TOKYO INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

ATCE-II
ADVANCED TOPICS IN CIVIL ENGINEERING

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Temporary Structures

Excavations and Excavation Supports

ATCE-II

ADVANCED TOPICS IN CIVIL ENGINEERING

Lesson 5: Excavations and Excavation Supports

(Earth-Retaining Structures)

Overview

The seventh lesson provides an overview on excavation supports and earth-retaining structures. Excavation support systems are temporary earth retaining structures that allow the sides of excavation to be cut vertical or near vertical. They are used to minimize the excavation area, to keep the sides of deep excavations stable, and to ensure that movements will not cause damage to neighboring structures or to utilities in the surrounding ground.

Lesson Objectives

By the end of this lesson you will be able to:

- describe stability of slopes for excavations and methods of preventing the movement of excavation walls;
- recognize shallow trenches and deep cuts;
- describe soldier beam and lagging;
- describe soil nailing systems;
- recognize excavation bracing systems.

Reading Assignment

Class notes.

Optional Reading- Ratay, Chapter 8 “Earth-Retaining Structures.”

Introduction

In many construction jobs deep excavations must be made before the structure can be built. Excavation support systems are temporary earth retaining structures that allow the sides of excavation to be cut vertical or near vertical. This is done to maximize the size of an excavation; when the price of real estate is high or space is limited by property lines, utilities or existing structures. When excavations have the potential to endanger lives or adjacent properties, bracing to support the soil must be designed. The Occupational Safety and Health Act (OSHA) requires that all trenches exceeding 5 feet in depth be shored. In large construction areas, excavation walls may be sloped, instead of providing structural support.

Slope failure mechanisms can be classified in three categories: rotational slump in homogeneous clay, translational slice in cohesionless sand or gravel, and slip along plane of weakness. Driving forces are the component of soil weight downslope (forces causing instability), and resisting forces are the soil strength acting in the opposite direction (resisting forces). Slope failure occurs when driving forces exceed the resisting forces (Figure 1a).

