Teaching/Learning Soil Mechanics with Mnemonics, Intuition, Insight and Inspiration

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Teaching (Learning) Soil Mechanics with Mnemonics, Intuition, Insight and Inspiration (MI^3)

ABSTRACT: This paper focuses on soil mechanics/physics engineering education with mnemonics, intuition, insight and inspirational study. One of the early giants of soil mechanics pioneers, Ralph Peck, Prof. Karl Terzaghi's assistant once said that "Soil has a merit of memory and it never lies, … ". Nene and Lsssandge (2009) [10] summarized mnemonics as "the art of assisting the memory, by using a system of artificial aids - rhymes, rules, phrases, diagrams, acronyms and other devices—all to help in the recall of fundamentals of soil mechanics concepts, names, principles, facts and figures, etc." We all have used this technique knowingly or unknowingly in our life and educational learning. Many engineering subjects, for example, soil mechanics, contain abstract concepts, principles and ideas. In the beginning, soil mechanics may appear hard for students to visualize, comprehend and remember at first. As a professor instructing soil mechanics and geotechnical engineering, we are obligated to help and motivate students to learn as much as possible besides developing their enthusiasm for the soil mechanics subject. To achieve these objectives, educators and many authors of classical textbooks on geotechnical engineering have used effective methods of teaching which strengthens these concepts and help students to retain, retrieve and apply the concepts mastered in soil mechanics class. The paper presents some of the effective mnemonics techniques learned or created over the years which should be helpful for teaching and learning soil mechanics and engineering. Students are also encouraged to cultivate their own mnemonics, intuition, insight and become inspired by their independent study or reading inspiring pioneers of soil mechanics creators and developers.

INTRODUCTION

Soil mechanics or geotechnical engineering is a fundamentally core course required by almost all the universities' ABET accredited civil engineering programs. For example, Northwestern University has Introductory Soil Mechanics, Soil Mechanics I through IV, Unsaturated Soil Mechanics, Constitutive Models for Soils and Foundation Engineering, etc. Purdue University at West Lafayette offers many more soil mechanics related courses [13], for example Geotechnical Engineering I and II course and many other geotechnical engineering courses, etc. At Purdue University Nothwest Westville campus, we have been offering Soil Mechanics I (Soil Engineering), Soil Mechanic II and Foundation Engineering courses.

Unlike many other fundamental engineering courses, soil mechanics and its applications in foundation and earth structural engineering are very practical. Many geotechnical engineers will tend to agree that everything students learn in geotechnical engineering are useful and practical if the they chose to practice in these fields. Teaching soil mechanics with assigning students to review and study real world soil reports helps make students aware of this hard fact truth and at the same time prepares them to take on a geotechnical/soil engineer responsibility immediately after graduation.

Like "In the beginning was the word", at the beginning of soil mechanics introductions are plethora of definitions wherein we introduce many fundamental definitions and facts about soil

classification as they form the language of soil mechanics and engineering.   So obviously helping students to remember and master all the fundamental principles and facts are extremely important. Hence this puts a lot of pressure to student memory overloading sometimes due to so many concepts, ideas, facts and definitions being introduced for the first time in a short time. This is especially true with some students claiming disability due to difficulty of taking notes, hearing loss due to exposure to high or even low level but constant noises which may have caused some of the learning or mental concentration problems [28-31].

In the following sections, to help students solve the memory overloading problems and making the most of learning soil mechanics fun and memorable, various mnemonics and sometimes even remotely related connections are introduced to help students master the fundamentals of soil mechanics. Also the wide application of soil subjects in different art, science and engineering fields' connections are introduced to illustrate soil mechanics/physics importance in our life and culture. Intuition, insight and inspiration were also resorted to help pique students' interests and passion and love of learning soil mechanics and engineering for the benefits of mankind.

SOIL MECHANICS MNEMONICS – 1D, 2D, 3D Threads of Knowledge Points [2-15]

Every science and engineering subject should have some major principal threads which connect all key knowledge points together. This is especially true with soil mechanics and engineering. For example, when students are learning water content soil laboratory tests, this is usually a very good starting point of a one dimensional knowledge thread. The Atterberg limits, for example shrinkage limit (SL), liquid limit (LL) and plastic limit (PL) are essentially all fundamental water content which are just measured at different stages of their states. So is the optimum water content used in the standard proctor test or modified compaction laboratory test to achieve the maximum dry density. I believe that civil engineering student, and especially those who declare geotechnical engineering as their profession, should be constantly reminded of how important the concept of water content is in their future professional life.

Water content is defined as weight relationship as w = Ww/Ws. So given, w, known or easily measured from the lab, we can quickly figure out how much water is in a soil mass with the Ws easily estimated/measured or known. This water or moist content concept should be emphasized throughout the soil mechanics courses and even throughout a geotechnical engineer's career as well. Water content, w, is important because Atterberg limits like Liquid limit (LL) plastic limit (PL) are all fundamentally water content. And without emphasizing this fact, it is easy to forget this fundamental idea and concept. In this regard, the author recommends that LL and PL be written as w_{LL} and w_{PL} as in several classical soil mechanics textbooks. Putting the w, water content before LL and PL will help reminding students that LL and PL are still essentially water content. This water content test also comes up in the Standard and Modified Proctor tests as the optimum water content w_{opt}. Later in the student engineers' geotechnical engineering practice, the water content will also somehow be correlated with the soil strength properties [7] as shown in Holtz et al (2011).

Relative density is defined as Dr = $\frac{e_{max} - e}{e_{max} - e_{min}}$ which is commonly used to indicate the in situ denseness or looseness of granular soils (Holtz et al, 2011; Coduto et al, 2011). On the other hand, for the cohesive soils, the relative consistency of cohesive soil in its natural state, liquidity

index (LI), is defined as $LI = \frac{w - PL}{LL - PL}$ or $LI = \frac{w - w_{PL}}{w_{LL} - w_{PL}}$ where $LL - PL = w_{LL} - w_{PL}$ is defined as PI, plasticity index [3,7].

