THE SWELLING CHARACTERISTICS OF SOME ARKANSAS SOILS

RESEARCH CONDUCTED BY
CIVIL ENGINEERING DEPARTMENT
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ARKANSAS STATE HIGHWAY DEPARTMENT
PLANNING AND RESEARCH DIVISION
IN COOPERATION WITH
U. S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

RESEARCH PROJECT 16

THE SWELLING CHARACTERISTICS OF SOME ARKANSAS SOILS

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FINAL REPORT

of

HIGHWAY RESEARCH PROJECT NO. 16
"The Swelling Characteristics of
Some Arkansas Soils"

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INTRODUCTION

Highway Research Project No. 16, "The Swelling Characteristics of Some Arkansas Soils," was approved by the Bureau of Public Roads and the Arkansas Highway Department in February, 1963. Work commenced on the project in March, 1963, with Mr. Melton L. Odom, Instructor in Civil Engineering, as the Principal Investigator. Mr. Odom resigned his University appointment effective May 31, 1963, and the duties of Principal Investigator were assumed temporarily by Mr. Miller C. Ford, Jr., Assistant Professor of Civil Engineering. Mr. Ford directed the project until August 31, 1963. Although during the first six months two Principal Investigators directed the project, some continuity was maintained. However, no work plan was submitted for the project.

The present investigator assumed direction of Project No. 16 on a one-eighth time basis on September 1, 1963. The immediate objectives of the new investigator were to review the proposal, study the research already accomplished, review and study the supporting literature and prepare a work plan for the remainder of the project. After approval of the work plan, the investigator then hoped to accomplish the objectives and goals as set forth in the project proposal.

During the study of the research accomplished on this and preceding Highway Research Projects and the supporting literature, the investigator reached certain tentative conclusions which he believes the previous investigators would also have reached if circumstances had permitted them to continue in the direction which they had started. In order to check the tentative conclusions without undue expense to the sponsoring agencies, it was requested in December that Project No. 16 be halted effective in January, 1964, with the exception that the one-eighth time salary of the Principal Investigator and limited secretarial services be continued until May 31, 1964. It was intended that this would provide time for investigation of the tentative conclusions and for writing a report. However, the time provided was insufficient. The reasons for the cessation of work will be explained below.

PURPOSE OF THE PROJECT

Basic to all research projects is the consideration of previous research results. Conclusions, both supported and unsupported, frequently provide avenues for further study and investigations. In the case of Highway Research Project No. 16, the purpose of the project is based on an "unsupported conclusion" drawn from interpretation of data from the results of Highway Research Project No. 4 (1). This "unsupported conclusion," as contained in the introduction to the approved proposal of Project No. 16, is restated below (2):

> "In the course of investigating the performance of flexible pavements in the loess-terrace soil area in Eastern Arkansas, it was noted that the highway subgrades, in many instances, had a measured in-place density considerably lower than the maximum modified AASHO density obtained in the laboratory and concomitantly the subgrade moisture content was found to be above the optimum moisture content. This led to the unsupported conclusion that the subgrade had lessened in density from the original density obtained during construction and that the loss in density was the result of swelling of the soil due to capillary moisture subsequent to construction."

Re-examination of previously collected data, augmented by a study of the results of research already accomplished on the present project and the results of other researchers available on related studies, indicated to the present investigator that the above "unsupported conclusion" could no longer be considered valid. The investigator, therefore, felt it his responsibility to stop progress on the project and present arguments tending to support his conclusions. Cessation of the project was, in the opinion of the writer, justified by the following data, comparisons and objective reasonings.

1. Decrease in Subgrade Density:

In the above-quoted paragraph from the introduction of the approved project proposal, reference is made to the comparison of the measured in-place density to the "maximum modified AASHO density" for subgrade soils. The writer questions this comparison since the Standard Specifications for Highway Construction, Arkansas Highway Commission, 1959, page 68 (3) states that:

> "The density of compacted material, as determined by AASHO Designation T-147, shall not be less than 95% of maximum density obtained by the standard method of tests for the compaction and density of soils, AASHO Designation T-99, modified to use material passing a 3/4 inch sieve. The moisture content of the material being compacted throughout each entire layer shall be substantially that of optimum moisture for the particular soil type."

Thus, the Arkansas State Highway Department specifies only 95 percent of standard AASHO maximum density. Therefore, the reason the observed measured in-place density of highway subgrades was "considerably lower than the maximum modified AASHO density" is that the densities were never intended to be that high.

Furthermore, in the purpose of the subject project proposal (2) it is stated that:

> "The range of measured subgrade densities on Project No. 4 varied from 83 to 87 percent of modified AASHO density, which is notable because the indicated current field density is less than the density presumably achieved during roadway construction."

