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R-VALUE
TEST MODIFICATION

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Final Report
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Prepared in cooperation with the
U. S. Department of Transportation
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George Pavlick, Head Soils Technician, directly supervised and conducted the field sampling and laboratory testing. He also assisted in interpretation of test results for input into final report.

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16. Abstract

The purpose of this research study is to determine the feasibility of modifying the Standard R-Value test. Moisture content of subgrade material sampled under existing pavements was compared to the moisture content of same material at 300 p.s.i. exudation pressure. Although the average moisture values at 300 p.s.i. exudation were higher, there were enough individual exceptions which would preclude changing the Standard R-Value test. A modified test, based on uniform compactive effort at three different moisture contents, was developed to afford flexibility for particular environmental conditions. Soil suction test results on potentially swelling soils were encouraging, but further research is needed to establish a standard method.

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Introduction

This research project is an examination of R-value test moisture and evaluation of the swell potential of soils.

The R-value is "a numerical value expressing the measure of a soil or aggregate's ability to resist the transmission of vertical load in a lateral or horizontal direction.(3) It is a measure of the capacity of the subgrade soil to provide support to the overlying pavement structure. R-value of the subgrade soil and other factors, such as traffic, climate, and drainage, are used to determine the strength or thickness of the pavement structure. In cases where the design is determined by the weight of the pavement layers required to confine the expansive forces which develop in the soil, the R-value is a laboratory measure of these expansive forces. Colorado's current R-value test procedure very seldom results in an R-value determined by expansive forces.

The R-value of a soil sample is determined briefly as follows: Three specimens are compacted from a mixture of the soil and water. The pressure at which water exudes from the specimens is determined (exudation pressure). The specimens are then placed on expansion pressure devices, covered with water, and the expansion pressure developed overnight is determined. Each specimen is then placed in a Stabilometer and an R-value is determined. These R-values are plotted against exudation pressure and the R-value at 300 psi is taken from this plot. Expansion pressure is also used to calculate an R-value. The R-value used for design is the lower of the two R-values (300 psi or expansion pressure). A more complete and more detailed description of the R-value test, plus a description of the variations of this test pertinent to this report are included in the definitions and in Appendix D. Even more detail can be found in ASTM D 2844(1) or AASHTO T-190(2).

In flexible pavement design, the R-value is used to enter the design nomograph (3, 4) from the soil support scale on the left (See Figure 1). A straight line is drawn through the 18 k EDLA (a weighted average of projected traffic) to the structural number (SN) scale. This number expresses the relationship between the thickness of the component layer in a pavement structure and the type of material used in constructing the layer. From this point a straight line is drawn through the regional factor (based on local environment and drainage,) to the weighted structural number line to obtain the weighted structural number (WSN). This number determines the thicknesses of the layers in the pavement structure as follows:

$$WSN = a_1D_1 + a_2D_2 + a_3D_3$$

where

a_1, a_2, a_3 = strength coefficients of the pavement layers
D_1 = thickness of bituminous surface course (inches)
D_2 = thickness of base course (inches)
D_3 = thickness of subbase (inches)

A more comprehensive treatment of the use of R-value in pavement thickness design can be found in the CDOH Roadway Design Manual.(3) R-value is also used in rigid pavement (Concrete) design.

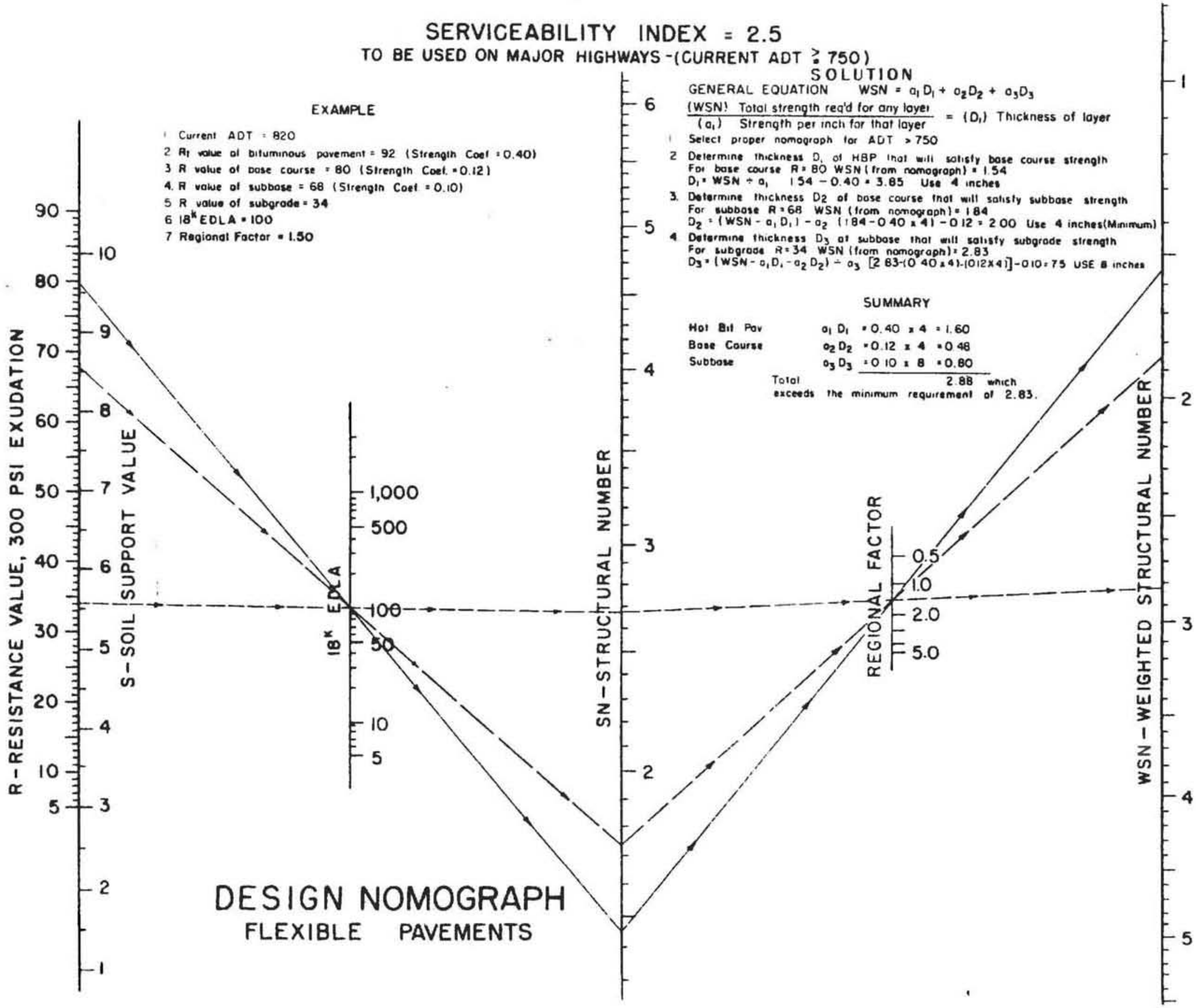
Third Cycle

The "Third Cycle" expansion pressure test is conducted to determine if certain material will expand (with increased moisture content) when remolded and compacted as roadway embankment. (See Definitions or Appendix B.) If expansive material is placed in the upper 4 feet of subgrade embankment, distortion of pavement may occur.(8)

The test requires the soil specimen be remolded and compacted to T-99 maximum dry density and optimum moisture. The proper amount of soil and water is calculated to obtain the desired density and moisture for a specimen 4 inches in diameter and 2.5 inches high. The required amounts of soil and water are then thoroughly mixed and allowed to stand overnight before being placed into the mold. Vertical pressure is then applied (at the rate of 0.05 inch per minute) until specimen height is 2.5 inches. After the specimen has been properly remolded, it is placed in an expansive pressure device and 200 ml of water is applied and allowed to stand for 16 to 24 hours. Then, any expansion pressure that has developed is relieved and the deflection gauge is set to zero. This procedure is repeated twice more and the deflection dial is read at the end of the third cycle.

Deflection dial readings are applied to a conversion chart in order to obtain pressure in terms of pounds per square inch. The final step in this test procedure is to indicate what pressure value is allowed at various depths. Research, done by the California Division of Highways

Figure 1



SERVICEABILITY INDEX = 2.5

TO BE USED ON MAJOR HIGHWAYS -(CURRENT ADT $\geq$ 750)

EXAMPLE

1 Current ADT = 820
2 R_t value of bituminous pavement = 92 (Strength Coef = 0.40)
3 R value of base course = 80 (Strength Coef. = 0.12)
4. R value of subbase = 68 (Strength Coef = 0.10)
5 R value of subgrade = 34
6 18^k EDLA = 100
7 Regional Factor = 1.50

SOLUTION

GENERAL EQUATION $WSN = a_1 D_1 + a_2 D_2 + a_3 D_3$

$$\frac{(WSN)\ \text{Total strength req'd for any layer}}{(a_1)\ \text{Strength per inch for that layer}} = (D_1)\ \text{Thickness of layer}$$

1 Select proper nomograph for ADT > 750
2 Determine thickness D_1 of HBP that will satisfy base course strength
For base course R = 80 WSN (from nomograph) = 1.54
$D_1 = WSN \div a_1$ 1.54 − 0.40 = 3.85 Use 4 inches
3. Determine thickness D_2 of base course that will satisfy subbase strength
For subbase R = 68 WSN (from nomograph) = 1.84
$D_2 = (WSN - a_1 D_1) - a_2$ (1.84 − 0.40 x 4) − 0.12 = 2.00 Use 4 inches(Minimum)
4 Determine thickness D_3 of subbase that will satisfy subgrade strength
For subgrade R = 34 WSN (from nomograph) = 2.83
$D_3 = (WSN - a_1 D_1 - a_2 D_2) \div a_3$ [2.83-(0.40 x 4)-(0.12X4)]-0.10 = 7.5 USE 8 inches

SUMMARY

Hot Bit Pav	$a_1 D_1$	= 0.40 x 4 = 1.60
Base Course	$a_2 D_2$	= 0.12 x 4 = 0.48
Subbase	$a_3 D_3$	= 0.10 x 8 = 0.80
Total		2.88 which

exceeds the minimum requirement of 2.83.

DESIGN NOMOGRAPH

FLEXIBLE PAVEMENTS

(1967), has indicated what pressure values are allowable at depths from 12 to 48 inches below profile grade. This correlation between subgrade depth and "third cycle" pressure (p.s.i.) is used to make recommendations for the treatment of roadway embankment.

The "third cycle" expansion pressure test is the only standard procedure used for evaluation of swelling soils by the Colorado Division of Highways, at the present time. This test has certain limitations because soil samples must be remolded in order to perform the test. The test may be valid for embankments and gives a quantitative indication of swell potential for such material. However, it is doubtful that the "third cycle" test should be used to assign quantitative values to undisturbed soil or rock in cut sections. There is even some doubt that qualitative determinations are accurate when applied to undisturbed soils or bedrock.

Previous R-Value Research In Colorado

When Colorado began using R-value and the AASHTO flexible pavement design method(4), the Washington R-value Scale(5,6) was selected to correlate with the AASHTO Soil Support Scale on the Design Nomograph. No complete correlation between the R-value and subgrade performance had been established. The AASHTO Road Test correlated one subgrade soil type with performance and it was realized that additional correlation would be required. There is a great need for R-value correlation with field performance, (i.e. field strength), especially for silt, sandy silt, and clayey silt soils, but not excluding other soil types (granular and clayey soils).

To examine the scaling of R-value on the Design Nomograph, a research project titled "Correlation of Subgrade Modulus and Stabilometer R-Values"(7) was initiated in 1974. The final report on this research was printed in November of 1978. The main thrust of this research was as follows:

The relationship between the resilient modulus of subgrade soil and Soil Support is known. Resilient moduli of in-place embankment soils were determined by computer analysis of Dynaflect data taken on embankments. These moduli were correlated with the R-values of soil from the corresponding embankments. Since the relationship between modulus and soil support is known, the above correlation provided a comparison of R-value and soil support. The results of the correlation indicated that scaling of R-value on the Design Nomograph is correct.

However, in the course of this previous soils research, questions were raised concerning the moisture and density of R-value test specimens.

The moisture and density can have a profound effect on the strength of soil. Therefore, the R-value test specimen at 300 psi exudation pressure should be similar to the expected moisture and density of the subgrade soil several years after construction of the highway. The following evidence indicates that in many cases the moisture of a test specimen compacted for exudation at 300 psi using the present R-value test procedure is much higher than that found under existing Colorado highways under normal conditions.

The present R-value method results in essentially no designs based on expansion pressure. This is due to the high moisture content of the specimens required for exudation. These specimens are too moist to absorb enough water while in the expansion pressure device to expand substantially.

Currently, overlay thicknesses in Colorado are determined by one of two analytical approaches. Design by component analysis is based on strengths of existing pavement components and the R-value of the subgrade. Design by deflection analysis is based on deflection measurement using a Dynaflect or a Benkelman Beam which provide an indication of the strength of the pavement-subgrade combination. Both component and deflection analyses consider expected traffic. For several projects where both analyses were applied, component analysis required a substantially thicker overlay. It is thought that this was because the R-value test specimens contained considerably more moisture than the subgrade soil under the road.

A general approach to solve excessive specimen moisture would be to replace the exudation pressure and expansion pressure portions of the R-value, which are very empirical in nature. For example, the specimens could be compacted at a density related to T-99 maximum dry density and a moisture related to optimum moisture or saturation moisture. These specimens would be tested in the stabilometer to determine an R-value. These specimens should be compacted to simulate subgrade conditions expected under a typical road after a few years. Adjustments for atypical conditions would be made in the regional factor. This factor corrects for precipitation, elevation, surface drainage, subgrade saturation, groundwater level, irrigation, and frost action. If the exudation pressure and expansion portion of the R-value test are deleted, some other method of identifying and evaluating soils must be adopted.

This research was initiated to answer the following questions:

1. What is the moisture and density of the subgrade soil under Colorado highways five to ten years after construction?
2. How do the above moistures and densities compare to the 300 psi moistures and densities of R-value test specimens?
3. Can soil suction replace current CDOH methods of evaluating swelling soils?

Soil Suction

A methodology for using soil suction testing for evaluation of potentially swelling soils was developed by Larry Johnson and Don Snethan at the Waterway Experimental Station at Vicksburg, Mississippi.(9) Soil suction is a measure of the pulling force exerted on water by a soil. To determine suction, an undisturbed chunk of soil is sealed in a one-pint can containing a psychrometer. A psychrometer is a device which uses thermocouples to measure relative humidity in the following manner: One thermocouple is cooled by applying a direct current (Peltier cooling). When the thermocouple reaches the dew point termperature at the ambient relative humidity, condensation inhibits further cooling. The temperature of the cooled thermocouple is determined by reference to another thermocouple in the psychrometer. Relative humidity can be calculated from the temperature of the cooled thermocouple, since that temperature is the dewpoint.

Air in a sealed container holding distilled water or an over-saturated soil sample will go to 100% relative humidity at equilibrium. If the container holds a soil sample with appreciable soil suction, the relative humidity will be depressed below 100%, an amount directly related to the soil suction of the sample. Thus, the suction of a soil sample can be determined using a sealed container, a psychrometer and electronic equipment required to operate and read out the psychrometers. The air-tight cans containing the soil samples and psychrometers must be placed in an insulated box and allowed to come to temperature equilibrium for the thermocouples to operate accurately. Once the suction of a soil is known for a range of moisture contents, the amount of heave can be calculated. This calculation requires other soils information which includes void ratio, specific gravity, compressibility, initial moisture content, and assumed final moisture content. The assumed final moisture content is the most critical and most uncertain part of the calculation.

