THE USE OF RELATIVE DENSITY FOR COMPACTION CONTROL

by

Erhard Gerstner Bruns

B. S., Universidad del Cauca
Popayán, Cauca, Colombia

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Approved by:

Wayne W. Williams
Major Professor

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INTRODUCTION

The compaction control of the different kind of fills has been the concern of the engineers for many years. The adequate compaction of a fill guarantees its stability and will minimize the differential settlement of structures built on it.

The sand, classified as a cohesionless soil, shows special behavior during the compaction process. The Proctor Curve for clean sand takes the shape of a U in the different ASTM test procedures. This characteristic induced this research effort for a compaction control that takes into account the sand properties. One of these methods is the concept of relative density, widely used in the world. This test requires the use of costly equipment besides the uncertainty of the results. The construction specifications do not allow the use of a compaction control different from that previously specified, and the interpretation of the relative density result may delay the construction of the project or end in a quarrel between the constructor and the owner. The relative density test involves many errors and the use of other control methods seem to be worthwhile to develop.

SCOPE AND PURPOSE OF THE STUDY

The study will cover a review of the literature available on relative density and Proctor density, and a description of the more recent test methods, in order to have the best idea of the use of the relative density as a construction control criterion, the use of correlations of relative density with engineering properties of granular soils, and a series of data that uses the concept of relative density with the Standard and Modified compaction test and the percent compaction criterion.

LITERATURE REVIEW

Compactions Methods

The Proctor density compaction method was first described by R. R. Proctor (1), 1933, and it was developed for controlling the compaction of soil. Proctor found that soil can be compacted to a maximum dry density with the least amount of effort at a specific moisture content which he termed the optimum moisture content. The laboratory test procedure is called the Standard Proctor density test and is described in detail in ASTM D-698.

In recent years heavier compacting equipment has come into use and, in order to reproduce the greater densities obtained with this equipment, modified compaction tests have been developed (2). The laboratory test procedure is called the Modified Proctor density test and is described in detail in ASTM D-1557.

Tamping is the oldest method of compaction. It provides momentary pressure at the instant of impact and some vibration, and because of this dual action it is effective in both cohesive and cohesionless soils (3).

Rolling produces pressure that is applied for a relatively short time, depending on the roller speed. The sheepsfoot roller consists of a steel drum with projecting lugs or feet. It applies a high static pressure to a small area. Because of the small width of the loaded area, the sheepsfoot roller is adapted best to cohesive soils such as clays. A modified sheepsfoot roller with wider feet is far better for silty soils of low cohesion (3). It has been reported (Southwest Builder and Contractor, 1936) that the sheepsfoot roller originated as a result of a flock of sheep crossing a scarified, oil treated road surface in Southern California in 1906 (4).

The pneumatic tire has proved to be an excellent compactor for cohesionless and low cohesion soils, including gravels, sands, clayey sands, silty sands, and even sandy clays. It applies a moderate pressure to a relatively wide area so that enough bearing capacity is developed to support the pressure without failure (3). Rubber tired rollers can usually compact in less time and at lower cost than a sheepsfoot roller (4).

The smooth-drum paving roller is sometimes used for compacting cohesionless soils. It is satisfactory if the layers are thin and well leveled, but it tends to bridge over low spots (3).

Vibratory rollers are designed to produce vertical forces. Vibratory rollers may be equipped with rubber tires, smooth wheel drums, or tamping feet, and have been used successfully in compacting sand, gravel, rock fill, and some cohesive soils. Another form of vibratory compaction equipment is the vibrating base plate compactors which produce results similar to that of vibratory rollers (4).

Cohesionless Soils

Hilt, Jack W. (1975) (4) wrote: "Because these soils are relatively pervious even when compacted, they are not affected significantly by their water content during the compaction process. Consequently, the peaked curve relationship between dry density and water content (Proctor curve) that is characteristic of all cohesive soils is ill defined or non-existent for clean sand and gravels. For a given compactive effort on the latter soils, the dry density obtained is high when the soil is completely dry and high when the soil is completely saturated with somewhat lower densities occurring when the soil has intermediate amounts of water. The explanation of this involves the phenomenon of bulking in sands where small capillary stresses in the partly saturated soil tend to resist the compactive effort. This bulking phenomenon is not present in completely dry sand and disappears when the moist sand is saturated."

For these soils, where the Proctor curve concept is not applicable, the normally used compaction criterion is relative density introduced by Terzaghi (1925), defined by

$$Dr = \frac{e_{max} - e}{e_{max} - e_{min}} \qquad \text{-----------------------------} \quad (7.3)$$

where

e_{max} = void ratio of the soil in its loosest state

e = void ratio of the soil being tested

e_{min} = void ratio of the soil in its densest state

Dr = relative density, usually expressed as a percentage

Since void ratio is related to dry density for a given specific gravity, Eq. (7.3) can be written

$$Dr = \frac{\gamma d_{max} \ (\gamma d - \gamma d_{min})}{\gamma d \ (\gamma d_{max} - \gamma d_{min})}$$

where

γd_{max} = dry density of the soil in its densest state

γd_{min} = dry density of the soil in its loosest state

γd = dry density of the soil being tested."

