PAPER MILL WASTE (AMMONIUM LIGNIN SULFONATES AND SUGARS) AS A STABILIZING AGENT FOR PALOUSE CLAY

by

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To the Resident Instructional Staff:

The members of the Committee appointed to examine the thesis of ELVIN G. ERICSON find it satisfactory and recommend it be accepted.

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PAPER MILL WASTE (AMMONIUM LIGNIN SULFONATES AND SUGARS AS A STABILIZING AGENT FOR PALOUSE CLAY

CHAPTER I

INTRODUCTION

Palouse Clay. -- A major part of the southeastern corner of the State of Washington is covered with a soil described by geologists as a loess, and is commonly referred to as Palouse clay by highway engineers. Loess is an exceedingly fine grained soil of relatively uniform size. It is loose in structure and has no horizontal stratification, but vertical cleavage is quite common. The thickness of this mantle is variable rather than uniform due to the method of transportation and deposit. It consists of sharp cornered particles of feldspar, quartz, and numerous other minerals mingled with clay.

L. D. Luck in his investigations into the shear characteristics of Palouse clay[1] determined its typical mechanical properties to be those shown in Table 1.

The U. S. Bureau of Public Road textural classification

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[1]Leon D. Luck, "An Investigation of the Shear Characteristics of Palouse Clay" (Unpublished M.S. thesis, Dept. of Civil Engineering, University of Minnesota, March, 1951) pp. 2-14.

TABLE 1

MECHANICAL PROPERTIES OF PALOUSE CLAY

Grain Size		Per Cent by Weight
Gravel	over 2.00 mm	0.0
Coarse Sand	2.00 mm to 0.50 mm	0.0
Medium Sand	0.50 mm " 0.25 mm	0.0
Fine Sand	0.25 mm " 0.10 mm	1.0
Very Fine Sand	0.10 mm " 0.05 mm	7.0
Silt	0.05 mm " 0.005 mm	61.0
Clay	below 0.005 mm	31.0
Liquid Limit		31.0 to 32.5
Plastic Index		8.9 " 12.2
Specific Gravity		2.71

chart[1] shows that a soil having the grain size given in Table 1 is a silty-clay. The Highway Research Board group index method of soil classification[2], which uses not only the grain size but also the liquid limit and the plastic index, shows the soil to be an A-4 (8) or A-6 (9), and this is again in the silty-clay group.

Soils of the silty-clay type have low cohesive strength and a low value of internal friction. High capillarity, low permeability, susceptibility to volume changes due to moisture

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[1] Arthur G. Bruce and John Clarkeson, Highway Design and Construction, (3d ed.; Scranton: International Textbook Co., 1950), p. 280.

[2] L. J. Ritter, Jr. and R. J. Paquette, Highway Engineering, New York: (The Ronald Press Co., 1951), pp. 180-189.

and frost action are also characteristic of this soil. Upon saturation, this soil becomes soft and compressible, but when dry it readily separates into individual particles. Silty-clay soils are considered to be from fair to poor as a road building material, and for good results some method of treatment is necessary.

Stabilizing agent.--The stability of any material is defined as its ability to resist deformation under load; therefore, a stabilized road surface is one that will stay in place regardless of weather or load conditions. Soil stabilization may be defined as the improvement of local soils to produce a firm material capable of supporting given traffic loads under all weather conditions, by the combination and manipulation of these soils with or without the aid of admixtures.

In the interest of economy in highway construction, the use of local materials, or readily available materials, to produce these stable mixtures is a paramount consideration to the designing engineers. The most efficient and economical method of producing a satisfactory subgrade material is of course the combination of local materials. In many areas, such as the Palouse, suitable soil materials that might be combined to produce a stable soil are not readily available; therefore, the use of stabilizing agents or admixtures such as bituminous materials, Portland cement, various chemicals, etc. must be used to gain an improvement.

The purpose of a stabilizing agent in Palouse clay should be to improve its supporting strength and its resistance to weather by increases in density and cohesion.

Paper-mill waste.--Sulphite waste liquor, commonly known as paper-mill waste, is a by-product of wood pulping by the sulphite process. Orzan A[1], which is the particular product used in this study, is produced from the sulphite process using an ammonia base. Table 2 lists the technical data for Orzan which are pertinent to this study.

TABLE 2

TECHNICAL DATA FOR ORZAN A*

Physical Properties of Orzan A	3 per cent H_2O
Color	Light Brown
Particle size	0.0004 to 0.0006 inches in diameter
Specific Gravity.	1.5
Bulk Density.	about 30 lbs./ cu. ft.
Melting point (bone dry).	none
Solubility.	water in all proportions
Constituent Analysis of Orzan A	Percent of total solids
Lignin sulforic acids	55.0
Reducing sugars as glucose.	16.7
Alkali liberated as NH_3	2.8
Sulfate	1.6
Sulfated ash.	2.0

*Source: Technical Bulletin 531, Industrial Products Division, Crown Zellerbach Corp.

[1] "The chemical by-product of wood pulping by the sulphite process using an ammonia base or ammonium lignin sulfonates and sugars, occurring in fixed proportion....Orzan A is a mixture of organic chemicals derived principally from the nonfibrous portions of wood. The two major classes of compounds present are ammonium lignin sulfonates and sugars." "Orzan", Technical Bulletin 531, (North Portland: Industrial Products Div., Zellerbach Corp.), pp. 1 and 6.

Hereafter, throughout this paper the terms paper-mill waste, sulphite waste liquor, and Orzan are used synonymously.

Statement of the problem.--Palouse clay is well known in highway work for its poor quality as a road building material. The load bearing capacities of this soil must be improved in some manner before it may be used successfully. This thesis is a report of work by the author, to study the effect of paper-mill waste on the mechanical properties of Palouse clay for road construction. Although an economic study is not a part of this paper, such considerations have been continuously in mind, not only in the selection of the stabilizing agent studied, but also in consideration of test procedures and quantities of material used. No attempt has been made to study the chemical or physical changes taking place within the soil structure due to the addition of Orzan, as this field of study is the work of the soil physicist and is not to be considered here.

CHAPTER II

DISCUSSION OF TESTS

Compaction.--The importance of compacting soils to a high degree of density and the effect of the moisture content of the soil on these densities is well known. The stability of soil is dependent upon its resistance to shear, and this shearing resistance in turn depends upon the properties of internal friction and cohesion. These combined properties of a soil are affected by the amount of voids in the soil and the quantity of water in these voids. The greater the percentage of voids in a soil the more unstable the soil is when exposed to high moisture conditions. The lower the percentage of voids the more resistant the soil mass is to the entrance of free water; therefore, the more compact mass is apt to be more stable.

The density to which any given soil can be compacted is dependent upon its moisture content and the amount of compactive effort exerted upon it. If a given soil in an air dry condition is placed in a container and submitted to a definite compactive effort, a certain density will be obtained. In its air dry condition the soil particles do not have a sufficient film of adsorbed moisture to have much influence upon the density, but as more moisture is added to the soil, before compacting another sample, the adsorbed film on the particles tends to get thicker and lubricate or facilitate slippage of the particles over each other under compactive effort. Because of this lubrication, the addition of small amounts of water aids compaction and greater densities are obtained with the same compactive effort. The limit of increasing densities is reached when enough water is added to force or hold the soil particles apart. At this point water fills the void spaces except for small amounts of entrapped air, which remain essentially constant. A further increase in moisture tends to overfill the voids, but does not materially decrease the air content. As the density of soil is about 2.7, the wet density, as well as the dry density, of the entire mass will decrease as water displaces the volume otherwise occupied by soil particles. Therefore, it is apparent that there must be a point of maximum density at a point of optimum moisture content. This phenomenon will be demonstrated in Chapter 3, in the determination of maximum densities of materials used.

The real purpose of any laboratory compaction test is to determine the proper quantities of water that must be present in the soil in the field to obtain maximum densities from the type of compaction equipment being used on the job. To accomplish this purpose, any laboratory test which will give a degree of compaction closely comparable to that which can be obtained in the field is to be recommended. Laboratory tests at the present time are of three basic types: (1) dynamic, (2) static, (3) kneading.

Dynamic compaction is perhaps the best known and most widely used of all laboratory tests at the present time. The standard AASHO test[1] was first developed by R. R. Proctor in 1933, but many engineers in recent years have felt that this test gave densities much lower than those obtainable in the field with improved modern compaction equipment. To remedy this situation the standard test has been modified to give values of greater density by increasing the hammer weight, its height of fall, or the number of blows per layer of soil. Because of this change of compactive effort, increased densities are obtained with the same or lower moisture content. The standard AASHO test consists of compacting a series of soil samples with increasing moisture content into a 1/30 cu. ft. mold by dropping a 5 lb. hammer having a 2 in. diameter face a distance of 12 in. of free drop. The soil is compacted in three layers, slightly more than filling, the mold, at twenty-five blows of the hammer per layer. T. William Lambe, in a manual for soil testing,[2] compares the several methods of laboratory compaction for silty-clay soils against field values and finds that the standard AASHO test gives results more closely associated to field compaction than do the other methods.

Static compaction of laboratory samples for moisture-density determination is not widely used. Most laboratory manuals do not even mention this method, and the AASHO does not

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[1] American Association of State Highway Officials, "Standard Method of Test for the Compaction and Density of Soils, Standard Specifications for Highway Materials and Methods of Sampling and Testing, (6th ed.; Washington: American Association of State Highway Officials, 1950), Part II 241.

[2] T. William Lambe, Soil Testing for Engineers, (New York: John Wiley and Sons, Inc., 1951), pp. 43-44.

include a procedure in its Methods of Sampling and Testing. The test itself is simple and easy to perform. Either the single or double plunger cylinder may be used with equal success if care is exercised in test procedure. To accomplish the test the soil is compacted in a cylinder by means of a piston or pistons at a set rate of consolidation until the maximum compactive effort in pounds per square inch specified in the test has been reached. The test is then repeated on the soil at varying degrees of moisture, as in the dynamic type test.

In recent years engineers in their search for a more realistic method of laboratory compaction have developed the kneading type compactor. One of the early studies of this type compaction was made at Northwestern University.

> "..., P. C. Rutledge and J. O. Osterberg at Northwestern University in 1946, set up the following desirable characteristics for a laboratory soil compactor device: (1) the compacting foot should not apply impact to the soil; (2) the compacting foot should apply a controlled pressure to the soil for a controlled period of time, and variation of both the contact pressure and the contact time over reasonable ranges corresponding to those anticipated in the field should be possible; (3) the compacting foot should cover a moderately small portion of the surface area of the soil sample being compacted so that shear deformations involving lateral flow of the soil could take place; (4) the operation of the device should be as nearly automatic as possible.
>
> The compaction device to meet these characteristics was designed by J. O. Osterberg and constructed by Northwestern University Soil Mechanics Laboratory in 1946-47.[1]

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[1]J. L. McRae and P. C. Rutledge, "Laboratory Kneading of Soil to Simulate Field Compaction", <u>Highway Research Board Proceedings of the Thirty-First Annual Meeting</u>, (Washington: Highway Research Board, 1952), XXXI, 595.

In May 1948 the Triaxial Institute sponsored the design and development of a kneading compactor based on the experience gained in the use of kneading compactors by the California Division of Highways. In the fall of 1948 the results obtained from a pilot model constructed at the University of California were studied and revisions made. In the summer of 1950 arrangements were made by the California Division of Highways to construct several models for their use. The State College of Washington purchased a compactor of the latest design for use in its highway and soils laboratory in 1952. This was the third piece of equipment of this type to be put into operation in the Northwest. Thus, this test is very new and its results are not recognized as a standard test, although many soils engineers feel that more satisfactory results are obtainable than by methods previously used.

The entire compactor is so built that its action is under perfect control at all times and practically automatic.

> ...Through a pressure foot shaped like a segment of a circle, the compactor applies a series of individual strokes to the specimen as it is gradually built up in a cylindrical forming mold and for a certain period after the specimen is formed. The mechanical system employs a toggle-press principle powered by an electric motor through a speed-reduction gear, fly wheel, and connecting rod. On each stroke, the power builds up, dwells for a fraction of a second and is gradually released. The end-area of the pressure foot is 3.2 sq. in., and since the end area of the specimen in the mold is about 12 1/2 sq. in., particles not directly under the foot tend to orient themselves in somewhat the same manner as particles ahead of a roller during actual construction. The pressure exerted on the specimen during compaction is controlled by a combination hydraulic-pneumatic control system. Air from a high pressure line passes through a pressure regulator into the upper portion of the oil reservoir. A feeder valve controls the flow of oil from the reservoir into a cylinder

> containing a piston, which is attached to the lower link of the press. When the compactor is started, and as the sample builds up, the load on the pressure foot remains constant, since, as soon as the piston tends to exert more pressure on the oil than exists on the compressed air above the oil, oil is squeezed out from under the piston through a one-way check valve back into the oil reservoir until the pressures are equalized....Exhaustive studies by several investigators have shown that samples fabricated by the above kneading action closely resemble field-compacted samples in particle orientation and stability....The density of the specimen fabricated by the compactor can, of course, be controlled by the pressure applied on each stroke and the total number of strokes.[1]

The various methods of compacting laboratory specimens have been thoroughly discussed, because it was felt that the effect of the controlled density of compacted specimens was of utmost importance, and a description of methods considered should be presented. Although not to be considered a direct part of this thesis, a large number of preliminary tests were made to correlate the three types of tests discussed above. It was determined that results closely approaching those of the standard AASHO and field conditions developed by the lighter sheep's-foot rollers could be obtained with the kneading compactor using 100 psi foot pressures. As the compactive effort could be more closely controlled, and this was found to be a very important feature, the author decided to use the California kneading compactor for all moisture-density determination.

The equipment which is used in these tests discussed above is shown in the views on Plate I and Plate II.

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[1]Carl E. Minor, "Procedures for Testing Stability of Bituminous Mixtures", Proceedings of Second Annual Road Builders Clinic, (Pullman: The State College of Washington, 1951), pp. 43-44,

