United States Universities Council on Geotechnical Education and Research

Special Project Grant 2017-2018

Soil Magic 2.0: Creation of a library of in-class demonstration activities to create 'aha moments' in geotechnical engineering classrooms

Final Report

October 2018

by

Hoyoung Seo, Ph.D., P.E.
Assistant Professor
Department of Civil, Environmental, and Construction Engineering
Texas Tech University
Tel.: 806-834-5690 | Email: hoyoung.seo@ttu.edu

Project Start Date: 9/1/2017
Project End Date: 10/31/2018

Submitted to:
USUCGER Board of Directors
October 31, 2018

TABLE OF CONTENTS

ABSTRACT iii

1. INTRODUCTION 1

2. PROJECT SUMMARY 1

3. RESULTS 2

REFERENCES 3

APPENIDX A – LEARNING MODULE FOR EACH ACTIVITY 4

A-1: Slope Stability – A Sliding Cup 5

A-2: Playdough Revival 9

A-3: The Magic Wand 13

A-4: Can You '*Bear*' It? 17

A-5: A Sweet Tube 24

A-6: Reinforced Soil 27

A-7: Are You Active Or Passive? 33

A-8: Water Race 40

ABSTRACT

This report presents the results of Special Project Grant awarded through United States Universities Council on Geotechnical Education and Research (USUCGER). The project team developed eight classroom activities for live demonstrations and visual illustrations of geotechnical principles/concepts to create 'aha moments' for students. Each demonstration activity was recorded with a high-definition camera and compiled into a whiteboard-style animation video. The completed instructional videos, referred to as *Aha Moment Videos*, were uploaded onto *YouTube* for public access. Along with the *Aha Moment Videos*, a corresponding learning module was developed for each activity. The learning modules may be considered as lesson plans to be used by instructors intending to conduct the prepared demonstrations in a classroom setting.

1. INTRODUCTION

The Felder-Silverman learning style model classifies students as 1) sensing learners, 2) visual learners, 3) inductive learners, 4) active learners, and 5) sequential learners (Felder and Silverman 1988). Surveys have shown that most engineering students are active, sensing, and visual learners. However, as pointed out by Felder and Brent (2005), "most engineering instruction is overwhelmingly verbal, emphasizing written explanations and mathematical formulations of physical phenomena over demonstrations and visual illustrations." This project aims to develop a library of classroom activities for live demonstrations and visual illustrations of geotechnical principles/concepts to create 'aha moments' that can make something click within a student's mind and their new insight shifts the way they, as students, see engineering applications in the physical world. Special emphases are placed on developing activities demonstrating soil behavior at both particulate and continuum levels. Wonderful resources, such as Dr. Elton's two books, *Soils Magic* (Elton 2001) and *Grounded! Amazing Classroom Demonstrations in Soil Mechanics* (Elton 2015), are already available for various demonstration activities, and this project develops new demonstrations along with instructional materials.

2. PROJECT SUMMARY

The development of a library of in-class demonstration activities was performed at Texas Tech University by Dr. Hoyoung Seo (Principal Investigator), Liang Li (graduate student), and Ilysia Fealy, Andrés Richa, Emily Marie Sanford, and Collin Sprang (undergraduate students). The project began on September 1, 2017 and ended on October 31, 2018.

The project was divided into three sub-tasks: (1) video recording of demonstration activities, (2) development of whiteboard-style animations, and (3) development of learning modules. The video recordings of the demonstration activities were combined into whiteboard-style animations to create *Aha Moment Videos*. Complementary learning modules were created to provide step-by-step instructions on how to perform each activity presented in the *Aha Moment Videos* with further discussions.

2.1 Creation of Aha Moment Videos for Each Activity

In this project, we have developed eight demonstration activities. All activities are intended to be used for undergraduate course work, but some activities may be bridged into graduate courses as well. The PI performed each demonstration activity for the undergraduate student team before they video-recorded their independent recreation of each demonstration using a Sony NEX-5 digital camera. To add background and emphasize the engineering significance of each activity, VideoScribe software was purchased to create whiteboard-style animations. After developing the instructional animations using VideoScribe, each demonstration video and animation file were merged into a single video file to be uploaded to *YouTube*. Prior to their uploading, the PI performed a quality check on the students' draft videos, and multiple revisions/edits were made based on the PI's expert reviews.

2.2 Development of Learning Modules for Each Activity

Along with the *Aha Moment Videos*, learning modules for each activity have been developed in this project. The learning modules consist of 1) Activity Objective, 2) Introduction, 3) Materials Needed, 4) Set-Up Procedure, 5) Operation of Activity, 6) Aha Moment, 7) Video Link and 8) Further Discussion. Learning modules are intended to be used by the instructors conducting these demonstrations in a classroom and should be considered as a lesson plan for each activity.

3. RESULTS

As stated earlier, a total of eight demonstration activities were developed in this project. Table 1 summarizes each demonstration activity. Learning modules for each demonstration activity are presented in Appendix A. We anticipate that the geotechnical engineering community will find our videos and learning modules to be valuable resources for educational and outreach purposes.

Table 1. Summary of demonstration activity developed in this project

Activity name	**Category/Principle**	**YouTube link**
A-1. Slope stability – A sliding cup	Slope stability against a planar failure	https://youtu.be/kLRCf9uznLE
A-2. Playdough revival	Clay-water interactions	https://youtu.be/z_gW_LE9E1U
A-3. The Magic wand	Shaft resistance of deep foundations	https://youtu.be/j_O0ahZqNhA
A-4. Can you bear it?	Bearing pressure; Bearing capacity; Terzaghi's shallow foundation failure mechanism	https://youtu.be/v6XbIiBVk6k
A-5. A sweet tube	Sampling of granular materials	https://youtu.be/5szIx2AgKbo
A-6. Reinforced soil	Mechanically stabilized earth walls	https://youtu.be/fOEErsJIh4Y
A-7. Are you active or passive?	Lateral earth pressure; Mohr circle analysis	https://youtu.be/j_Dd04hgPUw
A-8. Water race	Hydraulic conductivity	https://youtu.be/bTkYxus6z6k

A playlist of all eight videos that plays in order can be found at the following link:

- https://www.youtube.com/playlist?list=PLtVDeC7E2e6K6ZSSblmcp5qPKgF3A7YKu

REFERENCES

Elton, D. J. (2001). *Soils Magic*. Geotechnical Special Publication 114, American Society of Civil Engineers

Elton, D. J. (2015). *Grounded! Amazing Classroom Demonstrations in Soil Mechanics*. American Society of Civil Engineers

Felder, R. M. and Silverman, L. K. (1988). "Learning and Teaching Styles in Engineering Education." Engineering Education, 78(7), pp. 674-681

Felder, R. M. and Brent, R. (2005). "Understanding Student Differences." Journal of Engineering Education, 94(1), pp. 57-72

APPENIDX A – LEARNING MODULE FOR EACH ACTIVITY

A-1: SLOPE STABILITY – A SLIDING CUP

Activity Objective

To demonstrate the behavior of cohesionless soil slope at a continuum level and give students an "aha moment" by surprising them through a counterintuitive demonstration activity.

Introduction

Analysis of slope stability against a planar failure is introduced at the junior level in an introductory geotechnical course and serves as a basis for the ordinary method of slices. For dry, cohesionless soils, stability against a planar failure only depends on the slope angle and the friction angle of the soil, regardless of the soil's weight. This activity illustrates this concept.

Materials Needed

- 3" binder (or larger)
- Small plastic cups
- Water

Setup Procedure

1. Place the 3" binder on the table.
2. Make sure the binder angle is steep enough for the cup to slide down. If the cup does not slide down, increase the binder angle by propping it up with a book.

Operation of the Activity

1. Present the following equation for the Factor of Safety (*FS*) for slope stability against planar failure:

$$FS = \frac{cL_s + (W_M \cos \alpha_s - uL_s) \tan \phi}{W_M \sin \alpha_s} \qquad \text{(Eq. 1)}$$

2. Explain each term in the equation:
   - c = Cohesion of soil
   - W_M = Weight of sliding body
   - α_s = Slope angle
   - ϕ = Friction angle
   - u = Porewater pressure
   - L_s = Length of slope in contact with the sliding body

   Relate each variable in the equation with the 3-ring binder and a cup filled with water (see Figure 1).

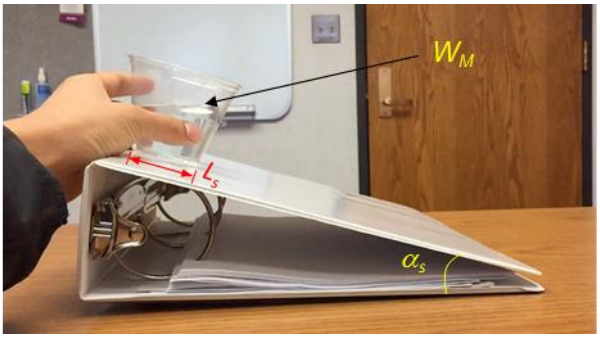
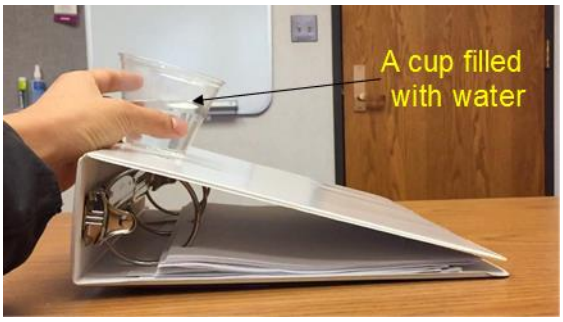


Figure 1. Cup and binder are presented as a "soil" with material properties of c and ϕ.

3. Emphasize that the numerator is a resisting force and the denominator is a driving force.
4. Put the cup filled halfway with water on top of the binder and let it go. The cup will slide down [shown in Demonstrations 1(a) and 1(b)].

   Ask students: "Which force is greater in this case: the driving force or the resisting force?"

   Answer: Driving force



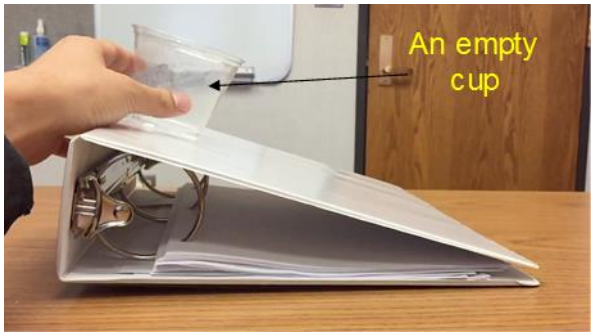
Demonstration 1(a)

Demonstration 1(b)

5. Pour the water out of the cup and hold the empty cup on top of the binder [shown in Demonstration 2(a)].

   Ask students: "Will the cup slide down now?"

   Answer: [Many students say it will not because the weight of the cup (or driving force) is now smaller. Allow students to suggest possible outcomes before demonstrating.]



Demonstration 2(a)

6. Direct students' attention on the *FS* equation (Eq. 1) and remind them that there is neither cohesion (c) nor porewater pressure (u) at the cup-binder interface (i.e., it is a dry, cohesionless soil). Give students time to discover how the equation changes if $c = 0$.

Ask students: "Will the cup slide down the surface?"
Answer: [Some students may change their answer after reevaluating the *FS* equation.]

7. Release the empty cup from your hold at the top of the binder to demonstrate that it will still slide down the surface. [Demonstration 2(b)].

Demonstration 2(b)

8. Revisit the equation and derive a simplified *FS* equation for cohesionless soil (c = 0):

$$FS = \frac{\cos \alpha_s \tan \phi}{\sin \alpha_s} = \frac{\tan \phi}{\tan \alpha_s} \qquad \text{(Eq. 2)}$$

9. Emphasize that the *FS* of dry, cohesionless soils only depends on the slope angle, α_s, and the friction angle, ϕ, of soil, and therefore the cup will keep sliding down as long as the slope angle remains greater than the friction angle, regardless of its weight, W_M.