Following Holtz, W. G. (1973) (5) we have: "There are three parameters which must be determined--1) e_{max} or γ_{min}, which describes the most loose state that a particular soil can be structured; 2) e_{min} or γ_{max} which describes the most dense state that the soil can be structured; and 3) e or γ which is the in-place density of a natural deposit or fill, or perhaps the density of a laboratory sample or research test specimen, which we desire to describe in terms of that soils densest or loosest states. Therefore, the most loose state is zero percent relative density, and the most dense state is 100 percent relative density, and theoretically, no lower or higher density states, respectively, should exist without changes in gradation.

Some years ago when we were working on vibrated sand backfill for the San Diego Aqueduct and other large conduits, I proposed some limits of soil types for compaction by vibration purposes. These limits which were based on tests of several different sand and sand-gravel soils with different amount of -200 fines were as follows:

1. GW, GP, SW, and SP soils are suitable (the fines in the soils are limited to 5 percent by definition).

2. Borderline GW-GW, GW-GC, GP-GM, and GP-GC soils containing less than 8 percent fines are usually suitable.

3. Borderline SW-SM, SP-SM, SP-SC soils are suitable (fines in these soils are limited to 12 percent by definition).

4. SM and SC soils require special consideration and suitability depends upon gradation of the sand and the plasticity of the fines. Some SM soils with fines as high as 16 percent have been found to be suitable.

In this case, suitability was defined as limiting amount of fines where the specified minimum percent relative density became less than the specified minimum percent compaction based on ASTM Tests for Moisture-Density Relations of soils, using 5.5 lb. Rammer and 12 in. drop (D-698-70)."

Percent Compaction

Following Poulos, S. J. and Hed, Alexander, 1973 (6), we have:

"Percent Compaction - the percent compaction is defined as 100 times the ratio of the field dry density, γ_f, to the maximum dry density measured in a compaction test, γ_A.

$$P\% = 100 \frac{\gamma t}{\gamma A}$$

It is difficult to assess the physical meaning of the values of relative density, but the values of percent compaction have a direct physical meaning. The percent settlement (namely, the vertical strain) of a given layer of fill in one dimensional compression is given by the difference between the final (which may exceed 100 percent) and original percent compaction,

$$\varepsilon v\ (\%) = 100 \times \frac{\rho}{H} = P^1 - P \text{ .''}$$

Definitions and Standards

William T. Cavanaugh, Managing Director of ASTM, wrote in the April 1972 issue of Materials Research and Standard: "The evolution of language in the slow victory over Babel was man's greatest forward move in his eternal struggle to bring order out of chaos. Standardization, of course, is nothing more than the forced-draft creation of language. Language itself is a set of standard symbols for things and concepts. The standards that ASTM produces comprise a language for commerce, a language for research, a language for regulation, and a language, if you will, for accommodating the fruits of science and technology to our culture."

In Tables 1, 2 and 3 we find a density description according to Lambe and Whitman (1969) (7), Terzaghi (1925) (8) and Burmister (1948) (9).

From the mentioned tables we see that compact-dense has a different meaning for Lambe, Terzaghi and Burmister, and it is necessary to provide uniform definitions (5).

Relative Density Test

Standard Method of test for Relative density of cohesionless soils ASTM Designation D2049-69 (10).

"Scope: this method covers the determination of the relative density of cohesionless free-draining soils for which

Table 1 - Density Description According to Lambe and Whitman

Relative Density %	Descriptive Term
0-15	Very loose
15-35	Loose
35-65	Medium
65-85	Dense
85-100	Very dense

Table 2 - Density Description by Terzaghi

Relative Density %	Descriptive Term
0-33	Loose sand
33-66	Medium compact sand
66-100	Dense sand

Table 3 - Density Description by Burmister

Relative Density %	Descriptive Term
0-38	Loose
38-70	Medium
70-90	Compact
90-100	Very compact

impact compaction will not produce a well-defined moisture density relationship curve and the maximum density by impact methods will generally be less than by vibratory methods. Soils for which this method is applicable may contain up to 12 weight % of soil particles passing a N° 200 (75 μm) sieve, depending upon the distribution of particle sizes which will cause them to have free-draining characteristics. This method utilizes vibratory compaction to obtain maximum density and pouring to obtain minimum density."

Standard Proctor Compaction Test

Standard Methods for Moisture-Density Relations of soils using 5.5 lb. (2.5 kg) Rammer and 12 in. (304.8 mm) Drop Designation D698-70 (10)

"Scope: These methods cover the determination of the relationship between the moisture content and density of soils when compacted in a mold of a given size with a 5.5 lb. (2.5 kg) Rammer dropped from a height of 12 in. (304.8 mm). Four alternate procedures are provided as follows:

	Sections
Method A - A 4 in. mold: soil material passing a No. 4 (4.75 mm) sieve	3 and 4
Method B - A 6 in. mold: soil material passing a No. 4 (4.75 mm) sieve	5 and 6
Method C - A 4 in. mold: soil material passing a 3/4 in. sieve	7 and 8
Method D - A 6 in. mold: soil material passing a 3/4 in. sieve	9 and 10

The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Method A shall govern."