Another easily confusing concept with relative density, Dr., is relative compaction, R, defined as $R = \frac{\gamma_{d(field)}}{\gamma_{d(max-lab)}}$. Relative compaction R is an important parameter for field inspection quality control and quality assurance of field compaction work. And this relative density, Dr, and Liquidity Index (LI) happen to be the author's email signature initials after each and every email while communicating with his students from his Soil Mechanics I and II, and soil engineering classes. The author hopes that this constant encountering and reminding of them will help them remember these important definitions. It is worthy to remind and help the students observe and notice that Relative Density, $Dr = \frac{e_{max} - e}{e_{max} - e_{min}}$ and $\frac{w - w_{PL}}{w_{LL} - w_{PL}} = LI$, Liquidity Index, are somewhat symmetrical where $w_{LL}(e_{max})$ is the maximum water content (maximum void ratio) while $w_{PL}(e_{min})$ corresponds to the minimum water content (minimum void ratio) during the plastic stage. Juxtaposing irrelevant definitions together may help lead to something unforgettable, like this one, "The PI of soil memory mnemonics is Dr. R. LI". Quiz like explaining the soil mechanics definitions in the above short statement may help students learn and review important soil concepts in several chapters, for example Plasticity Index, pre-consolidation stress, relative density, relative compaction and liquidity index that we just discussed. In this regard, the author strongly agrees that personal experience is everything (Hudson and Harrison, 2007) [8].

The same pedagogy techniques are also told to students and ask them to remind themselves to recall and think of time factor, $Tv = \frac{C_v t}{H_{dr}^2}$, where Cv is coefficient of consolidation, t is real time, and H_{dr} is drainage path length whenever the students are watching news or entertainment on the Television, TV.

While studying at college, students may be required to remember the definitions of USCS soil texture classification size dimensions for the exams or tests. But the memory of them usually may not last long, especially if the instructor does not heavily emphasize soil grain size importance, and our human memory tend to retain and remember those more frequently encountered and used. For this, many of the entry level engineers may have personally gone through this experience on their initial jobs on site soil classification during excavation or drilling construction observations. So helping students and in particular the geotechnical engineering students to remember the different soil sizes dimensions with a lasting memory is important. And it is not an easy task without proper mnemonics to help memorize that.

Over the years, the author figures out how and why the boulder, cobble, gravel, sands and fines (silt and clay) are demarcated or differentiated. To help students remember this, it is a good idea to draw an increasing arrow with increasing sizes similar to the explanation of Atterberg limits arrows. However, without a detailed mnemonics to help students retain the teachings of their respective sizes, students can quickly forget them because we usually do not use them daily in our busy life.

However, if the professor or instructor adds some comments that for any soil/rock larger than the length of his or her foot or 12 inches, the soil/rock is defined as boulder, the students will have a longer and maybe even a lifelong memory of boulder size in the USCS soil classification. Next size boundary is 3 inches length, about one of a person's figure length, also equal to 1 foot (12 inches) divided by number four (#4 sieve). So any rock/soil larger than 3 inches, a finger's length, but smaller than 12 inches or one foot is considered as cobbles.

The number 4 sieve, roughly 5 mm (4.75mm) is approximately the width of a person's pinky finger nail width.

So if the students remember their body parts, their foot length of 12 inches, finger length of 3 inches and pinky finger nail width (4.75mm or 5 mm) all approximately, the students should easily remember major soil sizes gradation and have an overall big picture view of how the soils are classified from the texture point of view.

The soils passing number 4# sieve but retained on number 200# (0.075mm) are all considered as sandy soil. All those soils retained on 200# sieve are categorized as coarse grained soils whose behavior is controlled by their texture, respectively. For those passing through #200 sieves, they are hard/difficult and even impossible to tell one grain from another with average human eyesight. Those soils are usually considered as fines including silt and clay. Silt and clay soil mechanics are dominated by the water content in the soil. By explaining this way to the students, almost all of the students in the instructor's soil engineering (soil mechanics I and II), engineering geology classes find it much easier to remember and retain the lectures covered on USCS soil classifications from the size point of view.

This one (1) dimensional knowledge points could also be connected via two (2) dimensional diagrams, such as soil weight-volume relationship of the three phase diagrams, plasticity chart, normal and over consolidated soil behavior loading paths, and sieve analysis curves, etc. When teaching three phase diagrams, a very important goal or objective is to help students understand that the immediate goals are to estimate/evaluate initial conditions of soils, like the different unit weights or densities, initial void ratio and water content, porosity ratio, etc. As the forthcoming second objective from these different unit weights are used to evaluate current overburden effective stress. It will be used in foundation compression/settlement evaluation together with initial void ratio. Whether soil will fail upon external stress change should consider pre-consolidation pressure, excavation disturbance, superstructure loading or groundwater level fluctuations and thus effective stress change. The current overburden effective stress and additional stress change combined with Mohr-Coulomb strength theory will help lead to different lateral earth pressure theory and foundation bearing capacity theory development.

Nene and Landge (2009) [10] discussed three major types of visual, auditory and kinesthetic learners and some corresponding learning tricks such as cartoons, hard to forget rude rhymes and models, etc. To really expand all those soil mechanics learning mnemonics, an extension of such a rude rhyme is provided here. This can help the students quickly recall most of the important knowledge points that they learned after each class or a whole semester. Rude rhymes are very difficult to forget, like alphabet ABC from A to Z. **A** for Atterberg, **B** for Bernoulli and Boussinesq, **C** for Coulomb and **D** for Darcy; **E** for Effective stress, **F** for Flow lines, **G** for Gs,

specific gravity or **GI** (Group Index), **H** for Hydraulic Head; **I** for Hydraulic gradient, i, as well; **J** is unit seepage force; **K** is for Hydraulic conductivity, etc. … ; **T** is for Terzaghi, Texture, **T**ransmissivity and **T**riaxial Tests, **T**ime factor Tv; **U** is for Degree of Consolidation, UCS, USCS, etc.; **V** is for volume of void, void ratio, volumetric strain, Vadose zone; **W** is for water content, well-graded; **Z** is for ZAV and for elevation head used in Bernoulli Equations [2-5], [7], [11-13].

