Report No. CDOH-P&R-R&SS-74-1

implementation package for swelling soils treatment in colorado

M. C. Safford
Planning and Research Division

F. W. Egger
Staff Materials Division

Colorado Division of Highways
4201 E. Arkansas Avenue
Denver, Colorado 80222

December 1974

Prepared for

FEDERAL HIGHWAY ADMINISTRATION
Research and Development
Washington, D. C. 20590

DOH Form No. 758 Rev. July 1972
Form DOT F 1700.7 (8-69)

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Implementation Package for Swelling Soils Treatment in Colorado		5. Report Date December 1974 6. Performing Organization Code
7. Author(s) M. C. Safford F. W. Egger		8. Performing Organization Report No. CDOH-P&R-R&SS-74-1
9. Performing Organization Name and Address Colorado Division of Highways Planning and Research Division Research Unit Staff Materials Division - Soils Unit		10. Work Unit No. 11. Contract or Grant No. 1481
12. Sponsoring Agency Name and Address State Department of Highways 4201 E. Arkansas Avenue Denver, Colorado 80222		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Results from this report indicate that minor subgrade treatment often is not sufficient to prevent post-construction swelling. Treatments vary in complexity and unit costs, however, the area, type of subgrade and its condition often dictate which treatment is preferred.

Hopefully, this report will be useful as a guideline for soils engineers in the Colorado area as well as those where soil characteristics are similar to that found in Colorado.

The information forming the basis for this "Implementation Package" is taken primarily from Colorado Report No. CDOH-P&R-R&SS-73-6 "Clifton Highline Canal Experimental Project I 70-1(14)" and No. CDOH-P&R-R&SS-73-7 "Seibert Experimental Project." These reports have been submitted to Colorado Division of the Federal Highway Administration.

17. Key Words Swelling Soils, Lime Treatment, Asphalt Membrane, Subexcavation, Cost, Depth of Treatment		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 29	22. Price

TABLE OF CONTENTS

INTRODUCTION

The implementation package summarizes Colorado research projects which have investigated the causes and treatments of swelling in cut sections of highways. The results show that several inches or a few feet of granular material placed on subgrades under pavement is a poor design in soils that have swell potential. A waterproofing of the subgrade or increasing the moisture content to AASHTO T99 optimum down for a few feet will result in a more stable roadway.

THE PROBLEM

Swelling soils in Colorado have been causing considerable problems and expense for maintenancemen and hazards for motorists since highways were paved. The trouble spots are in cut sections. Embankments made of swelling soils but with closely controlled moisture and density cause very few problems.

A research project was begun in 1962 by the University of Colorado in an attempt to determine the mechanism of expansion of certain clay soils in Colorado. As a result of this and subsequent investigations, Colorado Division of Highways engineers and University of Colorado investigators(1) concluded in 1967 the following:

1. The distress is in the form of differential swelling or volume change.
2. The swelling is deep-seated - probably effective down to depths of 20 to 25 feet, although the majority of the volume change is from the upper portion of the subgrade, due to surface water.
3. The swelling is definitely associated with an increase in moisture in the subgrade, although some volume change may take place with very little increase in moisture if the soil is already quite moist.
4. The soil classification alone is not a very good indication of the amount of swell which a subgrade

will display. The moisture in the soil must also be considered. In the case of the distressed area on this project, it appears that the natural field moisture was 15%, the top foot or two was manipulated and compacted at nearly 30%, but the layers below this level remained very close to 15% moisture. The clays and shale are actually absorbing water up to approximately 35%, and increasing in volume by 10% in going from 15% to this 35% value.

Prior to that time, the usual surfacing design for highways was for a thickness of subbase based on the California Bearing Ratio, four to six inches of aggregate base course and three to eight inches of pavement. This was proven to be an inadequate design in cuts through swelling soils.

GUIDELINES TO SOLUTION

Maintaining the swelling soil subgrade moisture content at the in situ amount is one method of preventing future distress of highways. Good drainage - wide ditches and subdrains to intercept water - is a conventional method of solution. Increasing the moisture content to AASHTO T99 optimum and maintaining it is another, but avoiding areas of swelling soils is the best method. Since it is virtually impossible to avoid these soils in Colorado, the other solutions are recommended for this State.

TESTING PROCEDURES USED BY COLORADO

There are many methods of testing soils to determine whether or not there is a swelling potential. We do not know of a universal test, however, that will accurately predict the amount of swelling that will occur in a particular section of highway.

Colorado Division of Highways relies a great deal on the plasticity index of a soil as an indication of swelling potential. A high plasticity index usually means that the material is a swelling soil.

The PI, as it is commonly called, is determined by AASHTO T89 Mechanical Method (for liquid limit), and AASHTO Method T90 (plastic limit and plasticity index). See Appendix A page 10 for a description of these test methods.

If a soil has a high PI and, therefore, is suspected of being a swelling type soil, then the District Materials engineer may request Staff Materials to perform a third cycle expansion pressure test on a sample of the soil in question. This test is Colorado Procedure L-3103 and is printed as Appendix B page 22 along with an example. This will indicate the amount of cover - reconditioned subgrade, subbase, base and surfacing material - required to oppose the swelling force. Even though the results of the third cycle expansion pressure test indicate total cover required, the test is used primarily to determine the existence of an expansive soil at field moisture conditions and if subgrading is required. If so, the actual depth of treatment is determined using the plasticity index as outlined in Appendix C.

Some designers use DOH Memo #323 Appendix C page 28 for a guide to specify the amount of subexcavation and backfilling needed in swelling soils.

COLORADO'S EXPERIMENTAL TREATMENTS OF SWELLING SOILS

Clifton Project[2] This project had several different test sections in roadway cuts through Mancos Shale and some standard design sections in embankments. CBR swell tests indicated that this shale had a potential swell of 0.4 to 3.1% with an average of 1.6%. A description of the treatment of the subgrades for each section is given.

Section Number	Treatment
1. & 7.	Subexcavated 2 ft., backfilled with coarse aggregate (3/4" to 1/4").
2. & 8.	Subexcavated 2 ft., backfilled with Class 2 subbase (95-100% pass the 3 in. sieve and 5-15% pass the No. 200).

Section Number	Treatment
3., 5., 15., & 19.	Subexcavated 2 ft., backfilled with fine sand.
4. & 6.	Subexcavated 2 ft., backfilled with Structure backfill (granular).
9. & 11.	Standard (scarified 1 ft. deep, wetted and compacted).
10.	4% hydrated lime mixed in the top 1 ft. of subgrade.
12.	Lime shafts, 6" diameter filled with hydrated lime paste.
13.	1% hydrated lime mixed in the top 3 ft. of subgrade, sprinkled for three weeks and compacted.
14.	Scarified top 3 ft. of subgrade, sprinkled for three weeks and compacted.
16.	Subexcavated 2 ft., top of subgrade covered with asphalt membrane and backfilled with fine sand.
17.	Subexcavated 2 ft., backfilled with A-4 material (silty soil).
18.	Subexcavated 2 ft., asphalt membrane applied and backfilled with silty soil.

