REPORT OF DEPARTMENT OF MAINTENANCE

C W McCLAIN, *Chairman*

REPORT OF PROJECT COMMITTEE ON DISTORTION OF PAVEMENTS

C W McCLAIN, *Chairman*

THE RESULTS OF TESTS TO DETERMINE THE EXPANSIVE PROPERTIES OF SOILS

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SYNOPSIS

The study of the swell of soils was begun in Kansas after it was found that soil swell was directly associated with the distortion or "warping" of concrete pavements The tests, the results of which are given in summary form in this report, cover a wide range of conditions of initial moisture content and state of compaction for soils of the A-2, A-4, A-6, and A-7 groups The results show that the amount of swell is dependent upon the characteristics of the soil itself as indicated by the test constants, upon the structural arrangement of the soil in its natural state, and upon its state of compaction and initial moisture content The greatest swell was observed on expansive soils which existed in a comparatively dry, compact state prior to being allowed to absorb water and swell Expansive soils exhibited the least swell when they were compacted to maximum density at moisture contents closely approaching their lower plastic limits

PART I

LABORATORY TESTS

The laboratory study of the expansive properties of subgrade soils was begun in Kansas in 1933 Prior to the beginning of laboratory study considerable time had been spent and many data obtained in the field study of subgrades under distorted ("warped") concrete pavement slabs The results of the field studies of the existing density and moisture content of the subgrade soil under warped pavement slabs, as well as under pavements unaffected by warping, showed definitely that the warping of pavements was due largely, if not wholly, to the uplift caused by the swelling of the subgrade soil The swelling resulted from the soil absorbing water which entered through leaky joints and cracks and at the edges of the slab

The results of the field studies showed that the amount of uplift varied not only with different soils having different characteristics, but also with different conditions of initial moisture content and state of compaction for a single soil

The Problem.

The establishment of the fact that pavement warping was definitely associated with soil condition as well as with soil type showed the need for further study of the swell of representative soils of the various groups under different conditions in the laboratory It also showed that the moisture content at which soil is compacted and the density to which it is compacted immediately prior to being allowed to absorb water were items which should be given consideration in the laboratory study

The problem laid out for study was as follows.

1 To devise a test to measure the

relative swells of soils when they are allowed to absorb water.

2. To study the relative swells of manipulated soils, as follows:
   - A. Variation in swell of a single soil, with
     - a. Variation in state of compaction, and
     - b. Variation in initial moisture content.
   - B. Variation in swell of different soils under comparable conditions of moisture content and density.
3. To correlate swell characteristics of soils as determined by the swell test with soil characteristics as identified by the test constants determined by the Standard U. S. Bureau of Public Roads Soils Tests.

Experimental Test Procedure:

Before a definite test procedure was adopted, a number of individual experimental tests were made to determine the suitability of the various methods by which it had been proposed to measure the swell of soil. These preliminary experiments were divided into two groups; (1) the determination of the swell of specimens of soil which had been prepared by being compacted in a mold and removed for test; and (2) the determination of the swell of soils in the molds in which they had been compacted.

(1) A number of tests were made on specimens compacted in a cylinder in accordance with the Proctor procedure and removed from the cylinder for test. Pieces of blotting-paper were placed on the ends of the specimens after which they were coated with a rubber paint as shown in Figures 1 and 2. The rubber coated specimens were then placed in a pan of water—some being only partially submerged and others totally submerged, to determine the effectiveness of the two methods. Initial, intermediate, and final volumes were determined by the use of a Marsh overflow volumeter. Some tests were conducted to determine the relation between slaking characteristics and swelling characteristics for a given soil.

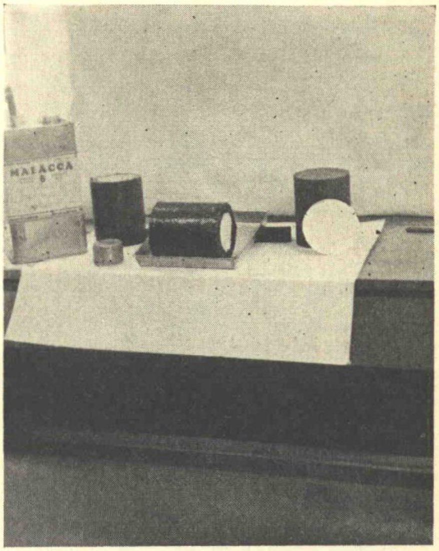

Figure 1. View showing method of covering samples with rubber paint. The rubber paint is placed in the shallow pan to the desired depth and the specimen turned slowly until the desired thickness of coating is obtained.

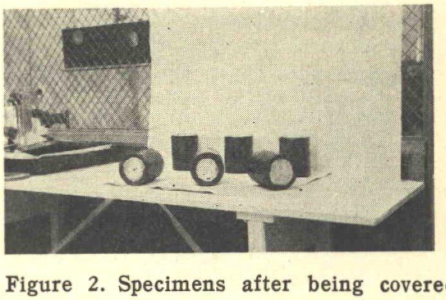

Figure 2. Specimens after being covered with rubber. Note blotting-paper on end of specimen.