In the attempt to substantiate that 83 to 87 percent of maximum modified AASHO density was less than the specified 95 percent of maximum standard AASHO density, data was collected from several sources (6, 7) including results from Arkansas soils obtained from the thesis of Mr. Walter Graves (4). These results are shown in Table I.

The results of this attempt, however, did not substantiate the statement that the range of 83 to 87 percent of modified AASHO density was below that density specified by the Arkansas State Highway Department. Rather it clearly demonstrated for the four Arkansas soils tested, and for all other data obtained from the literature, that a range of 82 to 88.5 percent of modified AASHO density would likely be equivalent to the specified 95 percent of standard AASHO density. Since, in the results of Project No. 4 (page 29, Ref. 1), it is stated that:

> "Job records do not indicate what the density of the base or subgrade was at the time of construction.",

it would seem only reasonable to assume that the contractor, considering his cost, would only achieve that minimum density required of him, i.e., 95 percent of standard AASHO density.

The above discussion leads to the conclusion that it is doubtful whether the subgrade densities measured in Project No. 4 were

TABLE I

Comparisons of Maximum Densities
as determined by Modified and
Standard AASHO Procedures

Source	Soil Designation	Maximum Density Modified AASHO pcf	Maximum Density Standard AASHO pcf	95 percent Standard pcf	Percent Modified Equivalent to 95% Standard
(4)	A-4	120	112	106	88.5
(4)	A-6	121	109	103.5	85.5
(4)	A-7-6 (14)	117	106	100.5	85.8
(4)	A-7-6 (24)	113	99	94	83.0
(5)	Silty Clay	131	120	114	87.0
(6)	Clay	107	92	87.5	81.9
(7)	Clay	119	107	101.5	85.3

in fact below the 95 percent standard AASHO specified by the Arkansas State Highway Department. Since in the course of testing subgrade materials in Project No. 4, no standard AASHO density tests were performed, there seems to be no evidence that would support the "unsupported conclusion" that the densities have decreased.

2. Increase in Subgrade Water Content

In the introduction of the project proposal, quoted above, reference is made to the fact that the subgrade water content was observed to be higher than that corresponding to the modified AASHO density test procedure. Once again, the Arkansas State Highway Department specifies compaction at "substantially" optimum water content according to the standard AASHO test procedures. Naturally, the optimum obtained from the modified AASHO test is lower than the optimum obtained from the standard AASHO test. Furthermore, the writer knows of no procedure whereby the optimum according to the standard tests may be obtained from the optimum according to the modified tests.

However, observation of a large number of standard AASHO density tests has indicated that the average optimum water content is only a few percent less than the average plastic limit. In order to check this observation, the results of 12 soils tested previously by the writer (7) were averaged. It was found that the average optimum water content as determined by the standard AASHO procedure was only 2 percent less than the average plastic limit. A further check of other published values by Havens, et.al (8) shows that for 31 Kentucky soils, the average optimum water content as determined by standard AASHO tests was 2.9 percent less than the average plastic limit. An additional comparison was obtained from the files of the Arkansas State Highway Department, Division of Materials and Test. Mr. Joe Magness reported on January 19, 1965, results of tests performed on 21 randomly selected specimens, ranging from A-2 to A-6 soils. These results show the average plastic limit to be 3.7 percent higher than the average standard AASHO optimum water content. Other published data show similar results (9, 10, 11). Thus from all test data collected a good approximation of the optimum water content according to standard AASHO procedure would appear to be in the order of:

$$\text{Std. Opt. w/c} = PL - 3$$

where PL represents the plastic limit.

The data in Table 2 was taken from the results of Highway Research Project No. 4 (Table 8, Ref. 1). This data shows the average plastic limit and in-place water content for the job investigated. Included is an estimate of the standard AASHO optimum water content.

From the estimate in Table 2, it would appear that the in-place water contents observed on Project No. 4 are not wet of the standard AASHO optimum specified by the Arkansas Highway Department, but rather are slightly dry of optimum. This is in disagreement with the project proposal which states that:

> ".....the subgrade moisture content was found to be above the optimum water content."

TABLE 2

Estimate of Standard AASHO
Optimum Water Content
from Plastic Limit

Job	Soil Type	Plastic Limit	In-Place Water Content	Estimated Optimum Water Content (PL-3)	Remarks
A	A4	21	17	18	1% dry
B	A6	22	20	19	1% wet
C	A4	21	18	18	------
F	A4	22	16	19	3% dry
I	A4	24	19	21	3% dry
J	A4	22	17	19	2% dry
M	A4	25	18	22	4% dry

Therefore, it is the conclusion of the writer that the subgrade soils reported in Project No. 4 have not gained in water content appreciably since compaction.

