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Development of a Laboratory Compaction-Degradation Test for Shales

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Hard but nondurable shales must frequently be incorporated in embankments in the Midwest. It is essential that these shales be thoroughly degraded and compacted into thin, dense lifts. Yet there is no simple, widely accepted laboratory test for predicting the difficulties of mechanical degradation. The development of a laboratory compaction-degradation test that will make it possible to compare the behavior of shales in the laboratory with their behavior during the construction process is described. After testing three very different Indiana shales over a range of gradation and compaction variables, it was concluded that two types of compaction tests are suitable for this purpose: impact and static. Degradation was evaluated by sieving both before and after compaction and was expressed as the reduction in mean aggregate size caused by compaction (the index of crushing). The static compaction test allows the ready evaluation of compactive work (rather than nominal compactive energy), and the impact test has the advantages of familiarity and acceptance by almost all testing laboratories. It is likely that the impact test will be more widely accepted for the stated purpose. The development of the laboratory test is an important first step, but correlation of the laboratory values with breakdown under field rolling is necessary before the total engineering objective is achieved.

The excessive settlements and failures of many embankments constructed of shale materials have led to major investigations concerning the properties and behavior of shales. It has been found that the deterioration of shale that results from weathering plays a major role in the poor performance record of shale embankments.

Durable shales, which can withstand the weathering process, will perform satisfactorily when placed as rock fill. Nondurable shales, however, must be thoroughly broken down during compaction and placed as soil fill. Shales that are mechanically hard but nondurable present special problems in relation to construction techniques.

The current practice of breaking nondurable shales down into soil fill makes it all the more important to understand shale degradation during compaction. Laboratory tests may be helpful in defining the compaction and degradation functions of shales. These functions may ultimately be related to field conditions.

The work by Bailey (1) established a basis for laboratory degradation tests. The study reported here concentrated on the development of a single standard testing procedure and its application to troublesome Indiana shales.

REVIEW OF LITERATURE AND EXPERIENCE

Shales are the most abundant of the common sedimentary materials. Although shales are generally defined as argillaceous sediments that display fissility, a large number of definitions have been developed (2). The definition presented by Pettijohn (3) and by Underwood (4) and adopted for this study is that shale is the more highly indurated and generally fissile equivalent of claystone and/or siltstone.

Mead (5) proposed a classification system that divided shales into two groups: compaction shales and cemented shales. The compaction shales are consolidated by the weight of overlying sediments and lack significant amounts of intergranular cementation. The cemented shales are strongly bonded by either cementing agents or recrystallization of the clay minerals. The compaction shales are generally softer and more subject to slaking (a rapid disintegration caused by cycles of wetting and drying) than the cemented shales. The cemented shales are harder and more durable and may be successfully used as rocklike materials in embankment construction.

According to Pettijohn (3), the fissility exhibited by shales is the result of both the compaction and concommitant recrystallization during formation as well as the parallel orientation of the micaceous constituents at the time of deposition. Ingram (6) used three dominant types of breaking characteristics to classify the fissility of shale as massive, flaggy, or flaky. Massive shales have no preferred direction of breaking and produce blocky fragments. Flaggy shales break into fragments of varying thickness that have much greater lengths and widths and two approximately parallel, flat sides. Flaky shales split along irregular surfaces parallel to the bedding planes and produce flakes, thin chips, and wedgelike fragments.

Road cuts for highways constructed in the midwestern United States often encounter shale. Economic and environmental considerations generally make the use of the excavated material in nearby compacted embankment sections more desirable. However, the poor strength and durability characteristics of many shales, along with inadequate construction procedures, have resulted in several undesirable experiences with compacted shale embankments.

Excessive settlement and slope failures of large shale embankments have occurred in several states (7). Such embankment failures led to the initiation of research and development programs by the Indiana State Highway Commission (ISHC) through the Joint Highway Research Project at Purdue University (8). Reports from these studies on the following subjects have been completed: the classification of shales (2,9), shale compaction and degradation characteristics (1), the storage and retrieval of existing data on Indiana shales (10), the shear-strength parameters of compacted shales (11), and the compressibility of compacted shales (12). In addition to the work at Purdue, the U.S. Army Engineer Waterways Experiment Station has conducted a three-phase shale research project for the Federal Highway Administration (FHWA) (13).

