Delivering Geotechnical Engineering to Elementary School Children

By Eduardo Suescun-Florez, Magued Iskander, Ph.D., P.E., F.ASCE, Ryan Cain, and Vikram Kapila, Ph.D.

The American educational system must provide an ever-increasing number of technology workers for the U.S. to maintain its leadership position in the global economy. However, few students are attracted to engineering because they lack the required academic preparation in science, technology, engineering, and mathematics (STEM) to study engineering in college. Additionally, many lack knowledge regarding career options in engineering, or an understanding of what an engineer does. This problem is further compounded by negative stereotypes of engineering held by many Americans. Many consider engineering education to be more demanding than education in other disciplines, while perceiving engineering to be less prestigious than professions such as medicine and law.

Still others continue to view engineering as a male profession and tacitly discourage female students from becoming engineers. Finally, math and science studies are not perceived to be "fun" by many students. It is therefore essential that students develop a positive attitude towards math and science in elementary school while they are still impressionable. Early development of academic talent in science and math guarantees that students will perform better as they progress in the education system.

Exposing elementary school students to engineering through simple hands-on experiments is one of the best ways to improve student performance in math and science, and trigger their interest in pursuing engineering careers. Geotechnical engineering employs mathematics, solid mechanics, and fluid mechanics, which could be adapted in simplified form in elementary schools. Additionally, introducing students to engineering activities during their formative years stimulates creativity and invention.

Several attempts to introduce geotechnical engineering to young students have been made. Polytechnic Institute of New York University (NYU-Poly) operates the Applying Mechatronics to Promote Science Project (AMPS) under the National Science Foundation (NSF) Graduate Fellows in K-12 Education (GK-12) program. AMPS also receives funding from several philanthropic foundations joined under the Central Brooklyn STEM Initiative. The GK-12 program teams Graduate Fellows with K-12 teachers and students to improve the Graduate Fellows' communication and teaching skills while enhancing STEM lesson content for teachers and students. AMPS emphasizes the use of LEGO robotics to promote interest in STEM.

The program's geotechnical activities were carried out by one graduate fellow instructing in two schools with a total of about 60 second, third, and fourth graders. Each activity required 90 to 135 minutes divided over two or three 45-minute class periods. The activity was introduced during the first period, where students were challenged to identify the problem,

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imagine possible solutions, and make a plan to implement the solution. In the second and third periods, students implemented the plan and sought to improve it.

Soil Permeability Activity

Soil permeability is introduced to elementary school students in many educational systems in such diverse locations such as Egypt, Iran, India, and the U.S. In New York City, soil permeability is presented as part of the water cycle unit, typically taught to third, fourth and fifth graders. However, the topic is typically introduced in a dry manner and, by middle school, few students have any recollection of the topic. AMPS uses a different approach.

For soil permeability, the role of permeability in civil engineering is first discussed and is followed by introduction of a transparent falling head permeameter made especially for this activity. Several permeameters containing gravel, sand, silt, clay, and play marbles are set up to illustrate the effect of grain size on flow rate (Figure 1). Before testing, students were challenged to predict which soil samples would have the highest and lowest permeability. After the predictions were made, the permeameters were filled and saturated to allow the students to visualize the flow of water in various soil samples, and students were asked to revise their guesses if they wanted. This process permitted the graduate fellow to discuss the experiment, the importance of soil particle size, the concept of saturation, and the need to repeat the test until the effluent volume and flow was equal between the tests.

Afterward, a falling head test was conducted in the permeameter and the students applied their math to calculate the flow rate. The rate of discharge was measured using a clock/ruler and an ultrasonic sensor that was read using a LEGO NXT controller, a device that can read electronic sensors or build robots using LEGOs. Collecting the data using two methods opened up a discussion on accuracy of measurements and the role of error in everyday measurements. This also permitted students to analyze the pros of and cons of using an automated data acquisition system.