Modified Proctor Compaction Test

Standard Methods of test for Moisture-Density Relations of soils using 10 lb. (4.5 kg) Rammer and 18 in. (457 mm) Drop Designation D1557-70 (10).

"Scope: These methods cover the determination of the relationship between the moisture content and density of soils when compacted in a mold of a given size with a 10 lb. (4.5 kg) Rammer dropped from a height of 18 in. (457 mm). Four alternative procedures are provided as follows:

	Sections
Method A - A 4 in. (102 mm) mold: soil material passing a No. 4 (4.75 mm) sieve	3 and 4
Method B - A 6 in. (152 mm) mold: soil material passing a No. 4 (4.75 mm) sieve	5 and 6
Method C - A 4 in. mold: soil material passing a 3/4 in. (19 mm) sieve	7 and 8
Method D - A 6 in. mold: soil material passing a 3/4 in. sieve	9 and 10

The method to be used should be indicated in the specification for the material being tested. If no method is specified, the provisions of Method A shall govern."

Equipment type	Applicability	Requirements for Compaction of 95 to 100 Percent Standard Proctor Maximum Density			Possible variations in equipment
		Compacted lift thickness, in	Passes or coverages	Dimensions and weight of equipment	
Sheepsfoot rollers	For fine-grained soils or dirty coarse-grained soils with more than 20 percent passing the No. 200 sieve. Not suitable for clean coarse-grained soils. Particularly appropriate for compaction of impervious zone for earth dam or linings where bonding of lifts is important.	6	4 to 6 passes for fine-grained soil; 6 to 8 passes for coarse-grained soil	Soil type / Foot contact area, in^2 / Foot contact pressures, psi: Fine-grained soil $PI > 30$ — 5 to 12 — 250 to 500 Fine-grained soil $PI < 30$ — 7 to 14 — 200 to 400 Coarse-grained soil — 10 to 14 — 150 to 250 Efficient compaction of soils wet of optimum requires less contact pressures than the same soils at lower moisture contents.	For earth dam, highway and airfield work, drum of 60-in dia., loaded to 1.5 to 3 tons per lineal foot of drum generally is utilized. For smaller projects 40-in dia. drum, loaded to 0.75 to 1.75 tons per lineal foot of drum is used. Foot contact pressure should be regulated so as to avoid shearing the soil on the third or fourth pass.
Rubber tire rollers	For clean, coarse-grained soils with 4 to 8 percent passing the No. 200 sieve.	10	3 to 5 coverages	Tire inflation pressures of 60 to 80 psi for clean granular material or base course and subgrade compaction. Wheel load 18,000 to 25,000 lb.	Wide variety of rubber tire compaction equipment is available. For cohesive soils, light-wheel loads, such as provided by wobble-wheel equipment, may be substituted for heavy-wheel load if lift thickness is decreased. For cohesionless soils, large-size tires are desirable to avoid shear and rutting.
Do....	For fine-grained soils or well-graded, dirty coarse-grained soils with more than 8 percent passing the No. 200 sieve.	6 to 8	4 to 6 coverages	Tire inflation pressures in excess of 65 psi for fine-grained soils of high plasticity. For uniform clean sands or silty fine sands, use large size tires with pressures of 40 to 50 psi.	
Smooth wheel rollers	Appropriate for subgrade or base course compaction of well-graded sand-gravel mixtures.	8 to 12	4 coverages	Tandem type rollers for base course or subgrade compaction, 10 to 15 ton weight, 300 to 500 lb per lineal inch of width of rear roller.	3-wheel rollers obtainable in wide range of sizes. 2-wheel tandem rollers are available in the range of 1 to 20 ton weight. 3-axle tandem rollers are generally used in the range of 10 to 20 ton weight. Very heavy rollers are used for proof rolling of subgrade or base course.
Do...	May be used for fine-grained soils other than in earth dams. Not suitable for clean well-graded sands or silty uniform sands.	6 to 8	6 coverages	3-wheel roller for compaction of fine-grained soil; weights from 5 to 6 tons for materials of low plasticity to 10 tons for materials of high plasticity.	
Vibrating baseplate compactors	For coarse-grained soils with less than about 12 percent passing No. 200 sieve. Best suited for materials with 4 to 8 percent passing No. 200, placed thoroughly wet.	8 to 10	3 coverages	Single pads or plates should weigh no less than 200 lb. May be used in tandem where working space is available. For clean coarse-grained soil, vibration frequency should be no less than 1600 cycles per minute.	Vibrating pads or plates are available, hand-propelled or self-propelled, single or in gangs, with width of coverage from 1½ to 15 ft. Various types of vibrating-drum equipment should be considered for compaction in large areas.
Crawler tractor	Best suited for coarse-grained soils with less than 4 to 8 percent passing No. 200 sieve, placed thoroughly wet.	10 to 12	3 to 4 coverages	No smaller than D8 tractor with blade, 34,500 lb weight, for high compaction.	Tractor weights up to 60,000 lb.
Power tamper or rammer	For difficult access, trench backfill. Suitable for all inorganic soils.	4 to 6 in for silt or clay, 6 in for coarse-grained soils.	2 coverages	30-lb minimum weight. Considerable range is tolerable, depending on materials and conditions.	Weights up to 250 lb, foot diameter 4 to 10 in.