(2) Experimental tests in which molds were used to determine the swell of soils were, as follows:

A. Soils tested in molds of 2.37 in. and 4 in. diameters with and without loads being placed upon the soil pat during the swelling process.

B. Tests, using the 4-in. diameter mold, to determine the relation between swell and the thickness of the compacted soil pat.

C. Tests on different methods of introducing water into the specimens by means of pressure and by means of capillary absorption.

All experiments, which were made to determine the best test procedure for

Figure 3. View of unassembled mold (showing compacting piston, "pressure pad," measuring device, filter paper, and soil pat) used in making swell tests in molds.

the use of molds in the study of soil swell, were made on a single soil. In each instance the soil was compacted to a predetermined density for each of the various desired depths. The moisture contents used were held uniform as far as possible so the data would be comparable.

Miscellaneous Tests:

In addition to the above experimental tests, a part of which are discussed later in this report, a number of other tests have been made in the laboratory and in the field. Among these are: Leveling of warped pavement slabs by equalizing the subgrade moisture content; construction of an experimental slab in the laboratory to study the causes of pavement warping; study of the force exerted by a soil when it is allowed to absorb water; study of the swell of undisturbed samples of soils in their natural structured state; and study of the swell of columns of soil in their natural positions in the soil profile. Although this report deals primarily with the results of field and laboratory swell tests, these studies are mentioned to indicate the scope of the study of swell of soils.

PRESENT TENTATIVE PROCEDURE FOR LABORATORY DETERMINATION OF SOIL SWELL

More than 150 individual swell tests were made before a definite test procedure was agreed upon. The apparatus used and the procedure adopted are as follows:

Apparatus:

The molds, which are used in making the swell tests, are 4 in. inside diameter and 6½ in. inside height (Figure 3). They are brass molds similar to those used by the United States Bureau of Public Roads in measuring the swell of bituminous mixtures. Steel rods are attached to the mold to accommodate the use of a micrometer for measuring the vertical rise of the soil in the mold. A special frame is built onto the micrometer to hold it in place while obtaining measurements. A brass piston and compression machine are used in compacting the soil in the mold.

Built-up pressure pads, which can be loaded through a considerable range of weight, are used in loading the soil with a load equivalent to that of the pavement slab upon the subgrade The pressure pads are enough smaller in diameter than the mold to allow free vertical movement without binding

Additional apparatus includes a supply of blotting-paper, scales, graduates, sieves, trowels and pans for mixing, thermometer, and other incidentals necessary for the preparation of the sample and the consummation of the test

Preparation of the Sample

The soil as it is received from the field is oven dried, broken down, and screened over the No 10 mesh sieve All soil is dried in a constant temperature oven at a temperature of 110°C All particles of mineral aggregate retained on the No 10 mesh sieve are discarded All particles of mineral aggregate, retained on the No 10 mesh sieve, which can be reduced in size without crushing the sand grains are broken down to a size passing the No 40 mesh sieve That portion passing the No 10 mesh sieve is then remixed with the portion passing the No 40 mesh sieve The sample is again oven dried immediately prior to the preparation of the specimen

Preparation of Specimen and Testing

After the sample has been prepared, oven dried (at 110°C), and allowed to cool, it is mixed with enough distilled water to result in the desired initial moisture content Mixing is done by hand using a small trowel Mixing is continued until the soil has a uniform color and no wet lumpy masses or dry particles are evident

After completion of mixing, a 50 gram sample is taken out and weighed to obtain the moisture content of the soil immediately prior to its being compacted into the molds

A piece of blotting-paper is placed in the bottom of the mold and the initial reading is taken Sufficient soil is then placed in the mold to give the desired thickness of the pat and compacted

The soil is compacted by applying a unit load of 300 lb per sq in by means of a piston and compression machine If additional tests are made, they are made on samples compacted at unit pressures of 75, 150, 600, and 1000 lb per sq in

The compacting load is applied slowly and held for a period of ten seconds This is repeated three times When the pressure is released on the third compression, the amount of rebound is noted and recorded

The depth or thickness of the compacted soil specimen is 2 in plus or minus 0 02 in

Example Assume that the initial moisture content of soil will be 10 per cent and that a 2-in thickness of soil pat is required Assume also that a compaction curve has been made on the soil (by using 300 lb per sq in pressure) and that the results of compaction indicate that a density of 1 65 will be obtained at a moisture content of 10 per cent.

