Compaction of Fine-Grained Soils Using the Proctor Method

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Writer's Comment: Writing a technical description for an engineering process posed the daunting task of identifying a process that captures the essence of the diverse profession. Having recently taken a course on soil mechanics, I inevitably began to gravitate towards a concept with which most civil engineering students are familiar: the compaction of soils. I hoped to capture the minutiae associated with laboratory compaction processes, and that would also demonstrate the importance of proper compaction to construction processes and the performance of structures. The technical complexity of this article supplements civil engineering students' laboratory and classroom of understanding of the processes governing compaction. Authoring this article truly tested my own understanding of the subject and encouraged me to write in a manner that is both engaging and informative for my peers. This article would have been less success without Dr. Katie Rodger's great syntactical tips, which she provided me throughout the drafting process. Finally, I'd like to thank my soil mechanics professor, Dr. Arash Khosravifar, for helping me to understand the importance of the recurrent theme of compaction in civil engineering.

Instructor's Comment: Students in my Professional Science Writing course are often among the most ambitious undergraduates I teach. Many are in the final quarters of their degree programs, and are eager to apply the concepts and theories that they've studied to professional writing styles and forms that they will need to master as scientists in their respective fields. One of the essential skills we discuss is the ability to clearly write a technical description about a process. For many *students, this is a far more difficult assignment than they anticipate, but Charuni Kurumbalapitiya rose to the task, and exceeded my expectations with her description aimed at civil engineers. Her "Compaction of Fine-Grained Soils using the Proctor Method" balances the demands of this kind of technical writing—providing a clear and logical description of the method with appropriate and professional details. Charuni is an excellent writer and thinker, and I look forward to following her career in engineering.*

– Katie Rodger, University Writing Program

Scope

The audience for this technical description is upper division civil engineering students who have demonstrated an interest in soil mechanics and who are currently enrolled in a geotechnical laboratory class. Hence, the reader is assumed to possess a thorough understanding of the core concepts and terminology associated with soil mechanics. The reader will have completed relevant coursework in lower division math and physics and will be familiar with concepts pertaining to density and dimensional analysis. This article demonstrates how compaction tests are performed in the laboratory to generate compaction curves for a specific soil type. This document may serve as a supplement to ASTM standards delineating laboratory methods for compaction.

Introduction

Fig. 1: Field Compaction using a Sheepsfoot Compactor.
Fig. 2: Field compaction with smooth steel drum roller.

Prior to the construction of a structure, it may be necessary to strengthen the engineering properties of the soil present at a site by subjecting it to compaction. *Compaction* is the process by which mechanical energy is used to induce the densification and stabilization of a soil matrix. Compaction processes may also alter both the water content and the grain size distributions of the soil. The objectives achieved through compaction include the following: reduction of settlement in structures, increase in slope stability, increase in the bearing capacity of soil, reduction of hydraulic conductivity of soil, reduction in swelling of the soil matrix, and the creation of uniformity within soils. The successful compaction of soil is crucial to the stability and function of modern structures such as retaining walls, pavement subgrades and foundations, as well as dams and other hydraulic structures.

Theory of Compaction for Soils

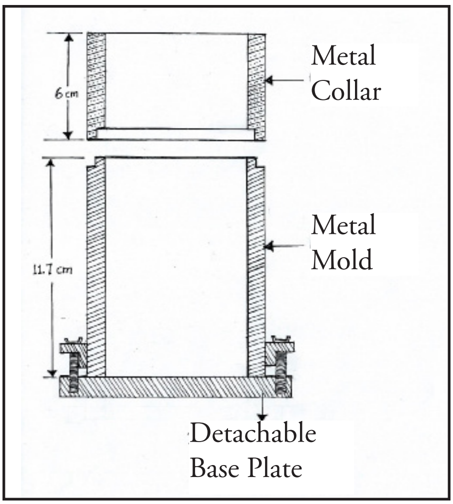

Fig. 3: Apparatus and specifications for the Standard Proctor Method of Compaction

The principles of compaction were first developed by R.R. Proctor in 1933. Although his concepts were initially used for field compaction, Proctor's methods led to the creation of two popular standard laboratory compaction tests: the *Standard Proctor* and the *Modified Proctor* tests.

The primary objective of performing a Proctor test is to determine the maximum dry density ($\rho_{d,max}$) and the optimum water content (ω_{opt}) at compaction effort. In the laboratory, both Proctor tests are used for the compaction of fine-grained soils. The choice of Proctor test is determined by the application: the modified Proctor produces denser soil fabrics than the standard Proctor. A typical Proctor test consists of placing a remolded soil sample within a ring mold and hammering the sample with a dropped weight to induce compaction (see Fig. 3 & 5). However, the tests differ with respect to the weight and drop height of the hammer, as well as the number of soil layers placed in the ring mold.

