Soil Classification – The Bigger Picture

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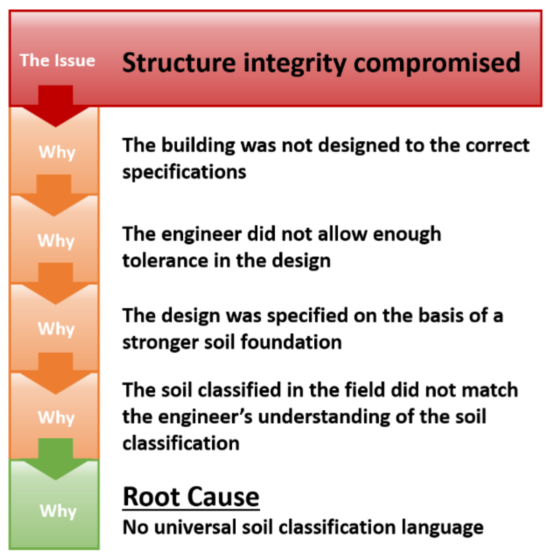
The names Atterberg, Casagrande and Terzaghi are well versed in the soil mechanics industry. Back in the fall of 2014, Tracy Barnhart wrote a wonderful article on the 'Three Musketeers in Soils Testing: Atterberg, Casagrande, and Terzaghi'. This summer, we have decided to expand on the works of one individual in particular, Casagrande, and his development of the Unified Soil Classification System (USCS).

The USCS is a…. Let's stop right there, or rather, hold that thought for a moment. Before we start getting into the nitty-gritty details about what it is, we should take a step back and ask, why was it invented? You probably don't even realize that you use the system in numerous AASHTO and ASTM standards, with some examples being: determining the amount of sample to use in T 88/D422 (hydrometer) or for how long to soak a sample in T 99/D698 and T 180/D1557 (standard and modified Proctor test methods). To garner a better understanding of the issues that prompted the creation of the USCS as the resolution to 'nonconformities' across the industry, why don't we employ the familiar Root Cause Analysis (RCA) investigation technique.

The Issue

The need to develop a universal classification system most likely stemmed from an underlying and reoccurring problem. The problem must have been widespread and potentially had significant consequences, possibly leading to failure (think Leaning Tower of Pisa). For a simplified understanding of this, we will generate a RCA example based on the extreme end of the spectrum and say in our project that the structural integrity was compromised. A RCA into the failure can be summarized in the neighboring graphic.



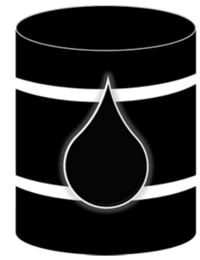
Have you ever heard of the children's game called 'Telephone'? It is a game in which one person whispers a message to another. The message is then repeated individually through a line of people with the last person announcing what they heard to the group. The end message is often vastly different from the original message. The rise in awareness of soil mechanics and its application without a soil classification system was similar to a game of Telephone. Field staff would observe what they thought were the essential components of the soil and pass the characteristics along the chain of command. As the message moved from the field to quality assurance to design, often several echelons of people would be involved. With each additional involvement, the original description could be reworded to highlight the properties of the soil that they believed to be the most critical. By the time the description reached the final engineer, something was being conveyed to the engineer that they themselves would have classified entirely differently.

The Task

For as long as civilizations have been building monuments, soil mechanics has been used; just not as the industry understands it now. Although no records describe the study of soil mechanics prior the 1700s, it does not mean civilizations had no ability to recognize foundational issues and compensate for them. The engineers of ancient and not-so-ancient civilizations learned to create stable structures through their experience of working with the local materials, the experience of their predecessors, and trial and error. Evidence of compensating for poor soil conditions can be seen in the foundations of archeological sites such as Egyptian pyramids, Mesopotamians ziggurats, Greek temples, Roman roads, and Chinese bridges.

Another industry that developed systems for describing soil early on was the agriculture industry. There are records from China, India, and Roman civilizations from early second century B.C.E describing local soils for agricultural purposes. The majority of early soil classifications were concerned with identifying soils and their known fertility properties. In other words, soil was being classified only on the soil's qualitative properties.

Soil properties did not become quantified until Charles-Augustin de Coulomb wrote an essay and developed a calculation for active and passive soil pressure on retaining walls in 1773 using calculus that had only been developed a century ago. After this point, more scientists in different countries (mostly in Europe) started publishing soil calculations that are still known today like Darcy's Law, Elastic Constant, and Mohr's stress diagrams. Unfortunately, these types of calculations only described properties of individual soils, and the calculations did not actually classify the soils.



Did you know, Darcy's law plays a key part in petroleum engineering?

Classification did not become necessary until massive structural failures across multiple countries started occurring in the last decade of the 1800s and the first decade of the 1900s. Governments needed a way to convey specifications for soils and aggregates for construction projects to the people on project sites and a way to control what material was being used on site. The Swedish government had Albert Atterberg develop his clay classification scheme after a massive railroad embankment failure had occurred. The classification scheme took sixteen years of study to create.

