Predicting Field Compacted Strength and Variability

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A sheepsfoot and a rubber-tired roller compacted samples in the field that were tested to determine how water content, dry density, and compactive effort affect the magnitude and variability of the unconfined shear strength of a glacial, silty clay soil. The samples taken were tested in both the as-compacted and the soaked conditions. Statistical analyses were used to determine the most useful predictive models for the dry density and shear strength for each roller type and soil condition. In all cases, only the wet-of-optimum water content results could be studied. The regression models for the as-compacted unconfined strength indicated that water content and compactive effort were the most influential variables regardless of the roller type and had the greatest effect on the soaked strength of the soil compacted by the rubber-tired roller. No significant model was found for the soaked soil compacted by the sheepsfoot roller. Variability from field operations appears to be a major cause of differences between field and laboratory compacted soils. Variability in the magnitude of unconfined strength in the field was found to be significant, predictable, and larger than in the laboratory and prevents consistently accurate determination of the true state of the compacted mass by a few samples. This variability can be reduced by controlling variability of the water content at compaction.

The engineer designing an embankment must select or estimate the expected soil strength and devise specifications to ensure its achievement. One method for estimating expected strength is to construct a special fill section by using a range of compaction processes and then to test samples from the soil mass after each process.

Such a test pad and the associated costs of field sampling, laboratory testing, and analysis, however, are not economically feasible for most projects. The problem is compounded if more than one soil type is used within the proposed embankment. Therefore, the design engineer must infer the strength behavior of field compacted soils from laboratory developed compaction curves. Because this inference process may not be the most desirable, our objective in this paper is to develop a rational method of predicting the field post-compaction strength response from laboratory tests.

A special test pad was constructed from which samples were taken and tested for unconfined strength. The water content, dry density, and compactive effort were known for each sample. Relations among the variables were developed to formulate prediction equations for field strength.

Because soil type and condition are not uniform and because compaction processes and sampling and testing programs cannot be precisely duplicated, the resulting dry density and strength characteristics vary within some definitive range. This report investigates variation in the field compacted soil and attempts to develop a method to predict its magnitude. This will allow a design engineer to predict both the expect average unconfined soil strength and the expected variation from it. It will also give him or her a tool with which to better control field variability. Once this has been been accomplished, the engineer will have a method for developing a compaction specification for subgrades and low embankments that ensures a minimum soil strength.

PROJECT PURPOSE

Strength-Density Assumptions

Engineers who design fill sections and embankments are concerned with developing compaction specifications that ensure adequate strength behavior of the compacted soil mass. Three general types of specifications are currently in use.

The first type, which requires a desired end result, usually demands the post-compaction field density to be some predetermined percentage of the maximum density derived from a standard laboratory compaction test. Also, a range in permissible water content is usually stated.

The second specification format requires the use of a particular compaction process. Equipment type and operation, lift thickness, and number of passes are partially or wholly regulated.

The third format is a combination of the first two. Density, water content, lift thickness, equipment type, and equipment use are all specified. This is the most rigid of the specification types and requires a highly competent engineer to achieve an economical design result.

All three compaction-specification formats are similar in that they are either directly based on or are concerned with the resulting field density relative to standard laboratory compaction test density on the same soil. None directly addresses the soil strength property, even though it is often the primary reason for compacting the soil.

One reason for specifying density rather than strength is economics. The cost of an inspector's making a few density control-test determinations is less than that of a field sampling and laboratory testing program for shear strength determinations. Another reason for regulating density rather than strength is that, while little research has been undertaken to relate the field conditions and compaction processes directly to the resulting strength, much research on field compacted soils has been directed toward the determination of the resulting density. Similarly, an enormous quantity of research has been published on the relationship between soil conditions and compaction processes and the density and shear strength results of laboratory compacted soil. As a result, field shear strength derived from any of the specification formats is usually inferred from the measurement of the density.

This inference process may not be the most desirable because it is based on three assumptions whose applicability varies according to soil types, soil conditions, and compaction processes. The first assumption is that strength varies directly with density for a given water content; the second assumption is that the strength curve must be similar, both in shape and in orientation, to the density curve corresponding to the same compaction process; the third assumption is that field strength is related to the laboratory density in a manner nearly identical to that of laboratory strength.

There are two possible approaches to making the transition from field strength to laboratory strength. The first directly relates the field strength obtained from a particular soil condition and compaction process to the laboratory strength derived under similar conditions. The second assumes that field strength is related to field density as laboratory strength is to laboratory density. A correlation must then be shown to exist between the field and laboratory compaction curves.