Typically, any compaction process is governed by four main parameters unique to a soil sample. These parameters include type of soil (clayey or sandy), dry density (ρ_d), water content (ω), and compactive effort (C.E). The C.E (measured in N-m/m3) is a measure of the mechanical energy required for compaction and is a function of the following experimental parameters: volume of the mold, mass of the mold, height of the hammer drop, number of drops and the number of soil layers used.

By determining the parameters governing a compaction procedure with the aid of both the Standard and Modified Proctor tests, a civil engineer can find the optimum conditions at which compaction should be performed at a site. These optimum conditions are interpolated from the peaks of compaction curves (plots of ρ_d vs. ω), which are graphed using the data obtained from the standard and modified Proctor compaction tests (Fig. 4).

Conducting Proctor Methods of Compaction

Having established the significance of the Proctor Methods, it is possible to distinguish how standard and modified Proctor tests are conducted in the lab. However, note that both Proctor Methods are preceded by a stage of soil preparation (discussed below). Here Yolo Loam, a soil typical to the area, is used.

Preparation of Soil Sample and the Determination of ω_n

Acquire ten separate 2.0 kg samples of Yolo Loam; participants may obtain one sample at a time, as needed. Sieve these ten soil samples using a #4 sieve and include all soil particles that pass through the sieve. Any material that has been retained on the surface of the sieve must be discarded to prevent contamination of the sieved samples of Yolo Loam. Using a microwave, determine the natural water content of the sieved soil samples. To obtain a value for ω_{opt} that is numerically close to the estimated ω_{opt}, students must reconstitute soil samples before layering the soil within the Proctor Mold. Each soil sample is remolded with reference to a target water content (see Table 1.0, Appendix 1.0), which was selected using the estimated ω_{opt}. Hence, the mass of the soil sample and its ω_n, can be used in Equation 3 (see Appendix 1.0) to determine the additional quantities of water required to achieve the desired water content of the soil samples. To begin the remolding process, place the soil in a stainless steel bowl. Ensure that the sample is stirred continuously with a spatula, while the soil is sprayed consistently with a mist of water. Avoid pouring water into the sample, as it prevents uniform mixing of the water and soil. Once the required amount of water has been added, continue to mix the soil until its appearance and texture are both uniform.

Compaction of Specimen

First, obtain the height, diameter and the mass of the Proctor Mold; an average of three measurements is required for best results. Then, assemble the collar onto the 4-inch mold, using thumb screws. To compact the soil according to the Standard Proctor Method, arrange one layer of soil within the mold and compact it by delivering 25 blows (per layer) with a 5.5lb hammer at a 12-inch drop height; repeat for three layers of equal thickness. Ensure that each layer is well compacted before placing the next layer. Similarly, to compact the soil by the *Modified* Proctor Method, place a layer of soil within the mold, and compact it by delivering 25 blows (per layer) with a 10lb hammer, at an 18-inch drop height. Repeat for five layers of equal thickness. For both methods, scarify the top of each compacted layer of soil with a metal spatula to ensure cohesion between layers. Estimate the height of each layer, such that the top of the mold is exceeded by no more than 0.25" after compaction of the topmost layer. During compaction, move the hammer in a circular manner around the mold to ensure the uniform compaction of each layer. Following compaction, remove the collar and trim any excess soil protruding from the top of the ring mold. For best results, use a straight-edged trimming device. It is suggested that prior to the removal of the collar the top of the specimen be pried with a thin metal spatula to prevent breakage. Next, re-weigh the mold and the base; include the compacted soil sample. Using an extruder, remove the compacted specimen from the mold. Remove a 20g piece of soil from the center of the specimen and use the extracted piece to determine the water content of the soil sample.

By repeating the Proctor methods for compaction for various target water contents (Table 1.0) and obtaining the water contents of the soil samples, a compaction curve (Fig. 4) can be plotted. Values of ω_{opt} and $\rho_{d\ max}$ can be interpolated from this compaction curve. As the structure of a soil is a function of the molding water content, knowing the ω_{opt} and ω_{dmax} allows the student to assess if the structure of the soil fabric is flocculated or dispersed, and to speculate the contribution of the soil structure to the engineering properties of the compacted Yolo Loam.