Since Density =

$$\frac{\text{Weight of soil (dry) in grams}}{\text{Volume (cc) for a 2-in. depth}}$$

Then 1 65 =

$$\frac{\text{Weight of soil (dry) in grams}}{411\ 88\ \text{cc}}$$

and weight of dry soil (grams) = 679 6
Weight of moist soil (grams) = 679 6 + (679 6 × 0 10) = 747 56

It has been found that after some trials it is not difficult to approach the desired thickness of soil pat within plus or minus 0 02 in , a variation which will not produce an appreciable error, due to pat thickness, in the results obtained All soils are compacted as nearly as possible at a temperature of 70°F to avoid compaction irregularities due to temperature changes

Immediately after the soil has been compacted in the mold and the data recorded, the pressure pads are placed in the mold and pushed firmly against

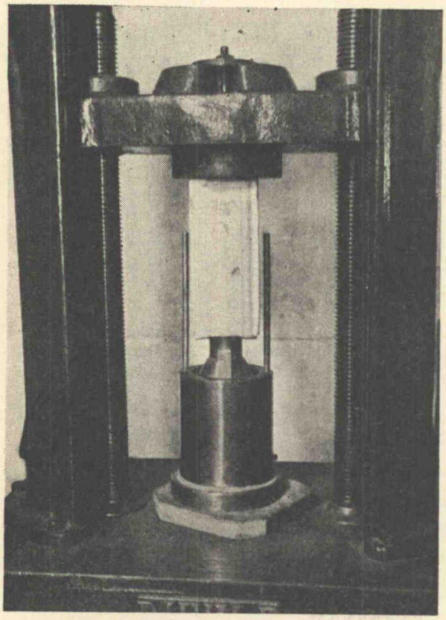

Figure 4. View showing the method used in compacting the soil in the "swell test" mold.

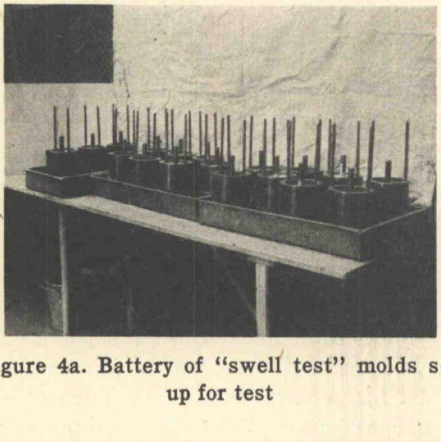

Figure 4a. Battery of "swell test" molds set up for test

the soil. The total weight of the pressure pad is $7\frac{1}{2}$ lb. The unit weight (lb. per sq. in.) is approximately that of concrete pavement upon the subgrade. The micrometer is then used to take the initial reading to obtain the elevation of the top of the soil with the assembled "swell" measuring apparatus. The time is recorded and the mold placed in water of such depth that the water level is approximately that of the level of the top of the soil pat in the mold.

Readings are taken at intervals of four hours or less, as may be necessary, during the first 40 hours of the test. The swell tests are continued for a minimum period of 100 hours. If, at the end of 100 hours, the volume change is found to be increasing in increments greater than one-tenth per cent in the final 24-hour period, the tests are continued until the volume change increases one-tenth per cent or less in 24 hours time.

The data obtained are reported on forms in the manner indicated on the sample data sheet. Additional data include complete United States Bureau of Public Roads soil tests including specific gravity, and temperatures of the room and the drying oven. Occasionally molds are set aside and not placed in the water bath to determine if all of the rebound occurs immediately upon release of compression during compaction of soil.

DISCUSSION OF RESULTS

Experimental Studies

Soil Samples Removed from Molds for Test: The use of the Proctor compaction cylinder and method of compaction in preparing swell test specimens was studied primarily with the hope that a practical test might be devised which could be conducted in field laboratories when special studies of some soils appeared necessary. Several difficulties were encountered. There was some lack of uniformity in the hand compaction of the specimens, which was overcome to some extent by the use of a specially designed hammer which reduced the effect of the personal element. Although the rubber paint accomplished the purpose of holding the specimen together, it was difficult to handle after the soil had become soft It was found necessary to use extreme care in handling the specimens while measuring their volume to prevent injury to the paper ends which had been provided for the entrance of water into the sample and the exit of air from the sample This test was conducted on specimens which were totally submerged and on specimens which were only partially submerged The totally submerged samples resulted in the greater swell Figure 5 shows the results of tests of this nature on a silt loam soil This soil when tested in molds under load showed a negligible amount of swell

in diameter) mold Undoubtedly, the amount of swell was influenced considerably by friction between the soil and the side of the mold The larger mold which allowed the greater swell has a lower ratio of sidewall area (in contact with the soil) to cross sectional area than does the smaller one Evidence of the extent of friction between the soil and the sidewalls of the mold is shown on Figure 6 It will be noted that, although the values of initial moisture content and density differed but little, the resulting swell showed a marked increase with decrease in the depth of the soil in the mold The difference in the friction