In previous construction practices, shales that appeared competent were placed in large pieces as rock fills. Softer shales were placed as soil fills, but the presence of harder sedimentary rocks (limestone or sandstone) prevented complete compaction (14). These procedures left large voids within the embankments. Disintegration of the shale led to collapse of the openings, a loss of interlocking among the pieces, and the disruption of drainage, which resulted in serious settlements and possible embankment failures.

According to Deo (2), shales that are identified as nondurable, or "soillike", should be thoroughly broken down during construction to eliminate the presence of large voids within the compacted mass. This approach is supported by Wood and others (14) and is currently used by ISHC. Soft, nondurable shales generally do not present a major problem in relation to breakdown during compaction. However, many shales in Indiana are hard and difficult to degrade despite their lack of durability. For these shales, special compaction procedures must be used to increase the probability of a successful embankment service life.

The policy of thoroughly breaking down shales during embankment construction emphasizes the importance of understanding the shale degradation that results from compaction. Appropriate definition of the degradation functions would be most directly achieved through field compaction tests. Yet the expense of field tests and limitations of current knowledge on shale degradation would reduce the effectiveness of any major field testing program. A standard compaction-degradation test and an assortment of compaction variables could be used to generate the degradation functions in the laboratory. Ultimately, the results and experiences from the laboratory studies could be coupled with compaction observations in the field. If there were sufficient data from both laboratory and field studies, shale degradation during field compaction could be quantitatively predicted from the results of laboratory testing only.

Bailey (1) established a basis for studies of shale degradation. He performed four types of laboratory compaction tests on samples of Attica (Indiana) shale and analyzed the relation among degradation, compaction effort, and unit weight. From these results, Bailey found that both densification and degradation appeared to be self-limiting reactions regardless of compactive effort, moisture content, or initial gradation. Bailey's experiences were used as guidelines in this study, the purpose of which was to develop a single standard test procedure and to apply the test to selected, troublesome Indiana shales.

DEGRADATION TEST PROGRAM

The degradation of shale that occurs during compaction is affected by a number of factors. The most evident factors are type of shale, method of compaction, and compactive effort. Other variables include initial gradation, maximum size, and moisture content. This paper reports the testing of three shales by two methods of compaction and over a range of compactive efforts. The effects of initial gradation, maximum aggregate size, and moisture content were also covered and are reported elsewhere (15).

Numerical Representation of Gradations

During the compaction process, fracturing, abrasion, and moisture effects break down individual shale pieces. The result is a compacted material that has a gradation different from that of the uncompacted material. Therefore, a measure of the gradation change serves as an indicator of the amount of degradation that has occurred.

Gradation coefficients have been developed to provide a numerical value representing a grain-size curve. The index of crushing (IC) is a gradation index based on the summation of the weighted fractions of several size groups. Aughenbaugh and others (16) have described the use of the IC as a measure of aggregate degradation during compaction. The percentage of the sample by weight within a size range is multiplied by a factor equal to the mean equivalent mesh size of that range. The summation of the values from each size group represents one gradation. The actual IC value is computed as the difference between the numerical representations of the initial and final gradations and is expressed as a percentage of the value from the initial gradation. As Hale (15) shows, the gradation values in the IC represent the mean or average aggregate size of the initial and final gradations. The IC is thus a measure of change in the mean aggregate size.

The IC makes it possible to compare samples that have dissimilar initial gradations. The IC is based on real measures of aggregate size and weight percentages. According to Bailey (1),

> When degradation is expressed as the percent change in the gradation index, thus relating both initial and final conditions, the "real" base of the weighting factors allows direct comparison of samples without the need for scaling or oversize corrections. This enables degradation comparisons between small-scale laboratory tests and actual field compaction.