Seibert Project(3) Lime shafts were used in one area of known swelling and lime till in another. Two standard sections were used for comparisons.

Elk Springs Project(4) On this project there are several test sections with different thicknesses of Plant Mixed Bituminous Base Course placed directly on the subgrade. An asphalt membrane was applied to the ditch areas from the edge of the base course to the same elevation on the back slope of the cut. There are two sections which have as a base course a one foot thick layer of dry embankment material completely surrounded by an asphalt membrane.

Agate Project(5) There are three test sections in this short project. One was subexcavated four feet and backfilled with a clay soil, and the middle section was subexcavated two feet deep and backfilled with a clayey sand. The last section has an asphalt membrane applied directly to the subgrade and covered with a two inch sand cushion. The surfacing throughout the project consists of four inches of untreated base course and eight inches of Portland cement concrete pavement.

Whitewater Project(6) Two small instrumented test sections were constructed in Mancos Shale on US 50 south of Grand Junction. In one section a plastic membrane was used to protect the subgrade from moisture transferred from the subbase. In the other no protective membrane was provided.

Other Projects(7) Lime shafts, lime till, asphalt membrane and subexcavation with clay backfill have been evaluated in different swelling soil areas of the State.

TREATMENT RESULTS

1. Thin sections (six inches and less) of bituminous pavements which had been placed directly on swelling soils had the shortest life.
2. Test sections which were subexcavated and backfilled with granular or permeable material had the next to worst performance.
3. Lime till of one or three feet depth of treatment indicated average to good performance.
4. Lime shafts six inches in diameter had average performance.
5. Lime shafts one foot in diameter performed very well.
6. Asphalt membrane sections had good performance.
7. Sections subexcavated and backfilled with impervious material had good performance.

It was noted that the amount of swelling in the Clifton Project did not vary in proportion to the depth of cut but apparently with the type of treatment.

TREATMENT COSTS

Based on Colorado's 1972 Cost Data and computed for a 100 foot length of a four lane divided highway, the costs for the various treatments are listed below.

Description	Cost
Scarify 3', sprinkle for 3 weeks and compact	$ 540
Subexcavate 2', backfill with silty or clayey soil	960
Scarify 3', mix in 1% hydrated lime, sprinkle for 3 weeks and compact	1,240
Apply asphalt membrane to top of subgrade	1,250
Mix top 12" of subgrade with 4% hydrated lime, sprinkle and compact	1,660
Subexcavate 2', apply asphalt membrane and backfill with silty or clayey soil	2,210
Subexcavate 2', backfill with fine sand	2,530
Subexcavate 2', backfill with subbase	2,860
Subexcavate 2', backfill with Structure Backfill	3,000
Lime Shafts	3,310
Subexcavate 2', place asphalt membrane and backfill with fine sand	3,780
Subexcavate 2', backfill with coarse aggregate (3/4" to 1/4")	3,970

RECOMMENDATIONS

The following recommendations are based on the experiences of Colorado Department of Highways in semi-arid areas but may be applicable in other states.

1. In areas of low (0 to 10 PI) or zero swell potential - standard design or full depth asphalt surfacing.
2. In roadway cuts of medium (10 to 30 PI) swell potential - subexcavate and backfill* with a uniform impermeable soil, preferably a silt or clay, A4 to A6 classification.

*Backfill should be accomplished according to our Standard Specifications which limit the thickness of the horizontal layers placed to eight inches. Each layer should then be brought to optimum moisture and compacted to 95% of laboratory density determined by AASHTO T99 Method C or D.

3. In roadway cuts of high (above 30 PI or in areas of dry dense shales) swell potential - apply asphalt membrane across the full width of roadway and beyond the side ditches. Due to the energy crisis, availability is restricted and cost is high. A substitute for this treatment would be the method mentioned for Recommendation No. 2. The description of depth and manner of treatment is included in Appendix C on page 28. It should be kept in mind that the procedure outlined in Appendix C is dependent on variables other than PI value. The moisture content, liquidity index or other parameters may reduce or eliminate swell potential resulting in Appendix C not being used.

   In areas of very dry dense subgrade such as the Mancos Shale formations in the semi-arid areas of western Colorado, subgrading according to DOH Memo 323 may not be recommended. In these cases an asphalt membrane is used to keep the subgrade in an in situ condition.

   Lime till has been successfully used in Colorado experimental projects only. Since lime till costs about 58% more than No. 2 above, it has not been used as a standard construction procedure.

   Lime shafts have been used by maintenance. They can be installed through surfacing and base course which reduces inconvenience to the public on established highways. They are usually spaced on 5' centers and drilled 10' deep using a 12" auger. Smaller diameter shafts have been ineffective.

   Maintenance subexcavation costs may approach or surpass the cost of lime shafts. This would require the removal of surfacing, base course and subexcavate, and then replace everything.

   If there is a water bearing layer at or just beneath the top of subgrade, other treatments would be necessary. One method would be to leave this section unpaved until the swelling caused by unloading has nearly ceased. One of the test sections on the Elk Springs Project was located in this type of situation. Perforated underdrains had been installed four to six feet beneath each side ditch, but there was considerable swelling in the roadway after it had been paved. This section had only four inches of hot bituminous pavement placed directly on the subgrade with an asphalt membrane extending from beneath the edge of pavement, under the ditch and up the backslope. The remainder of this cut is paved with nine inches of HBP and is performing very well.

Full depth asphalt has performed quite well in Southeastern Colorado and is recommended for a drier and warmer climate.

SUGGESTIONS FOR RESEARCH

Perhaps the phenomenon of swelling soils is too complicated, but a great help to highway engineers would be a simple quick test that would accurately predict the amount of swell in different soils.

In many instances engineers have not allowed for a resulting amount of swelling, and maintenance costs have been exorbitant. Conversely, engineers have overdesigned and construction costs were more than necessary.

Research in a large coordinated effort is needed to determine the feasibility of a simple test for swelling soils. If the results are promising, then the actual test should be determined and standardized for other states.

REFERENCES

(1) Colorado Division of Highways, Swelling Soils Study at Cedar Point - I 70-4(6) - Final Follow-Up Report, May 1967.

(2) Gerhardt, B. B., and Safford, M. C., Clifton Highline Canal Experimental Project I 70-1(14), Colorado Division of Highways, December 1973.

(3) Safford, M. C., and Swanson, H. N., Seibert Experimental Project, Colorado Division of Highways, December 1973.

(4) Colorado Division of Highways, Asphalt Membrane Project at Elk Springs - First Interim Report, February 1970.

(5) Colorado Division of Highways, Treatment of Swelling Soils West of Agate, Colorado, February 1969.