Specific gravity, Gs, is an important concept introduced in soil mechanics defined as Gs = γ_s/γ_w. However, many times we forget why we introduce and define Gs as the ratio of γ_s/γ_w, where γ_s is unit weight of soil solid particle, γ_w is unit weight of water. We introduce the new concept of Gs as a bridge as sometimes we need to figure out the unit weight of soil solid particle γ_s which is defined as Ws/Vs. So given Gs is known, γ_s will just be equal to Gs γ_w as unit weight of water is supposed to be an engineering constant property. Herein Gs is like a bridge introduced often to help evaluate unit weight of soil solid particles. Other similar concepts introduced include volume coefficient of compressibility $m_V = \frac{\Delta\varepsilon}{\Delta\sigma} = \frac{\frac{\Delta e}{(1+e_{av})}}{\Delta\sigma}$ with its purpose to evaluate the vertical strain change $\Delta\varepsilon$; compression index, Cc, swelling index Cs are introduced to help evaluate void ratio change Δe along the NC and OC clay loading paths whose ultimate goal are used to calculate vertical strain $\Delta\varepsilon = \frac{\Delta e}{(1+e_{av})}$ because the settlement calculation are fundamentally using the very simple idea of soil strata thickness times the vertical strain induced in the soil under the foundation or external load. In a word, both the elastic settlement, primary consolidation and secondary consolidation settlement calculation all used the same idea of soil thickness times the vertical strain induced. Skempton pore water pressure parameters $B = \frac{u_o}{\sigma_3}$ and $A = \frac{u_d}{\sigma_3-\sigma_3}$ are introduced to evaluate excess pore water pressure change during the loading on saturated soil; Poisson ratio, $v = -\frac{\varepsilon_h}{\varepsilon_v}$ is to help find ε_h and lateral earth pressure coefficient Ka, Ko, Kp in increasing order for the same type of soils are introduced to calculate the horizontal effective stress σ_h' as $K = \frac{\sigma_h'}{\sigma_v'}$ wherein the σ_v' is a parameter relatively easy to evaluate or calculate. σ_h' is needed for the design of the lateral earth pressure load exerted on retaining wall.

This unit weight of soil particles, γ_s, could be easily confused with the soil dry unit weight γ_d which is defined as Ws/Vt. Put them side by side for comparison will show the difference between them. γ_s = Ws/Vs while γ_d = Ws/Vt. It is logical to have the conclusion that that volume of soil solids is smaller than total volume of soil, i.e., Vs << Vt, so γ_s >> γ_d. The difference between γ_s and γ_d is due to the different volume is used. For soil solid particle unit weight, the volume is the total volume of all the soil solid particles, Vs, which excludes the volume of voids in the soil. For soil dry unit weight, the volume used is the total volume of the dry soil, Vt, which includes not only volume of soil solid particles, Vs, but also the volume of voids, Vv.

From the physical three phase diagram to the simplified geometric three phase diagram is a great scientific simplification process and yet still maintains the fundamental essence of soil mechanics. Like an enigmatic three layer boxes, students are encouraged to play and learn the weight and volume relationship using the enigmatic box with guidance and learning. By showing the students how all the different parts are estimated based on the fundamental

definitions, the students will learn a life-long learning skills and will have a hard time to forget the fundamental ideas why we introduce all these different concepts like Specific Gravity, water content and all the different soil unit weight and soil density concepts.
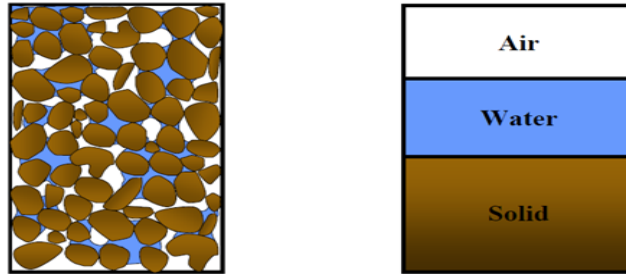

Figure 1. From physical to idealized three phase diagram of soil weight volume relationship

At this stage, students should also be reminded that the goal of the three phase diagram are to help find the different unit weight or void ratios which will later be used in the foundation settlement and bearing capacity estimations. With such a clear objective and goal stated, the students should have more motivation and interests in studying the three phase diagrams by having the vision of utilizing them in their future geotechnical engineering careers through estimating the bearing capacity and foundation settlement, etc.

The weight volume relationship of soil three phase diagram can also be used to introduce the vertical strain $\varepsilon = \frac{\Delta e}{1+e}$ concept which will be very helpful and utilized in consolidation settlement estimation. The difference of Δe can be obtained from normal consolidated or over consolidated soil consolidation test curves. The original void ratio e_o can be estimated from the following three phase diagram as well.

