Excavation and Excavation Supports

In many construction jobs deep excavations must be made before the structure can be built.

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

- Rotational Slump in homogeneous clay
- Translational slice in cohesionless sand or gravel
- Slip along plane of weakness
Excavations and Excavation Supports

**Slope Stability**
- **Driving forces**: the component of soil weight downslope (forces causing instability).
- **Resisting forces**: the soil strength acting in the opposite direction (resisting forces).
- Mechanism of failure: When driving forces exceed the resisting forces.
- Factor of safety (FS): the ratio of resisting forces (or moments) to the driving forces (or moments).

- If $FS \leq 1$, the slope will fail
- If $FS > 1$, the slope is theoretically stable.
- The usual FS required is between 1.3 and 1.5

---

**Slope Stability (Cont’d)**
- To estimate the factor of safety for a slope, the following information is required:
  1. The soil and water profile
  2. The kinematics of potential slope failure
  3. The strength and weight of soils, and
  4. The proposed slope geometry.
- This estimate is for homogeneous materials.
- Stability number is defined as:

$$N_s = \frac{H_c}{c}$$

where: $\gamma$ = unit weight of soil,
$H_c$ = critical height, and $c$ = cohesion.

---

**Slope Stability - Example 1**
- For clay soil, the stability number of a slope cut at 65°, with $\phi = 0$ is 5, if the upslope angle $\alpha = 0$.
  $$\Rightarrow N_s = 5$$
- If $\gamma = 110$ pcf and $c = 650$ psf, and slope height = 20 ft
  
  $$H_c = \frac{c N_s}{\gamma} = \frac{650 \times 5}{110} = 29.5 \text{ ft}$$

  and
  $$FS = \frac{29.5}{20} = 1.48$$

- Alternatively, the critical cohesion for the slope
  
  $$\Rightarrow c_{80\alpha} = \frac{\gamma H_c \times 20}{5} = 440 \text{ psf}$$

  and
  $$FS = \frac{c_{80\alpha}}{\gamma \times \phi} = \frac{650}{440} = 1.48$$
Excavations and Excavation Supports

**Slope Stability - Example 2**

- A cut slope is to be made in a soft clay with its sides rising an angle of 75° to the horizontal. Given $c = 650$ psf and $\gamma = 110$ pcf.
- Determine the maximum depth up to which the excavation can be carried out.
- From the graph: $N_s = 4.55$

\[
H = \frac{cN_s}{\gamma} = \frac{650 \times 4.55}{110} = 26.9 \text{ ft}
\]

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

\[
N_s = \frac{c}{\gamma} = \frac{110}{650} = 0.17
\]

**Slope Stability (Cont’d)**

Theoretical Safe Heights for Homogeneous Clay Cut Slope with Vertical Sides

<table>
<thead>
<tr>
<th>Soil Consistency</th>
<th>Unconfined Compressive Strength (psi)</th>
<th>Cohesion, $c$ (psf)</th>
<th>Safe Height, $H$ (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very soft</td>
<td>&lt; 500</td>
<td>&lt; 250</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Soft</td>
<td>500 – 1000</td>
<td>250 – 500</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Stiff</td>
<td>2000 – 4000</td>
<td>2000 – 4000</td>
<td>20 – 40</td>
</tr>
<tr>
<td>Very stiff</td>
<td>4000 – 8000</td>
<td>&gt; 4000</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Hard</td>
<td>&gt; 8000</td>
<td>&gt; 4000</td>
<td>&gt; 80</td>
</tr>
</tbody>
</table>

- 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.

**Slope Protection**

- 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.
- To prevent slope erosion in rainstorms, spray-on products 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.
- Chain link fence can be draped over a slope surface, when the slope contains significant amount of loose large rocks.
Excavations and Excavation Supports

Shallow Trenches
- Cross-trench bracing are used in utility trench excavations.
- Intermittent sheeting and bracing
- Continuous sheeting and bracing
- Trench shielding

Temporary Structures

Cross-trench bracing are used in utility trench excavations.

Temporary Structures

Shallow Trenches

Deep Cuts
- Excavation depths exceeding 10 to 20 ft 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.

PowerBrace System
Temporary Structures

Excavations and Excavation Supports

Excavation Support Methods

Soldier beam and lagging

- 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 in. 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.

Soldier Beam and Lagging

- The soldier pile and lagging method is inappropriate for perfectly cohesionless soil.
- For cohesionless soils sheeting must be used.
Excavations and Excavation Supports

**Soldier Beam and Lagging**

Workers install lagging

The soldier beam and lagging retaining wall

**Soldier Beam and Lagging**

Soldier beam and lagging retaining wall

Closeup of soldier beam and lagging

**Soil Nailing**

- Soil Nailing is an insitu 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.
Soil Nailing

- 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

NorthWest Animal Facility, UC Berkeley, CAL.

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.

Chemistry Building, Washington State University, Pullman, WA

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 psi 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.
Soil Nailing Examples
The Beckman Center, UC San Diego, CALIF.

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.

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.

- Cross-lot struts are not feasible for very wide excavations.

Excavation Bracing (Cont'd)
- For very wide excavations, raker bracing is used.
- The support for the rakers (driven piles or footings) are installed at the bottom of the excavation.
Temporary Structures

Excavations and Excavation Supports

**Excavation Bracing** (Cont’d)
- 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.

**Tieback Systems**
- 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.
**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.*

- Anchors or tiebacks eliminate obstructions in the excavation inherent in rakers or struts.
- They consist of rods that extend well beyond any potential failure surface into firm undisturbed soil or rock.
- Some tiebacks are made with high tensile cables grouted into rock and prestressed against a wale, and others utilizing ordinary steel rod or reinforcing steel.

**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. It is often used as the back form for the permanent basement of the structure.*

*Tiebacks, if left in place, are always cut to relieve tension when the permanent structure can safely carry the load.*
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 phasing and 500 tiebacks.

Movement limits associated with braced excavation supports

- The opposite figure was developed from data gathered on a number of braced excavation projects.
- It can be used to estimate settlement induced adjacent to an excavation.
- Example: You want to estimate the settlement 15 ft from the bracing wall of a 30-ft-deep excavation in soft clay.

<table>
<thead>
<tr>
<th>Distance from excavation</th>
<th>Settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.06%</td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

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 walkings, 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.