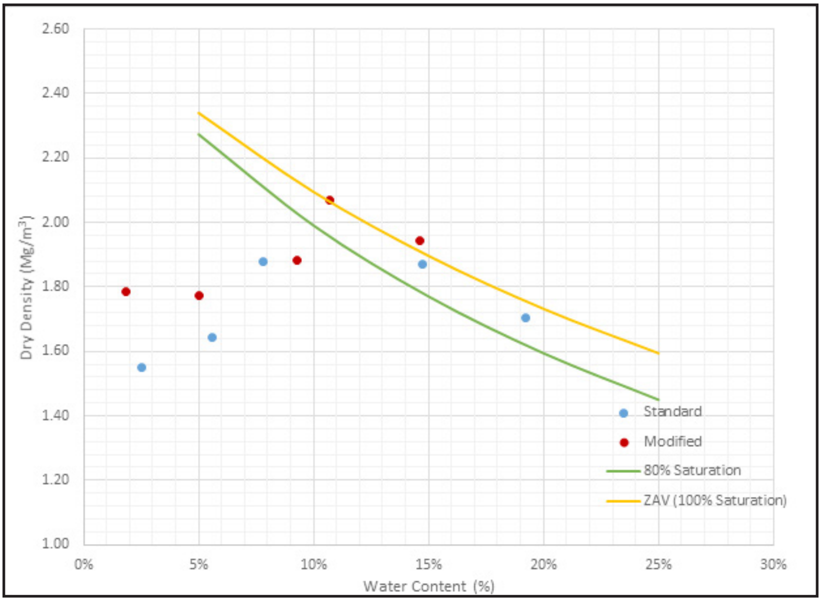

Fig. 4: Compaction Curve for Yolo Loam

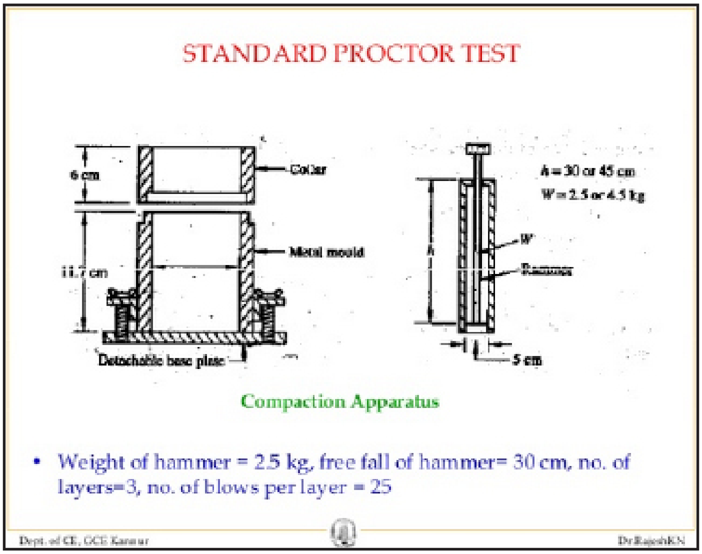

Fig. 5: Performing the Proctor Method of compaction in the Lab

Conclusion

The fortification of the engineering properties of soil through compaction can significantly affect the longevity of structures built at a site. Using the Standard and Modified Proctor methods in the determination of the optimum conditions for field compaction (ω_{opt} and $\rho_{d\ max}$) is necessary during quality control assurance at the time of construction. Engineers' knowledge of $\rho_{d\ max}$ is crucial to gauging the level of relative compaction reached on field.

Knowledge of compaction and accurate interpretation of data from relevant testing procedures is indispensablein the realm of soil mechanics. Hence, the civil engineering student greatly benefits from understanding not only the significance of the Proctor Method but also the correct method for performing such compaction tests in a laboratory environment.

Appendix

Equation 1: Water Content

$$\omega = \frac{M_w}{M_s}$$

Where: M_w = Mass of water
M_s = Mass of soil

Equation 2: Dry Density

$$\varrho_d = \frac{\varrho_t}{(1+\omega)}$$

Where: ϱ_t = Total/ Wet Density
ϱ_d = Dry Density ω = Water Content

Equation 3: Amount of Water to be added

$$\omega_f = \frac{M_{wi} + \Delta M_w}{M_{si}}$$

Where: f = Final target water content
M_{wi} = Initial mass of water in soil
ΔM_w = Amount of water to be added
M_{si} = Initial mass of soil

Table 1.0: Target water contents for each Proctor Method Method of compaction

Method of Compaction	Target water content				
Standard Proctor	3%	8%	12%	16%	20%
Modified Proctor	3%	6%	9%	12%	15%

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