Aha Moment

Many students initially think the empty cup would not slide down because the driving force is smaller than the cup filled with water. So, when the empty cup slides down, they get caught by surprise because it is somewhat counterintuitive. Further examination of the *FS* equation reveals that there is a weight component in the numerator, indicating that the resisting force would become smaller as well. In fact, for the case of dry, cohesionless soil, the weight component, W_M, in the *FS* equation cancels out and the factor of safety (*FS*) against planar failure depends only on α_s and ϕ, which remain constant throughout the activity. This demonstration stimulates students' abilities to link mathematical expressions to physical behavior.

Video Link: https://youtu.be/kLRCf9uznLE

Further Discussion

This demonstration explains the importance of the slope angle for maintaining stability. However, soil slopes that are safe during a dry season often fail after heavy rainfall, without any change in the slope angle. If the stability of cohesionless soils only depend on α_s and ϕ, how do we explain this? With the presence of porewater pressure (i.e., $u \neq 0$), the W_M component in the *FS* equation does not cancel out anymore with c = 0 (refer to Eq. 1). In fact, with the constant W_M, the numerator (resisting force) becomes smaller as u increases, leading to a decrease in the factor of safety, *FS*.

The effect of porewater pressure on slope stability (or shear strength) is beautifully demonstrated by Dr. John Burland from the Imperial College in London provided in the following link: **https://youtu.be/a-6YbkZJ5UY**

A-2: PLAYDOUGH REVIVAL

Activity Objective

To demonstrate clay-water interaction by reviving dried-out playdough.

Introduction

Due to its large specific surface area and interaction with water, a clay exhibits plasticity. However, a clay powder without water does not show such plasticity. This activity demonstrates the clay-water interaction by increasing the water content to revive dried-out playdough. Considering that the clay-water interaction theory is not covered in detail in typical undergraduate-level geotechnical engineering courses, this demonstration activity may be used to effectively and efficiently present the clay-water interaction theory.

Materials Needed

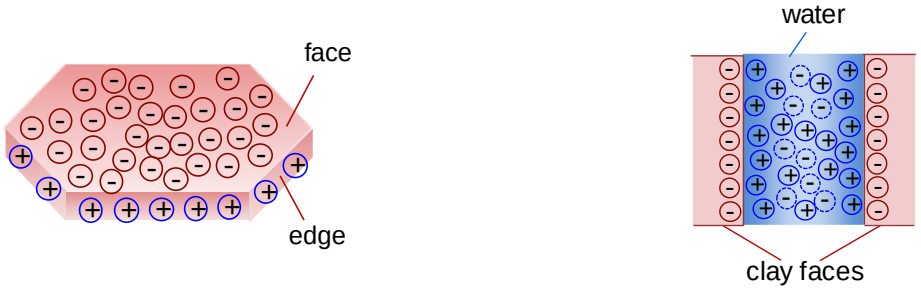
- Dried-out, hard playdough
- Moist playdough
- Air-tight container (plastic bag or the original playdough container)
- Napkin or paper towel
- Water

Setup Procedure

Prepare dried-out playdough by leaving a small chunk outside of the air-tight container to let it dry out (needs to be done well before class).

Operation of the Activity

1. Explain that a clay particle has a large specific surface area and is net-negatively charged (refer to Fig. 1(a)). Explain further that a dry clay powder is not plastic, but it will become plastic when water is added because the net-negatively-charged clay particles attract and hold positively-charged water particles just like the opposite poles of a magnet attract each other (refer to Fig. 1(b)).



(a) (b)

Figure 1. Schematic illustrations of (a) net-negatively-charged clay particle and (b) clay-water interaction.

2. Further explain that a thin water film forms between the faces of the clay particles, and with the "right" amount of water, the clay particles are pulled together by attractive forces and at the same time are held apart by the water films (again refer to Fig. 1(b)).
3. Show students a moldable chunk of moist playdough and tell them it has the right amount of water.
4. Now, show the dried-out playdough and explain to students that the sample has lost its moldability because there is not enough water.

   Ask students: "According to clay-water interaction theory, shouldn't the dried-out playdough become moldable again if we add water back in?"
5. Tell students that the Play-Doh® website indeed suggests adding more water to soften the dried-out playdough.
6. Open the webpage (https://playdoh.hasbro.com/en-us/faq) and read the two methods shown on the webpage to students (Fig. 2).

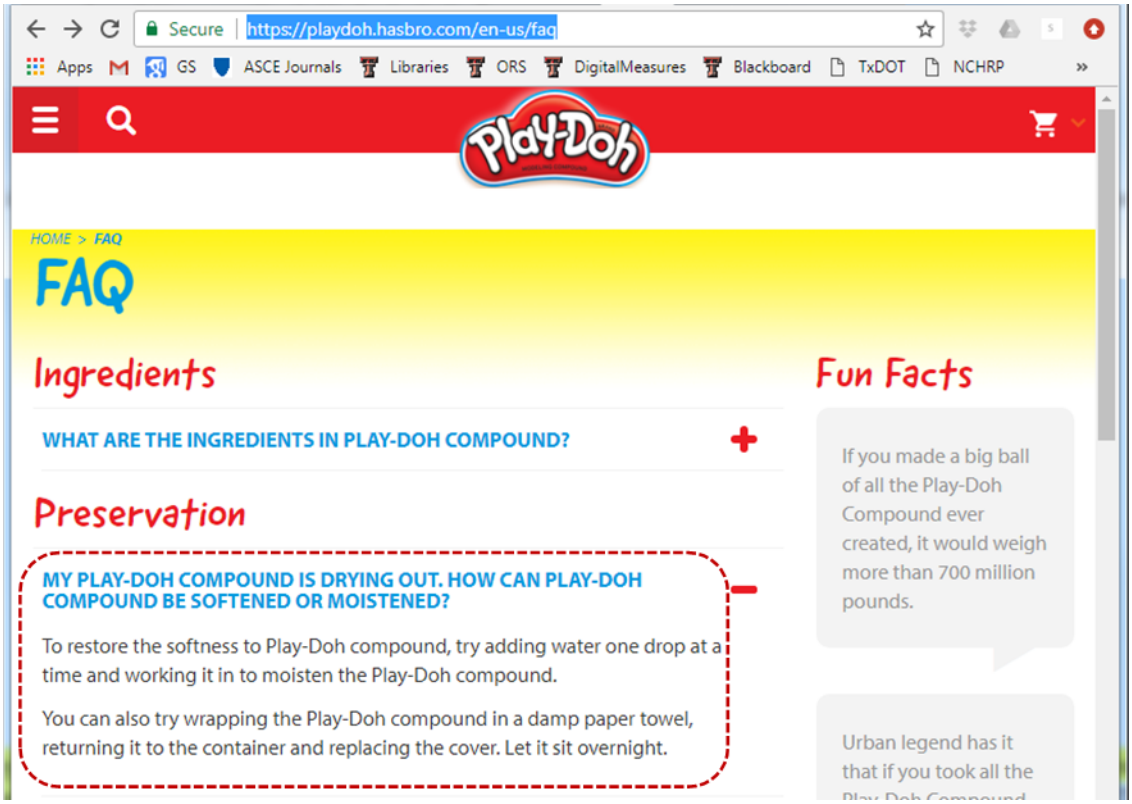


Figure 2. Screenshot of Play-Doh® webpage that shows how to revive dried-out playdough.

7. Tell students we will follow the second method: *"wrapping the Play-Doh compound in a damp paper towel, returning it to the container and replacing the cover. Let it sit overnight."*

8. Soak a paper towel in water [Demonstration 1(a)], and then squeeze the water out of the paper towel to make it damp rather than wet [Demonstration 1(b)] (a paper towel with too much water makes the playdough have a consistency similar to a liquid).

Demonstration 1(a)

Demonstration 1(b)

9. Wrap the dried-out playdough with the damp paper towel [Demonstration 1(c)], return the prepared sample to the air-tight container and seal it [Demonstration 1(d)].

Demonstration 1(c)

Demonstration 1(d)

10. Appoint one student and ask him/her to keep the container with the dried-out playdough in it until the next class period. Engage the student by telling him/her they must attend the next class and bring the container back without opening it.
11. In the following class, thank the student for showing up and ask the student to take out the playdough container and open it.
12. Take out the playdough and unwrap the paper tower [Demonstration 2(a)]. Tell students the paper towel dried because the playdough absorbed the moisture to rehydrate itself. Demonstrate the restored moldability of the playdough by molding it into different shapes using your fingers [Demonstration 2(b)].

Demonstration 2(a)

Demonstration 2(b)

Aha Moment

Many students anticipate that the dried-out playdough might recover its moldability if they follow instructions given in the webpage. However, not many students had actually tried it before and wonder about how well such methods would work. Through this demonstration, students relate the clay-water interaction theory with a real-life example by actually seeing the dried-out playdough fully recover its moldability, and such a visual observation helps student understand clay-water interactions in a more tangible way. If the moisture of the paper towel was too much, the playdough would show more liquid-like behavior than the fresh playdough, but it is still very effective to show the role of water in clay-water interactions. Furthermore, the student who carries the responsibility of keeping the playdough and bringing it back to the next class is fully engaged through this activity and gets a personalized experience about the subject which might stimulate the student's learning.

Video Link: https://youtu.be/z_gW_LE9E1U

Further Discussion

After the demonstration, students may ask why clays are moldable and sands are not. This question can be answered by explaining that clays are governed by a surface force while sands are governed by a body force due to their large differences in specific surface area (SSA). Due to clays' large net-negatively-charged surface areas and their interactions with water, the attracting force (i.e., surface force) overcomes the gravity (i.e., body force) and hence clays become plastic or "magnetic". However, because sand particles are too "heavy," they do not move even if they are slightly magnetic.

A-3: THE MAGIC WAND

Activity Objective

To demonstrate shaft resistance (or skin friction) of deep foundations.

Introduction

Deep foundations resist to loads applied at the head through two components: 1) friction between the shaft and the surrounding soil and 2) compressive resistance of the soil below the base. The frictional resistance is called shaft resistance (or skin friction) and the compressive resistance is known as the base resistance (or end bearing). The shaft resistance is "visualized" in this demonstration by lifting a certain weight using friction between soil and a wooden dowel.

Materials Needed

- A wooden dowel (about 15 mm in diameter and 600 mm in length)
- A flexible container with sands
- A cylindrical container (about 60 mm in diameter and 300mm in length)

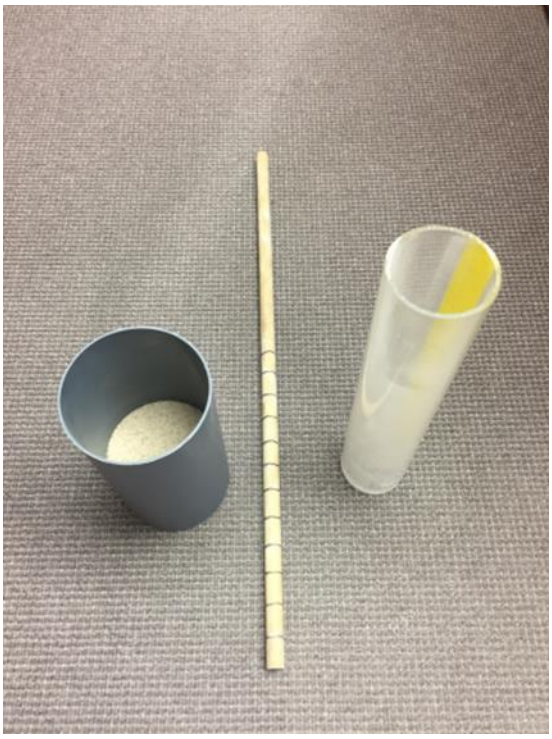


Figure 1. Materials required

Setup Procedure

No specific pre-setup is required.