$Wa = 0$	Air (a)	$Va = e - Va = e - wGs$
$Ww = wWs = w1Gs\,\gamma_w = wGs\,\gamma_w$	Water (w)	$Vw = Ww/\gamma_w = wGs$
$Ws = Vs\gamma_s = Vs\,Gs\,\gamma_w = 1Gs\,\gamma_w$	Solid (s)	$Vs = 1$
$Wt = Ws + Ww + Wa$ $= 1Gs\,\gamma_w + wGs\,\gamma_w + 0$ $=(1+ w)Gs\,\gamma_w = Gs\,\gamma_w\,(1+ w)$		$Vt = Vs + Vw + Va$ $= 1 \;+\; e$

$$V_v = V_a + V_w =$$

Figure 2. Soil weight volume relationship (aka soil three phase diagrams)

In soil mechanics, we introduce and define void ratio, e, as the ratio between volume of voids divided by volume of solids, i.e., $e = Vv/Vs$. Herein suppose we have volume of soils is $Vs = 1$ volume unit, so we have $e = Vv/Vs = Vv/1 = Vv$, and thus, total volume of voids is $Vv = e$ which implies that the volume of voids is just equal to the void ratio e. If we can calculate V_w, then volume of air is $V_a = V_v - V_w = e - V_w$. With Vs =1 assumed, we can calculate the weight of solids Ws, which is just the γ_s times $Vs = 1$. Unit weight of soil solid particles $\gamma_s = Gs\,\gamma_w$ is derived from the fundamental definition of $Gs = \gamma_s/\gamma_w$. And hence, $Ws = Vs\,\gamma_s = Vs\,Gs\,\gamma_w = 1Gs\,\gamma_w$.

With Ws found, we can figure out the weight of water, Ww, in the three phase diagram. At this point, we need to recall that definition of water content is defined as weight of water divided by weight of solid, $w = Ww/Ws$. And hence $Ww = w \, Ws$. With Ws just estimated as $Ws = 1 Gs \, \gamma_w$, we have $Ww = w \, 1 Gs \, \gamma_w = w \, Gs \, \gamma_w$. Many and almost all modern and classical textbooks write $Ww = w \, Gs \, \gamma_w$ instead of $Ww = w \, 1 \, Gs \, \gamma_w$. The equation $Ww = w \, Gs \, \gamma_w$ may look neat and terse, however it may not help students to see the fundamental truth of how $Ww = w \, Gs \, \gamma_w$ is derived where there should be a volume of $Vs = 1$ assumed. In this sense, the authors recommend some classical and modern soil mechanics textbooks may adopt the above sign conventions. Sometimes how we write the same equations does matter as it may better help students understand soil mechanics fundamental principles effectively or not.

In geotechnical engineering, the mass or weight of air is quite small and negligible on the Earth, so we can assume weight of air is zero, i.e., $Wa = 0$ weight unit. With all the three phases weight obtained, the total weight of the three phases, i.e., the total weight the soil (air, water and solids) is just the sum of the three weight, and hence $Wt = Wa + Ww + Ws$, rewritten as $Wt = 0 + w G_s \gamma_w \, 1 + G_s \, \gamma_w \, 1 = w G_s \, \gamma_w + G_s \, \gamma_w = (1+w)G_s \, \gamma_w$. At this point, all the weight relationship is found as shown in Figure 2.

To figure out all the volume relationship, we need to resort to the equation of unit weight of water γ_w times V_w to have the weight of water as W_w. From there, we go rightward toward east, to obtain volume of water $V_w = W_w/\gamma_w = w G_s \, \gamma_w \, / \, \gamma_w = w G_s$. At this point, we have the volume of water $V_w = w G_s$ and volume of solid $Vs = 1$. As the total volume of void $Vv = e$, so the volume of air is $V_a = V_v - V_w = e - w G_s$. The sum of total volume of soil is $Vt = Va + Vw + Vs = (e - w G_s) + w G_s + 1 = 1 + e$.
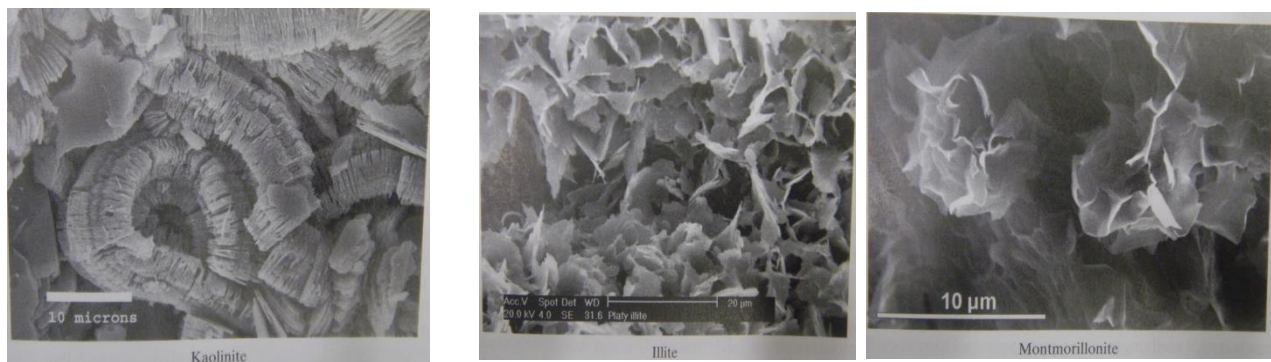

Figure 3. Diagram of structures of (a) Kaolinite (b) Illite (c) Montmorillonite (after Coduto, Yeung and Kitch, 2011, Images courtesy of Clay Mineral Society)[3]

Figure 3 shows the actual micrograph of structures of three commonly encountered clays, Kaolinite, Illite and Montmorillonite. They are all actually measured micro photograph of the three different clay mineral soils. However, just showing that without a schematic visualized clay structures, students will have a hard time to visualize their key features related to their engineering behavior. Compared with Figure 3, Figure 4 from Das and Sobhan (2018) may better help students retain and memorize their key features and especially if the instructors may be