A review of the literature by Price (1) showed that inferring strength from measurements of water content and density may not ensure that a minimum desired strength has been achieved. A first step in devising a better method of predicting the field strength from laboratory compaction and strength tests was finding relationships for field compaction results.

Variation of Compaction Results

Variation in compaction results occurs regardless of the stringency of methods taken to prevent it. Just as uniformity in soil strength characteristics is one criterion necessary for providing an adequate foundation for highway pavements, so should compaction techniques that reduce the resulting variability as much as is economically feasible be employed.

Williamson and Yoder (2) and Williamson (3) performed tests on a wide variety of soils compacted in the field by sheepsfoot, rubber-tired, and steel-wheeled rollers. Measurements of water content, density, and standard maximum density were taken by using accepted procedures of the following field control-testing equipment: sand cone, water-filled rubber balloon, and three calibrated nuclear gauges. They concluded that there were three major contributors to variance.

1. Compaction process variability: This involved the inability to compact the soil in a precisely replicative manner throughout the fill section or between different fill sections. Variations in equipment type, roller operating speed, soil temperature, air humidity, lift thickness, material handling procedures, and amount of compactive effort all contribute to this.
2. Testing variability: Any conventional field sampling and testing program is difficult if not impossible to duplicate. Equipment accuracy and precision and operator proficiency largely determine this variability. The amount usually increases if more than one operator performs the tests, if different instruments of the same kind are used, or if different equipment types are employed.
3. Material variability: Soil within any fill lift can vary to some degree because of the heterogeneous conditions within the borrow area. Mixing various soil types during the soil-handling process can make the fill soil even less homogeneous. Changing water content within a test lift also causes soil conditions to differ and further contributes to the material variability.

Tables 1 and 2, reprinted from Essigmann (4), indicate the results of attempts to isolate the effects of material variability and equipment. Of importance in these tables are the great density variabilities that have been found and can be expected to be found by using normal construction procedures.

Essigmann also developed a technique for predicting expected dry density and unconfined strength variabilities for a clayey silt tested in the as-compacted condition. Scott (8) used a similar analysis for the same soil tested in the soaked condition. In both studies, the soil was laboratory compacted by the impact method. The results indicate that the variations in dry density and strength depend on the compaction process and soil conditions at the time of compaction. Also disclosed in these works is the first indication that interrelationships between the compaction process and soil conditions can significantly influence density and strength magnitude and variability. This means that discussions of the effects of variables one-on-one with a property could be failing to include a major consideration.

As all the above research studies indicate, the great variations in dry density and unconfined strength that exist can be attributed to varying soil conditions, testing ability, and compaction processes. Only a few of the currently used compaction specifications regulate both the soil conditions and compaction process, and no specification known to us has been devised to account for the expected variability found in compacted soil. Without knowing expected variability in density or strength and without using this information when specifying an end result of the compaction process, the design engineer's ability to predict the strength property of the fill or embankment is severely handicapped.

EXPERIMENTAL PROCEDURE

A special test pad was prepared by the Indiana State Highway Commission (ISHC); the soil, similar to that used by Essigmann (4) and Scott (8), was compacted and then sampled. A sheepsfoot roller compacted half the test-pad soil while a rubber-tired roller compacted the other half. Samples from each roller's work were tested in unconfined compression in the as-compacted and in the laboratory-induced soaked condition, which simulates that of an in-service soil. The data from these tests were statistically analyzed to establish relationships among the water content, dry density, compaction effort, and unconfined strength.

Soil Classification and Testing Schedule

The soil was obtained from a borrow area located within the right-of-way along state road 109 near Anderson, Indiana. The table below summarizes the identification tests performed on this soil.

Test	Value
Liquid limit, %	28
Plastic limit, %	18
Plastic index, %	10
Specific gravity of solids	2.73
Unified classification	CL
AASHTO classification	A-4(7)
Descriptive name	Silty clay

Once the test lift soil had been prepared in a routine manner (in sections, each section at a different water content), the compaction equipment made a designated number of routine passes over the entire test lift. Five samples were taken from each test section. The location of each sample was selected from a random number chart, and each sample was assigned its testing role in this manner.