PLATE I

COMPACTION EQUIPMENT

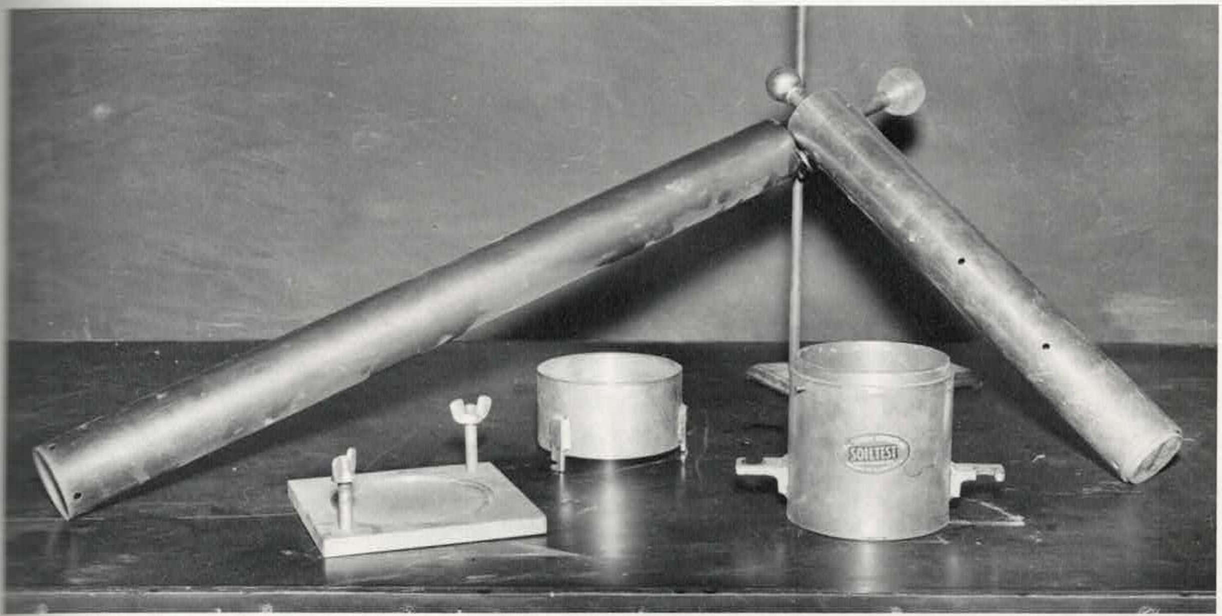


Figure A -- Standard and Modified AASHO Hammers and Mold

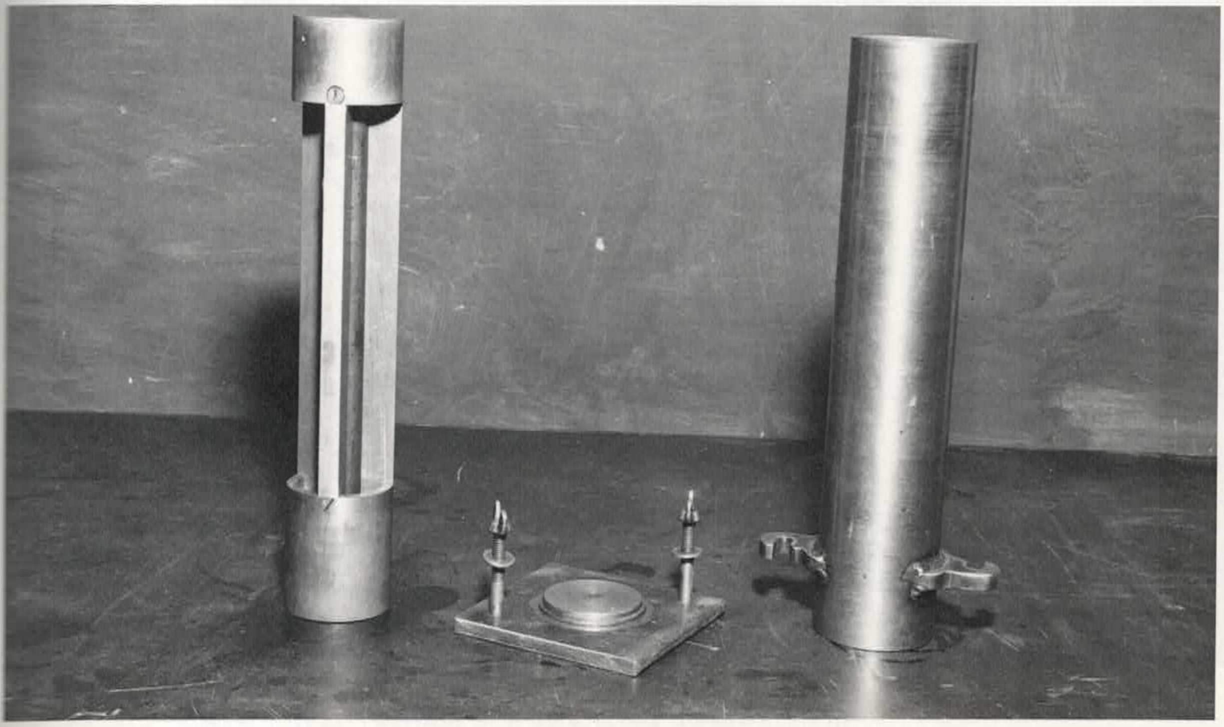
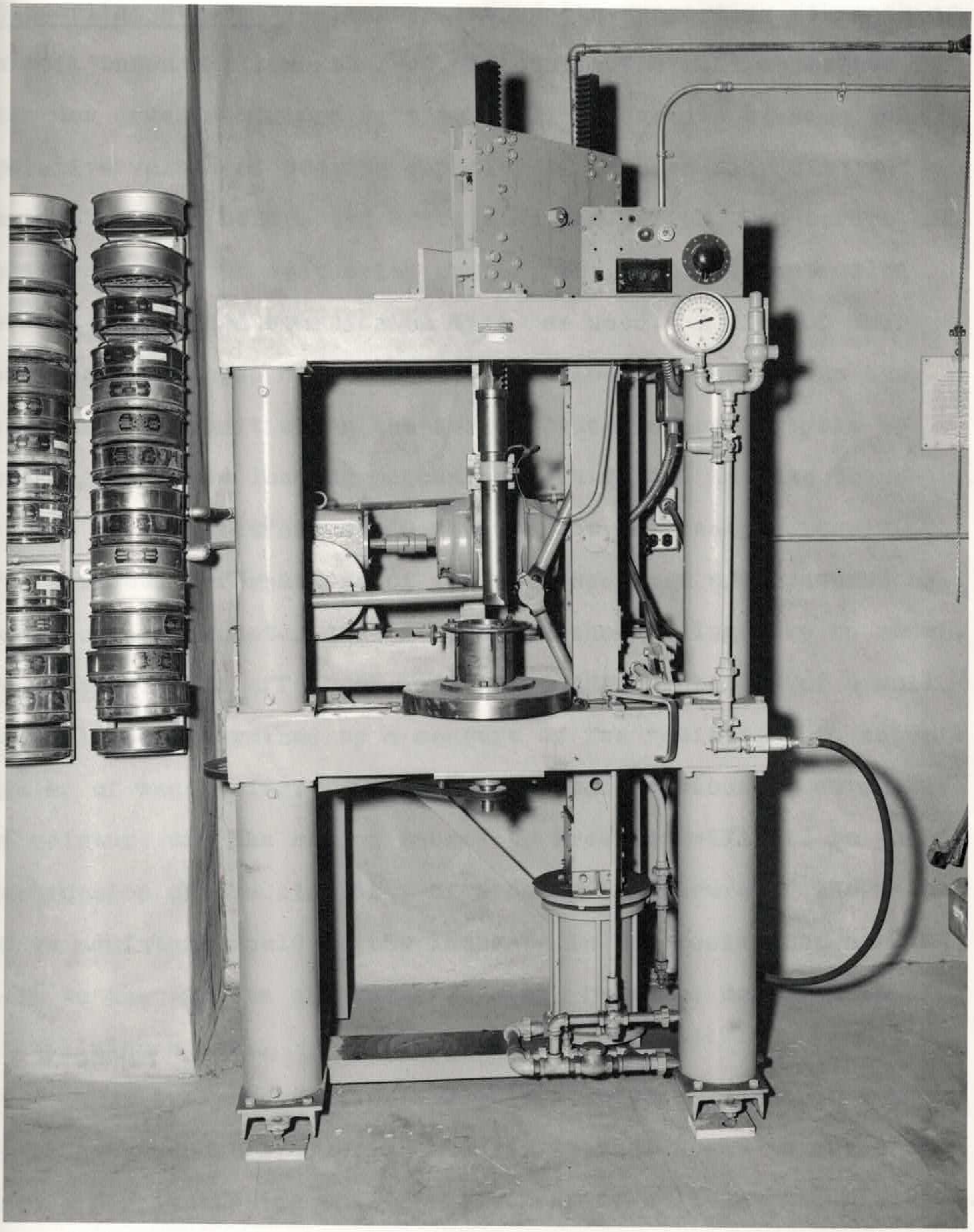


Figure B -- Special Static Compactor and Cylinder

PLATE II



CALIFORNIA KNEADING COMPACTOR

<u>Supporting Strength</u>.--Improvement of the supporting strength of a soil through all weather conditions is the main objective in the use of an admixture in this soil. To arrive at some comparative values of bearing capacity of Palouse clay with and without Orzan, before and after a curing period, and before and after exposure to weathering cycles, the standard controlled stress unconfined compression test was used. A view of this equipment is shown on Plate III. The load is applied to the specimen, in position on the scale through a loading yoke by means of a screw loading mechanism. This load is then transmitted to the platform scale through the soil sample itself. The vertical deformations of the soil specimen are measured by means of a micrometer dial resting on the loading yoke as shown.

<u>Weathering</u>.--The effect of weather on the durability of a soil can only be determined by a measure of its resistance to repeated cycles of weathering. As has been stated previously, an excess of moisture and the action caused by freezing will aid in the destruction of the stability of a soil. A measure of the value of an admixture would be the increase in the resistance of a soil to the effects of weather cycles from the use of this stabilizing agent.

At the present time the only standard procedures for testing the durability of chemically treated soils is the procedure for evaluating the effectiveness of soil-cement mixtures.[1]

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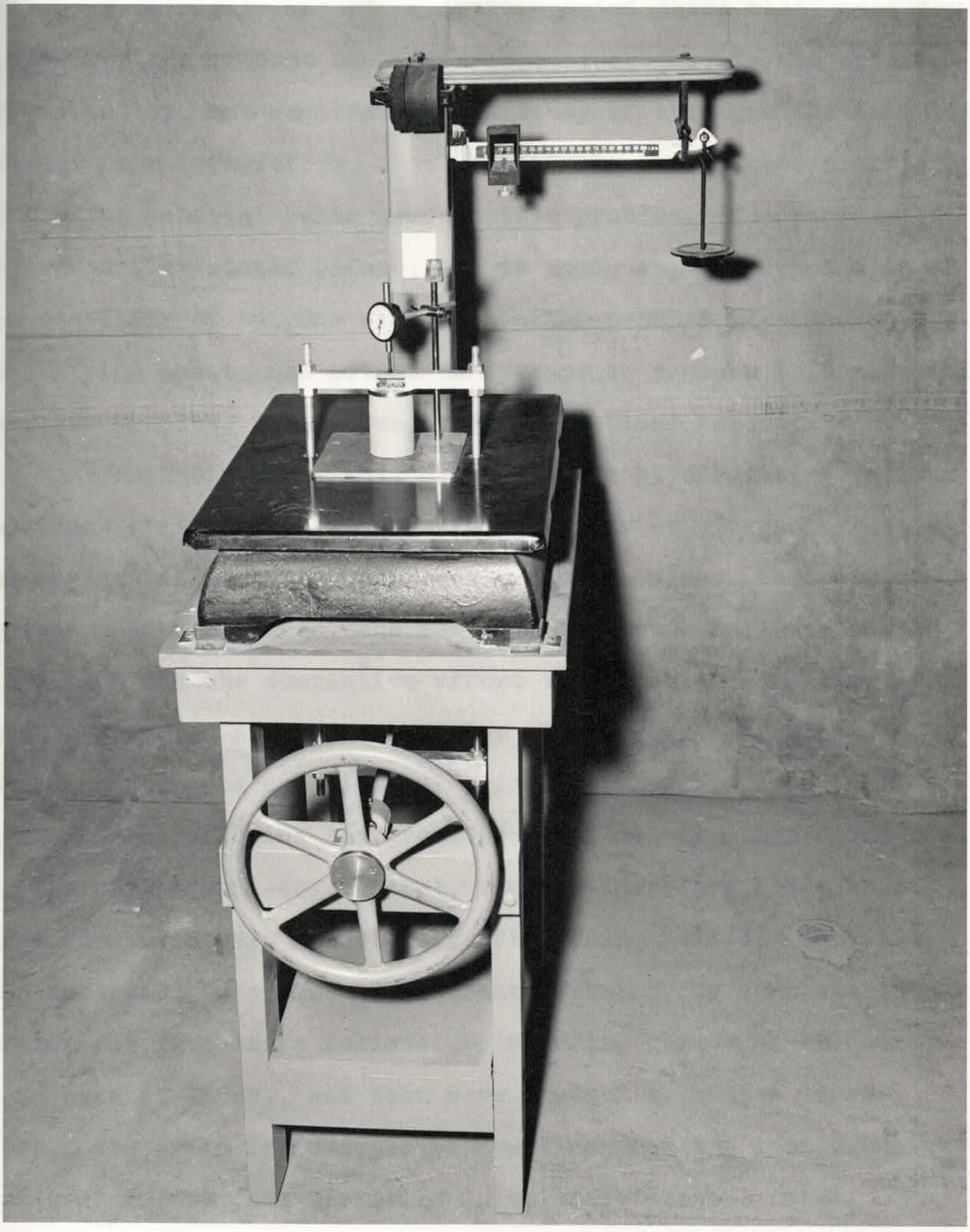
[1]Standard Method of Wetting-and-Drying Test of Compacted Soil Cement Mixtures; AASHO Designation: T 135-45 and Standard Method of Freezing-and-Thawing Test of Compacted Soil Cement Mixtures; AASHO Designation: T 136-45.

PLATE III



UNCONFINED COMPRESSION MACHINE

Preliminary investigations revealed these tests were too severe for the product under consideration, and, in the opinion of the author, not applicable to a study of this product in their present form. Therefore, these tests were revised and modified to fit the material being used in this problem. The purpose of this paper, as stated before, was to study any improvement in the stability of Palouse clay from using paper-mill waste as a stabilizing agent, and not as an attempt to compare this material to other chemical admixtures, such as Portland cement.

Weathering of a soil may be tested by submitting various specimens of the material to several cycles of alternate wetting and drying and/or cycles of freezing and thawing. When preparing the molded specimen, the composition of the soil may remain a constant and the compactive effort varied or the quantity of admixture varied and the compactive effort remain constant, depending upon the question being investigated.

When following the procedure outlined by AASHO standards for the wetting-and-drying test, the specimens are first moist cured for seven days immediately after being molded. They are then subjected to cycles of alternate wetting, by complete submersion for five hours followed by a drying period of 42 hours in an oven at 160°F., and then were brushed to remove loose scale. The cycle is repeated twelve times and the loss of weight, change of volume, and variation in moisture content noted. Palouse clay with and without Orzan did not pass a single cycle of this extremely severe test, so the test was modified as will be outlined in Chapter III.

The wet-dry test is particularly severe on silty-clay soils. The dry cycle sets up high shrinkage stresses in the specimen, which are in turn relieved during the wet period. The adsorption of excessive water forces the particles apart and destroys cohesion. When the specimen is completely submerged these particles are carried away and the process repeated until failure occurs.

The freezing and thawing test was performed by following quite closely the procedure outlined by the AASHO standards, except for the method of curing. It was found that the moist cure for soil-Orzan mixtures was highly unsatisfactory; therefore the air cure method was used. This method more closely approaches what would be actual field conditions as was suggested by R. C. Mainfort in his report on soil stabilization.[1] The effect of alternate freeze-thaw cycles is well known, especially when the specimen is exposed to free moisture during the period of thaw.

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[1] R. C. Mainfort, A Summary Report on Soil Stabilization By the Use of Chemical Admixtures, Technical Development Report No. 136, (Indianapolis: Civil Aeronautics Administration Technical Development and Evaluation Center, 1951), p. 4.

CHAPTER III

DISCUSSION OF EXPERIMENTAL PROCEDURES AND RESULTS

Moisture-density.--Preliminary studies have shown that the point of maximum density at optimum moisture, as determined by a moisture-density test, varied with the compactive effort of the procedure used. By varying the foot pressures and the number of applications of loading, the California type kneading compactor was easily correlated to standard testing procedures and expected field results. Because a light sheep's-foot roller would be the type of equipment most commonly used, where the soil stabilization under consideration would find favor, it was decided to use densities such as would be readily gotten in the field by this weight roller for this study. To obtain in the laboratory, what would be the approximate field density expected from using a light sheep's-foot roller, a foot pressure of 100 psi and 40 blows to a 2 1/2 inch specimen was chosen.

As no standard testing procedure has been established for this specific type test, a procedure was developed by modifying the standard compaction test such as is found in any soils manual or AASHO designation: T 99-49[1]. The variation from the standard was in the preparation and compaction of the specimens, but the calculations and interpretation of results remains un-

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[1] American Association of State Highway Officials, op.cit., p. 241.

changed. The final procedure used was as follows:

1. Weigh out approximately 5500 g. (a sufficient quantity to make up at least seven specimens without remolding) of a representative sample of air dried material passing a number 4 sieve.
2. Thoroughly mix the 5500 g. sample with a sufficient amount of water to bring the total moisture content of the sample to approximately 12 per cent.
3. Set mold on its base in compactor, and start compactor in operation. Fill mold with wetted soil at such a uniform rate that the entire specimen (about 2 1/2 in. high compacted) will be placed in the mold during the first 15 applications of load or blows of the compacting foot. After entire quantity of soil is in mold, allow compaction to continue until the total of 40 blows of the tamping foot has been applied.
4. Remove mold from compactor. Extract specimen from mold, measure height, and weigh.
5. Break specimen and obtain portion from center for true moisture determination.
6. Mix remaining soil sample with additional water sufficient to increase moisture content about one per cent and repeat steps 3 to 5. (Soil once molded should not be reused.)[1] This series of determinations should be continued until soil becomes too wet to compact under

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[1]Donald W. Taylor, Fundamentals of Soil Mechanics, (New York: John Wiley and Sons, Inc., 1948), 375.

foot pressures used. There should also be an equal number of specimens on the dry side of optimum moisture as there are on the wet side.

7. The water content, wet density, dry density, voids ratio, and porosity for each specimen is then determined by following standard procedure.

Plotting of the moisture density data results in a curve parabolic in form such as shown in Figure 1. The moisture content which corresponds to the peak of this curve is the optimum moisture content, and the unit weight for this same peak is the maximum dry density or oven dry weight of the soil at optimum moisture for the compactive effort specified.