The successful use of the IC by Bailey, the ability to use the IC for samples that have different initial gradations, and the concept of mean aggregate size led to the use of the IC as the primary measure of degradation for this study.

Selection and Description of Test Shales

Three Indiana shales--New Providence, Osgood, and Palestine--were selected for use in the testing program. The relative proportions of the clay minerals in each shale were estimated by using the peak amplitudes from X-ray diffraction as a rough quantitative guide (see Figure 1). These clay minerals are the ones commonly expected in midwestern shales. Swelling is not a major concern with these shales.

New Providence shale lies at the base of the Valmeyeran (Osage) series of the Mississippian system. The shale is gray, medium hard, and flaky. It is classified as hard and nondurable (17) and has a specific gravity of 2.77.

The Osgood shale is a member of the Salamone dolomite and lies at the base of the Niagaran series in the Silurian system. The Osgood shale is blue-gray, hard, and flaggy. It is classified as hard and nondurable (15) and has a specific gravity of 2.81.

The Palestine shale is part of the Palestine sandstone formation in the Chester series of the Mississippian system. The rocks of the Chester series consist of shales, sandstones, and limestones in relatively thin strata. The Palestine shale is brown-gray, soft, and flaky and can best be des-

Figure 1. Estimated relative proportions of clay minerals in test shales.

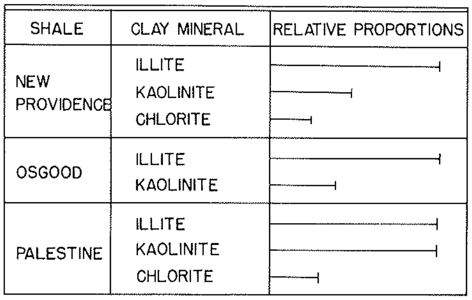


Table 1. Summary of compactive-effort variables.

Level	Total Compactive Effort (kJ/m³)	Weight of Hammer (kg)	Drop of Hammer (cm)	Number of Layers	Number of Blows per Layer
1	527	2.49	30.5	3	55
2	785	4.54	45.7	3	30
3	1443	4.54	45.7	3	55
4	2400	4.54	45.7	5	55

Note: 1 kJ/m³ = 20.9 ft·lbf/ft³; 1 kg = 2.2 lb; 1 cm = 0.39 in.
American Association of State Highway and Transportation Officials standard effort is 596 kJ/m³ and modified effort is 2680 kJ/m³.

cribed as a transition between shale and sandstone. It is classified as soft and nondurable (17) and has a specific gravity of 2.73.

Testing Procedure

Research has shown that the impact and static methods of compaction demonstrate features suitable for a standard compaction-degradation test (15). A testing program was developed to examine the repeatability of the compaction process involved in each method. Samples of the New Providence, Osgood, and Palestine shales were prepared in an identical manner to reduce the test variation. The use of four levels of compactive effort in both the impact and static tests permitted the effects of compactive effort on degradation and compacted density to be demonstrated.

Sample Preparation

The excavation methods used to obtain the shale produced a number of large pieces. The large pieces were broken down with a carpenter's hammer to prepare samples suitable for testing. The broken shale was then dry-sieved through a nest of sieves with mesh sizes of 38.1, 19.1, 9.52, 4.76, 2.38, 1.19, 0.59, 0.30, and 0.15 mm (1.5, 0.75, 0.375, no. 4, no. 8, no. 16, no. 30, no. 50, and no. 100) and a pan. A 5.0-kg (11.0-lb) sample was prepared immediately before testing by blending the different sizes to fit a cumulative distribution of gradation that conformed to the following general equation:

$$P/100 = (d/D)^n \quad (1)$$

where

P = percentage passing any sieve,
d = sieve mesh size, and
D = top aggregate size.

A value of n = 1 provided a well-graded mix in which the larger pieces predominated but the finer sizes were still included. Changes in maximum size and/or gradation were found to affect the magnitudes of degradation, but the relative values (for one shale with respect to others) were unchanged (15).

