Workshop on Expansive Clays and Shales in Highway Design and Construction

December 13, 14, and 15, 1972

SOIL MODIFICATION HIGHWAY PROJECTS IN COLORADO

72-11

Burrell B. Gerhardt

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
REGION EIGHT
BUILDING 40, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

February 6, 1973

IN REPLY REFER TO:

Mr. Burrell B. Gerhardt
Research and Special Studies Engineer
Colorado Division of Highways
4201 East Arkansas Ave.
Denver, Colorado 80222

Dear Mr. Gerhardt:

We wish to extend our thanks to you for your attendance and presentation at the recent "Workshop on Expansive Clays and Shales in Highway Design and Construction".

It is with great appreciation that we acknowledge your effort in preparing and presenting your paper entitled "Soil Modification Highway Projects in Colorado". We believe that your paper about studies done by Colorado to control the swell of expansive materials in highway construction contributed greatly to the overall intent and success of the workshop.

As you are aware, the subject of expansive materials is quite involved and many people and agencies are actively searching for practical solutions to control, within reasonable limits, the problems presented through the use of these materials. The workshop was conceived with the thought in mind that an opportunity for the exchange of knowledge and ideas would further the search for the solutions we are all seeking. Again thank you for your participation.

Sincerely yours,

W. H. BAUGH
Regional Federal Highway Administrator

By: Robert A. Bohman
ROBERT A. BOHMAN, Asst. Chief
C & M Division and
Regional Materials Engineer
(Workshop Manager)

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
Colorado Division
10488 West 6th Place
Denver, Colorado 80215

IN REPLY REFER TO
08-05.4
740

cc: sent to Shumate, Haase, Zulian, Capron

August 8, 1973

Mr. Edward N. Haase, Chief Engineer
Colorado Division of Highways
Denver, Colorado

Dear Mr. Haase:

Subject: Report Entitled, "Soil Modification Highway Projects in Colorado" by Mr. Burrell B. Gerhardt

Mr. Gerhardt presented the subject report at the Swelling Soils conference held in Denver, December 13, 14, and 15, 1972. Many of the conclusions presented in the report are drawn from research conducted under Part II of the HP&R work program. We have reviewed these and based on our knowledge of the data available elsewhere and in the report find them to be reasonable.

We have been informed that the report is to be included in the conference proceedings now being readied for publication. Therefore, we are approving the report for publication in accordance with the provisions of paragraph 5u of PPM 50-1.2. You should include a credit reference to FHWA and disclaimer statement in this report and in future reports or papers incorporating HP&R work not previously published.

Our only technical comment on this report concerns an observation in the report that water migrated outward from lime shafts approximately 30 inches (see PLAN #5, page 4 of the report). It seems to us that this distance should vary greatly from site to site depending on the soil structure and type. Mr. Gerhardt may wish to deal with this specific subject in less general terms in future reports.

Sincerely yours,

A. R. Abelard
Division Engineer

Cox	Vernon	Chuvarsky	McPhil	Pearson	M.A. Kahn	Brakey	Zulian	J. Aiassen	Atchison	Berthorf	J. Montano	D. Phelps	K. Fowler	B.B. Gerhardt
					✓									✓

AUG 1973
COLORADO DEPARTMENT OF HIGHWAYS

WORKSHOP ON EXPANSIVE CLAYS AND SHALES
IN
HIGHWAY DESIGN AND CONSTRUCTION

New Albany Hotel
Denver, Colorado
December 13, 14, and 15, 1972

SOIL MODIFICATION HIGHWAY PROJECTS IN COLORADO

By
Burrell B. Gerhardt
Research and Special Studies Engineer
Colorado Division of Highways

Prepared For:
Federal Highway Administration
Office of Development
Washington, D. C. 20590

SOIL MODIFICATION HIGHWAY PROJECTS IN COLORADO

By
Burrell B. Gerhardt
Research and Special Studies Engineer
Colorado Division of Highways

The high incidence of roadway failures in eastern Colorado due to swelling soils has led to a multitude of attempts to prevent repeat performances. Some of the ideas that have been expressed for reducing subgrade swelling are the following:

1. Make cuts wide so water is far from pavement - Use fill sections only, if possible.
2. Subexcavate cuts and replace with nonswelling material.
3. Subexcavate cuts and replace with the same material - but treated to be nonswelling.
4. Spread some magic fluid or powder over the subgrade that will make the subgrade inert (nonswelling).
5. If this fluid will not soak in, pump it in or drill holes and let it soak in.
6. Place an impervious blanket over or around the shoulders and ditches to keep the water out.
7. Use a thick impervious pavement as a blanket to prevent water from entering the subgrade - deep strength pavement.
8. Construct the roadway over the swelling soil as economically as possible and when the subgrade reaches moisture equilibrium, place a thick leveling course over it to take out the bumps. (Compaction w/o moist-density control)

Since 1962, construction projects have been set up and carried out to test every one of these ideas at least once. This paper describes these projects and presents an analysis of the results in a brief form.