In order to ascertain if any change in density and optimum moisture takes place with the addition of Orzan, successive tests were run. First raw Palouse clay was used, then Palouse clay with 4 per cent, 6 per cent and 10 per cent Orzan by volume was tested.

Complete data and results for the above described moisture-density determinations are given in Tables 3, 4, 5, and 6 of the Appendix. The dry density at the various moisture contents for each soil sample has been plotted on Figure 1, using the values obtained from the above mentioned tables. The curves that were then drawn by connecting the plotted points show the maximum dry density and optimum moisture for each sample. It may be noted that as the percentage of Orzan increases the density increases while the corresponding moisture content decreases, which shows that a higher density may be obtained from the same

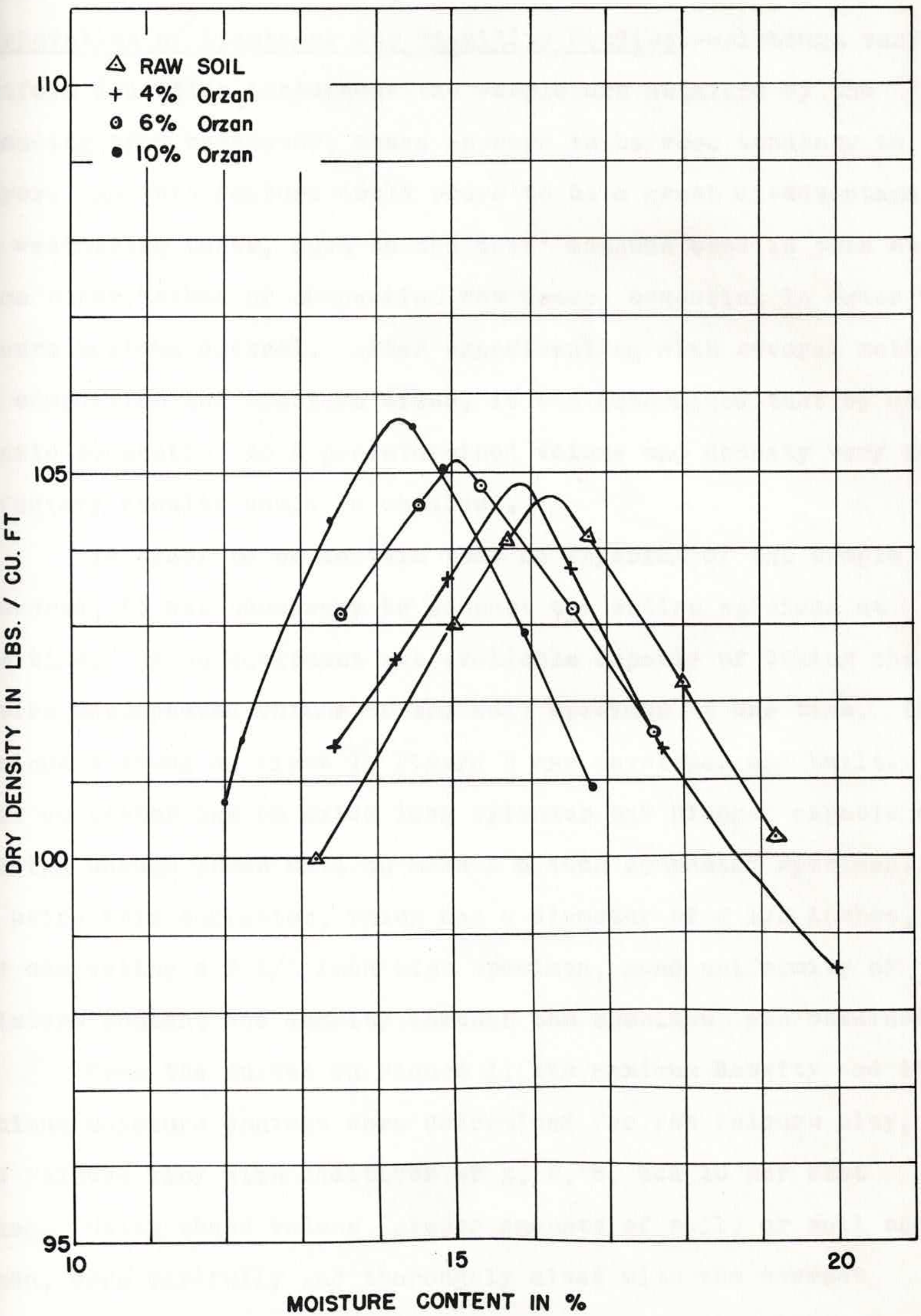


Fig. 1. -- Compaction Curves

compactive effort when Orzan has been used as an admixture.

Preparation of Specimens for Stability Studies.--Although very uniform densities throughout the sample are obtained by the kneading type compactor, there appears to be some tendency to layer. As this feature could prove to be a great disadvantage in weathering tests, such as the test methods used in this study, some other method of compaction was deemed essential in order to assure maximum control. After experimenting with several methods of compaction and specimen sizes, it was determined that by using static compaction to a predetermined volume and density very satisfactory results could be obtained.

In order to be certain that no layering of the sample occurred, it was necessary to compact the entire specimen at one time. As no equipment was available capable of taking the entire uncompacted volume of the soil specimen at one time, the equipment shown on Plate I, Figure B was developed and built. This compactor has an extra long cylinder and plunger capable of holding enough loose soil to make a 6 inch compacted specimen. By using this compactor, which has a diameter of 2 1/2 inches, and compacting a 3 1/2 inch high specimen, good uniformity of moisture content and density through the specimen was obtained.

From the curves on Figure 1, the maximum density and its optimum moisture content were determined for raw Palouse clay, and Palouse clay with additives of 2, 4, 6, and 10 per cent Orzan. Using these values proper amounts of soil, or soil and Orzan, were carefully and thoroughly mixed with the correct quantity of water to obtain the maximum wet density at its optimum moisture content for the fixed volume of each specimen.

A total of 10 specimens was molded for each soil sample: 2 for standard controls, 2 for the wetting and drying test, 2 for the freezing and thawing test, and 2 for spares. Trial tests had demonstrated the necessity for the two standard control samples for no purpose other than visual observation, and the two spares for replacements in case a poor specimen was found after the period of curing.

The procedure used for molding the specimens, after the quantity of soil and water necessary had been determined, measured and thoroughly mixed to assure even distribution of moisture, was as follows:

1. Carefully weigh out the required amount of wet soil necessary to make a single specimen. Immediately pour this entire amount of soil into mold, rodding carefully with a 3/8 inch rod to be certain that there is no bridging of the soil in the mold.
2. Place plunger in mold and apply load slowly until specimen has been compacted to desired volume. (This may be measured by depth to which plunger has moved.) Release load slowly and allow to stand for approximately 5 minutes. Reapply load until plunger reaches previous position, then release.
3. Remove specimen from mold, weigh, and measure to check density.

Samples of the wet soil should be taken at frequent intervals for moisture content check. As was found in trial tests, if at any time water is forced from specimen during compaction it should be rejected, because the calculated density has been exceeded.

The amount and type of curing of soils stabilized with chemical admixtures before they are subjected to use is of great importance. Of the four common methods in use today, two were given consideration and preliminary testing in this study. It was found that the moist cure method, which is used for soil-cements, was not as satisfactory as the method of air-drying to a constant weight; therefore, the latter method was used. Another factor, which influenced the selection of method for curing specimens, was that air-drying of laboratory specimens closely approaches field curing conditions. All specimens, except one of each soil sample, were then subject to a curing period, which lasted seven days, before being subjected to any further testing.

<u>Alternate cycles of freezing-thawing and wetting-drying.</u>--The compacted specimen cylinders were then subjected to the freeze-thaw and wet-dry tests, with both tests being conducted simultaneously on like specimens.

The procedure followed for the freeze-thaw test followed very closely that outlined in AASHO Standards. Two specimen cylinders of each soil sample are to be subjected to the cycles of change at the same time. One specimen, the control specimen "A", was for determination of volume and moisture changes, and the second specimen "B" was to be used to measure soil losses. The specimens were first carefully weighed and measured, then subjected to the first 24-hour period of freezing. The "A" specimens were weighed and measured at the end of this period, and then both "A" and "B" specimens were placed in the moisture cabinet, as specified in the standard procedure, for the 24-hour period of thawing. At the end of the thawing period, specimen "B" was brushed with a wire brush as directed, and weighed, while specimen "A" was again only weighed and measured. The entire cycle was repeated until the "B" specimen of any soil sample reached a 100 per cent soil loss, then specimen "A" of this soil was withdrawn from further cycles of the test. The data from these tests are shown on Tables 7 to 11 in the Appendix.

The per cent of volume change at the end of each period, relative to initial molded volume was calculated, and the moisture content as a percentage of the original oven dry weight of the soil was also calculated for the same time. Using this calculated moisture content determined for the control specimens "A" and assuming that specimens "B" had a similar moisture content, the loss of soil at the end of each cycle was determined as a percentage of soil loss relative to initial dry weight.

Figure 2 shows the plotting of the volume changes against the time interval in days, as given on Tables 7 to 11, for each soil sample. It may be noted that the volume change of soils containing percentages of Orzan is greater than that for raw Palouse clay. It should also be noted that at 15 days or just as the test was discontinued for the raw soil specimens the volume change for soils containing 4 and 6 per cent Orzan was

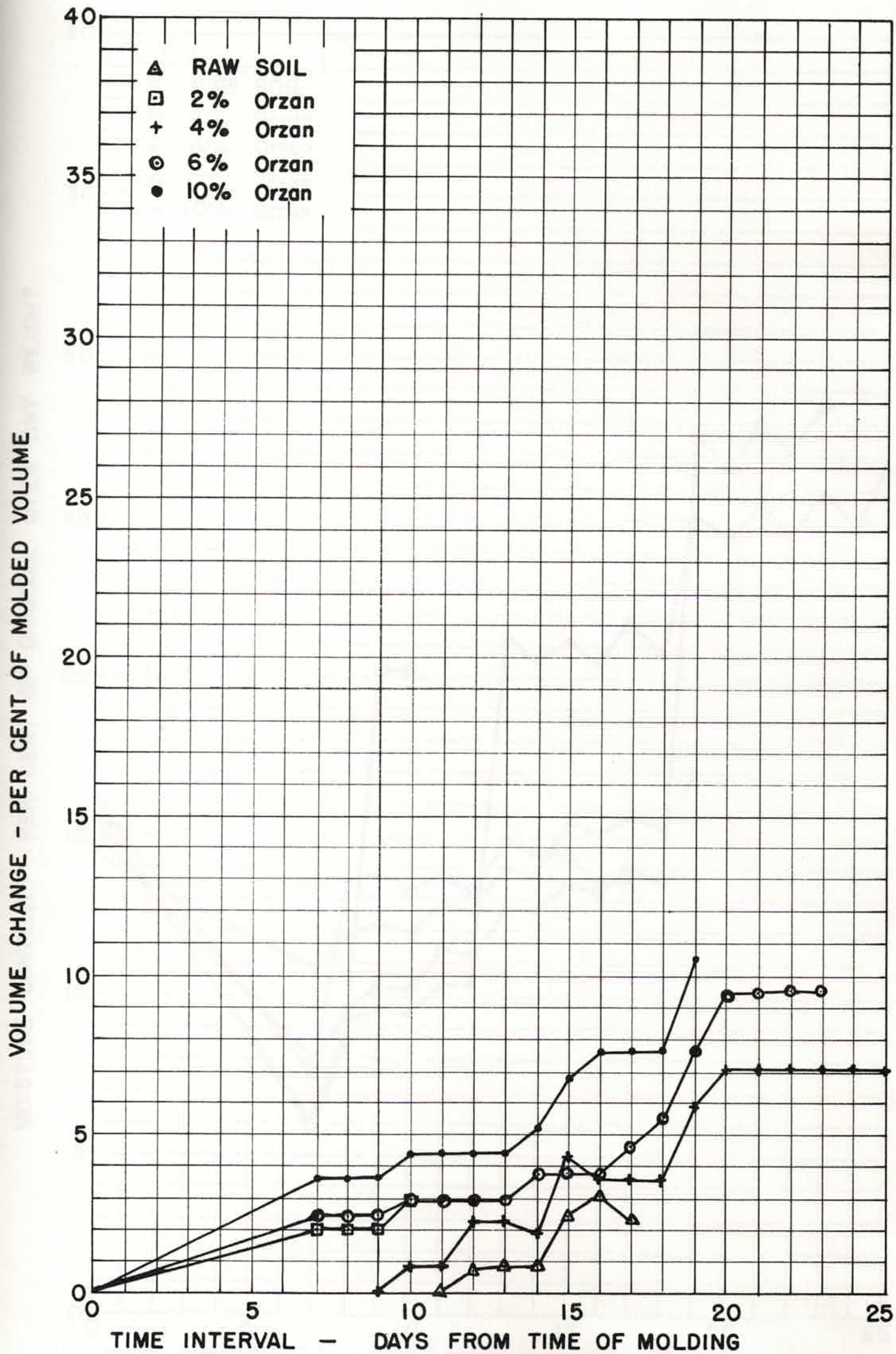


Fig. 2. -- Volume changes during cycles of freeze-thaw test.

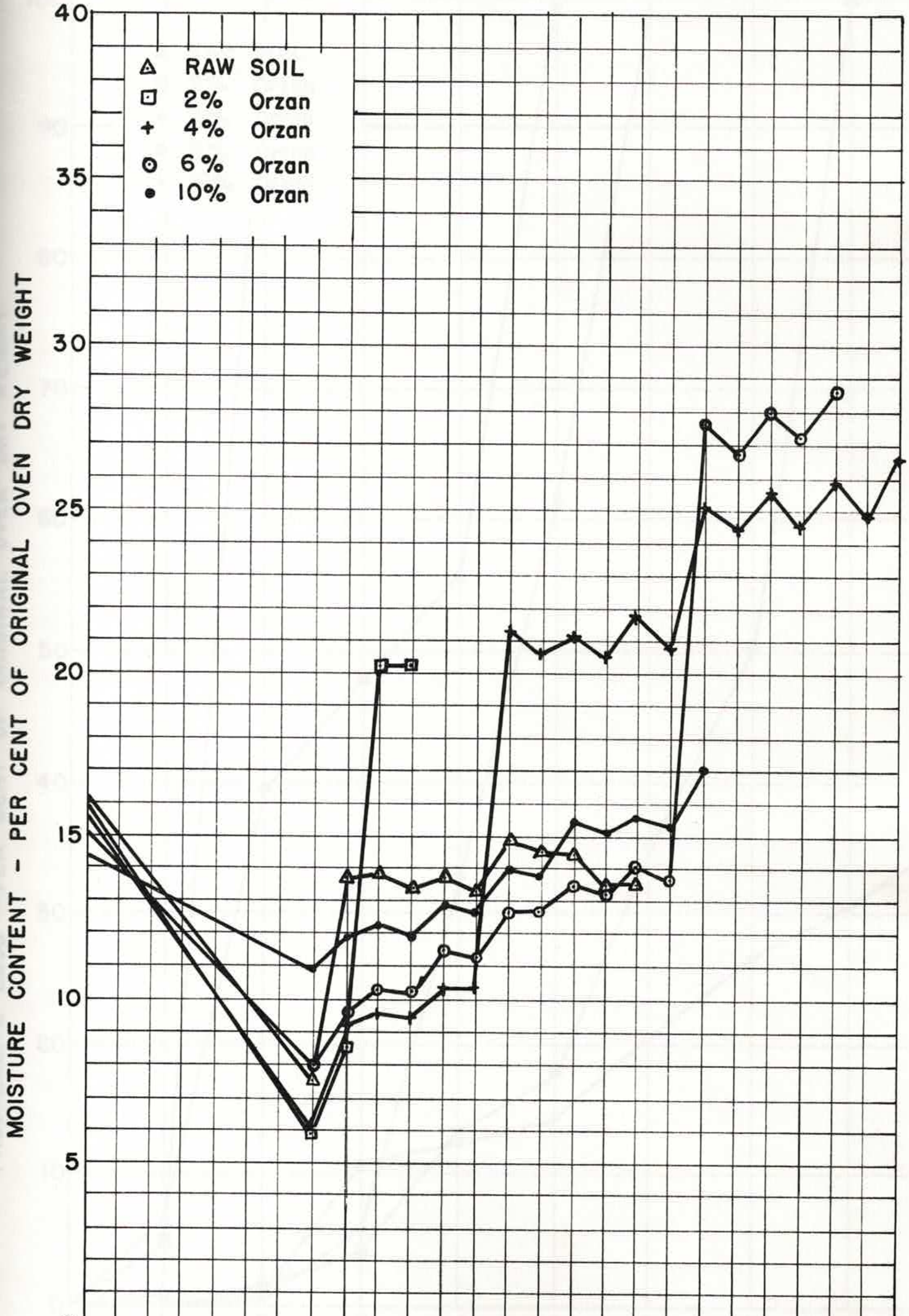


Fig. 3. -- Moisture changes during cycles of freeze-thaw test.