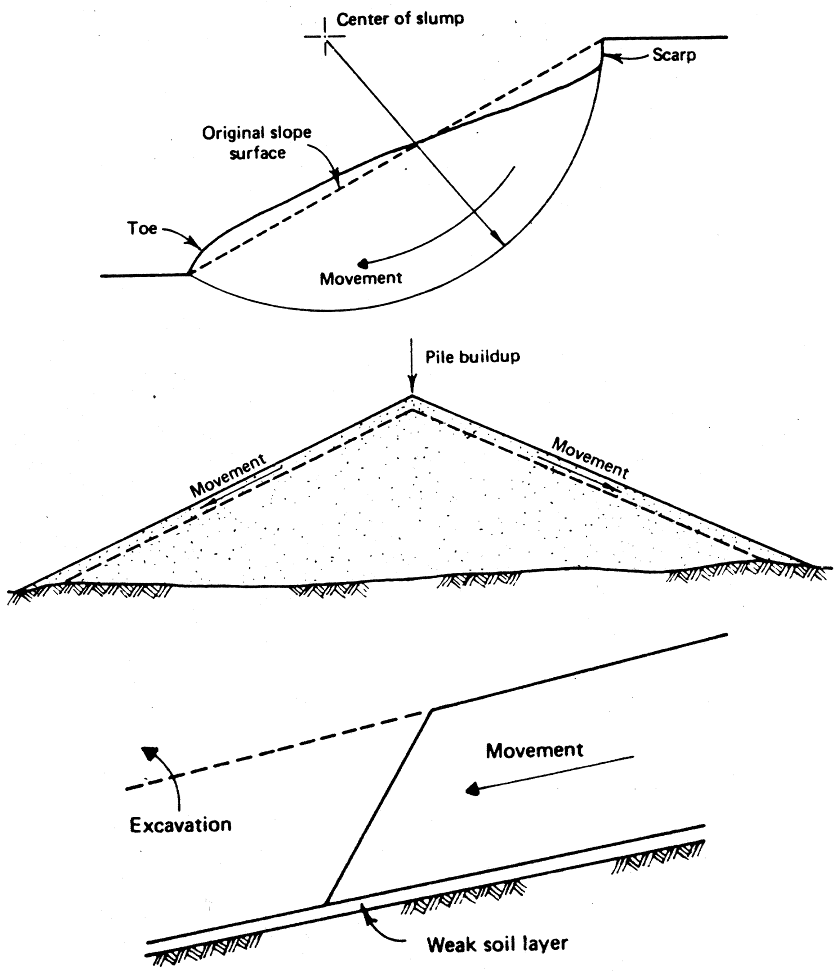


Figure 1a – Slope mechanisms. From top to bottom: rotational slump in homogeneous clay, translational slide in cohesionless sand or gravel, and slip along plane of weakness.

Factor of safety (FS) is defined as the ratio of resisting forces (or moments) to the driving forces (or moments). If FS ≤ 1, the slope will fail, if FS > 1, the slope is theoretically stable. The usual FS required is between 1.3 and 1.5.

The information required to estimate the factor of safety for a slope are: the soil and water profile, the kinematics of potential slope failure, the strength and weight of soils, and the proposed slope geometry. The stability number, which depends on soil cohesion and friction and the slope angle from the horizon is defined as:

$$N_S = \frac{\gamma H_C}{c}$$

Where γ is the unit weight of soil, H_c is the critical height, and c is the cohesion. Critical height is the maximum depth up to which the excavation can be carried out without causing a failure.

Example: A cut slope is to be made in a soft clay with its sides rising an angle of 75° to the horizontal. The resulting stability number is 4.55. Given soil cohesion, c = 650 psf and soil unit weight, γ = 110 pcf, determine the maximum depth up to which the excavation can be carried out.

$$N_S = \frac{\gamma H_C}{c} \Rightarrow H_c = \frac{cN_s}{\gamma} = \frac{650 \times 4.55}{110} = 26.9 \text{ ft}$$

If the cut described above is made to only 10 feet, what is the factor of safety of the slope against sliding?

$$\text{FS} = \frac{H_C}{H} = \frac{26.9 \text{ ft}}{10 \text{ ft}} = 2.7$$

Table 1 shows the theoretically safe depths for vertical cuts in different soil consistencies, which indicates that the slope failures are probable in shallow excavations only for very soft to medium homogeneous clays. By flattening the slope angle from 90° to 45°, significant improvement in the factor of safety for a slope of a given height can be achieved.

Table - 1: Theoretical Safe Heights for Homogeneous Clay Cut Slope with Vertical Sides

Soil Consistency	*Unconfined Compressive Strength, q_u (psf)*	*Cohesion, c (psf)*	*Safe Height, H (ft)*
Very soft	< 500	< 250	< 5
Soft	500 – 1000	250 – 500	5 –10
Medium	1000 – 2000	500 – 1000	10 – 20
Stiff	2000 – 4000	1000 – 2000	20 – 40
Very stiff	4000 – 8000	2000 – 4000	40 – 80
Hard	> 8000	> 4000	> 80

Temporary slope protection should be provided to prevent sloughing of soil materials into the excavation, such as coating or other impervious material applied to the slope. Direct rainfall on such slopes causes rapid erosion. To prevent slope erosion in rainstorms, spray-on product are used on silty soil materials to bind the soil particles on the surface. Plastic covering can be used to prevent changes in moisture content on the surface of the slope to maintain stability, as shown in Figure 1b. Chain link fence can be draped over a slope surface, when the slope contains significant amount of loose large rocks.