PLAN: #1 WIDEN THE CUTS-or even better, eliminate the cuts. Use fill section at all times if possible.

Project: C 34-0070-00 Agate to Limon June 1972, 100,000 cu. yd. at 50¢/cu. yd.

Original distance between ditch and shoulder on swelled section was designed and constructed less than 9'.

New distance between ditch and shoulder is at least 30 feet. See Fig. 1.

Subgrade: LL=80, PI=50, 98% pass #200 A-7-6(58) 15" swell on project during first 4 years after construction.

Effect: Only 8" of rainfall since ditch widening, but no sign of distress at this time.

Conclusions: Too early for final conclusions, but improving drainage always reduces swell. Use fill sections only, if possible. Cut sections are the source of all roadway evils. Benefits of the fill sections are certainly realized during snow storms.

PLAN: #2 SUBEXCAVATE SUBGRADE AND REPLACE WITH NON SWELLING MATERIAL (Sand or Gravel)

Projects: Strasburg E & W, Clifton Palisade and Four Corners

Swelling subgrades A-7-6(20+) replaced with sand or open graded sand and gravel in top 2', 4', or 6'.

Effect: Clean, open graded materials provided a reservoir for water beneath the pavement structure. While the top 2', 4', or 6' did not swell, subgrade material below and on the sides of the clean material swelled even more.

Conclusions: Do not replace top 2', 4', or 6' of subgrade with anything that is open graded that will let moisture in either by surface runoff or hydrogenesis.

Cost: Do not use open graded gravel between the pavement and a swelling subgrade whatever the cost.

PLAN: SUBEXCAVATE SUBGRADE AND REPLACE WITH SAME MATERIAL TREATED SO #3 THAT IT IS NON SWELLING

Project: I-225 Mississippi North, Deer Trail-Agate and Clifton. Swelling subgrade A-7-6(20+) subexcavated 2' to 6' and wetted, relayed and compacted with AASHO T-99 Spec. (Not T-180 Spec.).

Effect: Where properly undertaken and carried out, the results have been good if subexcavated depth is proportioned to the Plasticity Index. 2' is not sufficient if PI is over 25, 4' is not sufficient if PI $>$ 45. CDOH Memo 323 published and used today. See Fig. 2.

Conclusions: Cost is approximately $400 per 2 lane Station (100') for 2' depth. Some difficulty in subexcavating and recompacting over 2' depth, and cost is $500 to $600/2 lane Station.

PLAN: SPREAD MAGIC FLUID OR POWDER OVER SUBGRADE TO MAKE IT INERT
#4
(nonswelling)

Projects: Byers East, Seibert-Bethune and Clifton.

Laboratory tests indicate that the only practical fluid or powder is lime slurry or hydrated lime.

Subgrade: Plastic Indices of 45 may be reduced to 25 with 2% lime, or to 10 with 4% lime in many instances.

Effect: If lime can be mixed well, the swelling can be considerably reduced in the top foot or so, but only about 5% or 10% of the swell comes from top foot.

Conclusions: Difficult to spread lime deeper than 12". Cost is approximately $470 per 2 lane Station (100') for 4% lime. Swell in the top 12" only is reduced by this method.

PLAN: FORCE OR SOAK SOME DE-SWELLING FLUID INTO SUBGRADE
#5

Projects: Denver North, Limon-East, Soda Lake-East, Seibert-Vona and Punkin Center-West.

Subgrade: A-7-6(20+) opened up by means of drilling to 5'-20' with 12" dia drill on 5 foot centers. 20 pounds of lime and approximately 50 gallons of water added per hole. Hole backfilled with open graded sand to leave as much slurry in the hole as possible. No attempt made to force slurry in under pressure as was done in Oklahoma and Louisiana.

