Development of a Soil Compaction Method for Non-standardized Energy Levels

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Introduction

Soil compaction has been used to improve stability and durability of engineering structures for hundreds of years. Today, soil compaction is pivotal to the integrity of dams, highway embankments, and other transportation structures.[1] Since its creation in 1933, the Proctor compaction test has been a prominent means to analyze the relationship between a soil's water content and dry unit weight when compacted with a particular compaction energy. When compaction to a particular dry unit weight and water content is necessary, no method currently exists to estimate the corresponding compaction energy. This project aims to identify trends in soil properties that can be used to predict compaction behavior at other non-standardized energy levels.

Significant Equations

1) $R.E. = \frac{Test\ Energy}{12375}\left(\frac{ft-lb}{ft^3}\right)$

2) $R.C. = \frac{\gamma_d}{(\gamma_{d\_max});\ Standard}$

3) $\gamma_d, (S = x\%) = \dfrac{62.4}{\frac{1}{G_s} + \frac{\omega}{S}}$

R.E.: Relative Energy

R.C.: Relative Compaction

γ_d: *Dry Unit Weight (pcf)*

ω: *Water Conent (%)*

G_s: *Specific Gravity of soil*

S: Degree of Saturation (%)

Description of Method Used

Proctor tests were performed on a clay soil and limestone sand, and compaction curves were created from the gathered data points. The procedure of the testing followed ASTM standards[2,3]; the only exception was the application of WD-40 to the interior of the Proctor mold to ease sample removal. The materials were compacted at three levels: Standard, Modified, and Low Energy. Standard and Modified Energy are defined by ASTM; this project defines Low Energy as 40% below Standard Energy. The shale compaction information provided by the Nebraska Department of Transportation (NDOT) only includes Standard and Modified Energy compaction curves.[4] *Figures 1A, 2A, and 3A* illustrate the results of the compaction tests for all three materials.

Saturation lines for each material were calculated and plotted with the compaction curves. Intersections between the compaction curves and saturation lines were identified and the corresponding dry unit weight was recorded. With this data, the Relative Compaction (R.C.) and Relative Energy (R.E.) for each saturation line at Standard, Modified, and Low Energy were calculated. An R.C. vs. R.E. graph was produced on partial-logarithmic axes, and a log-linear trendline was plotted for points of the same saturation. *Figures 1B, 2B, and 3B* show these trendlines and their respective equations.

Results

The log-linear trendlines on the R.C. vs. R.E. graph show a linear relationship between a soil's R.C. and R.E. exists at any given saturation. The equations for these trendlines have a structure similar to linear trendlines, but incorporate the natural logarithm of the independent variable. All three materials, although possessing different properties, display this linear relationship. The fact that these characteristically different materials display the same trend indicates that the relationship between R.C. and R.E. is present regardless of the material analyzed. It should be noted, however, that the trendlines are unique for different types of material; in each of the observed materials, the lines have different average slopes and order on the R.C. vs. R.E. graph. The trendline equation can be found for any saturation and used to predict the compaction behavior for any energy at that particular saturation.

Method Validation

To test the accuracy of the trendline equations, the clay soil and limestone sand were compacted at energy levels outside of Standard, Modified, and Low Energy. The parameters for the compaction test and the predicted dry unit weight were determined by the following steps:

1) Calculate the amount of energy used in the test
2) Calculate the Relative Energy for the compaction using *Equation 1*
3) Select a Degree of Saturation for compacting
4) Solve the saturation's trendline equation for Relative Compaction
5) Solve *Equation 2* for the predicted Dry Unit Weight
6) Solve *Equation 3* for the water content that corresponds to the other test parameters

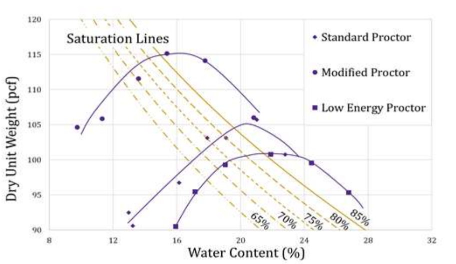
Table 1 summarizes the parameters for the tests, the predicted dry unit weight, and the calculated dry unit weight.