allowed to use not only scientific languages descriptions only. That way, students can connect their engineering behavior with microstructures.
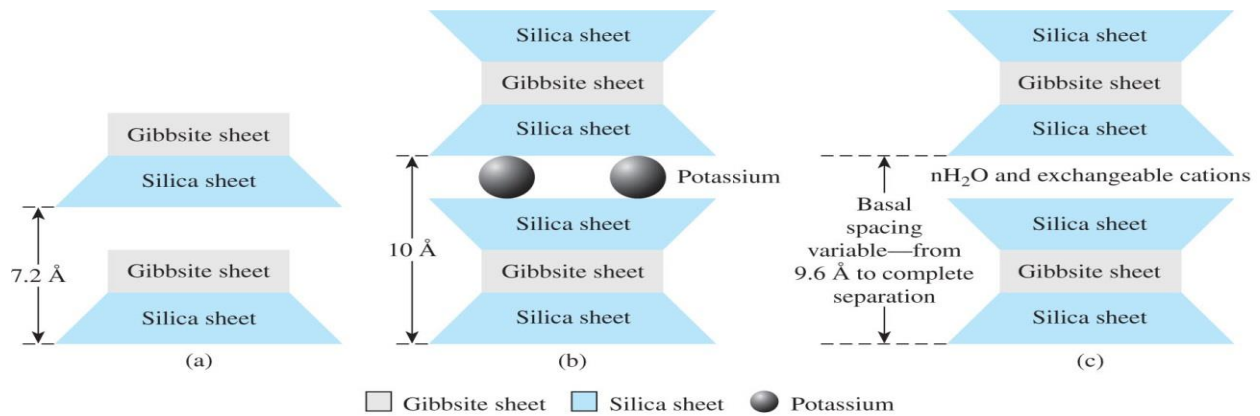

Figure 4. Diagram of structures of (a) Kaolinite (b) Illite (c) Montmorillonite (after Das and Sobhan, 2018)[6]

The three different structures of the clay minerals Kaolinite, Illite and Montmorillonite can be compared to three ladies who all prefer to wear a "skirt", and "hat" except Kaolinite. Based on their different structure characters, each has "her" own distinct engineering behavior. For example, lady clay Montmorillonite likes to drink a lot of water while lady clay Illite prefers to drink mineral water with Potassium. Lady clay "Kaolinite" may like regular water. This kind of language description may help students retain the key features of the three common clay mineral features. This way, it may be of interests and helpful for the students to retain the key characteristics of the three different clay minerals. Understanding their seemingly different striking features and the bonds between the clay layers may better help students appreciate their different engineering behavior from a macroscopic points of view.

Soil Mechanics – Sieve Analysis Connection to Mathematical Science [16]

For soil mechanics sieve analysis laboratory, the sieves even find their applications in mathematical sciences in the theoretical research on prime numbers. Example of Professor Yitang "Tom" Zhang using sieve analysis in his famous twin prime conjecture research can be found in this blog article "Doing It With Twins: the Twin Prime Conjecture"[16]. The article's website is shown as follows http://blog.reigndesign.com/blog/tag/twin-primes/. Interested readers may read that blog for more information. Soil mechanics laboratory sieve analysis is not only useful in civil/geotechnical engineering, but also made contributions to the ideas of mathematics research development.

Soil mechanics and engineering also use mathematical differential equations frequently. For example, elliptic Laplace Equation, $k_x \frac{\partial^2 h}{\partial^2 x} + k_z \frac{\partial^2 h}{\partial^2 z} = 0$, is applied for seepage analysis which however in introductory soil mechanics and engineering often graphical solution methods of flow net analysis for seepage estimation is used. Parabolic soil consolidation differential equation, $C_v \frac{\partial^2 u}{\partial^2 z} = \frac{\partial u}{\partial t}$, is discovered and introduced by the Father of soil mechanics, Karl von Terzaghi, for consolidation settlement mechanism explanation. Following an introductory soil

mechanics course, in foundation engineering, we resort to the hyperbolic wave differential equation, $v_c^2 \frac{\partial^2 u}{\partial^2 z} = \frac{\partial^2 u}{\partial^2 t}$, for deep foundation driven pile driving analysis. Obviously when civil/geotechnical students first time study these differential equations, they will have much more motivation and enthusiasm if the pertinent engineering background are introduced which however in many cases may have been delegated later to the engineering professors who tend to emphasize their greater engineering application importance in their different practicing fields, respectively. In consideration of this general observation, it may be a good idea to offer and require the Partial Differential Equations (PDEs) as a mandatory core graduate level course for MS and PhD graduate students. As finite element course and solving the PDEs relies heavily on Matrix and Vector background, so a graduate course of Matrix and Vector may be required as prerequisite for PDEs graduate course. Ideally both of those courses may be better taught by a professor from an engineering department or a math professor with an engineering background as these courses may often be taught in many other universities graduate programs.

Soil Mechanics – Connections to Agricultural, Biological, Food & Military Science [12, 25-26]

Invariably soil is intimately tied to agricultural and food science and engineering. For the teaching of effective stresses, example of military submarines and fish swimming in deep oceans can be used to help illustrate the concepts of effective stress. Due to most of the body part of fish is filled with pore water and pore water pressure, and the inside and outside of fish pressure difference is not that big and actually quite small compared with the submarine the pressure difference will be much larger since inside submarines it is mainly filled with air for the people to breathe while the fish can breathe through the water. For class room or laboratory demonstration of effective stress concepts, Professor Joseph A Caliendo suggested (2015) using a sealed plastic bag filled with "clays" – effective potato chips to help illustrate the concept [25]. With the bag completely sealed and the air kept inside, the potato chips, or soil "clay" particles in soil mechanics terms are relatively hard to break. But once there is leaking of air from the potato chips bags, and hence increase of effective stress, the clay particles or potato chips will be easier to break [26]. This somehow also can effectively help introduce and teach the effective stress concepts to students.

Understanding soil science and engineering geology sometimes may also play a critical role in the determination of battle or war success or failure during some critical time at some critical places. Not aware or misunderstanding battle ground soil and rock conditions may have changed the world history of human kind [12].