Preliminary Engineering

This research project consisted of a field phase and a laboratory phase. The first step of the work plan was to select field sites to be used for sample collection. A total of 21 field sites (see Table 1 and Figure 2) were chosen by examining soil surveys of projects which were completed at least five years prior to the start of this research project. The criteria used for the site selection was that sites must consist of uniform embankment material and that several different soil classes be represented by the different sites.

Twenty of the sites chosen contained embankment material which was sufficiently uniform in nature to be used. Unfortunately, the distribution of environmental conditions, represented by the sites, were not as varied as had been hoped for. All but six of the sites were located east of the Front Range and none of the sites were located above 6500 ft. elevation. Overall, the sites chosen provided suitable conditions for the research project. Soils obtained from the sites included A-1-b, A-2-4, A-2-6, A-4, A-6, and A-7-6 classifications with A-6 and A-7-6 being predominate. Table 1 shows site location and soil types.

A resilient modulus tester, used for a previous research project,* was to be used for the present research. As noted on page 67 of Appendix D (CDH-DTP-R-78-10), excessive and variable deformation in the frame and loading system was a problem with this apparatus. Also, it was noted that this problem could be eliminated by mounting Linear Voltage Differential Transducers (LVDTs) on the loading heads, which would require a larger chamber.

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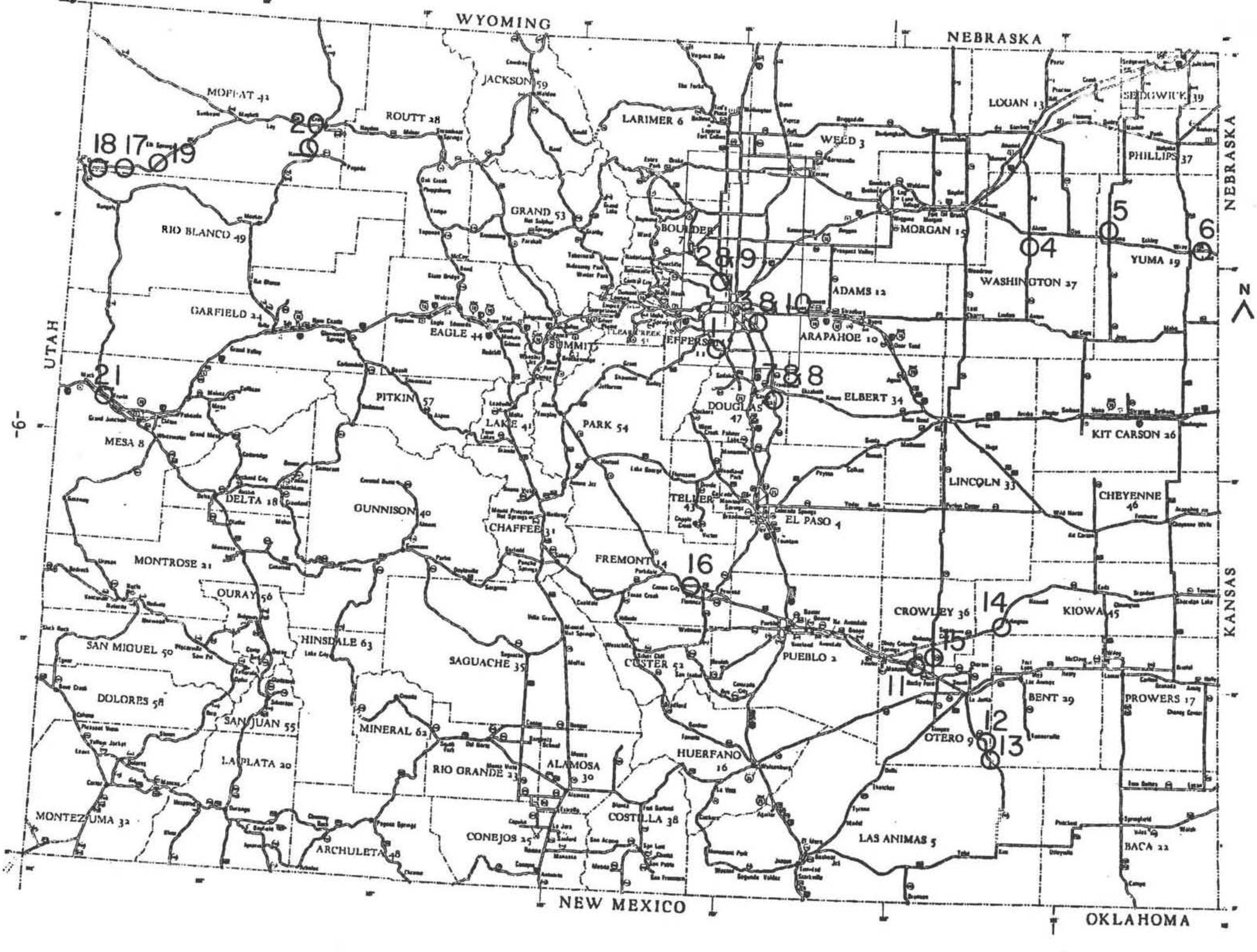
* Report No. CDH-DTP-R-78-10, Appendix D.

TABLE 1

TEST SITE LOCATIONS

Site Number	Location	Soil Classification	Comments
1	Wadsworth near Chatfield Dam	A-6, A-7-6	
2	Wadsworth bypass at 104th Avenue	A-6	
3	I225 Frontage Road North of Iliff	A-6	
4	Akron South	A-2-6	
5	Yuma North	A-4	
6	East of Wray	-----	Non-uniform soils- no tests
7	South of Franktown	A-2-4, A-1-b	
8	South of Franktown	A-7-6	
9	Wadsworth bypass and Airport Road	A-7-6	
10	I225 Frontage Road North of Iliff	A-2-4	
11	Manzanola East and West	A-7-6	Very poor drainage
12	Purgatory River South	A-6, A-7-6	
13	Purgatory River South	A-7-6	
14	Arlington West	A-6, A-7-6	
15	South of Ordway	A-7-6	
16	Canon City East	A-7-6	
17	Massadona West	A-4	
18	West of Elk Springs	A-6	
19	West of Elk Springs	A-7-6	
20	North of Hamilton	A-2-4	
21	South of Loma	A-6	


WYOMING
NEBRASKA
NEBRASKA
KANSAS
OKLAHOMA
NEW MEXICO
UTAH
N
MOFFAT 41
ROUTT 28
JACKSON 59
LARIMER 6
WELD 3
LOGAN 13
SEDGWICK 39
PHILLIPS 37
RIO BLANCO 49
GRAND 53
BOULDER 7
MORGAN 15
WASHINGTON 27
YUMA 19
ADAMS 12
ARAPAHOE 10
GARFIELD 24
EAGLE 44
SUMMIT 61
CLEAR CREEK 51
JEFFERSON 11
DOUGLAS 47
ELBERT 34
KIT CARSON 26
MESA 8
PITKIN 57
LAKE 41
PARK 54
LINCOLN 33
CHEYENNE 46
DELTA 18
GUNNISON 40
CHAFFEE 31
TELLER 43
EL PASO 4
MONTROSE 21
FREMONT 14
CROWLEY 36
KIOWA 45
OURAY 56
HINSDALE 63
SAN MIGUEL 50
SAGUACHE 35
CUSTER 52
PUEBLO 2
DOLORES 58
SAN JUAN 55
MINERAL 62
OTERO 9
BENT 29
PROWERS 17
LA PLATA 20
RIO GRANDE 23
ALAMOSA 30
HUERFANO 16
MONTEZUMA 32
COSTILLA 38
CONEJOS 25
ARCHULETA 48
LAS ANIMAS 5
BACA 22
18
17
19
20
5
6
4
2
9
3
8
10
1
7
8
21
16
14
15
11
12
13

The above mentioned modifications were made on this resilient modulus tester. However, we were unable to combine the Linear Variable Differential Transformers output and calibrate them properly. As a result, we could not record accurate deformation measurements of the specimens. Because of this, we decided to abandon this portion of the research project for the present.

Equipment to measure soil suction was purchased. This equipment was used to identify and measure the swell potential of subgrade soil samples. The basic components of this equipment are: a polystyrene thermal box, sample containers (one pint metal cans), microvoltmeter, thermocouple psychrometers, rubber stoppers (to seal metal cans), electrical supplies, calibration standards (minimum of three WESCOR osmolality standards - 290, 1000, and 1800 MOs/kg) and a Class D Balance (AASHTO M 231). The microvoltmeter had been modified to include a reference thermocouple and to supply a cooling current.

Field Sampling

Field samples were obtained with an auger type drill rig. Five test holes, spaced about 100 feet apart, were drilled through the pavement at each of the 21 sites. One undisturbed sample of subgrade material was taken with a shelby tube directly below the subbase and one sack of disturbed material was taken in the upper five feet of subgrade.

The shelby tube samples were sealed at the ends with wax so that the moisture of the undisturbed sample would be preserved. Density and soil suction tests were also conducted on the undisturbed material. The sack sample material was collected for soil classification, compaction and R-value determinations.

Laboratory Testing

Sieve analysis and Atterberg limit tests were conducted on all sack samples for soil classification. Compaction tests were run on a representative sample from each site to determine maximum dry density and optimum moisture.

In-place moisture and density, as well as specific gravity and degree of saturation, were determined for soil samples from each test hole.

Stabilometer tests were run on soil from each drill hole to determine R-Values and moisture content at 300 p.s.i. exudation pressure.

Soil samples, with high P.I. Values, from seven test sites, were chosen for soil suction testing. These tests were performed according to procedures outlined by the Waterways Experimental Station.(9) Although the soil samples selected for these tests were the most likely (of the research samples taken) to indicate swell potential, the test results were inconclusive. Because of this, additional samples were obtained from three other sites where undisturbed claystone of high swell potential was located. Results of all the tests will be discussed later in this report.

Testing Procedures

1. Classification - All disturbed soil samples were first dry prepared by Colorado Procedure 20-72(10). Then a Mechanical Analysis was conducted using Colorado Procedure 21-72.(10) The Atterberg Limits were determined by AASHTO T 89 and AASHTO T 90. Results of these tests were used to identify all soil samples by the AASHTO designations.
2. Compaction - One compaction test (AASHTO T 99) was run on a representative soil sample, from each site, to determine maximum dry density and optimum moisture.
3. R-Value - R-Value and moisture content at 300 p.s.i. exudation pressure was determined for soil samples, from each drill hole, according to AASHTO T 190-78.

   A modified procedure was used to obtain R-Values for A-6 and A-7-6 soils representing subgrade soils from 14 different sites. This procedure was based on uniform compactive efforts on three specimens with moisture contents at optimum, optimum +2, and optimum +4. A curve constructed from the three R-Values obtained in this manner allowed R-Values to be chosen at various moistures relative to optimum.
4. In-Place Moisture - Moisture content determinations were made on soil samples from the shelby tube specimens.
5. In-Place Dry Density - Dry density determinations were made from the same shelby specimens, using AASHTO T 233-70.(2)

6. Specific Gravity - Specific Gravity was determined for soil from each test hole by the AASHTO T-100 method.(2)
7. Degree of Saturation - Percent of saturation was calculated from results of moisture content, dry density, and specific gravity determinations.
8. Soil Suction - Tests were conducted using the equipment, calibration and test procedure, data reduction and interpretation as described in Appendix A of Report No. FHWA-RD-77-51 (Technical Guidelines for Expansive Soils in Highway Subgrades - June, 1979.)

I. Discussion of Test Results

Moisture and density values are the major factors involved in determining R-values. Tests were conducted on an A-6(6) soil, from a location other than the research sites, to show the relative importance of moisture versus density. Results of these tests are illustrated in Figures 3 and 4. When the tests were run at 90, 95, and 100% of maximum dry density (AASHTO T-99) and at optimum moisture, the difference in R-value was only 6. However, when the moisture was varied 7%, the difference in R-value was 62. These test results strongly indicate that moisture, not density, is the critical factor affecting R-values.

300 P.S.I. Exudation Moisture Versus In-Situ Moisture

As noted in the Introduction, the Standard R-value is determined by plotting R-values at various exudation pressures and using the R-value at 300 p.s.i. exudation pressure (See Figure 5.) The exudation pressure varies with moisture content, and in turn, so does the R-value. It is important that the 300 p.s.i. exudation moisture approximates the in-situ moisture. If the 300 p.s.i. exudation moisture is higher than the in-situ moisture, then the R-value is low and conservative. A graph, showing the average moisture for each site containing A-7-6 soils, is shown in Figure 6. The graph compares 300 p.s.i. exudation moisture and in-situ moisture values. The graph also shows that the average 300 p.s.i. exudation moisture is 2.7% higher than the average in-situ moisture.

Although the average 300 p.s.i. exudation moisture is higher than the average in-situ moisture for the A-7-6's, it is important to note that there is a wide variation and overlap. The fact that the 300 p.s.i. exudation moisture values are not consistently higher than the in-situ moisture values, leaves some doubt that the present R-value test method (AASHTO-190) is too conservative.

Figure 7 shows the average moisture for each site containing A-6 soils. This graph indicates less difference between the average 300 p.s.i. exudation moisture and the average in-situ moisture for these A-6 sites than for the A-7-6 sites. The average 300 p.s.i. exudation moisture is only 1.0% higher than the average in-situ moisture.

There is some variation and overlap between the 300 p.s.i. exudation moistures and the in-situ moistures for the A-6 soils. However, three out of seven sites have 300 p.s.i. exudation moistures and in-situ moistures that are nearly equal. The moisture values for A-6 soils correlate very well and tend to verify the 300 p.s.i. exudation pressure method for determining R-values. For soil classifications other than A-7-6 and A-6, there were not enough sites to support any conclusions.

300 P.S.I. Exudation Density Vs. In-Situ Density

A variation of dry density values has less effect on R-values than does a variation of moisture values, as previously explained.

Figure 8 shows the average dry density values for A-7-6 soils. The average in-situ dry density for A-7-6 soils is 2.8 lbs. per cu. ft. higher than the average 300 p.s.i. exudation dry density. There is more variation in the in-situ dry densities than the 300 p.s.i. dry densities. Overall, the difference in dry densities for these soils does not seem great enough to alter the strength characteristics significantly.

Dry density values at in-situ conditions vary less for the A-6 soils than for the A-7-6 soils, as indicated in Figures 8 and 9. The average 300 p.s.i. exudation dry density is 2.2 lbs. per cu. ft. higher for all A-6 sites. The differences between 300 p.s.i. exudation and in-situ dry densities are minor and insignificant.

Alternate R-Value Methods

R-values could be obtained by several methods, other than the Standard AASHTO T-190 with 300 p.s.i. exudation pressure. A discussion of several methods used or attempted to be used for this research project follows:

(1) One Pointers - This test is conducted on a soil at a chosen moisture and density, related to optimum moisture and maximum density (AASHTO T-99).

Several problems are inherent with this test method. The compactive effort must be varied to obtain desired density and this results in a non-uniform soil specimen. The one-point method also fails to give any indication of the moisture sensitivity of the soil, since R-value is determined at only one moisture.

(2) Three Pointers - A three point test method, using the same compaction procedure as the standard T-190, but using three specific moistures, such as T-99 optimum, optimum +2% and optimum +4% can be used to select an R-value at different moisture contents. R-values obtained in this manner are usually higher than the standard R-value at the same moisture, as shown by the example in Figure 10. This is probably due to the exclusion of the exudation procedure.

A disadvantage of the three point test method (related to optimum moisture) is that compaction of the soil by the Proctor method must precede this test procedure. The time delay in obtaining required R-values by this method could present problems with project schedules.

(3) Other Alternatives - Modifications of the previously mentioned R-value test methods could be used. The three point method (related to optimum moisture) plus exudation is an example. This would conform more closely to the standard T-190 method. The standard 300 p.s.i. exudation pressure method could be used with the exudation pressure points plotted in terms of moisture content. From this plot, R-values could be determined at moisture values related to T-99 values. These modified procedures would allow greater flexibility in determining R-values for special environmental or construction conditions.