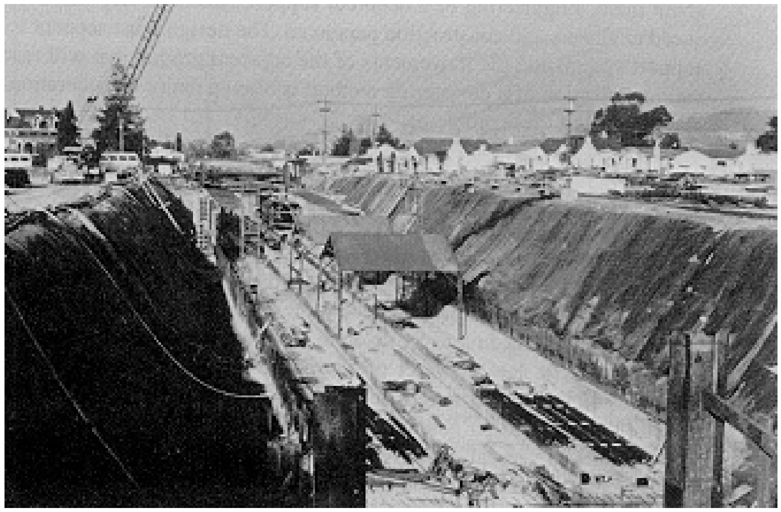


Figure 1b - Use of plastic sheets for slope protection in a shallow excavation

Shallow Trenches

The primary function of any trench support method is to protect people from caving ground. The secondary function is to provide support to nearby structures and allow equipment access to the work. For deep trenches the most feasible and cost effective support method should be devised by weighing different alternatives for trench method of excavation, pipe laying, backfill, schedule and obstructions. In any given project several trench support methods may be used to accommodate different conditions. There is no "one-size-fits-all" solution to the process of selecting and designing a trenching support method. The first steps are to read the plans, specifications and geotechnical reports to understand the constraints and conditions that will be encountered.

Where the soil will not remain open without caving, a form of trench support can be utilized. Temporary support methods such as trench boxes or hydraulic shoring have been utilized. Trench boxes are generally used in open areas, it is a structure that supports the sides of an excavation and is designed to prevent cave-ins (Figure 2). Trench boxes are different from shoring because, instead of shoring up or otherwise supporting the trench face, they are intended primarily to protect workers from cave-ins and similar incidents. The excavated area between the outside of the trench box and the face of the trench should be as small as possible. The space between the trench boxes and the excavation side are backfilled to prevent lateral movement of the box.

Figure 2 – A typical trench box

The permeability of the geologic material must be low enough to avoid the necessity of dewatering for these methods to be successful. For most shallow trenches bracing system should be used. For the utility trench excavations, cross-trench bracing is used, but it somewhat restricts the work area. Figure 3 shows three types of bracing systems for shallow cuts.

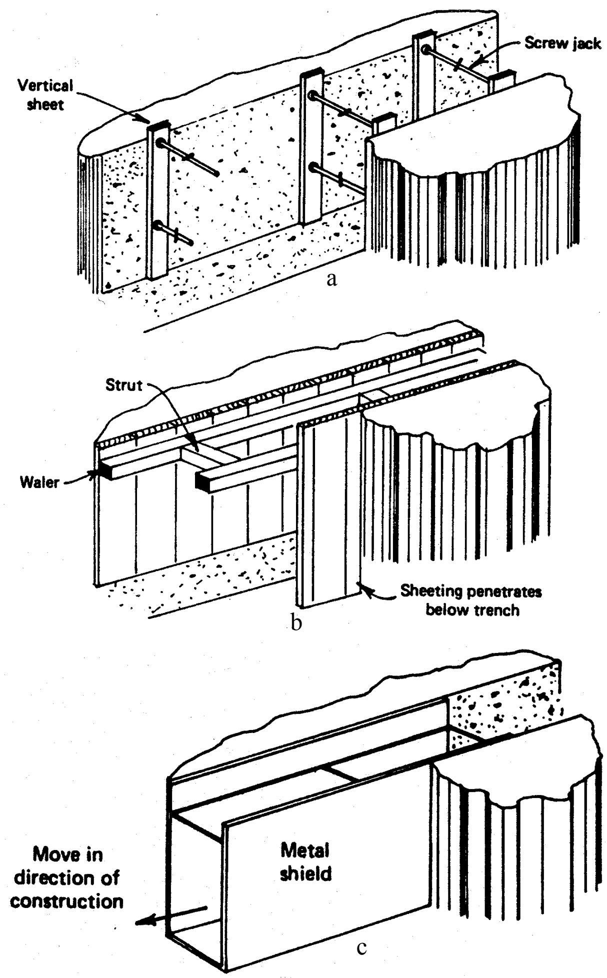


Figure 3 - Bracing for shallow trenches. From top to bottom: a) intermittent sheeting and bracing, b) continuous sheeting and bracing, and c) trench shielding