(6) Colorado Division of Highways, The Whitewater Experimental Project: An Instrumented Roadway Test Section to Study Hydrogenesis, November 1970.

(7) Colorado Division of Highways, Lime Shaft and Lime Till Stabilization of Subgrades on Colorado Highways - 1967.

METHODS OF SAMPLING AND TESTING

APPENDIX A

Standard Methods of

Determining the Liquid Limit of Soils

AASHO DESIGNATION: T 89–68

DEFINITION

1.1 The liquid limit of a soil is that water content as determined in accordance with the following procedure at which the soil passes from a plastic to a liquid state.

(AASHO STANDARD SPECIFICATIONS FOR HIGHWAY MATERIALS — 10th EDITION)

APPARATUS

2.1 The apparatus shall consist of the following:

2.1.1 *Dish.*—A porcelain evaporating dish or similar mixing dish, about 4½ in. (115 mm) in diameter.

2.1.2 *Spatula.*—A spatula or pill knife having a blade about 3 in. (76 mm) in length and about ¾ in. (19 mm) in width.

2.1.3 *Liquid Limit Device.*—A mechanical device consisting of a brass dish and carriage, constructed according to the plan and dimensions shown in Fig. 1.

2.1.4 *Grooving Tool.*—A combined grooving tool and gage conforming to the dimensions shown in Fig. 1.

2.1.5 *Containers.*—Suitable containers such as matched watch glasses which will prevent loss of moisture during weighing.

2.1.6 *Balance.*—A balance sensitive to 0.01 g.

2.1.7 *Oven.*—A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5 C (230 ± 9 F) for drying moisture samples.

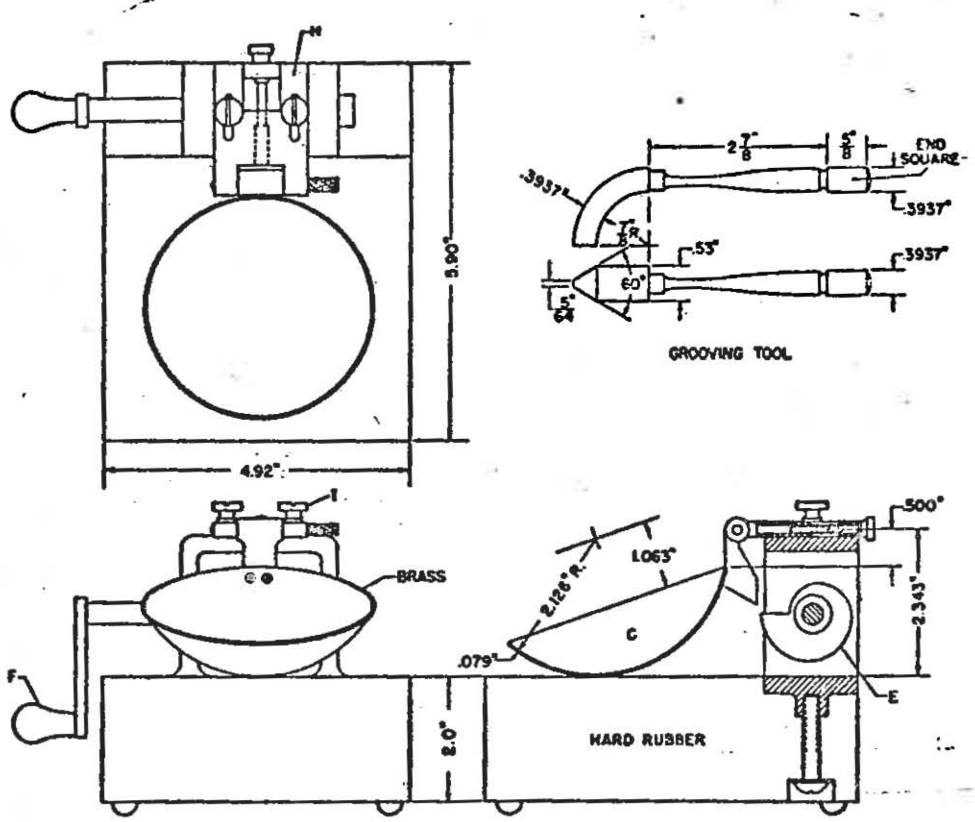


Fig. 1.—*Mechanical Liquid Limit Device.*

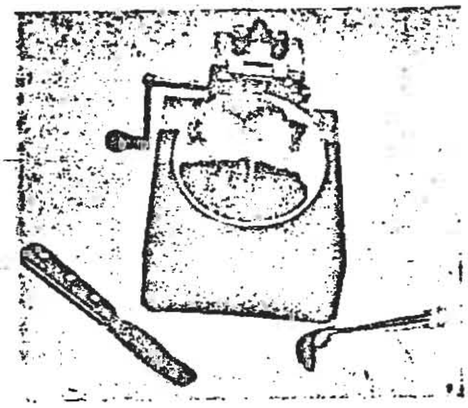


FIG. 2.—*Liquid limit device with soil sample in place.*

MECHANICAL METHOD

SAMPLE

3.1 A sample weighing about 100 g. shall be taken from the thoroughly mixed portion of the material passing the 0.425 mm (No. 40) sieve which has been obtained in accordance with the Standard Method of Preparing Disturbed Soil Samples (AASHO T 87), or the Standard Method of Wet Preparation of Disturbed Soil Samples for Test (AASHO T 146).

ADJUSTMENT OF MECHANICAL DEVICE

4.1 The liquid limit device shall be inspected to determine that the device is in good working order; that the pin connecting the cup is not worn sufficiently to permit side play; that the screws connecting the cup to the hanger arm are tight; and that a groove has not been worn in the cup through long usage. The grooving tool shall be inspected to determine that the critical dimensions are as shown in Fig. 1.

4.2 By means of the gage on the handle of the grooving tool, and the adjustment plate H, Fig. 1, the height to which the cup C is lifted shall be adjusted so that the point on the cup which comes in contact with the base is exactly 1 cm. (0.3937 in.) above base. The adjustment plate H shall then be secured by tightening the screws, I. With the gage still in place, the adjustment shall be checked by revolving the crank rapidly several times. If the adjustment is correct a slight ringing sound will be heard when the cam strikes the cam follower. If the cup is raised off the gage or no sound is heard, further adjustment shall be made.

PROCEDURE

5.1 The soil sample shall be placed in the mixing dish and thoroughly mixed with 15 to 20 cc of distilled or demineralized water by alternately and repeatedly stirring, kneading, and chopping with a spatula. Further additions of water shall be made in increments of 1 to 3 cc. Each increment of water shall be thoroughly mixed with the soil as previously described before another increment of water is added. The cup of the liquid limit device should not be used for mixing soil and water.