Operation of the Activity

1. Explain to students that the wooden dowel represents a deep foundation and that the sand in the container represents the ground. [This experiment requires extra hands, so request a student volunteer to help with the demonstration.]
2. Ask the student volunteer to hold the wooden dowel upright in the center of the cylindrical container (Demonstration 1a).
3. Pour the sand slowly into the annulus area between the cylinder wall and the dowel until it reaches near the top of the container (Demonstration 1b).
4. When the sand reaches the top of the container, explain to students that the configuration represents a deep foundation embedded in the ground (Demonstration 1c).
5. Tell students that we will now pull the dowel out of the sand. Then pull the dowel up slowly.
6. The dowel will not be pulled out of the sands, and the cylindrical container will be lifted up instead (Demonstration 1d). Some students will be caught by surprise. [*Note that if sands are poured too quickly, the deposited sand becomes much looser than the slowly deposited sand and, therefore, the wooden dowel may be pulled out of the sand rather than lifting up the container*.]

   Ask students: "What is holding the container or what force is resisting the gravity?"

   Answer: Friction or shaft resistance.

   Ask students: "What is the magnitude of the shaft resistance?"

   Answer: The shaft resistance is equal to the weights of the container filled with sand and the dowel.

   Reply to such responses saying that it is the shaft resistance *mobilized under the current experimental setting* but not the maximum value because it may take more load. Explain further that the maximum value is called *limit shaft resistance*.

Demonstration 1(a)

Demonstration 1(b)

Demonstration 1(c)

Demonstration 1(d)

Aha Moment

When the concept of shaft and base resistances of deep foundations are introduced to undergraduate students, they often think that the shaft resistance would be very small compared to base resistance. So, when the instructor lifts up the container using the stick, many students are caught by surprise because the frictional resistance is greater than they expected. Through the demonstration, students can relate the shaft resistance with the friction concept and clearly

understand that the shaft resistance is a major component for load-carrying capacity of deep foundations. Furthermore, by emphasizing that the wooden dowel (deep foundation) could have taken more load, students can distinguish the difference between mobilized shaft resistance and limit shaft resistance.

Video Link: https://youtu.be/j_O0ahZqNhA

Further Discussion

This demonstration does not simulate installation methods of displacement piles such as driven piles. If the instructor wishes to simulate the installation process of displacement piles as well as the shaft resistance, the wooden dowel can be forced into the soil and then be lifted up. The following videos show such demonstrations:

- https://youtu.be/R7g6wdmYB78?t=28 (NSF: Granular Materials)
- https://youtu.be/Jy6vbMlePPo (*Grounded!* Chapter 2: Rice Is Nice)

A-4: CAN YOU '*BEAR*' IT?

Activity Objective

To illustrate the concepts of bearing pressure and bearing capacity and to visualize the bearing capacity failure mechanism.

Introduction

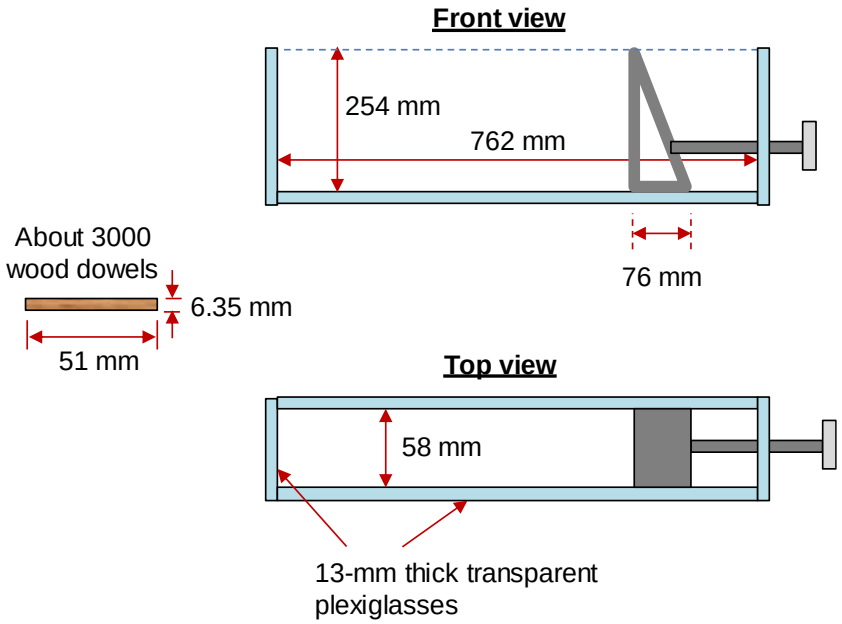
Terzaghi's bearing capacity equation is first introduced in a junior- (or senior-) level geotechnical engineering course, and the bearing capacity is defined as a maximum bearing pressure that the soil beneath the foundation can take. This activity demonstrates the concept of bearing pressure using textbooks (dead weights) and a wooden bookend (strip foundation). Furthermore, a slow-motion video of how the foundation collapses during this activity provides a wonderful visual aid to help further explain the failure mechanism of shallow foundations.

Materials Needed

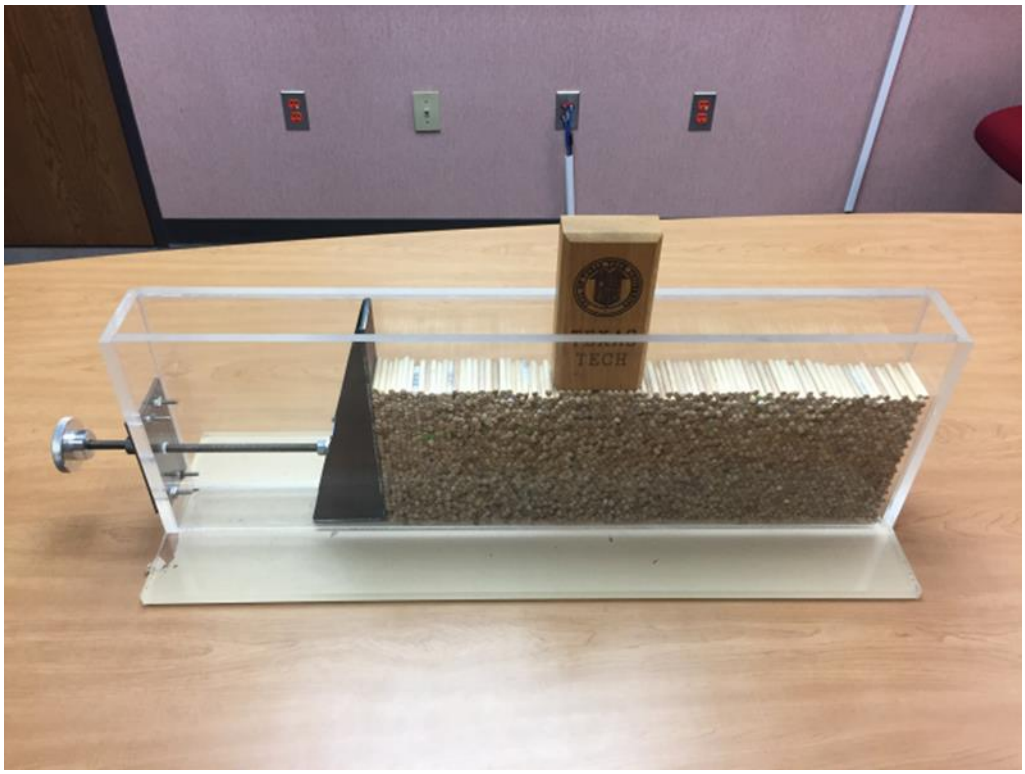
- A wooden bookend (31 mm x 86 mm x 165 mm)
- 6.35-mm-diameter wood dowels (need to be cut into about 3000 small pieces)
- 13-mm-thick Plexiglas plates
- Several thick hardback textbooks

Setup Procedure

Using the schematic drawing shown in Fig. 1(a), build a test set-up. A bird's-eye view of completed test set up is shown in Fig. 1(b).



(a)



(b)

Figure 1. (a) Schematic drawing and (b) bird's-eye view of completed test set-up.

Operation of the Activity

1. Define the ultimate bearing capacity q_{ult} as the bearing pressure required to produce a bearing capacity failure.
2. Present the following equation for ultimate bearing capacity of a strip footing:

$$q_{ult} = c'N_c + \sigma'_{zD}N_q + 0.5\gamma'BN_\gamma \qquad \text{(Eq. 1)}$$

3. Explain each term in the equation:
   - c' = effective cohesion of soil
   - γ' = effective unit weight of soil
   - σ'_{zD} = vertical effective stress at a depth of footing base
   - B = footing width
   - N_c, N_q, and N_γ = bearing capacity factors as functions of friction angle
4. Explain to the students that for this experiment the wooden dowels represent soil particles and the wooden bookend represents a strip footing.
5. Show the shorter dimension of the bookend to students and place it onto the leveled surface of wooden dowels.
6. Add one textbook to the bookend; nothing happens (Demonstration 1a).

   Tell students that the weight of the book is transmitted to the base of the bookend and, therefore, bearing pressure has increased. However, the bearing capacity is greater than the current bearing pressure because the footing did not collapse.

Demonstration 1(a)

7. Add another textbook. Collapse happens (Demonstration 1b).
   Point out to the students that the bearing pressure has now exceeded the bearing capacity, thus causing a failure [*note that depending on the initial state of the wooden dowels and the weights of textbooks, three books may be required to cause a collapse*]. Remove the textbooks and level the surface of wooden dowels before restarting the experiment.

Demonstration 1(b)

8. Tell students that we will redo this activity by using the longer dimension of the bookend. Show the longer dimension of the bookend and place it on the surface of the wooden dowels.
9. Add the first textbook; the footing does not collapse (Demonstration 2a).

Demonstration 2(a)

10. Add the second textbook; the footing does not collapse (Demonstration 2b).
    Ask students: "Why does the footing not collapse using this side of the bookend even though we have applied the same amount of load?"
    Answer: The bearing pressure is smaller now because the footing dimension is larger.

Demonstration 2(a)

11. Revisit the Terzaghi's bearing capacity equation.
    Ask students: "What else might have contributed to prevent the collapse from happening?"
    Answer: Terzaghi's equation suggests bearing capacity increases as footing width *B* increases (refer to the third term in Terzaghi's bearing capacity equation).

12. Further explain to students that wider footings mobilize deeper failure mechanism and soils have higher frictional resistances at deeper depths due to higher confining stresses.