Prefabricated trench boxes are used to maintain trench integrity during excavation and backfilling operations. These can be quickly setup and placed in a section of trench. The trench box is slid along the trench with excavation occurring just ahead of the trench box and backfilling occurring in the back half of the trench box. Hydraulic shores can also be used to provide additional stability to the trench until it is backfilled. The temporary shores are placed in the excavation immediately after the trench is excavated to provide a temporarily supported trench between the excavation and backfilling operations.

Deep Cuts

Excavation depths exceeding 10 to 20 feet, require specialized planning for support. Lateral earth pressure is proportional to the vertical pressure. As a cut is made, the soil at the face tend to expand and move into the cut area. If a support is placed against the excavation surface to prevent the soil movement, then the pre-excavation stress is maintained.

Excavation Support Methods

Excavation support systems are used to minimize the excavation area, to keep the sides of deep excavations stable, and to ensure that movements will not cause damage to neighboring structures or to utilities in the surrounding ground. In this lesson we will discuss soldier beam and lagging and soil nailing systems.

Soldier beam and lagging

Soldier piles or soldier beams are H-piling set in predrilled holes around the periphery of an excavation. Predrilling as opposed to driving is used to provide close control of alignment and location. These piles are then grouted in place with weak concrete. Lagging is the timber placed horizontally between the soldier piles to retain the soil behind the excavated area.

Pairs of soldier beams are driven to a depth slightly below the final excavation. Their spacing is in the order of 6 to 10 feet so that available timber can be used for lagging. The lagging timber, which is slightly shorter than the spacing but on the order of 2 to 4 inches thick, are installed behind the front flange to retain the soil as excavation proceeds. Some hand excavation is usually required to get the lagging into the place. Figure 4 illustrates the method graphically.

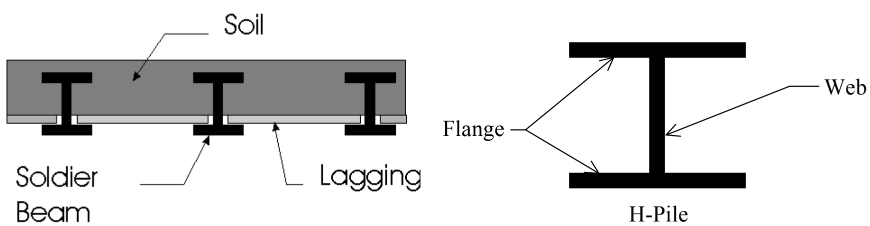


Figure 4 - Graphical illustration of soldier beams and lagging

Soldier piles are installed with conventional pile-driving equipment or in augured holes. The horizontal sheeting or lagging is installed behind the flange closest to the excavation (inside flange). The sheeting can be installed on the inside face of the front flange and held in place by various methods such as clips, welded studs, or bars, etc. Figure 5 shows two photos of excavation supports using soldier beam and lagging. The soldier pile and lagging method is inappropriate for perfectly cohesionless soil. For cohesionless soils sheeting must be used.

Figure 5 - Two examples of soldier beams and lagging method used for retaining walls

Figure 6 is a photo of excavation support system for the Getty Center art museum garage in Los Angeles, California. The excavation is about 75 feet deep. The sides of the excavation are supported by soldier piles and lagging. The soldier piles were driven before excavation began, and the wood lagging were installed as the excavation proceeded down. On the sides of the excavation the soldier pile and lagging wall is supported by post-tensioned anchors drilled and grouted into the soil around the excavation. The corners were supported by corner braces.