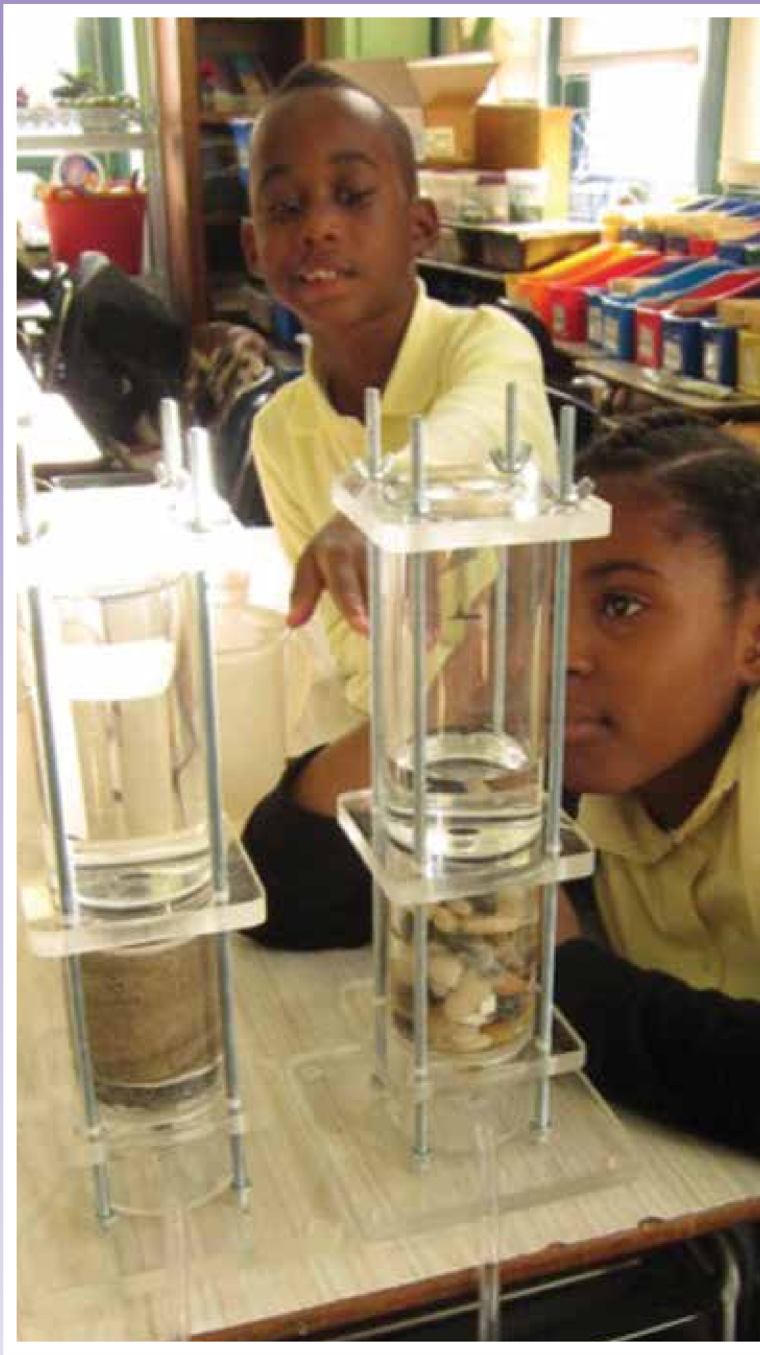

Figure 1. Elementary school students conducting falling head permeability test.

Contact Stress Activity

The contact stress activity is designed for students to understand how external loads affect the stresses in a soil deposit. Because elementary school students had not been previously exposed to the concept of stress in materials, the human body was used as a simple analogy. For this example, the human body was considered to be the structure, with legs as the columns and feet as the foundation system. Based on that assumption, students were asked to find out the stress their bodies apply directly to the floor.

Students calculated the contact area of one foot by tracing their foot on grid paper, then counting the number of squares included in the trace. Partial squares were included so students could apply their addition and fractions instruction to calculate the total area of a student's foot. Next, each student's weight was measured, opening the topic of scales and load sensors for an introductory explanation. Because two- and three-digit division is not part of the K-4 curriculum, pennies were employed to

Figure 2. Simulating stress with pennies for the contact stress activity.

simulate load, with each penny representing one pound.

Students were then asked to evenly place the number of pennies representing their weight on top of the numbered squares of their traced foot (Figure 2), and were told the number of pennies stacked on one square equals the contact stress on the floor. These activities permitted students to not only practice their math skills, but also to visualize the division operation and comprehend the concept of stress as load divided by area. Most students successfully explained how many pounds per square inch their bodies applied to the floor when they were standing on one foot. Finally, students were challenged to explain what happens to the stress when they stood on both feet. Many students found this question tricky, but they eventually answered correctly.

Foundations in Stratified Soil Activity

Another activity was designed to teach students the difference between shallow and deep foundations and to investigate the important role of foundations, as well as to teach students the concept of bearing capacity. The students were first introduced to natural soil profiles with a brief introduction to rock formations and their weathering into soils. Students were already familiar with the role of grain size in affecting soil properties from the permeability experiments. Various types of soils were defined according to their grain size, and then groups of five students each made their own soil profile model (Figure 3). Pictures of various natural soil profiles were shown to encourage students to come up with reasonable ideas. Students filled acrylic transparent cubes with their choice of a layered system made of any combination of gravel, play dough, natural sand, and colored sand.

