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Displacement Derived Energy Levels for Harvard Miniature Compaction

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Introduction

Often, the strength of natural soil that is found on a site is not suitable to prevent structural failure, soil settlement, and/or proper water drainage. Soil compaction, which reduces the volume of air in soil by the application of compactive effort, is frequently used to enhance the mechanical properties of soil in earthworks such as dams, roads, railways (Li et al., 2017). During compaction, soil particles slide, roll, and reorient. Compaction provides a significant increase in the density of the soil that leads to an increase in the shear resistance of the soil. At the same time, a reduction in void ratio, pore size, and porosity decrease soil permeability.

The design, planning and execution of proper compaction at a site is the result of laboratory-based soil compaction tests such as the Standard Proctor Test (Kotdawala, 1994). The data obtained from such test is presented in form of a soil compaction curve. Specifically, the 1) moisture-density relationship, 2) the maximum dry density, and 3) the optimum water content are obtained from a series of four to five compaction tests performed at a specific energy level. However, the compactive effort produced in the field varies across the site and cannot be accurately represented by a single energy curve. For this reason, Daniel and Benson (1990) proposed the use of several compactive efforts in the laboratory that span a range of compactive efforts expected in the field. In addition to Standard Proctor (ASTM D698), that represents medium compactive effort, Daniel and Benson (1990) suggested using the of Modified Proctor (ASTM D1557) for earthwork projects to represent an upper limit on the compactive effort. Additionally, Daniel and Benson (1990) presented a Reduced Proctor, an altered Standard Proctor where all parameters are kept the same except that 12-12-13 drops of the hammer per layer are performed, instead of 25 blows per layer to produce a lower limit on the compactive effort. The result is three compaction curves that shift up and to the left as compactive effort increases (Figure 1). The purpose of the Daniel and Benson (1990) method is to obtain a broad range of compaction energies that can compared to such obtained on the field.

Other, not so common laboratory tests, such as the Harvard Miniature are also used to determine proper compaction on a site. The Harvard Miniature test is a smaller scale apparatus that produces samples in less time and with the use of 2080g less material per specimen than the proctor apparatus.

With this paper a comparison between the Harvard Miniature test and the Proctor test will be provided to prove if the methods specifically, modifications to the Harvard Miniature tamper were evaluated to determine if modified, standard, and reduced energies could be obtained. As described, the results obtained from the proctor method and Harvard method where compared for evaluation.

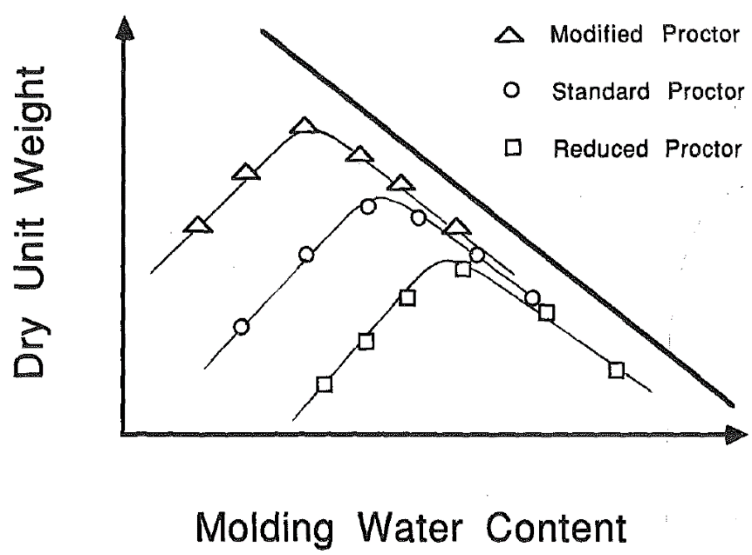

Figure 1. Compaction curves for the reduced, standard and modified compaction energies (Daniel and Benson, 1990).

Background

The most common soil compaction test is the Standard Proctor test that was originally proposed by R. R. Proctor in 1933 (Davis, 2008). According to the ASTM D698 (2012) standard, during the Proctor test, fractions of similar soils with different moisture contents are compacted in a four inch [101.6mm] diameter mold with a 5.5lb [24.47N] hammer dropped from a height of 12in [304.8mm]. Following ASTM

D698 (2012) soil, at a selected molding water content, is placed in three layers into the mold and, each layer is compacted by 25 blows from the hammer to produce a compactive effort of 12,400 foot-pounds per cubic foot [600 kN-m/m^3]. This testing procedure can also be performed using modified effort. According to Davis (2008) the modified Proctor test was introduced as an ASTM Standard in 1958. The modified proctor test is also a laboratory compaction test using a four-inch mold. Following the ASTM D1557 (2012) standard, the modified test consists of a 10lb [44.48 N] hammer being dropped from a height of 18in [457.2mm]. Using the ASTM D1557 (2012) method, soil, at a selected molding water content, is placed in five layers into the mold, each layer is compacted using 25 blows producing a compactive effort of 56,000 foot-pounds per cubic foot [2,700kN-m/m^3]. In a similar fashion, a reduced Proctor test is performed in a four-inch mold with a 5.5lb [24.47N] hammer dropped at a height of 12in [304.8mm] following Daniel and Benson (1990). For the Daniel and Benson (1990) method, soil, at selected molding water content, is placed in three layers into the mold, with the respective layers being compacted by 12, 12, and 13 blows, to produce a compactive effort of 6187.5 foot-pounds per cubic foot [296.317kN-m/m^3].