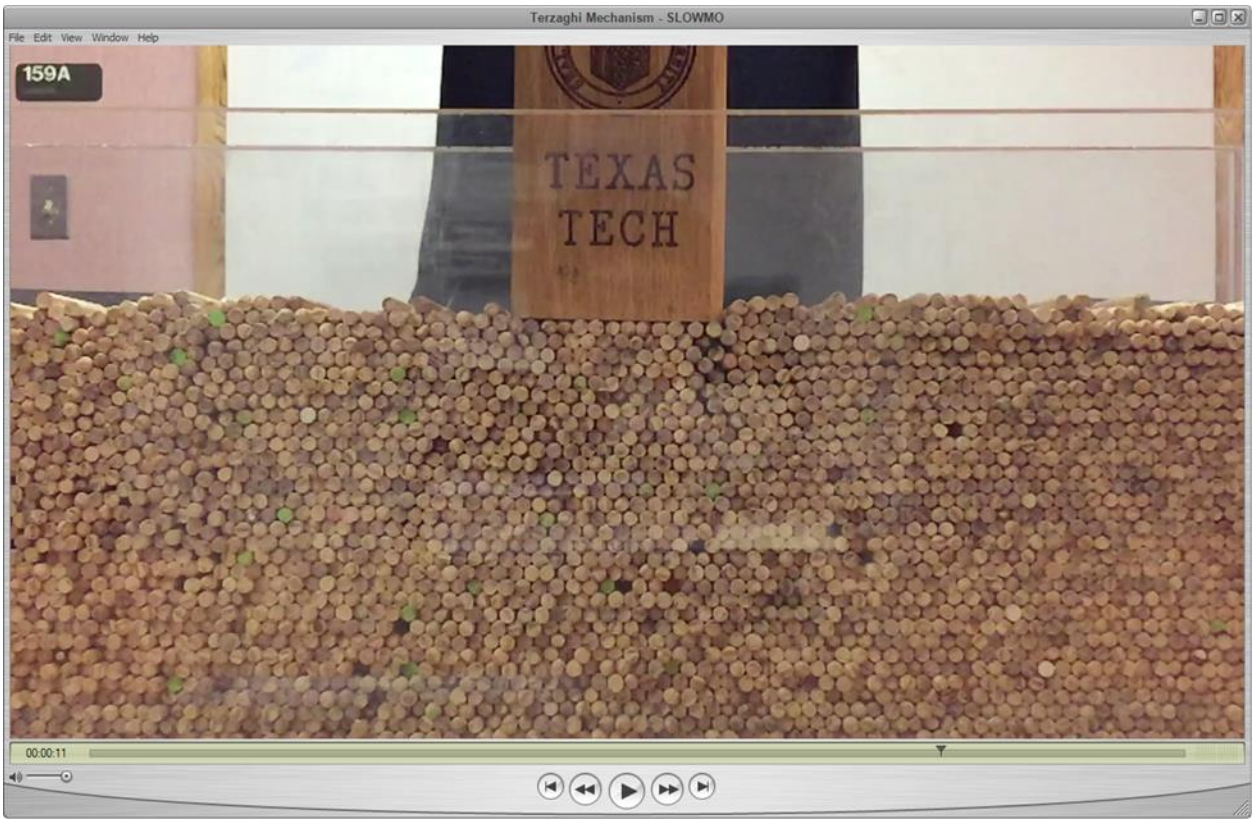
Aha Moment

This activity illustrates that, for a given load (represented by hardback textbooks), less pressure is transferred to the soil when using a larger foundation. Serving as a visual explanation, this activity conceptualizes the essence of foundation design. Having likely been covered prior to this experiment, this activity also reinforces the principle of the effect of confining stress on the shear strength of granular soils for students because the increased bearing capacity from the wider footing (hence deeper failure mechanism) is related to such principle.

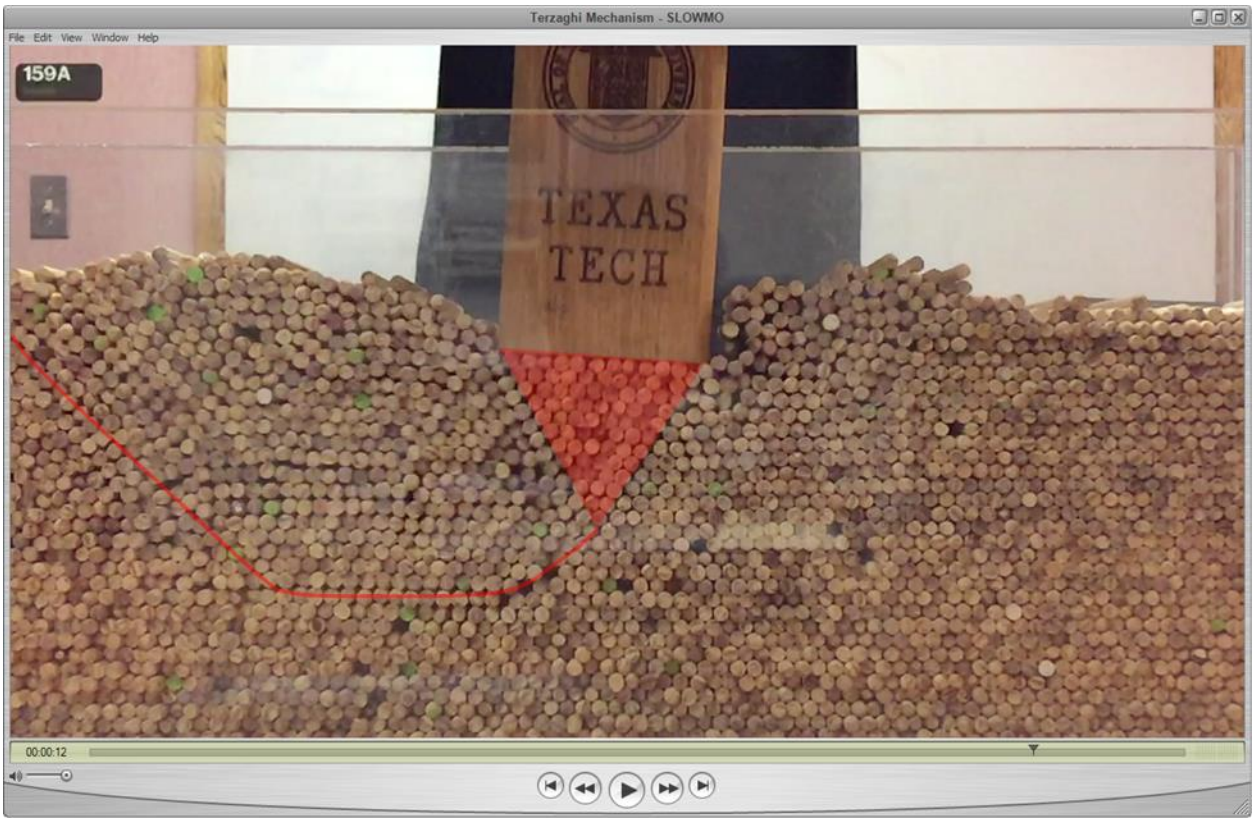
Video Link: https://youtu.be/v6XbIiBVk6k

Further Discussion

While this activity is conducted, the footing collapse can be recorded using the slow-motion camera feature of modern mobile phones which provides an excellent visualization of the failure mechanism per Terzaghi’s theory. Screen captures from the slow-motion video, which can be seen in the Aha Moment Video A-4 on *YouTube*, are provided below.



A-4: Can You ‘Bear’ It?



A-4: Can You ‘Bear’ It?

A-5: A SWEET TUBE

Activity Objective

To demonstrate the sampling process of granular soils.

Introduction

When students learn how disturbed granular samples are obtained using split-spoon samplers, some students wonder how the sand particles can remain inside the hollow tube when the sampler is pulled up. Although a core catcher is commonly used to retain the sample inside the split-spoon sampler, the interlocking of sand particles under high confining stress plays a big role as well. This activity demonstrates the interlocking behavior and sampling process of granular soils using a plastic straw and sugar.

Materials Needed

- Sugar
- A flexible container (cut-out water bottle)
- A standard plastic drinking straw

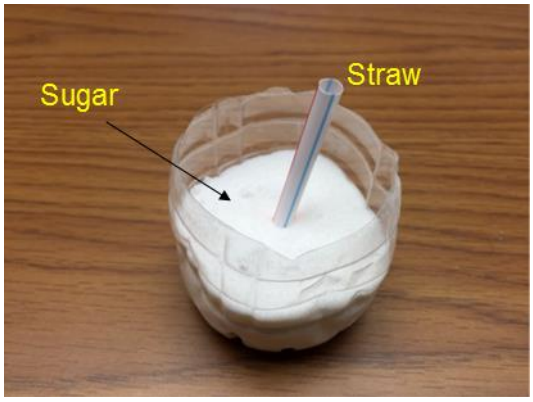


Figure 1. Needed materials

Setup Procedure

No specific pre-setup is required.

Operation of the Activity

1. Explain to students that the plastic straw represents a split-spoon sampler and sugar in the container represents granular soils.
   Tell students that split-spoon samplers are driven into the ground using a drop hammer but we will push the straw into the sugar.
2. Put the container in the palm and push the straw into the sugar (Demonstration 1a).
3. Take out the straw and tap it gently onto the palm. No sugar is collected (Demonstration 1b). At this point, students are somewhat disappointed and think it is not going to work.
   Tell students that, in reality, in-situ soils at deeper depths are subjected to much higher stress levels.

4. To simulate such high stress levels, squeeze the container very tightly and then push the straw into the sugar (Demonstration 1c).
5. Take out the straw and tap it gently onto your palm. A certain amount of sugar is now collected (Demonstration 1d).
6. Explain to students that when the sugar particles are forced to enter inside the straw under high stress levels, the individual grains can interlock, just like the teeth of two gears, and provide higher frictional resistance against gravity.

Demonstration 1(a)

Demonstration 1(b)

Demonstration 1(c)

Demonstration 1(d)

Aha Moment

Taking a sugar grain sample using just a straw seems impossible at first glance, especially when the instructor fails to do so in the first try. Students become a bit skeptical, but also more curious about how the instructor might overcome the challenges. When the instructor successfully takes the sugar grain sample by squeezing the container, the students easily relate the squeezing action with the high stress levels of in-situ soil, providing a better understanding of the soil sampling process using split-spoon samplers.

Video Link: https://youtu.be/5szIx2AgKbo

Further Discussion

In reality, split-spoon samplers are driven into the ground using a drop hammer whereas the straw was pushed into the sugar in this activity. Also, the diameter of a split-spoon sampler is much greater than that of a plastic straw's. Therefore, recovery of the granular soil sample using a split-spoon sampler is more difficult, especially for fine sand below the groundwater table. In practice, a core catcher is commonly placed inside the split-spoon sampler as shown in Fig. 2.

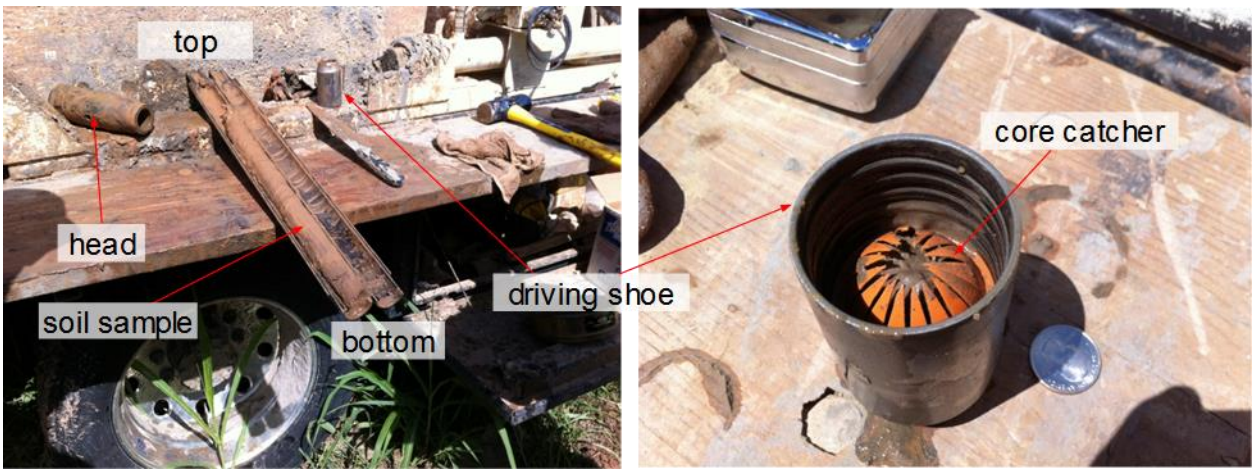


Figure 2. Split-spoon sampler and core catcher.

A-6: REINFORCED SOIL

Activity Objective

To illustrate the concept of reinforced soil and to demonstrate the principle of mechanically stabilized earth (MSE) walls.

Introduction

Most retaining walls we see on the highway are artificially reinforced with metal strips, grids, wire mesh, geogrids, geotextiles, etc. This activity demonstrates the concept of reinforced soil and the principle of MSE wall using easily accessible laboratory materials.

Materials Needed for Demonstration 1

- Three (3) Coffee Filters
- A Variety of Dead Weights
- Two (2) Gallons of Sand
- A Large Sheet Pan

Figure 1. Materials needed for Demonstration 1

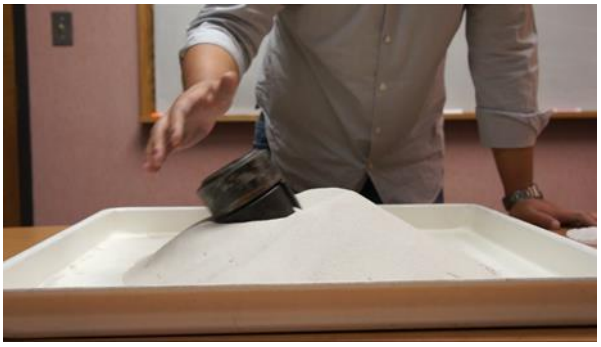
Setup Procedure for Demonstration 1

1. Fold two of the three coffee filters in half twice until they are triangular wedges and then cut 1-inch or 2-inches off the edge so that the three coffee filters will have different diameters (as shown in Fig. 1).
2. Pour the sand into a mound in the middle of the sheet pan (see Fig. 1).

