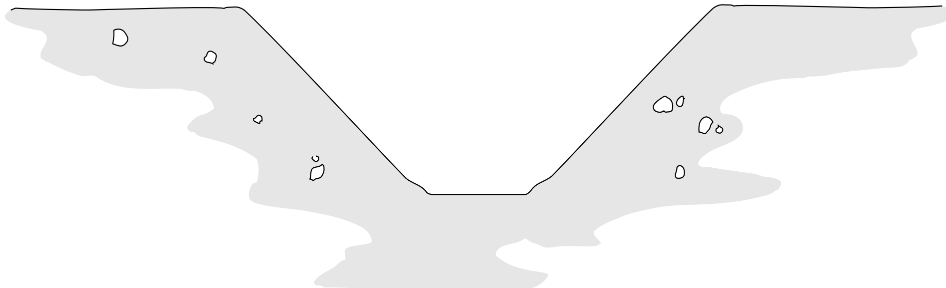
Cohesive soils are composed of clay (fined grained soil), or soil with a high clay content, which has cohesive strength. Cohesive soil does not crumble, can be excavated with vertical side slopes, and is plastic[11] when molded. Cohesive soil is hard to break up when dry, and exhibits significant cohesion even when submerged. Cohesive soils include clayey silt, sandy clay, silty clay, clay and organic clay.

10 **Unconfined Compressive Strength** - the load per unit area at which a soil will fail in compression. It can be determined by laboratory testing, or estimated in the field using a pocket penetrometer, or thumb penetration test, and other methods.

11 **Plastic** - as it applies to a soil means a property of the soil which allows the soil to be deformed or molded without cracking or changing is volume appreciably.

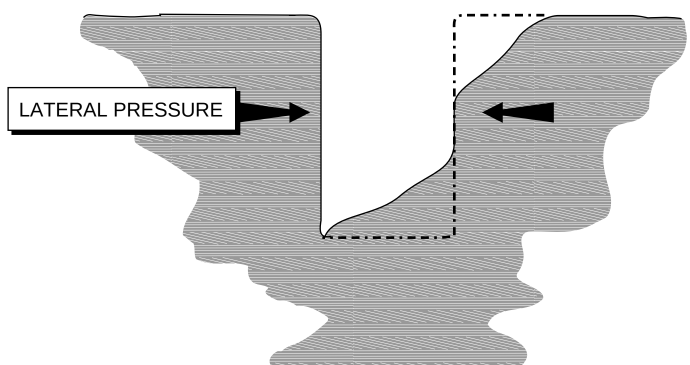
Granular Soil

Granular soil includes gravel, sand, or silt, (coarse grained soil) with little or no clay content. Granular soil has no cohesive strength. Some moist granular soils exhibit apparent cohesion. Granular soil cannot be molded when moist and crumbles easily when dry.



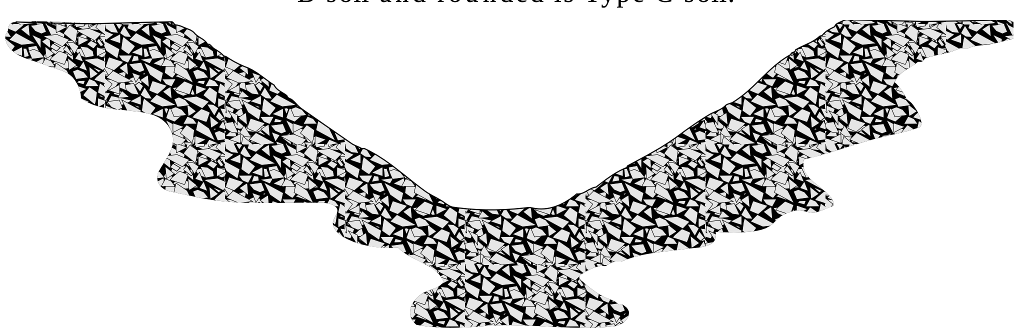
Granular Cohesionless Soil

Granular cohesionless soils include angular gravel (similar to crushed rock), and the soil textures of silt, silt loam, sandy loam and in come cases, silty clay loam and sandy clay loam. Generally, granular cohesionless soils are very unstable and may require protection from cave-ins due to the high lateral pressure exerted by angular gravel.