Figure 6 - The excavation is of a 75-feet deep garage

Soil Nailing

Soil Nailing is an in situ reinforcing of the soil while it is excavated from the top down. An array of soil nails which are passive inclusions are installed in a grid that functions to create a stable mass of soil. This mass of reinforced soil functions to retain the less stable material behind it. In the right soil conditions, soil nailing is a rapid and economical means of constructing excavation support systems and retaining walls.

In many applications soil nailing can be the least disruptive way to construct a retaining wall. Soil nailing requires an unusual amount of hand work, craftsmanship and geotechnical knowledge to construct.

The typical construction sequence begins with the excavation of a shallow cut. Then shotcrete is applied to the face of the cut and soil nails are drilled and grouted. This sequence is then repeated until subgrade is reached.

Soil Nailing Examples

Figure 7 - North West Animal Facility, University of California at Berkeley

Construction of an underground laboratory at the UC Berkeley, required temporary shoring on all four sides of the excavation. The tolerances for the shoring was specified to be no more than plus or minus one inch. The excavation depth varied from 15 to 37 feet, and was constructed in colluvial soils, consisting of stiff sandy clays and dense clayey sands with gravel and some cobbles. Approximately 14,000 square feet of area was soil nailed (Figure 7).

Figure 8 - Chemistry Building, Washington State University, Pullman, Washington

The 40-ft deep excavation at this site was made in stiff to hard, slightly clayey silt, with standard penetration resistances ranging from 15 to 45. The silt had a cohesion of 200 psf and a friction angle of 28 degrees. At one corner of the site, a two story brick auditorium was located ten feet behind the soil nailed wall. The movement was less than 0.3 inches at the face of the wall, less than 0.2 inches at 18 feet behind the wall, and less than 0.1 inches at 36 feet behind the wall. Eight rows of soil nails were designed to support the excavation (Figure 8).

Figure 9 - The Beckman Center, University of California San Diego

Construction of the New Chemical Science Building at the Scripps Research Institute required an excavation of up to 57 feet deep. The job consisted of 75% soil nailing and shotcrete and 25% of soldier beam and tieback shoring - a total of 24,080 sq ft. The soldier beams and tiebacks were utilized where soil nails would have interfered with existing buildings and new or existing utilities. The deepest section was shored with 10 lifts of permanent soil nails. A permanent shotcrete facing was installed in front of the shoring system which was completed in ten weeks (Figure 9).

Excavation Bracing

For narrow excavations, internal struts are most appropriate. Before struts are installed, a horizontal member called waler is placed against the soil support. Intermediate struts are then installed from waler to waler across the excavation. Figure 10 shows an schematic sketch of the system.

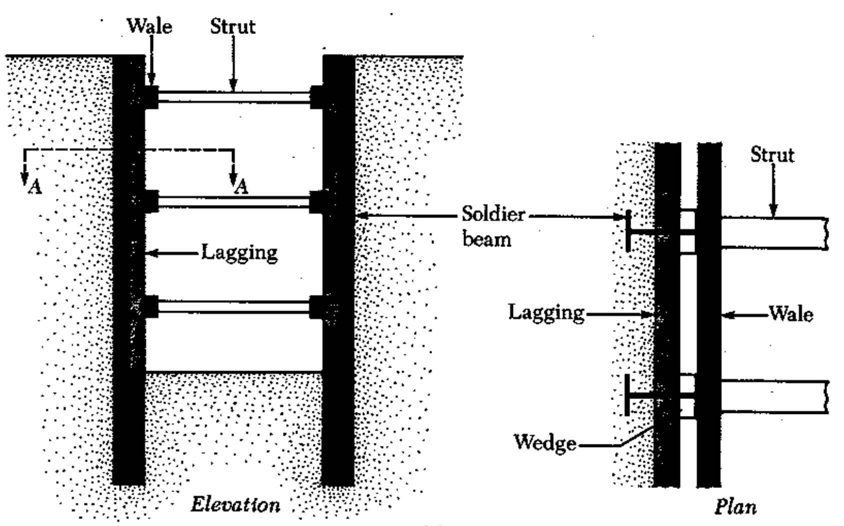
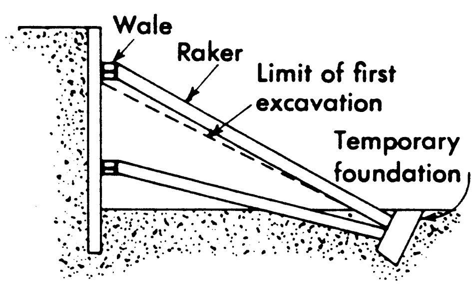