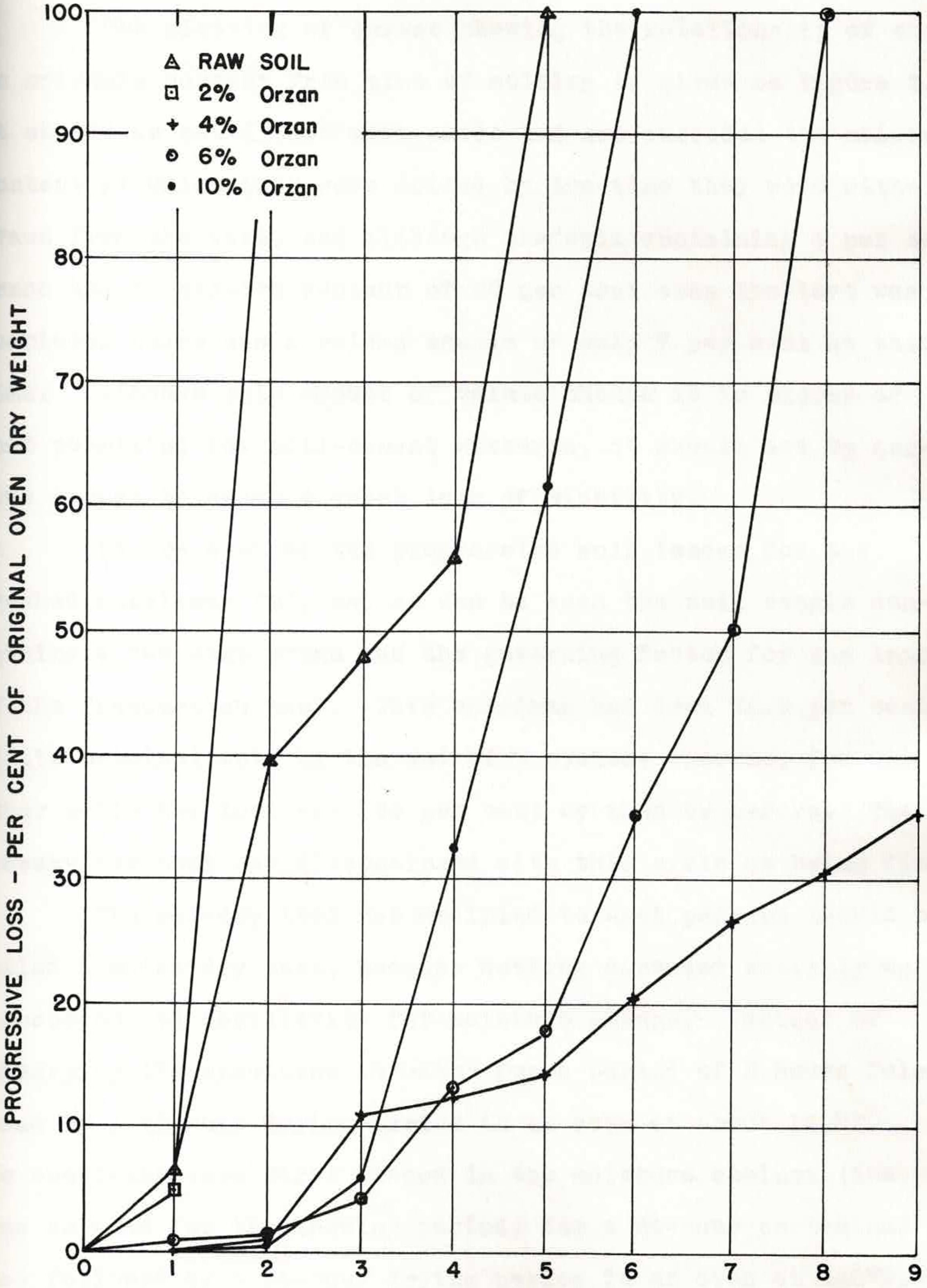


Fig. 4. -- Soil losses resulting from cycles of freeze-thaw test.

approximately the same.

The plotting of curves showing the relationship of change in moisture content from time of molding is given on Figure 3. It should be noted that most soils had not exceeded the moisture content at which they were molded by the time they were withdrawn from the test, and although the soil containing 4 per cent Orzan had a moisture content of 25 per cent when the test was completed there was a volume change of only 7 per cent at that time. Although this amount of volume change is in excess of that permitted for soil-cement mixtures, it should not be serious enough to cause a great loss of stability.

Figure 4 shows the progressive soil losses for the brushed specimens "B", and as can be seen the soil sample containing 4 per cent Orzan was the governing factor for the length of the freeze-thaw test. This specimen had lost 35.5 per cent of its original soil by the end of 9 cycles; whereas, for all other soils the loss was 100 per cent by then or before. The freeze-thaw test was discontinued with this cycle as being final.

The wet-dry test was modified to what perhaps should be called a moist-dry test, because wetting depended entirely on absorption and capillarity for moisture change. Instead of submerging the specimens in water for a period of 5 hours followed by a 42-hour drying period in an oven at about 160°F., the specimens were first placed in the moisture cabinet (the same as used for the thawing period) for a 24-hour period and then followed by a 24-hour drying period in an oven at 140°F. The test otherwise followed the procedure as outlined in AASHO standards. Two specimens "c" and "d" were used in the wet-dry test for the same purposes as specimens "A" and "B" in the freeze-thaw test. Other than the fact that the cycles for this particular test consisted of alternate periods of wetting and drying instead of alternate periods of freezing and thawing, the procedure for the test, the calculations, and the plotting of results followed that of the freeze-thaw test completely. The necessity for having the two types of tests is due to the difference in the action of soils where water is concerned is quite different from that when frost is encountered; therefore, the results of both wetting and freezing should be investigated. The test data results for the wet-dry test are given in Tables 12 to 16 in the Appendix.

The moisture changes during the cycles of alternate wetting and drying are shown on Figure 5. In this case it may be seen that the raw Palouse-clay specimen is affected more adversely by moisture changes than those containing Orzan. Soil containing 4 per cent Orzan varied little in moisture content between the wet and dry periods until after the specimen had passed through five complete cycles. At that point, however, the variations became progressively greater.

As may be seen from Figure 6, moisture changes in the soil have a great effect on the volume change for raw Palouse clay, but soil containing Orzan does not display as great a volume change from period to period. It may be noted that the soil having a volume content of 4 per cent Orzan has a small rather regular pattern of volume variation up until the time the test

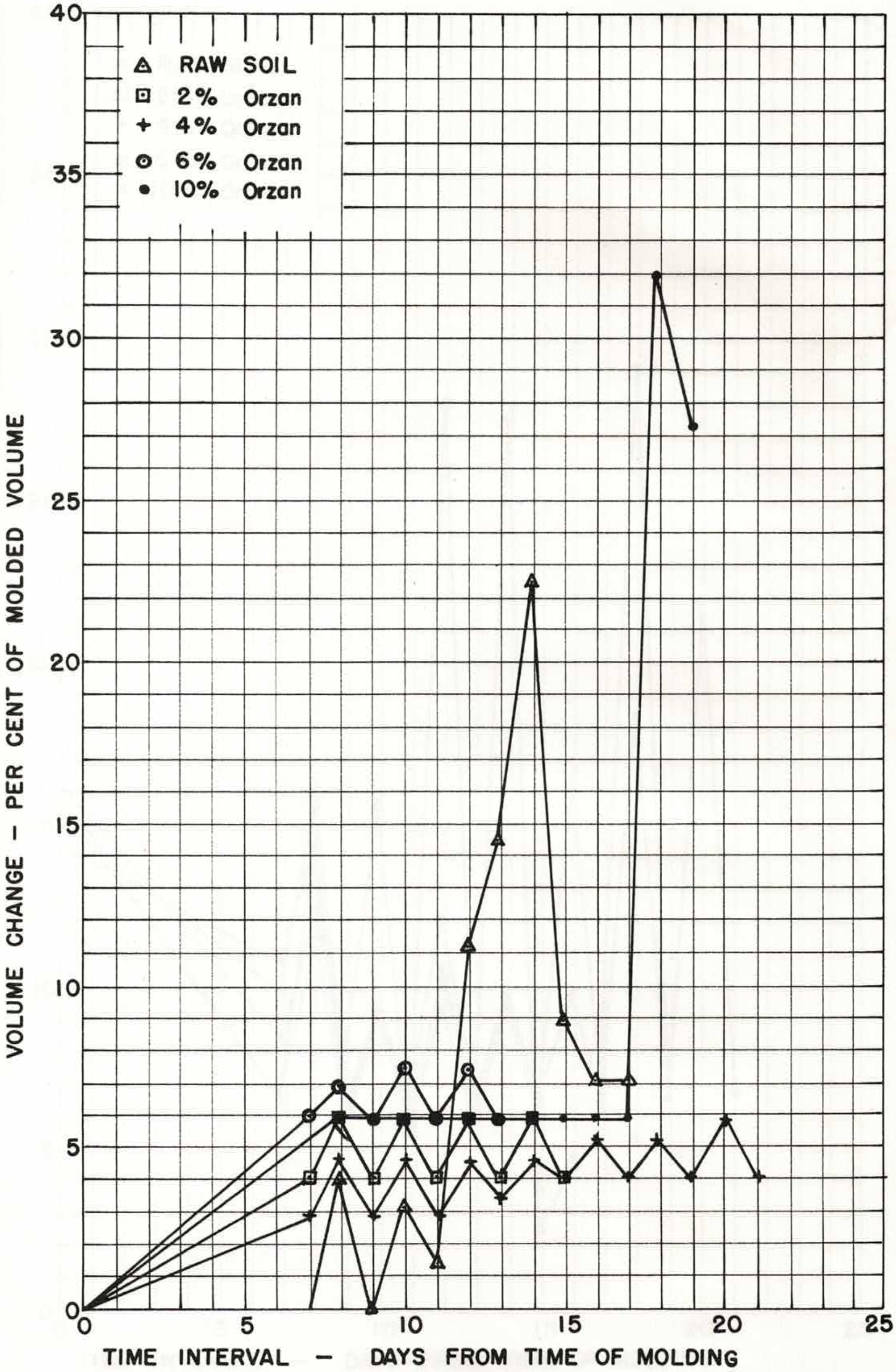


Fig. 5. -- Volume changes during cycles of wet-dry test.

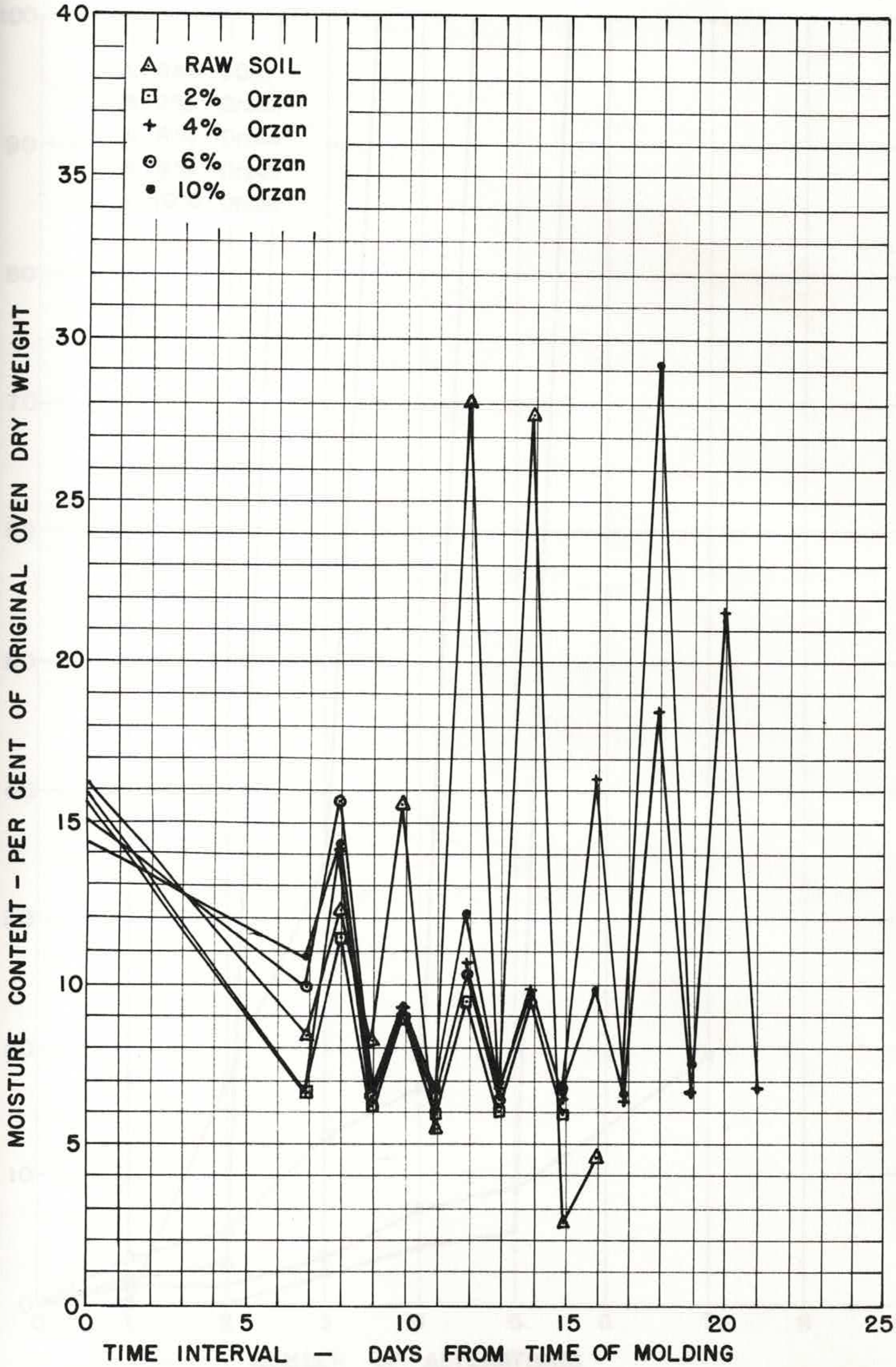


Fig. 6. -- Moisture changes during cycles of wet-dry test.