In 1950 Willson developed a smaller compaction apparatus, identified as the Harvard Miniature apparatus. According to Wilson (1950), The Harvard Miniature apparatus was created to address, “The time and effort and quantity of material required to obtain moisture-density curves are serious shortcomings of the presently laboratory compaction procedures.” Specifically, the apparatus was developed to obtain data by means of using a small mold, a tamper, a collar remover and a sample ejector. The tamper contains a one-half inch [12.7mm] diameter metal rod with an adjustment nut to preset the compression of the spring to a desired energy level. The mold has a 1 1/15in [27.09mm] inside diameter and a volume of 1/454 cubic feet [62.37ml]. When the operator pushes down onto the housing of the metal rod resting on the soil in the mold, the load is transfered through the spring into the soil. Dimensions of the tamper are presented in Figure 2. This kneading action imitates the compactive effort of a sheepsfoot roller (Willson, 1950).

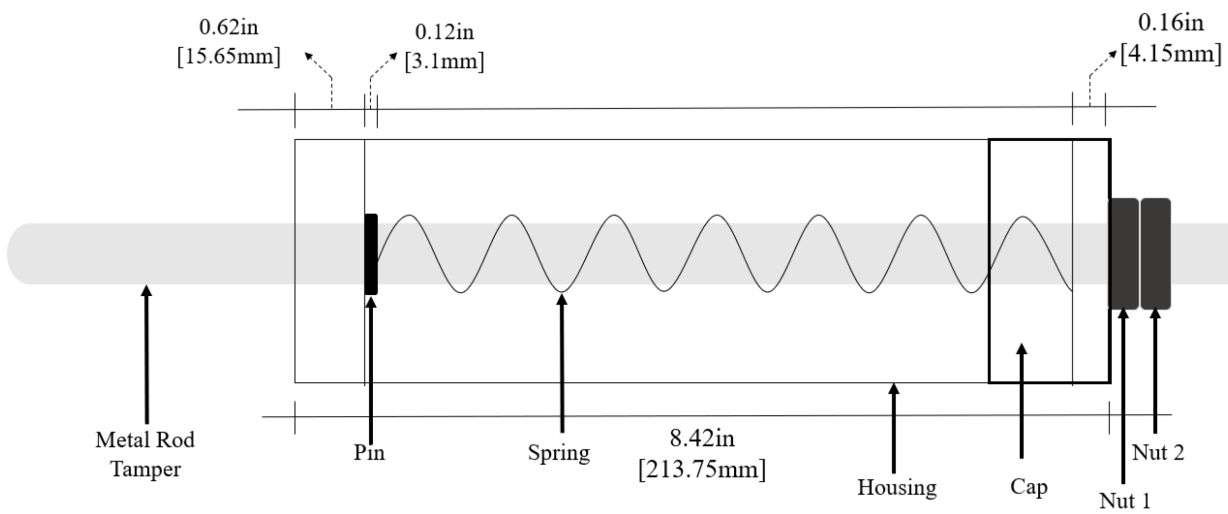

Figure 2. Harvard Miniature tamper dimensions

The Harvard Miniature apparatus has been used throughout the years. together with the Proctor test and other laboratory compaction tests, to obtain compactive curves that span a range of compactive efforts. The information obtained from the Harvard Miniature apparatus is not only used in practice to determine compaction procedures in the field but has also been used for further research in the geotechnical realm. Examples of the use of the Harvard Miniature apparatus include those of Olsen and Leonard (1982)

Olsen and Leonard (1982) presented a series of strength tests in a calcareous Playa Lake clay. A moisture density relationship was found for Standard Proctor tests (ASTM D698), Modified Proctor tests (ASTM D1557) and Harvard Miniature tests. Specimens performed using the Harvard Miniature where compacted in three lifts using twenty-five tamps per lift of a 40lb [179N] spring. The optimum water content for all three compactive curves was 15 ± 2 percent. The maximum dry density increased by 5 lb/ft^3 for Standard Proctor, Harvard Miniature and Modified Proctor tests, respectively.

Kotdawala (1994) performed a variety of tests using different soil types and compaction methods (including Proctor tests and Harvard Miniature tests) to develop a knowledge-based system to assist field engineers with inspection of the soil compaction based on theory and practice. Proctor tests were performed at Standard and Modified energy. Harvard Miniature tests were performed at three different efforts: 15 tamps per layer (H1), 25 tamps per layer (H2) and 35 tamps per layer (H3). The results showed that, regardless of the soil type, the Harvard Miniature samples from a given effort level generated a higher degree of saturation compared to Proctor samples (Kotdawala, 1994). The maximum dry density of all tests performed at different efforts varied arbitrarily depending on the soil type.