5.2 When sufficient water has been thoroughly mixed with the soil to form a uniform mass of stiff consistency, a sufficient quantity of this mixture shall be placed in the cup above the spot where the cup rests on the base and shall then be squeezed and spread into the position shown in Fig. 2 with as few strokes of the spatula as possible, care being taken to prevent the entrapment of air bubbles within the mass. With the spatula the soil shall be leveled and at the same time trimmed to a depth of 1 cm at the point of maximum thickness. The excess soil shall be returned to the mixing dish. The soil in the cup of the mechanical device shall be divided by a firm stroke of the grooving tool along the diameter through the center line of the cam follower so that a clean sharp groove of the proper dimensions will be formed. To avoid tearing of the sides of the groove or slipping of the soil cake on the cup, up to six strokes from front to back or from back to front counting as one stroke, shall be permitted. The depth of the groove should be increased with each stroke and only the last stroke should scrape the bottom of the cup.

5.3 The cup containing the sample prepared as described in 5.2 shall be lifted and dropped by turning the crank F at the rate of two revolutions per second until the two sides of the sample come in contact at the bottom of the groove along a distance of about ½ inch (12.7 mm). The number of shocks required to close the groove this distance shall be recorded. The base of the machine shall not be held with the free hand while the crank F is turned.

NOTE 1.—Some soils tend to slide on the surface of the cup instead of flowing, if this occurs, more water should be added to the sample and remixed, then the soil-water mixture placed in the cup, a groove cut with the grooving tool and 5.2 repeated. If the soil continues to slide on the cup at a lesser number of blows than 25, the test is not applicable and a note should be made that the liquid limit could not be determined.

5.4 A slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, shall be removed and placed in a suitable container. The container and soil shall then be weighed and the weight recorded. The soil in the container shall be oven-dried to constant weight at 110 ± 5 C (230 ± 9 F) and weighed. This weight shall be recorded and the loss in weight due to drying shall be recorded as the weight of water.

5.5 The soil remaining in the cup shall be transferred to the mixing dish. The cup and grooving tool shall then be washed and dried in preparation for the next trial.

5.6 The foregoing operations shall be repeated for at least two additional portions of the sample to which sufficient water has been added to bring the soil to a more fluid condition. The object of this procedure is to obtain samples of such consistency that at least one determination will be made in each of the following ranges of shocks: 25 — 35, 20 — 30, 15 — 25, so the range in the three determinations is at least 10 shocks.

CALCULATION

6.1 The water content of the soil shall be expressed as the moisture content in percentage of the weight of the oven-dried soil and shall be calculated as follows:

$$\text{Percentage moisture} = \frac{\text{wt. of water}}{\text{wt. of oven-dried soil}} \times 100$$

PREPARATION OF FLOW CURVE

7.1 A "flow curve" representing the relation between moisture content and corresponding number of shocks shall be plotted on a semilogarithmic graph with the moisture contents as abscissae on the arithmetical scale, and the number of shocks as ordinates on the logarithmic scale. The flow curve shall be a straight line drawn as nearly as possible through the three or more plotted points.

LIQUID LIMIT

8.1 The moisture content corresponding to the intersection of the flow curve with the 25 shock ordinate shall be taken as the liquid limit of the soil. Report this value to the nearest whole number.

MECHANICAL METHOD (ALTERNATE)

SAMPLE

9.1 A sample weighing about 50 g. shall be taken as described in Section 3.

PROCEDURE

10.1 The procedure shall be the same as prescribed in Section 5.1 through 5.5 except that the initial amount of water to be added in accordance with Section 5.1 shall be approximately 8 to 10 cc and the moisture sample taken in accordance with Section 5.4 shall be taken only for the accepted trial.

10.2 At least two groove closures shall be observed before one is accepted for the record, so as to assure that the accepted number of blows is truly characteristic of the soil under test.

NOTE 2.—Some soils are slow to absorb water, therefore it is possible to add the increments of water so fast that a false liquid limit value is obtained. This can be avoided if more mixing and/or time is allowed.

10.3 Groove closures between 15 and 40 blows may be accepted if variations of ± 5 percent of the true liquid limit are tolerable.

10.4 For accuracy equal to that obtained by the standard three-point method, the accepted number of blows for groove closure shall be restricted between 22 and 28 blows.

CALCULATION

11.1 The water content of the soil at the time of the accepted closure shall be calculated in accordance with Section 6.

LIQUID LIMIT

12.1 The liquid limit shall be determined by one of the following methods: the nomograph, Figure 3; the multicurve chart, Figure 4, the slide-rule with a special "blows" scale, Figure 5, of by any other method of calculation that produces equally accurate liquid limit values. The standard three-point method shall be used as a referee test to settle all controversies.

12.2 The key in Figure 3 illustrates the use of the nomograph (mean slope).

12.3 The chart (multi-flow-curve), Figure 4, is used by plotting on it a point representing the moisture content vs. number of blows for the accepted trial, and drawing a line through the plotted point parallel to the nearest chart curve. The moisture content corresponding to the intersection of this line with the 25-blow line shall be recorded as the liquid limit.

12.4 The special slide-rule, Figure 5, is used by setting the hair line of the indicator slide coincident with the A-scale value of the moisture content for the accepted groove closure, and moving the special scale until the number of blows used for closure is also under the hair line. The liquid limit will then be found on the A-scale opposite the end index of the B-scale, or opposite the middle index of the B-scale, which in turn is directly in line with the 25-blow mark of the special scale.