The graduate fellow then introduced the concept of foundations using models made of LEGO pieces to represent shallow and deep foundations embedded in transparent soils (Figure 4). Students understood that all man-made structures are supported by foundations. They also learned that geotechnical engineers must know the properties of soil layers of a specific site to design suitable foundations. With this background, groups of students constructed their own buildings using LEGO pieces. Shallow foundations were simply made of long flat pieces placed under the structure.

Figure 3. Students and fellow discussing a bearing capacity test conducted using a soil model made by the students.

Figure 4. Elementary school students discussing the difference between shallow and deep foundations using a LEGO building and layered transparent soil model made of Aquabeads.

Figure 5. Flood aftermath showing student-designed model buildings that were manufactured using a 3-D printer.

Deep foundations were made using multiple small pieces stacked under each other.

Once the building units were completed, the students given a brief introduction to foundations and then were asked to carefully place them on top or in their soil profiles by using shallow and deep foundations respectively. The models were loaded and students observed that models with deep foundations are able to carry more load than those with shallow foundations. Students also observed soil settlement as the buildings were loaded. This led to a discussion on bearing capacity, complete with pictures of real bearing-capacity failures. The activity ended with a discussion of total collapse versus excessive deformation that prevents a building from meeting the needs of its occupants.

Soil Erosion Activity

An erosion table is a physical model used to demonstrate to children why mountains erode and how sediment erodes and is transported. Such a table was designed and built in a second grade classroom to support the water cycle unit of the New York City curriculum. The table was made from a hydraulic bench that pumps water in a sand bed to represent a meandering river and permit simulating erosion due to water flow in the river. The table also was used to investigate the relationship between water velocity and soil erosion.

First, the students learned why soils erode when they are in contact with water and the importance of preventing soil erosion for the safety of riverside buildings and bridges. Each student then designed a building using the Google Sketchup application, which allowed each student to express his or her imagination and to take ownership of the experiment. The teacher then made a scaled model of each student's building using a 3-D printer donated to the class by one of AMPS' industrial supporters.

Students then placed their buildings along the riverbank in a location that provided a nice water view and where they believed the building was safe from erosion. The hydraulic bench pump was initially operated at a small flow rate that resulted in water running under laminar flow. Some of the buildings collapsed due to soil erosion but most survived (Figure 5). The flow rate was then incrementally increased simulating larger storms and turbulent flow. This experiment permitted students to observe the increase in the rate of erosion with the increase in flow rate, which resulted in failure of many buildings.

Students worked individually so they developed a strong affinity to their designed building and its location. Because students were asked to position their buildings in areas where they believed damage would not occur, they paid special attention when the flow was increased. Afterward, the students, graduate fellow, and several teachers engaged in a discussion of the dangers of natural disasters, occurrence rates of hurricanes, building codes, the importance of deep vs. shallow foundations, the role of sinuosity in erosion, and the rates of erosion of various soils. This activity illustrated how natural disasters are serious events that have to be designed for by experienced geotechnical professionals, stressing the importance of math and science as a foundation for the modern built environment.

Assessing the Program's Effectiveness

Questionnaires conducted immediately after each activity, and in one case just before the activity, indicated that students had an increased conceptual understanding of soil mechanics and were enthusiastic about the LEGO robotics. For example, following the bearing capacity exercise students were asked, "What happens to the soil when foundations fail?" Students typically answered that the soil beneath the footing is pushed to the side and bulges up, or that the soil to the side of the foundation moves because the soil underneath pushes it. Another question was "If a bridge was to be placed on a deep foundation, how deep would the deep foundation need to go?" An outstanding answer from a fourth grader was that the deep foundation would need to be located at the deepest place, or where soil was the strongest.

The assessment also demonstrated that physical models are helpful in elementary schools and that these students can understand somewhat complex geotechnical engineering concepts through the use of physical models. The classroom activities allowed students to use their knowledge of mathematics to a real-world application. This is important for developing an affinity to STEM subjects, and establishing a permanent connection between STEM studies and engineering at a young age.

It is difficult to assess the long-term impact of the geotechnical engineering activities on student long-term achievement because many of the main objectives need time to determine their effect. Nevertheless, all evidence suggests that the students enjoyed the interactions and it helped them to apply their math skills. Most students were motivated by the opportunity to act as geotechnical engineers. Additionally, many students affirmed that soil mechanics lessons were their favorite aspect of the science course. Teachers believed that concepts learned in hands-on soil mechanics activities were more memorable to students than those encountered in a traditional class. The AMPS team also believes that the opportunity for elementary school students to interact closely with goal-oriented role models will help them to develop academic goals for themselves.

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AUTHORS

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