Compaction and Sampling Program

Specifications for the sheepsfoot and the rubber-tired roller are shown in the lists below. For the sheepsfoot roller they are

Case Model 815,

Operating weight 18.1 t (20 tons),
Wheels, tamping foot,
Drum width 97 cm (38 in),
Chevron foot pattern,
60 feet per wheel,
12 feet per row,
116 cm^2 (18 in^2) per foot, and
Foot length 19 cm (7.5 in).

The specifications for the rubber-tired roller are

Ferguson Model RT-2511,
Operating weight 22.7 t (25 tons),
Tires 9:00 x 20 SWTC,
Tire loading 2066 kg (4545 lb),
Tire pressure 586 kPa (85 lbf/in^2),
Contact area 388 cm^2 (60 in^2),
Ground pressure 515 kPa (74.7 lbf/in^2), and
Tire deflection 2.629 cm (1.035 in).

Thin-walled, stainless steel tubes that were 27.9 cm (9 in) long and of a 5.1-cm (2-in) outside diameter and a 0.17-cm (0.066-in) wall thickness were driven into the test section to obtain samples. Samples were extruded from the tubes and each was placed in a plastic bag and carefully positioned in a styrofoam chest for transportation to the laboratory.

At the Purdue soil mechanics laboratory, each sample was trimmed, measured, weighed, and prepared for the as-compacted compression test or stored for the soaked compression test. End trimmings of the samples prepared for the soaked tests were used to find original water content. The as-compacted compression sample was placed in a plastic bag and stored for five days in a humidifier in a constant-temperature room to cure it and to produce the lowest strength test results (4).

The samples used for the soaked tests were individually wrapped in cellophane and then dipped in a parafin bath until a thick coating of wax formed around each sample. Two plastic bags were placed around the samples, which were then stored in constant humidity (≅ 100 percent) and temperature. Lack of available equipment made it necessary to store these samples for as long as eight months. A small change in the water content (average of 0.5 percent) usually resulted from storage.

It must be noted that the use of relatively routine field operations created nonhomogeneities that caused some attrition in samples.

Table 1. Effect of soil homogeneity on density variability.

Source	Soil Type	N	Dry Density Mean (% $\gamma_{d_{max}}$)	Dry Density SD(%)
Sherman, Watkins, and Prysock (5)	Clayey, silty sand, medium plasticity, homogeneous	50	92.9	2.4
	Clayey, silty sand, boulders to 15 cm, heterogeneous	50	90.5	3.1
	Heavy clay, sand, stone, shale, very heterogeneous	44	93.6	5.5
Jorgenson (6)	Glaciated soil area	100	88.7	4.5
	End moraine area	98	89.9	8.04
	Nonglaciated area	54	97.8	4.8
Williamson (2)	Silt to silty clays, low plasticity, homogeneous	200	92.4	5.76
	Low plasticity silty to moderately plastic clays, heterogeneous	140	95.5	6.02
	Highly plastic clayey sand, very heterogeneous	138	96.1	6.33
Smith and Prysock (7)	Uniform material, none greater than 1.8 cm	200	92.86	2.44
	Fairly uniform material greater than 1.8 cm to occasional 15 cm	200	90.54	3.09
	Extremely heterogeneous	176	93.64	5.52

Note: 1 cm = 0.39 in.

Table 2. Effect of compaction equipment on density variability.

Compaction Method	No. of Samples	Dry Density[a] (%) Mean	Dry Density[a] (%) SD	Moisture Content[a] (%) Mean	Moisture Content[a] (%) SD
Sheepsfoot roller	70	98.4	7.1	-2.0	3.2
Sheepsfoot and pneumatic tire equipment[b]	101	95.1	4.5	-5.2	2.9
Turtle[c]	40	93.1	5.3	-3.1	3.3
Total	211	94.9	5.7	-3.5	3.2

[a]With respect to maximum density and optimum moisture from AASHTO T99-70.
[b]Areas where sheepsfoot and rubber-tired construction equipment were operating.
[c]A hand-operated vibratory compactor used in small confined areas.

Laboratory Testing Program

The as-compacted samples were tested in unconfined compression following the procedure of Essigmann without exception. All tests were run at a small temperature fluctuation of ± 2°C from an average of 22°C (average 70° ± 3.5°F).

All field samples used to simulate the in-service conditions were soaked [in triaxial cells with a cell pressure of about 351 kPa (51 lbf/in^2) and a back pressure of 345 kPa (50 lbf/in^2)] and tested by using the procedure of Scott (5) with minor changes as listed by Price (1).