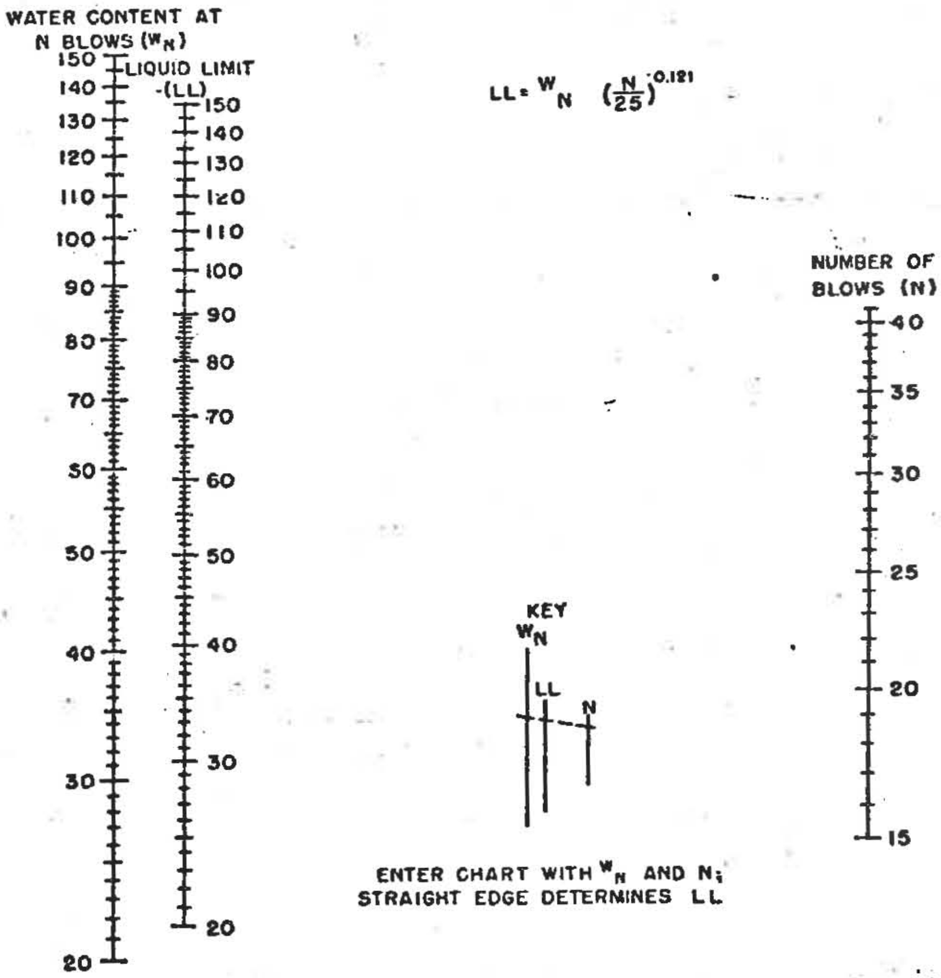


FIG. 3.—*Nomographic Chart Developed by the Waterways Experiment Station, Corps of Engineers, U. S. Army, to Determine Liquid Limit Using Mean Slope Method.*

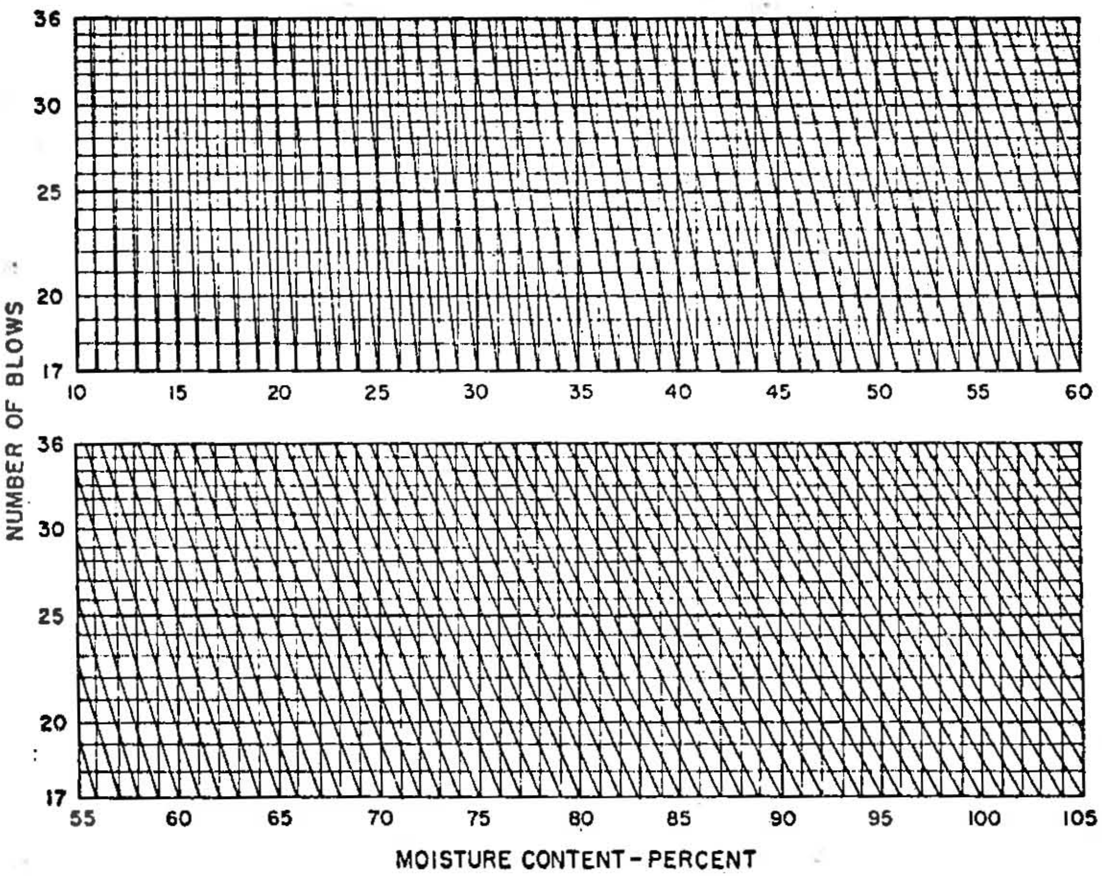
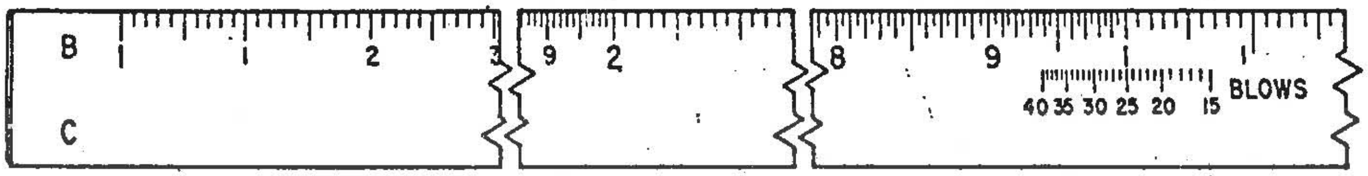
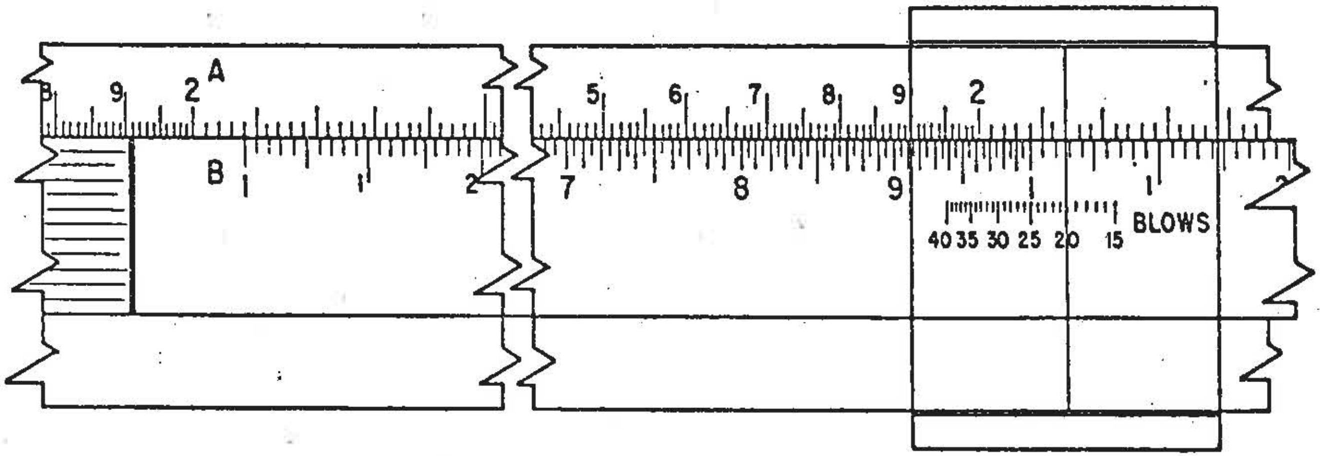