Gravel

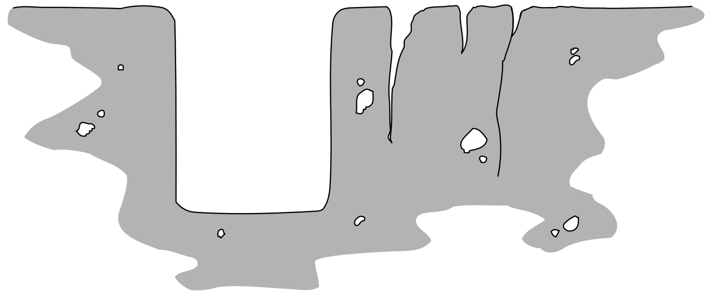
A soil is said to be gravel any time that more than one half of the visible grains are larger than 3/16”. It is important to identify if these individual grains are rounded or angular. Typically soils with gravel containing rounded grains are less stable than soils with angular grains. Angular gravel is commonly Type B soil and rounded is Type C soil.



Soil Conditions

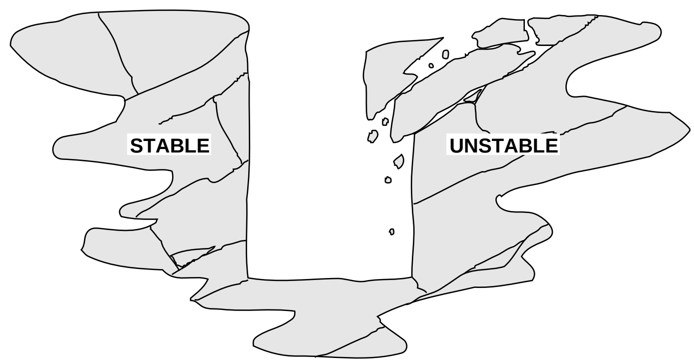
Fissured Soil Condition

A fissured soil condition exists when a soil has a tendency to break along definite planes of fracture with little resistance. It includes conditions where soil exhibits open cracks, such as tension cracks, on an exposed surface. These cracks can be observed in the trench wall and in the area adjacent to the trench.



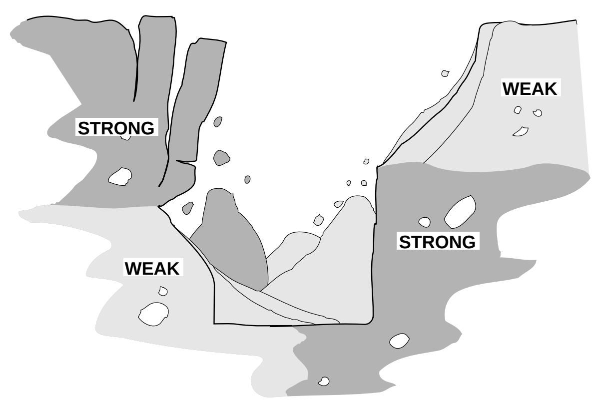
Fractured Rock Condition

Fractured rock is similar to fissured soil, in that it has a tendency to break along definite planes of fracture. Fractured rock may or may not be unstable depending on the slope of the fractures.