Operation of the Demonstration 1

1. Place one weight (2.3 kg) on the top of the sand mound (Demonstration 1a).
2. Place a second weight (1.8 kg) atop the first weight; the sand pile collapses (Demonstration 1b).
3. Remove the weights and reform the sand mound to include the coffee filters (Demonstration 1c). It is best to form the mound in stages and place three coffee filters (in decreasing diameter) between each layer (Demonstration 1d).
4. Once the sand mound has been reshaped, place the weights atop the mound in the same order as during the first trial (2.3 kg and then 1.8 kg). The sand pile does not collapse (Demonstration 1e).
5. Place additional weights atop the sand mound; it still does not collapse (Demonstration 1f). Explain to the students that when the sand mound does not have coffee filters in it, the sand easily collapses under the applied load. However, when the sand mound is reinforced with the coffee filters, the sand does not spread laterally because the coffee filters offer frictional resistance.

Demonstration 1(a)

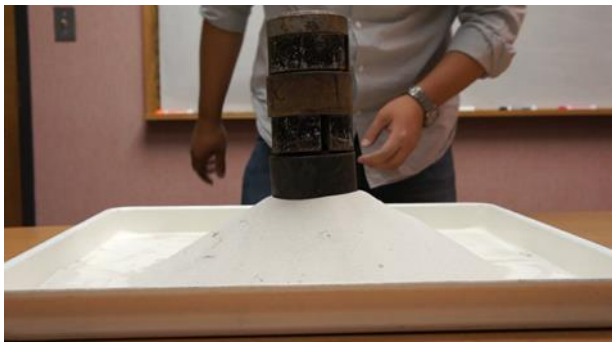


Demonstration 1(b)

Demonstration 1(c)

Demonstration 1(d)

Demonstration 1(e)



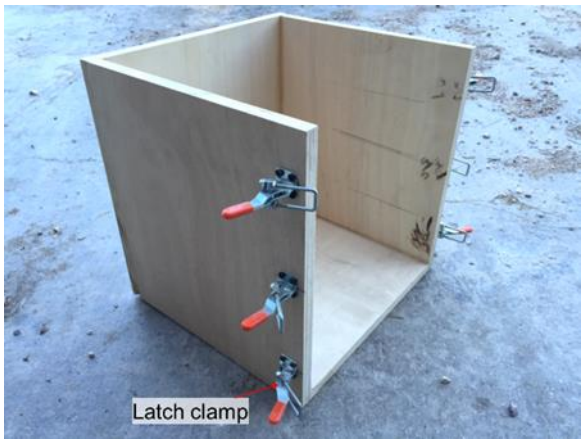
Demonstration 1(f)

Materials Needed for Demonstration 2

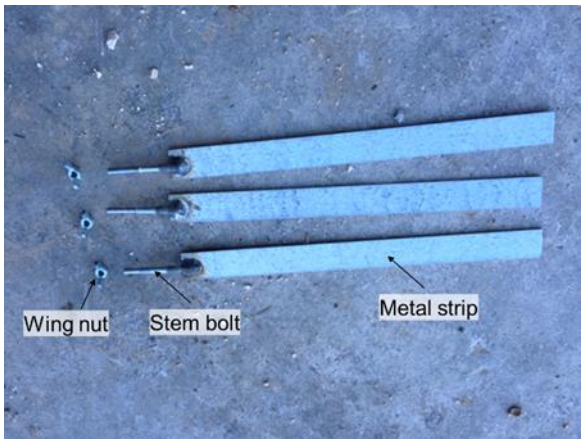
- Metal Strips (9)
- Wing Nuts (9)
- Stem Bolts (9)
- Wood Boards (5)
- Latches (6)
- Gravels {enough to fill the wooden box}

Setup Procedure for Demonstration 2

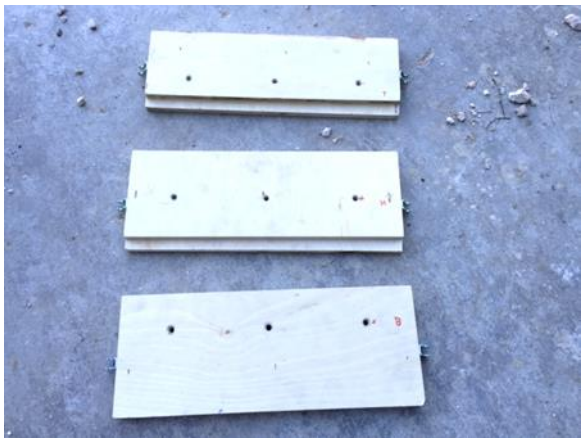
1. Build a soil box using wood boards with front side open (Fig. 2a).
2. Place latch clamps on two of the outside walls of the soil box like Fig. 2a.
3. Weld one stem bolt onto each metal strip. Prepare nine in total (Fig. 2b).
4. Build three front panels and drill three holes for the stem bolts to fit through (Fig. 2c).
5. Place latch holders on shorter sides of each front panel, just like in Fig. 2d.



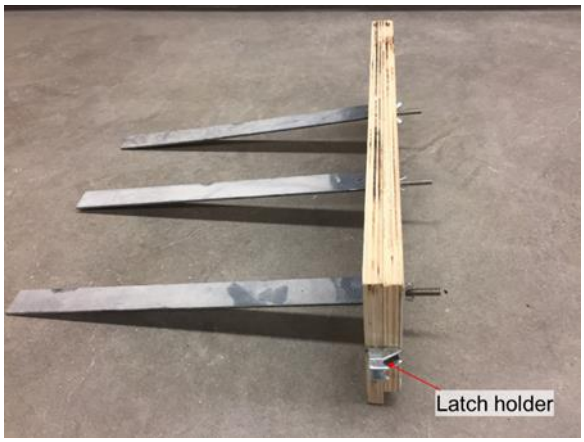
(a)



(b)



(c)



(d)

Figure 2. Materials needed for Demonstration 2

Operation of the Demonstration 2

1. Present the pre-recorded images showing the model retaining wall collapsing without any metal strips to support to the soil (Demonstrations 2a and 2b).
2. Engage the students by declaring that the collapse can be prevented by reinforcing the soil and then begin building the model on the floor. Show the metal strips and wingnuts to the class since they do not need to be pre-assembled
3. Put the bottom panel on the empty side of the soil box and close the latches to attach the two parts. Do not insert the metal strips until the gravel has been poured level to the three drilled holes (Demonstration 2c).
4. Insert three of the metal strips into the box so that they are flat along the surface of the gravel with the stem bolts on the outside. Once all strips have been inserted, screw on the wingnuts (Demonstration 2d) and latch in the middle panel (Demonstration 2e) before continuing to add gravel. Stop pouring when the gravel reaches the same elevation as the middle panel's three holes (Demonstration 2f).
5. Insert three metal stripes just as before (Demonstration 2g) and then latch in the top panel before continuing to pour more gravel into the box.
6. Finish building the wall by adding the final three metal strips into the top panel and leveling the gravel with the surface of the box frame (Demonstration 2h). Note that all latches are closed at this time.
7. Ask students to play a drum roll before opening all six latches. The model MSE wall does not collapse (Demonstration 2i).

   Ask students: "What is holding the front panels?"

   Answer: The frictional resistance between the metal strips and gravel is holding the three front panels in place.
8. Select a student to come forward and set onto the gravel surface with the latches unhooked. The weight of the student is inconsequential to the demonstration as the panels will most likely remain in place.
9. The model MSE wall will remain intact even with additional weight applied to the surface (Demonstration 2j).

Ask students: "We applied the additional vertical stress – a student's weight, and that induced additional horizontal stress being applied to the front panels. How is it that the box did not collapse?"
Answer: When there is an increase in normal stress, the frictional resistance also increases.

Demonstration 2(a)

Demonstration 2(b)

Demonstration 2(c)

Demonstration 2(d)

Demonstration 2(e)

Demonstration 2(f)

Demonstration 2(g)

Demonstration 2(h)

Demonstration 2(i)

Demonstration 2(j)

Aha Moment

The sand pile being able to withhold a much greater weight by merely adding a few coffee filters into the sand pile catches students by surprise in Demonstration 1. Based on this simple activity, the concept of the reinforced soil is expanded in Demonstration 2 by building a model MSE wall. When a student is asked to step on the gravel surface, they are unsure whether the front walls will support the additional load. After seeing the successful application of an MSE wall in Demonstration 2, students have a better understanding of the role of confining stress on frictional resistance and the working principle of a mechanically stabilized earth wall.

Video Link: https://youtu.be/fOEErsJIh4Y

Further Discussion

Metal strips are one particular type of reinforcements. Instructors can further introduce other types of reinforcements such as geotextiles, geogrid, steel grids or meshes, etc. Although the primary purpose of Demonstration 2 is to illustrate the principle of the MSE wall, Demonstration 2 can also be used to illustrate the internal and external stabilities further.

A-7: ARE YOU ACTIVE OR PASSIVE?

Activity Objective

To illustrate the concept of active and passive earth pressures and to analyze the observed failure surfaces using the pole method.

Introduction

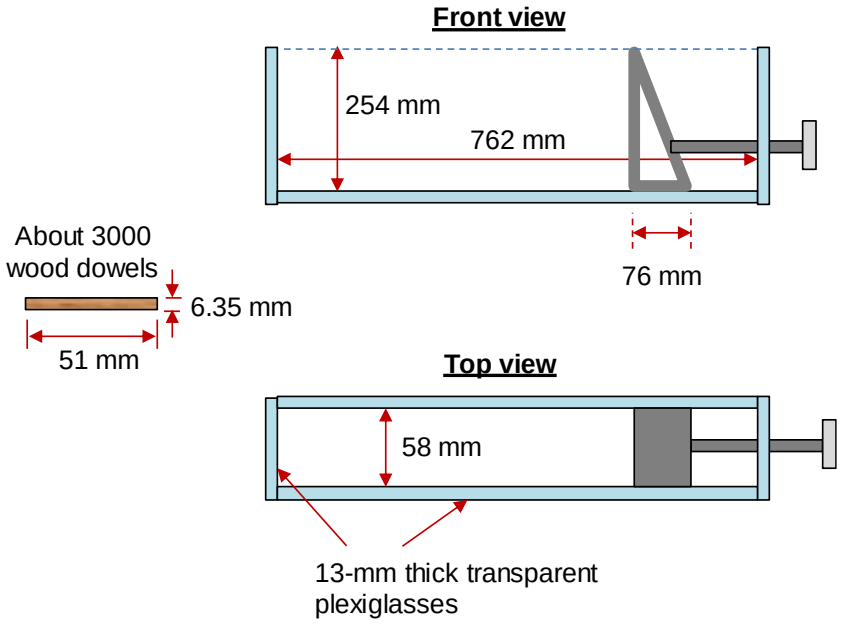
Coefficients of active (K_a) and passive (K_p) earth pressures per Rankine's theory are introduced in undergraduate geotechnical engineering classes. This activity demonstrates the two lateral earth pressure conditions using a model retaining wall and help visualize failure surface at such conditions. The failure surfaces observed in the physical demonstrations are explained using Mohr circle and the pole method.

Materials Needed

- A wooden bookend (31 mm x 86 mm x 165 mm)
- 6.35-mm-diameter wood dowels (need to be cut into about 3000 small pieces)
- 13-mm-thick Plexiglas plates
- Metal plates
- Stem bolt
- Knob

Setup Procedure

Using the schematic drawing shown in Fig. 1(a), build a test set up. A bird's-eye view of completed test set up is shown in Fig. 1(b).