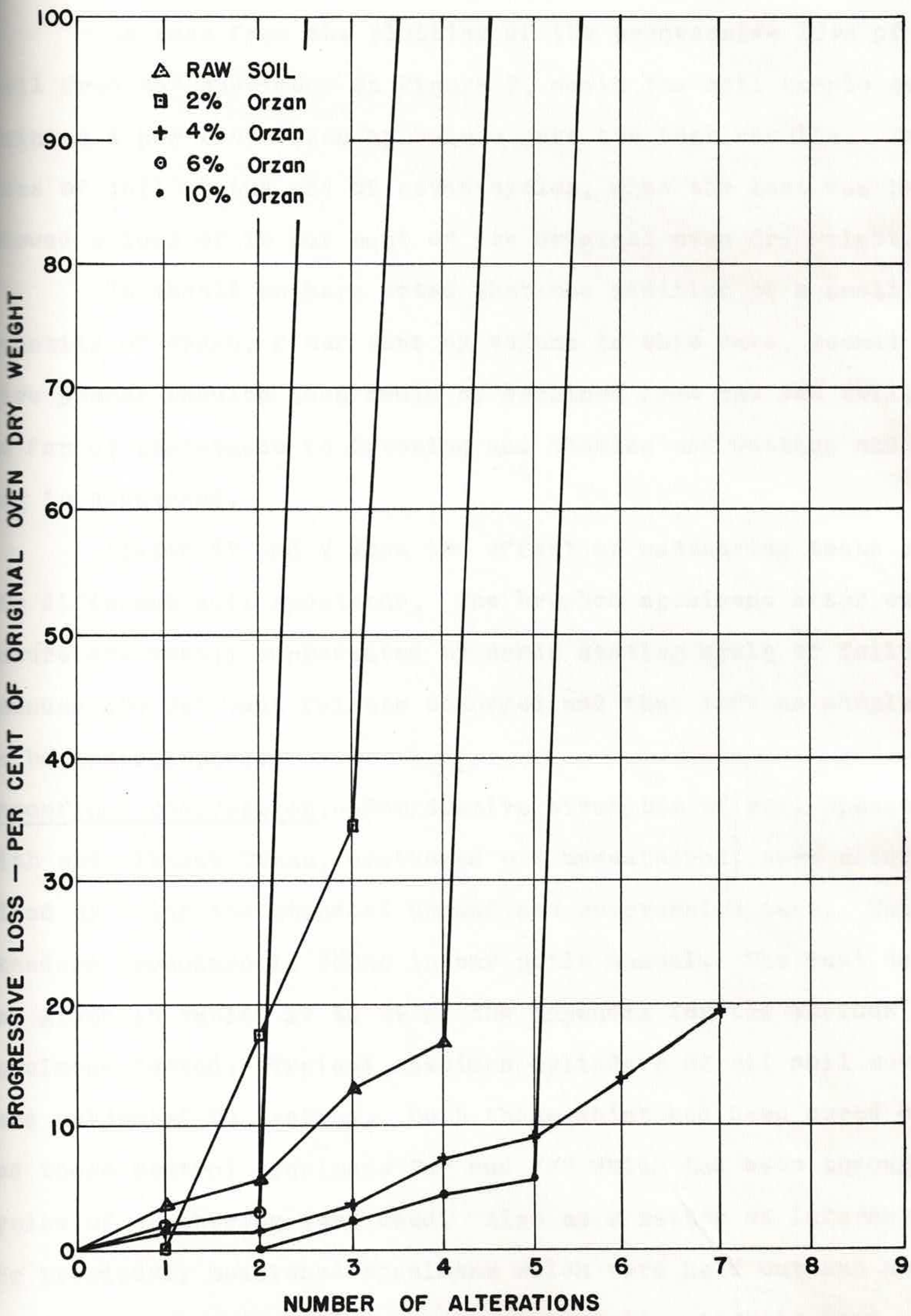


Fig. 7. -- Soil losses resulting from cycles of wet-dry tests.

was discontinued.

As seen from the plotting of the progressive loss of soil from "c" specimens on Figure 7, again the soil sample containing 4 per cent Orzan by volume gave the best results. The loss of soil at the end of seven cycles, when the test was halted, showed a loss of 19 per cent of its original oven dry weight.

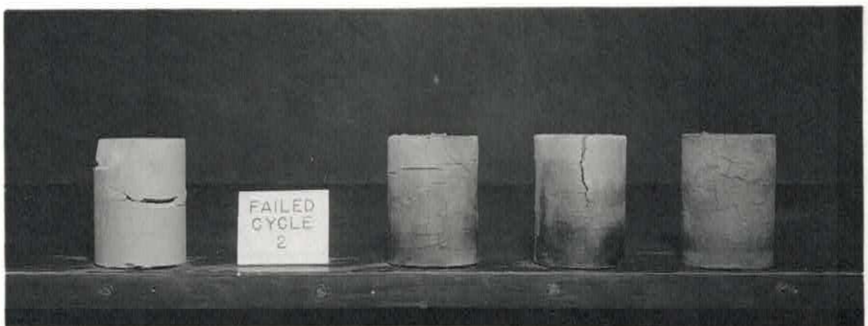
It should be here noted that the addition of a small quantity of Orzan, 2 per cent by volume in this case, seemed to give poorer results than could be obtained from the raw soil, as far as resistance to freezing and thawing and wetting and drying is concerned.

Plates IV and V show the effect of weathering tests on the different soil specimens. The brushed specimens after exposure are mostly represented by cards stating cycle of failure, because 100 per cent failure occurred and thus left no sample to be photographed.

Unconfined compression.--Comparative strengths of soil specimens, with and without Orzan, weathered and unweathered, were determined by using the standard unconfined compression test. This standard procedure is found in any soils manual. The test data are given in Tables 17 to 29 of the Appendix for the various specimens tested. Typical specimen cylinders of all soil samples were subjected to testing. Both those which had been cured only, and those control specimens "a" and "c" which had been through cycles of weathering were used. Also as a matter of information, the previously mentioned specimens which were held out and not cured, were tested. It was rather interesting to note that as

PLATE IV

Before Exposure

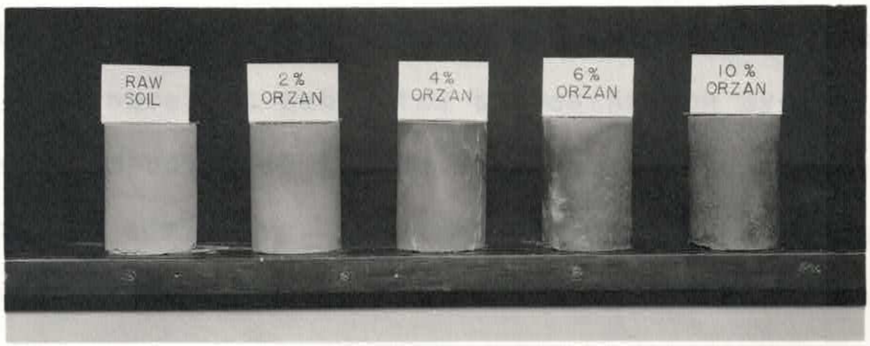


Unbrushed Specimens After Cycles of
Freezing and Thawing

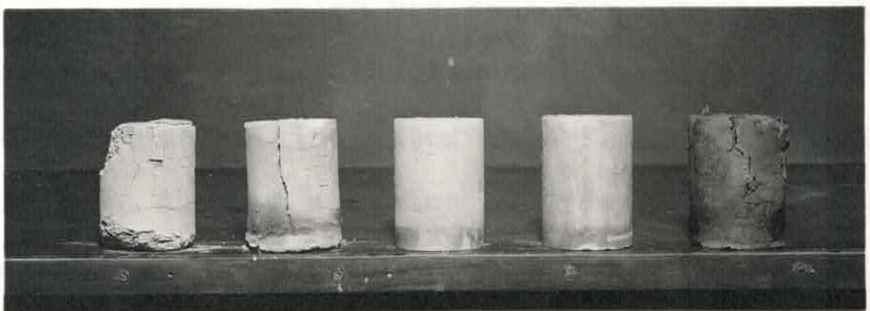
Brushed Specimens After Cycles of
Freezing and Thawing

EFFECT ON SPECIMENS FROM CYCLES OF
FREEZE-THAW TEST

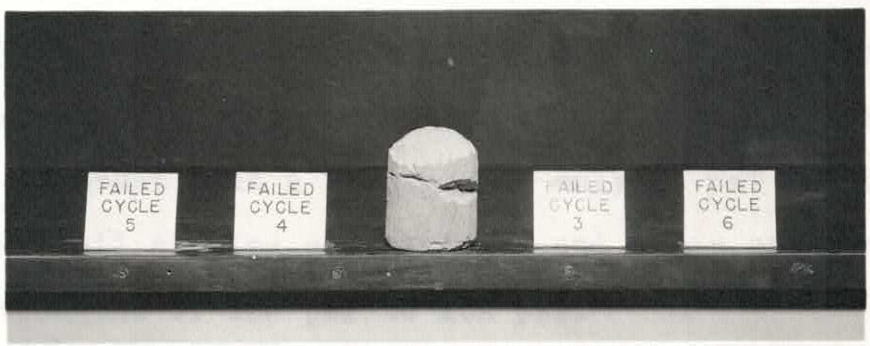
PLATE V



Before Exposure



Unbrushed Specimens After Cycles of
Wetting and Drying



Brushed Specimens After Cycles of
Wetting and Drying

EFFECT ON SPECIMENS FROM CYCLES OF
WET-DRY TEST

the percentage of Orzan admixture increased there was a progressive lowering of strength.

Figure 8 shows the comparative strengths of the cured specimens that were not subjected to weathering cycles. There was a notable improvement in the strength of the soil with the addition of the admixture. Raw Palouse clay shows a strength of slightly over 60 psi, while that having Orzan varies from 85 psi to 158 psi.

On Figure 9 are shown the plotted results of the unconfined test on specimens which had been through the cycles of freezing and thawing. Here the raw soil specimen gives the best results, but it must be also noted from Figure 4 that this specimen had only been through 4 cycles of freeze-thaw test, while those containing 4, 6, and 10 per cent Orzan had completed 9, 8, and 6 cycles, respectively. This should have some bearing upon the interpretation of results.

The results of the test on the specimens subjected to the wet-dry test are plotted on Figure 10. Although here the raw soil only completed three cycles of wetting and drying, the effect was so great that a strength of only 16 psi was obtained; whereas, the soil samples containing 4 and 6 per cent Orzan attained strengths of 130 psi to 152 psi.

Conclusion.--This study has shown that there appears to be an improvement, from the use of Orzan as a stabilizing agent, in those stability characteristics of Palouse clay that were tested. A brief review of the preceding test results gives the following information. As the percentage of Orzan was increased the maxi-

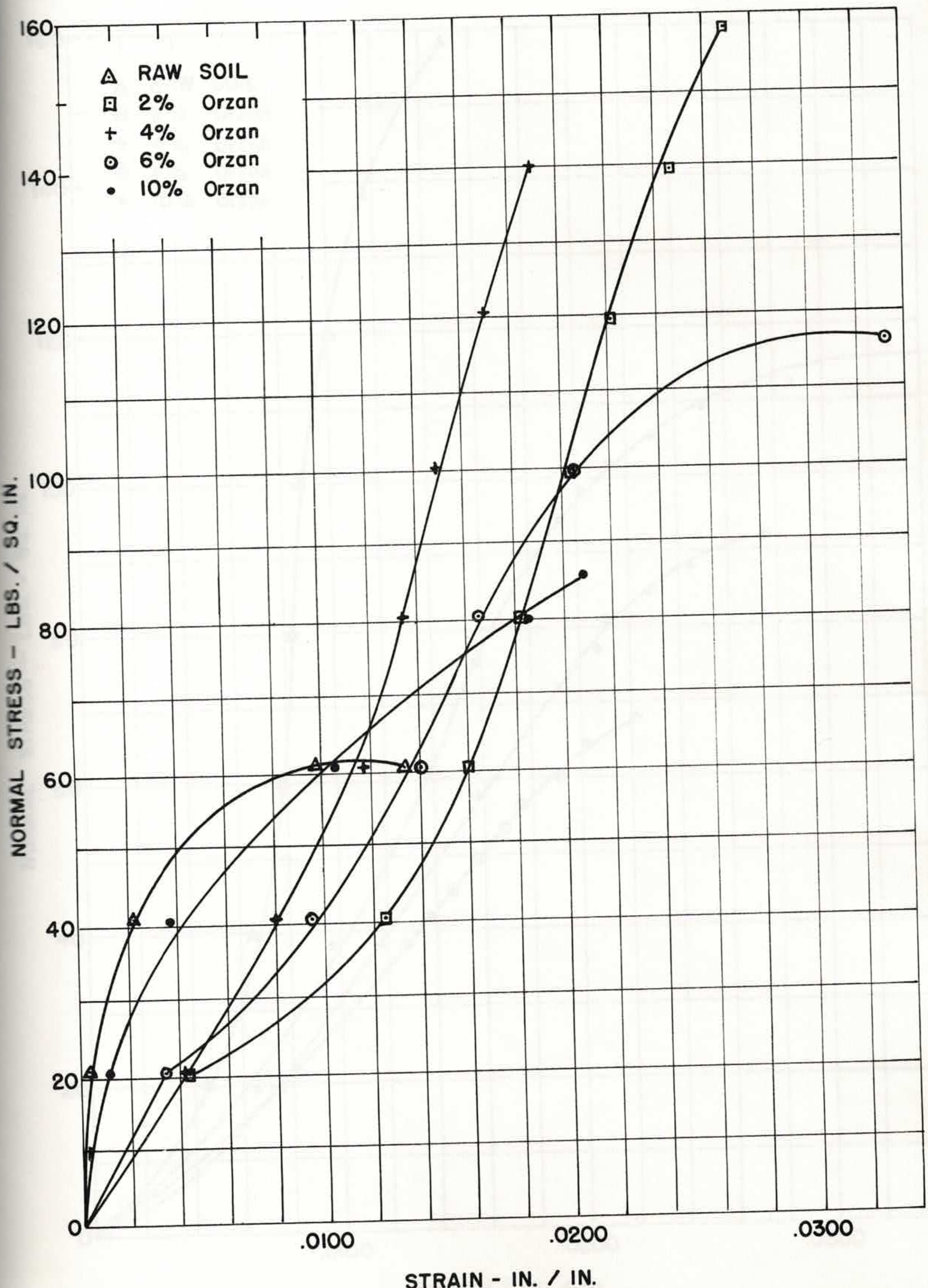


Fig. 8. -- Unconfined compression tests for soil specimens not subjected to weathering.

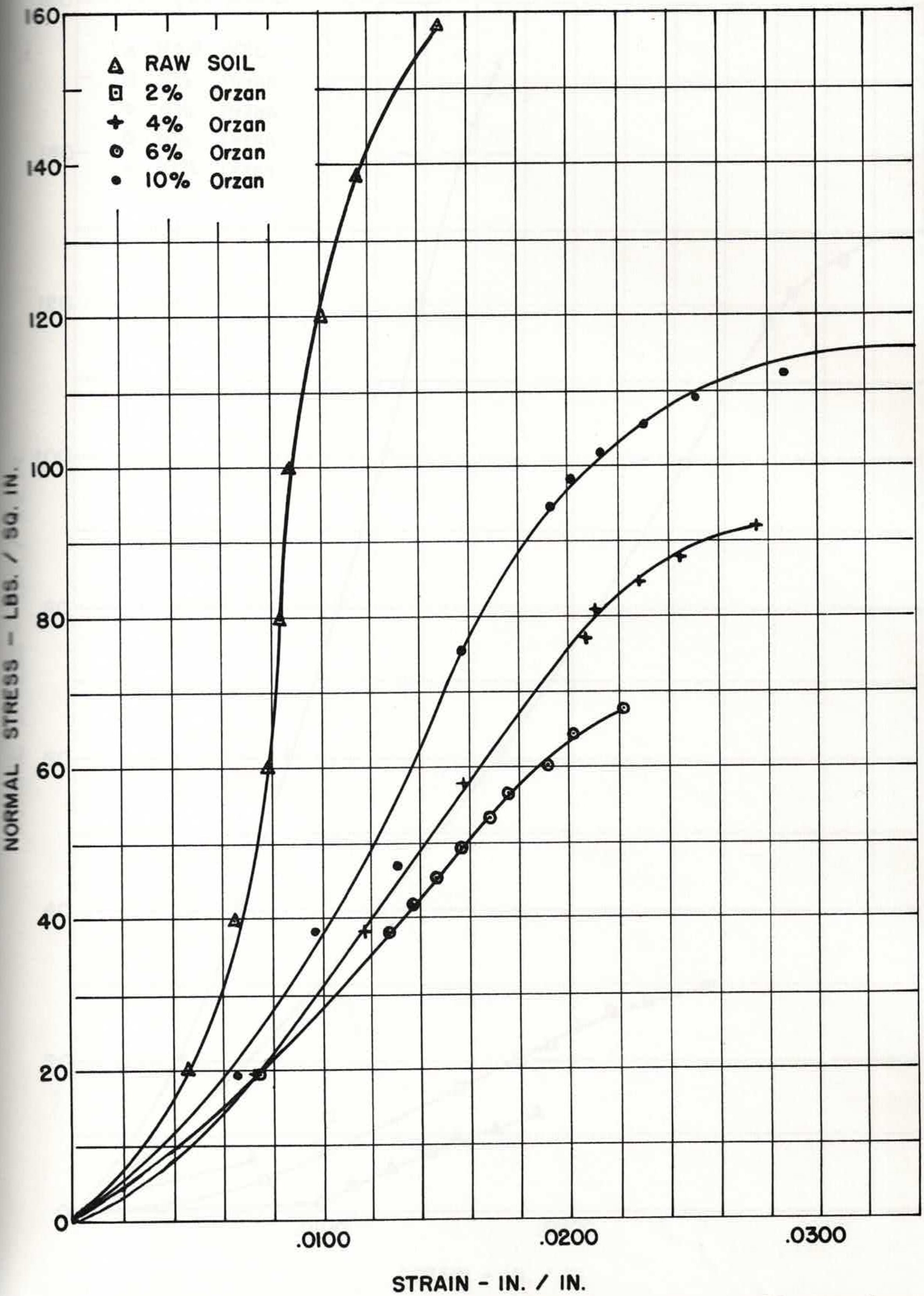


Fig. 9. -- Unconfined compression tests for soil specimens subjected to freeze-thaw cycles.

