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Introducing Soil Property Evaluation in Geotechnical Engineering – Some Food for Thought

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After completing my undergraduate studies at Cal Poly, San Luis Obispo, I worked for a private geotechnical consulting firm in California for over 15 years. My consulting career provided a broad range of experience on mostly public works projects. Over the last 10 years I have managed the geotechnical laboratory which served more than 5 offices throughout the state for domestic and international projects. I have been teaching mostly geotechnical laboratory courses at Cal Poly for over 10 years. Utilizing Cal Poly's 'Learn by Doing' mantra, I share my practical project experience with my students during laboratory activities.

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Every student has at least some knowledge of food, though this knowledge will admittedly vary with the individual's palette. Instructors often use this fact to their advantage when demonstrating important concepts related to mechanics and materials. Have you ever witnessed the use of dry pasta to demonstrate an important concept in physics or engineering? Indeed, geotechnical engineering instructors often apply food analogies in classroom and textbook discussions. Butter, peanut butter, and cheese prove illustrative when describing the consistency of clayey soils at varying moisture contents.

In this paper, we present some food for thought when addressing soil property evaluation in geotechnical engineering instruction. Specifically, we summarize the results of a laboratory test program designed to assess the "engineering behavior" of different foods. For example, as shown on Figure 1, part of our investigation focused on the consistency of different cheeses. We present our test results with interesting graphics, photographs, and illustrations ready for use as props by other instructors, in either the classroom or laboratory. The food analogies presented in this paper can serve as a lighthearted yet engaging introduction to soil mechanics and soil property evaluation in a first-class on geotechnical engineering. Student testing of soil samples and in-depth discussions of actual soil behavior would presumably follow such an introduction. Bon appetite.

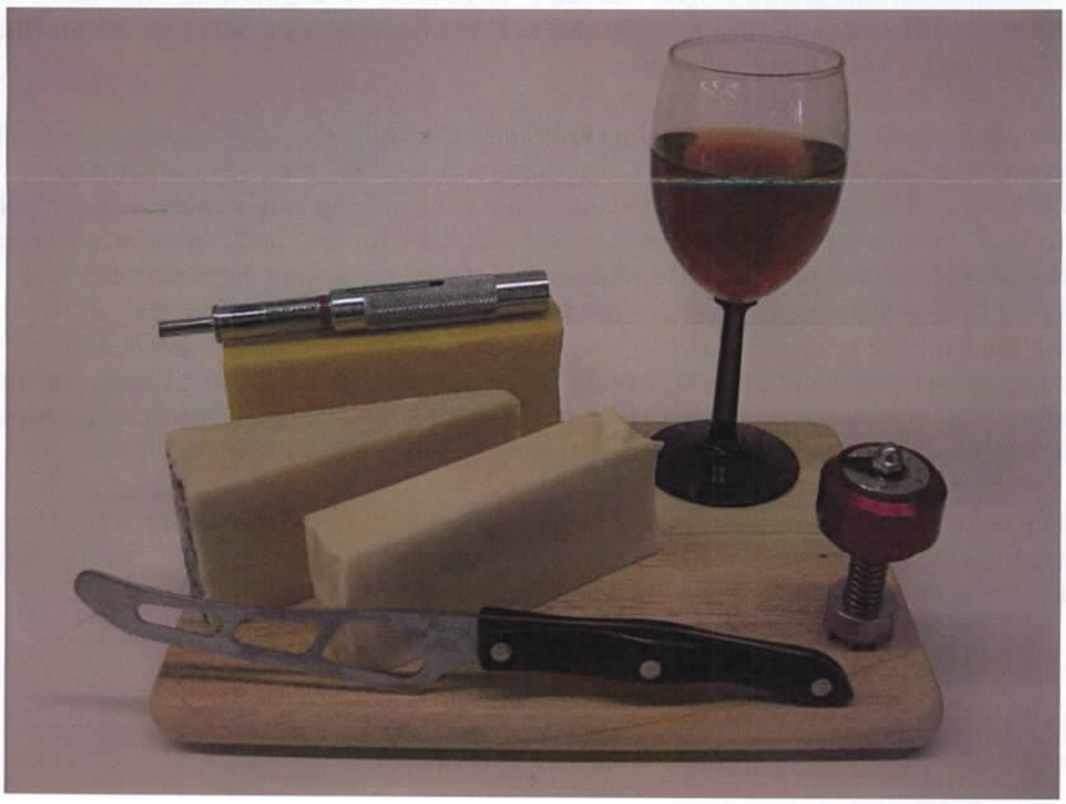


Figure 1 - Food for Thought: Consistency Measurements for Different Cheeses (It's cranberry juice, of course. We work on a dry campus.)