Effect: Water in the very thin slurry migrated approximately 30" and forced the clay to expand into the empty shaft instead of upwards. Lime migrates only an inch or so but it helps to make the water migrate further. A release of swell pressure down to any conceivable depth could be accomplished.

Conclusions: At a cost of approximately \$600/2 lane Station (100'), potential swell can be reduced to almost nil for any depth.

PLAN: #6 PLACE AN IMPERVIOUS BLANKET ACROSS THE SHOULDERS AND DITCHES TO KEEP THE WATER OUT

Projects: Elk Springs-West, Deer Trail-Agate, Limon

Subgrade: A-7-6(17) soils covered with Catalytically blown asphalt approximately 3/16" thick from back slope down through ditches, up across shoulders and perhaps across the roadway. Polypropylene fiber mats were also used. See Fig. 3.

Effect: Continuous membranes shed moisture well. Vegetation grows well over blanketed ditch section. Bumps develop at ends of membraned sections. 2" mats do not serve as membranes. They allow water to enter and soak the subgrade. Our new 2" mats have shown a porosity of approximately 2 gallons/sq ft per day, which is a considerable rate of moisture flow into a subgrade. We have measured as high as 4 gallons/day.

Conclusions: Catalytically blown asphalt costs \$77/ton at 11.2 #/yd^2 or \$.43/sq. yard, which is about \$450/2 lane Station. Polypropylene fiber costs \$.75/sq. yard or about \$720/2 lane Station.

PLAN: #7 USE A THICK IMPERVIOUS PAVEMENT AS A BLANKET TO PREVENT WATER FROM ENTERING THE SUBGRADE - FULL DEPTH PAVEMENT

Projects: Ordway (8" to 11"), Utah Line (9"), County Line (3"), Boulder (pcc 8").

Subgrade: A-7-6(14) covered with pcc or asphalt plant mix. Shoulders feathered out to 2". Old pcc pavement 8" thick had clay and grass shoulders which were a constant source of maintenance and danger in wet weather. See Fig. 4 and Fig. 5.

Effect: 4" mat is very insufficient, 6" mat may suffice on low 18 KIP loads, but 8" is necessary for usual 18 KIP loading. Colorado Interstate now being designed for 9". PCA advocated 8" concrete for years and this thickness didn't become inadequate until about 20 years ago.

Conclusions: Cost is $1200/2 lane Station (100') for Interstate type construction, but this cost also includes the cost of the base course and subbase which would be about $1200/2 lane Station anyway, so the swell control is economical--in fact, it is free. CDOH has decided on this design across mancos - Utah Line east for 20 miles.

PLAN: CONSTRUCT THE ROADWAY OVER THE SWELLING SOIL AS ECONOMICALLY AS POSSIBLE, PROVIDING COMPACTION OF THE FILLS WITHOUT ANY MOISTURE-DENSITY CONTROL. AFTER ABOUT 3 YEARS THE SUBGRADE AND PAVEMENT STRUCTURE SHOULD REACH MOISTURE AND DENSITY EQUILIBRIUM, AND THEN A THICK OVERLAY CAN BE PROVIDED TO TAKE OUT THE BUMPS.

Projects: Four Corners, Utah Line, and Denver N.

Effect: Absence of moist-dens control results in non uniform swell and settlement. Only where fill material was naturally moist is the appearance good.

Conclusions: At locations where the cost of water (and haul) is high (say over $5.00/1,000 gallons), there is some savings if close control can be maintained to haul in fill material that is moist. If the sources of fill material are naturally dry, performance of the embankments will be poor. Performance of the cuts will be extremely poor in clays and shales. This type of construction is only satisfactory where there is +70% rock content, and usually soils with a high rock content are not swelling soils.

Compaction without Moist-Dens Control is predicated on the final development of some equilibrium moisture and density in the field. The research effort was to determine these equilibrium values for subgrade soils.

The study of roadways in Colorado confirmed the U.S. Corps of Engineers' conclusion that equilibrium moist depends mostly on the PI, but density seldom comes to equilibrium - it varies with season, traffic, geometry, moisture and overburden. See Figure 5A.

High fills are generally well drained, and so some data can be developed from their performance. See Fig. 6.

Without Moist-Dens Control, the initial swell in a new roadway will vary from 0 to 10% depending on the moist content at the time of compaction. See Fig. 7 for Colorado shales.