3. The Immediate Goals of Project No. 16

The immediate goals of Project No. 16, as set forth in the approved proposal, were:

> "1. To measure the change of density resulting from a change of moisture content in highway embankment soils.
> 2. To determine if a 'natural maximum density' exists for a given soil."

It was anticipated that if a "natural maximum density" were found, it would be useful in planning compaction controls for future highway construction projects.

To accomplish these goals a series of swelling tests was performed on four Arkansas soils compacted at various moisture contents and densities. These tests were all performed prior to the arrival of the present investigator. Although no duplication of tests was reported, the results for the most part appear in line with other reported data. These results are shown subsequently in this report. The hypothesis that a "natural maximum density" exists for a given soil will also be discussed in relation to results obtained and supporting literature studied.

RESULTS OF EXPANSION TESTS

To study the swelling characteristics of some Arkansas soils, Graves (1) selected four soils of varying properties and characteristics and performed numerous swell tests. The characteristics of the soils selected for this study are given in Table 3. The physiochemical properties of these soils are partially explained by the cation exchange capacities given in Table 4. No attempt was made to identify the clay minerals present.

Soil samples four inches in diameter and 2.5 inches high were compacted at various moisture contents and densities and placed in a water sink. Enough water was placed at the lower level to create a continuum between the water and the soil. This usually amounted to about an eighth of an inch submergence. Dial gages were placed directly over the sample to record the vertical movement. Each sample was then loaded with a surcharge equal to about two inches of asphaltic pavement and six inches of base material, or about 0.6 pounds per square inch. The results of these studies are represented graphically in Figures 1 through 4.

Figure 1 shows the results of soil 161, an A-4 soil. As can be seen, only moderate volume changes were observed for specimens which were compacted at water contents near the line of optima. Those specimens compacted slightly wet of optimum water content consolidated under the surcharge weight. However, those specimens compacted at water contents dryer than the dashed line, representing 2 percent less than the line of optima, underwent considerable increases in water contents, which resulted in decreases in densities.

The obvious conclusion which may be drawn from this data is that control of the initial "as molded" water content is of extreme

TABLE 3

Physical Characteristics of the Soils Investigated

Soil No.	Soil Classi-fication	Liquid Limit (%)	Plasticity Index (%)	Specific Gravity	Silt (%)	Clay (0.002mm.) (%)
161	A-4(8)	34	9	2.70	65	20
162	A-6(12)	40	18	2.72	60	28
163	A-7-6(14)	49	24	2.72	56	34
164	A-7-6(24)	70	41	2.70	38	49

Soil No.	Standard AASHO Density (pcf)	Standard AASHO Optimum Moisture (%)	Modified AASHO Density (pcf)	Modified AASHO Optimum Moisture (%)
161	112.4	15.0	120.0	13.5
162	109.0	18.0	121.0	13.5
163	105.9	19.5	116.9	14.5
164	99.0	24.0	113.0	16.0

TABLE 4

Cation Exchange Capacity and K^+, Ca^{++}, Mg^{++}, Na^+ Present in the Soils Investigated

Ion (Milliequivalent per 100 grams)	Soil Classification A-4(8)	A-6(12)	A-7-6(14)	A-7-6(24)
K^+	0.2	0.2	0.2	0.4
Ca^{++}	4	4	2	4
Mg^{++}	1.7	0.5	0.5	7
Na^+	0.6	3.0	1.2	4.0
Total Cation Exchange Capacity	16.0	17.0	18.0	27.8