Correlations of Relative Density With Engineering Properties

From the study of the effect of particle shape on the engineering properties of granular soils by I. Holubec and E. D'Appolonia, 1973 (12), we find the following conclusion:

"The test data show that the particle shape has a significant effect on the engineering properties of cohesionless soils, and it should be considered as an index property in correlations of properties of granular soils. A standard procedure to measure the particle shape should be adopted. For this purpose, an indirect method based on either the porosity or permeability of the sand is suggested because of its simplicity. Any method involving measurements of individual particles is too cumbersome.

The variation of the engineering properties due to particle shape can be of the same order of magnitude as the variation of the properties due to changes in relative density. Therefore, the use of existing correlations of relative density with engineering properties to predict soil behavior should be undertaken with caution and with the full understanding of the assumptions and limitations of the current published correlations for granular soils."

Factors Controlling Maximum and Minimum Densities of Sands

In the Burmister's publications (1938, 1948, 1962) (13, 9, 14), the most important factor controlling maximum and minimum densities is the range of particle sizes--the greater the range of the particle sizes, the greater the density. Other important factors were grading curve, particle size, and particle shape.

Youd, T. L., (1973) (15) "confirmed the findings of previous investigators that particle size range, particle shape and type of grading curve are the primary factors controlling e_{max} and e_{min}. Contrary to previous studies, it was found that particle size per se has no significant influence on the density limits."

<u>Effect of Variations in Minimum Density on Relative Density</u>

The conclusions of R. C. Gupta and J. D. McKeown (1973) (16) about the topic are as follows:

"In terms of statistical significance, the effects of variation in minimum density on relative density are startling. Although this variation will decrease at increasing values of relative density, it still creates a dilemma for effective quality control in the field in terms of enforcing the requirements of design as spelled out in a contract specification. A problem definitely exists if the case in question is that of a contract specification asking for lower relative densities, say in the range of 50 to 75 percent. Seemingly, there is an urgent need for establishing an effective criterion in view of the extreme sensitivity of the minimum density test values. It is considered that the minimum density test results are difficult to reproduce.

The tests described herein were conducted in an on-site laboratory, and therefore, were not performed under the strict control normally associated with research work; however, conditions were certainly typical of normal construction control--the one which is most likely to be encountered in practice.

It may also be pointed out that the results are based on tests carried out on a specific material. The statistical analysis was performed under certain assumptions. In addition, such things as compaction equipment, field moisture content, grain size distribution, climatic conditions, and test procedure are some of the variables which may have a bearing on the measured value of relative density. Consequently, caution must be exercised in using the data."

Errors of In-place Density Measurements in Cohesionless Soils

D. F. Griffin's (1973) (17) conclusions are: "When a soil is physically sampled during the process of conducting an in-place density measurement, a shearing action of the soil is unavoidable. Cohesionless soils are sensitive to volume change during shear; dense sands tend to expand and increase in volume; loose sands tend to contract and decrease in volume. Thus, in general, measured in-place density of dense sand is found to be relatively low and for loose sand, it is found to be relatively high compared to control values.

A plot of measured values versus control values provides a means for adjusting the value measured in the field more closely toward the true value. All measuring methods tested require such correction plots. Moreover, specific plots generally are not applicable to other sands of even slightly different character or water content. Each method requires a separate plot for each soil or soil moisture condition."

Types of Error in Relative Density

According to Selig, E. T. and Ladd, R. S. (18), the errors are generally classified into three categories: "1) systematic, 2) random, and 3) mistakes. Examples of each of these in connection with relative density measurement are the following:

Systematic

1. Deviation from prescribed values of vibration frequency, amplitude and surcharge.

2. Weighing scales out of adjustment.

3. Calibration errors in in-situ density measuring devices.

4. Incorrect volume for mold used in determining maximum and minimum density.

5. Use of non-standard test procedures.

Random

1. Sample variability - particle size, shape, and gradation.

2. Variation in measurement techniques from test to test such as in a) pouring sand in minimum density test, and b) preparation of hole for in-situ density measurement.

3. Changes in environmental conditions.

4. Round-off errors in reading weights and volumes.

5. Density variations in fill.

Mistakes

1. Misreading scales.
2. Using wet unit weight instead of dry unit weight.
3. Calculations errors.
4. Taking single amplitude value as double amplitude.

Errors by mistake must be avoided and can only be avoided by careful work and constant checking.

Systematic and random errors often can be difficult to distinguish. For example, if scales are out of adjustment by different amounts in different labs, the variations caused in relative density among the labs will appear as a random error. However, the difference in average values obtained between two independent labs will appear as a systematic error from this cause."

PROCEDURES FOR TESTING THE SAND

Maximum and Minimum Density Tests

Maximum density tests were performed in accordance with the ASTM D-698-70 and ASTM D-1557-70 methods, using the dry method, wet method, and saturated method and a mold of 1/30 cu. ft. (Method A).

The dry method was performed using oven dried sand and compacting the material in a 4 in. (1/30 cu. ft.) mold.

The wet method was performed using wet sand and compacting the material in a 4 in. (1/30 cu. ft.) mold in order to determine the shape of the Proctor curve.