Objective

Previously, the amount of energy provided by the Harvard tamper was adjusted by changing the number of blows per lift or the number of lifts or was not adjusted at all. However, this research was conducted to investigate the effect of adjusting the displacement of the spring (increased or decreased) to change the potential energy of the spring and therefore change the compacive effort with a specific type of soil. Thus, the objective was to match the compaction energies using the Harvard miniature method with the compaction energies obtained using the Proctor method. Specifically, the goal was to show that a change in the resistance of the spring could imitate Proctor compaction at reduced, standard, and modified compactive efforts.

Experimental Work/ Method

To properly compare compaction results obtained from the Proctor method and the Harvard Miniature method, an equivalent energy must be applied from the Proctor hammer and the Harvard tamper. The energy obtained during results from the Proctor test results from the number of lifts, the number of blows per lift, the hammer weight, the hammer drop height, and the volume of the mold. As previously mentioned, standard energy of the Proctor mold should be 12,400 foot-pounds per cubic foot [600kN-m/m^3], modified energy should be 56,000 foot-pounds per cubic foot [2,700kN-m/m^3], and reduced energy should be 6187.5 foot-pounds per cubic foot [296.317kN-m/m^3].

For the Harvard Miniature method, the energy was calculated in terms of the number of layers, the number of blows per lift, the potential energy of the spring in the tamper, and the volume of the mold. As previously shown the Harvard tamper is composed of a spring compassed within the housing of the tamper. The potential energy of the tamper relates to the potential energy of the spring: $\frac{1}{2}\mathrm{kx}^2$. The spring constant [k] was determined for each spring separately through the use of a load frame shown in Figure 3. The load frame was set up using a 100 lb [45.36kg] load cell. Each spring was placed inside the tamper with no additional displacement. The spring within the tamper was compressed using the load frame and the load and displacement were recorded at 0.05 inch [1.27mm].

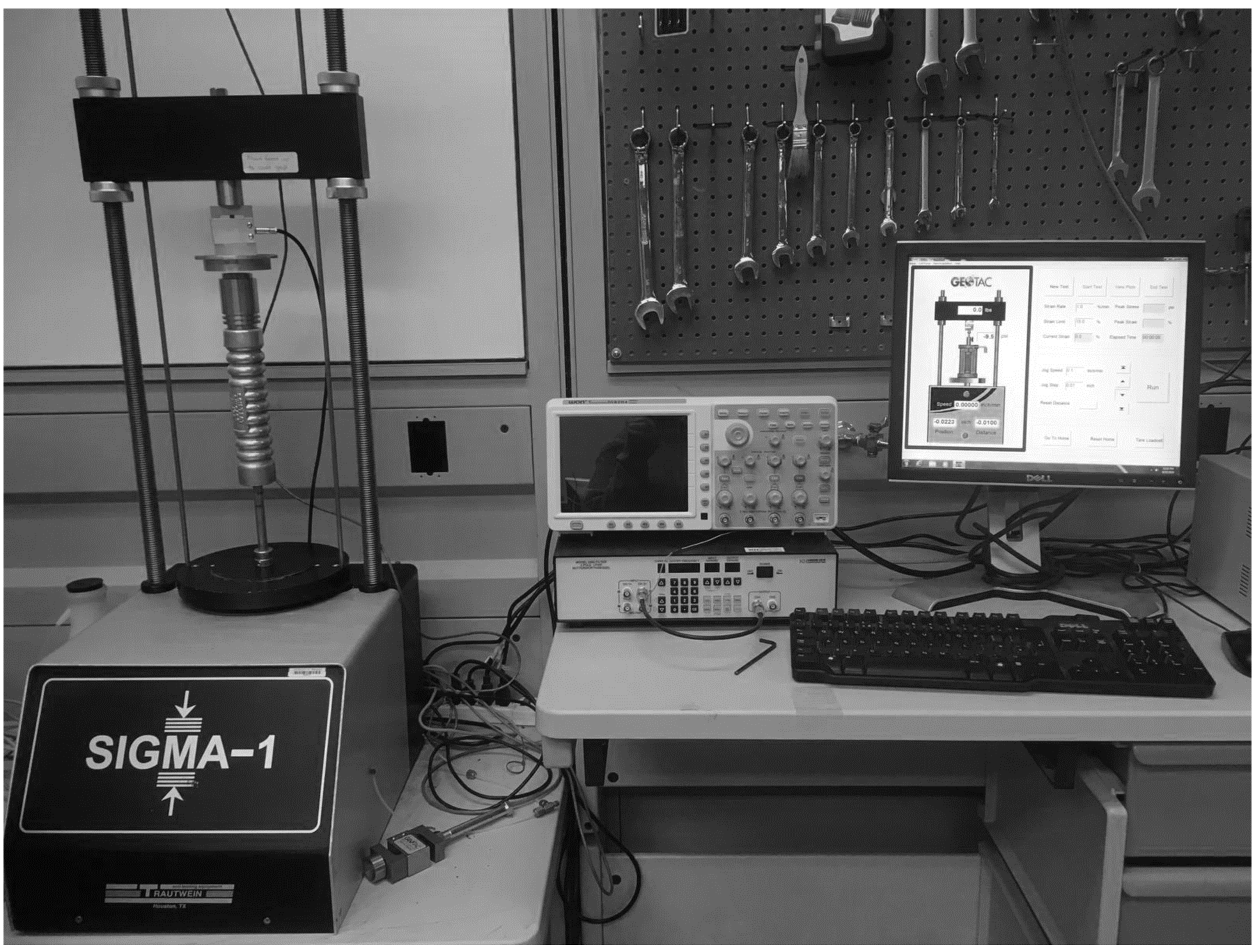

Figure 3. Loading cell setup.