ANALYSIS OF DATA

A total of 168 field-compacted samples were tested in unconfined compression. Of these, 74 were compacted by the sheepsfoot roller, 62 were tested in the as-compacted condition, and 12 were tested in the soaked condition. The remaining 94 samples were compacted by the rubber-tired roller; 72 of these samples were tested as compacted and 22 were soaked before testing.

Twelve as-compacted samples for each roller type were separated from the remaining samples before the statistical analysis was performed. These samples were used to verify the predictive ability of the regression models derived from the larger group of samples. A random number chart was used to select samples for the verification process. As a result, the statistical analysis for the as-compacted specimens was performed on 50 samples from the sheepsfoot roller and 60 from the rubber-tired roller. Because so few samples were tested in the soaked condition, no soaked samples were excluded from the statistical analysis and no corresponding verification was made of the in-service predictive models.

Dry Density and Unconfined Strength

The initial portion of this analysis isolated the prediction models that best estimated the "true" or population relationships between the dependent and independent variables. Three successive steps were employed to identify these models.

In the first step the dependent variables were plotted against each independent variable—dry density against water content and compactive effort, unconfined strength against water content, compactive effort, and dry density. If the scattergrams showed a linear relationship with first-order variables, higher-order terms were not used in further analyses. However, if a distinctly linear

Table 3. Dry density and strength regression models.

Roller Type	Soil Condition	Model Type	Regression Model
Sheepsfoot	As compacted	Original	$\hat{\gamma}_d = -22.37w + 2134.88$
		Original	$\hat{q}_u = -14.20w + 4.036E + 2.437\gamma_D + 117.23$
		After substitution	$\hat{q}_u = -17.60w + 4.036E + 442.22$
Rubber tired	As compacted	Original	$\hat{\gamma}_d = -0.762w^2 + 2.704E + 1959.36$
		Original	$\hat{q}_u = -15.34w - 1.069E + 0.506\gamma_D + 358.18$
		After substitution	$\hat{q}_u = -0.0241w^2 - 15.34w - 0.987E + 420.21$
Rubber tired	Soaked	Original	$\hat{\gamma}_d = 24.46E - 1.533wE + 1772.0$
		Original	$\hat{q}_u = 8.204w + 1.346E + 6.697\gamma_D - 816.75$
		After substitution	$\hat{q}_u = 8.204w + 11.56E - 0.639wE - 77.00$

Note: γ_D is in kilograms per cubic meter; w is in percentages; and q_u is in kilopascals.

trend was not found, all terms were considered important.

In the second step of the isolation process we used Purdue computer programs developed by Nie and others (9) to select prediction models in a manner identical to that explained by Essigmann (4). As suggested by Scott (8), the residuals were examined to determine if they were normally distributed independent random variables.

The model isolation process was completed by the use of a Purdue computer program developed by Casella and de Branges (10). The prediction models selected by the first two steps of the isolation process were inserted into this program. Essentially, the computer replicated the data manipulation of the first program but added a designated amount of bias to the variable coefficients on each successive run for each model. As more bias was added to the coefficients, each coefficient was eventually driven to zero. If the variable coefficients were extremely sensitive to the data (a small change in the data produces a large change in the coefficients), a small amount of bias added to a regression run would cause the coefficients to quickly approach zero. Models whose coefficients exhibited this trend were not considered for continued analyses.

Once all three isolation processes were completed, the selection of the most appropriate prediction model for each independent variable had been made. The results of the statistical analysis are presented in Table 3.

Variability of Dry Density and Unconfined Strength

Two measures of the dry density and strength variabilities are of interest to this report's objectives. Although each test-pad section was planned to have a nearly constant water content, a large variation in the water contents persisted and prevented determination of an optimum water content for any energy level. The average water content for the sheepsfoot and rubber-tired roller sections were 3.3 and 3.7 percent, respectively. The assumption was made that the variations found within the samples were no greater than the variations found within the test-pad section. Thus the average range of water content found within the test-pad sections was considered the expected range that must be accounted for in predicting the dry density and shear strength variabilities.

The compactive effort was measured in number of passes and, as such, no variation in the measurements is assumed. The magnitude of the dry density variability changes the degree of confidence that is chosen. We arbitrarily use a 95 percent confidence criterion here. Thus, 95 percent of the compacted soil from which the samples were taken should have a dry density within the range bounded by the expected mean value, plus or minus the appropriate factor times the standard deviation.