The United States had different motivations for having the soil classification systems. The Bureau of Reclamation of the Department of Agriculture wanted a soil classification scheme for building earthen dams and irrigation, but progress was little to none when compared to Swedish developments. Although clay classification was pioneered by Atterberg, many scientists and countries had at least developed a grain size classification system, some modern differences can be neatly summarized based on appropriate sieve number depicted in the Sieves (M92/E11) vs. Grain Size Classification chart at the end of the article.

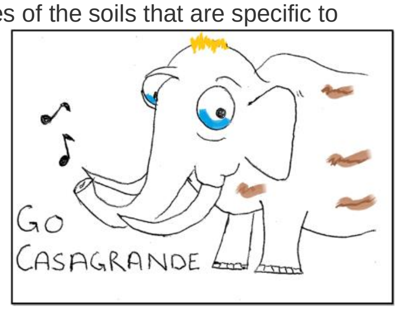
Karl Terzaghi and Chester Hogentogler, while researching for the American Association of State Highway Officials (now known as AASHTO), developed the first soil classification for the United States government in 1929. Unfortunately, a widely accepted soil classification system was not created until after the First International Convention on Soil Mechanics and Foundational Engineering in 1936. The convention was the idea of Arthur Casagrande, presided over by Karl Terzaghi, and hosted by Harvard University. The event was thought of as a surprising success. In the 1948, Arthur Casagrande, commissioned by the Federal Aviation Administration (FAA), developed the Airfield Classification System which eventually became the Unified Soil Classification System (USCS). Modified versions of the USCS are used across the world today.

The Decision

We have discussed why having a common language is important, but how difficult can it be to invent a widely accepted soil classification language? It is actually very difficult, almost impossible, and this is because the fundamentals of soils are not based on quantitative mathematics. With the increased scientific focus on soils in the 1900s a major stumbling point was creating a quantitative delineation. The fundamental components (soil forming factors) of soils are not composed of just isotropic material but also a variety of discrete and composite factors. A simple way to understand this is to say, "I am an American because I was born in America." However, we know that each American is different because of their background and it suddenly starts to get more complicated with globalization, as you could have parents from South America and Europe but be born in the United States (much like a soil!).

Even after decades of simplifying the soil forming factors to just three: organic matter production, amount of water available for leaching, and time (Runge, 1973), it is still impossible to quantitatively measure. The more homomorphic approach by Simpson (1959) of soil genesis involving additions, removals, transfers, and transformations of material still could not generate quantitative data as the processes weren't specific enough and were not expressed as a functional unit (Huggett-Geoderma, 1975). This forces the classification of soils to be generated based on physical properties like size, color, shape and composition that can be quantitatively calculated but inherently arbitrary. Thus take a moment to stop and think how hard it is to convince not just yourself or your boss, but an entire continent and the world that your arbitrary classification system is the correct one. Then, in addition, consider how the properties of soil can influence multiple commodities with vastly unique needs (for instance agriculture vs engineering), where users desire to highlight only properties of the soils that are specific to each industry. That's a feat worthy of scoring perfect 10s in your performance review.

Even though there are still multiple classification systems worldwide (hopefully by now it is abundantly evident as to why!), like ISO 14688 (Geotechnical Investigation and Testing) that is used in Europe, we would be bold enough to say that Casagrande not only did an incredible job, his effort was a mammoth achievement that will still be the focus of development in years to come.



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Sieves (M92/E11) vs. Grain Size Classification

E11 Sieves Sizes		USCS (D2487/D422)		AASHTO (M145/T88)		USDA (Soil Survey Manual)		USGS/ Udden-Wentworth		International (ISO 14688-1)	
Metric (mm)	Size (in.) or No.										
											L
630		Boulder				Boulder		Boulder			
600										Boulder	
300				Boulder & Cobble		Stone					
256		Cobble									
250								Cobble			
200						Cobble					
75	3									Cobble	
63	2 1/2										
50	2								VC		
37.5	1 1/2		C				C				C
31.5	1 1/4										
25.0	1	Gravel							C		
19.0	¾							Gravel/ Pebble			
16.0	5/8			Gravel							
12.5	1/2		F			Gravel/ Pebble	M		M	Gravel	M
9.5	3/8										
8.0	5/16										
6.3	1/4 (No. 3)								F		
4.75	No. 4										
4.00	5		C				F				F
2.36	8							(Granule)	VF		
2.00	10								VC		
1.7	12						VC				
1.18	16								C (T)		C
1.00	18		M		C						
0.850	20						C		C (U)		
0.600	30	Sand									
0.500	35			Sand							
0.425	40					Sand	M	Sand	M	Sand	M
0.300	50										
0.250	60										
0.212	70		F		F				F		
0.150	100						F				
0.125	120										F
0.106	140								VF		
0.075	200						VF				
0.063	230								C		
0.050	270										C
0.031	450	Silt									
0.020	635			Silt					M		
0.016								Silt	F	Silt	M
0.008						Silt					
0.006									VF		
0.005											
0.004		Clay						Clay			F
0.002				Clay				C/S boundary for mineral analysis			
0.001						Clay				Clay	
0.0002		Colloid		Colloid			F	Colloid			

http://aashtoresource.org/university/newsletters/newsletters/2016/08/05/soil-classification-the-bigger-picture