The recorded loads and displacements were plotted together and the slope of the line of best fit that corresponded to the spring constant. The initial displacement of the spring due to the assembly of the tamper was determined by precisely measuring the tamper components. A caliper was used to measure the initial length of the spring, the length of the entire housing, and the lengths of the parts of the tamper. The initial displacement of the spring was then calculated using Equation 1.

$$D_i = L_s - H - \Delta H \qquad [Eqn.1]$$

The following parameters were used in Equation 1.

D_i= The initial displacement of the spring,

L_s= The initial length of the spring,

H= The length of the housing, and

ΔH= The change in housing due to design of cap and pin of tamper.

The Harvard Miniature energy was set equal to the desired Proctor energy and the total displacement needed was determined using Equation 3 which is a rearranged version of Equation 2.

$$E = \frac{\#blows/lift \ \times \#lifts \times \frac{1}{2}kx^2}{V} \qquad [Eqn.2]$$

$$x = \sqrt{\frac{E \times V \times 2}{\#blows/lift \times \#lifts \times k}} \qquad [Eqn.3]$$

The following parameters were used in Equations 2 and 3

x = The total displacement [ft],

E = The energy required [lb $\mathrm{ft/ft^3}$],

V = The volume of mold [$\mathrm{ft^3}$], and

k = The spring constant [lb/ft].

The additional displacement required by the spring within the tamper, to achieve the required amount of energy, was calculated by using Equation 4.

$$D_r = x - D_i \qquad [Eqn. 4]$$

The following parameters were used in Equation 4

D_r = The required additional displacement,

x = The total displacement, and

D_i = initial displacement, as obtained from Equation 1.

The required displacement was achieved by placing the tamper, with the spring inside, into the load frame. The tamper was then compressed by the required amount of displacement, as determined to four significant digits. At the required compression, the intersection of tamper rod and tamper housing was marked and the tamper was removed from the load frame. The tamper was then displaced to the prescribed distance for use in compaction at a prescribed energy level.

A minimum of five Proctor tests and five Harvard Miniature tests were performed for each energy level (reduced, standard, and modified). For the Proctor tests, the energy was changed as a result in the change in the number of blows, number of lifts, hammer weight, and/or hammer drop height with the only constant being the volume of the mold. For the Harvard molds, the energy was only changed by a change of the potential energy of the tamper, specifically by the displacement of the spring in the tamper. Constants included the number of layers and number of blows per lift at five and 25, respectively, the spring constant (k=121.2 lb/ft [1.769 kN/m]) as the provided "40lb" spring was used for each energy level, and the volume of the mold was constant (V=0.0022 ft^3 [62.88 cm^3]).

Results

The results for maximum dry density and optimum water content for Proctor tests and Harvard Miniature tests at reduced, standard, and modified energy are summarized in Table 1.

Table 1. Optimum water content and maximum dry density results.

	Reduced		Standard		Modified	
	Opt w [%]	Max γ_d $[lb/ft^3]$	Opt w [%]	Max γ_d $[lb/ft^3]$	Opt w [%]	Max γ_d $[lb/ft^3]$
Proctor	16.0	107.7	15.1	109.6	10.6	124.6
Harvard	17.4	107.1	15.2	110.1	15.2	110.8

Data points for the Proctor test and Harvard Miniature test, at standard energy, are shown in Figure 4. The maximum dry density of the Standard Proctor test was 110.15 lb/ft^3 as compared to the Standard Harvard Miniature test that was 109.62 lb/ft^3. Additionally, the optimum water content obtained from the Standard Proctor and the Standard Harvard Miniature test were 15.07% and 15.16%, respectively.