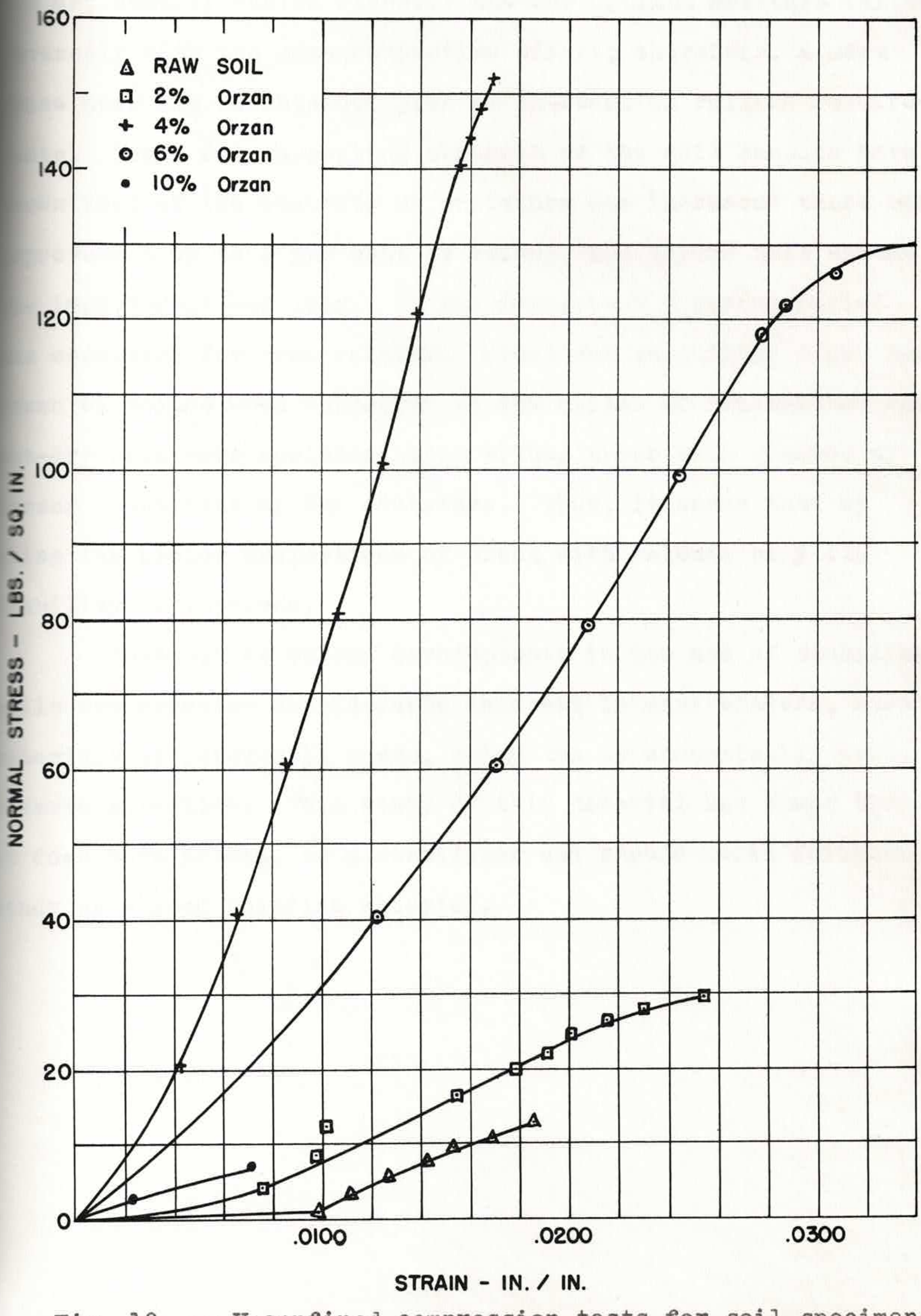


Fig. 10. -- Unconfined compression tests for soil specimens subjected to wet-dry tests.

mum dry density varied directly and the optimum moisture varied inversely with the same compactive effort; therefore, a more dense mass can be obtained with no increase in rolling requirements. Tests for supporting strength of the soil samples have shown that as the quantity of admixture was increased there was improvement up to 4 per cent by volume, but beyond this amount the improvement was less. It was found that a curing period was essential for good results. Specimens containing 4 per cent Orzan by volume when subjected to the cycles of freeze-thaw and wet-dry were more resistant than either those with greater or lesser quantities of the admixture. Thus, it seems that by using the proper proportions of Orzan with Palouse clay its stability is improved.

Inasmuch as recent developments in the use of stabilized soils are creating considerable interest in road binders, such materials as paper-mill waste, which can be economically used, deserve attention. This study of this material has shown that it does have promise as a stabilizer and should merit further study as a road building material.

APPENDIX

TABLE 3

COMPACTION TEST

Test No. 19 Test type California kneading type compactor Date 2/24/54
Soil sample Palouse-clay no additive Spec. Grav. 2.71
Location W.S.C. Campus at 15 ft. depth Mold 4.00 in. dia. 12.566 sq. in. area

Description	Unit	Run No. 1	2	3	4	5	6	7
Density								
Height-compacted soil specimen	in.	2.547	2.612	2.468	2.437	2.377	2.490	2.442
Volume-compacted soil specimen	cu.in.	32.007	32.823	31.014	30.624	29.870	31.290	30.687
Weight-compacted soil specimen	g	948.8	991.6	964.4	968.0	951.8	991.5	962.3
Wet density	lbs/cf.	112.9	115.1	118.5	120.4	121.4	120.7	119.5
Dry density	lbs/cf.	99.8	100.6	103.0	104.1	104.1	102.2	100.2
Voids ratio	%	69.0	68.1	64.2	62.3	61.6	65.5	68.9
Porosity	%	41.0	40.5	39.1	38.4	38.1	39.6	40.8
Water Content								
Can No.	--	16	12	11	13	10	21	15
Weight-wet soil and can	g	104.72	91.13	109.79	105.53	105.70	103.90	103.12
Weight-dry soil and can	g	95.30	82.71	98.61	94.53	94.04	91.88	90.43
Weight-can	g	23.97	24.01	24.30	24.34	24.09	25.24	24.39
Weight-water	g	9.42	8.42	11.18	11.00	11.66	12.02	12.69
Weight-dry soil	g	71.33	58.70	74.31	70.19	69.95	66.64	66.04
Water content	%	13.21	14.34	15.04	15.67	16.67	18.05	19.22

TABLE 4

COMPACTION TEST

Test No. 20 Test type California kneading type compactor Date 2/24/54
Soil sample Palouse-clay + 4 % Orzan by volume Spec. Grav. 2.66
Location W.S.C. campus at 15 ft. depth Mold: 4.00 in. dia. 12.566 sq. in. area

Description	Unit	Run No. 1	2	3	4	5	6	7
Density								
Height-compacted soil specimen	in.	2.456	2.539	2.464	2.325	2.359	2.360	2.171
Volume-compacted soil specimen	cu.in.	30.863	31.906	30.964	29.207	29.644	29.657	27.282
Weight-compacted soil specimen	g	931.1	980.0	968.0	925.1	940.1	928.9	846.2
Wet density	lbs/cf.	114.9	117.0	119.1	120.6	120.8	119.3	118.2
Dry density	lbs/cf.	101.4	102.5	103.6	104.0	103.7	101.4	98.5
Voids ratio	%	63.7	61.8	60.0	59.4	60.2	63.7	68.5
Porosity	%	38.9	38.2	37.5	37.3	37.6	38.9	40.7
Water Content								
Can No.	--	4	6	8	14	3	17	5
Weight-wet soil and can	g	106.25	91.77	95.27	108.15	109.64	106.11	103.00
Weight-dry soil and can	g	96.54	83.36	86.08	96.65	97.54	93.84	90.00
Weight-can	g	23.92	24.19	24.43	24.62	24.10	24.49	24.93
Weight-water	g	9.71	8.41	9.19	11.50	12.10	12.27	13.00
Weight-dry soil	g	72.62	59.17	61.65	72.03	73.44	69.35	65.07
Water content	%	13.37	14.21	14.91	15.97	16.48	17.69	20.00

TABLE 5

COMPACTION TEST

Test No. 21 Test type California kneading type compactor Date 2/26/54
Soil sample Palouse-clay + 6% Orzan by volume Spec. Grav. 2.64
Location W.S.C. Campus at 15 ft. depth Mold: 4.00 in. dia. 12.566 sq. in. area

Description	Unit	Run No. 1	2	3	4	5	6	7
Density								
Height-compacted soil specimen	in.	2.518	2.452	2.515	2.667	2.482	2.361	--
Volume-compacted soil specimen	cu.in.	31.642	30.813	31.604	33.515	31.190	29.669	--
Weight-compacted soil specimen	g	971.0	967.3	1002.9	1057.7	978.8	931.1	--
Wet density	lbs/cf.	116.9	119.6	120.9	120.2	119.6	119.6	--
Dry density	lbs/cf.	103.1	104.5	104.8	103.2	102.3	101.6	--
Voids ratio	%	59.7	57.7	57.2	59.6	61.0	62.1	--
Porosity	%	37.4	36.6	36.4	37.3	37.9	38.3	--
Water Content								
Can No.	--	18	24	2	25	20	1	--
Weight-wet soil and can	g	101.80	102.70	105.18	101.63	100.72	98.58	--
Weight-dry soil and can	g	92.79	92.79	94.50	90.84	89.68	87.42	--
Weight-can	g	25.82	24.29	24.80	25.35	24.11	24.17	--
Weight-water	g	9.01	9.91	10.68	10.73	11.04	11.16	--
Weight-dry soil	g	66.97	68.50	69.70	65.49	65.57	63.25	--
Water content	%	13.45	14.47	15.32	16.48	16.84	17.64	--

TABLE 6

COMPACTION TEST

Test No. 22 Test type California kneading type compactor Date 2/27/54
Soil sample Palouse-clay + 10% Orzan by volume Spec. Grav. 2.59
Location W.S.C. Campus at 15 ft. depth Mold: 4.00 in.dia. 12.566 sq.in. area

Description	Unit	Run No. 1	2	3	4	5	6	7
Density								
Height-compacted soil specimen	in.	2.586	2.474	2.481	2.419	2.339	2.309	2.209
Volume-compacted soil specimen	cu.in.	32.497	31.089	31.177	30.398	29.393	29.016	27.759
Weight-compacted soil specimen	g	970.1	938.1	967.1	964.0	930.2	908.7	850.8
Wet density	lbs/cf.	113.7	114.9	118.2	120.8	120.6	119.4	117.9
Dry density	lbs/cf.	101.6	102.4	104.3	105.6	105.0	102.9	100.9
Void ratio	%	59.0	57.7	55.0	53.1	53.8	56.9	60.2
Pososity	%	37.1	36.6	35.5	34.7	35.0	36.3	37.6
Water Content								
Can No.	--	11	4	21	17	6	14	10
Weight-wet soil and can	g	92.98	102.20	103.05	96.44	109.82	103.54	109.70
Weight-dry soil and can	g	85.64	93.69	93.94	87.36	98.73	92.69	97.37
Weight-can	g	24.30	23.92	25.24	24.49	24.19	24.62	24.09
Weight-water	g	7.30	8.51	9.11	9.08	11.09	10.85	12.33
Weight-dry soil	g	61.34	69.77	68.70	62.87	74.54	68.07	73.28
Water content	%	11.97	12.20	13.26	14.44	14.88	15.94	16.82

TABLE 7

FREEZING AND THAWING TEST DATA

Soil sample: Raw Palouse-clay Specimen cylinder no. 1a 1b
Date molded: 4/9/54 Curing: 7 day air-drying to constant weight
Initial molded measurements
2.5 in. ave. dia. 3.5 in. ave. height 17.182 cu. in. volume
472.6 g dry weight 549.2 g wet weight 16.2% moist cont.

Cycle No.	Space No.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
0	1a	4/18	508.1	2.50	3.50	17.182	0	7.4	--	Curing
	1b	4/18	509.0	2.50	3.50	17.182	0	7.7	--	"
1	1a	4/19	538.3	2.50	3.50	17.182	0	13.7	--	Freezing
	1a	4/20	539.1	2.50	3.50	17.182	0	13.8	--	Thawing
	1b	4/20	502.0	--	--	--	-	13.8	6.6	"
2	1a	4/21	536.7	2.50	3.50	17.182	0	13.3	--	Freezing
	1a	4/22	538.6	2.50	3.50	17.182	0	13.7	--	Thawing
	1b	4/22	327.2	--	--	--	-	13.7	39.3	"
3	1a	4/23	536.3	2.50	3.52	17.280	0.6	13.2	--	Freezing
	1a	4/24	543.6	2.50	3.53	17.329	0.8	14.8	--	Thawing
	1b	4/24	279.9	--	--	--	-	14.8	47.9	"
4	1a	4/25	541.5	2.50	3.53	17.329	0.8	14.4	--	Freezing
	1a	4/26	541.6	2.52	3.53	17.604	2.4	14.4	--	Thawing
	1b	4/26	233.1	--	--	--	-	14.4	56.9	"
5*	1a	4/27	539.2	2.52	3.55	17.703	3.0	13.3	--	Freezing
	1a	4/28	540.6	2.52	3.52	17.554	2.2	13.5	--	Thawing
	1b	4/28	Failed					13.5	100.0	Thawing

*Test disc. after 5th cycle

TABLE 8

FREEZING AND THAWING TEST DATA

Soil sample: Palouse-clay + 2% Orzan Specimen cylinder no. 2a 2b
Data molded: 4/9/54 Curing 7 day air-dry to constant weight
Initial molded measurements:
2.5 in. ave. dia. 3.5 in. ave. height 17.182 cu. in. volume
473.1 g dry weight 548.8 g wet weight 16% moist. cont.

Cycle No.	Spec. No.	Date	Nat. Wt. g.	Volume: Ave. dia. in.	Volume: Ave. ht. in.	Volume: Ave. vol. cu.in.	Volume: Change %	Moist. Cont. %	Loss in % of initial dry wt.	Completed Operation
0	2a	4/18	501.2	2.50	3.57	17.525	2.0	5.9	--	Curing
	2b	4/18	501.7	2.50	3.54	17.378	1.1	6.0	--	Curing
1	2a	4/19	513.4	2.50	3.57	17.525	2.0	8.5	--	Freezing
	2a	4/20	572.3	2.50	3.57	17.525	2.0	20.1	--	Thawing
	2b	4/20	542.5	--	--	--	-	20.1	4.6	Thawing
2	2a	4/21	574.3	2.50	3.60	17.672	2.9	20.1	--	Freezing
	2a	4/22	Failed							Thawing
	2b	4/22	338.1	--	--	--	-	-	--	Thawing
3*	2b	4/23	Failed							Freezing

*Test disc. after 2nd cycle

TABLE 9

FREEZING AND THAWING TEST DATA

Soil sample: Palouse-clay + 4% Orzan   Specimen cylinder no. 3a 3b
Date molded: 4/10/54   Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia.   3.50 in. ave. height   17.182 cu.in. volume
473.6 g dry weight   548.0 g wet weight   15.7% moist. content

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume: Ave. dia.	Volume: Ave. ht.	Volume: Ave. vol.	Volume: Change	Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
			g.	in.	in.	cu.in.	%	%		
0	3a	4/18	502.9	2.50	3.50	17.182	0	6.0	--	Curing
	3b	4/18	505.9	2.50	3.57	17.525	2.0	6.8	--	Curing
1	3a	4/19	517.0	2.50	3.50	17.182	0	9.1	--	Freezing
	3a	4/20	518.5	2.50	3.50	17.182	0	9.5	--	Thawing
	3b	4/20	519.0	--	--	--	-	9.5	0.0	Thawing
2	3a	4/21	518.0	2.50	3.53	17.329	0.9	9.4	--	Freezing
	3a	4/22	521.9	2.50	3.53	17.329	0.9	10.2	--	Thawing
	3b	4/22	515.6	--	--	--	-	10.2	1.1	Thawing
3	3a	4/23	521.8	2.51	3.55	17.565	2.2	10.2	--	Freezing
	3a	4/24	573.7	2.51	3.55	17.565	2.2	21.1	--	Thawing
	3b	4/24	510.1	--	--	--	-	21.1	11.2	Thawing
4	3a	4/25	571.3	2.51	3.54	17.516	1.9	20.5	--	Freezing
	3a	4/26	573.4	2.52	3.59	17.903	4.2	21.0	--	Thawing
	3b	4/26	504.2	--	--	--	-	21.0	12.2	Thawing
5	3a	4/27	570.4	2.52	3.51	17.804	3.6	20.4	--	Freezing
	3a	4/28	575.9	2.52	3.57	17.804	3.6	21.6	--	Thawing
	3b	4/28	496.3	--	--	--	-	21.6	14.1	Thawing
6	3a	4/29	571.6	2.52	3.57	17.804	3.6	20.7	--	Freezing
	3a	4/30	592.1	2.55	3.58	18.203	5.9	25.0	--	Thawing
	3b	4/30	468.9	--	--	--	-	25.0	20.9	Thawing