Degradation was also significantly affected by moisture content (15), but the shales were tested at their natural moisture levels to avoid the undesirable effects of either wetting or drying (1). Although the values of moisture content varied among the three shales, the moisture contents for samples from any particular shale were relatively uniform.

Impact Tests

The impact tests were similar to the Proctor-type compaction procedure in that a small-faced hammer was dropped on the sample material a specified number of times. The equipment and compactive efforts were modified to satisfy the special needs of the testing program (15).

A 15.24-cm (6-in) diameter steel Califoria bearing ratio (CBR) mold was used to accommodate the top aggregate size of the sample gradation. Bailey (1) reported problems of additional degradation induced during the removal from the mold of the more tightly compacted shale samples. To alleviate this problem and aid sample removal, all samples were compacted in a split CBR mold.

The different levels of compactive effort were controlled by the weight and drop of the hammer, the number of layers, and the number of blows per layer. Table 1 summarizes the combinations of variables used to obtain each effort level.

The compacted samples were separated by hand and dry-sieved through the nest of sieves used in the sample preparation. A more complete description of the sieving process is given by Hale (15). After sieving, the material from each of the size groups was weighed on a scale accurate to 0.1 g. A portion of the sample material was oven-dried at 105°C (220°F) for one week to determine the sample moisture content. Once the initial and final sample gradations were known, the IC was determined.

Static Tests

The static tests were characterized by the slow application of a load distributed over the entire face of the sample. As in the impact tests, modifications in equipment and procedures were developed to satisfy the special requirements of the static testing (15).

The static compaction test had an advantage over the impact test in the determination of compactive energy. The total compactive work done on a sample could be calculated by measuring the load during the compaction process and the residual deformation of the sample. A dial gage was attached to the loading ram to evaluate the deformation of each statically compacted sample. The compactive effort in the static tests varied only in the highest load applied to the sample. The four levels used were 500, 1000, 2000, and 3000 kPa (72.5, 145.0, 290.0, and 435.0 lbf/in²).

Each sample was compacted in three layers. A loose layer of material was placed in the mold, the loading ram was positioned and seated, and the entire assembly was then placed in a compression testing machine for loading. The load was increased to the desired level and then released immediately. After compaction of the final layer, the sample was trimmed, weighed, and dry-sieved by using the procedure described for the impact tests.

Load and deformation were monitored for each layer. Values from the compression-machine load gage were recorded at regular time intervals during

Figure 2. Load versus time.

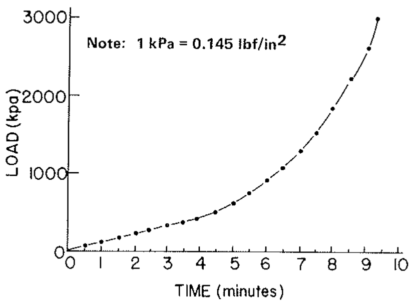


Figure 3. Deformation versus time.

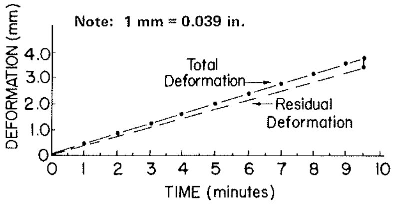
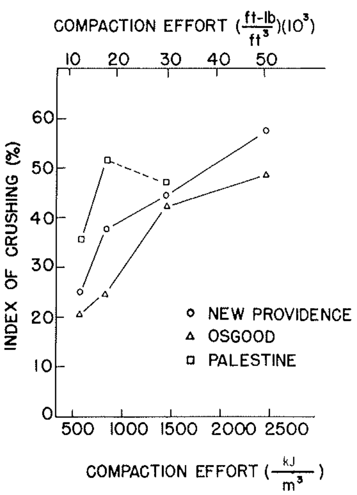


Figure 4. Compaction effort versus IC for impact compaction.



the compaction process. As the load approached the higher values, the slope of the load-time curve increased sharply (see Figure 2).