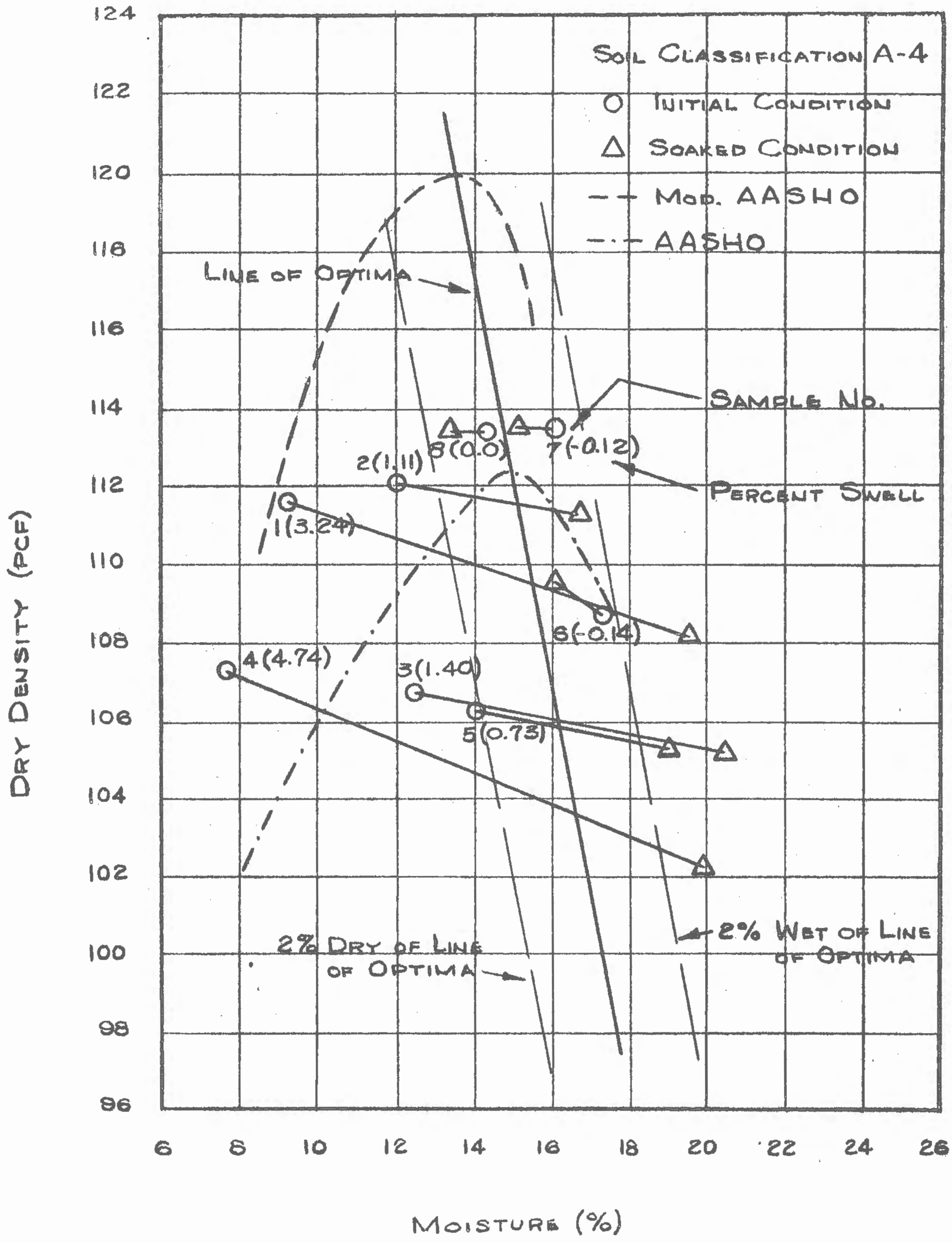

Figure 1. Initial and Final Moisture-Density Condition for Soil 161. After Graves (1)