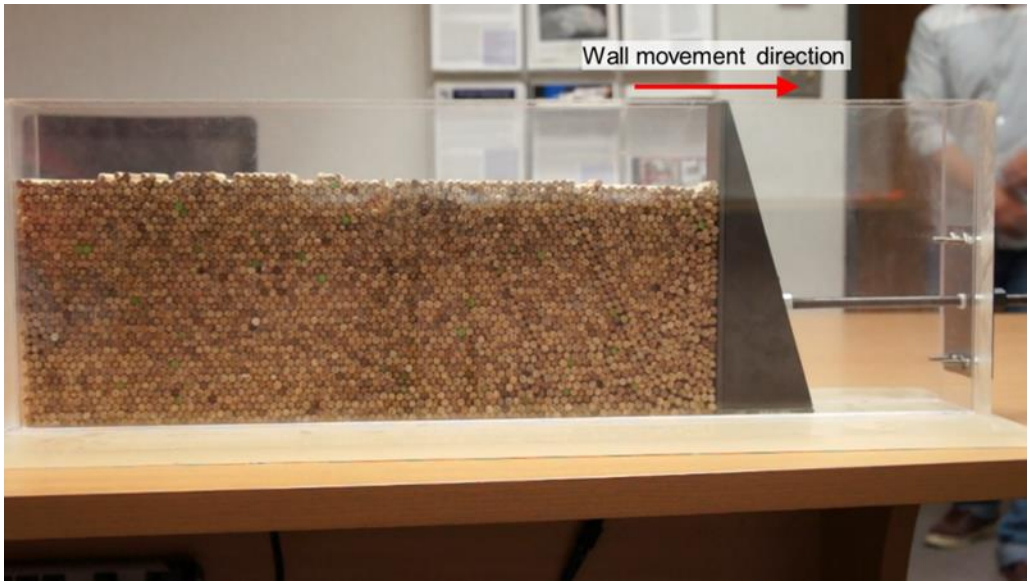
(a)

(b)

Figure 1. (a) Schematic drawing and (b) bird's-eye view of completed test set-up.

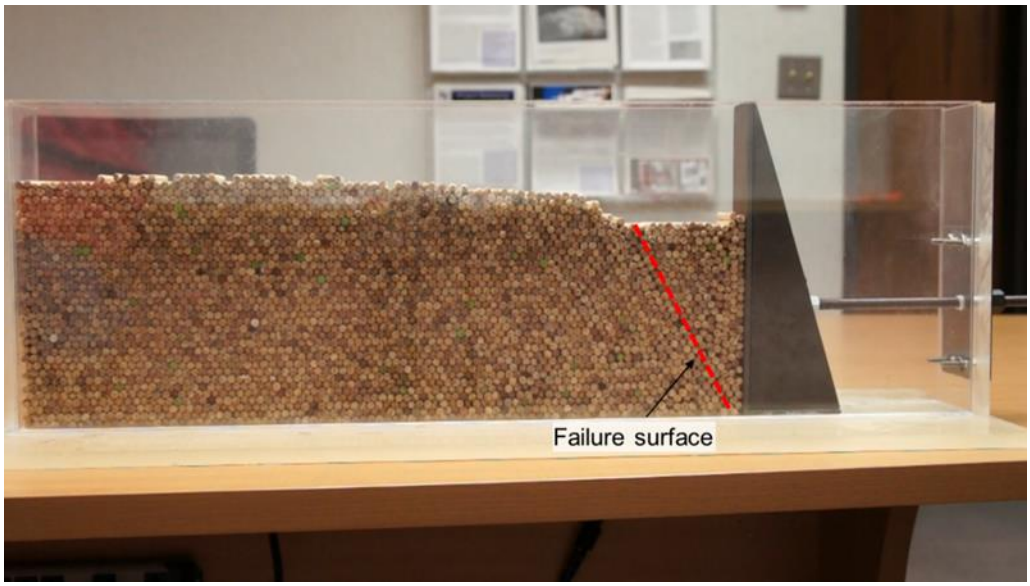
Operation of the Activity

1. Explain to the students that the wooden dowels represent soil particles in plane-strain condition and the metal plate represents a retaining wall.
2. Define the active condition as an earth pressure condition in which the wall moves away from the soil mass (Demonstration 1a).



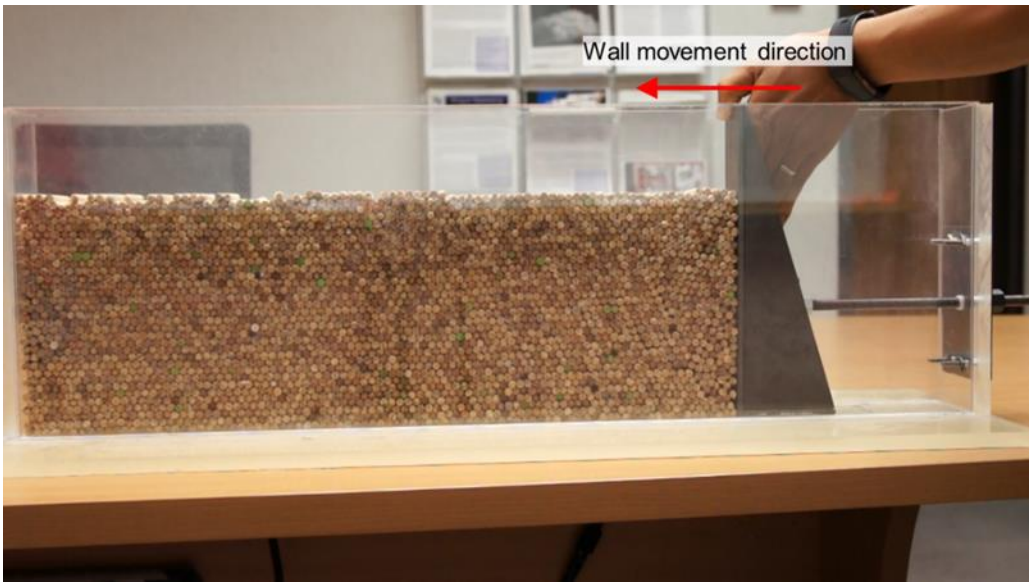
Demonstration 1(a)

3. Pull the wall away from wooden dowels by turning the knob.
4. As the wall moves, the wooden dowels slide down. Point out the failure surface to students (Demonstration 1b) and remind them that the failure is caused by an active condition. After pulling the wall away for a short distance, push the wall back to its original position and level the surface of wooden dowels before restarting the experiment.



Demonstration 1(b)

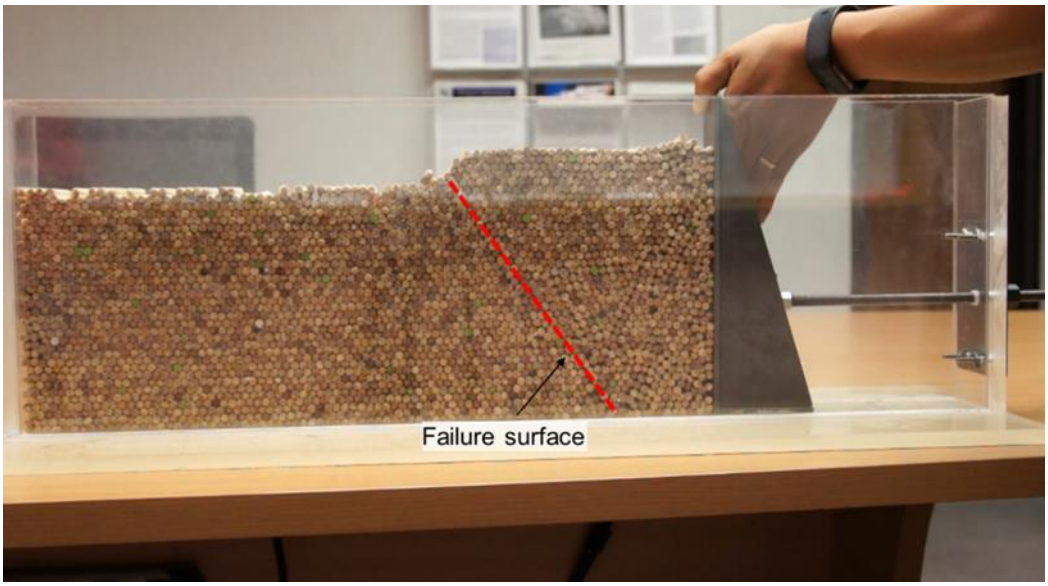
5. Define the passive condition as an earth pressure condition in which the wall moves into the soil mass (Demonstration 2a).



Demonstration 2(a)

6. Push the wall into the wooden dowels by turning the knob.

7. As the wall moves into the soil mass, the wooden dowels move up. Point out the failure surface to students (Demonstration 2b) and remind them that it is caused by a passive condition. Tell students that more knob turns are required to have passive failure than active condition. Also, explain to students that the volume of soil mass within the passive failure zone is greater than that within the active zone. Finally, point out that the failure surface from a passive condition is formed at a smaller angle to the horizontal than the active condition.



Demonstration 2(b)

8. Come back to the whiteboard, and draw a Mohr circle representing initial (at rest) stress condition (Fig. 2a):

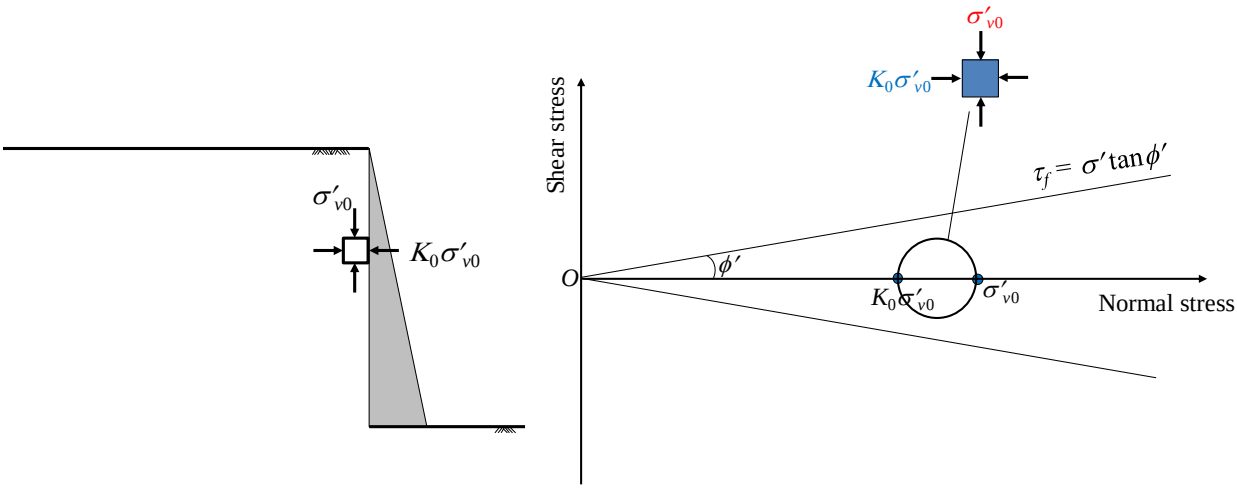


Figure 2. (a) Mohr circle representing stress state of at-rest condition

9. Explain to the students that when the wall moves away from the soil mass (active condition) the vertical stress remains constant, but the horizontal stress σ'_h decreases.

Explain further that the vertical and horizontal stresses remain as principal stresses without shear stress acting on the wall (per Rankine's theory).

Ask students: "How will the Mohr circle move as the wall moves away from the soil?"

Answer: The Mohr circle expands to the left until touching the failure envelope (Fig. 2b).