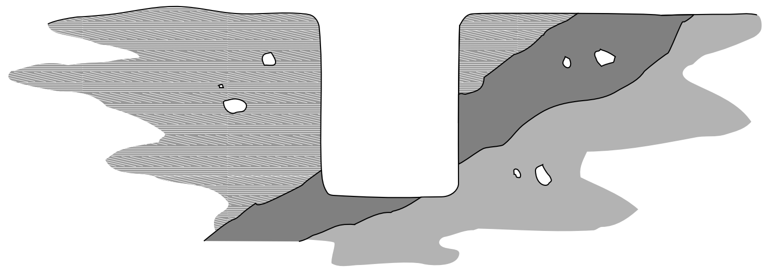
Layered Soil Condition

A layered soil system is two or more distinctly different soil or rock types arranged in layers. Micaceous seams or weakened planes in rock or shale are considered layered. Depending on soil type, layered systems may be less stable than unlayered systems.



Sloped Layered Condition

A Sloped Layered System exists any time the layers are at an angle. This is of special importance when the layers slope into the trench. If the upper layer is the weakest it may slide into the trench. If the lower layer is the weakest it may collapse and allow the upper layer to fall into the trench.



Soil Moisture

As A Stability Factor

Each soil can go from being very crumbly to runny mud depending upon the amount of moisture in the soil. Soil at either end of the moisture spectrum could create an unsafe trench. However, for any soil there is a critical amount of moisture that gives the soil its maximum bonding power or cohesion.

OSHA Soil Moisture Terms

OSHA has defined five soil conditions associated with the amount of moisture in the soil. They are:

- Dry soil
- Moist soil
- Wet soil
- Saturated soil
- Submerged soil

These conditions and their impact on the soil classification system are described in detail in the lesson on soil classification.

Frozen Soil

Stability

Frozen soil and permafrost can be very stable. In conditions where the soil is frozen well below the trench bottom the stability of the trench walls may be equal to that provided by stable rock.

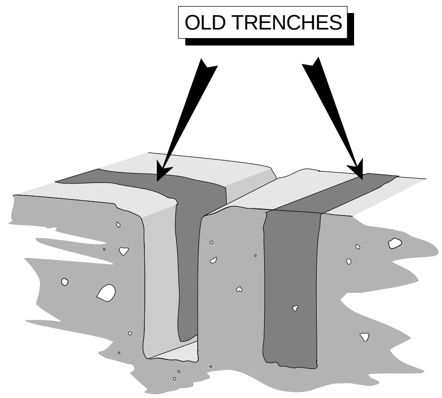
Instability

The major safety considerations with frozen soil are the presence of unfrozen soil at the bottom or just below the bottom of the trench and thawing of the trench walls. These conditions can turn a stable soil into a liquid like material that is at the low end of the stability table.

Presence or Absence of Adjacent Disturbed Soil

Impact of Disturbed Soil

Undisturbed soil is almost always stronger than disturbed soil, regardless of the tamping methods used and the degree of compaction. When replacing an old water line, it is common practice to dig adjacent to the old line and other underground utilities and thus adjacent to an old trench. The prism of soil between the two trenches is very unstable. Likewise at any point that you cross a previously dug trench the side walls of the new trench will be weakened.



Gravitational Factors

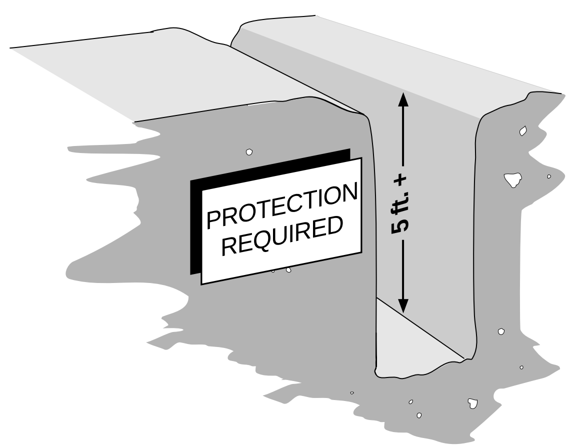
Five Factors

These are the factors that work to overcome the stability of soil. There are five of them and we shall take a quick glance at each.