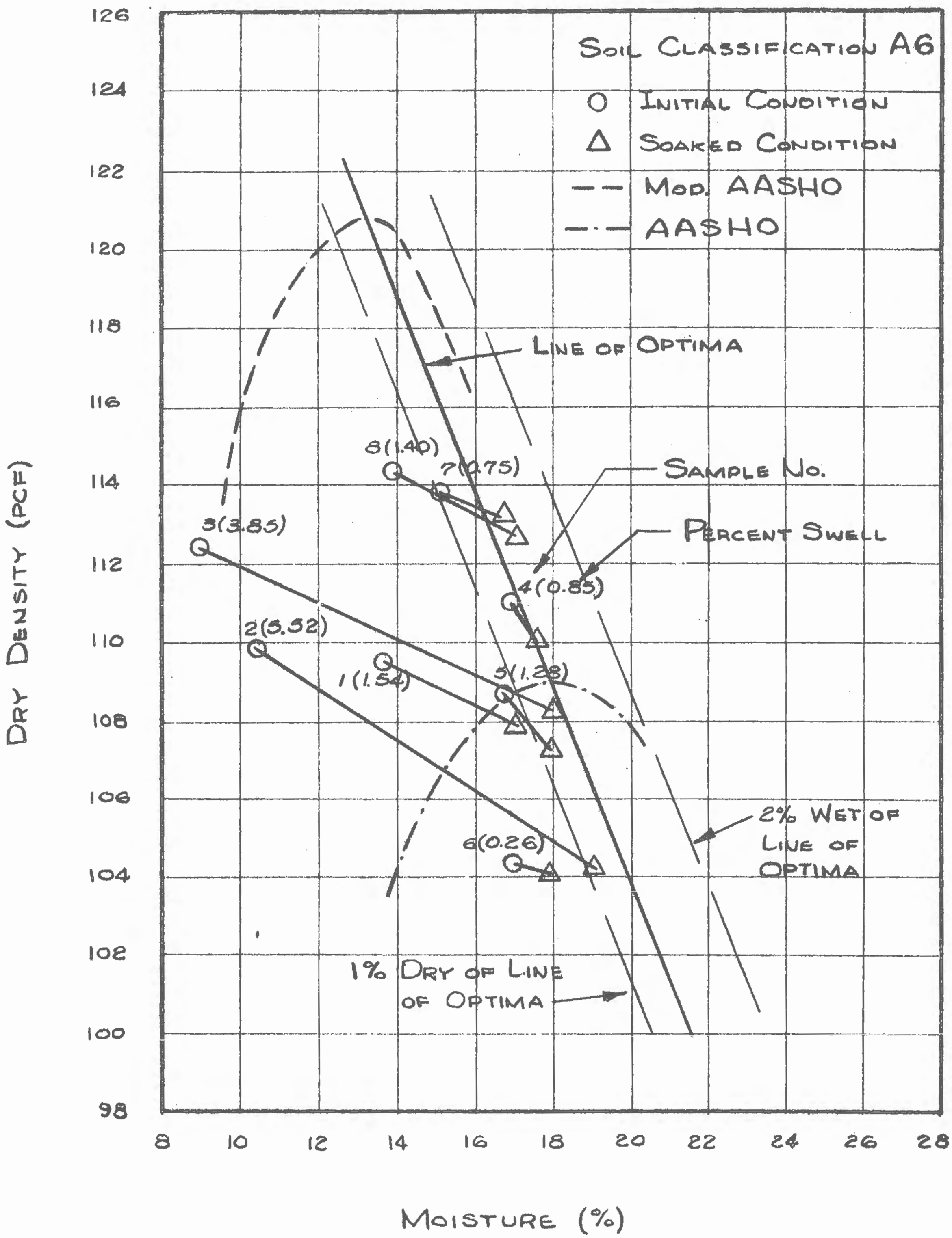

Figure 2. Initial and Final Moisture-Density Condition for Soil 162. After Graves. (1)