Once the dry density variability is evaluated, the expected variation in shear strength can be determined. The amount of variation assumed for this evaluation is zero for compactive effort, plus or minus the test-pad sections' half-range variation for water content and plus or minus the 95 percent confidence variability found for dry density $V(\hat{\gamma}_d)_{0.95}$. The table below presents these limits.

Variability Item	Sheepsfoot Roller	Rubber-Tired Roller
Compactive effort, no. of passes	± 0	E ± 0
Water content, %	± 1.65	w ± 1.85
Dry density, kg/m³	$\gamma_d \pm V(\hat{\gamma}_d)_{0.95}$	$\gamma_d \pm V(\hat{\gamma}_d)_{0.95}$

Typical results of the unconfined strength variability analysis are presented in Figure 1 for the sheepsfoot roller, as-compacted condition.

Verification of Prediction Equations

To verify whether or not the regression equations obtained by the statistical analysis were good prediction models, the data from the 24 samples that were withheld from the analysis were compared to regression results obtained from the sample data. Dry density was calculated for each sample by using the regression equation suitable for the roller type by which the sample had been compacted. Figure 2 shows a plot of the expected values of dry density against the measured values of dry density for the sheepsfoot roller. The points must lie reasonably close to the 45° line for the regression equation to be considered a good prediction equation.

The same method was used for comparing the expected and measured values of the unconfined strength (see Figure 3). Again, the smaller the deviation from the 45° line, the better the model's predictive ability. Some deviation was expected, though, because of the variability associated with the compaction process and the testing program.

The total data show that a large difference may exist between an expected value and the corresponding value observed during testing. This does not mean that the model poorly represents the relationship between the variables; it suggests, rather, that the condition of a compacted soil after construction is very heterogeneous. Therefore any one measurement of either the dry density or the strength parameter can be unrepresentative of the average value of the parameter and as such does not reflect the true quality of the compaction results.

DISCUSSION OF RESULTS

Field Compaction Results

Dry Density and Strength Magnitude

A major benefit of determining prediction models for

Figure 1. Expected dry density and unconfined compressive strength variability versus water content for sheepsfoot roller, as-compacted condition.

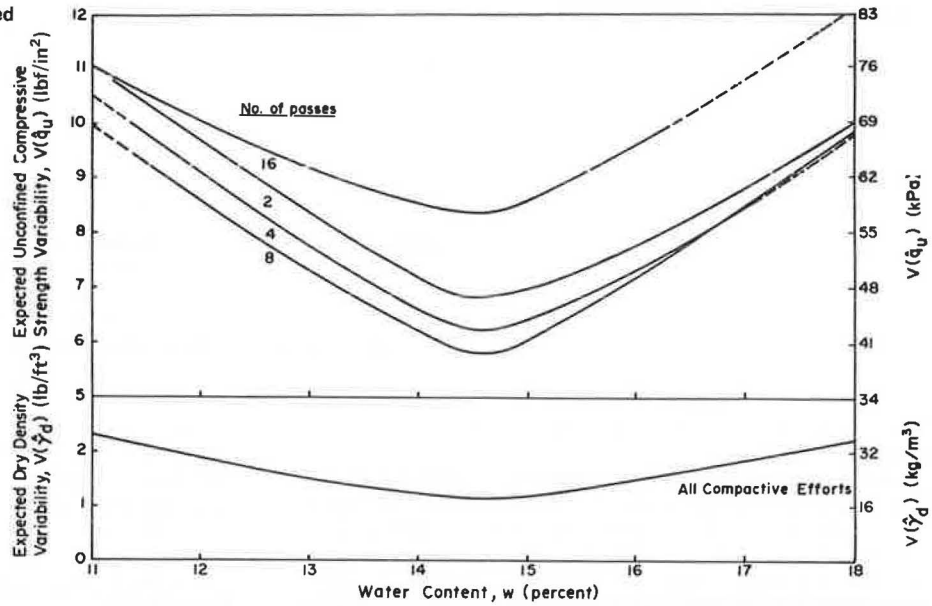


Figure 2. Expected versus measured dry density for sheepsfoot roller, as-compacted condition.