The saturated method was performed using saturated sand and compacting the material in a 4 in. (1/30 cu. ft.) mold, with enough water to produce a layer of water in the surface (after compacting) not more than 1/8 in. thick.

Minimum density tests were performed pouring the dry sand through a glass funnel that was held 1/8 in. above the sand surface.

PRESENTATION OF DATA

Laboratory Tests

A river sand from the Kansas River Valley at Manhattan was used to perform the tests. This sand had the following physical characteristics:

Specific Gravity (G_s): 2.63

Atterberg Limits: non-plastic

Maximum Dry Density (ASTM D-698): 112.7 lb/cu. ft.

Maximum Dry Density (ASTM D-1557): 114.4 lb/cu. ft.

Minimum Dry Density: 100.1 lb/cu. ft.

Classification AASHO: A-1-b (0)

USC: SP

Uniformity Coefficient, C_u: 2.8

The laboratory dats sheets for these tests may be found in Appendix A.

ANALYSIS OF DATA

Standard Proctor (ASTM D-698-70)

Maximum dry density: 112.7 lb/cu. ft.

Minimum dry density: 100.1 lb/cu. ft.

$$Dr = \frac{\gamma d_{max} \ (\gamma d - \gamma d_{min})}{\gamma d \ (\gamma d_{max} - \gamma d_{min})}$$

for $\gamma d = .95 \times 112.7 = 107.1$ lb/cu. ft.

$$Dr = \frac{112.7 \ (107.1 - 100.1)}{107.1 \ (112.7 - 100.1)} \times 100 = 58\%$$

$$e_{max} = 0.639$$

$$e_{min} = 0.456$$

$$e_{(95\%)} = 0.532$$

$$Dr = \frac{(e_{max} - e) \times 100}{e_{max} - e_{min}} = \frac{(0.639 - 0.532)}{0.639 - 0.456} \times 100 = 58\%$$

With an error of +1 lb/cu. ft. in the maximum and minimum density

$$Dr = \frac{113.7 \ (107.1 - 101.1)}{107.1 \ (113.7 - 101.1)} \times 100 = 50\%$$

With an error of -1 lb/cu. ft. in the maximum and minimum density

$$Dr = \frac{111.7 \ (107.1 - 99.1)}{107.1 \ (111.7 - 99.1)} \times 100 = 66\%$$

With an error of $\pm$ 1 lb/cu. ft. (Approx. 1% max. & min. density) in the maximum and minimum density there are values of relative density of 50 and 66%, for a 95 percent compaction.

<u>Modified Proctor</u> (ASTM D-1557-70)

Maximum dry density: 114.4 lb/cu. ft.

Minimum dry density: 100.1 lb/cu. ft.

for γd = .95 x 114.4 = 108.7 lb/cu. ft.

$$Dr = \frac{114.4\ (108.7 - 100.1)}{108.7\ (114.4 - 100.1)} \times 100 = 63\%$$

$$e_{max} = 0.639$$

$$e_{min} = 0.435$$

$$e_{(95\%)} = 0.510$$

$$Dr = \frac{0.639 - 0.510}{0.639 - 0.435} \times 100 = 63\%$$

With an error of +1 lb/cu. ft. in the maximum and minimum density

$$Dr = \frac{115.4\ (108.7 - 101.1)}{108.7\ (115.4 - 101.1)} \times 100 = 56\%$$

With an error of -1 lb/cu. ft. in the maximum and minimum density

$$Dr = \frac{113.4\ (108.7 - 99.1)}{108.7\ (113.4 - 99.1)} \times 100 = 70\%$$

With an error of $\pm$ 1 lb/cu. ft. (Approx. 1% max. or min. density) in the maximum or minimum density there are values of relative density of 56 and 70%, for a 95 percent compaction.

CONCLUSION

a) Relative density should be used with care when dealing with engineering properties of the soil.

b) In the compaction control there are other methods, such as percent compaction, that seems to be more suitable than the relative density concept.

c) The percent compaction method utilizes equipment available in most of the laboratories of soil mechanics, and the operation of that equipment does not involve as many variables as the relative density test.

d) If the Proctor curve for the specific soil has the U shape, the maximim density can be determined using the 1 point compaction with the soil saturated.

e) For an error of ± 1 lb/cu. ft. (Approx. 1% max. or min. dry density) in the maximum and minimum density test, there are values of relative density of 50 and -66% for the Standard Proctor, and 56 and 70% for the Modified Proctor, for a 95 percent compaction of the sand used in the study.

f) The in-place density should be corrected using control values for every sand and sand conditions.

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APPENDIX A

Physical Characteristics of the Sand Used in the Tests

Table 4

Sieve Analysis

Soil sample: Sand K.R.V. test No. 1 Date: Sept./76 Tested by E.G.