Figure 10 - Schematic diagram of narrow excavation bracing

Figure 11 shows the sheet pile wall around a building excavation is supported by pipe struts. Those in the foreground, which extend from one side of the excavation to the other, are termed "cross-lot" braces. In the corner of the excavation the sheet piles are supported by corner braces. Corner braces reduce the constriction in part of the working area.

Figure 11 - Internal struts

For very wide excavations, raker bracing is used. The support for the rakers (driven piles or footings- Figure 12) are installed at the bottom of the excavation.



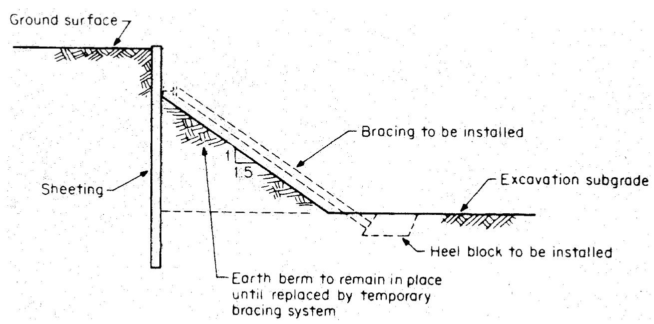


Figure 12 - Support for Rakers

Construction of the soil support and removal of the remainder of the excavation then begins. Compared to cross-lot bracing, in raker bracing system the central portion of the work area is relatively uncluttered.

In Figure 13, the wall is supported by "rakers," or inclined struts. The bottom ends of the rakers are braced against the central part of the building foundation slab. The excavation was carried to full depth at the center first so that the foundation slab could be placed. Prior to installation of the rakers, the lower part of the slurry trench concrete wall was supported by an earth berm. The earth berm remains at the far side of the excavation.

Figure 13 - Raker bracing for wide excavations

Tieback Systems

Anchors or tiebacks eliminate obstructions in the excavation inherent in rakers or struts. Tieback systems are generally very successful in preventing movements of the excavation walls. Usually, the excavation wall is left in place after the permanent construction inside the braced excavation is complete. Its is often used as the back form for the permanent basement of the structure (Figure 14). Tiebacks, if left in place, are always cut to relieve tension when the permanent structure can safely carry the load.