FIG. 4.—*Chart Developed by Washington State Highway Department for the Calculation of the Liquid Limit.*



A - LOCATION OF SPECIAL SCALE (BLOWS) WITH RESPECT TO B SCALE OF SLIDE RULE



B - SLIDE RULE SET FOR 21.4 PERCENT MOISTURE AT 20 BLOWS, INDICATING CALCULATED LIQUID LIMIT OF 20.8

Fig. 5.—*Slide Rule with Special Scale for the Calculation of the Liquid Limit.*

HAND METHOD (ALTERNATE)

SAMPLE

13.1 A sample weighing about 30 g. shall be taken from the thoroughly mixed portion of the material passing the 0.425 mm (No. 40) sieve which has been obtained in accordance with the Standard Method of Dry Preparation of Disturbed Soil Samples (AASHO T 87) or the Standard Method of Wet Preparation of Disturbed Soil Samples for Test (AASHO T 146).

PROCEDURE

14.1 The air-dried soil shall be placed in the mixing dish and thoroughly mixed with distilled or demineralized water until the mass becomes a thick paste. The mass of soil shall then be shaped into a layer 1 cm (approximately ⅜ in.) in thickness at the center and divided into two portions with the grooving tool as shown in the illustration at the top of Fig. 6.

14.2 The dish shall be held firmly in one hand, with the groove parallel to the line of sight, and tapped lightly with a horizontal motion against the heel of the other hand 10 times. The intensity of the blows shall be such that the effect on the soil sample is equivalent to that produced by 25 shocks applied to a sample of the soil at the same moisture content by dropping the brass cup of the mechanical device through a distance of 1 cm. (0.3937 in.) at the rate of two drops per second.

14.3 If the lower edges of the two-soil portions do not flow together, as shown at the bottom of Fig. 6, after 10 blows have been struck, the moisture content is below the liquid limit. More water shall be added and the procedure repeated. If the lower edges meet before 10 blows have been struck, the moisture content is above the liquid limit and the soil should be dried in an air current or by some other suitable method until more than 10 blows are required to close the groove. Small increments of water should then be added until the groove can be closed with 10 blows. Dry soil shall not be added to increase the number of blows required to close the groove.

14.4 When the lower edges of the two portions of the soil cake flow together for a distance of approximately ½ in. (12.7 mm) as shown in the illustration at the bottom of Fig. 6. after 10 blows have struck, the moisture content equals the liquid limit.

14.5 A slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, shall be removed and placed in a suitable container. The container and the soil shall then be weighed and the weight recorded. The soil in the container shall be oven-dried to constant weight at 110 ± 5 C (230 ± 9 F) and weighed. This weight shall be recorded and the loss in weight due to drying shall be recorded as the weight of water.

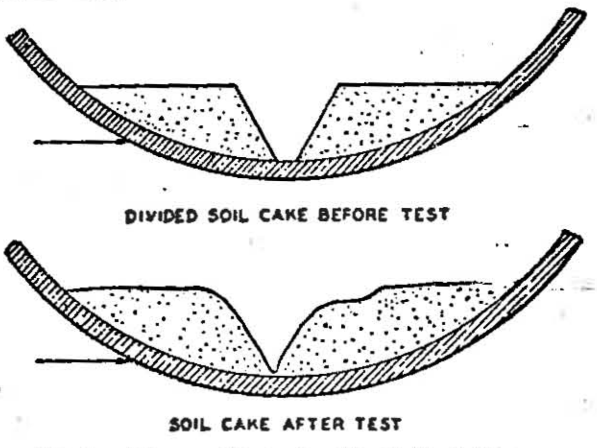


FIG. 6.—*Diagram Illustrating Liquid Limit Test.*

CALCULATION

15.1 The liquid limit is expressed as the moisture content in percentage of the weight of the oven-dried soil and shall be calculated as follows:

$$\text{Liquid limit} = \frac{\text{wt. of water}}{\text{wt. of oven-dried soil}} \times 100$$

CHECK OR REFEREE TESTS

METHOD TO BE USED

16.1 In making check or referee tests, the mechanical method shall be used. The results of liquid limit tests are influenced by:

16.1.1 The time required to make the test.

16.1.2 The moisture content at which the test is begun.

16.1.3 The addition of dry soil to the seasoned sample.

PROCEDURE

17.1 Therefore, in making the mechanical liquid limit test for check or referee purposes, the following time schedule shall be used:

17.1.1 Mixing of soil with water—5 to 10 minutes, the longer period being used for the more plastic soils.

17.1.2 Seasoning in the humidifier—30 minutes.

17.1.3 Remixing before placing in the brass cup—Add 1 cc. of water and mix for 1 minute.

17.1.4 Placing in the brass cup and testing—3 minutes.

17.1.5 Adding water and remixing—3 minutes.

17.2 No trial requiring more than 35 blows or less than 15 blows shall be recorded. In no case shall dried soil be added to the seasoned soil being tested.

———o———

Standard Methods of

Determining the Plastic Limit and Plasticity Index of Soils

AASHO Designation: T 90–70

DEFINITIONS

1.1 The plastic limit of a soil is the lowest water content determined in accordance with the following procedure at which the soil remains plastic. The plasticity index of a soil is the range in water content, expressed as a percentage of the weight of the oven-dried soil, within which the material is in a plastic state. It is the numerical difference between the liquid limit and plastic limit of the soil.

APPARATUS

2.1 The apparatus shall consist of the following:

2.1.1 *Dish.*—A porcelain evaporating dish, or similar mixing dish about 4½ inches (115 mm) in diameter.

2.1.2 *Spatula.*—A spatula or pill knife having a blade about 3 inches (76 mm) in length and about ¾ inch (19 mm) in width.

2.1.3 *Surface for Rolling.*—A ground glass plate or piece of smooth, unglazed paper on which to roll the sample.

2.1.4 *Containers.*—Suitable containers, such as matched watch glasses, which will prevent loss of moisture during weighing.

2.1.5 *Balance.*—A balance sensitive to 0.01 g.

2.1.6 *Oven.*—A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5 C (230 ± 9 F) for drying samples.