Wt. dry soil: 1533 g

Sieve No.	Sieve Opening mm	Wt. Soil Retained g	Percent Retained	Cumulative Percent Retained	Percent Finer
10	2.0	--	0	0	100
20	0.840	120	7.8	7.8	92.2
40	0.420	760	49.6	57.4	42.6
60	0.250	425	27.7	85.1	14.9
140	0.105	170	11.1	96.2	3.8
200	0.074	15	1.0	97.2	2.8
Pan	--	43	2.8	100	--

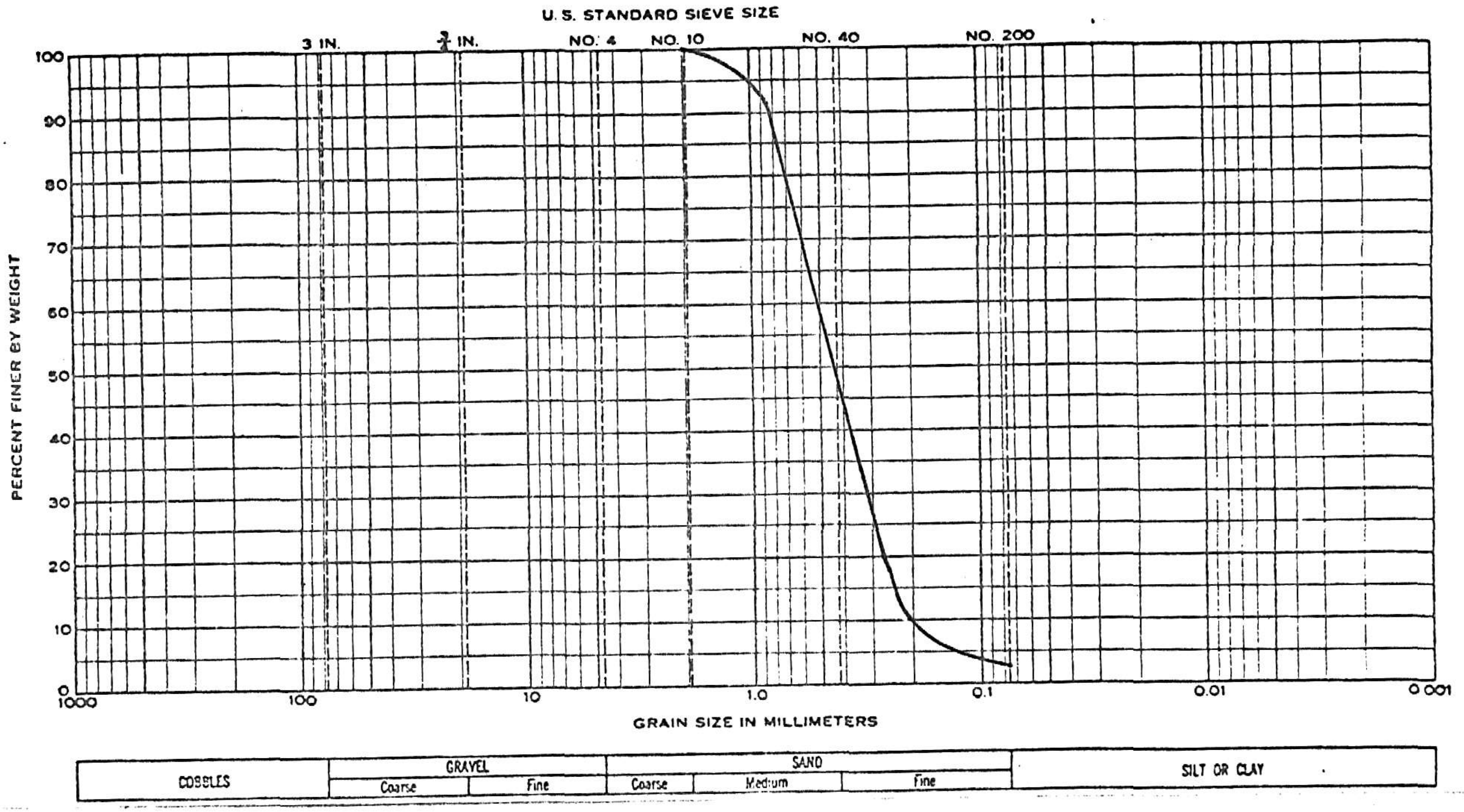

Fig. 1 - Sieve Analysis

Table 5

Specific Gravity Test

Soil sample: Sand K.R.V. Test #1 Date: Sept./76 Tested by E.G.

Determination No.	1	2	3
Bottle No.	1	2	3
Wt. bottle + water + soil, W_1, g	711.17	705.96	710.43
Temperature T °C	29.6	29.3	29.9
Wt. bottle + water, W_2, g	678.03	674.20	675.81
Evaporating dish No.	1	2	3
Wt. dish + dry soil, g	492.24	490.15	494.63
Wt. dish, g	438.90	438.91	438.90
Wt. soil, W_s, g	53.34	51.24	55.73
Specific gravity of water at T, GT	0.996	0.996	0.996
Specific gravity of soil, G	2.63	2.62	2.63

$$G_s = \frac{GT\ W_s}{W_s - W_1 + W_2}$$

$G_s = 2.63$

Table 6

Compaction Test

Soil sample: Sand K.R.V.   Test #3   Date: Sept./76

Compaction test: loose   Tested by E.G.