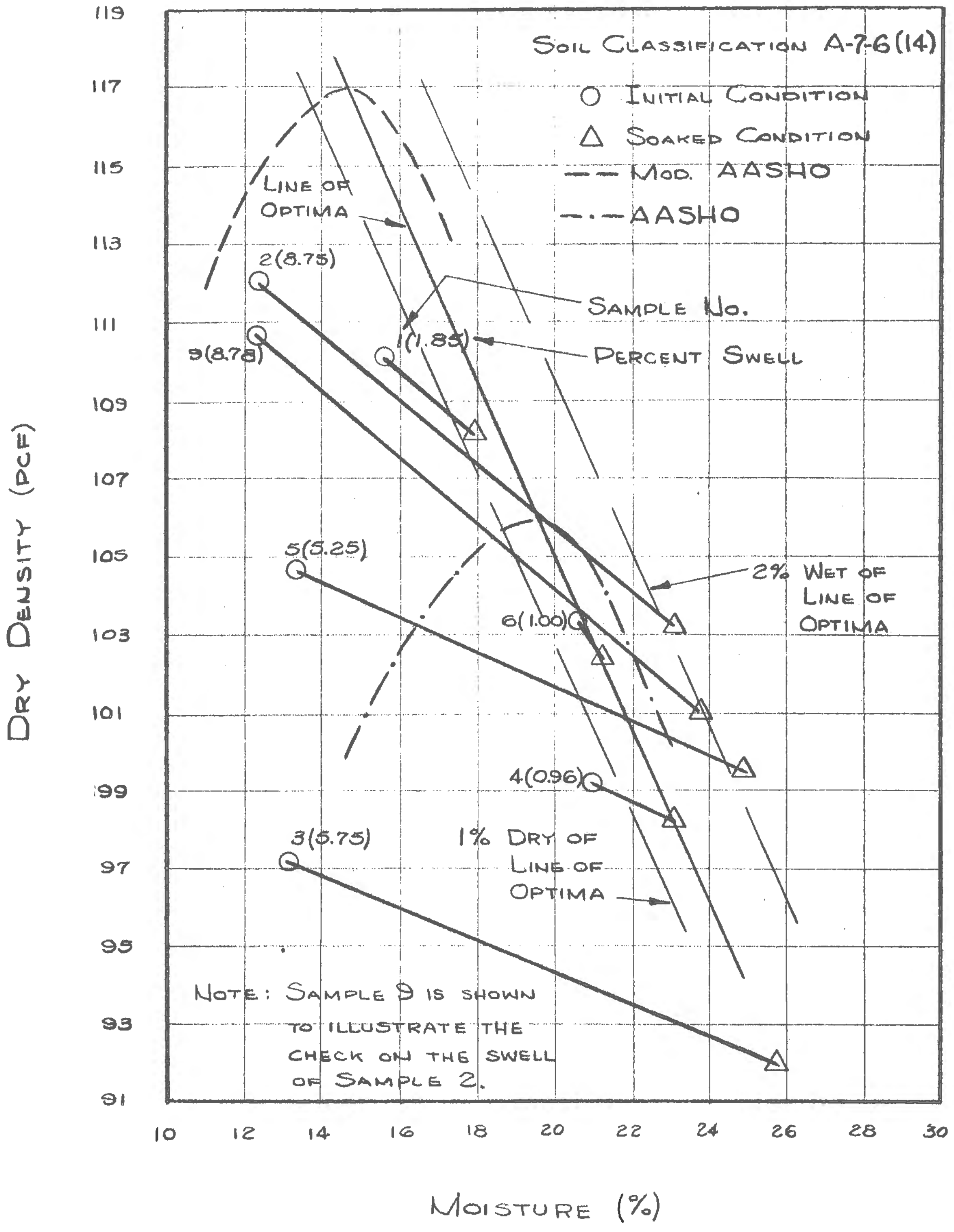

Figure 3. Initial and Final Moisture-Density Condition for Soil 163. After Graves (1)

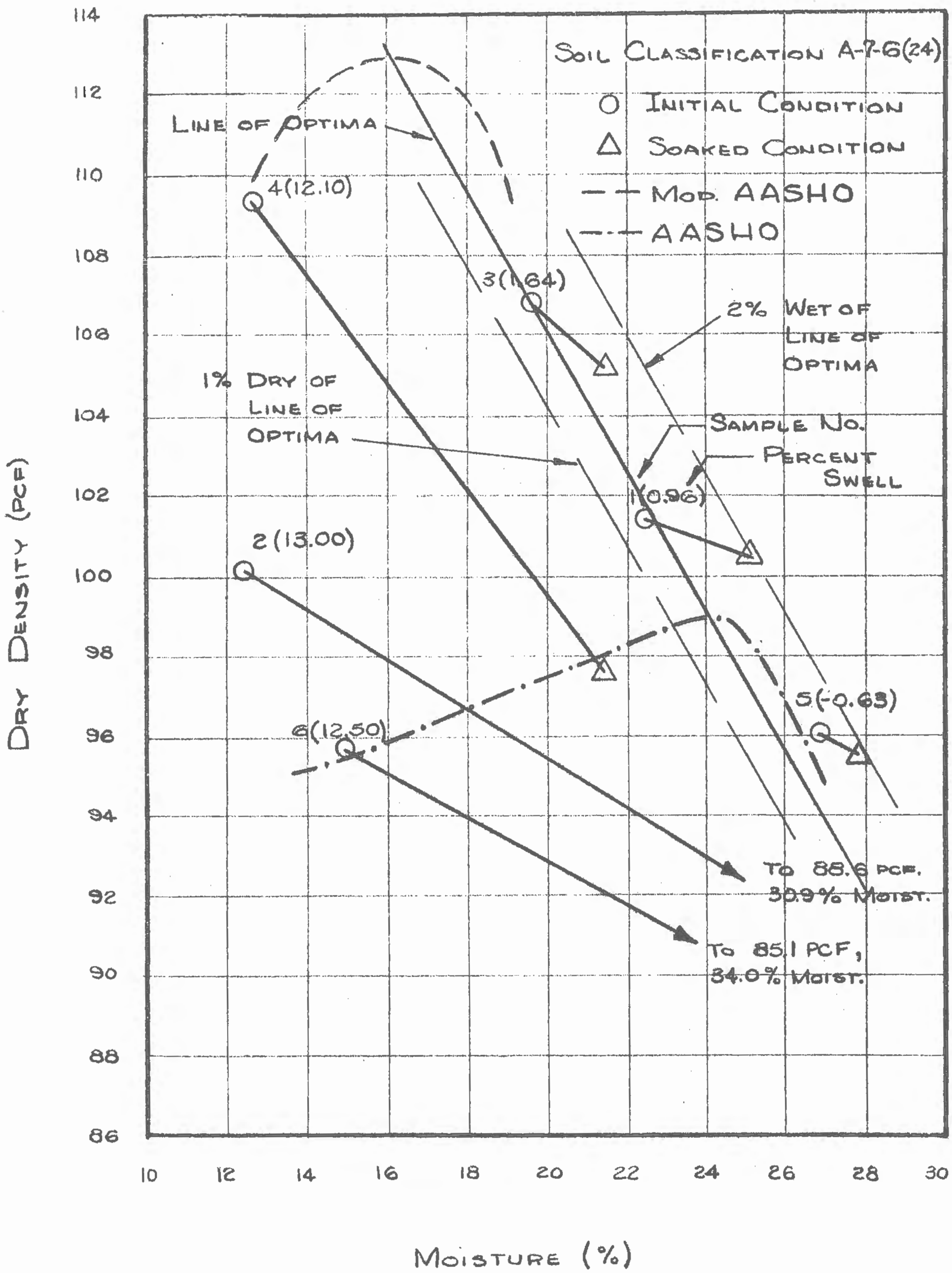

Figure 4. Initial and Final Moisture-Density Condition for Soil 164. After Graves (1)