Soil Mechanics – Connections to Soil Memory, Biomedical Sciences [2, 5-6; 28-31; 17]

In the case of an extreme event, like during the ice age, soil can become exposed to a tremendous amount of overburden thick glaciers pressure, which changes the nature and strength of the soil. Soil has a merit of memory because it can remember the maximum past overburden pressure – pre-consolidation stress σ_c' and different loading paths happened to it including the iceberg extreme weight pressure even though the iceberg may have dissolved and disappeared eventually. Ralph Peck once said that "Soil has a merit of memory and it never lies ..."
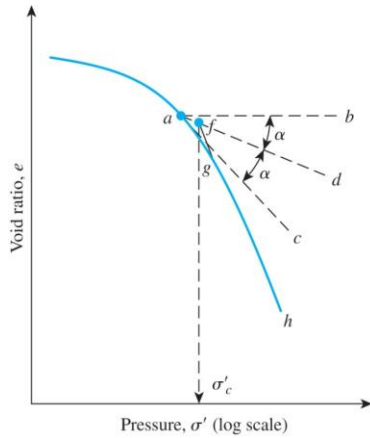
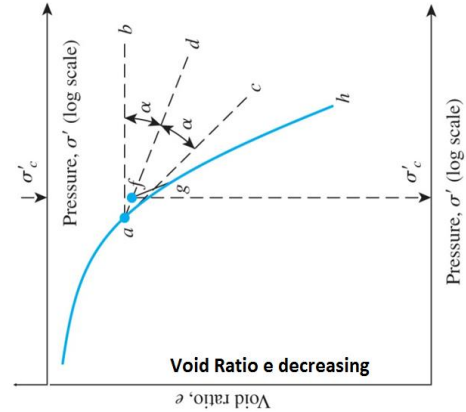Figure 5. σ_c' is essentially initial yield stress, plotted in the void ratio ~ $\log\sigma'$ space.

Figure 6. σ_c' plotted in classical stress ~ strain space, $\log\sigma'$ ~ void ratio space

(after Das and Sobhan, 2018)[5, 6]

Figure 5 shows that soil has a memory of initial yield stress as pre-consolidation stress σ_c' and replotted in the space of $\log\sigma'$ ~ void ratio equivalently to the stress ~ strain space. Replotting the same figure in the traditional solid mechanics manner may better help undergraduate students recall and reconnect with their prerequisite courses including mechanics of materials and/or strength of material subject courses, etc. Herein we use $\log\sigma'$ instead of just σ' has the same reason as that we plot the sieve analysis on a semi-log plot, i.e., to plot low and high stress increase on the same photograph plot. The adoption of the void ratio instead of strain is due to the large strain induced in geotechnical engineering and it is not convenient to use the original soil strata thickness during the relatively large consolidation settlement or deformation calculation. Above figure shows essentially one of the important soil memory concept of pre-consolidation stress along the 1D vertical z direction, σ_c' (or σ_{zc}'). Over consolidation ratio, OCR, is introduced and defined as $\frac{\sigma_c'}{\sigma_o'} = \frac{\sigma_{zc}'}{\sigma_{zo}'}$ wherein σ_o' (σ_{zo}') is currently overburden effective stress.

Theoretically in three dimensions as introduced in the Soil Mechanics II course incorporating critical state soil mechanics frame work, students are exposed to critical thinking by adopting their mindset to a higher three dimensional concept of pre-consolidation pressure $p_c' = \frac{\sigma_{zc}'+\sigma_{yc}'+\sigma_{xc}'}{3}$ and current over burden pressure $p_o' = \frac{\sigma_{zo}'+\sigma_{yo}'+\sigma_{xo}'}{3}$. And hence a pre-consolidation ratio $R_o = \frac{p_c'}{p_o'} = \frac{\sigma_{zc}'+\sigma_{yc}'+\sigma_{xc}'}{\sigma_{zo}'+\sigma_{yo}'+\sigma_{xo}'}$ which has similar concept to OCR $= \frac{\sigma_c'}{\sigma_o'} = \frac{\sigma_{zc}'}{\sigma_{zo}'}$ as introduced earlier, but they are not necessarily exactly the same equal to each other. Students are encouraged to think critically in a higher dimensions of invariant stress of generalized normal and deviatory shear stresses p', q and void ratio space, as embodied in the critical state soil mechanics frame work [2]. Theoretically, geotechnical field problems may be involved in four or five dimensions of space (x, y, z, t, gravity, passion/love or interest of the subjects) which may better prepare and help learners to see the truth out there. The interest, enjoyment or love of a subjects as mentioned in the blockbuster "Interstellar" is borrowed herein and adopted in the soil mechanics II courses introduction to help boost or pique students' interest in studying the subject at a higher level of

understanding of soil mechanics theoretical subjects. The same general formula may be applied to many other different art, science and engineering disciplines study as well.

Soil mechanics and its theory has also found its applications to biomechanics and engineering. Researchers from Cambridge University and Italy have used soil mechanics in their study of brain tissue mechanics. For example, in the PhD thesis titled "The Mechanics of Human Brain Tissue"[17] by Giulia Franceschini (2006), soil mechanics has been recommended as an effective tool for modelling "human brain tissue as a porous, fluid-saturated, nonlinear solid with very small volumetric (drained) compressibility".

In Ted Aloisio's book[1] "Blood Never Lies" (2004), he quotes Dr. Norterhn, "We have sick people because our soils were and are sick (probably mainly because of pollution) which means sick plants, sick animals and hence sick people". This may be partly due to modern agricultural engineering of mass crop production and application of large amount of pesticide in the crops field, etc. Therefore understanding soil science and mechanics should be helpful for dealing with the human health scientific and medical issues.

Soil Mechanics – Applications to Design of Earth Structures [2, 4-9, 13-15]

The lateral earth pressure theory includes active, at rest static and passive earth pressure, respectively. To help the students have some feel or relate to their physical experience of the pressure, simile and comparing themselves as passengers on the bus or subway can be resorted to help reveal the relative characteristics and magnitudes of the three different pressure. The active earth pressure can be compared to the passengers, herein soil particles, trying to get off the bus or subway train full of people (soil), while the passive earth pressure can be imagined for passengers trying to get on an already crowded vehicle which of course needs to require much higher horizontal pressure to be pushed into the vehicle. Similarly, a much higher horizontal stress/force is needed to cause passive earth pressure failure than active earth pressure failure. The static earth pressure may be thought of as all passengers are on the vehicle and even for the passengers standing at the door won't feel much earth pressure (or human body contact) pressure.