Study of roadway failures through Colorado shales shows that without Moisture-Density Control, 33% of the failures are in fills and 67% are in cuts. With Moisture-Density Control, 0% of the failures are in fills and 100% are in cuts.

Oklahoma University personnel studied subgrade moisture variations and reported the following:

"Moisture variations caused by thermal soil moisture flow were quite small compared to variations caused by precipitation and capillarity. It is therefore concluded that temperature-induced subgrade moisture migration is a secondary effect, compared (in magnitude) to those produced by precipitation and capillarity, in Oklahoma subgrades. However, it is possible that the relatively small migration produced by temperature gradients, when coupled with the "dry of optimum" subgrades usually existing under new construction in Oklahoma, may, in time, cause enough moisture transfer to the upper levels of the subgrade for resultant heave to crack the pavement and open the way for large precipitation/evaporation-induced moisture variations."

CONCLUSIONS about roadway construction over swelling soils, based on Colorado experience.

1. Do not use CUT SECTIONS unless absolutely necessary. They are the main source of trouble with Swelling Soils.
2. Keep moisture from going deep by the use of catalytically blown asphaltic membranes or thick impervious pavement layers.
3. If cut sections must be used, make ditch line at least 25' from shoulder, subexcavate 4'+ and replace with soil wetted and compacted to T-99 Standards, or use lime shafts (generally best for maintenance operations).
4. DO NOT expect good engineering results without moisture-density treatment and good drainage in Swelling Soils.

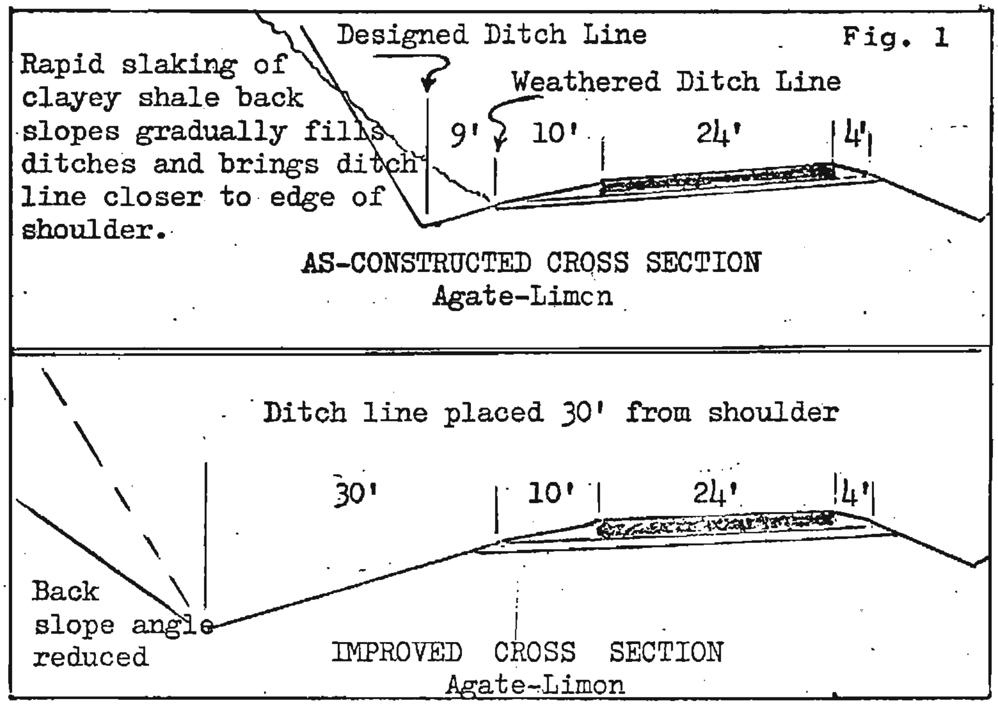
Fig. 1
Rapid slaking of clayey shale back slopes gradually fills ditches and brings ditch line closer to edge of shoulder.
Designed Ditch Line
Weathered Ditch Line
9'
10'
24'
4'
AS-CONSTRUCTED CROSS SECTION
Agate-Limcn
Ditch line placed 30' from shoulder
30'
10'
24'
4'
Back slope angle reduced
IMPROVED CROSS SECTION
Agate-Limon