Laboratory Results

In this section, we present the results of laboratory experiments for "index and engineering properties" of various grocery store food items. We briefly describe the tests we performed, though we generally followed appropriate testing standards established by ASTM. We present the results in what we hope are visually appealing figures and tables. We believe a geotechnical instructor could easily incorporate these graphics into brief introductory lessons on soil behavior and property evaluation.

When introducing experiments in our own geotechnical laboratory, we provide the following graphics as props for our students. In addition, we sometimes conduct additional instructor-led demonstrations with food. The introductory discussions and demonstrations are brief, lasting 5 to 10 minutes. We follow our introductory remarks with in-depth lessons on actual soil behavior and student testing of soil samples. We do not ask our students to test food in the geotechnical laboratory. However, we see the potential benefits of having students develop and test their own food analogies as part of a separate, informal learning activity.

Particle Size and Distribution

To cover the range of particle sizes from boulders to fine-grained soil, we sampled food items such as watermelon, nuts, grains, and flour. Fruits such as apples, strawberries, and grapes provided sizes analogous to cobbles and gravels. We selected seeds, grains, and spices to span the particle sizes from coarse to fine sand. Powders such as flour and cocoa substituted for fine-grained soil types.

We used calipers and an engineer's scale to measure nominal diameters for the fruits and larger specimens. Conventional geotechnical sieves provided nominal sizes for smaller specimens. We performed full mechanical sieve analyses on mixed nuts, muesli, instant coffee, and iodized salt. Figure 2 identifies different food items adjacent to the size scale for equivalent rock or soil particles, as well as conventional distribution curves. We intended Figure 2 as a familiar complement during an introduction to particle size and distribution. During a discussion of particle size and distribution, an instructor could have samples of different size foods present to emphasize equivalent sizes. Edible props often prove popular with students, as long as one is careful in their selection. For example, we recommend strawberries over Brussel sprouts.

As evident in Figure 2, our quest to find a more well-graded food item proved challenging. All of the distribution curves indicate poor gradation, though there is a wider range of particle sizes present in the muesli. We were optimistic when selecting a 10-ounce can of mixed nuts for testing. However, we were disappointed to find only a half-dozen cashews, five brazil nuts, and one-half a pecan(!) within our "mixed nut" selection. Mostly peanuts were present – so typical.

Table 1 includes a summary of our research regarding the particle sizes of different food items. We compare grocery store items directly with the various soil fractions (and identifiers). Included in the table are nominal (or effective) diameters for each of the selected food items.

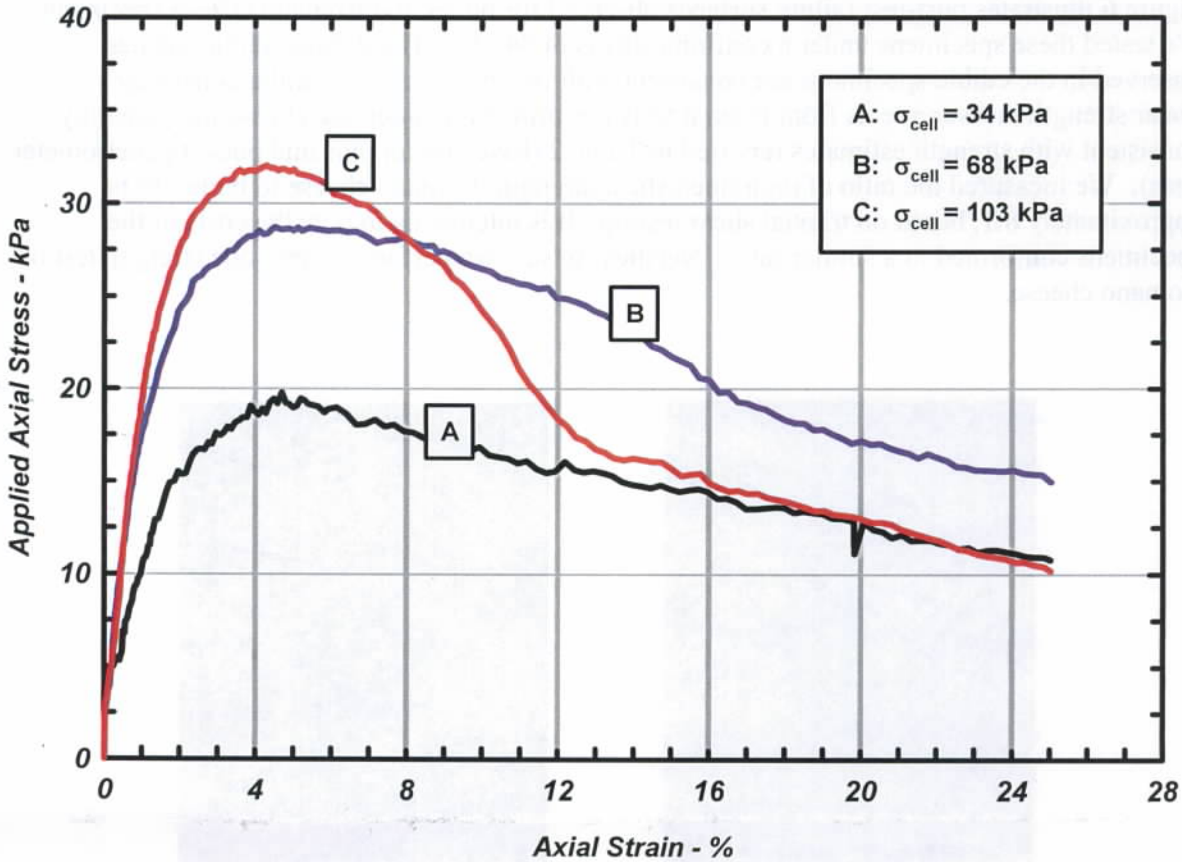
Table 1 - Effective Particle Diameters for Different Foods