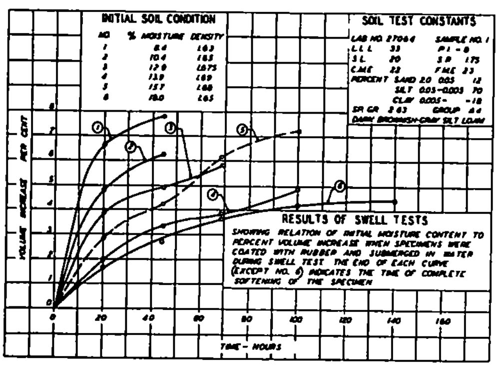

Figure 5

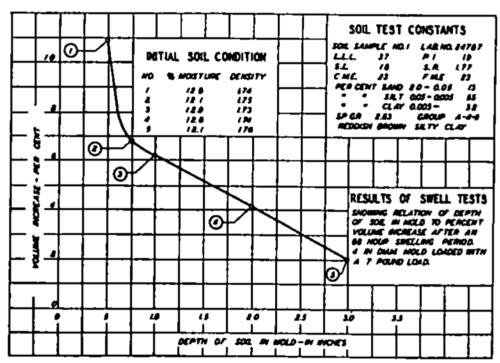

Figure 6

When heavy clay soils, compacted to higher densities at the higher moisture contents, (compacted to a condition approaching that of minimum air voids) are only partially submerged, a condition is eventually reached where the evaporation through the top blotter equals the upward movement of water by capillarity Thus the upper part of the specimen never undergoes complete swell This type of test would, undoubtedly, be more successful if the specimen did not exceed 2 in in depth

In the tests to determine the relation between volume change and size of the mold, it was found that the larger mold (4 in in diameter) resulted in a greater soil swell than did the smaller (2 37

which existed after swelling for a given period was readily determined by observing the force required to push the sample out of the mold

The final distribution of the moisture in the specimens (after swell) was of particular interest A higher moisture content resulted in the top part of the sample than in the bottom part which was in actual contact with water The resulting moisture content was as much as 3 per cent higher in the center than at the edges (adjacent to the walls of the mold) of the specimen

The results of the experimental tests were of interest primarily because they indicated a need for rigid adherence to a fixed testing procedure if uniform results were to be obtained

TESTS CONDUCTED UNDER TENTATIVE STANDARD PROCEDURE FOR STUDYING SWELL OF SOILS

Upon the adoption of a definite procedure, it was decided to make a thorough study of the swell of a single soil under a wide range of conditions of initial moisture content and state of compaction A series of five different compaction pressures (Figure 7) were used to obtain a range of densities for each moisture content at which it was decided to study the swelling action The lower limit of initial moisture content was arbitrarily set at 10 per cent This is the approximate minimum moisture content experienced in soils of this nature under field conditions The upper limit of initial moisture content was set at the lower plastic limit because at higher moisture contents the soil was too wet and would flow under pressure causing the compacting piston to stick

Figure 7 shows the range of conditions at which this soil was tested for swell Each point on each compaction curve represents three individual tests Figure 8 shows the swell obtained on the samples compacted at a pressure of 300 lb per sq in at various initial moisture contents Figure 9 shows graphically the variation in rate of swell of samples compacted at three different moisture contents

Figure 10 shows an analysis of the

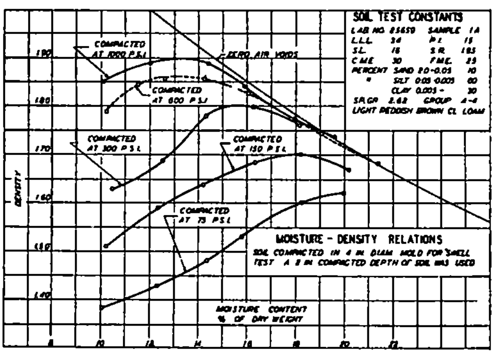

Figure 7

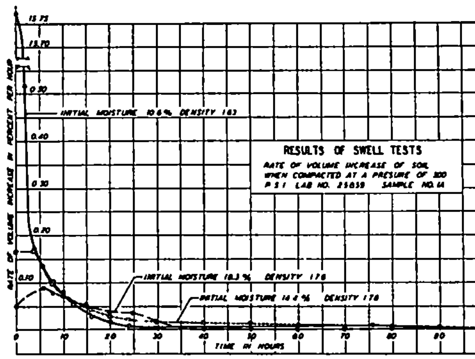

Figure 9

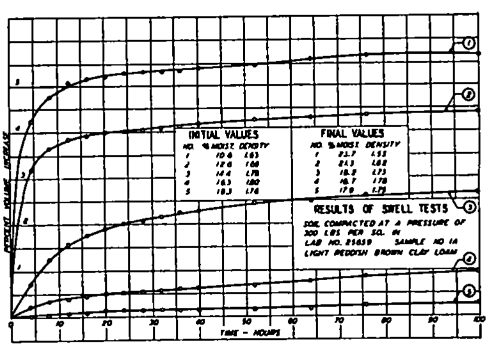

Figure 8

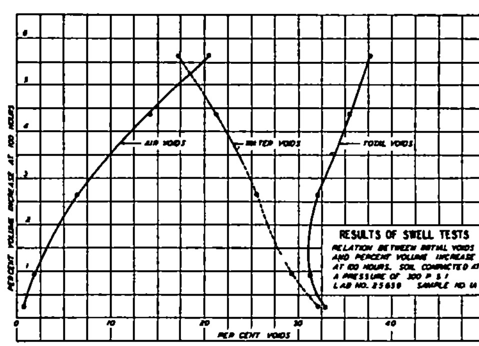

Figure 10

results obtained for the 300 lb per sq in series of tests on the clay loam soil The results show definitely that the swell varies in proportion to the percentage of air voids present in the compacted soil prior to being allowed to absorb water and swell In every instance, for each of the five series of compressions, the condition of minimum swell was found to be consistent with a condition of minimum air voids Thus, the contributing condition toward soil swellage is neither moisture content nor state of compaction, singly, but that combination which results in the minimum air voids for a given soil compacted under a given pressure