Depth of Trench

Double Depth Increases Weight by 4

As was mentioned in the introduction, soil has a tendency to slide from the wall of the trench in a wedgelike fashion. Therefore, the volume and the weight of the soil will increase as the trench is deepened. A rule of thumb that can be used is that if you double the depth of a trench you increase the volume of the soil that could fall into the trench by a factor of four. A five foot deep trench could drop 625 pounds of soil for each foot of length. As a safety factor, OSHA has established that a trench more than five feet deep, regardless of the soil type, must be shored or otherwise protected against cave-in.



State Specific

Some States have set this minimum depth at 4 feet. It is important that you determine the minimum depth for your State.

Soil weight

Material Type, Weight, Moisture

The density of the soil, that is, the weight of each cubic foot of soil, is dependent upon the nature of materials that make up the soil particles and thus the weight of each particle. It is also dependent upon the porosity of the soil. The greater the porosity, the more moisture the soil can hold and therefore the more it will weigh for each cubic foot. For example, dry clay may weigh as little as 65 pounds per cubic foot and wet clay as much as 110 pounds per cubic foot.

WEIGHT of SOIL in lbs./cu. ft.

SOIL TYPE	Dry	Wet
Clay	85	110
Loose Earth	75	105
Packed Earth	95	115
Sand & Gravel	90-120	125

Impact of Moisture

Notice that soil moisture affects both the weight and the cohesiveness of the soil. Therefore, soil moisture is one of the key elements we need to be aware of when evaluating soil stability.

Responsibility of the CP

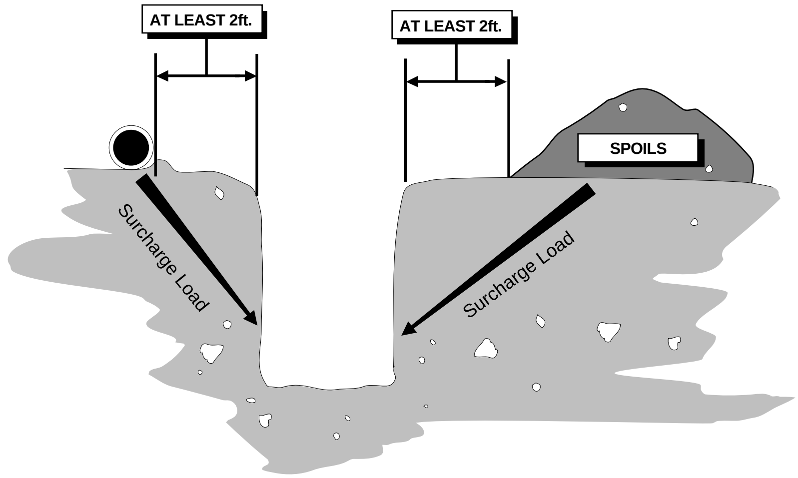
The Competent Person is responsible for identifying the soil moisture condition and classifying the soil moisture into one of the five OSHA soil moisture categories. This will be accomplished during the visual and manual testing. A detailed discussion of the various moisture conditions is found in lesson 3.