Shopping List	Effective Diameter (mm)	Size Range (mm)	Soil Fraction
Jack O'Lantern Pumpkin	334	>300	Boulders
Watermelon	290	75 to 300	Cobbles
Honeydew Melon	191		
Cantaloupe	135		
Granny Smith Apple	86		
Red Potato	71	19 to 75	Coarse Gravel
Strawberry	49		
Unshelled Walnut	26		
Kalamata Olive	18.1	4.75 to 19	Fine Gravel
M&M Candy	13.4		
Cheerios	12.4		
Garbanzo Bean	8.1		
Popcorn Kernel	5.3		
Shelled Sunflower Seed	4.1	2.0 to 4.75 (#10 to #4 sieve)	Coarse Sand
Fennell Seed	3.1		
Quinoa	2.4		
White Rice	1.7	0.425 to 2.0 (#40 to #10 sieve)	Medium Sand
Instant Coffee	1.2		
Cream of Wheat	0.5		
Iodized Salt	0.4	0.075 to 0.425 (#200 to #40 sieve)	Fine Sand
Granulated Garlic	0.2		
Curry Powder	0.1		
Baking Flour	<0.075	<0.075	Silt and Clay
Cocoa Powder	<0.075		

Table 2 - Criteria for Consistency of Fine-Grained Soil with Food Analogs

Consistency	SPT, N (bpf)	Undrained Shear Strength, s_u kPa (psf)	Manual Field Test	Food Analog	Estimate of s_u* kPa (psf)
Very soft	0-2	< 12 (< 250)	Thumb penetrates easily; extrudes between fingers when squeezed	Hazelnut Spread	2-5 (50-100)
Soft	2-4	12-24 (250-500)	Thumb will penetrate soil about 1 inch; molds with light finger pressure	Stick of Butter	14-24 (300-500)
Medium Stiff	5-8	24-48 (500-1,000)	Thumb will penetrate about ¼-inch with moderate effort; molds with strong finger pressure	Mozzarella Cheese	28-34 (600-700)
Stiff	9-15	48-96 (1,000-2,000)	Thumb indents easily and will penetrate ½-inch with great effort	Sharp Cheddar Cheese	57-72 (1,200-1,500)
Very Stiff	16-30	96-192 (2,000-4,000)	Thumb will not indent soil, but thumbnail readily indents it	Romano Cheese	115-139 (2,400-2,900)
Hard	>30	> 192 (> 4,000)	Thumbnail will not indent soil or will indent it only with difficulty	Baking Chocolate	> 192 (> 4,000)

*- Undrained shear strengths estimated for foods using the pocket penetrometer and torvane.