Figure 11 summarizes the results of the tests on the clay loam soil Although the initial moisture contents did not fall exactly into the groups as shown (10%, 12%, etc) they are sufficiently close to be so grouped For the particular soil being tested, it may be seen that a moisture content of 20 per cent is necessary to result in minimum swell for the 300 lb per sq in compression pressure

The expansion of soil due to freezing is of particular interest in connection with the study of pavement "warping" and soil swell Figure 12 shows the results obtained when molds were placed in water and insulated in such a manner that the freezing progressed from the top downward The test constants of the soil upon which this test was made are shown on Figure 13 In addition to tests of this nature, soils having various initial moisture contents were frozen in the molds to determine the effect of contained moisture upon volume change due to freezing No detrimental swell was observed at moisture contents as high as the lower plastic limit of the soils unless additional moisture was available as shown by Figure 12

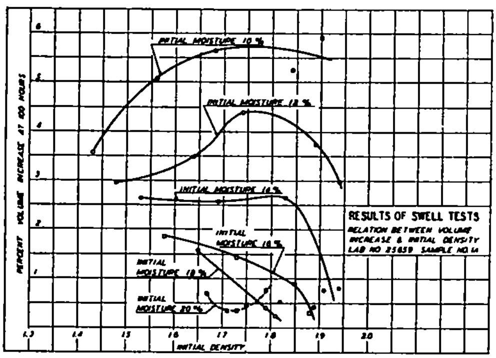

Figure 11

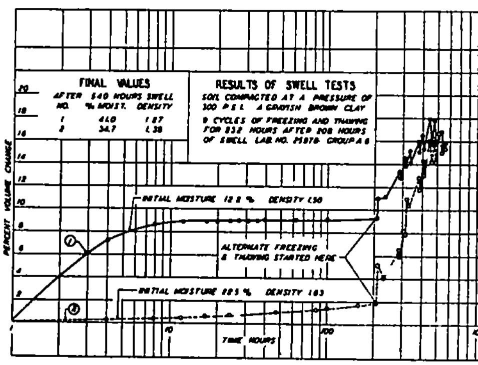

Figure 12

Results of Tests on Soils of the A-2, A-4, A-6, and A-7 Groups

In addition to the more complete study of the clay loam soil (Figs 7 to 11 inclusive), swell tests were conducted on four additional soils in order to obtain results on representative soils of the various groups In each of these tests the soils were compacted at five or six different moisture contents by using a pressure of 300 lb per sq in The results, therefore, show the comparative swell obtained on soils having different characteristics A summary of the maximum and minimum swell obtained on these soils is shown in Figure 13 It should be understood, in making comparisons of the swell obtained on different soils, that the initial moisture contents were not carried either sufficiently low or sufficiently high to warrant a statement that these are the absolute conditions under which maximum and minimum swell may be obtained For example, it is quite probable that the maximum swell of the clay of the A-7 group would more nearly approach the maximum swell of the clay of the A-6 group if the lowest initial moisture content of the A-7 soil would have been 12 2 per cent instead of 15 7 per cent It should be understood also, in comparing these values, that no effort was made in these tests to determine absolute values of swell for a number of given soils The object was rather to determine the trend or characteristics of swell for a few representative soils which would point toward obviating, or at least minimizing the

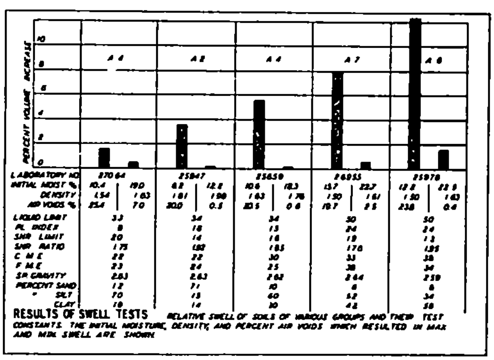

Figure 13

warping of concrete pavements placed upon the soils in question

The soil shown under laboratory number 27064 (Figure 13) is a typical A-4 Kansas alluvial silt loam, the sample having been taken from the flood plain of the Kansas river. No pavement warping has been found to occur on this soil which has very little binder material The tests show only a small amount of swell regardless of the initial moisture content or state of compaction This soil has, however, given some trouble due to frost action where water was available to be drawn up into the soil resulting in ice lenses and consequent heaving

The soils shown under laboratory numbers 25978 and 26955 are typical Kansas clay soils of the A-6 and A-7 groups Soils similar to these are associated with severe pavement warping At every location which has been studied in the field where warping has occurred on these soils, either the pavement was known to have been placed on a relatively dry compact subgrade, or the existing moisture content (high subgrade moisture content under joints and open cracks and relatively low subgrade moisture contents under the remainder of the slab) indicated that the subgrade was relatively dry at the time of paving It is significant that a similar trend is shown by the results of swell tests on similar soils; that is, for a given density the amount of swell decreases with increase in moisture content.