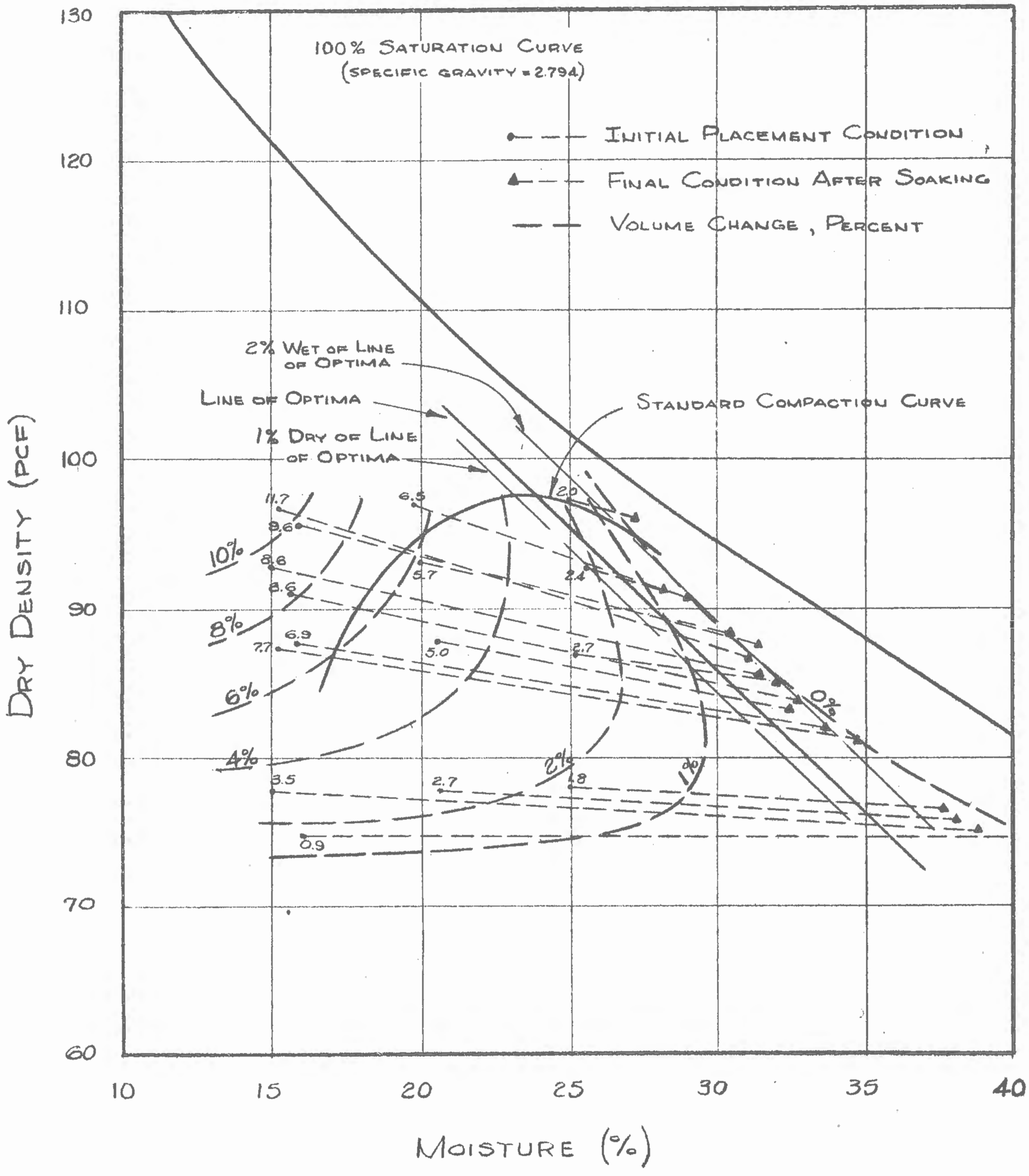

Figure 5. Percentage of Expansion for Various Placement Conditions for Soil Under a Load of 1 Lb. per Sq. In. After Holtz and Gibbs (12).

importance in reducing volumetric changes in compacted subgrade soils. A second observation which can be made from these data is that there appeared to be no "natural maximum density", but rather the final density was a function of initial water content and initial density. For example, specimens 3, 4 and 5 were compacted to practically the same density but at different water contents. The results show that the dryer the compacted specimen, the greater was the loss in density.