Sample #	Unit Weight kN/m^3 (pcf)	Confining Stress kPa (psf)	Applied Axial Stress at Failure kPa (psf)	Undrained Shear Strength kPa (psf)
A	8.80 (56)	34 (720)	20 (420)	10 (210)
B	8.96 (57)	68 (1,440)	29 (600)	15 (300)
C	8.96 (57)	103 (2,160)	32 (670)	16 (335)

Figure 5 - Results of UU Triaxial Tests Performed on Sticks of Butter

groove to come together and close the groove. If the groove closes over a distance of 12.7 mm (0.5 inches) with 25 blows, the soil is at its liquid limit.

Figure 7 - Liquid Limit Cup Test on Hazelnut Spread

We tested various spreads, peanut butter, cake icing, cream cheese, miso paste, and hummus with the goal of identifying the food item at the liquid limit consistency. Since temperature variations will affect the consistency for the food items, we tested all samples immediately after removing them from the refrigerator. Figure 8 provides the number of blows required to achieve the specified gap closure. Unfortunately, we were not successful identifying the food with the exact liquid limit consistency. However, we learned a soil's liquid limit will likely occur when the consistency of the soil is not as firm as cream cheese but is firmer than hummus. The search continues.

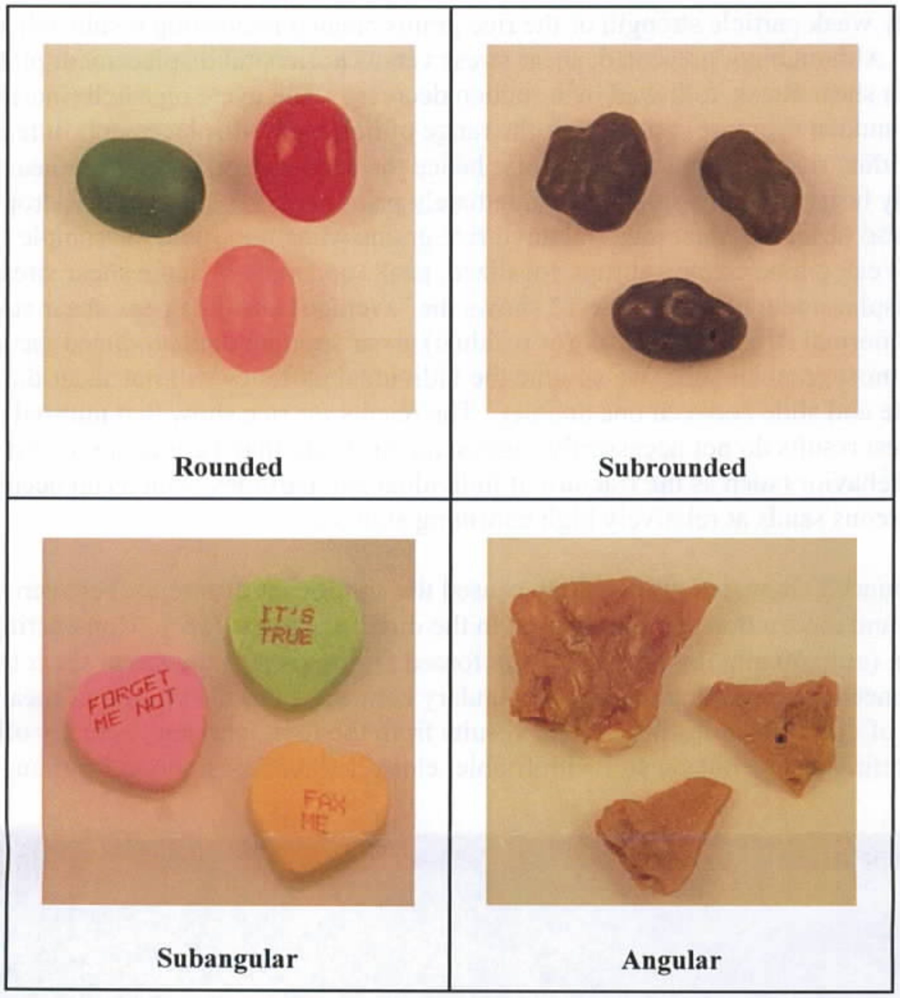


Figure 9 - Jelly Beans, Chocolate Covered Raisins, Candy Hearts, and Peanut Brittle to Describe Shapes of Coarse-Grained Soil Particles

Shear Strength of Coarse-Grained Materials

We investigated the shear strength of dry white rice and iodized salt by measuring the angle of repose and performing direct shear tests. Figure 10 illustrates the angle of repose for rice. The direct shear specimens for rice and salt had nominal diameters equal to 60 mm (2.4 inches). We prepared the specimens in the shear box using three, lightly-tamped lifts of dry material. Computer controlled testing equipment applied normal and shearing forces. Applied normal stresses ranged from approximately 25 to 75 kPa (500 to 1,500 psf). Figures 11 and 12 provide failure envelopes and estimates of effective friction angles for the salt and rice samples, respectively. The measured effective friction angle for the salt sample is consistent with direct shear results for soil samples with similar particle size, shape, and angularity.