The sample deformation, measured by the loading-ram dial gage, displayed the relation between linear deformation and time shown in Figure 3 during loading. On release of the load, the deformation showed a sharp decrease that indicated the elastic rebound of the sample. Only the residual deformation, measured as the difference in the dial-gage reading before and after loading, was used in calculating the work input. Since the elastic portion of the total deformation was assumed to have a linear relation with load, the relation between residual deformation and load was also linear.

The work input could be calculated by using the trapezoidal method to estimate the area beneath the load-residual deformation curve. The total compactive work input for a sample was taken as the summation of the work that had been applied to each layer in the sample. This quantity was normalized by multiplying the ratio of the mold volume to the final sample volume.

RESULTS OF TESTING PROGRAM

Impact Tests

Impact tests that involved four levels of compactive effort were performed on each of the three shales. As Figure 4 shows, degradation generally increased with increasing compactive effort. The relation between degradation and compactive effort generally agreed with the results of shale degradation tests performed by Bailey (1). Bailey also reported a limiting maximum value of degradation with increasing compactive effort. No limiting degradation values were observed for the shales in the compactive efforts used in these impact tests.

The Palestine shale at the third compactive level [1450 kJ/m³ (30 300 ft•lbf/ft³)] deviated from the trend of increasing degradation. The smaller IC value was attributed to problems with separation of the compacted sample before dry sieving. The coherence of the Palestine shale compacted at level 3 created a sample that could not be separated without inducing an unknown amount of degradation. Keeping the effort of separation to a minimum increased the probability of representing a lump containing several pieces as a single aggregate size. The problems encountered with the Palestine samples at level 3 prevented the degradation analysis of the Palestine shale at any higher level of effort.

Figure 5 shows a typical aggregate size distribution for the group of four impact compaction samples of New Providence shale and provides an important key to understanding the degradation pattern of the shales. The initial gradation is shown in Figure 6. Aggregates in the 38- to 19-mm (1.5- to 0.75-in) size group experienced the greatest percentage weight change. Fragments produced by the breakdown of the large pieces were distributed over the entire size range, which increased the amounts of smaller sizes. Aggregates in the medium size range also degraded. However, to some extent, fragments from larger aggregates replaced the broken, medium-sized aggregates. The overall degradation process produced a final differential frequency distribution that was flatter than the initial distribution and had a smaller mean aggregate size (compare Figures 5 and 6).

The dry density shown in Figure 7 also increased with increasing compactive effort. The compaction tests reported by Bailey (1) indicated limiting maximum values of dry density as the compactive effort increased. Although no actual limits were reached in this testing program, the density curves for each of the shales show a tendency to become asymptotic at the higher levels of compactive effort.

A direct comparison of the dry-density values for the three shales at any given compactive effort is misleading because of the differences in specific gravity among the shales. The use of the percentage solids is defined below:

$$\text{Percentage solids} = \text{volume of solids/total volume} \quad (2)$$

This provides a measure that corrects for the difference in specific gravity.

Table 2 gives the values of percentage solids for the shales at each level of compactive effort. The values in Table 2 indicate that, for a given effort level and a constant mold volume, the volume of solids is almost identical regardless of the shale type. An accompanying conclusion is that the volume of voids is also identical at a given effort level.

Figure 5. Aggregate size distributions for New Providence shale at impact compaction level of effort 1.