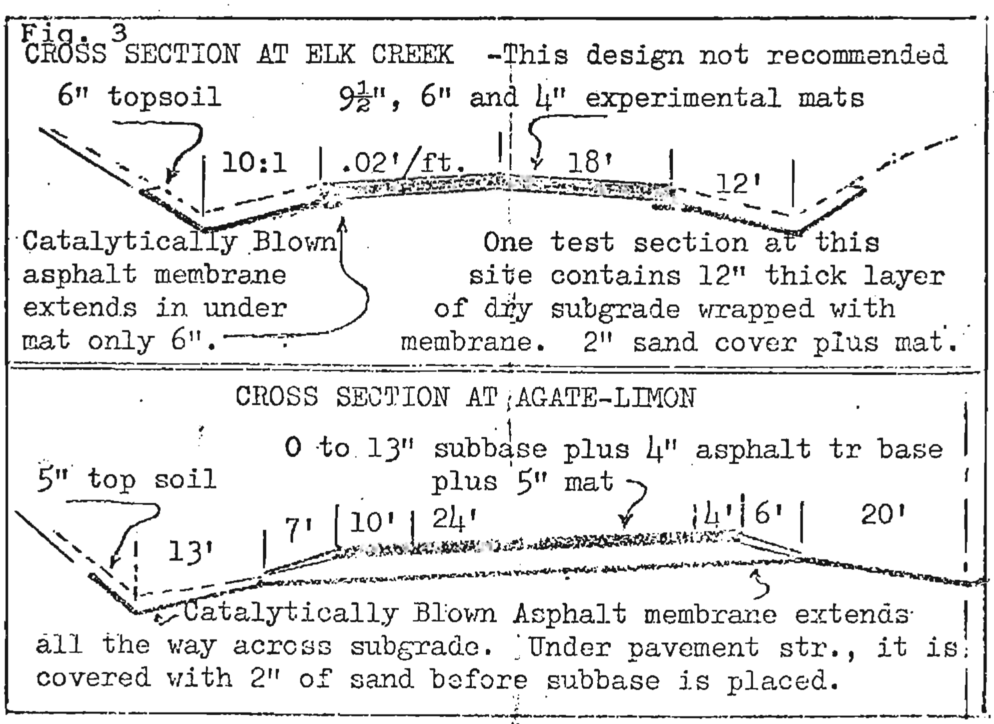
Fig. 3
CROSS SECTION AT ELK CREEK -This design not recommended
6" topsoil
9½", 6" and 4" experimental mats
10:1
.02'/ft.
18'
12'
Catalytically Blown asphalt membrane extends in under mat only 6".
One test section at this site contains 12" thick layer of dry subgrade wrapped with membrane. 2" sand cover plus mat.
CROSS SECTION AT AGATE-LIMON
0 to 13" subbase plus 4" asphalt tr base plus 5" mat
5" top soil
13'
7'
10'
24'
4'
6'
20'
Catalytically Blown Asphalt membrane extends all the way across subgrade. Under pavement str., it is covered with 2" of sand before subbase is placed.

Fig. 2

DOH Memo #323
1/5/66

COPY

(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.

/s/ L. C. BOWER

L. C. BOWER
Deputy Chief Engineer

TCR:ntw

Distribution

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Fig. 4 CROSS SECTIONS AT ORDWAY

Mat thickness on test sections are 8", 9½", and 11"