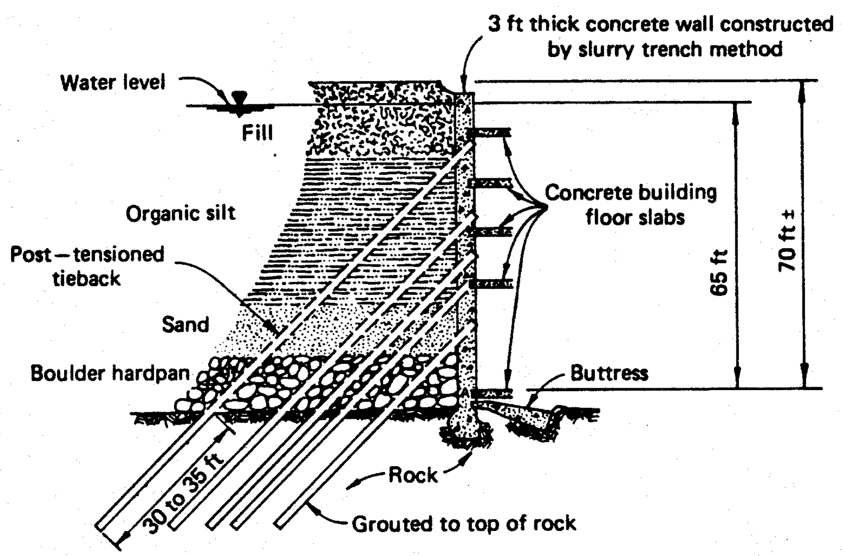


Figure 14 - Tied-back concrete wall constructed underground for excavation support

Tiebacks (or anchors) are structural system which acts in tension and receives its support in earth or rock. The system consists of: the earth or rock, which provides the ultimate support for the system, a tension member (or tendon) which transfers the load from the soil-retention system to the earth or rock. A stressing unit which engages the tendon, permits the tendon to be stressed, and allows the load to be maintained in the tendon.

Figure 15 - Tieback being installed

Earth anchors are usually installed at an angle of 10 to 20° down from horizontal. If the acceptable soil is not encountered at these levels, it is necessary to change the angle to engage the proper soil stratum (Figure 16).

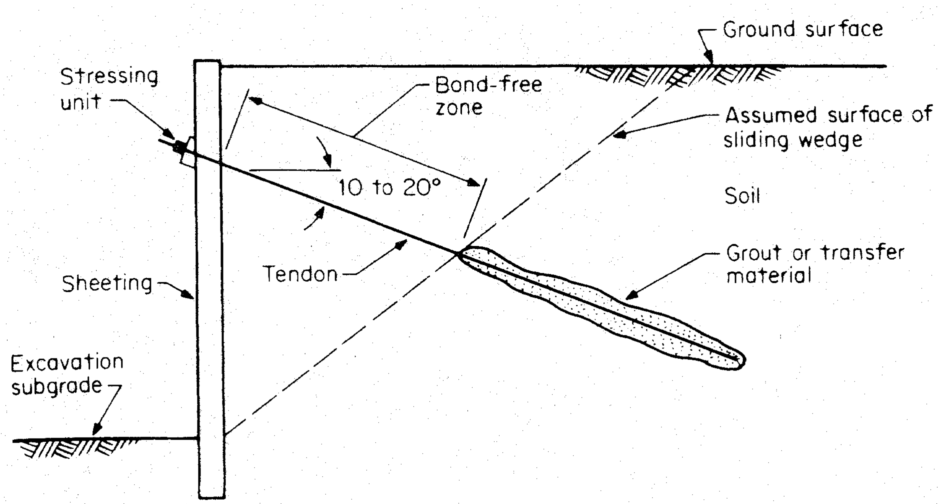


Figure 16 - Tieback installed at 10 to 20° down from horizontal

Excavation support systems most frequently use tiebacks or soil nails to resist the lateral earth pressures. In many soil conditions tiedback sheeting systems (tiebacks, soldier piles and wood lagging) are the most economical systems for temporary support of excavations. A typical construction sequence begins with the installation of soldier piles; then the site is excavated to a depth of five to seven feet. Wood lagging is installed to maintain the soil between the soldier beams and the tiebacks are installed to support the lateral earth pressures. This sequence is repeated until subgrade is reached. This top-down sequence provides continuous support of the cut and minimizes the disturbance behind the wall.

Tieback Examples

Figure 17 - Two Renaissance Square, Phoenix, Arizona

This is a 63-foot deep tiedback excavation. The subsurface material through which this major excavation was installed consisted of 25 feet of medium dense to dense sands and gravel, underlain by very dense sand, gravel and cobbles (SGC). The SGC contained a large percentage of cobbles up to 18 inches in diameter. The job consisted of 62,000 square feet of shoring and 500 tiebacks.

Figure 18 has been developed from the data gathered from a number of excavation projects. It is a tool to predict the ground movement in the surrounding areas as the result of an excavation for wide varying subsurface conditions. Using this figure one can determine the induced settlement adjacent to an excavation. It is an empirical and not a theoretical expression of actual expectations.