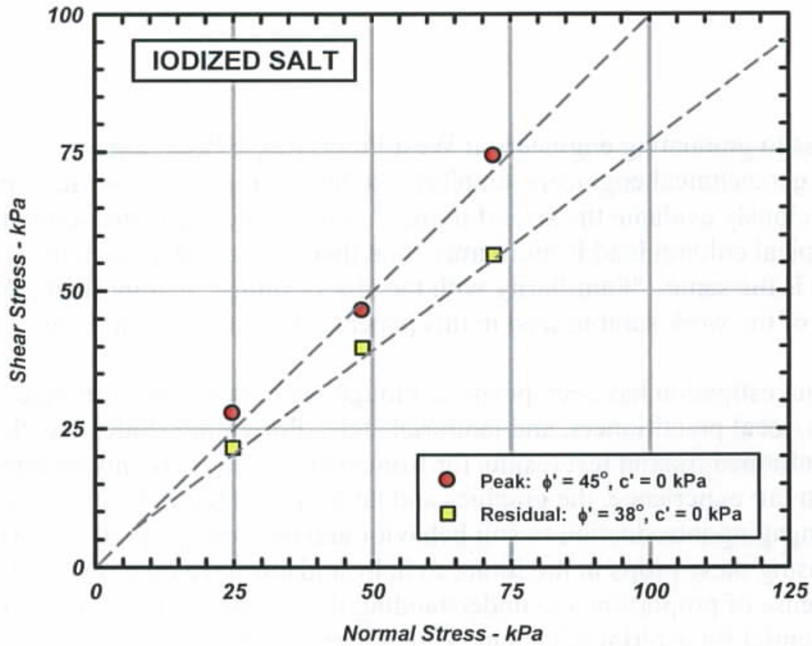


Figure 11 - Direct Shear Test Results for Iodized Salt

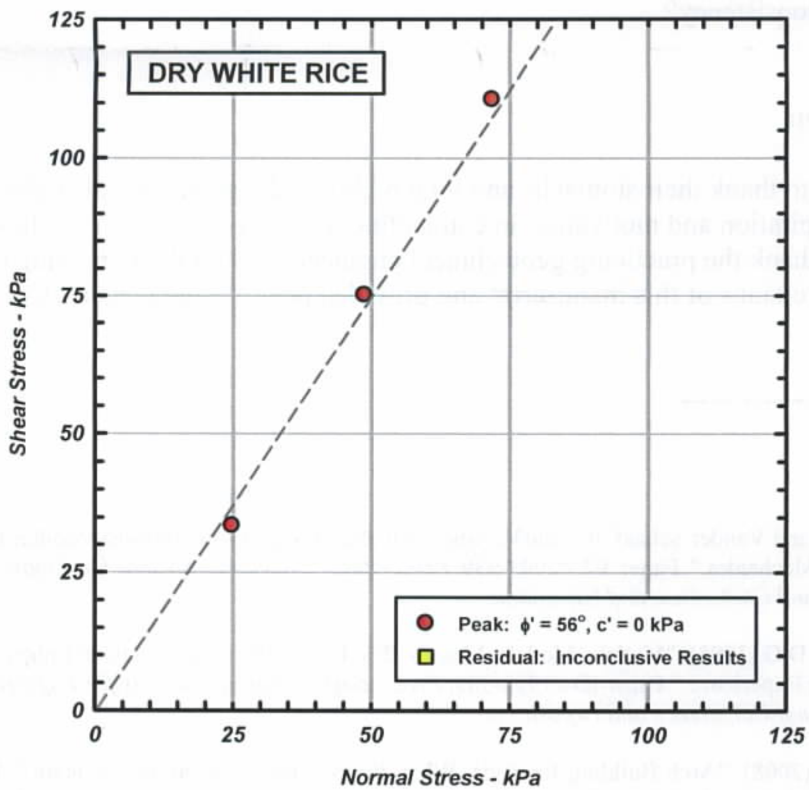


Figure 12 - Direct Shear Test Results for Dry White Rice

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