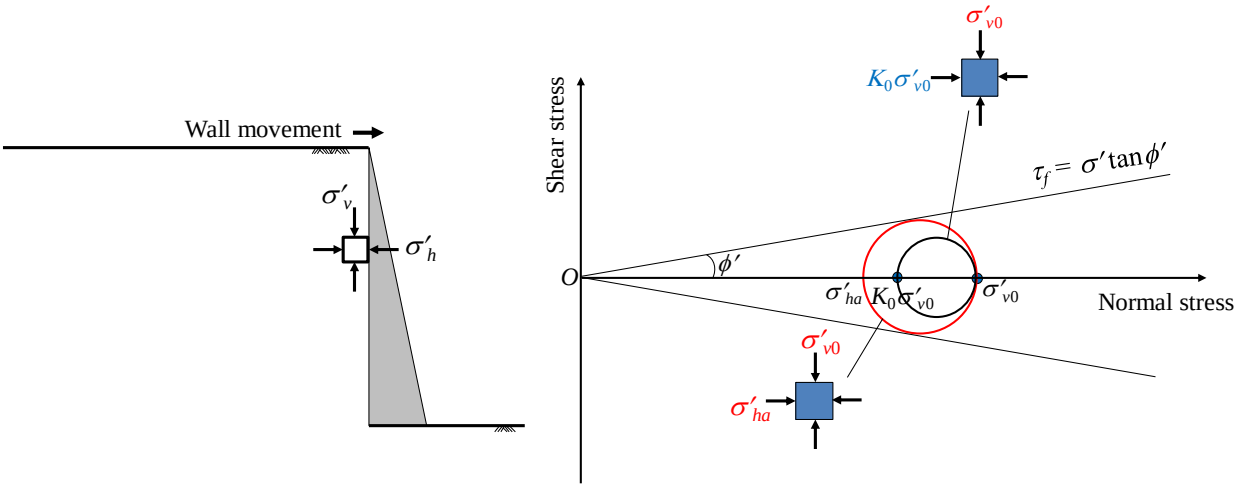


Figure 2. (b) Mohr circle representing stress state of active failure condition

10. Ask students to identify the location of the pole on the Mohr circle and directions of potential failure planes using the pole method. Relate the failure plane on Mohr circle with the physical failure surface behind the retaining wall (Fig. 2c).

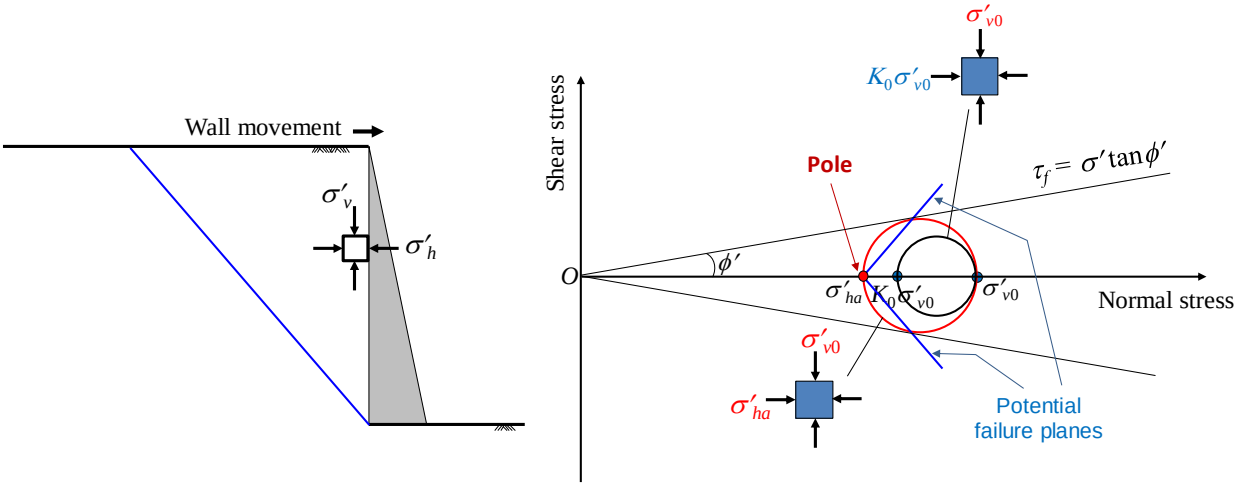


Figure 2. (c) Location of the pole and failure surface at active condition

11. Explain to the students that when the wall moves into the soil (passive condition) the vertical stress remains constant while the horizontal stress increases.
12. Continue to explain that this movement causes the Mohr circle to initially contract to the right until the horizontal stress becomes equal to the vertical stress. After that, Mohr circle expand further to the right until it touches the failure envelope (Fig. 3a).

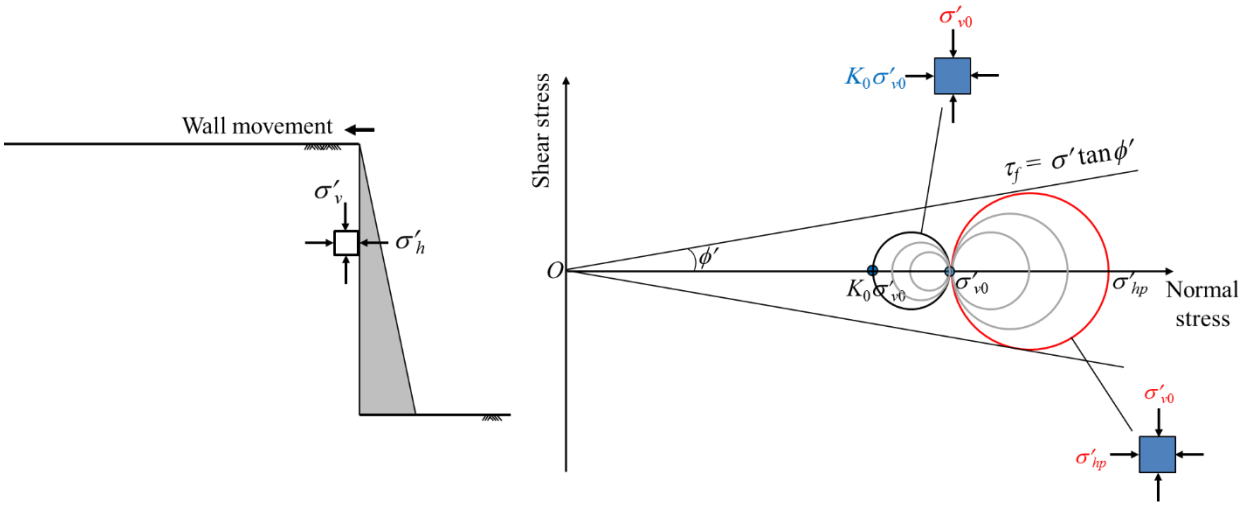


Figure 3. (a) Mohr circle representing stress state of passive failure condition

13. Ask the students to identify the location of the pole on the Mohr circle and the directions of the potential failure planes using the pole method. Relate the failure plane on Mohr circle with the physical failure surface behind the retaining wall (Fig. 3b).

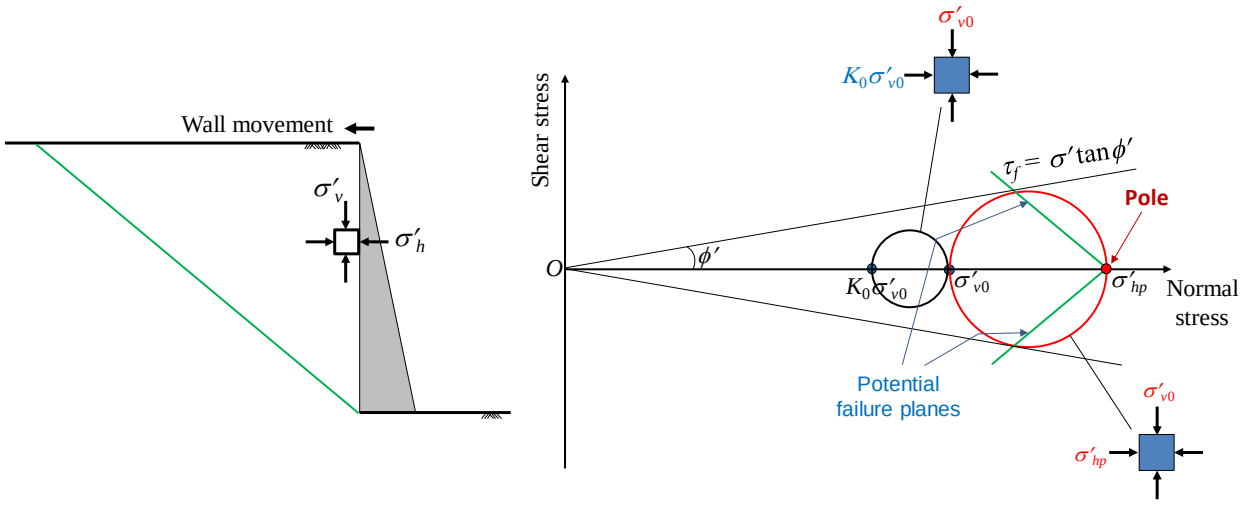


Figure 3. (b) Location of the pole and failure surface at passive condition

14. Present a comparison between the active and passive failure surfaces behind the retaining wall and emphasize that failure surface from passive condition is inclined at a smaller angle to the horizontal than the active condition (Fig. 3c). Remind students that this was indeed observed from demonstrations with the model retaining wall.

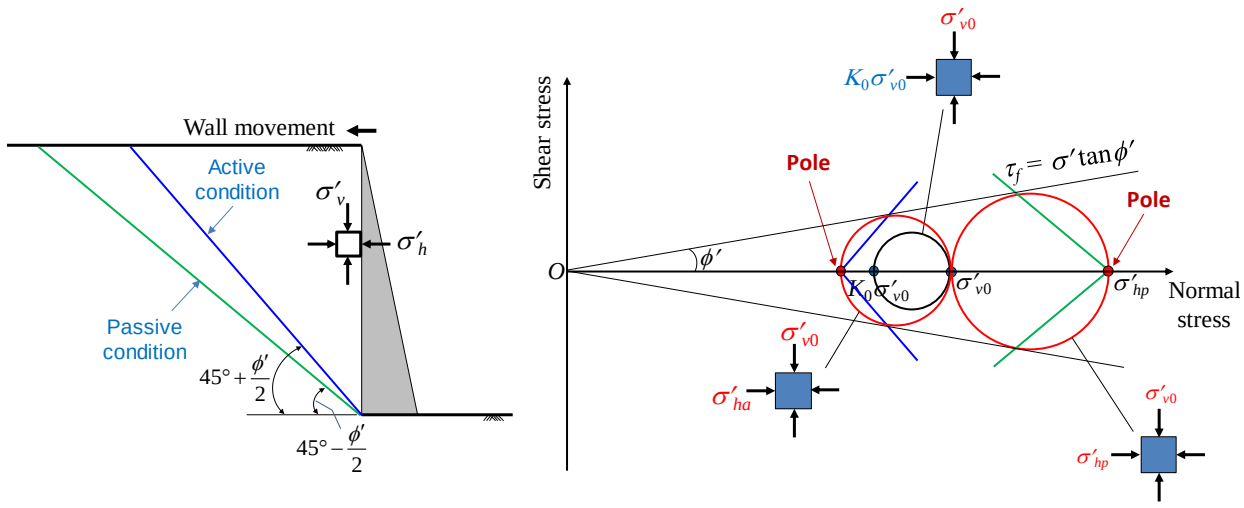


Figure 3. (c) Comparison between active and passive failure surfaces

Aha Moment

Students better understand the concept of active and passive earth pressures after viewing this activity. Furthermore, this activity effectively presents that more wall movements (or knob turns) are required to reach passive failure condition than active condition . Also, a simple analysis using the pole method explains why failure surfaces from active and passive conditions are formed at two different angles. A connection between earth pressure theory and physical observations through a model retaining wall stimulates students' intellectual excitements.

Video Link: https://youtu.be/j_Dd04hgPUw

Further Discussions

Equations for coefficients of active (K_a) and passive (K_p) earth pressures can be easily derived from the Mohr circles using trigonometry. Furthermore, the inclination angles of failure surfaces with the horizontal are obtained by the pole method to be "45° + ϕ'/2" for active condition and "45° – ϕ'/2" for passive condition. It can be further explained to students that the difference in inclination angles of failure surfaces between active and passive condition from this activity is rather small because the wood dowels representing granular materials have a smaller friction angle than actual granular backfill materials would.