Nowadays within the general big culture of the buzzing words "Great, Great Wall" being discussed and actually being built, students are also encouraged to actively participate in local geo-wall design competition to better help with their lateral earth pressure understanding and at the same time prepare themselves for the real world "Great, Great Wall" construction job opportunities after their graduation.

Soil Mechanics – Connections to Art, Poetry and Literature

Soils and soil mechanics indeed plays a great role in our human civilization and physical science and engineering advancement. Regarding its connections to physics and literature, the well-known poet William Blake famously said it all. "To see a World in a Grain of Sand, And a Heaven in a Wild Flower, Hold Infinity in the palm of your hand, And Eternity in an hour"[22] . These are the very first few line from his poem "Auguries of Innocence" to emphasize the importance of soil – sand in our culture and human civilization. Sand, a typical soil particle

connects very fundamental physics with many of our beloved classical poems. Another good example is the poem of "Mending Wall" by Robert Frost. "Something there is that doesn't love a wall, That sends the frozen-ground-swell under it, And spills the upper boulders in the sun; And makes gaps even two can pass abreast." These "intriguing" opening lines will be read very interestingly by a geotechnical engineer.

There are many other forms of art, poetry and literature using soils out there such as songs [19-21], architecture building, painting, pottery and glass made from sand. For example, soil colors serve as pigments in bricks and pottery [19]. Modern times civil geotechnical engineer, Geo-Poet, Mary C. Nodine (2013) [11] chairs a Geo-Poem column on ASCE Geo-Institute's Geo-Strata bimonthly magazines. She really brings in the practical soil mechanics into modern poems nowadays. Actually her poems are so popular and educational, that many professors tend to share it with their soil engineering students. Brock E Barry (2014) paper researched on the effectiveness of using poetry to reinforce civil and in particular geotechnical soil mechanics concepts [3].

Soils also come into play of poems written by ancient Chinese poet, Li Shen (in Chinese 李绅) who lived (772 – 846) in Tang dynasty and left one of the most famous poems of "Toiling Farmers" (in Chinese 悯农) by painting a series of pictures [27]. Literally on the paper, the poem seems to educate people to treasure and value each and every grain of food prepared on a tray as recited by Ivanka Trump's daughter Arabella Kushner on a youtube channel [46]. But the poem author, Shen LI, also describes the agricultural science and engineering and interaction of human being and natural earth/soil in the field.

<div align="center">

锄禾日当午，汗滴禾下土。

Farmers weeding at noon, Sweat down the field soon.

谁知盘中餐，粒粒皆辛苦。

Who knows food on a tray, Thanks to their toiling day?

</div>

Around noon the farmers are still working in the field weeding the grass competing with the growth of crops. Farmers know that that noon is the most effective working time to weed as the sun is up and hot upper there. And the weeded grass will die soon easily and thus leave more space and nutrition for the crop to get the nutrition from the soil in the field. Water, sweat from hard working human bodies drops to the ground below the crops and helps the crops grow, though may not be that effective at that time. It is indeed a beautiful picture of hard working farmers who are helping produce invaluable natural organic food that they need to have in order to survive.

Adopting the traditionally old fashioned way of ancient crops production methodology may partly help solve the medical and health issues related to the "sick soil" raised by Ted Aloisio's book [1]. People, the working farmers, not only get exercises weeding in the field and but also get enough sunlight exposure for Vitamin D transformation for bone health and prevention of autoimmune diseases, cancers, and cardiovascular. At the same time, the old traditional way of farming also helps produce healthy organic food sorely needed nowadays in modern society.

Soil Mechanics – Connections and Contributions to Modern Physics Sciences [18]

The famous beginning part of Hermann Minkowski's address [18] delivered at the 80th Assembly of German Natural Scientists and Physicians (21 September 1908) goes something as follows

where he emphasized the importance of soil physically or literally speaking. "The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

For consolidation settlement, mnemonics of using space and time are interchangeable by analogy of Albert Einstein's big idea of $E = MC^2$ is helpful. This may not necessarily is strictly accurate from a theoretical physics point of view, but at least it can help students to remember the fundamental differential equation of consolidation, $C_v \frac{\partial^2 u}{\partial^2 z} = \frac{\partial u}{\partial t}$, i.e., the change of "pore water pressure u – pronounced YOU" with respect to time is equivalent to the second derivative of "pore water pressure u – pronounced YOU" with respect to second derivative of vertical distance z herein. Also the interchange of time and space is meaningless if there is no "YOU - pore water pressure, u" in the equation. That is the reason why the u has come into the play. It is worthy to point out that the units [m²/s] of coefficient of consolidation, Cv, has the same units of kinematic viscosity, v, and diffusion coefficient, D, in Fick's 2nd Law which may imply or indicate some relationship between them as they all describe the diffusion of flux of a variable YOU.

The same form of consolidation Partial Differential Equation (PDE) also applies to Fick's 2nd law describing non-steady-state diffusion in materials science and engineering [23]. Additionally, the above equation also shows up in mechanical engineering heat equation [24] as well. Some researchers/scientists implied that Karl Terzaghi's consolidation equation was inspired from the heat transfer discipline science as his initial major was completed in mechanical engineering [7].

In the above different equations discussed, the variable come into play may refer to different variables, say concentration flux, heat flux, and pore water pressure flux and even YOU, as human being flux, from the wildest point of views as shown in next paragraph.