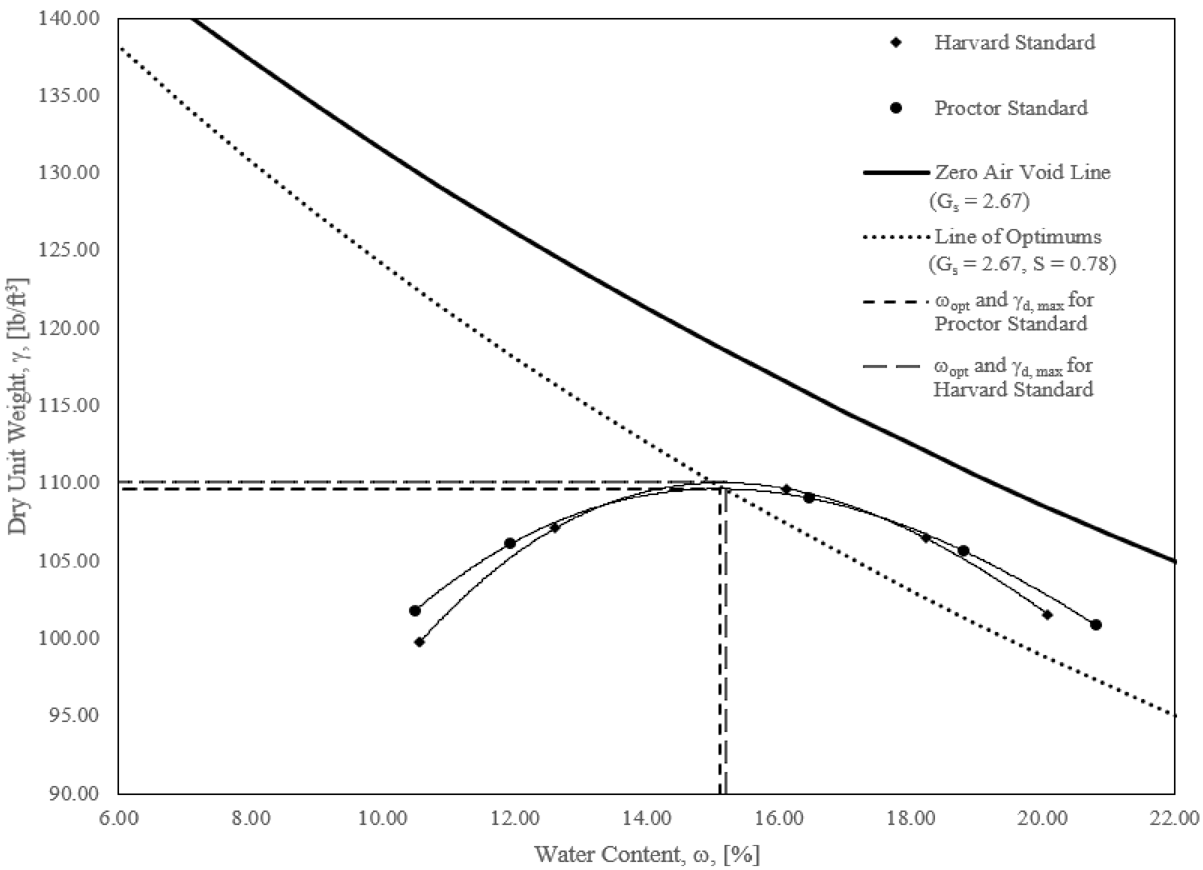

Figure 4. Data obtained Harvard Miniature and Proctor test at standard energy.

Conversely to the Standard Proctor and Standard Harvard Miniature data, the points for Harvard Miniature Test at modified energy were not in good agreement with results from the Modified Proctor Test (Figure 5). The optimum water contents varied by 5.4 percent. The maximum dry density for Modified Proctor was 124.6 lb/ft^3, which was significantly higher than 110.8 lb/ft^3 that was obtained from the Modified Harvard Miniature test.