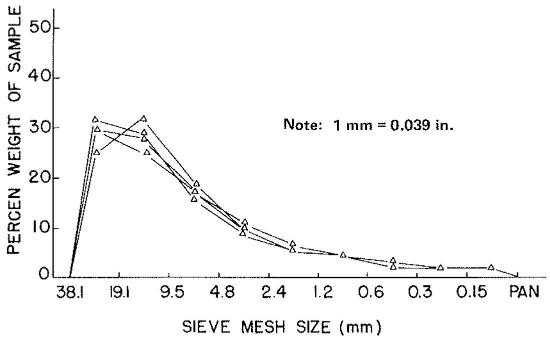
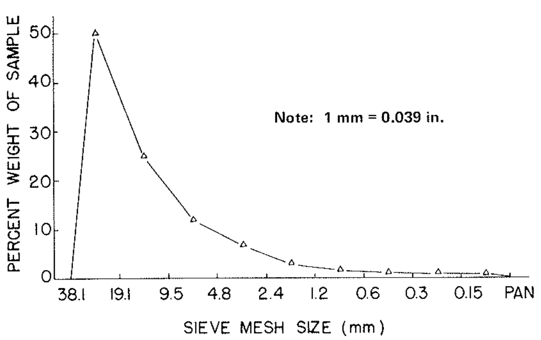


Figure 6. Aggregate size distribution for initial gradation.



The degradation of the material during compaction resulted in different final gradations for each shale. As explained previously, degradation is characterized by a reduction in the amount of large aggregates and an increase in the amount of smaller sizes.

The variability of the compaction process was indicated by examining the results of tests repeated four times at each effort level. The coefficient of variation (the ratio of the standard deviation to the mean, expressed as a percentage) provided an appropriate measure of variability. Table 3 gives the mean IC value and the coefficient of variation for each effort level.

The lowest compactive effort (level 1) consistently displaced the greatest variation. The variation decreased as the compactive effort increased to effort levels 2, 3, and 4. The Palestine shale did not follow this trend. The variation at level 3 for the Palestine shale was larger than the variation at levels 1 and 2 because of the problems encountered with sample separation.

The aggregate size distribution of the four samples of New Providence shale shown in Figure 5 helps to explain the observed variation. The variation in the IC value reflects the variability within particular size groups over the entire size range. The distributions for effort level 1 show the greatest variability within the 38.1- to 9.5-mm (1.5- to 0.38-in) size range and significant variation within the 9.5- to 0.3-mm (0.38- to 0.01-in) range. For effort levels 2, 3, and 4, the variation decreases and is generally concentrated in the 38.1- to 4.8-mm (1.5- to 0.19-in) size range.

The variability in the testing process and the shale accounts for the small range and relatively low values of the coefficent of variation observed for the higher levels of compactive effort. The large variation of the lowest level of effort reflects more than testing or material variability and is mainly the result of the relation between the mechanics of aggregate breakage and the forces produced by the compaction process. The delivery of the compactive effort creates loading conditions that cause compressive, shearing, bending, and torsional stresses. Individual aggregates fail when their ability to withstand the stresses is exceeded. The loads are transferred within the layer through the contact points between aggregates. Thus, the distribution of contact points in the sample directly affects the influence of the compaction process on single aggregates.

The breaking and rearrangement of aggregates during compaction create new contact points that transfer additional stresses to aggregates that may have previously experienced only limited loading. The loads at the lowest effort level caused some degra-

Figure 7. Effect of impact compaction effort on compacted dry density.

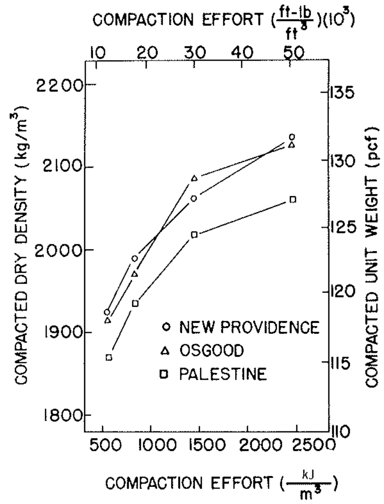


Table 2. Average values of percentage solids for impact compaction samples by level of compactive effort.

	Percentage Solids			
Shale	Level 1	Level 2	Level 3	Level 4
New Providence	68	71	73	76
Osgood	67	69	73	75
Palestine	68	70	73	75

Table 3. Mean IC value and coefficient of variation for impact compaction samples.