Figure 3. R-VALUE VS. DENSITY OF A-6(6) SOIL AT OPT. MOISTURE

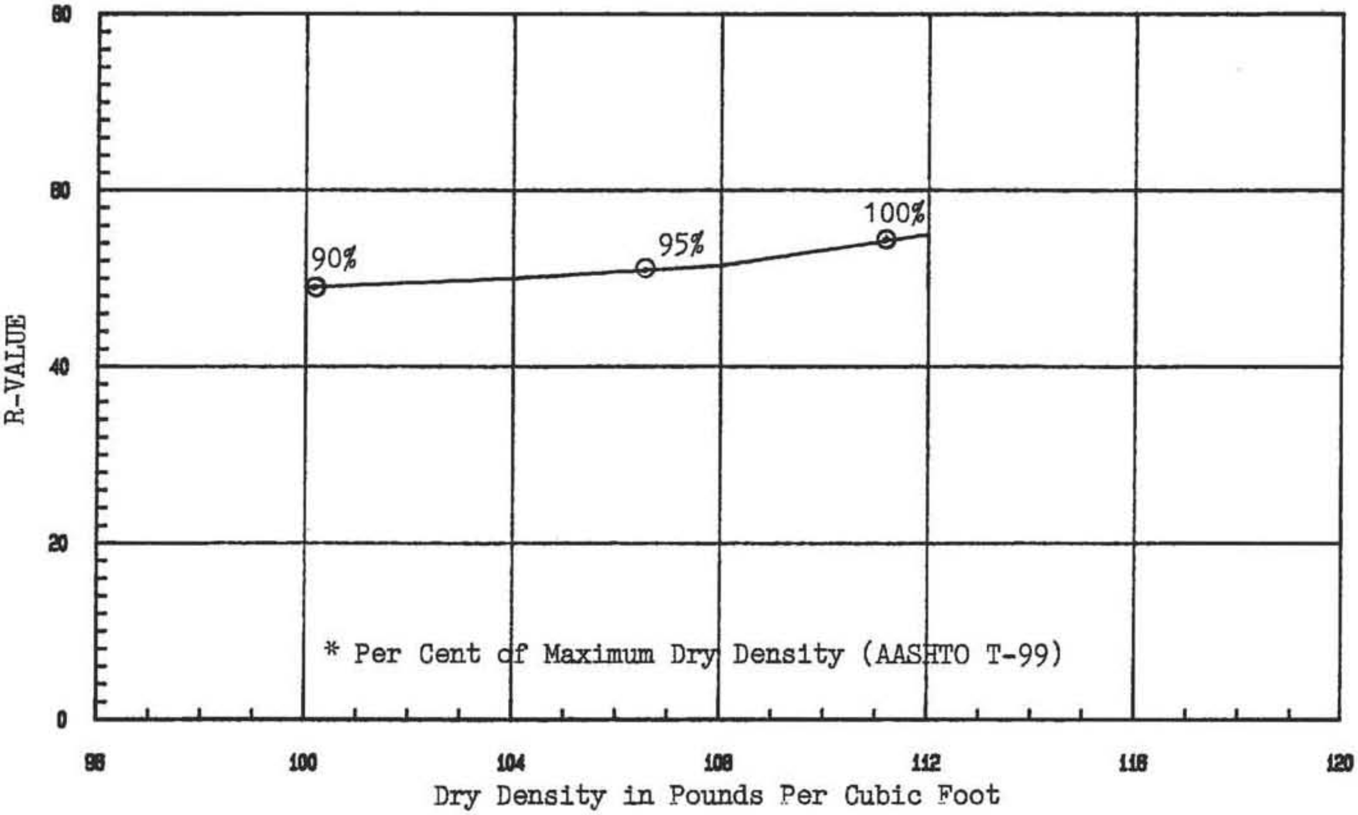


Figure 4. R-VALUE VS. MOISTURE OF A-6(6) SOIL AT MAX. DRY DENSITY

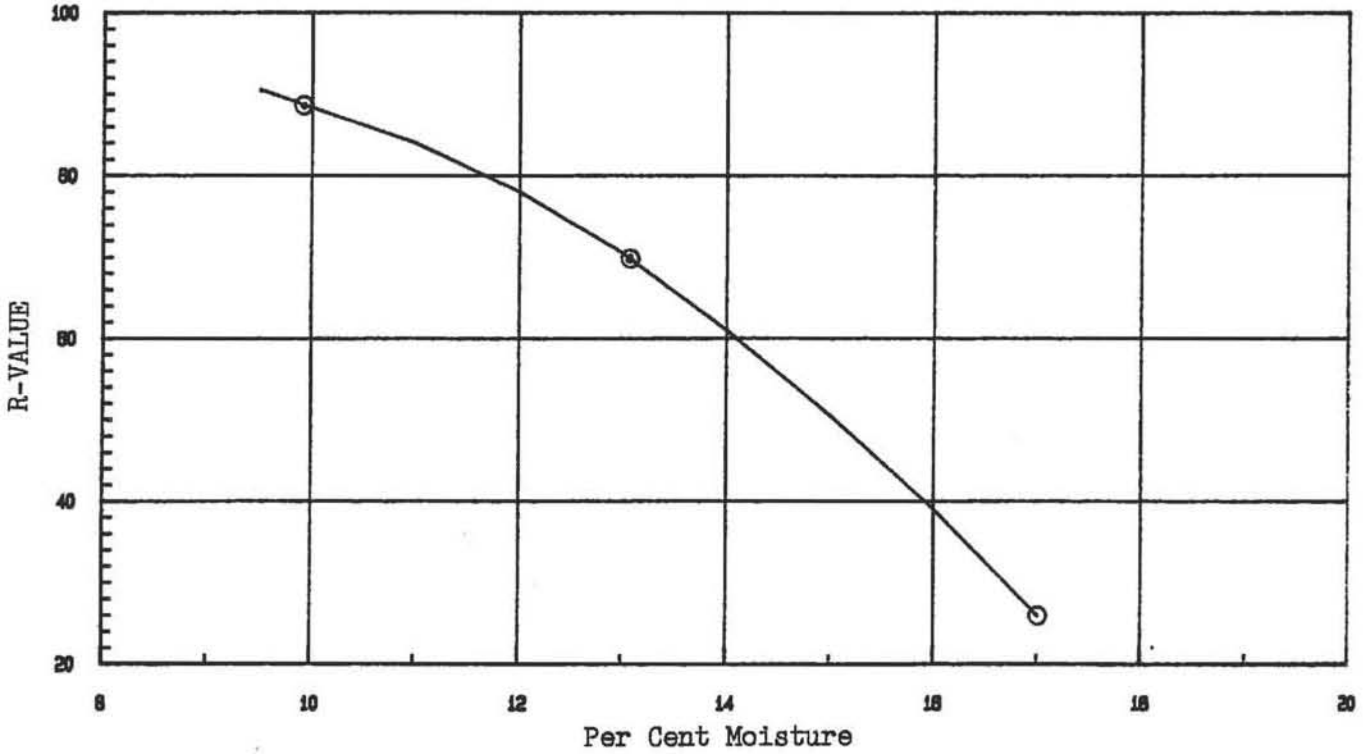
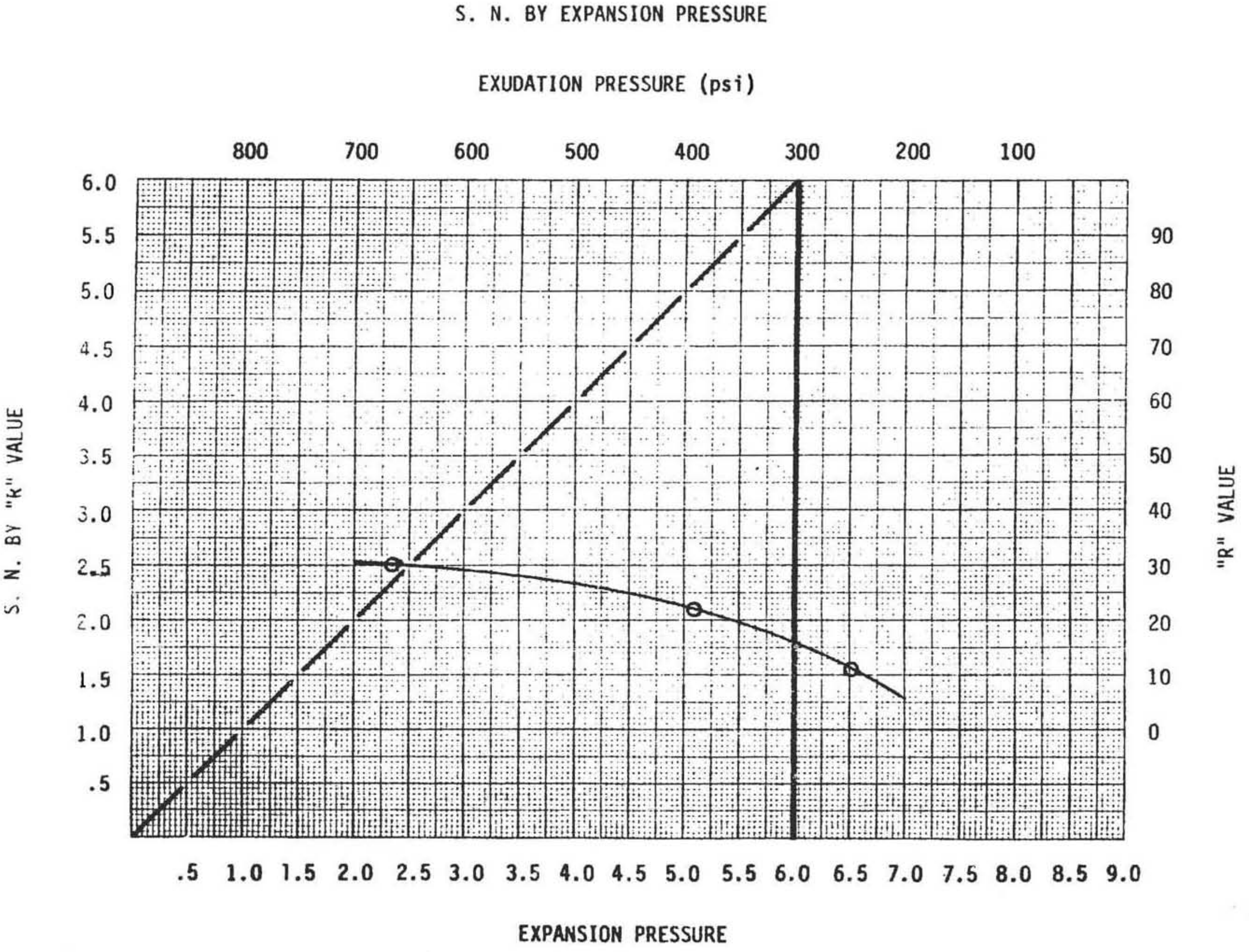
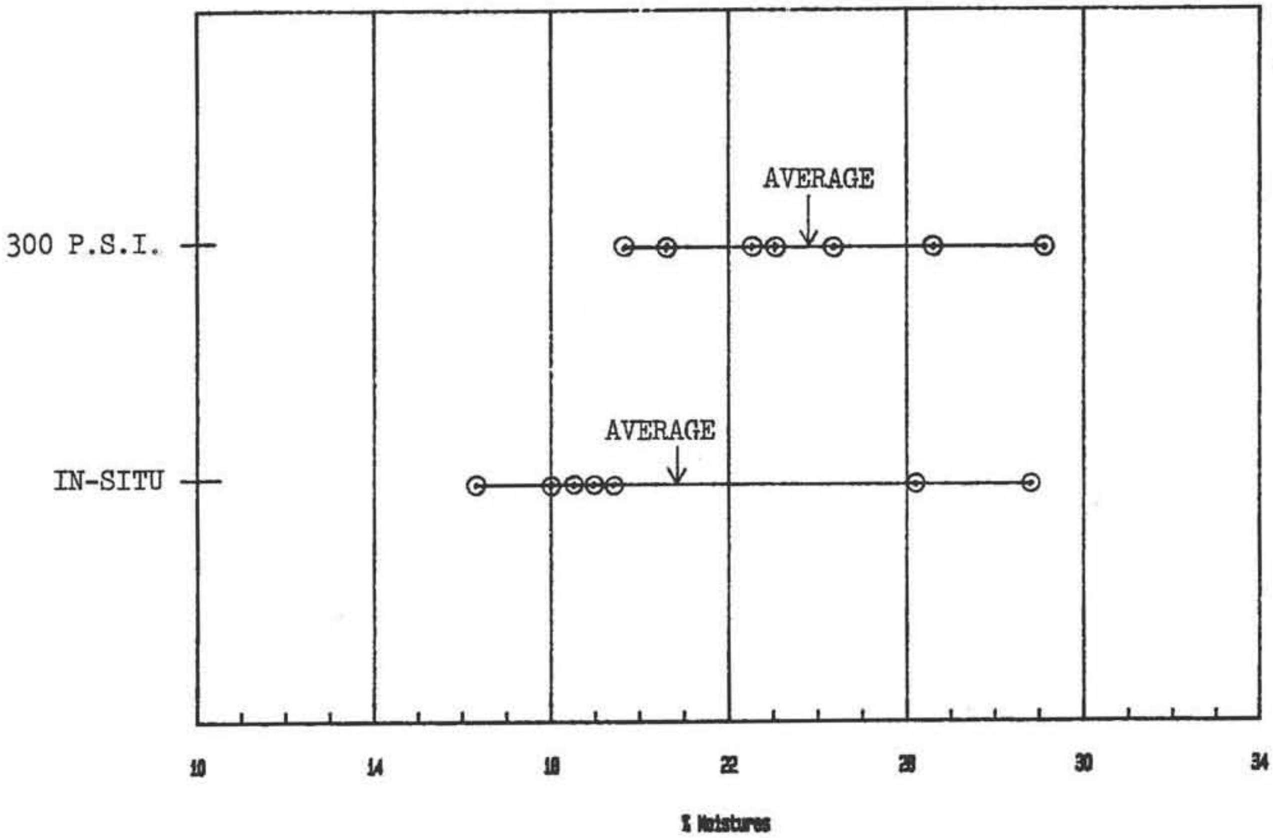