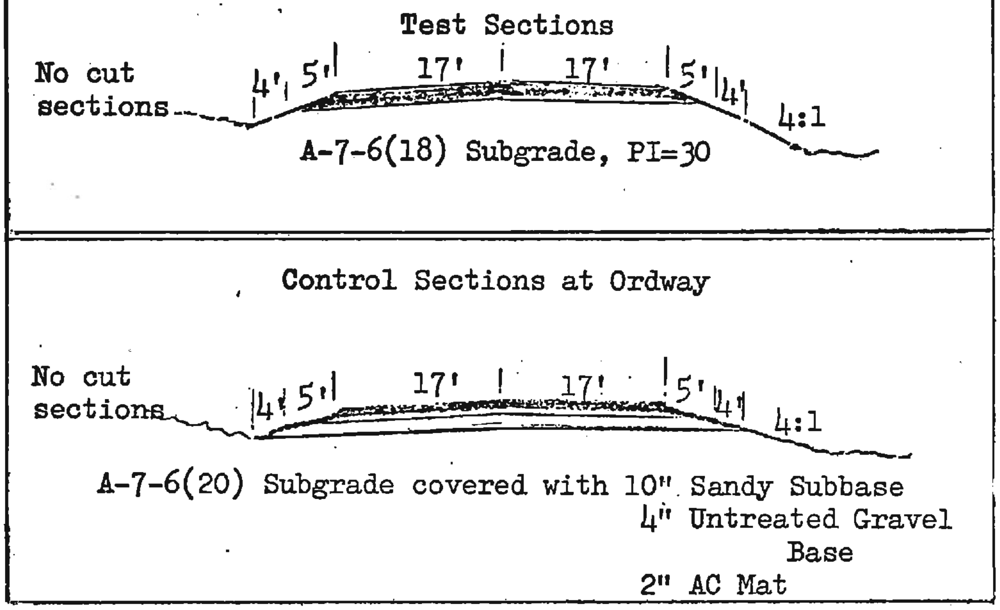
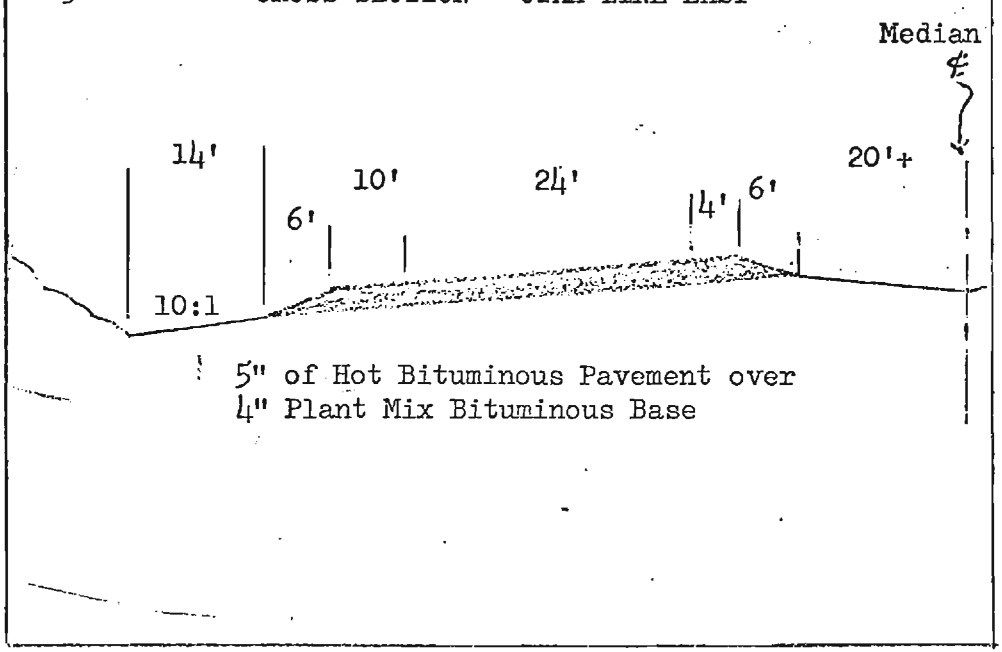