SAMPLE

3.1 If the plastic limit only is required, take a quantity of soil weighing about 20 g from the thoroughly mixed portion of the material passing the 0.425 mm sieve, obtained in accordance with the Standard Method of Dry Preparation of Disturbed Soil Samples for Test (AASHO T 87) or the Standard Method of Wet Preparation of Disturbed Soil Samples for Test (AASHO T 146). Place the air-dried soil in a mixing dish and thoroughly mix with distilled or demineralized water until the mass becomes plastic enough to be easily shaped into a ball. Take a portion of this ball weighing about 8 g for the test sample.

3.2 If both the liquid and plastic limits are required, take a test sample weighing about 8 g from the thoroughly wet and mixed portion of the soil prepared in accordance with the Standard Method of Test for Liquid Limit for Soils (AASHO T 89). Take the sample at any stage of the mixing process at which the mass becomes plastic enough to be easily shaped into a ball without sticking to the fingers excessively when squeezed. If the sample is taken before completion of the liquid limit test, set it aside and allow to season in air until the liquid limit test has been completed. If the sample taken during the liquid limit test is too dry to permit rolling to a ⅛ in. (3.2 mm) thread, add more water and remix.

PROCEDURE

4.1 Squeeze and form the 8-g test sample taken in accordance with 3.1 or 3.2 into an ellipsoidal-shape mass. Roll this mass between the fingers and the ground-glass plate or a piece of paper lying on a smooth horizontal surface with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling shall be between 80 and 90 strokes per min., counting a stroke as one complete motion of the hand forward and back to the starting position again.

4.2 When the diameter of the thread becomes ⅛ in. (3.2 mm) break the thread into six or eight pieces. Squeeze the pieces together between the thumbs and fingers of both hands into a uniform mass roughly ellipsoidal in shape, and reroll. Continue this alternate rolling to a thread ⅛ in. (3.2 mm) in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The crumbling may occur when the thread has a diameter greater than ⅛ in. (3.2 mm). This shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread ⅛ in. (3.2 mm) in diameter. The crumbling will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles; others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Heavy clay soils require much pressure to deform the thread, particularly as they approach the plastic limit, and finally, the thread breaks into a series of barrel-shaped segments each about ¼ to ⅜ in. (6.4 to 9.5 mm) in length. At no time shall the operator attempt to produce failure at exactly ⅛-in (3.2 mm) diameter by allowing the thread to reach ⅛ in. (3.2 mm) then reducing the rate of rolling or the hand pressure, or both, and continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal-shaped mass nearer to the required ⅛ in. (3.2 mm) final diameter.

4.3 Gather the portions of the crumbled soil together and place in a suitable tared container. Weigh the container and soil to the nearest 0.01 g and record the weight. Oven-dry the soil in the container to constant weight at 110 ± 5 C (230 ± 9 F) and weigh to the nearest 0.01 g. Record the loss in weight as the weight of water.

CALCULATIONS

5.1 Calculate the plastic limit, expressed as the water content in percentage of the weight of the oven-dry soil, as follows:

$$\text{Plastic limit} = \frac{\text{wt. of water}}{\text{wt. of oven-dry soil}} \times 100$$

Report the plastic limit to the nearest whole number.

5.2 Calculate the plasticity index of a soil as the difference between its liquid limit and its plastic limit, as follows:

$$\text{Plasticity index} = \text{liquid limit} - \text{plastic limit}$$

5.3 Report the difference calculated as indicated in 5.2 as the plasticity index, except under the following conditions:

5.3.1 When the liquid limit or plastic limit cannot be determined, report the plasticity index as NP (non-plastic).

5.3.2 When the plastic limit is equal to, or greater than, the liquid limit, report the plasticity index as NP.

———o———

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 AASHO 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 1, 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 1. The depth of cover (in inches to profile grade) is read in the opposite column.

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

Table 1

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

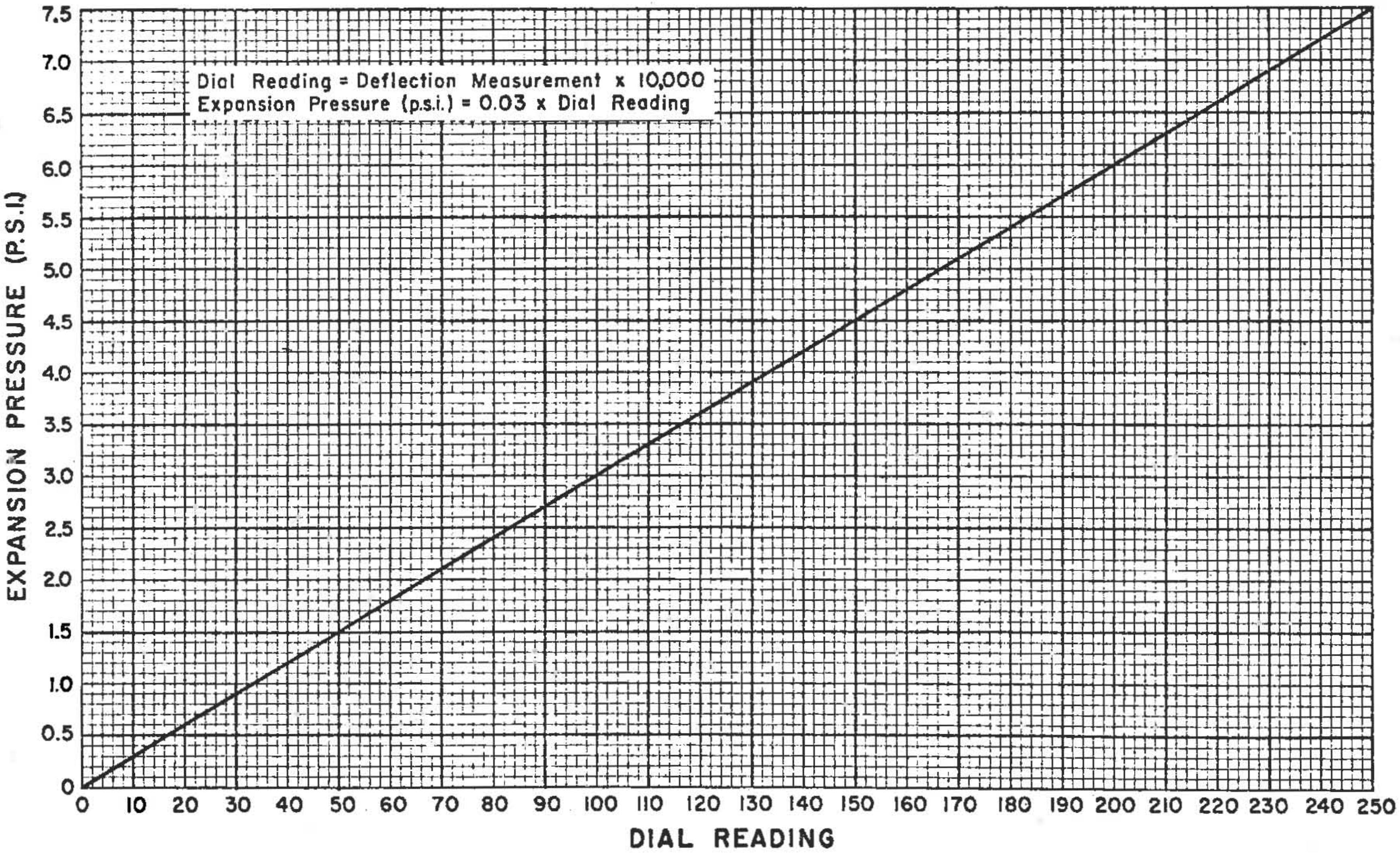


FIGURE 1

DIVISION OF HIGHWAYS
STATE OF COLORADO
Central Laboratory
Work Sheet No. (10-06) 15
Revised: October, 1973