Figure 5. Chart Showing R-Value at Different Exudation Pressures



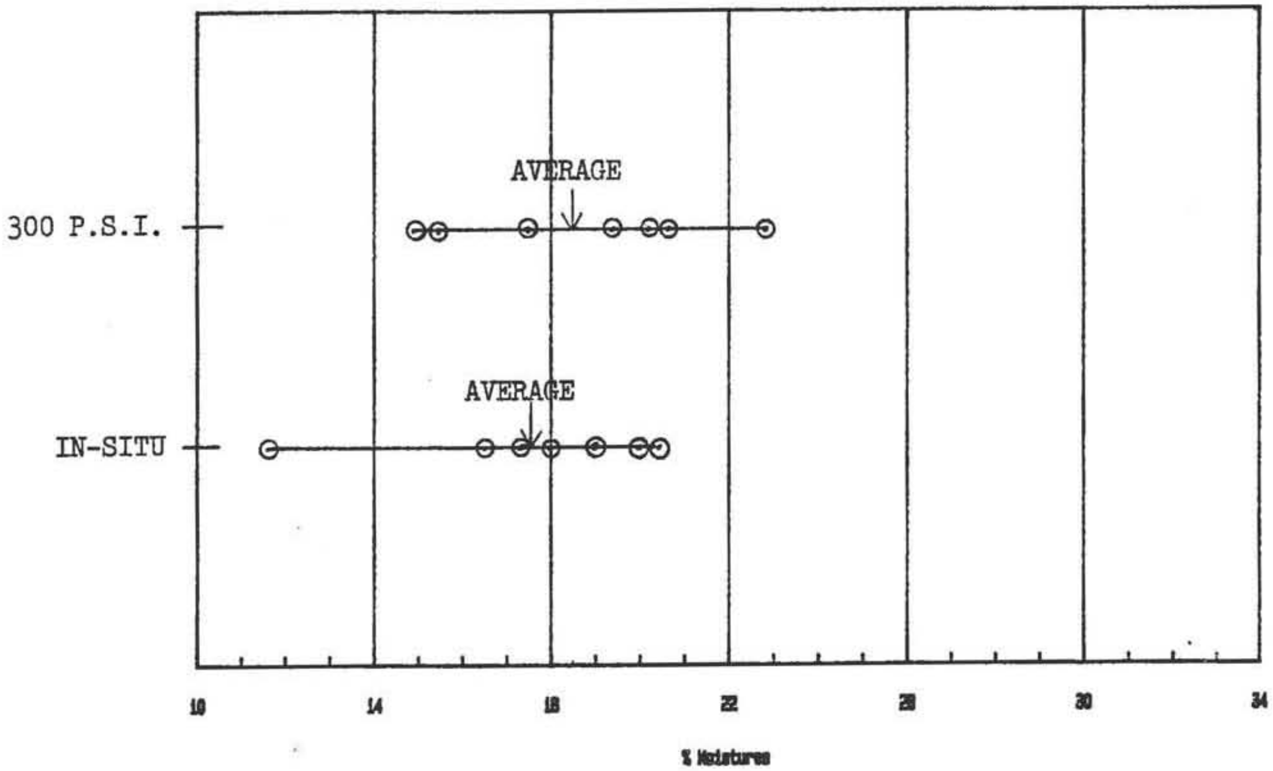
A-7-6 AVERAGE SITE MOISTURES

Figure 6



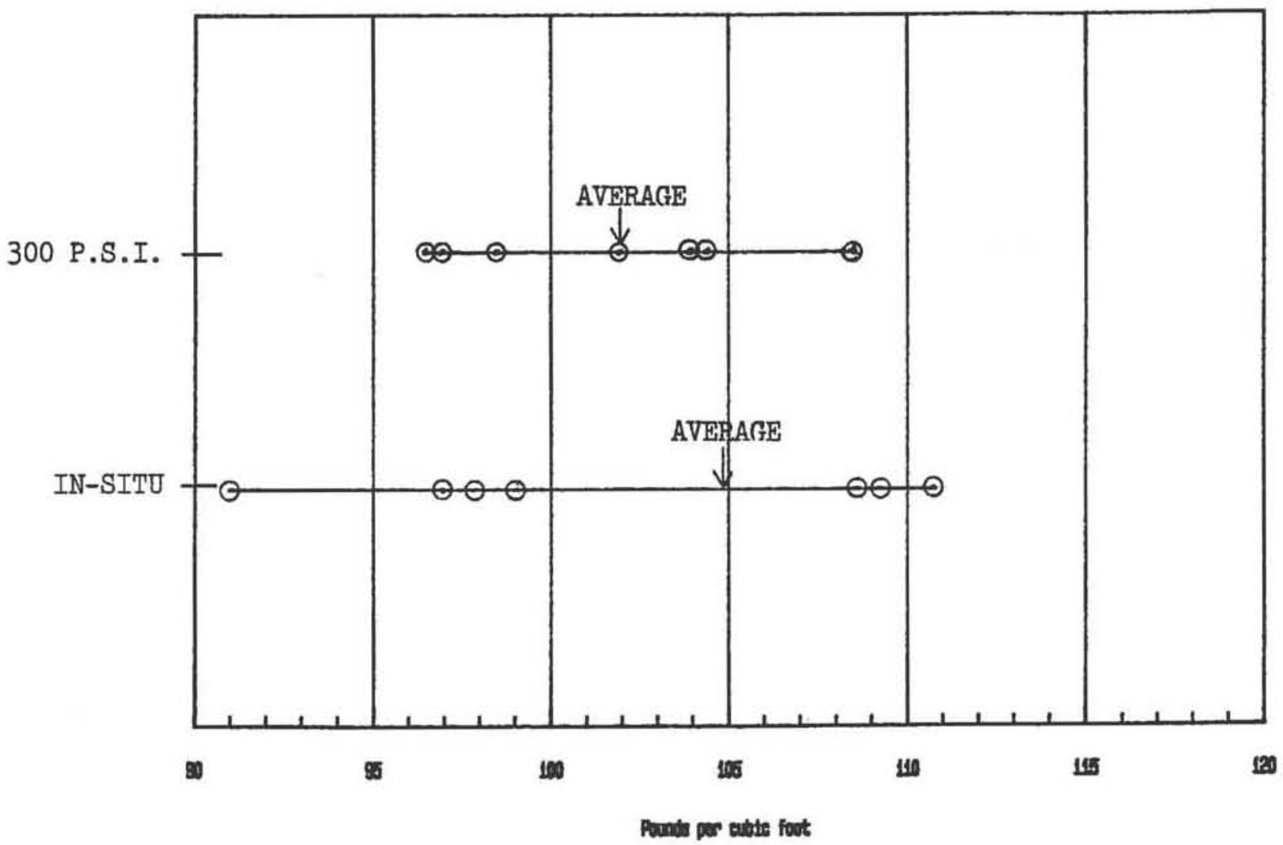
A-6 AVERAGE SITE MOISTURES

Figure 7



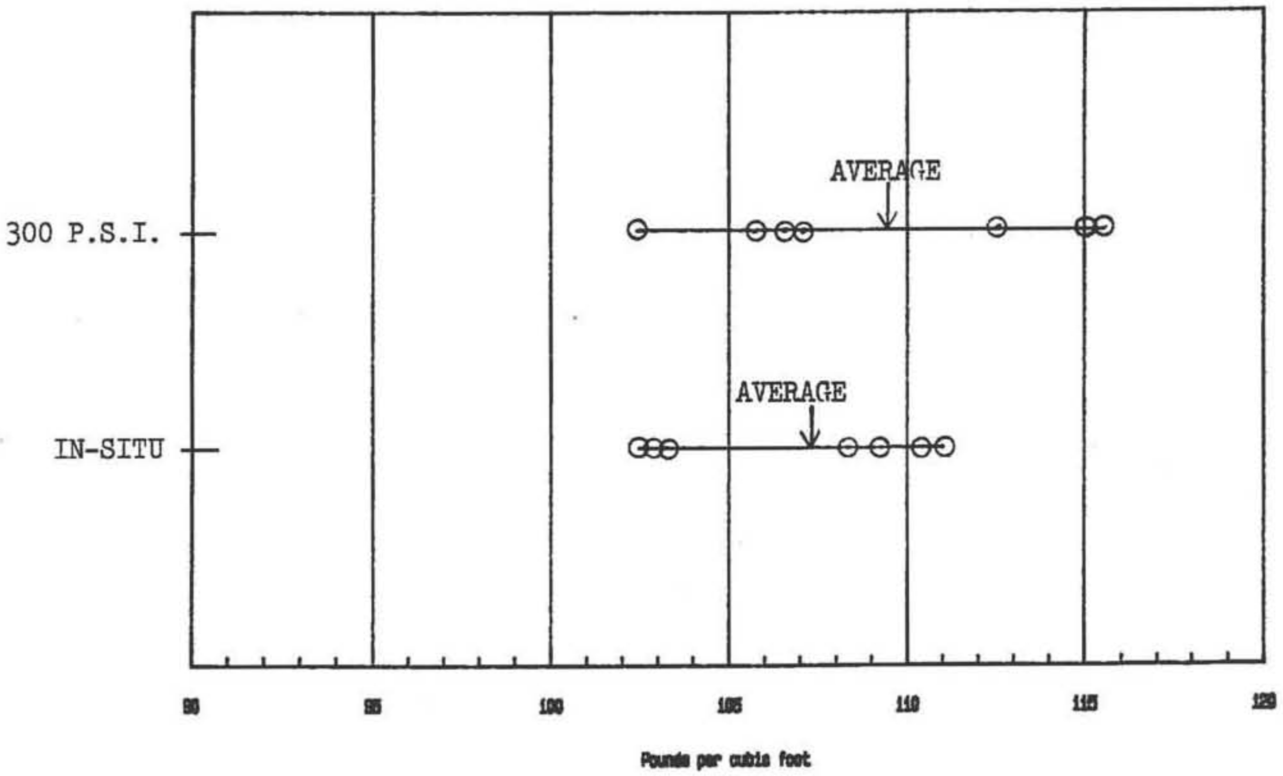
A-7-6 AVERAGE SITE DRY DENSITIES

Figure 8



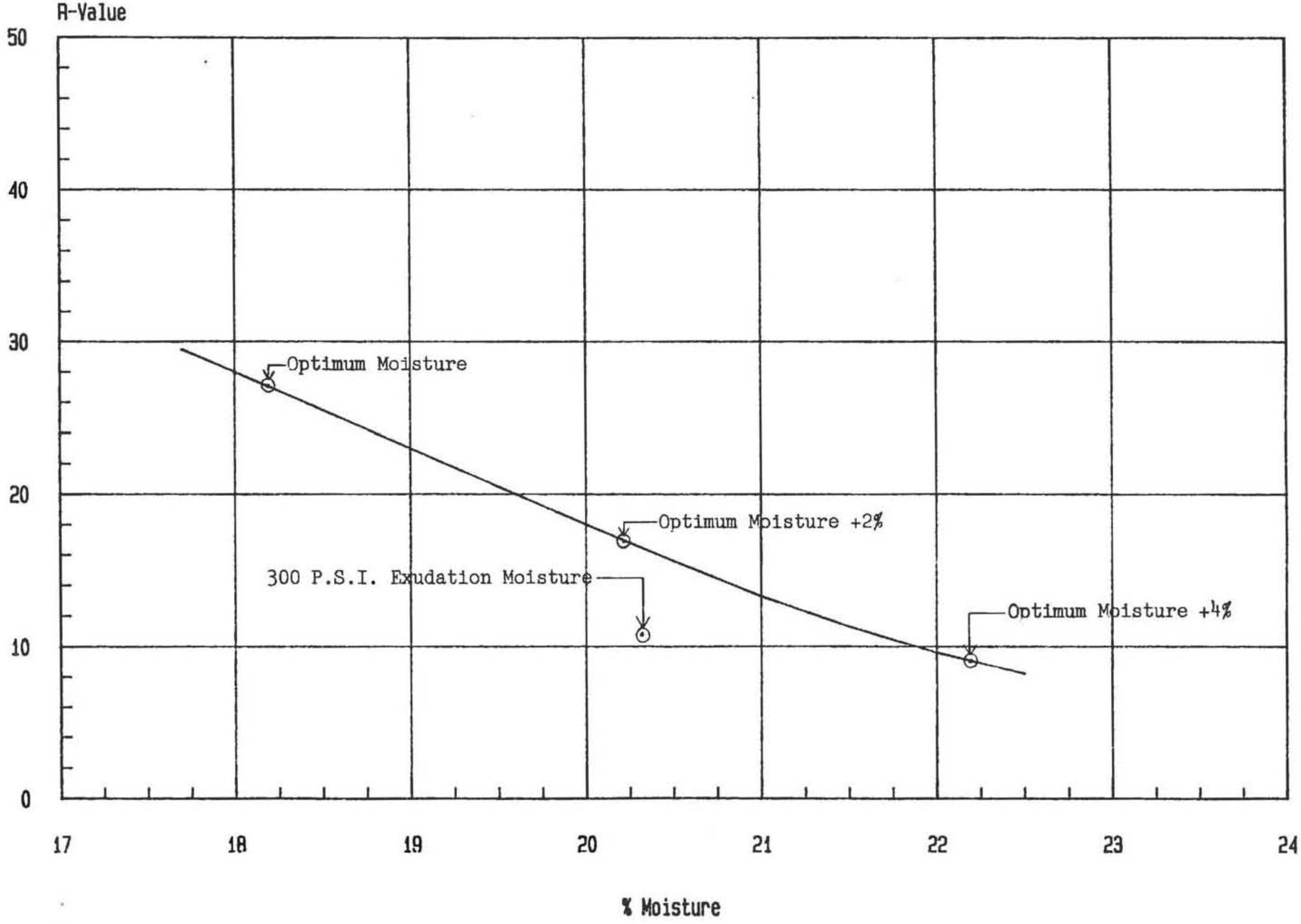
A-6 AVERAGE SITE DRY DENSITIES

Figure 9



TYPICAL THREE POINT R-VALUE CURVE

Figure 10



T-99 (AASHTO) Versus In-Situ

The T-99 test is used to determine the maximum dry density of a particular soil at a specified compactive effort. The optimum moisture content is the moisture content corresponding to the maximum dry density. An explanation of this test procedure is given in Appendix E.

The purpose of this test is to maintain control of compaction in the field. Nuclear test values obtained in the field must meet density and moisture values related to these laboratory test results. CDOH specifications require the placement moistures for A-6 and A-7 soils not be less than 2% below T-99 optimum moisture. Field dry densities must equal or exceed dry density values which are 95% of AASHTO T-99 for all A-6 and A-7 soils.

The relationship between in-situ and T-99 moisture gives relevant information on moisture conditions at the different research sites. Figure 11 shows the relationship between in-situ and T-99 moisture for A-7-6 and A-6 soils. Figure 12 shows the relationship between in-situ and T-99 density for A-7-6 and A-6 soils.

An analysis of in-situ moisture versus optimum moisture (T-99) indicates the following:

(1) Average in-situ moisture for A-7-6 and A-6 soils was very close to optimum moisture.

(2) Related to optimum, the average in-situ moistures ranged from -4.1 to +4.1 for A-7-6 soils and from -3.0 to +2.3 for A-6 soils.

(3) Average in-situ moistures were below the specified minimum(11) in five of the A-7-6 and A-6 sites.

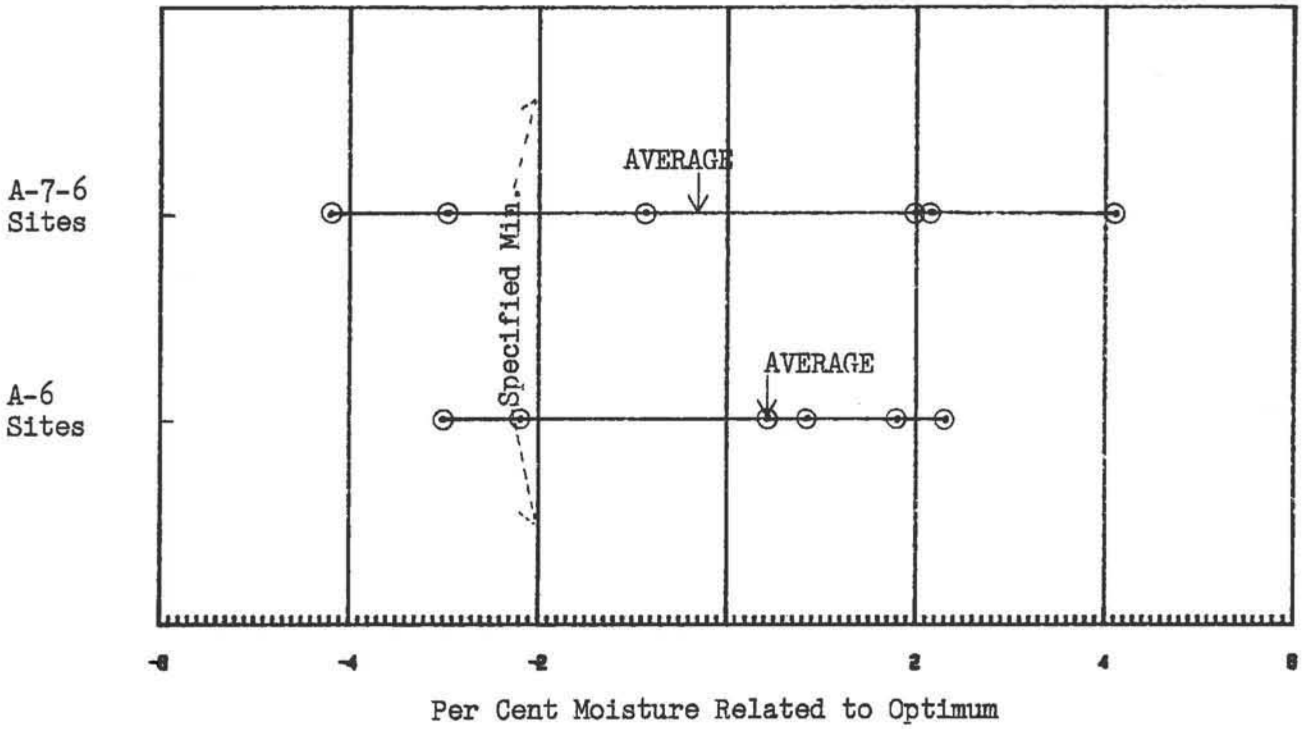
The average in-situ density was below the specified minimum(11) at only one of the A-7-6 and A-6 sites. The average in-situ density for all A-7-6 sites was 102% of maximum density (T-99) and the average in-situ density for all A-6 sites was 98% of maximum density (T-99).