		IC Value (%)	
Shale	Effort Level	Mean	Coefficient of Variation
New Providence	1	25.7	10.4
	2	37.6	5.6
	3	43.9	5.0
	4	57.7	3.9
Osgood	1	20.6	20.2
	2	25.1	4.4
	3	42.1	1.9
	4	48.6	3.3
Palestine	1	36.0	6.7
	2	51.8	1.7
	3	46.9	10.0

dation but did not produce a sufficient increase in contact points to establish a uniform distribution of contact points within the sample. Thus, based on their random position within the sample, some aggregates experienced only minimum stresses and did not fail.

The 38.1- to 4.8-mm (1.5- to 0.19-in) range in the size distributions for the compacted shale sample represents the largest and heaviest single aggregates. The variability in percentage weight observed for the larger sizes reflects the influence of a relatively small number of aggregates. Therefore, the variation of the low effort level (Figure 5) reflects differences in the number of large aggregates that survived the compaction process.

The more uniform distribution of contact points created by effort levels 2, 3, and 4 probably ensured that every large aggregate would be significantly loaded. Since every aggregate was influenced by the compactive forces, the variation in degradation decreased for samples compacted at these higher levels.

Figure 8. Compactive work versus IC: static compaction.

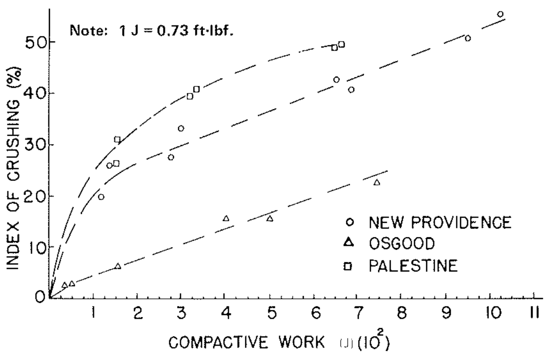


Figure 9. Percentage solids versus compactive work for all shales: static compaction.

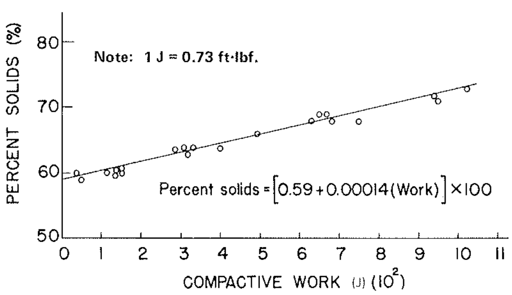


Figure 10. Load versus compacted dry density: static compaction.

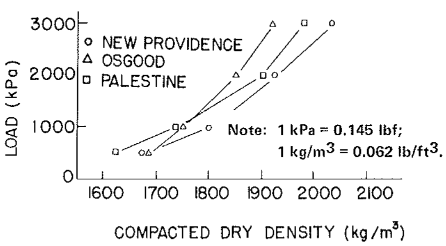
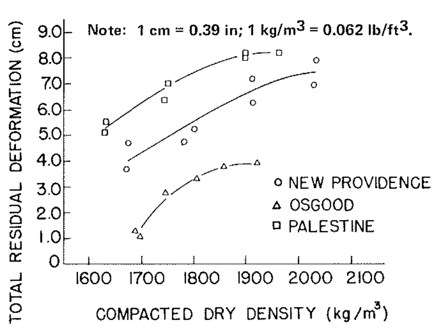


Figure 11. Residual deformation versus compacted dry density: static compaction.



Static Tests

The results of the static compaction tests repeated the general trends of the impact tests.

The compactive work input was determined from the area under the load-residual deformation curve for each statically compacted sample. The hypothesis adopted was that a measurement of the work actually performed on a sample would give a better insight into the relations among compactive effort, dry density, and degradation.