APPENDIX B (continued)

EXAMPLE

Const. ________
Lab No. 36-74
Test No. 14

THIRD CYCLE EXPANSION PRESSURE
STABILOMETER TEST

S.I. 2.0
18 K 10
Regional Factor 1.0
Exp. Pressure; R = ________, SN = ________
300 P.S.I.; R = ________, SN = ________

Project RS 0109 (8)
Location Purgatoire River - So.

% Passing	As Rec'd.	As Run
1"		
3/4"		
3/8"		
4	100	
10	99	
40	99	
200	92	

Classification A-7-6 (29)
Plastic Index 30

Cylinder No.	25					
C.C. H_2O						
% H_2O Added	15.0 - Field Moisture, 102.2 lbs./cu.ft. dry density.					
P.S.I. on Foot						
Exp. Pressure Dial Reading, 1st.	462					
" " " " 2nd.	210					
" " " " 3rd.	121					
Exp. Press. from chart, psi.	3.65					
Total cover req'd. to Profile Grade, inches	29"+					

STABILOMETER

Exudation Pressure, P.S.I.	Note: DOH Memo No. 323 requires a 2 foot					
Exudation Pressure, Pounds	treatment for this material in the					
1000 80	base of a cut, (Secondary system).					
2000 160						
Turns Displacement						
"R" Value						
Structural Number (SN)						

DENSITY OF SAMPLE

Height of Sample						
Weight of Cyl. & Sample						
Weight of Cylinder Tare						
Comp. Wet Wt. of Sample						
Dry Weight of Sample						
Comp. Moisture, %						
Dry Density, Lbs./cu.ft.						

Orig. Wt. ________
Dry Wt. ________
Hygro. ________

Treatment for expansive soils should be done as outlined in DOH Memo No. 323. Indication of swell potential will normally be based on the third cycle expansion pressure test. This test is a modification of the standard expansion pressure test. For expansive soils, the standard test does not allow enough volume change and high pressures sometimes develop which would be relieved if more volume change were permitted. The third cycle expansion pressure test consists of placing standard stabilometer "R" value specimens in the expansion pressure device. The specimen is allowed to expand overnight with water on top. The following day the expansion is read. Up to this point the standard test and third cycle test are the same and the standard test is finished. For the third cycle test, the expansion is read and released back to the starting point and the specimen is allowed to expand for a second time overnight. The reading is taken and the pressure is again released and the specimen allowed to expand for the third time. The expansion pressure taken the third time is taken for the test value. This value is then used to determine the depth below profile grade to treat by converting dial readings to pounds per square inch by means of a table. The pounds per square inch is then converted to depth of reworked, impervious material to be compacted over the undisturbed expansive soil.

The advantage of the "third cycle" test over the standard (one cycle) expansion pressure test is that it improves the discrimination between the relatively low-volume-change silty materials and the high-volume-change clays. The fact that some volume change is permitted in the specimen during the test apparently makes this possible.

The third cycle expansion pressure test was correlated with linear expansion in California.

APPENDIX C

DOH Memo #323
1/5/66

(CONSTRUCTION)
Swelling Soils

DEPARTMENT OF HIGHWAYS
STATE OF COLORADO
4201 East Arkansas Avenue
Denver, Colorado 80222

TO STAFF DIVISION ENGINEERS AND DISTRICT ENGINEERS:

For a number of years the Department has been studying the problem of swelling soils. To date we do not have the complete answer to this problem. However, sufficient research work has been performed that we feel the following method of control of swelling soils should be used by the Department until more information is available.

Pavement distortion from swell has been found only on expansive soils and was most prevalent on soils of the A-6 and A-7 groups and on borderline soils between the A-4 and the A-6 and A-7 groups. Also, certain A-2-6 and A-2-7 soils which are borderline with the A-6 and A-7 groups have produced some swell.

Critical problems in the past have occurred primarily in cut areas where moisture-density treatment has been to comparatively shallow depths (one foot or less).

The following tables are intended as a guide to determine the depth of treatment in cuts for the soil types described above.

SUGGESTED TREATMENT BELOW NORMAL SUBGRADE ELEVATION
FOR PROJECTS ON INTERSTATE AND PRIMARY SYSTEM

Plasticity Index	Depth of Treatment
10 - 20	2 feet
20 - 30	3 feet
30 - 40	4 feet
40 - 50	5 feet
over 50	6 feet

SUGGESTED TREATMENT BELOW NORMAL SUBGRADE ELEVATION
FOR PROJECTS ON SECONDARY AND STATE SYSTEM

Plasticity Index	Depth of Treatment
10 - 30	2 feet
30 - 50	3 feet
over 50	4 feet

Treatment shall consist of removing the material throughout the cut to the required depth. Swelling soils removed can be used elsewhere on the project because they will have been broken up and soil particles will have been disoriented. We have not experienced problems in embankments constructed of swelling soils. Backfill materials may be obtained from any other cut or source developed on the project and may be of the same soil classification as materials removed. Also, if it proves to be economically sound, the materials removed may be hauled back in and used as backfill. All backfill materials are to be compacted in accordance with plans and specifications. It is of primary importance that any swelling soils used either in embankments or as backfill be thoroughly broken up with sheepsfoot rollers or other suitable equipment which will assure complete disorientation of soil particles.

Agreement on actual depth to be treated should be reached between the Design Engineer, Materials Engineer and District Engineer prior to completion of the plans of each project involving swelling soils.

L. C. BOWER
Deputy Chief Engineer

TCR:ntw

Distribution

Districts 1 to 4, incl.	- 50	Staff Materials Engineer	- 10
District 5 + 6	- 25	Staff Construction Engineer	- 10
Mr. Shumate	- 1	Planning and Research	- 5
Mr. Bower	- 1	Staff Design	- 27
Mr. Merten	- 1	Wayne Capron	- 20
Mr. Zulian	- 1	R. B. Dudley	- 20
Office Services	- 2	Stock	- 50
[illegible]	- 10	~~BPR~~	- 5