Soil Suction Testing

Soil suction tests were conducted in the laboratory on soils from seven soils research sites. Soil specimens from these sites had plastic indexes ranging from 13 to 30. There was no indication of pavement

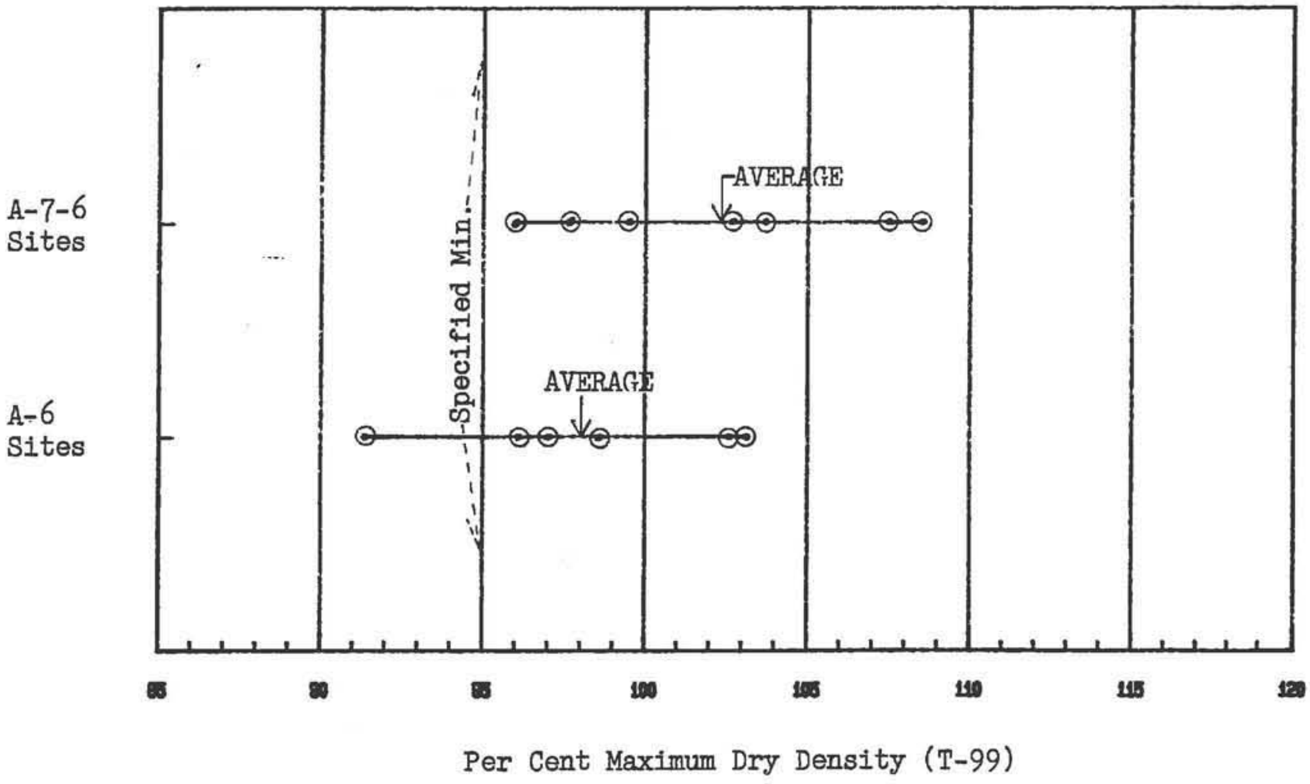
AVERAGE IN-SITU MOISTURE VALUES

Figure 11



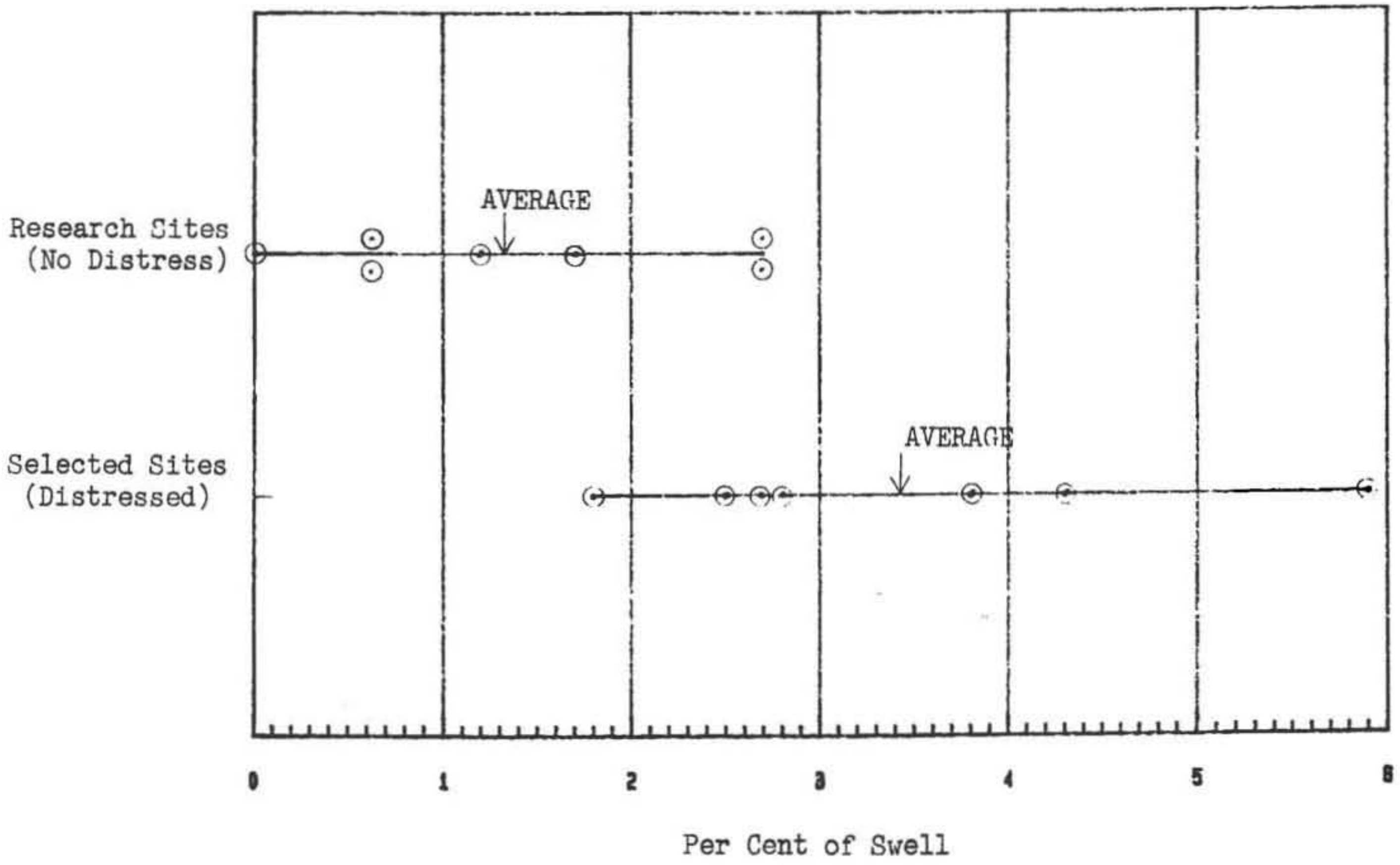
AVERAGE IN-SITU DRY DENSITY VALUES

Figure 12



SWELL VALUES OF SUBGRADE SOILS

Figure 19



distress in these roadways. For comparison, three locations (Cedar Point, Elbert-Lincoln Co. Line and Co. Line Road - Quebec I-25), other than the soils research sites, were chosen for soil suction tests in the laboratory. Pavement distress was evident at these locations and the soil specimens had plastic indexes ranging from 30 to 53.

Percent of swell was calculated from values obtained by these soil suction tests. The mathematical equation described in FHWA-RD-77-51 report(9) was used to determine soil suction ($\mathcal{T}_0$) and percent of swell values shown in Table 5. The final, or equilibrium moisture of the soil specimens was assumed to be 100 percent for calculating amount or percent of swell.

Percent of swell ranged from 0.0 to 2.7 for soils under the undistressed pavements and from 1.8 to 5.8 under the pavements exhibiting evidence of distress. A comparison of the swell values (Figure 13) show that there is a reasonable qualitative correlation. However, there was no accurate information on the actual amount of swell that occurred to the soil underlying the distressed pavement. More research is needed to determine if assumptions (especially final moisture content) used in the calculations for percent of swell are correct. A soil suction research project, now being conducted by the Soils Unit of the Colorado Highway Department, will provide more data on the present calculation method's accuracy and hopefully provide a new, more accurate way to determine quantitative values.

II. Conclusions

The standard R-value test, based on 300 p.s.i. exudation pressure, and currently used by the Colorado Highway Department, should be retained for routine soil testing. Tests conducted on A-7-6 and A-6 soils taken from research sites indicate that the 300 p.s.i. exudation moisture is generally greater than the in-situ moisture of these soils. However, there is a wide variation and overlap when comparing 300 p.s.i. exudation moistures with in-situ moistures. Because of this variation and overlap, there is a need to run the R-value at a higher moisture content than the average in-situ moisture to allow for some margin of safety in pavement design.

Alternative R-value test methods examined during this research project have shortcomings. All these methods are tied to T-99 results, which creates a time lag in obtaining results. The "One Pointer" R-value test (using predetermined density and moisture values) does not allow an evaluation of moisture sensitivity and it is difficult to obtain the required density. The "Three Pointer" R-value test requires more time, but has the advantage of being more flexible with moisture selection than the standard R-value test and can be used to advantage where drainage problems and moisture sensitive soils are involved.

More complete data can be obtained with the standard T-190 method, if the whole curve is used in analyzing the significance of the R-value at 300 p.s.i. exudation pressure. R-values selected at moistures other than the 300 p.s.i. value, may be appropriately used for such special conditions as moisture-sensitive soils. The R-value, obtained by the standard T-190 test, can be used in conjunction with a regional factor adjustment for special field conditions.

Soil Suction Tests conducted for this research project gave reasonable, qualitative results. Tests on subgrade soils, underlying pavements showing distress, gave higher swell values than tests on subgrade soils underlying pavements without evidence of distress.

Problems that developed in the soil suction testing equipment caused difficulty in calibrating some psychrometers. Apparently, the psychrometers (consisting of very fragile thermocouples) became contaminated by rust which formed inside the psychrometer containers. In future tests, stainless steel containers will be used to prevent contamination to the psychrometers. The use of stainless steel containers should provide more accurate and consistent soil suction values.

More work is needed to make sure the proper assumptions are made during calculation of swell or heave potential. The basic assumption, used during this research, was that the soil would attain 100 percent saturation to a specific depth.

A new research project, now underway by the Soils Unit of the Colorado Highway Department, will concentrate on the study of moisture increases in subgrade soils. Comparisons will be made between in-situ moisture of soil outside a highway cut and the moisture of subgrade soil at the same elevation in the cut. The difference in moistures will be used to calculate the amount of swell or heave. This value will be checked against the estimated amount of heave which actually occurred in the roadway. Assessment of these results should give reasonable assumptions as to what values should be used for final percent moisture and depth of moisture penetration.

REFERENCES

(1) ASTM Standards, American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

(2) Standard Specifications for Transportation Materials and Methods of Sampling and Testing, American Association of State Highway and Transportation Officials, 444 North Capitol St., N.W., Suite 225, Washington, D.C. 20001.

(3) Roadway Design Manual, State Department of Highways, Division of Highways, State of Colorado.

(4) The AASHTO Road Test, Highway Research Board, National Academy of Sciences - National Research Council, Washington, D.C.

(5) Van Til, C. J., McCullough, B. F., Fallerga, B. A., and Hicks, R. G., "Evaluation of AASHTO Interim Guides for Design of Pavement Structures," National Cooperative Highway Research Program (NCHRP) Report 128, Highway Research Board, National Academy of Sciences, 2101 Constitution Ave., Washington, D.C. 20418.

(6) "Flexible Pavement Design Correlation Study," Highway Research Board Bulletin 133, (1956).

(7) "Correlation of Subgrade Modulus and Stabilometer R-Value."

(8) "Re-evaluation of the Problem Concerning Expansive Soils Underlying Portland Cement Concrete Pavements," State of California, Division of Highways, Research Report No. M&R 643300, 1967.

(9) Johnson, L. D., Evaluation of Laboratory Suction Tests for Prediction of Heave in Foundation Soils, Soils and Pavement Laboratory, U. S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Miss., 39180, August, 1977.

(10) Materials Test Procedural Manual, State Department of Highways, Division of Highways, State of Colorado.

(11) Standard Specifications for Road and Bridge Construction, Division of Highways, State of Colorado, 1981.

APPENDIX A

LABORATORY TEST RESULTS

Table 2 - Laboratory test results on samples from each test hole.
Table 3 - Average of laboratory test results from five test holes at each test site.
Table 4 - Average of laboratory test results of the different AASHTO soil classes.
Table 5 - Soil Suction Test Results.