TABLE 9--Continued

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
7	3a	5/1	588.2	2.55	3.60	18.385	7.0	24.2	--	Freezing
	3a	5/2	593.6	2.55	3.60	18.385	7.0	25.4	--	Thawing
	3b	5/2	435.4	--	--	--	-	25.4	26.8	Thawing
8	3a	5/3	589.0	2.55	3.60	18.385	7.0	24.4	--	Freezing
	3a	5/4	595.7	2.55	3.60	18.385	7.0	25.8	--	Thawing
	3b	5/4	412.3	--	--	--	-	25.8	30.8	Thawing
9*	3a	5/5	591.0	2.55	3.60	18.385	7.0	24.8	--	Freezing
	3a	5/6	598.3	2.55	3.60	18.385	7.0	26.3	--	Thawing
	3b	5/6	386.6	--	--	--	-	26.3	35.5	Thawing

*Test disc. after 9th cycle

TABLE 10

FREEZING AND THAWING TEST DATA

Soil sample: Palouse-clay + 6% Orzan Specimen cylinder no. 4a 4b
Date molded: 4/10/54 Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia. 3.50 in. ave. height 17.182 cu. in. volume
475.4 g dry weight 547.2 g wet weight 15.1% moist. content

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
0	4a	4/18	513.0	2.50	3.58	17.574	2.3	7.9	--	Curing
	4b	4/18	519.7	2.50	3.64	17.869	4.0	9.3	--	Curing
1	4a	4/19	520.4	2.50	3.58	17.574	2.3	9.5	--	Freezing
	4a	4/20	523.8	2.50	3.58	17.574	2.3	10.2	--	Thawing
	4b	4/20	522.2	--	--	--	-	10.2	0.6	Thawing
2	4a	4/21	523.2	2.50	3.60	17.672	2.9	10.1	--	Freezing
	4a	4/22	529.0	2.50	3.60	17.672	2.9	11.3	--	Thawing
	4b	4/22	522.1	--	--	--	-	11.3	1.5	Thawing
3	4a	4/23	528.4	2.50	3.60	17.672	2.9	11.1	--	Freezing
	4a	4/24	536.0	2.50	3.60	17.672	2.9	12.7	--	Thawing
	4b	4/24	497.6	--	--	--	-	12.7	6.9	Thawing
4	4a	4/25	535.9	2.51	3.60	17.813	3.7	12.7	--	Freezing
	4a	4/26	539.6	2.51	3.60	17.813	3.7	13.5	--	Thawing
	4b	4/26	467.4	--	--	--	-	13.5	13.5	Thawing
5	4a	4/27	537.9	2.51	3.60	17.813	3.7	13.1	--	Freezing
	4a	4/28	541.9	2.52	3.60	17.953	4.5	14.0	--	Thawing
	4b	4/28	446.3	--	--	--	-	14.0	17.7	Thawing
6	4a	4/29	540.0	2.53	3.60	18.094	5.3	13.6	--	Freezing
	4a	4/30	606.0	2.54	3.65	18.494	7.6	27.4	--	Thawing
	4b	4/30	392.2	--	--	--	-	27.4	35.2	Thawing

TABLE 10 - Continued

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume: Ave. dia.				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
7	4a	5/1	602.1	2.57	3.62	18.777	9.3	26.6	--	Freezing
	4a	5/2	608.0	2.57	3.62	18.777	9.3	27.9	--	Thawing
	4b	5/2	301.6	--	--	--	-	27.9	50.4	Thawing
8*	4a	5/3	604.1	2.57	3.62	18.777	9.3	27.0	---	Freezing
	4a	5/4	611.1	2.57	3.62	18.777	9.3	28.5	--	Thawing
	4b	5/4	Failed							Thawing

*Test disc. after 8th cycle

FREEZING AND THAWING TEST DATA

Soil sample: Palouse-clay + 10% Orzan Specimen cylinder no. 5a 5b
Date molded: 4/10/54 Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia. 3.50 in. ave. height 17.182 cu. in. volume
476.3 g. dry weight 544.9 g. wet weight 14.4% moist. content

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
0	5a	4/18	528.1	2.50	3.63	17.820	3.7	10.9	--	Curing
	5b	4/18	523.7	2.50	3.67	18.016	4.9	9.9	--	Curing
1	5a	4/19	532.8	2.50	3.63	17.820	3.7	11.9	--	Freezing
	5a	4/20	534.0	2.50	3.63	17.820	3.7	12.1	--	Thawing
	5b	4/20	531.8	--	--	--	-	12.1	0.4	Thawing
2	5a	4/21	533.2	2.50	3.65	17.918	4.3	11.9	--	Freezing
	5a	4/22	537.8	2.50	3.65	17.918	4.3	12.9	--	Thawing
	5b	4/22	541.5	--	--	--	-	12.9	1.1	Thawing
3	5a	4/23	537.1	2.50	3.65	17.918	4.3	12.7	--	Freezing
	5a	4/24	543.1	2.50	3.65	17.918	4.3	14.0	--	Thawing
	5b	4/24	509.8	--	--	--	-	14.0	6.3	Thawing
4	5a	4/25	542.3	2.51	3.65	18.060	5.1	13.8	--	Freezing
	5a	4/26	549.2	2.53	3.65	18.345	6.8	15.3	--	Thawing
	5b	4/26	371.6	--	--	--	-	15.3	32.3	Thawing
5	5a	4/27	547.8	2.54	3.65	18.495	7.6	15.0	--	Freezing
	5a	4/28	550.9	2.54	3.65	18.495	7.6	15.6	--	Thawing
	5b	4/28	211.0					15.6	61.6	Thawing
6*	5a	4/29	548.7	2.54	3.65	18.495	7.6	15.2	--	Freezing
	5a	4/30	557.1	2.57	3.66	18.984	10.5	17.0	--	Thawing
	5b	4/30	Failed							Thawing

*Test disc. after 6th cycle

TABLE 12

WETTING AND DRYING TEST DATA

Soil sample: Raw Palouse-clay Specimen cylinder no. 1c 1d
Date molded: 4/9/54 Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia. 3.50 in. ave. height 17.182 cu. in. volume
472.6 g. dry weight 549.2 g. wet weight 16.2% moist. content

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
0	1c	4/18	511.8	2.50	3.50	17.182	0	8.3		Curing
	1d	4/18	504.6	2.50	3.50	17.182	0	6.8		Curing
1	1c	4/19	530.5	2.50	3.57	17.525	2.0	12.2		Wetting
	1c	4/20	511.1	2.50	3.50	17.182	0	8.1		Drying
	1d	4/20	496.0					8.1		Drying
2	1c	4/21	546.4	2.52	3.50	17.454	1.6	15.6	3.2	Wetting
	1c	4/22	499.2	2.52	3.47	17.305	0.7	5.6		Drying
	1d	4/22	470.5					5.6		Drying
3	1c	4/23	605.0	2.58	3.47	18.141	5.6	28.0	5.7	Wetting
	1c	4/24	502.4	2.60	3.47	18.422	7.2	6.3		Drying
	1d	4/24	437.5					6.3		Drying
4	1c	4/25	603.4	2.60	3.52	19.112	11.2	27.7	13.1	Wetting
	1c	4/26	483.9	2.60	3.38	17.944	4.4	2.4		Drying
	1d	4/26	401.2					2.4		Drying
5*	1c	4/27	495.0	2.62	3.30	17.790	3.5	4.7	16.9	Wetting
	1d	4/28	470.5	2.62	3.30	17.790	3.5	0		Drying
	1d	4/28	Failed							Wetting

*Test disc. after 5th cycle

TABLE 13

WETTING AND DRYING TEST DATA

Soil sample: Palouse-clay + 2% Orzan Specimen cylinder no. 2c 2d
Date molded: 4/9/54 Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia. 3.50 in. ave. height 17.182 cu. in. volume
473.1 g. dry weight 548.8 g. wet weight 16.0% moist. content

Cycle No.	Spec. No.	Date	Nat. Wt. g.	Volume Ave. dia. in.	Ave. ht. in.	Ave. vol. cu.in.	Change %	Moist. Cont. %	Loss in % of initial dry wt.	Completed Operation
0	2c	4/18	503.9	2.50	3.57	17.525	2.0	6.5	--	Curing
	2d	4/18	512.2	2.50	3.50	17.182	0	8.3	--	Curing
1	2c	4/19	527.1	2.50	3.60	17.672	2.9	11.4	--	Wetting
	2c	4/20	502.1	2.50	3.57	17.525	2.0	6.1	--	Drying
	2d	4/20	506.3	--	--	--	-	6.1	0	Drying
2	2c	4/21	515.2	2.50	3.60	17.672	2.9	8.9	--	Wetting
	2c	4/22	501.1	2.50	3.57	17.525	2.0	5.9	--	Drying
	2d	4/22	414.1	--	--	--	-	5.9	17.3	Drying
3	2c	4/23	517.4	2.50	3.60	17.672	2.9	9.4	--	Wetting
	2c	4/24	501.7	2.50	3.57	17.525	2.0	6.0	--	Drying
	2d	4/24	330.7	--	--	--	-	6.0	34.1	Drying
4*	2c	4/25	517.3	2.50	3.60	17.672	2.9	9.4	--	Wetting
	2c	4/26	500.8	2.50	3.57	17.525	2.0	5.9	--	Drying
	2d	4/26	Failed							Wetting

*Test disc. after 4th cycle

TABLE 14

WETTING AND DRYING TEST DATA

Soil sample: Palouse-clay + 4% Orzan Specimen cylinder no. 3c 3d
Date molded: 4/10/54 Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia. 3.50 in. ave. height 17.182 cu. in. volume
473.6 g. dry weight 548.0 g. wet weight 15.7% moist. content

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
0	3c	4/18	504.8	2.50	3.55	17.427	1.4	6.6	--	Curing
	3d	4/18	503.9	2.50	3.55	17.427	1.4	6.4	--	Curing
1	3c	4/19	540.1	2.50	3.58	17.574	2.3	14.1	--	Wetting
	3c	4/20	502.3	2.50	3.55	17.427	1.4	6.3	--	Drying
	3d	4/20	498.4	--	--	--	-	6.3	1.3	Drying
2	3c	4/21	516.5	2.50	3.58	17.574	2.3	9.1	--	Wetting
	3c	4/22	504.1	2.50	3.55	17.427	1.4	6.4	--	Drying
	3d	4/22	496.1	--	--	--	-	6.4	1.7	Drying
3	3c	4/23	523.6	2.50	3.58	17.574	2.3	10.6	--	Wetting
	3c	4/24	505.4	2.50	3.56	17.476	1.7	6.7	--	Drying
	3d	4/24	489.2	--	--	--	-	6.7	3.4	Drying
4	3c	4/25	520.4	2.50	3.58	17.574	2.3	9.9	--	Wetting
	3c	4/26	502.3	2.50	3.57	17.525	2.0	6.3	--	Drying
	3d	4/26	480.3	--	--	--	-	6.3	4.9	Drying
5	3c	4/27	550.9	2.50	3.59	17.623	2.6	16.3	--	Wetting
	3c	4/28	502.7	2.50	3.57	17.525	2.0	6.2	--	Drying
	3d	4/28	460.2	--	--	--	-	6.2	8.7	Drying
6	3c	4/29	560.1	2.50	3.59	17.623	2.6	18.3	--	Wetting
	3c	4/30	504.7	2.50	3.57	17.525	2.0	6.6	--	Drying
	3d	4/30	435.6	--	--	--	-	6.6	13.7	Drying
7*	3c	5/1	575.1	2.50	3.60	17.672	2.9	21.5	--	Wetting
	3c	5/2	505.6	2.50	3.57	17.525	2.0	6.8	--	Drying
	3d	5/2	410.4	--	--	--	-	6.8	19.0	Drying

*Test discontinued in 7th cycle

TABLE 15

WETTING AND DRYING TEST DATA

Soil sample: Palouse-clay + 6% Orzan Specimen cylinder no. 4c 4d
Date molded: 4/10/54 Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia. 3.50 in. ave. height 17.182 cu. in. volume
475.4 g. dry weight 547.9 g. wet weight 15.1% moist. content

Cycle No.	Spec. No.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
0	4c	4/18	522.6	2.50	3.60	17.672	2.9	9.9		Curing
	4d	4/18	511.0	2.50	3.57	17.525	2.0	7.5		Curing
1	4c	4/19	550.3	2.50	3.62	17.771	3.4	15.7		Wetting
	4c	4/20	504.9	2.50	3.60	17.672	2.9	6.2		Drying
	4d	4/20	496.5					6.2	1.9	Drying
2	4c	4/21	517.8	2.50	3.63	17.820	3.7	8.9		Wetting
	4c	4/22	505.3	2.50	3.60	17.672	2.9	6.3		Drying
	4d	4/22	490.1					6.3	2.9	Drying
3*	4c	4/23	524.1	2.50	3.63	17.820	3.7	10.3		Wetting
	4c	4/24	505.2	2.50	3.60	17.672	2.9	6.3		Drying
	4d	4/24	Failed							Wetting

* Test discontinued after 3rd cycle

TABLE 16

WETTING AND DRYING TEST DATA

Soil sample: Palouse-clay + 10% Orzan   Specimen cylinder no. 5c 5d
Date molded: 4/10/54   Curing 7 day air-dry to constant weight
Initial molded measurements:
2.50 in. ave. dia. 3.50 in. ave. height 17.182 cu. in. volume
476.3 g. dry weight 544.9 g. wet weight 14.4% moist. content

Cycle no.	Spec. no.	Date	Nat. Wt.	Volume				Moist. Cont.	Loss in % of initial dry wt.	Completed Operation
				Ave. dia.	Ave. ht.	Ave. vol.	Change			
			g.	in.	in.	cu.in.	%	%		
0	5c	4/18	528.3	2.50	3.60	17.672	2.9	10.9		Curing
	5d	4/18	530.1	2.50	3.60	17.672	2.9	11.3		Curing
1	5c	4/19	544.1	2.50	3.60	17.672	2.9	14.2		Wetting
	5c	4/20	508.4	2.50	3.60	17.672	2.9	6.7		Drying
	5d	4/20	516.8					6.7	0.0	Drying
2	5c	4/21	519.5	2.50	3.60	17.672	2.9	9.1		Wetting
	5c	4/22	508.3	2.50	3.60	17.672	2.9	6.7		Drying
	5d	4/22	507.7					6.7	0.0	Drying
3	5c	4/23	533.9	2.50	3.60	17.672	2.9	12.1		Wetting
	5c	4/24	509.0	2.50	3.60	17.672	2.9	6.8		Drying
	5d	4/24	495.8					6.8	2.1	Drying
4	5c	4/25	522.5	2.50	3.60	17.672	2.9	9.7		Wetting
	5c	4/26	507.6	2.50	3.60	17.672	2.9	6.6		Drying
	5d	4/26	486.9					6.6	4.2	Drying
5	5c	4/27	523.6	2.50	3.60	17.672	2.9	9.9		Wetting
	5c	4/28	507.3	2.50	3.60	17.672	2.9	6.5		Drying
	5d	4/28	478.3					6.5	5.9	Drying
6*	5c	4/29	615.6	2.65	3.61	19.909	15.9	29.2		Wetting
	5c	4/30	512.2	2.62	3.62	19.515	13.6	7.5		Drying
	5d	4/30	Failed							Wetting

*Test discontinued after 6th cycle

TABLE 17

UNCONFINED COMPRESSION TEST DATA

Soil sample: Raw Palouse-clay not subjected to weathering tests

Height 3.50 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq. in.	P Load lbs.	σ Stress lbs./sq. in.
.0099	--	--	1.0000	4.91	--	--
.0111	.0012	.0003	.9997	4.91	100	20.37
.0181	.0082	.0023	.9977	4.92	200	40.65
.0440	.0341	.0097	.9907	4.95	300	60.61
.0504	.0405	.0115	.9885	4.96	400	60.48
--	Sample Failed			-	420	