Density

Determination No.	1	2	3
Wt. Mold + dry soil, g	6030	6040	6030
Wt. Mold, g	4520	4520	4520
Wt. dry soil, g	1510	1520	1510
Dry density lbs/cu. ft.	99.9	100.5	99.9

γd = 100.1 lbs/cu. ft.

Pouring device: funnel

Table 7

Compaction Test

Soil sample: Sand K.R.V. Test #1 Date: Sept./76

Compaction test: Standard Tested by E.G.

Method A

Density

Determination No.	1	2	3
Wt. Mold + compacted soil, g	6190	6370	6500
Wt. Mold, g	4520	4520	4520
Wt. compacted soil	1670	1850	1980
Wet density lbs/cu. ft.	--	122.4	130.9
Dry density lbs/cu. ft.	110.5	109.1	112.7

Water Content

Container No.		1	2
Wt. container + wet soil, g		2250	2420
Wt. container + dry soil, g		2060	2150
Wt. water, g	Dry	190	270
Wt. container, g		486	487
Wt. dry soil, W_s, g		1574	1663
Water content, W, %	0	12.1	16.2

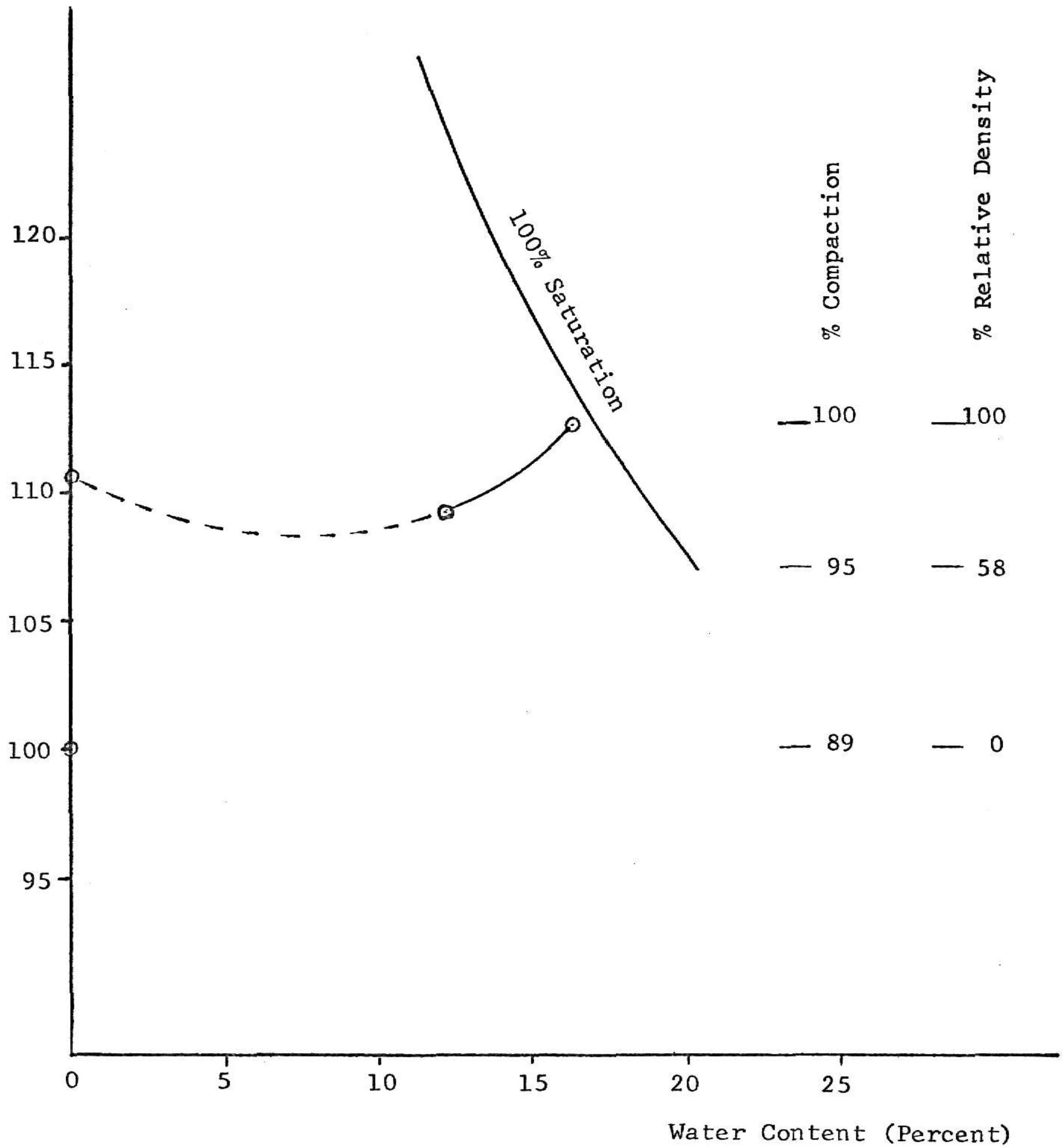

Fig. 2 - Standard Compaction Test

Table 8

Compaction Test

Soil sample: Sand K.R.V. Test #2 Date: Sept./76

Compaction test: Modified Tested by E.G.