TABLE 2

LABORATORY TEST RESULTS

Site No.	AASHTO Classification	L.L.	P.I.	Percent Passing No. 200	In-Place Dry Density	Max. Dry Density (T 99)	Moisture Data*				R-Value Data				
							In-Situ								
							% Moist	% Satur	Optimum	300 PSI	In-Situ Moist	Opt Moist	Opt + 2%	Opt + 4%	300 PSI Exudat
8	A-7-6(11)	41	25	57	102.9		19.6	84		18.4	18				13
	A-7-6(13)	41	23	67	109.0		16.4	84		21.6	30	34	22	18	10
	A-7-6(12)	44	24	60	108.6		18.0	90		21.4	22				16
	A-7-6(14)	42	24	66	108.7	110.6	18.9	95	16.0	20.0	19				13
	A-7-6(11)	42	21	63	111.4		17.1	93		21.0	26				10
9	A-7-6(24)	52	34	74	101.1	109.4	23.7	97	17.4	23.5	10				10
	A-7-6(23)	52	30	76	103.6		22.7	99		23.8	13				11
	A-7-6(15)	42	24	71	114.9		16.6	97		21.3	30	27	21	16	9
	A-7-6(16)	47	28	65	112.4		17.3	95		20.9	27				13
	A-7-6(19)	47	28	71	112.3		17.3	95		25.3	27				7
11	A-7-6(18)	47	23	76	84.1		33.0	88		23.4	10				16
	A-7-6(30)	58	30	88	91.8	94.6	28.1	91	24.6	30.4	11				12
	A-7-6(21)	45	23	88	88.8		29.8	90		24.1	10				11
	A-7-6(23)	45	23	92	94.8		27.0	94		24.0	13	20	14	11	18
	A-7-6(18)	38	20	90	95.2		25.5	90		20.0	16				19
13	A-7-6(19)	50	30	69	102.4		23.2	96		27.2	20				9
	A-7-6(16)	46	25	70	99.5		23.2	90		25.9	20				9
	A-7-6(34)	61	29	97	88.9	90.4	32.1	96	28.5	34.2	5	10	7	5	20
15	A-7-6(16)	43	24	71	106.2		19.5	87		24.8	50				11
	A-7-6(19)	46	28	73	109.5		19.2	94		26.2	50				9
	A-7-6(19)	46	27	73	106.6		19.6	87		26.8	48				10
	A-7-6(15)	44	24	70	115.8		14.2	81		25.6	60	25	18	14	12
	A-7-6(25	52	32	78	105.8	100.4	20.1	89	22.6	28.0	42				13

* Moisture data based on % of dry weight except % of saturation.

TABLE 2
LABORATORY TEST RESULTS

Site No.	AASHTO Classification	L.L.	P.I.	Percent Passing No. 200	In-Place Dry Density	Max. Dry Density (T 99)	Moisture Data* In-Situ % Moist	Moisture Data* In-Situ % Satur	Moisture Data* Optimum	Moisture Data* 300 PSI	R-Value Data In-Situ Moist	R-Value Data Opt Moist	R-Value Data Opt + 2%	R-Value Data Opt + 4%	R-Value Data 300 PSI Exudat
16	A-7-6(21)	44	20	94	108.7	107.0	15.6	71	19.4	23.4	70				12
	A-7-6(20)	44	19	93	113.2		17.5	90		22.8	55				13
	A-7-6(22)	45	22	93	113.9		16.8	87		21.6	60				14
	A-7-6(22)	45	21	94	112.8		16.8	85		22.2	60				13
	A-7-6(20)	44	20	90	105.6		15.1	64		22.4	75	41	30	21	14
19	A-7-6(21)	43	21	94	104.1		19.1	79		19.9	26	25	22	11	22
	A-7-6(19)	41	20	91	113.7		16.6	86		19.8	28				22
	A-7-6(19)	42	20	91	108.4		20.0	91		19.0	26				21
	A-7-6(20)	42	19	95	109.8		20.0	94		20.1	26				24
	A-7-6(24)	44	24	94	110.3	106.3	19.3	93	19.9	19.8	26				19
1	A-7-6(8)	42	25	49	99.7		11.7	47		18.7	53				14
	A-6(6)	36	20	49	102.3	113.5	11.7	49	14.7	15.2	53	30	20	12	30
	A-6(5)	35	18	50	103.8		12.2	54		15.0	49				28
	A-6(4)	33	16	47	110.3		12.5	65		15.1	46				21
	A-6(1)	29	13	38	102.5		10.5	45		12.5	60				29
2	A-6(10)	36	20	64	103.5		22.8	97		21.9	8	21	17	11	7
	A-6(4)	31	17	46	107.1		18.9	90		15.7	19				13
	A-6(6)	34	20	51	105.0		18.6	83		16.2	19				17
	A-6(11)	40	24	58	103.5	108.2	18.7	80	18.0	21.8	19				10
	A-6(15)	37	21	77	101.6		22.4	92		21.6	9				11
3	A-6(7)	31	15	64	109.1	112.2	17.5	90	15.5	15.5	14				28
	A-6(6)	30	15	58	112.1		16.1	90		14.0	21				28
	A-6(6)	33	17	54	108.4		17.5	89		15.2	14				26
	A-6(4)	26	11	65	110.2		16.2	87		13.7	20				29
	A-6(8)	32	16	67	106.2		14.0	67		16.0	50+	29	14	12	21

* Moisture data based on % of dry weight except % of saturation.

TABLE 2

LABORATORY TEST RESULTS

Site No.	AASHTO Classification	L.L.	P.I.	Percent Passing No. 200	In-Place Dry Density	Max. Dry Density (T 99)	Moisture Data*				R-Value Data				
							In-Situ % Moist	In-Situ % Satur	Optimum	300 PSI	In-Situ Moist	Opt Moist	Opt + 2%	Opt + 4%	300 PSI Exudat
12	A-6(10)	36	19	64	109.5		18.8	95		21.8	24				11
	A-6(18)	38	21	87	107.9		19.3	94		22.6	21	25	17	11	12
	A-6(10)	36	19	67	111.6		17.6	95		21.8	31				8
	A-6(10)	34	19	65	108.3		18.8	93		21.2	24				9
	A-6(13)	39	20	72	105.9	105.3	20.3	94	18.6	24.0	18				11
14	A-6(8)	34	18	61	106.7		19.3	88		17.9	14				13
	A-6(9)	38	21	58	111.6		16.8	87		18.3	19				15
	A-6(13)	40	24	64	108.9		15.9	77		20.2	20				8
	A-6(9)	37	21	59	113.7		16.5	90		21.1	19	20	16	12	7
	A-7-6(14)	42	24	66	109.7	111.5	18.3	90	16.3	22.8	16				8
18	A-6(21)	40	21	96	102.8	107.3	20.5	85	18.2	22.2	15				11
	A-6(20)	39	21	94	105.3		19.0	84		20.5	22				10
	A-6(20)	40	21	91	110.3		18.2	92		17.9	27				10
	A-6(20)	39	21	93	101.9		19.9	81		20.2	18				11
	A-6(17)	37	18	94	99.8		22.1	85		20.5	9	27	17	9	12
21	A-6(13)	36	15	85	111.3		18.4	92		16.9	25				43
	A-6(11)	35	14	83	109.0		17.3	82		17.2	30				29
	A-6(12)	36	15	83	114.9		16.9	93		17.6	32	27	18	8	26
	A-6(10)	34	13	84	112.7		17.5	91		17.2	29				40
	A-6(13)	37	15	87	106.4	108.2	19.4	86	18.1	18.4	21				29
5	A-4(0)	21	2	42	106.8		10.7	53		11.4					41
	A-4(0)	23	4	47	103.4	119.4	10.4	47	13.0	12.2					36
	A-4(0)	23	3	47	105.1		9.5	45		12.3					39
	A-4(0)	22	3	43	109.6		9.7	51		11.2					42
	A-4(0)	NV	NP	36	114.8		13.2	80		11.6					33

* Moisture data based on % of dry weight except % of saturation.

TABLE 2

LABORATORY TEST RESULTS

Site No.	AASHTO Classification	L.L.	P.I.	Percent Passing No. 200	In-Place Dry Density	Max. Dry Density (T 99)	Moisture Data* In-Situ % Moist	Moisture Data* In-Situ % Satur	Moisture Data* Optimum	Moisture Data* 300 PSI	R-Value Data In-Situ Moist	R-Value Data Opt Moist	R-Value Data Opt + 2%	R-Value Data Opt + 4%	R-Value Data 300 PSI Exudat
17	A-4(0)	NV	NP	56	111.1		13.4	71		11.8					63
	A-4(0)	NV	NP	51	110.0	120.3	13.7	70	12.0	9.5					65
	A-4(0)	NV	NP	56	96.2		16.2	58		10.7					58
	A-4(0)	NV	NP	39	118.7		9.7	64		11.5					66
	A-4(0)	NV	NP	36	121.1		8.7	60		11.8					63
4	A-2-6(0)	25	11	13	110.8		8.4	45		9.0					74
	A-2-6(0)	34	15	11	112.3	122.8	6.4	35		9.4					60
	A-2-6(0)	27	12	16	115.4		6.0	36		10.0					52
	A-2-6(0)	25	11	14	113.9		3.3	19		8.0					63
	A-2-6(0)	28	12	20	120.6		4.7	34		8.7					53
10	A-2-4(0)	26	10	34	111.8		12.2	68		12.9					23
	A-2-4(0)	21	4	26	114.9		11.6	70		11.5					43
	A-2-4(0)	22	4	26	107.4		8.3	41		11.1					45
	A-2-4(0)	NV	NP	17	104.8		6.7	31		10.5					77
	A-4(0)	24	8	40	111.2	119.9	9.5	52	12.1	11.9					44
20	A-2-4(0)	NV	NP	32	111.2		13.7	74		9.8					79
	A-4(0)	NV	NP	41	106.2		13.8	65		9.7					77
	A-2-4(0)	NV	NP	34	105.7		11.7	55		10.0					79
	A-2-4(0)	NV	NP	35	110.7	118.7	13.9	74	12.4	10.5					77
	A-2-4(0)	NV	NP	29	-		-	-		10.5					75
7	A-1-b(0)	NV	NP	12	112.2	118.9	8.0	47	9.3	8.9					81
	A-2-4(0)	NV	NP	13	104.5		5.7	27		9.4					81
	A-2-4(0)	NV	NP	13	101.7		6.0	26		8.8					82
	A-1-b(0)	NV	NP	11	108.4		3.9	20		9.0					78
	A-1-b(0)	NV	NP	10	105.9		4.0	20		9.2					79

* Moisture data based on % of dry weight except % of saturation.

TABLE 3

LABORATORY TEST RESULTS

Site No.	AASHTO Classification	L.L.	P.I.	Percent Passing No. 200	In-Place Dry Density	Max. Dry Density (T 99)	Moisture Data*				R-Value Data				
							In-Situ								
							% Moist	% Satur	Optimum	300 PSI	In-Situ Moist	Opt Moist	Opt + 2%	Opt + 4%	300 PSI Exudat
8	A-7-6(12)	42	23	63	108.1	110.6	18.0	89	16.0	20.5	23	34	22	18	12
9	A-7-6(19)	48	29	71	108.9	109.4	19.5	97	17.4	23.0	21	27	21	16	10
11	A-7-6(22)	47	24	87	90.9	94.6	28.7	91	24.6	24.4	13	20	14	11	15
13	A-7-6(23)	52	28	79	96.9	90.4	26.2	94	28.5	29.1	15	10	7	5	20
15	A-7-6(19)	46	27	73	108.8	100.4	18.5	88	22.6	26.3	50	25	18	14	11
16	A-7-6(21)	44	20	93	110.8	107.0	16.4	79	19.4	22.5	64	41	30	21	13
19	A-7-6(21)	42	21	93	109.3	106.3	19.0	89	19.9	19.7	26	25	22	11	22
1	A-6(4)	33	17	46	103.7	113.5	11.7	52	14.7	15.3	52	30	20	12	24
2	A-6(7)	36	20	59	104.1	108.2	20.3	88	18.0	19.4	15	21	17	11	12
3	A-6(6)	30	15	62	109.2	112.2	16.3	85	15.5	14.9	24	29	14	12	26
12	A-6(12)	37	20	71	108.6	105.3	19.0	94	18.6	22.3	24	25	17	11	10
14	A-6(10)	38	21	61	110.1	111.5	17.4	86	16.3	20.1	18	20	16	12	10
18	A-6(20)	39	20	94	104.0	107.3	20.0	85	18.2	20.3	18	27	17	9	11
21	A-6(12)	36	14	84	110.9	108.2	17.9	89	18.1	17.5	27	27	18	8	33
5	A-4(0)	22	3	43	107.9	119.4	10.6	55	13.0	11.7					38
17	A-4(0)	NV	NP	48	111.4	120.3	12.3	65	12.0	11.1					63
4	A-2-6(0)	28	12	15	114.6	122.8	5.8	34	10.7	9.0					60
10	A-2-4(0)	23	6	29	110.0	119.9	9.7	52	12.1	11.6					46
20	A-2-4(0)	NV	NP	34	108.4	118.7	13.3	67	12.4	10.1					79
7	A-1-b(0)	NV	NP	12	106.5	118.9	5.5	28	9.3	9.1					80

* Moisture data based on % of dry weight except % of saturation.

TABLE 4

LABORATORY TEST RESULTS

Site No.	AASHTO Classification	L.L.	P.I.	Percent Passing No. 200	In-Place Dry Density	Max. Dry Density (T 99)	Moisture Data*				R-Value Data				
							In-Situ								
							% Moist	% Satur	Optimum	300 PSI	In-Situ Moist	Opt Moist	Opt + 2%	Opt + 4%	300 PSI Exudat
--	A-7-6's	46	25	80	104.8	102.7	20.9	90	21.2	23.6	30	26	19	11	15
	A-6's	36	18	68	107.2	109.5	17.5	83	17.1	18.5	29	26	17	11	18
	A-4's	--	--	25	109.7	119.9	11.5	60	12.5	11.4					51
	A-2-6	28	12	15	114.6	122.8	5.8	34	10.7	9.0					60
	A-2-4(0)	--	--	32	109.2	119.3	11.5	60	12.3	10.9					63
	A-1-b(0)	NV	NP	12	106.5	118.9	5.5	28	9.3	9.1					80

* Moisture data based on % of dry weight except % of saturation.

TABLE 5

SOIL SUCTION TEST RESULTS

Site Location	Sample No.	Classification or Description	P. I.	In-situ Moist.	τ_0	Percent of Swell
Wadsworth Bypass @ 104th Ave.	1	A-6(10)	20	22.8	3.2	0.0
Wadsworth Bypass & Airport Rd.	5	A-7-6(19)	28	17.3	4.8	1.7
Manzanola East & West	2	A-7-6(30)	30	28.1	7.6	2.7
Purgatory River South	1	A-6(10)	19	18.8	12.7	1.2
West of Elk Springs	2	A-6(20)	21	19.0	5.6	2.7
West of Elk Springs	4	A-7-6(20)	19	20.0	3.7	0.5
South of Loma	4	A-6(10)	13	17.5	7.1	0.5
Cedar Point	1	A-7-6	53	36.4	5.8	1.8
Cedar Point	2	A-7-6	53	36.0	3.4	2.7
Elbert-Lincoln Co. Line	1	A-7-6	37	22.0	18.7	4.3
	1A	A-7-6	37	23.0	21.5	5.8
Co. Line Rd. - Quebec - I 25	4C	A-7-6(27)	31	17.0	7.0	3.8
	11A	A-7-6(33)	30	23.0	2.7	2.8
	16A	A-7-6(21)	32	22.0	3.5	2.5

APPENDIX B
COLORADO PROCEDURE L-3103
THIRD CYCLE EXPANSION PRESSURE TEST

SCOPE

1.1 This method covers the procedure for performing the third cycle expansion pressure test on expansive soils. The method also includes the determination of the cover required over subgrade soil to minimize its expansive potential.

APPARATUS

2.1 The equipment and tools required for this procedure are the same as those described in AASHTO T 190-66, with the following exceptions: the mechanical compactor, mold holder, funnel, and exudation device are not used.

SOIL PREPARATION

3.1 Air dry or oven dry (at a temperature not exceeding 140°F) a sufficient amount of soil to form a compacted specimen 4 inches in diameter by 2.5 inches high.

3.1.1 Determine the moisture content of the specimen.

3.2 Calculate additional water needed to obtain the desired moisture content.

3.3 Calculate amount of soil required to obtain the desired density for a specimen 4 inches in diameter and 2.5 inches high.