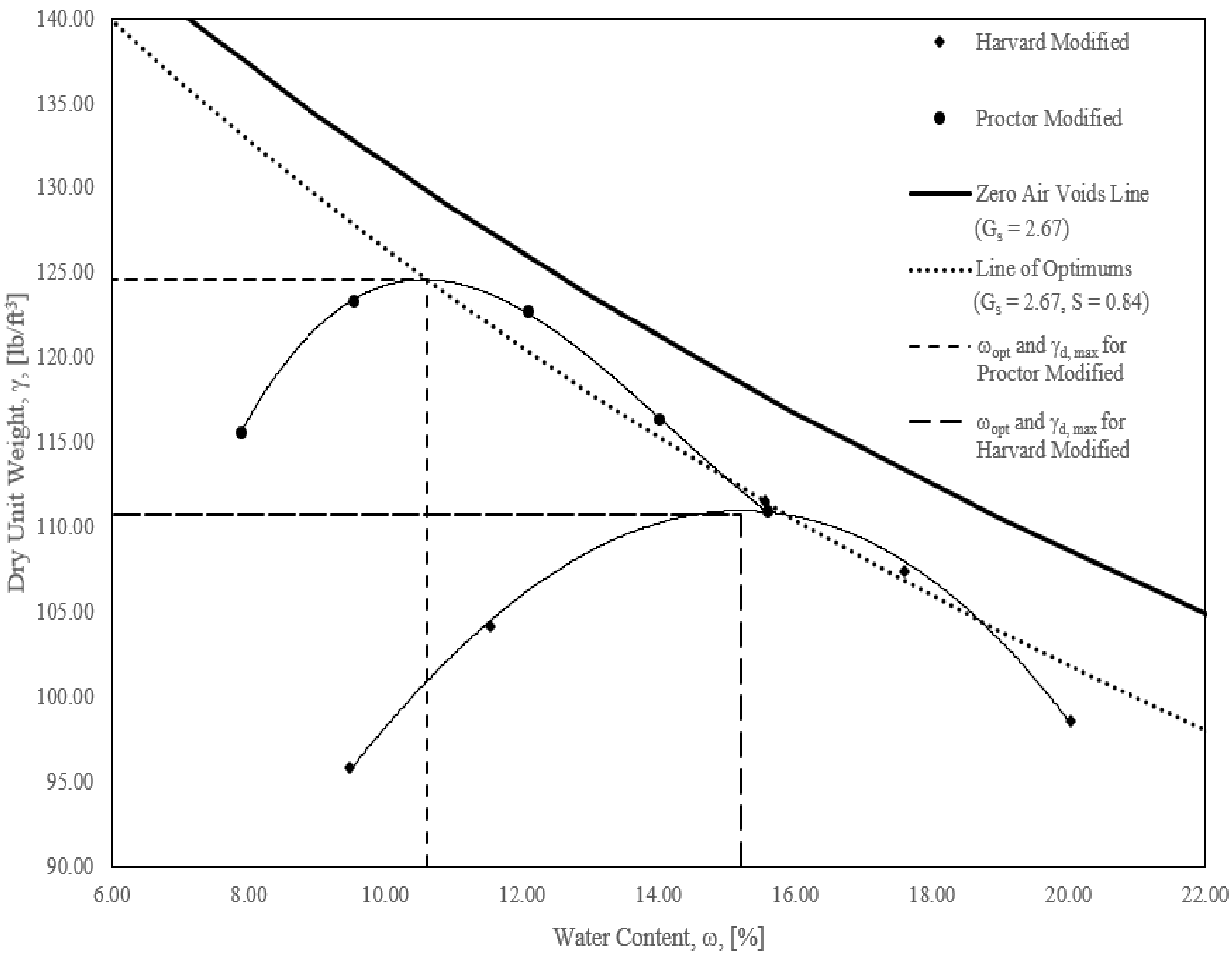

Figure 5. Harvard and Proctor at modified energy.

The maximum dry density values for the reduced energy curves are almost identical being 107.68 lb/ft^3 for Proctor test and 107.09 lb/ft^3 for Harvard Miniature test (Figure 6). The Reduced Harvard Miniature sample had a higher optimum water content compared to the Reduced Proctor sample; it varied by 1.4 percent. As is typical, the compaction curves obtained from the Proctor tests shifted up and to the left as the energy level increase from reduced to modified (Figure 7).

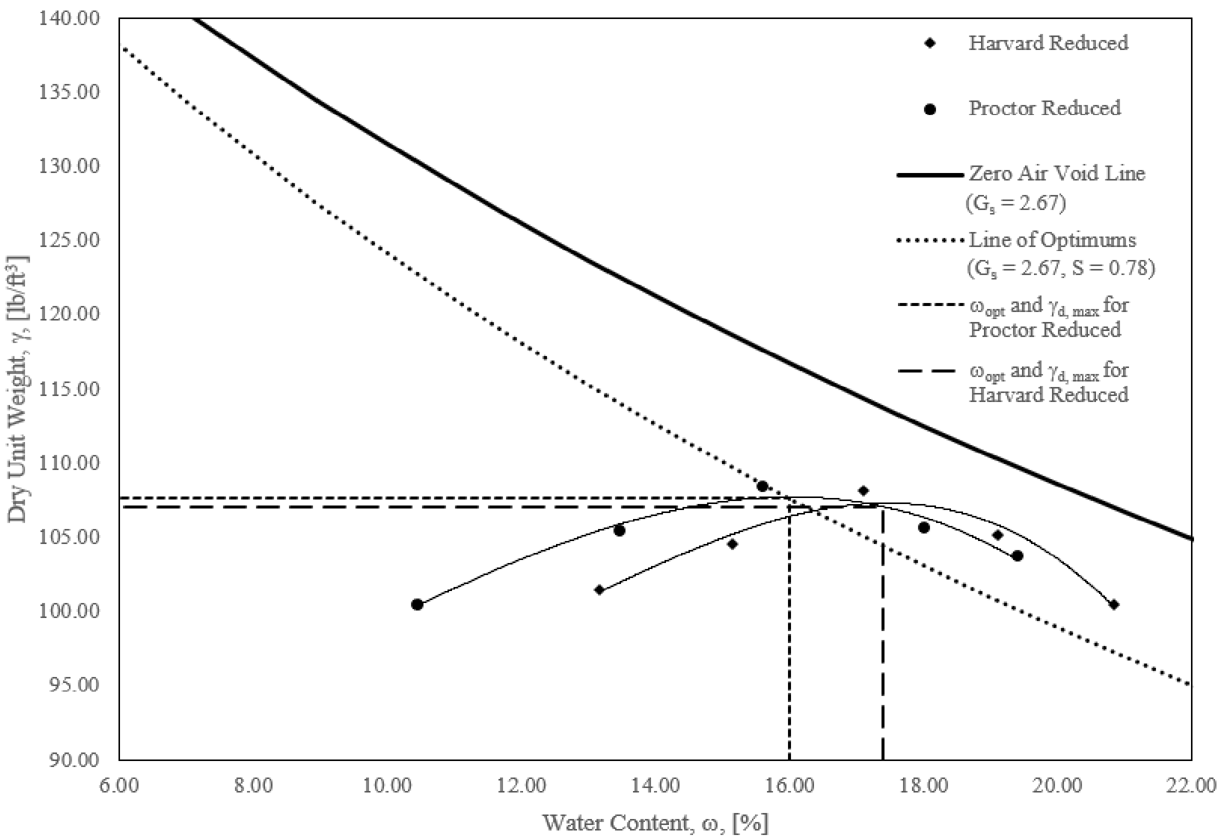

Figure 6. Harvard and Proctor at reduced energy.