Although no severe pavement warping has been associated with very sandy loams or clay bound sands, tests were conducted on the latter type (laboratory number 25947, Figure 13) primarily because it had been used as selective borrow to cover clay subgrades prior to paving in an effort to minimize pavement warping Although the grain size accumulation curve indicates only a small fraction of clay, the plasticity index of 18 indicates a binder consisting of a gluey colloidal nature This fact, undoubtedly, accounts for the relatively large swell obtained from so sandy a soil

Upon analysis of the test constants of the different soils it should be noted that those which resulted in relatively high volume change were plastic soils of the so-called expansive groups of subgrade soils

A study of the final moisture contents, after completion of swell, shows that for each soil tested the highest final water content occurred on the specimens which had the lowest initial moisture content and, thus, had the greatest percentage of air voids prior to being allowed to absorb water.

The results show conclusively that no single condition of moisture content and density exists at which the soil is permanent; that is, at which no volume change occurs. They do show, however, that for a single soil a condition of moisture content and state of compaction exists at which the soil offers the greatest resistance to volume change upon being allowed to absorb water.

PART II. FIELD TESTS

Introduction:

The swell tests, described in Part I, on specimens compacted in the Proctor mold were conducted on soils which had been given sufficient "breaking down" to destroy all semblance of structure. The soil in "cut" sections of roadway is not disturbed to great depths during construction. For this reason it was decided to conduct some swell tests on undisturbed soil to determine the relative difference in swell of soil in the structured state as compared to that in the manipulated state.

These tests are in two parts:

(1) Field tests on undisturbed columns of soil in place in the soil profile; and

(2) Field laboratory tests on undisturbed samples of soil carefully removed so as not to disturb the natural soil structure.

Two sites were chosen for study, both of which were located at the top of the back-slope within the right-of-way adjacent to warped sections of pavement. One of the locations (east location Sta. 439 + 36, Project 301 H, Figure 14) was adjacent to a section of pavement on which experiments had been carried on to straighten warped slabs by inducing soil swell under the central part of the slab by injecting water into the subgrade. The second location was adjacent to a section of pavement where the warping was of a severe nature.

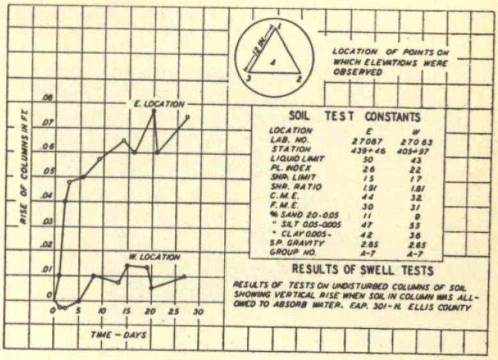

Figure 14

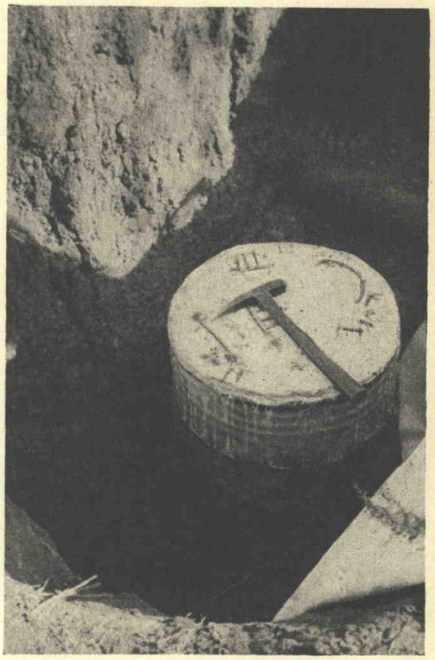

Figure 15. View showing pit after soil had been excavated leaving the undisturbed column of soil. The 7″ x 18″ diameter concrete top was grouted in place before excavation was begun.

Procedure:

Part 1. Test on Soil Column.

A pit approximately five feet square was dug so that its bottom was at the same elevation as the bottom of the pavement. The bottom of the pit was cut to a smooth level surface. A premoulded concrete cylinder 7 in. high and

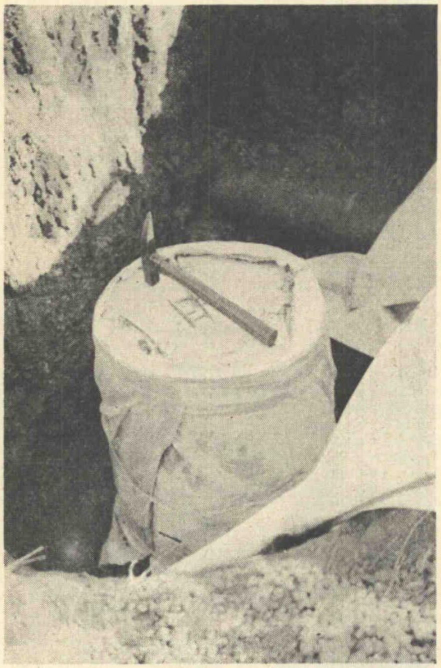

Figure 16. The entire soil column and concrete cap was wrapped with cloth to prevent the soil from slaking and flowing into the voids of the sand with which the pit was backfilled.