3.4 Thoroughly mix the soil and water and allow to stand overnight.

3.5 Place the soil into the mold.

3.5.1 Place a metal follower on the soil.

3.5.2 Apply a vertical pressure at the rate of 0.05 inch per minute until specimen height is 2.5 inches.

3.5.3 Allow specimen to rebound at least one-half hour.

3.5.4 Place deflection gauge in position on top bar of expansion pressure device.

3.5.5 Use an Allen wrench to raise or lower the adjustment plug until the deflection gauge is on minus 0.0010 inch.

3.5.6 Place a perforated brass plate with rod on top of test specimen.

3.5.7 Place mold on turntable after first placing a filter paper on turntable.

3.5.8 Seat perforated brass plate firmly on specimen with pressure applied from fingers.

3.5.9 Turn table up until dial indicator reads zero.

3.5.10 Pour approximately 200 ml of water on the specimen in mold and allow to stand for 16 to 24 hours.

3.5.11 At the end of the standing period relieve any expansion pressure that has been developed by turning the turntable down until the rod on the perforated plate barely breaks contact with the spring steel bar.

3.5.12 If, as a result of this relieving of pressure, the deflection gauge returned to the initial starting reading of minus 0.0010 in., immediately raise the turntable until the deflection gauge reads zero.

3.5.13 Allow to stand for 16 to 24 hours.

3.5.14 If the deflection gauge does not return to the starting value of minus 0.0010 in. (indicating that a set has been taken by the spring steel bar) use the Allen wrench to turn the adjustment plug and reset the deflection gauge to minus 0.0010 in.

3.5.15 Turn the turntable up to zero on the gauge as before.

3.5.16 Allow to stand for 16 to 24 hours.

3.5.17 At the end of the second standing period, relieve the expansion pressure which has developed and reset in accordance with the appropriate procedures listed above.

3.5.18 Allow to stand for another 16 to 24 hours.

3.5.19 Read and record deflection reading at the end of the third standing period.

DETERMINATION OF COVER REQUIREMENTS

4.1 Determine the third cycle expansion pressure value by converting the dial reading into expansion pressure in pounds per square inch by entering the abscissa on Figure 14, and recording the expansion pressure at the intersection with the diagonal line from the ordinate scale.

NOTE - The third cycle expansion pressure value in psi is located in Table 6. The depth of cover (in inches to profile grade) is read in the opposite column.

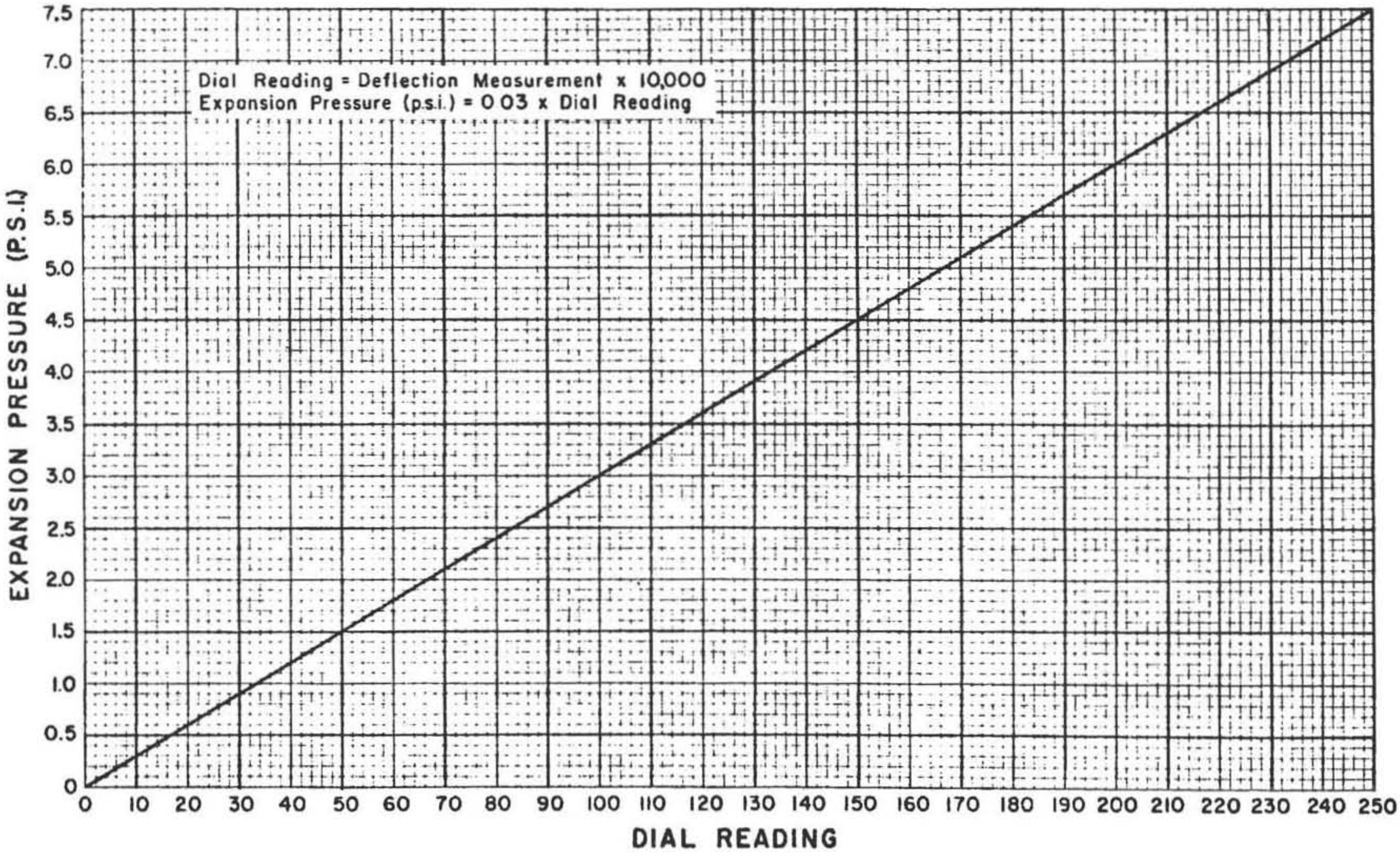
TABLE 6

MAXIMUM ALLOWABLE THIRD CYCLE EXPANSION PRESSURE VALUES

Depth Below Profile Grade (Inches)	Lbs/Sq. In.
12	1.88
13	1.99
14	2.09
15	2.20
16	2.31
17	2.41
18	2.52
19	2.63
20	2.73
21	2.84
22	2.95
23	3.05
24	3.16
25	3.25
26	3.34
27	3.43
28	3.52
29	3.61
30	3.70
31	3.80
32	3.89
33	3.99
34	4.09
35	4.18
36	4.28
37	4.36
38	4.43
39	4.51
40	4.59
41	4.66
42	4.74
43	4.83
44	4.91
45	5.00
46	5.08
47	5.17
48	5.25

Figure 14

CHART TO DETERMINE EXPANSION PRESSURE IN PSI FROM E.P. DIAL READINGS



APPENDIX C

DESCRIPTION OF SOIL SUCTION TEST

Testing Equipment required to perform the soil suction test includes:

(a) Psychrometric microvoltmeter (WESCOR Model MJ-55)
(b) Ten thermocouple psychrometers (WESCOR Model PST-55-15)
(c) Polystyrene thermal containers
(d) Ten metal sample containers (250 ml. stainless steel beakers)
(e) Ten rubber stoppers (size 13½)
(f) Switches (4), Switch box (1), and electrical connectors (10)
(g) Stopwatch
(h) Specimen cutting equipment (wire saw, knife, etc.)
(i) Tare containers
(j) Balance, sensitive to 0.01 g.
(k) Laboratory equipment for determination of dry density of the specimens by the volume displacement method.
(l) Calibration standards (WESCOR osmolality standards)

Equipment Set-Up involves inserting thermocouple psychrometer wires through holes (0.25 in. diameter) in the center of the rubber stoppers so the psychrometer tip extends approximately 1 inch from the bottom (small diameter end) of the rubber stopper. The protective sheathing around the psychrometer tip should form an air-tight seal in the hole of the rubber stopper. The electrical connectors are affixed to the psychrometer wires for easy connection to the switch box. The rubber stoppers are placed in the metal sample containers, which are placed in the thermal containers to minimize temperature variations. The switches are wired so that the output voltages (temperature and soil suction) can be monitored on each of the 10 psychrometers in turn. The equipment should be kept in a room where ambient termperature variations are minimal.

Calibration of the equipment involves normal operation of the equipment with standard solutions, which result in known relative humidities, placed in the sample containers. The different relative humidities result in corresponding retention forces or soil suction values. Several standard solutions are tested, and the resulting microvoltmeter output, when converted to a standard temperature of 25°C, yields a linear calibration line for the individual thermocouple psychrometer.

The calibration begins by placing a small piece of filter paper (type and grade variable) in the bottom of each sample container along with 3 ml. of the calibration standard. A minimum of three, preferably four, calibration standard concentrations should be used to adequately define the calibration line (i.e., 290, 1000, and 1800 mOs/kg). The equivalent moisture retention force or soil suction, in tons per square foot, is calculated by multiplying the concentration by 2.62×10^{-2} (i.e., 1800 mOs/kg x 0.0262 = 47.2 tsf). After sealing the sample containers with the rubber stoppers and placing them in the thermal containers, allow the temperature to equilibrate for approximately 24 hours. Begin taking temperature and soil suction output readings at least three times per day until the output readings stabilize. The time to stabilization varies with concentration of the calibration standard but will generally be in the range of 3 to 5 days.

The thermocouple voltage output (millivolts) is converted to temperature to (^{o}C) using the following conversion:

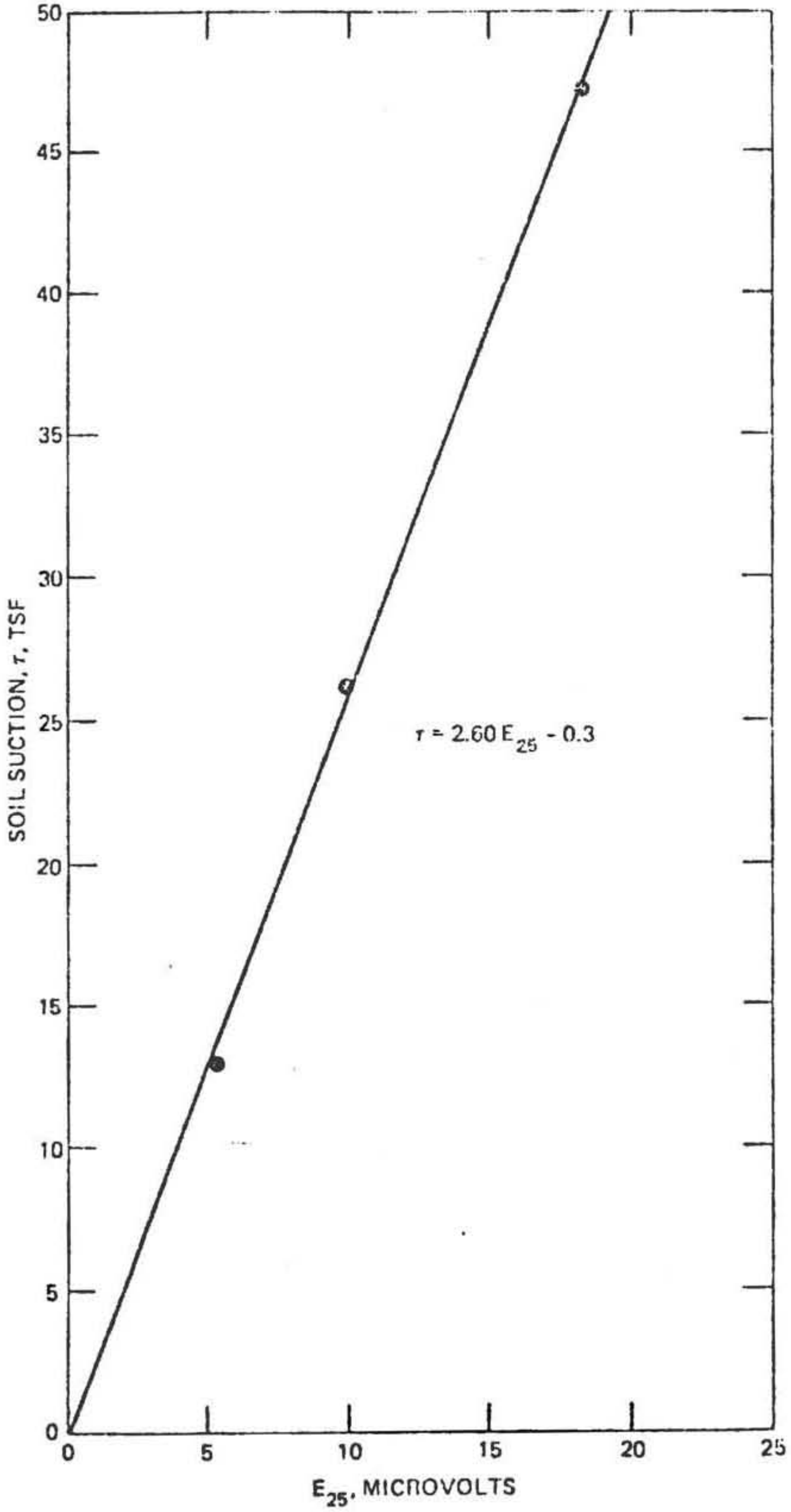
$$\text{Temperature, } {}^{o}C = \frac{\text{output in millivolts}}{0.0395 \text{ millivolts}/{}^{o}C}$$

The psychrometer (soil suction) voltage output, E_T (microvolts) is converted to the equivalent output at the calibration temperature of 25^{o}C, E_{25}, by

$$E_{25} = \frac{E_T}{0.325 + 0.027T}$$

When at least three stable output readings are obtained, the average of the three readings is plotted versus the corresponding moisture retention force or soil suction on arithmetic scales as shown in Figure 15. A convenient scale for plotting the calibration line for the range of indicated calibration standard concentrations is 2.5 tsf/cm for the ordinate and 2.5 microvolts/cm for the abscissa. Typical thermocouple psychrometer calibration lines are linear and can be expressed using the following equation:

Figure 15



Typical thermocouple psychrometer calibration line

$$\tau = mE_{25} - n \tag{3}$$

where

τ = soil suction, tsf
m = slope of the calibration line
n = y-intercept of the calibration line

The slope will always be positive, and the y-intercept should be equal to or less than zero. The calibration line is good for the useful life of the thermocouple psychrometer; however, under normal use an annual check of the calibration by at least one point will assure that the equipment is operating properly.

Collection of soil samples involves drilling into undisturbed claystone or shale and then obtaining soil samples in one of the following ways:

(a) Push shelby tube (thin-walled sampling device about 3 inches in diameter) at least 6 inches into undisturbed material and retrieve.
(b) Core into undisturbed material several feet with NX core barrel (about 2 inches in diameter).
(c) Retrieve "undisturbed" material with split-spoon sampler (about 1¼ inches in diameter and 18 inches in length.)

Samples obtained with the split-spoon sampler and the core barrel are protected from moisture loss by coating the entire soil sample with wax. The samples inside the shelby tubes are protected from moisture loss by applying wax to both ends of the tube.

The split-spoon sampling device is less desirable for retrieving samples because a 140 lb. hammer is used to pound the sampler into the soil. This method tends to cause more disturbance to the sampled material than do the other methods.

The testing procedure begins by dividing the sample into five soil specimens of equal sized cubes with side dimensions of approximately 1.5 inches. Place one of the specimens in the aluminum dish and insert into the metal sample container. Seal the sample container with the rubber stopper containing the thermocouple psychrometers, and place in the thermal box. This specimen represents the natural condition of the soil.

The remaining four specimens, depending on their natural water contents, are either wetted with varying amounts of distilled water or dried at room temperature for varying lengths of time to establish a range of water content conditions. In most cases, variations of 1.5 to 2.0 percent moisture from one specimen to another is established.

Place the specimens to be wetted into the metal sample containers, adding varying amounts of water to the specimens as described above. Immediately seal the wetted specimens with the rubber stoppers containing the thermocouple psychrometers and place in the thermal containers.