Surcharge

Spoil Bank

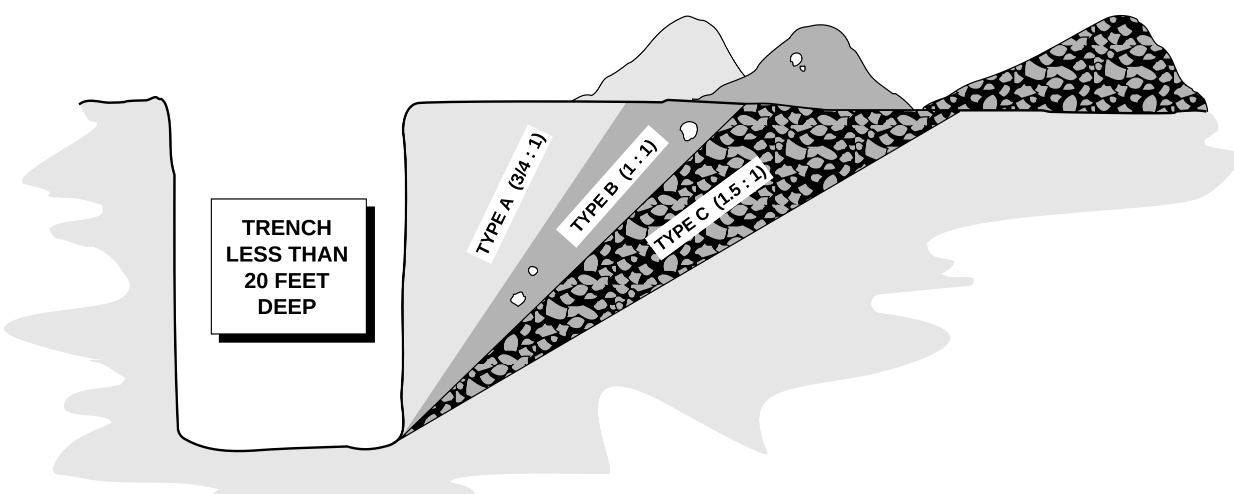
Additional Weight

When the spoils are placed too close to the trench wall they place additional load on the trench wall that could contribute to a cave-in. This added weight and the weight of any equipment placed next to the trench wall are referred to as surcharge[12] loads.



Reduction of Surcharge

To reduce the impact of the spoils bank[13] the spoils must be placed so that the toe of the slope of the spoils bank is at least two feet from the trench edge. This is a minimum distance. To determine the best placement of the spoil bank you must first identify the soil type and depth of the trench. Then run an imaginary line from the bottom of the trench to the top of the ground. The center of the spoil bank should be beyond this line. This places the least amount of load on the trench walls.

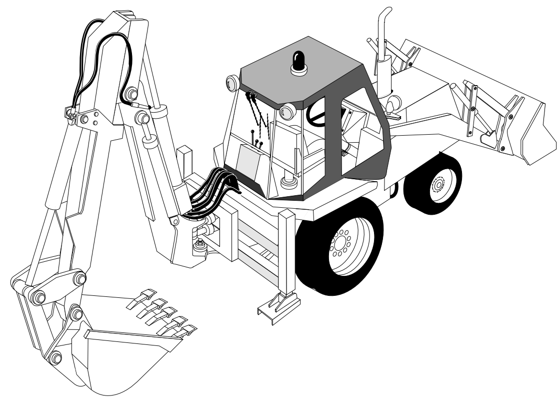


12 **Surcharge** - The weight contributed to the walls of a trench by the load adjacent to the trench. Typically this load is composed of the spoil bank and construction equipment.
13 **Spoil bank** - The bank of materials removed from a trench or excavation.

Rocks & Chunks

When the spoils contain larger chunks or boulders that may roll back into the trench, the spoils should be placed at a greater distance from the trench. In addition, extra protection, such as a berm, may be required to prevent the material from rolling and falling into the trench.

Surcharge - Equipment



Besides the weight of the spoils, the trench wall could be overloaded by equipment that is used alongside of the trench. In some cases it is necessary to move equipment along the trench edge. The equipment should be kept back of the point that would represent the center of the spoils bank, at least two feet from the trench, or the trench wall should be protected in some manner. When it is necessary to work in a trench where equipment is operating adjacent to the trench, the protection system must be designed for this additional load.