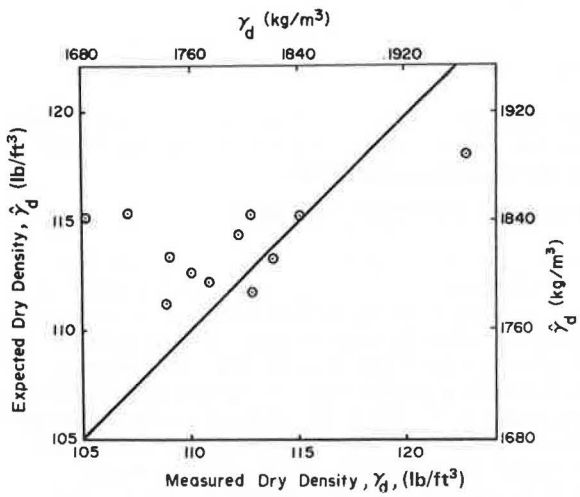


Figure 3. Expected versus measured unconfined strength for sheepsfoot roller, as-compacted condition.

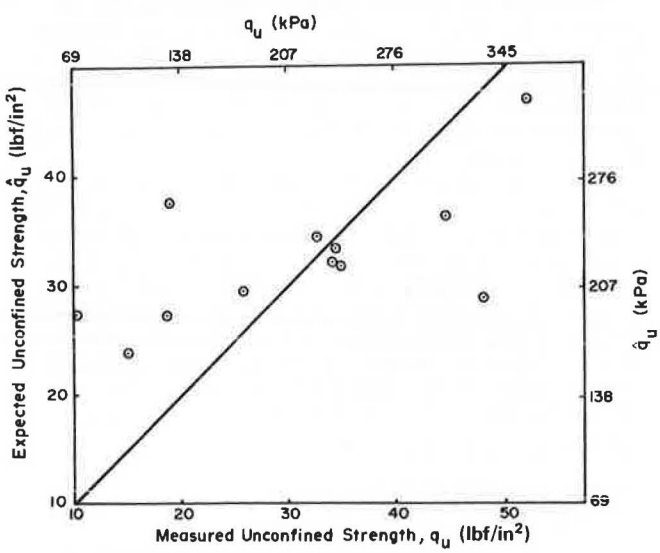
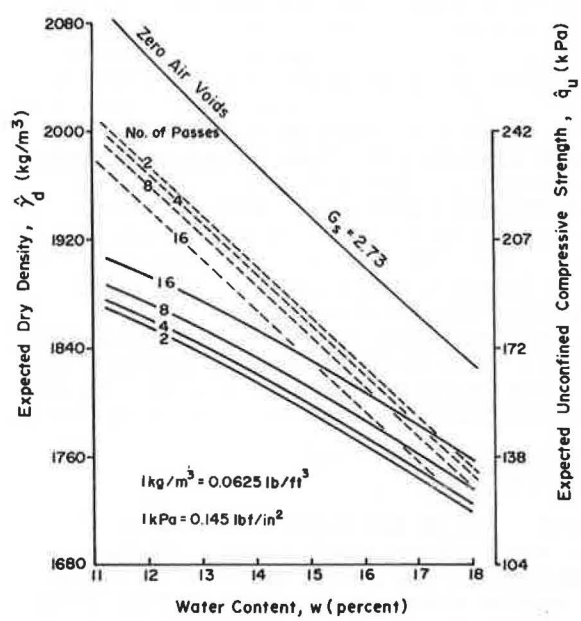


Figure 4. Dry density-strength relationship for rubber-tired roller, as-compacted condition.



both density and strength is that the density equation can be substituted into the strength equation. This enables the soil strength and its variability to be estimated by knowing only water content, water content variability, and compactive effort. Table 3 shows the statistical models of strength after substitution. Complete discussions of these relationships are found in Price (1). Only those for the rubber-tired roller are discussed here.

Rubber-Tired Roller, As-Compacted Condition

Dry density is dependent on the compactive effort level and increases with compactive effort as shown in Figure 4. The density curves become nearly parallel to the zero air-voids curve for the higher water contents.

Figure 5. Dry density-strength relationship for rubber-tired roller, soaked condition.