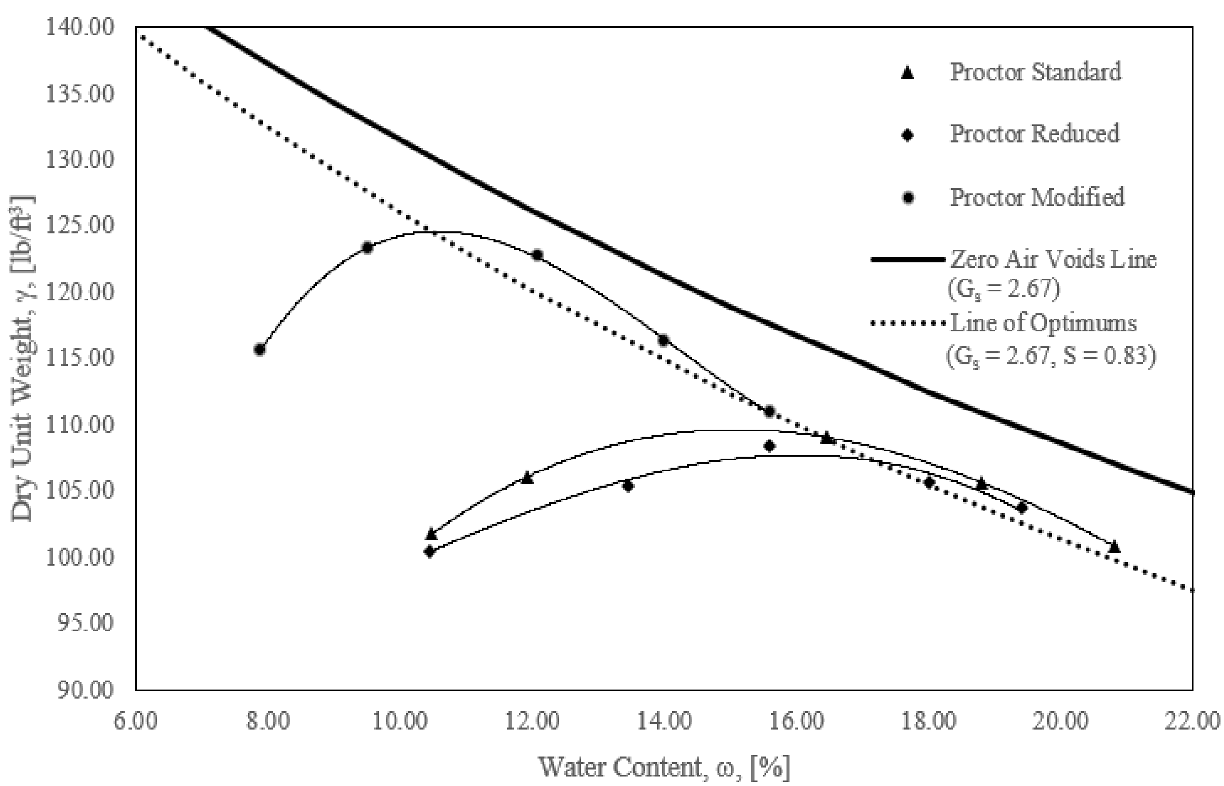

Figure 7. Proctor at reduced, standard and modified energy.

Discussion

The standard energy curves obtained from the Proctor and Harvard methods resembled each other for the points that approach optimum. On the edges of the curve where the soil is either too wet or too dry, the curves begin to deviate from each other. Further consideration should be addressed at these points to determine if this is a recurring feature among Harvard and Proctor tests at different energy levels, or if, when these energies are accurately applied at the modified and reduced energy levels, the curves approach each other more closely.

The Harvard modified energy level did not perform as expected. The optimum water content was higher (a difference of 5 percent) and the dry unit weight was lower than anticipated (a difference of 14 lb/ft^3). An increase in displacement was applied to the tamper to determine if the dry unit weight of the Modified Harvard mold could approach that of the Modified Proctor mold. A spacer was inserted inside the tamper, and the tamper was then displaced the maximum amount allowed by the tamper rod threading resulting in a total displacement of nearly 1.82 inches [46.23mm] as compared with the total displacement of 1.54 inches [39.12 mm] used for the original modified energy test. The increase in displacement did directly correlate to higher obtained dry unit weight values so it can be concluded that higher displacements do result in higher energy and thus higher dry unit weights. However, a higher displacement resulted in an applied energy level higher than the desired modified energy level of 56,250 lb ft/ft^3 calculated to match Modified Proctor. The tamper rod of the Harvard Miniature offers a small contact area with the soil, due to tthe design, compaction that occurred at higher energy levels resulted in lower dry unit weights than was expected. At these levels, the Harvard tamper rod experienced shear failure and went through the soil, and thus delivered less energy to the soil. The resulting samples had large air voids because holes were formed in the soil as a result of the rod penetrating through the soil. The tamper rod sank down into the lowest layer due to high water content values and visible holes formed. These holes corresponded to a lower total unit weight and thus a lower corresponding dry unit weight.