Surcharge-Vibration

Equipment & Traffic

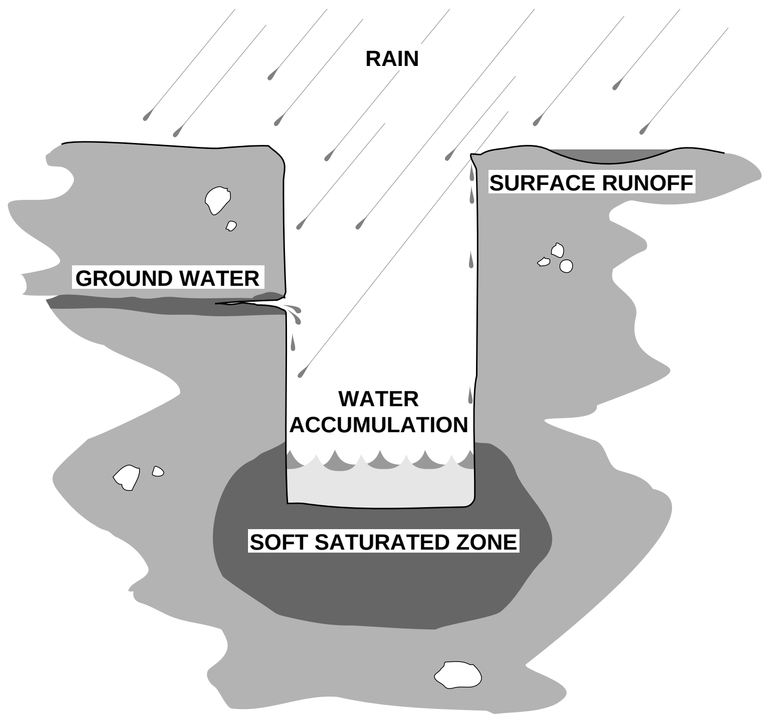
As important as the surcharge from the weight of the equipment are the vibrations caused by the presence of the equipment. Vibration caused by any equipment such as the backhoe, loader, boom truck, or tamping equipment can cause the soil to loosen and result in a cave-in. The equipment could be in, or alongside the trench and have the same impact. Large pieces of equipment or high volume traffic some distance from the trench can have the same impact on bank stability due to vibration.

Environmental Factors

Weather Conditions

Rain

There is a critical balance that exists between too much and too little moisture. There are various ways that this balance can be disturbed. For instance, lets say you open a trench in the morning and the walls are stable. A rain storm during the day could increase the soil moisture beyond the critical stage and cause the walls to collapse.



Time

When a trench is opened the walls are exposed to the air. Moisture in the soil will evaporate into the atmosphere. This causes the soil to dry and could cause the trench walls to crumble.

How Frost Weakens the Trench

Frozen ground may thaw and weaken and crumble. On the other hand an unfrozen open trench may be frozen and the expansion of the soil from the freezing could cause the walls to cave-in. Another factor to consider is the depth of the frost penetration. Should you dig below the frost line the soil may be mud and thus unstable causing the soil above it to cave-in.

Indicators of Failure

Observations

The Competent Person must frequently observe the trench floor, walls, and the area adjacent to the trench for early signs of conditions that can lead to a cave-in. Some of the more common conditions are:

- Tension cracks parallel to the trench wall
- Changes in moisture conditions of the trench wall or floor
- Spalling of the trench walls
- Crumbling of the trench walls
- Bulging of the walls near the trench floor

Conclusion

The strength of the soil, environmental and gravitational forces on the soil compete against each other and affect soil stability. The Competent Person must know about each set of factors contributing to soil instability and observe the effects produced by changes in the work site environment. They must be able to predict probable hazards and be knowledgeable in ways to increase the strength of the protective system to accommodate surcharge loads and changing conditions.

Causes of Cave-ins Worksheet

1. What are the three major items that impact soil stability?

   a. ______________________________

   b. ______________________________

   c. ______________________________

2. The ability of a soil to bind together is called?

3. Soil strength is measured in tons per square foot, the term which describes this is called?

4. What is the name given to soil that has a tendency to break along a definite plane?

5. At what size does soil become gravel?

6. Which is stronger, (a) disturbed soil or (b) undisturbed soil?

7. Name one positive and one negative impact moisture can have on a soil condition?

8. A Competent Person must be able to identify and classify soil into four OSHA classifications. These classifications are:

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

9. What do each of the following signs of distress indicate

   a. Spalling ______________________________

   b. Tension cracks ______________________________

   c. Slumping at the base of the trench wall ______________

   d. Bulging trench walls ________________________