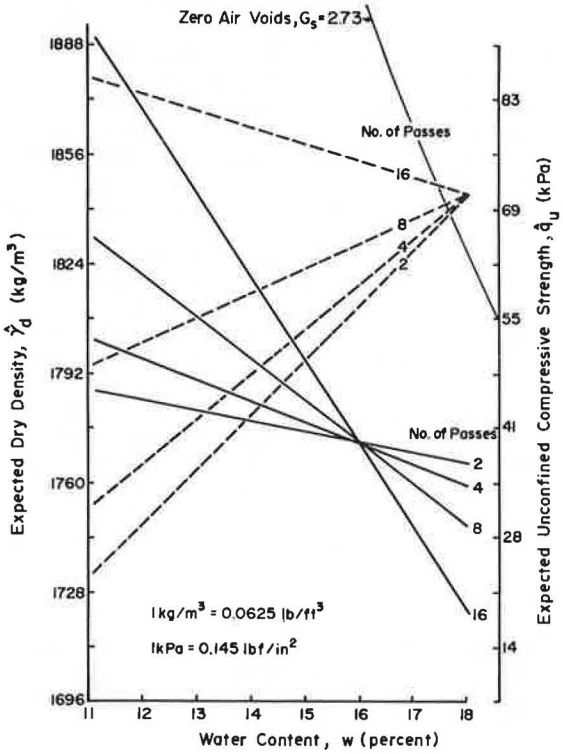


Figure 6. Isometric presentation of the minimum expected unconfined strength for rubber-tired roller, as-compacted condition.

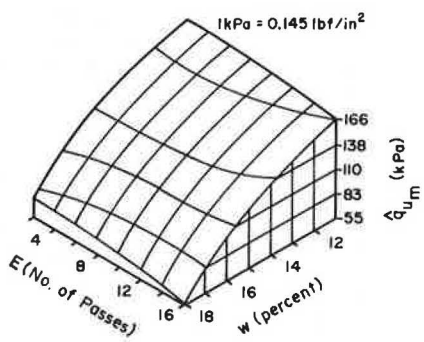
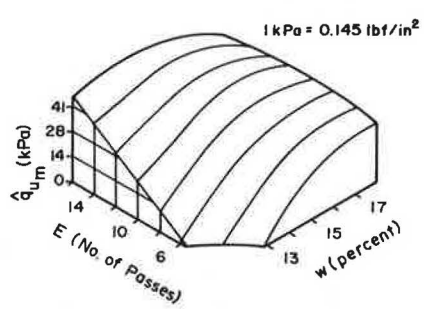


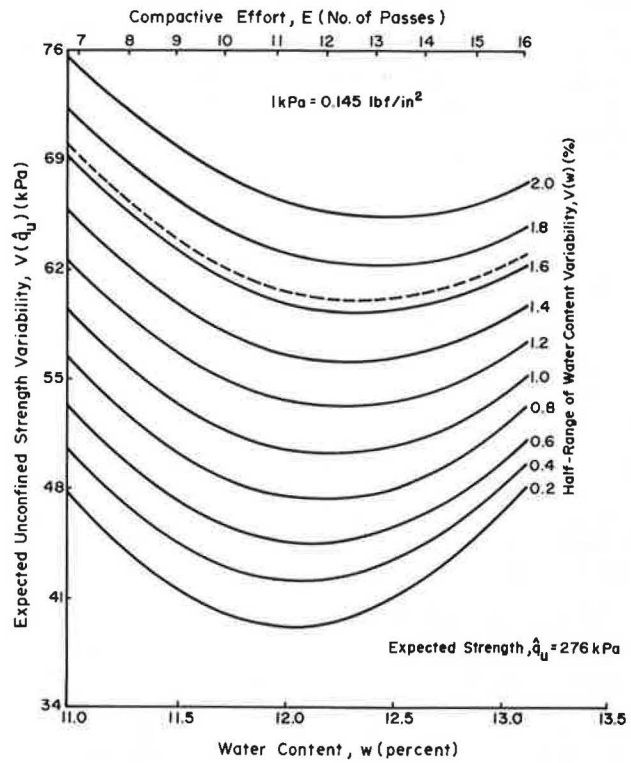
Figure 7. Isometric presentation of the minimum expected unconfined strength for sheepsfoot roller, soaked condition.



This indicates that extrapolation of the density-energy relationship beyond the 16-pass range could be in error. If the limit of compaction efficiency has been nearly reached with 16 passes, a sizable increase in compactive effort could cause only a small or negligible increase in dry density for the wetter soils.

Figure 4 presents the relationship between the expected dry density and the expected unconfined strength. The slopes of the density curves not only are different from the slopes of the strength curves but also change

Figure 8. Effect of water content variability on unconfined strength variability for sheepsfoot roller, as-compacted condition, 276 kPa expected strength.



with respect to the strength slopes. This complicates the strength-density prediction process; although, if the same criteria are met as described earlier, strength may be reasonably forecast from knowing the water content, compactive effort, and dry density of the soil mass. Of particular interest is that the density increases and the strength decreases with increasing compaction effort at a constant water content. This indicates that, if an inspector requires additional compaction with intentions of increasing the density to some minimum specification values, compaction may in fact reduce the strength (a form of overcompaction).