Allow the remaining specimens to dry at room temperature for varying lengths of time as described above. Place each dried specimen into the metal sample container and seal with a rubber stopper, containing a thermocouple psychrometer, and place in the thermal container.

Allow the specimens to come to equilibrium in the sealed containers. Temperature equilibrium is attained within a few hours after placing the cover of the thermal container. Equilibrium of the relative humidity of the air measured by the psychrometer and the relative humidity in the soil specimen is usually obtained within 48 to 72 hours.

Using the appropriate switch, read and record the temperature output of the thermocouple psychrometer in millivolts.

Change the switch from thermocouple to psychrometer, set the meter to zero, apply a cooling current of approximately 8 mA for 15 seconds, read and record the psychrometer output in microvolts. The cooling currents and times should be identical to those used to determine the calibration curves.

Repeat this procedure for each of the thermocouple psychrometers in the equipment setup.

After the readings are completed, remove the specimens from the containers. Determine the dry density (volume displacement method) from a specimen which represents the shelby tube sample.

After completing the test sequence, the specimens are removed, and the dry densities (volume displacement method) and water contents are determined for each. A suggested data sheet that assures correct collection of the required data is shown in Figure 16.

Data Reduction and Interpretation. The soil suction data is reduced by first converting the thermocouple output (millivolts) to temperature (^{o}C) using Equation 1. The psychrometer output (microvolts) is converted to an equivalent output at the calibration temperature using Equation 2. The soil suction of the individual specimens is determined by substituting the equivalent psychrometer output into the psychrometer calibration line equation. The data is then plotted versus water content on a semilog plot to establish the log suction versus water content relationship, Figure 17, which is linear and has the form

$$\log \tau = A - Bw \tag{4}$$

where

A = y-intercept
B = slope
w = water content, percent

Generally, three-cycle semilog paper is sufficient to accommodate all of the data points. A convenient scale factor for the abscissa (water content) is 10 percent per inch. By keeping track of the points representing natural conditions, all of the data points are used to establish the τ- w relationship. If some variation occurs at the upper or lower end of the curve because the limits of the measurement range are approached, the data points between soil suction values of 2 and 20 tsf should be used to establish the τ- w relationship. The slope, B, of the line is determined by calculating the inverse of the change in water content over one cycle of the log scale. The intercept, A, is calculated by applying Equation 4 at soil suction equal to 1 tsf.

Besides the A and B parameters, the prediction of volume change using soil suction data, a volumetric compressibility factor, α, is required that relates the change in volume to a corresponding change in water content. The value of α is determined by calculating the slope of the specific volume versus water content relationship. Convenient scale factors for the specific volume versus water content relationship are 0.25 units per inch for the ordinate (specific volume) and 5 percent per inch for the abscissa (water content). Occasionally, the specific volume versus water content data may indicate an a greater than one. In these limited situations, a should be taken as one since the compressibility factor cannot be greater than one.

Figure 16
Soil Suction Data Sheet

LAB NO. 208

SAMPLE NO. 1

PROJECT Research

LOCATION Site 12

V O L U M E

HEIGHT = 5.30 in.

DIAMETER = 2.375 in.

AREA, $A_o = .7854d^2 =$ 4.430 in.^{2}

VOLUME, $V_o = A_o \times H =$ 23.479 in.^{3}

$V_o \div 1728 =$ 0.0136 ft.^{3}

SPECIFIC GRAVITY, $G_s =$ 2.75

WET WEIGHT = 802.3 gms.

DRY WEIGHT, $W_s =$ 675.5 gms.

WEIGHT OF WATER, $W_w =$ 126.8 gms.

MOISTURE, W = 18.8 %.

V O I D   R A T I O

$V_w = W_w \times 3.534 \times 10^{-5} =$ 0.00448 ft.^{3}

$V_s = \frac{W_s}{G_s} \times 3.534 \times 10^{-5} =$ 0.00868 ft.^{3}

$V_v = V_o - V_s =$ 0.00492 ft.^{3}

$e_o = V_v/V_s =$ 0.57

$S = V_w/V_v =$ 91.1 %.

WET DENSITY = 130.1 pcf.

DRY DENSITY = 109.5 pcf.

S O I L   S U C T I O N

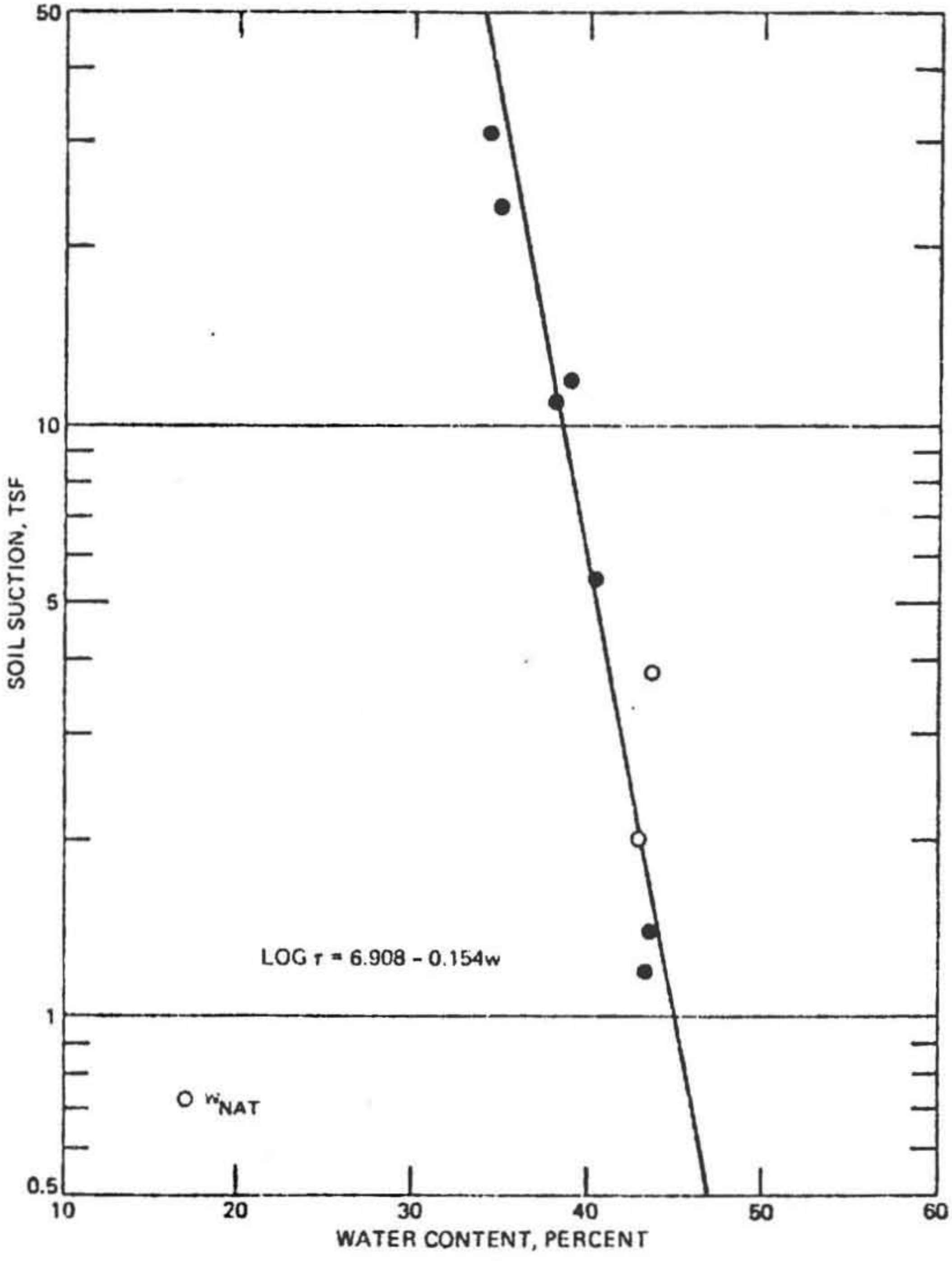
		PSYCHROMETER OUTPUT (E_T)								
t, millivolts	T, temperature °C	1.	2	3	4	5	6	7	8	9
.97	24.6	7.0	6.8	6.2	6.8	6.6	13.0	19.5	19.0	21.8
1.0	25.3	5.7	5.5	5.8	5.8	5.5	13.5	19.5	19.0	22.0
.96	24.3	3.8	3.9	3.6	3.4	3.6	13.5	20.5	19.5	23.0
*E_{25}, MICROVOLTS		3.9	4.0	3.7	3.5	3.7	13.8	20.9	19.9	23.4
**SOIL SUCTION, (τ)................		4.2	4.3	3.3	3.0	3.0	26.0	44.4	38.2	44.5
WEIGHT OF WET SOIL................		23.0	23.0	20.0	21.3	20.8	19.2	18.6	18.3	18.4
WEIGHT OF DRY SOIL................		18.5	18.7	16.2	16.5	16.3	16.7	16.7	16.3	16.7
MOISTURE CONTENT (%)..............		24.3	23.0	23.5	29.1	27.6	15.0	11.4	12.3	10.2
WATER CONTENT (0, +, -)...........		0	0	+	+	+	-	-	-	-

* $E_{25} = E_T/(0.325 + 0.027T)$

** Use individual calibration curve

$T(°C) = t/0.0395$ or use conversion chart

Figure 17



Typical soil suction versus water content relationship

Heave Prediction. The vertical heave of an expansive clay strata may be estimated using the following equation:

$$\frac{\Delta H}{H} = \frac{C_\tau}{1 + e_0} \left[(A - Bw_0) - \log\left(\tau_{mf} + \alpha\sigma_f\right)\right] \qquad (5)$$

where

H = stratum thickness, ft.
C_τ = suction index, $G_s/100B$
e_0 = initial void ratio
w_0 = initial moisture content, percent
τ_{mf} = final matrix soil suction, tsf
α = compressibility factor
σ_f = final applied pressure (overburden plus external load), tsf

The suction index, C_τ, reflects the rate of change of void ratio with respect to soil suction and can be calculated as shown above. The laboratory data necessary to apply Equation 5 include G_s, e_0, A, B, w_0, and α all of which (except G_s) can be easily determined in the soil suction test procedure. The remaining two variables, τ_{mf} and σ_f, are functions of the assumed depth of active zone and the assumed final soil suction profile, both of which will be discussed in subsequent paragraphs. The compressibility factor for CH clays is commonly set equal to one, because the voids of these soils are filled with water within a wide range of moisture contents (quasi-saturated). In the absence of measured data, the compressibility factor may be roughly estimated from the PI by

$PI < 5 \quad \alpha = 0$
$PI > 40 \quad \alpha = 1$
$5 < PI < 40 \quad \alpha = 0.0275\,PI - 0.125$

The equations described above provide predictions of in-situ volume change of a soil stratum with respect to field conditions of soil composition, structure, initial and equilibrium moisture profiles, and confining pressures. Vertical rise at the ground surface may be estimated by summing the volume change of each stratum in the soil profile.

APPENDIX D

DESCRIPTION OF R-VALUE TEST

The R-value as determined by the following procedure will be referred to as R. The details of this test method are described in ASTM D 2844(1) or AASHTO T-190(2).

The soil sample to be tested and water are mixed, allowed to permeate, then compacted on a kneader compactor to about a 2.5 in. height in the bottom of a 4 in. diameter rough walled mold. The 5 in. high mold is inverted and the specimen is pushed to the other end. A uniformly increasing pressure is applied to the specimen until water exudes from the bottom. The pressure at which this occurs is called the exudation pressure. Three specimens are prepared with exudation pressures between 100 and 800 psi.

The specimens are placed in expansion pressure devices and covered with water. The next day the expansion pressure which has developed is read.

Each specimen is pushed from the mold into the stabilometer and a metal follower is placed on top. A vertical load is applied to produce a uniform rate of movement of .05 in/min. At 2000 lbf the horizontal pressure is read. The vertical load is reduced to 1000 lbf and the horizontal pressure is adjusted to 5 psi. The horizontal pressure is raised from 5 to 100 psi by turning the stabilometer pump handle at about two turns per second. The number of turns are measured and are recorded as the turns of displacement, D, of the specimen. The resistance, R, is determined from the following formula:

$$R = 100 - \left[100/(2.5/D)(160/P_h - 1) + 1 \right]$$

where:

P_h = horizontal pressure, psi (kP_a)
D = turns displacement reading.

The R-values of the three specimens are plotted against exudation pressure and the R-value at 300 psi exudation pressure is taken from this plot.

Expansion pressure is also used to calculate an R-value.

APPENDIX E

Definitions

R-value - A numerical value expressing the measure of a soil or aggregate's ability to resist the transmission of a vertical load in a lateral or horizontal direction.

Stabilometer - A device used in R-value testing which measures the transmission of lateral pressure and turns displacement of a specimen subjected to a vertical load. The turns displacement is used to compensate for the coarse surface texture of the specimen.

Exudation Pressure - In R-value testing the pressure at which compression of the specimen causes water to exude from the bottom of the specimen. The presence of water is detected by the water making an electrical connection between the mold and contacts on the exudation indicating device.

Standard Compaction - AASHTO T-99(2) (Method A) - A test to determine the relationship between the moisture content and density of soil passing a No. 4 sieve, compacted in a mold of given size with a 5.5 lb. rammer dropped from a height of 12 in. Four specimens are usually compacted at water contents approximately 2 percentage points apart. Wet densities and moisture are determined and dry density is calculated. The dry densities are plotted as ordinates, and the corresponding moisture as abscissas. The moisture content corresponding to the peak of the curve is the "optimum moisture content" and the dry density at optimum moisture content is termed the "maximum dry density."

Resilient Modulus - The maximum applied stress divided by the recovered strain. The stress is applied and removed, causing a temporary deformation of the material.

Stress - Force per unit area. It is a measure of the intensity of the force.

Strain - Deformation per unit length. It is a measure of the intensity of deformation.

Test Site - A 500' segment of completed embankment chosen on the basis of uniformity and soil classification.

Test Location - A location on a test section chosen, at random, for field testing and sampling.

Sample - A representative fraction of the embankment soil collected at each test site for laboratory testing.

Pavement Structure - The combination of subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed.

18^k Edla - 18,000 pound single axle Equivalent Daily Load Applications. Used to describe traffic.

Regional Factor - A numerical factor expressed as a summation of the values assigned for precipitation, elevation, and drainage.

Soil Support Value - A number which expresses the relative ability of a soil or aggregate mixture to support traffic loads through the pavement structure.

Strength Coefficient - A factor used for expressing the relative strength of substitution value of, layers, one to the other, for conversion purposes in a pavement structure.

Flexible Pavement - A pavement structure which maintains intimate contact with and distributes loads to the subgrade and depends upon aggregate interlock, particle friction, and cohesion for stability.

Rigid Pavement - Pavements which due to high bending resistance distribute loads to the foundation over a comparatively large area, e.g., portland cement concrete pavement and brick, stone block, or bituminous pavement on a portland cement concrete base.

Soil Suction - Soil suction is a measure of the pulling force exerted on water by a soil or alternatively, it is the free energy present in soil water with respect to a pool of pure water located outside of the soil at the same elevation. This energy is available to pull in water and expand the soil against the pressure of overlying pavement structure.

Psychrometer - A device for measuring relative humidity.

Expansion Pressure Test - A method of measuring the amount of pressure exerted by and R-value test specimen (subsequent to exudation determination) when inundated with water.

<u>Third Cycle Expansion Pressure Test</u> - A method of determining the amount of vertical expansion pressure exhibited by a soil specimen (remolded at a specified moisture and density) when inundated with water. The test procedure is designated as Colorado Procedure L-3103 and is given in Appendix B.