A plot of degradation versus compactive work input is shown in Figure 8. The density-work relation becomes nearly linear for the shales when the differences in specific gravity are considered. The use of the percentage-solids term corrects for the differences in specific gravity and produces the relation shown in Figure 9. Linear regression analysis performed on the data points for work versus percentage solids resulted in the following equation:

$$\text{Percentage solids} = [0.59 + 0.000\,14\,(\text{work})] \times 100 \qquad R^2 = 0.95 \tag{3}$$

The loads applied during the compaction process lead to an increase in sample deformation and a corresponding increase in density. Both load and deformation may be related to density, as shown in Figures 10 and 11. The total sample deformation will eventually reach a maximum as the loads continue to increase. No further densification will occur after this point is reached and a corresponding limiting value for density is approached. Therefore, after maximum deformation (and maximum density) has been reached, compactive energy is wasted.

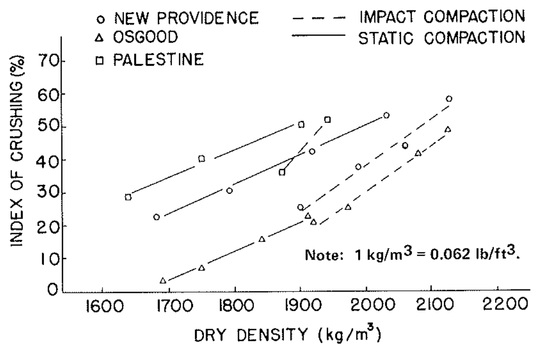
CONCLUSIONS AND SELECTION OF A STANDARD TEST

Both the impact and static compaction tests possess the simplicity and availability that are desired for a standard test. These tests also displayed sufficient repeatability at the moderate and high effort levels. The relations among compactive effort, dry density, and degradation established by each compaction method were similar, although not identical. Based on the above conclusion, either form of testing could serve as a standard test.

The unique features offered by each testing method were evaluated before one test was selected over the other. The main advantage of the static test was its ability to measure the compactive work. The linear relation between work and density, as well as the concept of limiting work and density values, indicate that the expression of compactive work is more logical than the expressions of nominal compactive energy currently used. Unfortunately, compactive work during field compaction is difficult to measure and is generally neglected in favor of terms describing the compaction equipment and number of passes.

A comparison of the density-degradation relation

Figure 12. Comparison of relation between dry density and degradation for impact and static compaction.



shown in Figure 12 reveals higher values of dry density for the impact samples than for static samples at equivalent levels of degradation. The higher density values for the impact tests reflect the amount of aggregate movement that occurred during the compaction process. This increased movement gave the pieces a greater opportunity to establish a more dense packing. Aggregate movement in the static compaction was more restricted. Because of this behavior, large aggregates would fracture during the static loading, but the resulting fragments would essentially remain in place. The increased degradation would have little effect on the dry density without the rearrangement of the broken fragments.

Although neither the impact nor the static test directly models field compaction, the aggregate movement of the impact test will more closely approach the behavior of shale during field compaction. The impact test also has the advantage of being a well-known and accepted procedure in geotechnical laboratories and is backed by a vast amount of experience.

The advantages of the compactive-work expression favor static compaction as a research tool. However, the results of this testing program indicated that the performance and background of the impact test favor the impact form of compactive effort. These reasons, along with the previous discussions, led to the selection of the impact test as the preferred compaction method for a standard test.

The four levels of compactive effort used in the impact tests provided an opportunity to observe the effect of compaction energy on degradation and dry density. However, only one effort level was desired to evaluate the effect of other compaction variables or to classify the degradability of shales. The lowest effort level consistently displayed the greatest variation in the test results. The higher compactive efforts--levels 2, 3, and 4--produced results with sufficient repeatability. However, levels 3 and 4 proved to be too severe for the softest shale. For these reasons, effort level 2 [790 kJ/m³ (16 500 ft•lbf/ft³)] was selected as the most appropriate effort level for the impact test.

In summary, the impact test method at the 790-kJ/m³ effort level was selected as the standard compaction-degradation test for shales. This test can now be used to evaluate the effect of laboratory compaction variables on shales or as a classification test for the mechanical degradability of shales. The practical meaning of the laboratory values must be developed through field experience.

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