Rubber-Tired Roller, Soaked Condition

The density-water content relationship is shown in Figure 5. Of interest in this illustration is the decreasing slope trend for decreasing compactive effort in the lower water contents. This trend suggests that differences in water content are more influential on the density magnitude at high compactive efforts than at lower compactive efforts. Again, this would suggest that swelling influence increases with increasing compaction energy.

Figure 5 shows the association between the expected dry density and the expected unconfined strength. Of importance is the sign difference of the slopes for the two curve types in the lower energy levels. The dry density decreases with additional water content while the strength increases.

Variability in Dry Density and Strength

Figures 6 and 7 show the minimum expected unconfined strength surface in the water content-compactive effort-

strength space system for the as-compacted and soaked soil conditions of the rubber-tired roller. The minimum unconfined strength is defined as the expected strength minus the expected variability in the strength. In each case, the surface is significantly different from the expected strength surface. Similar figures for the dry density surfaces would show comparable differences between the expected and minimum expected surfaces. Illustrated in these graphs is the notion that the variability in compaction results is significant and must be provided for in the project specifications in order to ensure a minimum strength compatible with the project needs.

By reducing the variability in the data, the probability that the regression model will represent the true relationship between the variables would be increased and the expected variability would be reduced.

Figure 8 shows the effect of reducing the water content variability on the expected strength variability. As shown, for any given water content and compactive effort, a higher degree of water content homogeneity results in significantly reduced strength variation. The design engineer is interested in accurately forecasting expected strength, so compaction specifications should include provisions that control the variability in the soil and compaction process.

Laboratory-to-Field Correlation

This report has shown marked differences between the relationships for a field and laboratory compacted soil. Variability appears to be larger in the field operation. More attention needs to be focused on this variability if reliable prediction of field behavior of compacted soils is to be possible.

The need for establishing the laboratory-to-field correlation is imperative for the economical implementation of this research. It is hoped that a number of test pads and similar research programs will allow a suite of density and strength relationships for various soil types and compaction processes to be developed. Without the corresponding research, similar to that of Essigmann (4) and Scott (8), and the proper correlation between the laboratory and field curves, the design engineer must require a test pad for each soil type. If, however, the correlation between the laboratory and field compacted soils can be made, the design engineer can simply take bag samples from the borrow area and perform compaction and strength tests. Then, from the results, he or she can determine where the soil matches the suite of curves. Therefore, with the proper laboratory-to-field correlation relationships, the design engineer can extrapolate the results of a relatively small number of test pads and corresponding laboratory studies for a large number of project soils without having to resort to extensive and expensive field sampling and testing programs.

CONCLUSIONS

Given the constraints established by the project, specifically the wet-of-optimum water-content limitation, the following conclusions (1) may be reached for this silty clay soil.

1. For the soil compacted by a sheepsfoot roller (a) the variable contributing most to the resultant as-compacted dry density magnitude is water content, and (b) the variables contributing most to the resultant as-compacted unconfined strength magnitude are water content and compactive effort.
2. For the soil compacted by a rubber-tired roller (a) the variables contributing most to the resultant as-compacted dry density magnitude are compactive effort and the square of the water content; (b) the variables contributing most to the resultant soaked dry density magnitude are compactive effort and the interaction between compactive effort and water content; (c) the variables contributing most to the resultant as-compacted unconfined strength magnitude are the water content, square of the water content, and compactive effort (an increase in the water content or compactive effort causes a decrease in the shear strength); and (d) the variables contributing most to the resultant soaked unconfined strength magnitude are water content, compactive effort, and the interaction between water content and compactive effort. The influence of either the water content or the compactive effort on strength depends on the magnitude of the other independent variable.
3. The magnitude of the strength variability from both rollers is reduced if water content variability is reduced.
4. The inherent variability in the compacted soil mass prevents consistently accurate measurement of the true construction quality by a one- or two-sample testing program. The average of a number of samples (possibly between five and seven) must be used as a measurement of water content, dry density, or unconfined strength.

ACKNOWLEDGMENT

We appreciate the financial support given by the Joint Highway Research Project of Purdue University, the Indiana State Highway Commission, and the Federal Highway Administration.

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Publication of this paper sponsored by Committee on Compaction.