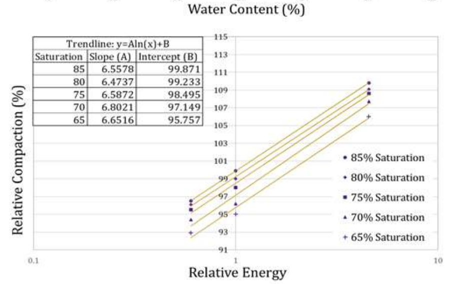
Table 1 Testing parameters and results

Material	Nominal Water Content (%)	Saturation (%)	Water Content (%)	Energy ($ft\text{-}lb/ft^3$)	Predicted Dry Unit Weight (pcf)	Calculated Dry Unit Weight (pcf)
Clay	22.1	85	21.92	5672.9	99.2	102.3
Limestone Sand	10.76	80	10.19	9900	121.9	124.28
Limestone Sand	8.47	65	8.09	9900	122.9	124.34

Conclusion

With the use of logarithmic trendlines, compaction behavior can be predicted when the water content and desired dry unit weight are known. The next steps for this project involve expanding the method evaluation phase. This expansion includes testing the method with additional types of soil, as well as determining procedures that will diminish error present in predictions and results.

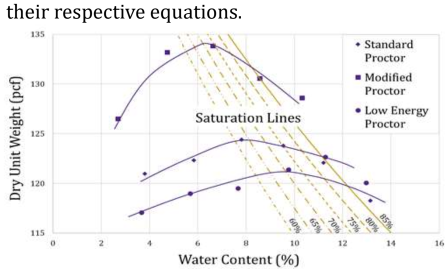


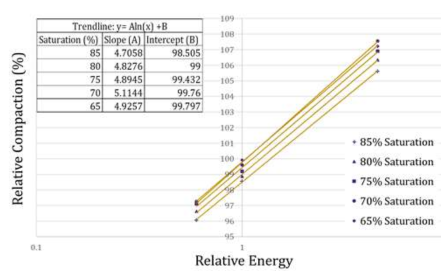


Trendline: y=Aln(x)+B		
Saturation (%)	Slope (A)	Intercept (B)
85	6.5578	99.871
80	6.4737	99.233
75	6.5872	98.495
70	6.8021	97.149
65	6.6516	95.757

Figure 1A (top) Clay Soil Compaction Results

Figure 1B (bottom) Clay Soil Relative Compaction vs. Relative Energy

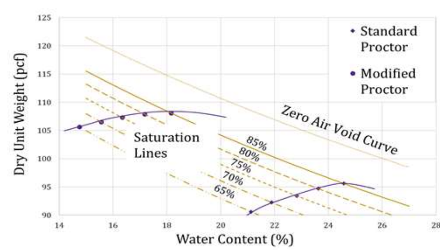


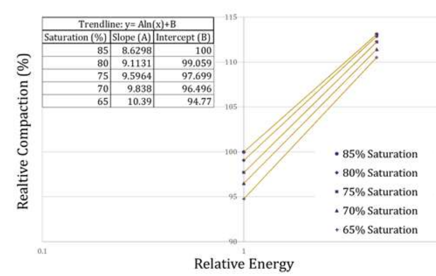


Trendline: y=Aln(x)+B		
Saturation (%)	Slope (A)	Intercept (B)
85	4.7058	98.505
80	4.8276	99
75	4.8945	99.432
70	5.1144	99.76
65	4.9257	99.797

Figure 2A (top) Limestone Sand Compaction Results

Figure 2B (bottom) Limestone Sand Relative Compaction vs. Relative Energy





Trendline: y=Aln(x)+B		
Saturation (%)	Slope (A)	Intercept (B)
85	8.6298	100
80	9.1131	99.059
75	9.5964	97.699
70	9.838	96.496
65	10.39	94.77

Figure 3A (top) Shale Compaction Results

Figure 3B (bottom) Shale Relative Compaction vs. Relative Energy

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