Two modified energy Harvard Miniature test were performed at 14 and 16 percent water contents after the application two collars at the bottom of the metal tamper rod to increase the surface area from 0.2 in^2 [129 mm^2] to 0.79 in^2 [509.68 mm^2] (Figure 8). The dry unit weights were 15.92 lb/ft^3 and 10.14 lb/ft^3 lower than the samples originally obtained without the collars for 14 and 16 percent water content, respectively. The additional surface area at the bottom of the tamping rod did not show that the calculated energy was more successfully transferred to the soil. The issue should be re-evaluated considering a better ratio of mold to added collar diameter and evaluating if the energy is properly transferred to determine if the issues are still present.

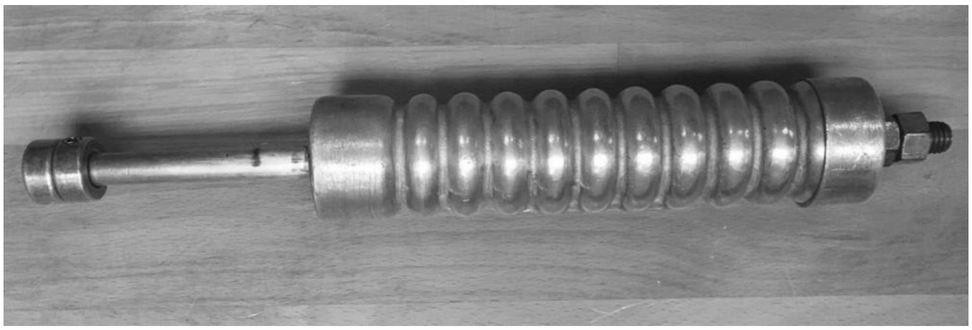

Figure 8. Tamper with added collars.

The Harvard reduced compaction curve had a higher water content value (17.4 percent) than that of the Proctor reduced compaction curve (16.0 percent) despite having similar dry unit weight values. Further testing of Harvard reduced should be completed with and without the additional surface area to determine if the Harvard reduced compaction curve approaches that of the Proctor compaction curve while maintaining the same dry unit weight value.

The springs utilized in the Harvard tamper each possess a distinctive spring constant, as two springs of the same type do not have identical spring constants. For example, two 40lb springs will not have equal spring constants. Thus, the spring constant for each spring must be determined even if the spring constant for a similar spring has already been identified. For this study, one spring with one spring constant (k = 121.2 lb/ft [1.769 kN/m]) was used for all the compactive efforts utilized. In this case the spring was displaced the amount required by tightening the tamper or adding an appropriate insert if the desired displacement was greater than the amount available on the tamper rod threading. Further investigation should be undertaken to determine whether the compaction curves plot similarly if different springs with different spring constants are used. The required displacement should change if the spring constant changes, but the energy applied should be the desired energy level which should result in similar water content values and dry unit weight values.

Conclusion

Soil compaction is of great importance as it enhances the mechanical properties of the soil on a site and prevents structural failure and future settlement of structures. To properly execute compaction, fieldwork engineers must reference laboratory-based soil compaction test. There are multiple laboratory-based tests that provide information regarding optimum water content, maximum dry density and compactive energy, the most common being the Proctor Test. The Harvard Miniature Apparatus has also been used throughout the years as a method of obtaining compaction data. It was created to optimize the time and excess material requirements of obtaining moisture-density curves. This research was conducted to investigate if the Harvard Miniature test could be used interchangeably with the Proctor test at reduced, standard and modified compactive efforts. To do so, the energy applied by the Harvard Miniature was analyzed in terms of the potential energy of the spring in the tamper. This energy was set equal to the desired Proctor energy by changing the displacement of the spring. Five tests were performed with each apparatus at each energy level.

Based on the results for standard energy, the compactive curves from the Proctor test and Harvard Miniature resemble each other at water contents closer to the optimum. However, the same conclusion cannot be made for either reduced or modified energy compactive curves. Harvard Miniature testes resulted in higher optimum moisture contend for both modified energy and reduced energy. This suggests that the kneading mode of compaction of the tamper generates a higher degree of saturation. Additionally, the design of the Harvard Miniature tamper offers a low surface area in which the effort is applied. As a result, the tamper rod goes straight through the soil when the level of energy is attempted to match the modified Proctor curve. The addition of a collars at the bottom of the tamper rod did not correlate to a higher unit weight. Future research is to be conducted to understand the behavior of the tamper with additional surface area. Finally, further investigation is recommended to understand how different soil types affect the results.

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