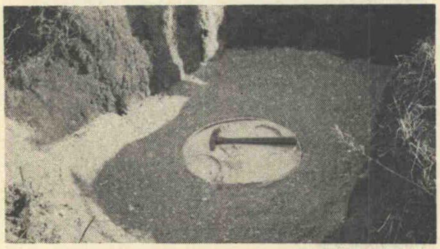

Figure 17. View showing pit filled with sand. Note the four (4) pins on which elevations were observed as the test progressed.

18 in. in diameter was grouted in place on the floor of the pit. The excavation was continued around the concrete cap and the soil removed in such a manner that a column of soil 18 in. in diameter and 18 in. high remained (Figure 15). The soil column was then wrapped with cloth to prevent slaking and flowing of the soil into the voids of the sand with which the pit was backfilled (Figures 16 and 17). Water was then added to the sand backfill twice daily for three weeks. Elevations were observed at four points on the concrete cap as the test progressed.

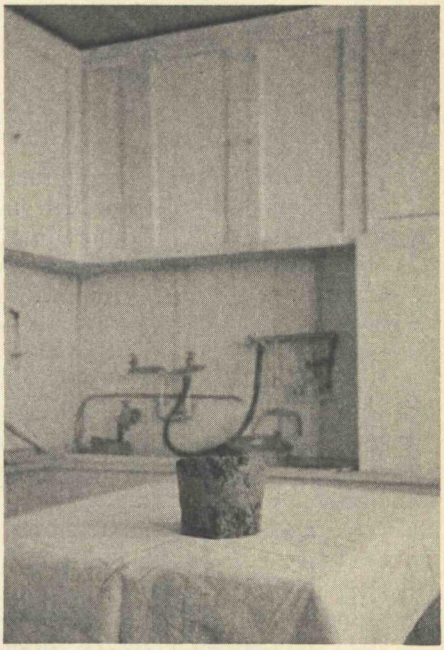

Figure 18. View showing undisturbed sample of soil taken from pit after it had been cut down preparatory to coating with liquid rubber.

Part 2. Tests on Undisturbed Samples of Soil.

The material from around the soil column was removed with the utmost care. Small picks and scutches were used to cut around chunks of soil in such a manner that the chunks were removed without injuring the soil structure. The chunks were rushed into the field laboratory (located at the end of the project) where they were carefully shaped as nearly as possible into cylindrical pieces (Figure 18) The specimens were then weighed and painted with liquid rubber Pieces of blotting-paper were placed on the top and bottom of the cylinder to allow entrance of water during the absorption period

After the sample was completely covered the total weight was recorded (soil, rubber, and paper) The specimens were then placed in the overflow volumeter and their volumes measured and recorded as original volume It was found that a thin spray of rubber paint over the blotting-paper at the ends sealed out the water during the first volume determination (This thin film was removed prior to swell) The specimens were placed in a tank of water, each specimen being about one-half submerged Volumes of four specimens were observed at close intervals of time over a period of 120 hours The final volumes of the remaining specimens were observed after complete softening had taken place

TABLE 1

RESULTS OF SWELL TESTS ON SAMPLES OF UNDISTURBED SOIL

Sample	Final			Initial Density	Initial Moisture	Final Density	Final Moisture
	Volume	Hours	Vol Increase				
			%				
1	777	39 5	31 7	1 64	14 0	1 24	37 6
2	3118	20 5	40 0	1 66	15 8	1 19	39 3
3	3411	41 0	44 9	1 71	16 9	1 18	42 9
4	3418	16 5	52 7	1 69	15 2	1 11	43 9
5	3779	20 0	53 6	1 66	17 4	1 08	47 7
6	1896	40 5	45 7	1 68	17 2	1 16	42 7
7	4256	67 0	42 9	1 66	16 2	1 16	30 6
8	909	24 5	36 9	1 64	12 3	1 20	41 3
9	697	25 0	34 9	1 69	8 3	1 26	34 8
10	487	66 5	26 8	1 56	13 2	1 23	38 0
11	378	25 0	29 5	1 57	11 4	1 21	37 9
12	1552	24 5	36 7	1 59	15 7	1 16	41 0
13	1439	39 0	29 7	1 44	12 5	1 11	46 8
14	375	66 5	20 2	1 45	17 3	1 20	35 5
15	4537	100 0	22 1	1 43	17 5	1 18	43 3
16	377	67 0	15 6	1 34	12 8	1 16	43 3
17	316	67 0	18 8	1 37	11 8	1 16	42 7
18	622	40 0	21 5	1 41	10 3	1 16	42 7

Samples 1 to 13—from Sta 439 + 46
Samples 14 to 18—from Sta 405 + 97

Discussion of Results

The test results shown on Figure 14 (E location) are from a test column of A-7 soil which was of a fine, cloddy to a coarse, granular structure The soil in the other column (W location) was also of the A-7 group but was more nearly of a massive or single-grained structure showing no well-defined lines of cleavage between soil aggregates as did the soil from the E location It may be seen that both soils had reasonably high plasticity indices Thus, their constants indicated both soils were of an expansive nature, yet the column of highly structured soil resulted in a considerably greater movement upon absorption of water than did the other