The results of swell tests performed in specimens of soil 162, an A-6 soil, are shown in Figure 2. The observed increases in water content and decreases in density follow the same general pattern as described above. However, the magnitudes of the density decreases are larger, as should be anticipated by the higher liquid limit value. For soil 162 a range of "as molded" water contents from 1 percent dry to 2 percent wet of the line of optima would result in minimum swelling. Once again it may be seen that no "natural maximum density" was observed.

The results of swell tests performed on specimens of soils 163 and 164, both A-7-6 soils, are shown in Figures 3 and 4. These results also illustrate that the "as molded" water contents influence the swelling magnitudes. Specimens compacted in the range of 1 percent dry to 2 percent wet of the line of optima tend to swell less and thus to decrease in density less than specimens compacted at initial water contents less than 1% dry of the line of optima. Again no "natural maximum density" was observed.

A much more elaborate investigation of expansive clays was conducted by Holtz and Gibbs (12) in 1956. Figure 5 shows some results of expansion tests on a "Poterville clay" from the Delta-Mendota Canal. These results also clearly indicate the importance of the initial as molded water content in control of clay expansion. Furthermore, no "natural maximum density" was found to exist.

Further analysis of the data presented in Figures 2 through 5 leads to the observation that compaction of clays to densities in excess of maximum standard AASHO density could result in greater expansions than may be tolerable, even if the initial as-molded water contents are within a reasonable range of the line of optima. Thus, for compaction of expansive clays, specifications should not only limit the range of "as molded" water contents and the minimum dry density, but the maximum dry density as well.

SUMMARY AND CONCLUSIONS

From the results of laboratory tests, data presented and supporting literature, the following conclusions seem to be justified:

1. Since the Arkansas State Highway Department specifies 95 percent of standard AASHO density, measured in-place densities considered low when compared to maximum modified AASHO density may in fact meet Arkansas specifications.

2. Ninety-five percent of maximum density according to the standard AASHO test procedure will generally fall within the range of 82 to 88 percent of maximum density according to the modified AASHO test procedure.

3. The subgrade densities measured and reported in the results of Project No. 4, which are in the range of 83 to 87 percent

of maximum density according to the modified test procedure, are near the Arkansas State Highway Department specifications of 95 percent of maximum standard AASHO density.

4. On the basis of comparisons of the optimum water content obtained from the standard AASHO test procedure with the plastic limit, a reasonable estimate of the standard optimum water content can be obtained from the relation:

$$\text{Std. Opt. w/c} \approx PL - 3 \quad (1)$$

5. The in-place water contents measured and reported in Project No. 4 are near, or slightly dry of, the optimum water content as specified by the Arkansas State Highway Department.

6. Therefore, the writer considers the "unsupported conclusion" that the subgrade soils have decreased in density due to an increase in water content subsequent to construction, to be invalid.

7. The introduction of the approved proposal states:

> "The data collected from the study of 'The Performance of Flexable Bases and Pavements', Highway Research Committee Project No. 4, apparently indicates that under a given condition highway subgrade soils in time reverts to a 'natural maximum density' regardless of the initial density at the time of construction."

The results of this project indicate that the "as molded" water content and the initial density both influence the final field density. It may be concluded, therefore, that no "natural maximum density" exists.

RECOMMENDATIONS

The following recommendations for field compaction control and future research were developed from the results of the current investigation:

1. In control of field compaction, the "as molded" water content is frequently not given proper emphasis. The practice of the Arkansas State Highway Department in specifying compaction at "substantially" optimum water content is considered adequate. However, the terms "substantially that of optimum" may be interpreted in different ways by different inspectors. Therefore, it would seem to be advantageous for the Department to more clearly define the desirable water content limitations, especially for those soils which may have a potential to swell, i.e., primarily A-6 and A-7 soils. For these soils an upper density requirement has some merit. For example, the writer offers the following as a suggestion for specifying compaction of A-6 and A-7 subgrade soils:

The density of compacted A-6 and A-7 soils, as determined by AASHO Designation T-147, shall not be less than 95 percent nor more than 100 percent of maximum density obtained by the standard method of tests for the compaction and density of soils, AASHO Designation T-99, modified to use material passing a 3/4 inch sieve. The water content of the compacted material shall be between one percent dry and two percent wet of the line of optima.

2. More research is needed along the lines of identification of potentially swelling soils. The writer is familiar with procedures used by some consulting engineers whereby the percent swell for a given surcharge can be estimated for certain groups of undisturbed soils with knowledge of the liquid limit and the difference

between the water content and the plastic limit. Further development of this concept could furnish guidelines for easy identification of potentially swelling soils.

3. A paucity of knowledge currently exists with respect to the clay mineral composition of soils and their potential to swell. Qualitatively it is widely known which minerals contribute to soil swelling. However, quantitative measurements of the influence of the more common clay minerals on soil swelling could be advantageous, especially if correlated to the study currently underway in Highway Research Project No. 19.

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