Method A

Density

Determination No.	1	2	3
Wt. Mold + compacted soil, g	6220	6440	6520
Wt. Mold, g	4520	4520	4520
Wt. compacted soil, g	1700	1920	2000
Wet density lbs/cu. ft.	--	127.0	132.3
Dry density lbs/cu. ft.	112.4	112.1	114.4
Water Content			
Container No.		1	2
Wt. container + wet soil, g		2280	2340
Wt. container + dry soil, g		2070	2090
Wt. water, g	Dry	210	250
Wt. container, g		486	487
Wt. dry soil, W_s, g		1584	1603
Water content, W, %	0	13.3	15.6

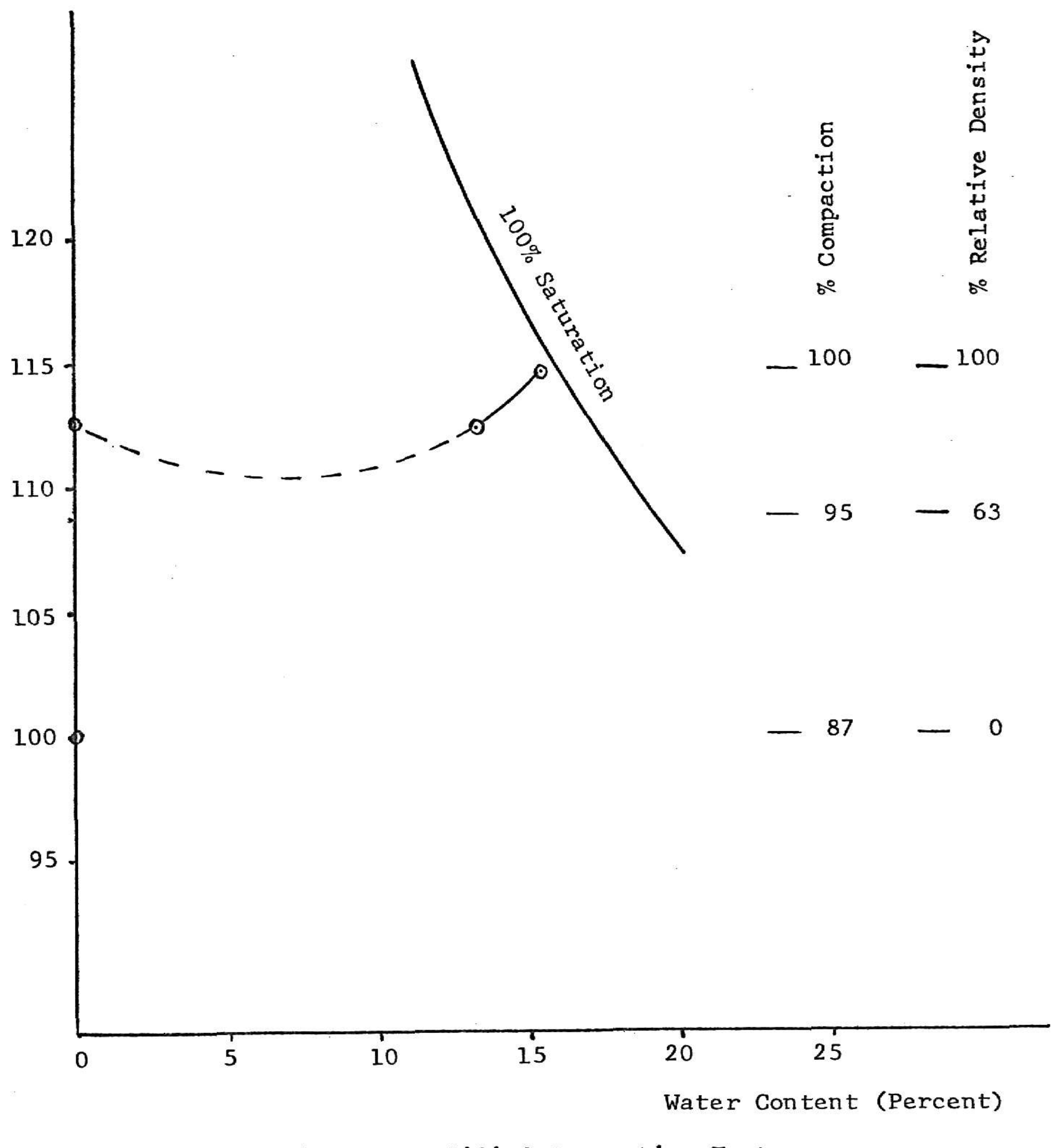

Fig. 3 - Modified Compaction Test

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THE USE OF RELATIVE DENSITY FOR COMPACTION CONTROL

by

Erhard Gerstner Bruns

B. S., Universidad del Cauca
Popayán, Cauca, Colombia

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AN ABSTRACT OF A MASTER'S REPORT

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Manhattan, Kansas

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ABSTRACT

The compaction control of fills of sand is widely based on the relative density concept. The relative density test involves three parameters that must be determined, errors or variations can be obtained in determining each of these three values, and the testing equipment is expensive and must be well maintained.

There are other compaction control methods, like the percent compaction concept, that seem to be adequate using equipment available in every soil mechanics laboratory.