Soil Mechanics – Connections to Political and Philosophical Sciences

Somehow, from a wild philosophical point of view, each one of our individual human being can be considered as an individual pore water particle under pressure, and we all tend to like to consolidate and somehow and someway people do behave like that. For example, the generalized pressure in the soil mechanics consolidation differential equation $C_v \frac{\partial^2 u}{\partial^2 z} = \frac{\partial u}{\partial t}$ may be considered in a form of finance, loud sound noises or even constant low level noise exposure could "expel u – pronounced YOU, pore water pressure" from a certain place or office location to a relatively quieter place within in the same building or organization's different buildings. Unknowingly, in many developed countries, many people tend to like to enjoy more of a comfortable indoor climate but forget or tried to ignore the loud air conditioning noises effects in their daily living or working places. Some college students having trouble of concentrations may have been exposed to this type of constant low level air conditioning noises or loud music exposure during their childhood or sometimes during their adult life, which eventually helps lead to the claimed disability service or may be due to other mental or physical health reasons. Part of the problems could be solved or reduced by better and improved engineering design together with optimized administration and operations management to eliminate the poverty or funding deficit associated

loud noises making air conditioning systems installed in the houses, buildings, or many apartments with high and even low level vibration noise generated from nearby working machines. Though the pressure may come from outside society such as environmental, economic and financial pressure, often this pressure may come from a person's inner side desire or drive to excel which tends to keep and guide his or her ways of thinking, working, living and moving from where they were brought up to their current places and positions.

Soil Mechanics – Inspirational Videos/Documentary Films

A documentary film in the same style of the popular Albert Einstein's documentaries film as seen on youtube has been suggested and recommended to the ASCE Engineering Geology & Site Characterization Committee for consideration of promotion of developing an inspirational movie about the father of soil mechanics [44-45]. On the internet, there are also many inspiring geotechnical promotional videos and educational webinars and distinguished lectures freely available. Students are also strongly encouraged to explore by themselves for the best effects of learning soil mechanics. For example, Hayward Baker and ISSMGE both produced short but very interesting and inspiring geotechnical videos "Introduction to Geotechnical Engineering for the CGEA" [32] and "What is Geotechnical Engineering" [33], respectively. Even NASA's 50 years of Mars Exploration [32, 35] short film maybe introduced at the beginning of soil mechanics instruction to help students become interested and getting excited for this century's new soil mechanics era of terraforming Mars [32, 35-42].

Although there are Terzaghi lectures frequently available at ASCE Geo-Institute Youtube channels and many other pioneers' lectures being delivered often to the geo-professionals, there is still a need of producing a Karl von Terzaghi film targeting the general public audience and particularly incoming college freshmen as the target audience. Therefore in honor and in memory of the father of soil mechanics and many other pioneering figures in the development of soil mechanics, there is indeed a need to inspire more students to study civil and in particular soil mechanics and geotechnical engineering.

What we need now is a best film script based on Karl von Terzaghi's biography "The Engineer as Artist" already published by ASCE Press written by Professor Richard E Goodman[7]. "The Engineer as Artist" is a great book to read and students will become inspired by Professor Goodman's vivid description and account of von Terzaghi's biography to develop soil mechanics and engineering. At Purdue University Northwest and many other universities, almost every university has some national student script winner writers, therefore, the author also encouraged his students to read Karl Terzaghi's biography and maybe even take a selective course like Script Writing during their college education if they have a strong interest of the father of soil mechanics, Karl von Terzaghi documentary film development.

Soil Mechanics – Terraforming of Extraterrestrial Planets
Terraforming extraterrestrial planets like moon and Mars for example into the "Earth 2.0" also will need the contribution and input of soil mechanics application [32, 35]. In this regard, Caltech has a series of "Measurements and Models at the Surface of Mars" webinars related to the soil mechanics on Mars Terramechanics. Interested readers or viewers are encouraged to check more the youtube channels listed in the reference [32, 35-39]. In the same spirit, Purdue University has

also established an Extraterrestrial Habitat Engineering program to meet this and next century needs of terraforming extraterrestrial planets [43].

CONCLUDING REMARKS

As a physical science and fundamental course in engineering sciences and civil engineering in particular, soil mechanics could be required as a core civil engineering courses, and maybe even as a general education course as well making it available to all those incoming college freshmen and in particular as a required or recommended selective course for engineering and sciences students. In many universities, biology is recommended and even as a required general education course, but not for soil mechanics or soil engineering. If it is not a required course, at least it may be made an optional one or even a recommended course for engineering and science major students. The article discusses from the points of view of piquing students interests in soil mechanics and how to effectively teach soil mechanics concepts, ideas and theory using mnemonics and by connecting soil mechanics' close relation and applications to agricultural, biological, mathematical sciences, fundamental modern physics and everyday life and their personal experiences. Students are also strongly encouraged to become visual image thinker like the pioneering physicist Michael Faraday which somehow better help students learn soil mechanics materials as well. Reminding and helping students to keep an image understanding of normal consolidated and over consolidated soils loading paths and corresponding equations are also helpful in soil mechanics study. This century and next century human kind may land on Mars, and there is a need to inspire students to study soil mechanics on Earth but also prepare them for terraforming Mars in the years to come.

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APPENDIX: A Simple Soil Mechanics Mnemonics Exercise

Explain the arbitrarily juxtaposed punch lines of following soil mechanics quiz using the soil mechanics language and mnemonics introduced in the article.

Question: "The PI of soil memory, σ_c' (or p_c'), mnemonics is Dr. R. LI"

Answer: PI: Plasticity Index = LL- PL = $w_{LL} - w_{PL}$; Soil Memory: σ_c' (or p_c'); Dr = $\frac{e_{max} - e}{e_{max} - e_{min}}$; R= $\frac{\gamma_{d(field)}}{\gamma_{d(max-lab)}}$ and LI = $\frac{w - w_{PL}}{w_{LL} - w_{PL}}$.

Above is an example of key knowledge points addressed in several different chapters of soil mechanics and engineering and reviewed and tested in a simple punch line statement sentence.