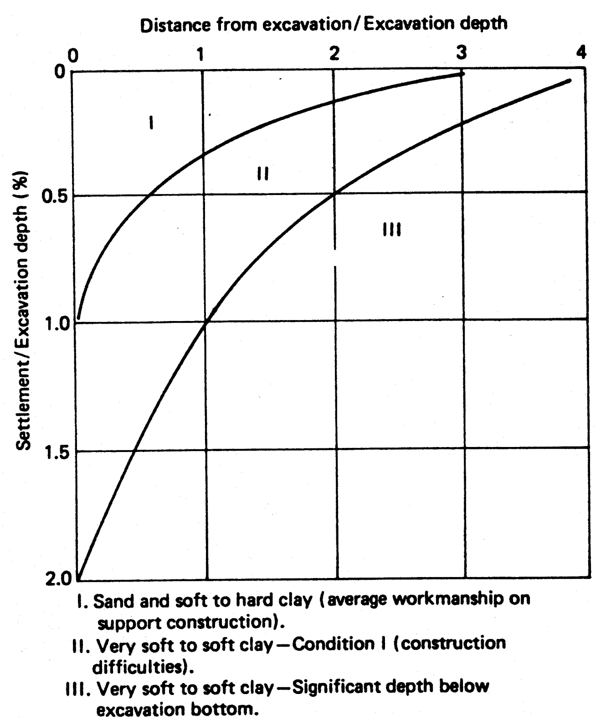


Figure 18 – Movement limits associated with braced excavation supports

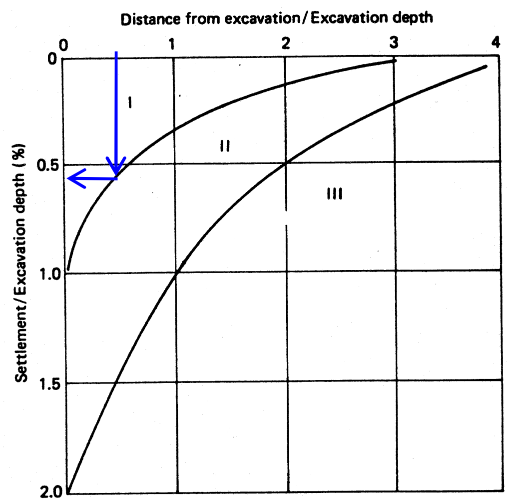
Example:

You want to estimate the settlement 15 ft from the bracing wall of a 30-ft-deep excavation in soft clay.

$$\frac{\text{Distance from excavation}}{\text{Excavation depth}} = \frac{15}{30} = 0.5$$

From Figure 18:

$$\Rightarrow \frac{\text{Settlement}}{\text{Excavation depth}} = 0.6\%$$



Therefore, expected settlement = 0.006×30 = 0.18 ft

GLOSSARY OF TERMS

Waler: Horizontal timber used to hold close sheeting in position.

Lagging: Lengths of sawn hardwood timber planks used to support the sides, walls or roof as necessary of shafts and drives and to prevent material from those faces falling into the excavation. The term is also sometimes used when referring to the layer of poling boards doing the same duty in trenches. The lagging is supported in turn by walkings, legs, caps, sets or frames, as applicable. (See also "lathes" below).

Lathes: Short lengths of hardwood timber usually split and about 1.25 to 1.5 metres long used to support the side walls (and roof in drives) and supported in turn by walings, legs or caps as applicable.

Strut: Hardwood timber (usually horizontal) in compression resisting thrust or pressure from the face or faces of an excavation.

Soldier: Vertical upright hardwood timber used for supporting a trench wall, taking the thrust from horizontal walers and supported by struts.

Summary

This lesson has discussed matters of considerable importance related to the stability of slopes for excavations and methods of preventing movements of excavation walls. The discussion given provides a look and some of the basics involved in these operations.