The results of the tests on undisturbed chunks, tested in the laboratory, showed a similar trend, the highly structured soil resulting in a greater swell (Table 1) The highly structured soil, however, had the greater initial density

These findings are significant in that

TABLE 2

SAMPLE DATA SHEET

Volume Increase of Soil Compacted at Pressure of 1000 lb per sq in

Mold No	Orig Moist Content: Wt Wet Soil	Orig Moist Content: Wt Dry Soil	Orig Moist Content: Per cent Moist	Wt Wet Soil Used	Wt Dry Soil Used	Depth Soil in Mold	Orig vol cc	Orig Density	Re-bound (in)	Orig Micr Reading	4 hours: Reading	4 hours: Swell (in)	4 hours: % Vol Incr	8 hours: Reading	8 hours: Swell (in)	8 hours: % Vol Incr	12 hours: Reading	12 hours: Swell (in)	12 hours: % Vol Incr	16 hours: Reading	16 hours: Swell (in)	16 hours: % Vol Incr
2	100	90 8	10 1	840	763	2 009	414	1 84	0 02	418	433	015	0 75	465	047	2 34	477	059	2 94	494	076	3 78
11	100	90 8	10 1	840	763	1 997	411	1 85	0 02	374	390	016	0 80	421	047	2 35	434	060	3 00	452	078	3 91
19	100	90 8	10 1	840	763	1 999	412	1 85	0 02	365	378	013	0 65	409	044	2 20	423	058	2 90	443	078	3 90
Ave								1 85					0 73			2 30			2 95			3 86

Mold No	20 hours: Reading	20 hours: Swell (in)	20 hours: % Vol Incr	24 hours: Reading	24 hours: Swell (in)	24 hours: % Vol Incr	27 hours: Reading	27 hours: Swell (in)	27 hours: % Vol Incr	2 hours: Reading	2 hours: Swell (in)	2 hours: % Vol Incr	36 hours: Reading	36 hours: Swell (in)	36 hours: % Vol Incr	40 hours: Reading	40 hours: Swell (in)	40 hours: % Vol Incr	47½ hours: Reading	47½ hours: Swell (in)	47½ hours: % Vol Incr
2	501	083	4 13	507	089	4 42	511	093	4 63	514	096	4 78	518	100	4 98	522	104	5 18	524	106	5 28
11	459	085	4 26	463	089	4 46	466	092	4 61	470	096	4 81	473	099	4 96	475	101	5 06	479	105	5 26
19	451	086	4 30	457	092	4 60	462	097	4 85	465	100	5 00	469	104	5 20	472	107	5 35	475	110	5 50
Ave			4 23			4 49			4 70			4 86			5 05			5 20			5 35

Mold No	52½ hours: Reading	52½ hours: Swell (in)	52½ hours: % Vol Incr	64 hours: Reading	64 hours: Swell (in)	64 hours: % Vol Incr	88 hours: Reading	88 hours: Swell (in)	88 hours: % Vol Incr	112 hours: Reading	112 hours: Swell (in)	112 hours: % Vol Incr	136 hours: Reading	136 hours: Swell (in)	136 hours: % Vol Incr	160 hours: Reading	160 hours: Swell (in)	160 hours: % Vol Incr	184 hour: Reading	184 hour: Swell (in)	184 hour: % Vol Incr
2	528	110	5 48	531	113	5 63	532	114	5 68	535	117	5 82	538	120	5 97	540	122	6 07	540	122	6 07
11	481	107	5 36	485	111	5 56	490	116	5 81	492	118	5 91	492	118	5 91	494	120	6 01	494	120	6 01
19	478	113	5 65	482	117	5 85	486	121	6 00	488	123	6 15	490	125	6 25	490	125	6 25	492	127	6 35
Ave			5 50			5 68			5 83			5 63			6 04			6 11			6 14

Mold No	232 hours: Reading	232 hours: Swell (in)	232 hours: % Vol Incr	Final Volume	Final Density	Pushout Pressure (total)	Final Moist Content: Weight W Soil	Final Moist Content: Weight D Soil	Final Moist Content: Per cent Moisture
2	540	122	6 07	439	1 74	840	899	765	17 5
11	495	121	6 06	436	1 75	780	790	675	17 0
19	491	126	6 30	438	1 74	780	884	655	17 1
Ave			6 14		1 74				

they show that the test constants of a soil do not entirely distinguish that soil in terms of the action which might be expected from it in its natural undisturbed structured state

SUMMARY AND CONCLUSIONS

Parts I and II

The results of the tests indicate that·

1 The amount of swell obtained by test on an expansive soil is dependent upon the limitations of the test itself

2 The amount of swell of an expansive soil is dependent to a large extent upon the initial moisture content and state of compaction

3 The swelling of soils tested under comparable conditions varies as do the characteristics of the different soils as shown by their test constants, provided the swell tests are made on soil which has been broken down and remolded

4 The swelling of soil in place in the soil profile is dependent to some extent upon its structural arrangement (or lack of arrangement) into soil aggregates