A-8: WATER RACE

Activity Objective

To give students a "feel" for what hydraulic conductivity is and to explain how it relates to different soil particle sizes.

Introduction

Hydraulic conductivity (*k*) is commonly used as a quantitative measure of the flow of water through soil in geotechnical engineering. The *k* value mainly depends on void size and has units of length/time, such as cm/s or ft/min, representing how permeable (or hydraulically conductive) the soil is. Different soil samples have *k* values that scale several orders of magnitude. For example, typical *k* values for fine sand ranges between 10^{-3} to 10^{-1} cm/s and those for clay range between 10^{-10} and 10^{-6} cm/s. The significance of hydraulic conductivity, *k*, is emphasized in undergraduate courses, however, students often do not fully appreciate the impact of such large difference in *k* values. This activity gives students a feel for the magnitude of that contrast.

Materials Needed

- Four (4) empty 500-mL water bottles
- Four (4) empty 1000-mL water bottles
- Four (4) water cups
- A push pin
- Small amounts of gravel, sand, silt, and playdough (clay)

Setup Procedure

1. Cut the empty water bottles as shown in Fig. 1(a). The top portions of the 500-ml water bottles will be used as containers for the various soil samples and the bases of 1000-ml bottles will be utilized as water containers. Prepare a total of four soil containers and four water containers.
2. For each soil container, create four small holes using a push pin at 90 degree angles (see Fig. 1b).
3. Place one soil sample in each soil container and place the container filled with soil into the water container (see Fig. 1c). For silt and clay, place a few paper napkins on the bottom of the water container before inserting the soil container (see Fig. 1d). Do not apply excessive force to the soil containers as you insert them into the 1000-mL bases because that action may create cracks in the clay or silt samples. It is necessary to saturate the sand soil sample with water before the experiment begins.
4. Set aside the four water cups with equal volumes of water.

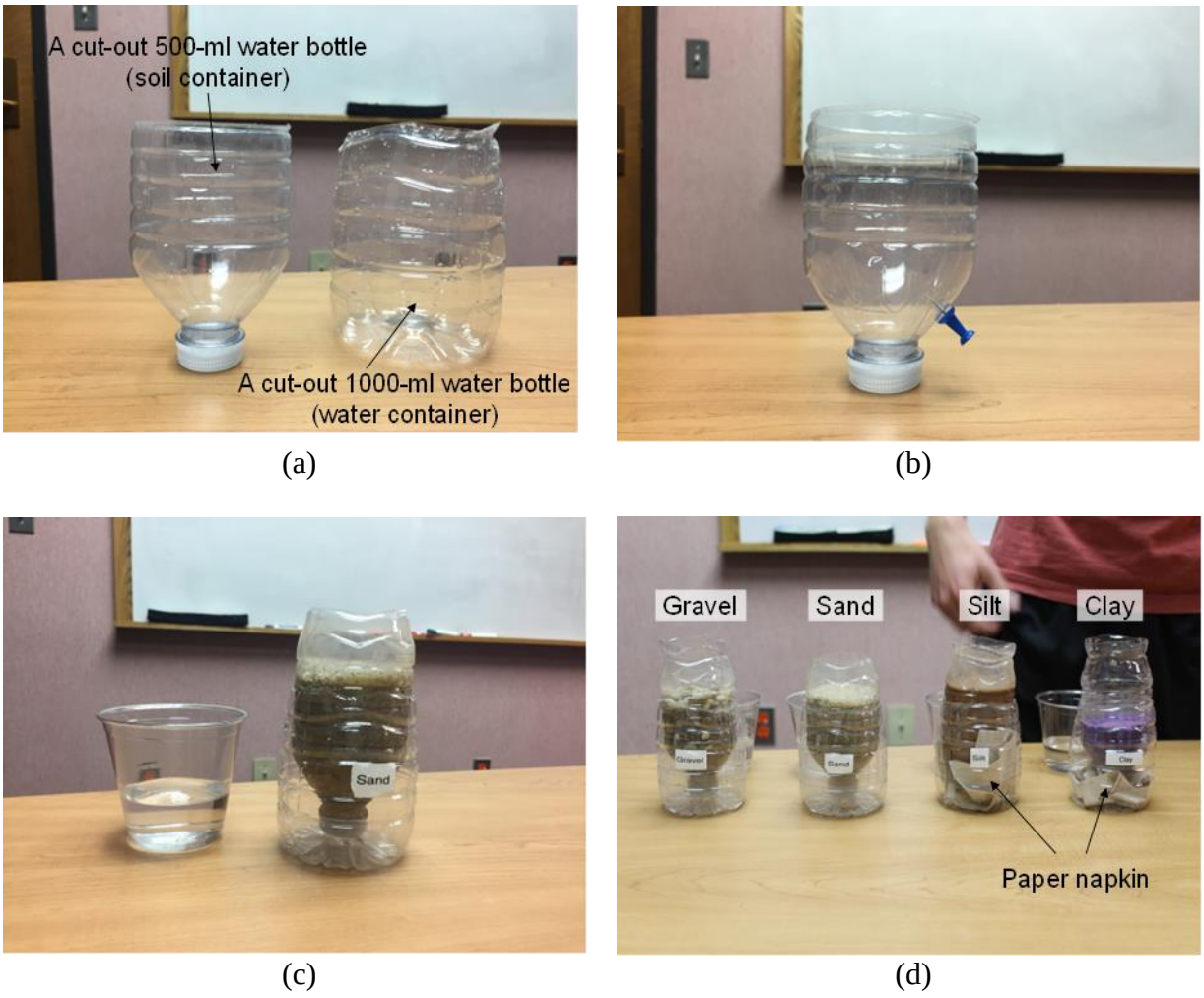


Figure 1. Materials needed and setup process.

Operation of the Activity

1. Introduce Darcy's law ($Q = kiA$) and define hydraulic conductivity, k. Explain to the students that the k value has units of velocity, representing how permeable (or hydraulically conductive) the soil is, and emphasize that the k value depends on void size. Present typical values of k for saturated soils to students: 1 to 100 cm/s for gravel, 10^{-3} to 1 cm/s for sand, 10^{-8} to 10^{-3} cm/s for silt, and 10^{-10} to 10^{-6} cm/s for clay. Note that the differences in k values are more than several orders of magnitude.

   Inform students that we will be performing a classroom version of a hydraulic conductivity test to get a feel for how significant the differences in k values are.
2. Direct the students' attention to the test station and explain the setup process. Tell students that there are small holes in the soil containers for the water drainage. Also, remind students that the amount of water in the water cups and the height of soil sample are roughly equal for each soil type. Point out that there are paper napkins in the water containers for silt and clay to better observe water drainage for these soils (Demonstration 1a).

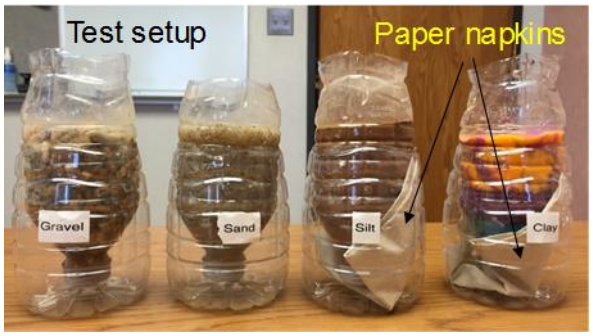
3. Ask two students to come forward and have them simultaneously pour water into each soil type (two containers for each student).
4. Bring the students' attention to the fact that the water in the gravel sample immediately drains out as the students pour the water (Demonstration 1b). Explain further that the water in the sand sample is also being drained, but at a slower rate (Demonstration 1b). Note that water in coarse to medium sands should be fully drained within a few minutes.
5. Engage students by asking whether the napkins in silt or clay will be wet or completely dry when we revisit the test station in 30 minutes.

Conduct a teaching lesson for about 30 minutes before revisiting the test station. Tell students that water is completely drained in gravel and sand samples, but the standing water will remain at the top of the silt and clay samples (Demonstration 1c).

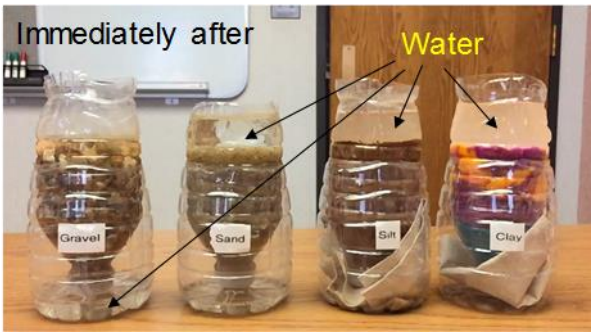
6. Carefully remove the soil container from the bottle bases before taking the napkins out and show them to students. Emphasize that the napkin in silt is wet, but that in clay is completely dry.
7. Explain students that the test setup is ordered in terms of hydraulic conductivity (i.e., k value for the four soil types are $k_{gravel} > k_{sand} > k_{silt} > k_{clay}$).

   Ask students: "What else were the four soil samples placed in order of?"

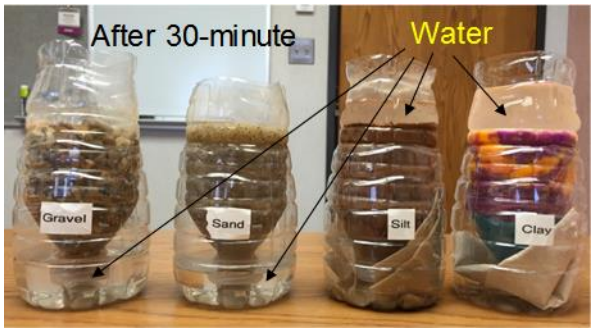
   Answer: Order of particle size.
8. Tell students that other people also observed that the hydraulic conductivity increases with increasing particle size and then present the Hazen's correlation ($k = CD_{10}^2$, where C is a Hazen's coefficient and D_{10} = effective particle size).
9. Emphasize how easily water is drained in gravel and how difficult it is in clay. Further explain to students that the gravel is commonly used as a backfill material for retaining wall not to have a water pressure behind it and that the clay is used for landfill as a contaminant barrier.



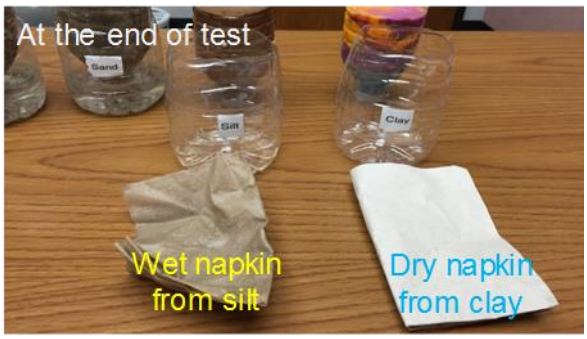
Demonstration 1(a)



Demonstration 1(b)



Demonstration 1(c)



Demonstration 1(d)

Aha Moment

Students have a good understanding that water flows easily in gravel and sand. However, they are not sure whether the napkins will be wet or completely dry in silt and clay after 30 minutes. This demonstration displays the sharp contrast in hydraulic conductivity among four basic soil types. Furthermore, by placing the soil samples in the order of hydraulic conductivity and pointing out that it is also the order of particle size, students naturally relate the hydraulic conductivity with particle size (or pore size).

Video Link: https://youtu.be/bTkYxus6z6k

Further Discussion

Degree of saturations are not fully controlled in this activity and therefore differences between unsaturated and saturated hydraulic conductivities are not discussed in this demonstration. Also, the activity is intended to provide students a visual explanation of hydraulic conductivity rather than quantitative measurements.

To further emphasize the impermeable nature of clay, a thinner clay layer than other soil sample heights can be used. Desiccation cracks impact hydraulic conductivity of clays but it is not discussed in this activity.