Fig. 5 CROSS SECTION - UTAH LINE EAST



SUMMATION OF DATA
FOR THE STUDY OF
MOISTURE UNDER COLORADO PAVEMENTS

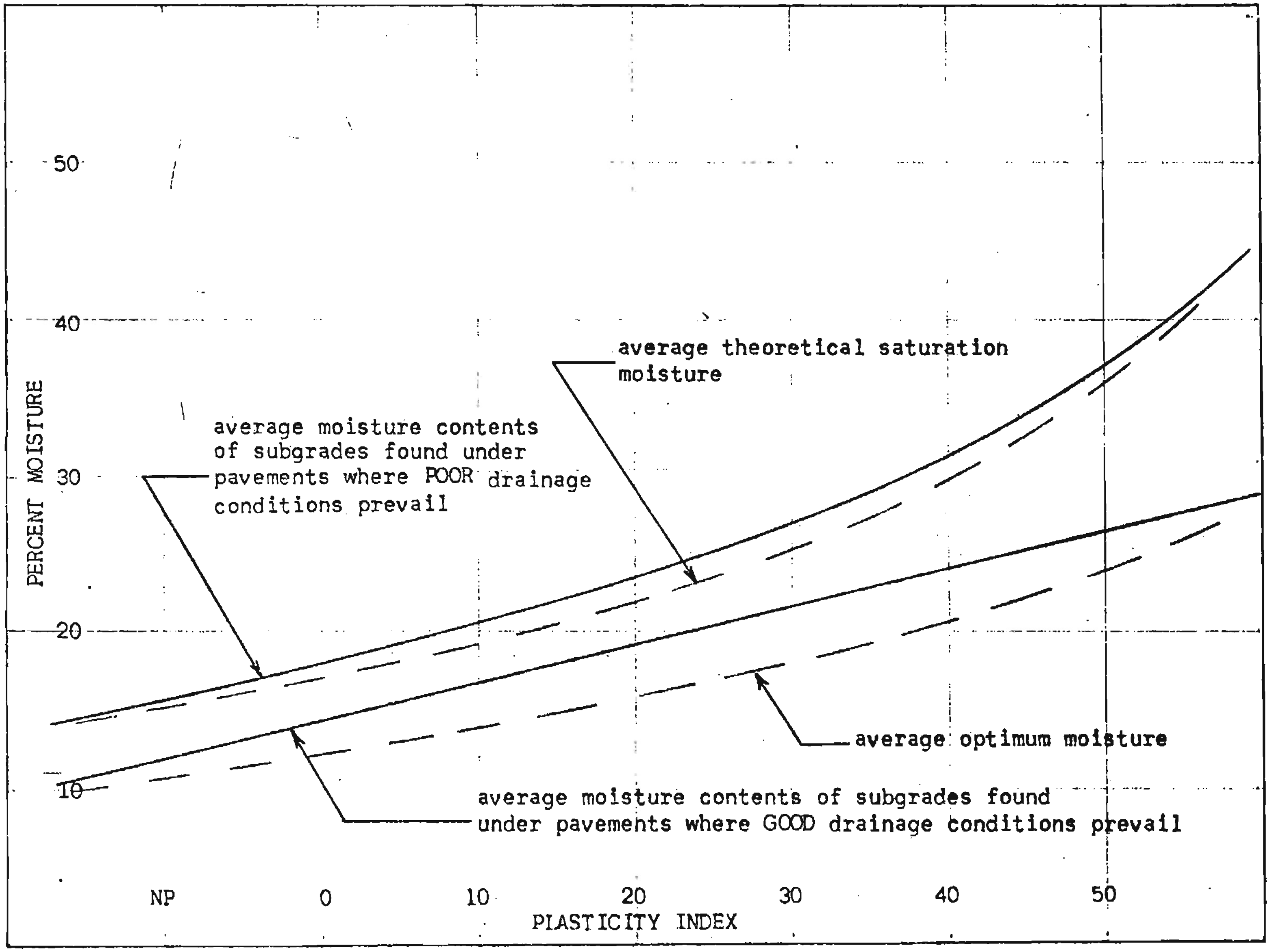


FIGURE 5A

Fig. 6 MOISTURE CONDITIONS IN HIGH FILLS

LOCATION	Monument to Larkspur	Farnham By-pass	Godalming By-pass	Boulder County Line	Slick Rock	South of Naturita	Lancing Brook	Near Cedar Point	Four Corners SH 40	Four Corners SH 40	Kingston By-pass	Crawley By-pass	Hailsham By-pass
YEAR OF CONSTRUCTION	1927	1940	1930	1966	1960	1964	1947	1958	1960	1960	1926	1937	1934
DEPTH OF FILL	20'	10'	25'	45'	18'	30'	15'	25'	40'	30'	20'	20'	25'
TRAFFIC	Light	Heavy	Heavy	Light	Light	Light	Medium	Medium	Light	Light	Very heavy	Heavy	Heavy
CONDITION OF FILL	Good	Good	Good	Good	Good	Good	Good	Good	Bad	Bad	Bad 3" settle	Bad 1" settle	Bad 6" settle
PLASTICITY INDEX	NP	NP	11	20	20	30	33	40	25	25	27	34	40
MOISTURE IN TOP 2'	11	-	-	15	17	15	-	24	11	12	-	-	-
MOISTURE BELOW 2'	8	8	17	10	16	15	24	27	14	15	27	25	28
AVERAGE DRY DENSITY	120	126	110	112	107	100	94	92	112	110	98	94	95
MOISTURE-DENSITY CONTROL?	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No

VARIATION IN THE % SWELL WITH THE COMPACTED MOISTURE CONTENT

Fig. 7