$\epsilon = \frac{\Delta}{h}$ $A' = \frac{A}{1-\epsilon}$ $\sigma = \frac{P}{A'}$

TABLE 18

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 2% Orzan Not subjected to weathering tests

Height 3.50 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq. in.	P Load lbs.	σ Stress lbs./sq.in.
.0015	--	--	1.0000	4.91	--	--
.0168	.0153	.0044	.9956	4.93	100	20.28
.0456	.0441	.0126	.9874	4.97	200	40.24
.0574	.0559	.0160	.9840	4.99	300	60.12
.0652	.0637	.0182	.9818	5.00	400	80.00
.0728	.0713	.0204	.9796	5.01	500	99.80
.0788	.0773	.0221	.9779	5.02	600	119.52
.0876	.0861	.0246	.9754	5.03	700	139.16
.0959	.0944	.0270	.9730	5.05	800	158.42
	Sample Failed				860	--

$\epsilon = \frac{\Delta}{h}$ $A' = \frac{A}{1-\epsilon}$ $\sigma = \frac{P}{A'}$

TABLE 19

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 4% Orzan Not subjected to weathering tests

Height 3.50 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1-\epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.0000	--	--	1.0000	4.91	--	--
.0145	.0145	.0041	.9959	4.93	100	20.29
.0281	.0281	.0080	.9920	4.95	200	40.40
.0414	.0414	.0118	.9882	4.97	300	60.36
.0468	.0468	.0134	.9866	4.98	400	80.32
.0527	.0527	.0150	.9850	4.98	500	100.40
.0591	.0591	.0169	.9831	4.99	600	120.24
.0666	.0666	.0190	.9810	5.00	700	140.00
	Sample Failed				720	

$\epsilon = \frac{\Delta}{h}$ $A' = \frac{A}{1-\epsilon}$ $\sigma = \frac{P}{A'}$

TABLE 20

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 6% Orzan Not subjected to weathering tests

Height 3.58 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.0066	--	--	1.0000	4.91	--	--
.0189	.0123	.0034	.9966	4.93	100	20.28
.0401	.0335	.0094	.9906	4.96	200	40.32
.0566	.0500	.0140	.9860	4.98	300	60.24
.0655	.0589	.0164	.9836	4.99	400	80.16
.0797	.0731	.0204	.9796	5.01	500	99.80
.1255	.1189	.0332	.9668	5.08	590	116.14

$\epsilon = \frac{\Delta}{h}$ $A' = \frac{A}{1-\epsilon}$ $\sigma = \frac{P}{A'}$

TABLE 21

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 10% Orzan Not subjected to weathering tests

Height 3.60 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1-\epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.0212	--	--	1.0000	4.91	--	--
.0254	.0042	.0012	.9988	4.92	100	20.32
.0347	.0135	.0037	.9963	4.93	200	40.57
.0585	.0373	.0104	.9896	4.96	300	60.48
.0877	.0665	.0185	.9815	5.00	400	80.00
.0961	.0749	.0208	.9792	5.01	430	85.83

$\epsilon = \frac{\Delta}{h}$ $A' = \frac{A}{1-\epsilon}$ $\sigma = \frac{P}{A'}$

TABLE 22

UNCONFINED COMPRESSION TEST DATA

Soil sample: Raw Palouse-clay Subjected to 5 cycles of Freeze-thaw test

Height 3.52 in. Diameter 2.52 in. Area 4.99 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1-\epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.7525	--	--	1.0000	4.99	--	--
.7365	.0160	.0045	.9955	5.01	100	19.96
.7301	.0224	.0064	.9936	5.02	200	39.84
.7250	.0275	.0078	.9922	5.03	300	59.64
.7231	.0294	.0084	.9916	5.03	400	79.52
.7210	.0315	.0089	.9911	5.03	500	99.41
.7165	.0360	.0102	.9898	5.04	600	119.05
.7110	.0415	.0118	.9882	5.05	700	138.61
.6995	.0530	.0150	.9850	5.06	800	158.10
.6975	.0550	.0156	.9844	5.07	820	161.74
.6935	.0590	.0168	.9832	5.08	840	165.35
	Sample Failed				860	

$$\epsilon = \frac{\Delta}{h} \qquad A' = \frac{A}{1-\epsilon} \qquad \sigma = \frac{P}{A'}$$

TABLE 23

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 4% Orzan Subjected to 9 cycles of Freeze-thaw test

Height 3.60 in. Diameter 2.55 in. Area 5.11 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.7221	--	--	1.0000	5.11	--	--
.6960	.0261	.0072	.9928	5.15	100	19.42
.6793	.0428	.0119	.9881	5.17	200	38.68
.6640	.0571	.0159	.9841	5.19	300	57.80
.6475	.0746	.0207	.9793	5.22	400	76.63
.6450	.0761	.0211	.9789	5.22	420	80.46
.6401	.0820	.0228	.9772	5.23	440	84.13
.6336	.0885	.0246	.9754	5.24	460	87.79
.6223	.0998	.0277	.9723	5.26	480	91.25
	Sample Failed				500	

$\epsilon = \dfrac{\Delta}{h}$ $A' = \dfrac{A}{1-\epsilon}$ $\sigma = \dfrac{P}{A'}$

TABLE 24

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 6% Orzan Subjected to 8 cycles of Freeze-thaw test

Height 3.62 in. Diameter 2.57 in. Area 5.19 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.8565	--	--	1.0000	5.19	--	--
.8292	.0263	.0073	.9927	5.23	100	19.12
.8106	.0459	.0127	.9873	5.26	200	38.02
.8069	.0496	.0137	.9863	5.26	220	41.82
.8038	.0527	.0146	.9854	5.27	240	45.54
.8002	.0563	.0156	.9844	5.27	260	49.34
.7958	.0607	.0168	.9832	5.28	280	53.03
.7927	.0638	.0176	.9824	5.28	300	56.82
.7879	.0686	.0190	.9810	5.29	320	60.49
.7838	.0727	.0201	.9799	5.30	340	64.15
.7760	.0805	.0222	.9778	5.31	360	67.80
	Sample Failed				380	

$\epsilon = \dfrac{\Delta}{h}$ $\qquad A' = \dfrac{A}{1-\epsilon}$ $\qquad \sigma = \dfrac{P}{A'}$

TABLE 25

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 10% Orzan Subjected to 6 cycles of Freeze-thaw test

Height 3.66 in. Diameter 2.57 in. Area 5.19 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.8107	--	. --	1.0000	5.19	--	--
.7870	.0237	.0065	.9935	5.22	100	19.16
.7745	.0362	.0098	.9902	5.24	200	38.17
.7633	.0474	.0130	.9870	5.26	300	47.03
.7525	.0582	.0159	.9841	5.27	400	75.90
.7401	.0706	.0193	.9807	5.29	500	94.52
.7370	.0737	.0201	.9799	5.30	520	98.11
.7325	.0782	.0214	.9786	5.30	540	101.89
.7260	.0847	.0231	.9769	5.31	560	105.46
.7180	.0927	.0253	.9747	5.32	580	109.02
.7050	.1057	.0289	.9711	5.34	600	112.36
.6830	.1277	.0343	.9657	5.37	620	115.46
	Sample Failed				640	

$$\epsilon = \frac{\Delta}{h} \qquad A' = \frac{A}{1-\epsilon} \qquad \sigma = \frac{P}{A'}$$

TABLE 26

UNCONFINED COMPRESSION TEST DATA

Soil sample: Raw Palouse-clay Subjected to 5 cycles of Wet-dry test

Height 3.30 in. Diameter 2.62 in. Area 5.39 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq. in.	P Load lbs.	σ Stress lbs./sq.in.
.8205	--	--	1.0000	5.39	--	--
.7852	.0353	.0098	.9902	5.44	10	1.84
.7800	.0405	.0112	.9888	5.45	20	3.67
.7743	.0452	.0126	.9874	5.46	30	5.49
.7692	.0513	.0142	.9858	5.47	40	7.31
.7649	.0556	.0154	.9846	5.47	50	9.14
.7600	.0605	.0168	.9832	5.48	60	10.95
.7531	.0674	.0187	.9813	5.49	70	12.75
	Sample Failed				80	

$\epsilon = \frac{\Delta}{h}$ $A' = \frac{A}{1-\epsilon}$ $\sigma = \frac{P}{A'}$

TABLE 27

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 2% Orzan Subjected to 4 cycles of Wet-dry test

Height 3.57 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1 - \epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.7980	--	--	1.0000	4.91	--	--
.7765	.0215	.0077	.9923	4.95	20	4.04
.7629	.0351	.0098	.9902	4.96	40	8.06
.7519	.0461	.0101	.9899	4.96	60	12.10
.7425	.0555	.0155	.9845	4.99	80	16.03
.7342	.0638	.0179	.9821	5.00	100	20.00
.7300	.0680	.0190	.9810	5.01	110	21.96
.7261	.0719	.0201	.9799	5.01	120	23.95
.7211	.0769	.0215	.9785	5.02	130	25.90
.7155	.0825	.0231	.9769	5.03	140	27.83
.7070	.0910	.0255	.9745	5.04	150	29.76
	Sample Failed				160	

$$\epsilon = \frac{\Delta}{h} \qquad A' = \frac{A}{1-\epsilon} \qquad \sigma = \frac{P}{A'}$$

TABLE 28

UNCONFINED COMPRESSION TEST DATA

oil sample: Palouse-clay + 4% Orzan Subjected to 7 cycles of Wet-dry test

Height 3.60 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1-\epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.8131	--	--	1.0000	4.91	--	--
.7975	.0156	.0043	.9957	4.93	100	20.28
.7892	.0239	.0066	.9934	4.94	200	40.85
.7820	.0311	.0086	.9914	4.95	300	60.61
.7745	.0386	.0107	.9893	4.96	400	80.64
.7682	.0449	.0125	.9875	4.97	500	100.61
.7632	.0499	.0139	.9861	4.98	600	120.48
.7570	.0561	.0156	.9844	4.99	700	140.28
.7555	.0576	.0160	.9840	4.99	720	144.29
.7540	.0591	.0164	.9836	4.99	740	148.30
.7521	.0610	.0169	.9831	4.99	760	152.30
	Sample Failed				780	

$\epsilon = \dfrac{\Delta}{h}$ $\quad A' = \dfrac{A}{1-\epsilon}$ $\quad \sigma = \dfrac{P}{A'}$

TABLE 29

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 6% Orzan Subjected to 3 cycles of Wet-dry test

Height 3.60 in. Diameter 2.50 in. Area 4.91 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1-\epsilon$	A' Corr. Area sq.in.	P Load lbs.	σ Stress lbs./sq.in.
.8358	--	--	1.0000	4.91	--	--
.8109	.0149	.0041	.9959	4.93	100	20.28
.7910	.0438	.0122	.9878	4.97	200	40.24
.7736	.0612	.0170	.9830	4.99	300	60.12
.7601	.0747	.0208	.9792	5.01	400	79.84
.7480	.0878	.0244	.9756	5.03	500	99.40
.7354	.1004	.0279	.9721	5.05	600	118.81
.7325	.1033	.0287	.9713	5.06	620	122.53
.7250	.1108	.0308	.9692	5.07	640	126.23
.7030	.1328	.0369	.9631	5.10	660	129.41
	Sample Failed				680	

$$\epsilon = \frac{\Delta}{h} \qquad A' = \frac{A}{1-\epsilon} \qquad \sigma = \frac{P}{A'}$$

TABLE 30

UNCONFINED COMPRESSION TEST DATA

Soil sample: Palouse-clay + 10% Orzan   Subjected to 6 cycles of Wet-dry test

Height 3.62 in.   Diameter 2.62 in.   Area 5.39 sq. in.

Dial in.	Δ Diff. in.	ϵ Strain in./in.	$1-\epsilon$	A' Corr. Area sq. in.	P Load lbs.	σ Stress lbs./sq.in.
.6165	--	--	1.0000	5.39	--	--
.6082	.0083	.0023	.9977	5.40	20	3.70
.5908	.0257	.0071	.9929	5.43	40	7.37
	Sample Failed				60	

$\epsilon = \frac{\Delta}{h}$ $A' = \frac{A}{1-\epsilon}$ $\sigma = \frac{P}{A'}$

BIBLIOGRAPHY

U. S. Department of Agriculture. Soil Survey of Spokane County, Washington Survey Report 1920. Washington: Government Printing Office, 1921.

American Association of State Highway Officials. Standard Specifications for Methods of Sampling and Testing, 1950.

Bateman, John H. Introduction to Highway Engineering. 5th ed. New York: John Wiley and Sons Inc., 1948.

Bruce, Arthur G. and Clarkson, John. Highway Design and Construction. 3d ed. Scranton: International Textbook Company, 1951.

Capper, P. Leonard and Cassie, W. Fisher. The Mechanics of Engineering Soils. New York: McGraw-Hill Book Company., Inc., 1949.

Crown Zellerbach Corporation, Industrial Products Division. Orzan, Technical Bulletin 531. North Portland: Crown Zellerbach Corporation (mimeographed).

Dawson, Raymond F. Laboratory Manual in Soil Mechanics. New York: Pitman Publishing Corporation, 1949.

Ekse, Martin. "The Triaxial Institute Kneading Compactor", The Trend in Engineering at the University of Washington. Vol. IV, No. 1, January, 1952.

Housel, William S. Manual of Soil Testing Procedures. Ann Arbor: University of Michigan, 1946.

Hveem, F. N. and Davis, Harmer E. "Some Concepts Concerning Triaxial Compression Testing of Asphaltic Paving Mixtures and Subgrade Materials", Triaxial Testing of Soils and Bituminous Materials, Special Publication No. 106. Philadelphia: American Society for Testing Materials, 1951.

U. S. Department of Interior, Bureau of Reclamation. Laboratory Procedure in Testing Material for Foundation and Construction Purposes. Denver: U. S. Department of Interior, 1946 (mimeographed).

Lambe, T. William. Soil Testing for Engineering. New York: John Wiley and Sons, Inc., 1951.

Longwell, Chester R. and others. Outlines of Geology. 2d ed. New York: John Wiley and Sons, Inc., 1945.

Luck, L. D. "Shear Characteristics of Palouse Clay". Unpublished Master's thesis, Department of Civil Engineering, University of Minnesota, 1951.

Mainfort, R. C. A Summary Report on Soil Stabilization by the Use of Chemical Admixtures. Indianapolis: Civil Aeronautics Administration, U. S. Department of Commerce, 1951.

McRae, J. L. and Rutledge, P. C. "Laboratory Kneading of Soil to Simulate Field Composition", Proceedings Thirty-first Annual Meeting of the Highway Research Board. Vol. XXXI, 1952.

Minor, Carl E. "Procedures for Testing Stability of Bituminous Mixtures", Proceedings of Second Annual Road Builders Clinic. Pullman: State College of Washington, 1951.

Morgan, Lloyd H. "Compaction in Laboratory and Field", Proceedings 1952 Northwest Conference on Road Building. Seattle: University of Washington, 1952.

Pickering, H. P. Suggested Procedures for Soil Testing. Berkeley: The Institute of Transportation and Traffic Engineering, Universities of California, 1951.

Piette, Guillaume. "Improved Soil Stabilization". Paper presented at the Fifty-eighth Annual General Professional Meeting of The Engineering Institute of Canada, at Quebec, on February 11, 1944. The Engineering Journal, 1944.

Plumber, Fred L. Notes on Soil Mechanics and Foundations. Ann Arbor: Edwards Brothers, Inc., 1938.

Sharma, Rattan Chand. "Annotated Bibliography of Soil Stabilization". Master's thesis, Department of Civil Engineering, University of Purdue. (mimeographed).

Sherman, Walter A. For Better Roads to Better Recreation by the Use of Sulphite Liquor. Park Falls: Flambeau Paper Company.

Smith, Julian C. "The Chrome Lignin Process and Ion Exchange Studies", Proceedings of the Conference on Soil Stabilization, Massachusetts Institute of Technology, 1952.

Spangler, Merlin Grant. Soil Engineering. Scranton: International Textbook Company, 1951.

__________. Soil Cement Mixtures, Laboratory Handbook. 3d ed. Chicago: Portland Cement Association, 1950.

Sowers, George B. and Sowers, George F. Introductory Soil Mechanics and Foundations. New York: The Macmillan Company, 1951.

Taylor, Donald W. Fundamentals of Soil Mechanics. New York: John Wiley and Sons, Inc., 1948.

__________. "Canadian Developments in the Treatment of Highway Subsoil", Roads and Engineering Construction, Vol. 90, No. 11, Canada: 1952.