Report No. CDOH-P&R-R&SS-75-5

Treatment of Swelling Soils West of Agate, Colorado Project I 70-4(48)347

Burrell B. Gerhardt
Colorado Division of Highways
Planning and Research Division
4201 E. Arkansas Avenue
Denver, Colorado 80222

Final Report
December 1975

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

Technical Report Documentation Page

1. Report No.
FHWA-CO-R&SS-75-5

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Treatment of Swelling Soils -
West of Agate, Colorado

5. Report Date
December 1975

6. Performing Organization Code

7. Author(s)
Burrell B. Gerhardt

8. Performing Organization Report No.
CDOH-P&R-R&SS-75-5

9. Performing Organization Name and Address
Colorado Division of Highways
Planning and Research Division
4201 East Arkansas Avenue
Denver, Colorado 80222

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
1471

12. Sponsoring Agency Name and Address
State Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

13. Type of Report and Period Covered
Final Report
March 5, 1968-
December 1975

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

This research was an attempt to determine the effectiveness of a 2 foot (.6 m) subexcavated section, a 4 foot (1.2 m) subexcavation and a catalytically blown membrane section in counteracting the effects of a swelling soil on a pavement system.

Roadways in similar subgrade areas just east of this project had shown as much as 15 inches (38 cm) of vertical rise after a 1960 construction project. However, an eastbound lane of Interstate 70 only 100 feet (30 m) south of the experimental westbound lane was also constructed in 1960, and it is in good condition after 15 years of service.

Apparently both the EB lane (constructed in 1960) and the WB experimental lane, constructed in 1968, were paved at a time when moisture content in the subgrade was well above optimum. In 1975, the serviceability index for both lanes is near 3.3, and the distress is mostly due to 1/4 inch to 3/8 inch (1 cm) faulting. The value of compacting swelling soils at moisture contents above optimum was demonstrated by this project, but very little was determined regarding the effectiveness of different depths of subexcavation and membrane treatment of swelling soils. The 2 foot (.6 m) subexcavated section appeared to show slightly more swelling than the 4 foot (1.2 m) subexcavated section or the catalytically blown asphalt membrane treated section.

17. Key Words
Swelling Soil, Asphalt Membranes, Optimum Moisture, subexcavation, wetting and compaction

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
47

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

SUMMARY

This research was an attempt to determine the effectiveness of a 2 foot (.6 m) subexcavated section, a 4 foot (1.2 m) subexcavation section and a catalytically blown membrane section in counteracting the effects of a swelling soil on a pavement system.

Because of a rainy spell during the end of the construction, the moisture content of the top 10 feet (3 m) of the subgrade became 4 to 5 percentage points wetter than optimum AASHO T-99 for all test sections. With this moisture content, there was very little swell potential left in this A-7-6 (43) type subgrade. Consequently, none of the test sections showed over 0.2 foot (6 cm) of elevation change.

Roadways in similar subgrade areas just east of this project had shown as much as 15 inches (38 cm) of vertical rise after a 1960 construction project. However, an eastbound lane of Interstate 70 only 100 feet (30 m) south of the experimental westbound lane was also constructed in 1960, and it is in good condition after 15 years of service.

Apparently both the EB lane (constructed in 1960) and the WB experimental lane, constructed in 1968, were paved at a time when moisture content in the subgrade was well above optimum. In 1975, the serviceability index for both lanes is near 3.3, and the distress is mostly due to 1/4 inch to 3/8 inch (1 cm) faulting. The value of compacting swelling soils at moisture contents above optimum was demonstrated by this project, but very little was determined regarding the effectiveness of different depths of subexcavation and membrane treatment of swelling soil. The 2 foot (.6 m) subexcavated section appeared to show slightly more swelling than the 4 foot (1.2 m) subexcavated section or the catalytically blown asphalt membrane treated section.

IMPLEMENTATION

The findings regarding the importance of high moisture content during the compaction of swelling soils have been known for a long time. This research demonstrated the value of subexcavation for getting that moisture into the subgrade and membranes for holding it there until the pavement was placed. Implementation of the findings from this project consists of getting this information to those in charge of Design and Construction.

In the seven years since 1968, this word has been passed on by means of inspections at the project site. Also attempts have been made to rewrite CDH Memo No. 323 which is a statement of the Colorado policy regarding design of roadways over swelling soils. The latest revision is included in the report, although it is not yet in final form. The information assembled as a result of this project will become a part of a much larger implementation package on SWELLING SOILS IN COLORADO.

TABLE OF CONTENTS

TREATMENT OF SWELLING SOILS
WEST OF
AGATE COLORADO

PROJECT I 70-4(48)

INTRODUCTION

Purpose of Report

This report is an attempt to record data which can be used to evaluate the performance of a roadway constructed on swelling soils in eastern Colorado. Since several different treatments were used in the design to counteract the expected volume change in the subgrade, the construction procedure was not a uniform one. This report may help to summarize various elements of the work and describe the condition of the roadway immediately after construction.

History of Roadway Performance in this Area

Figure 1 shows the location of Project I 70-4(48) in relation to the geology of eastern Colorado.

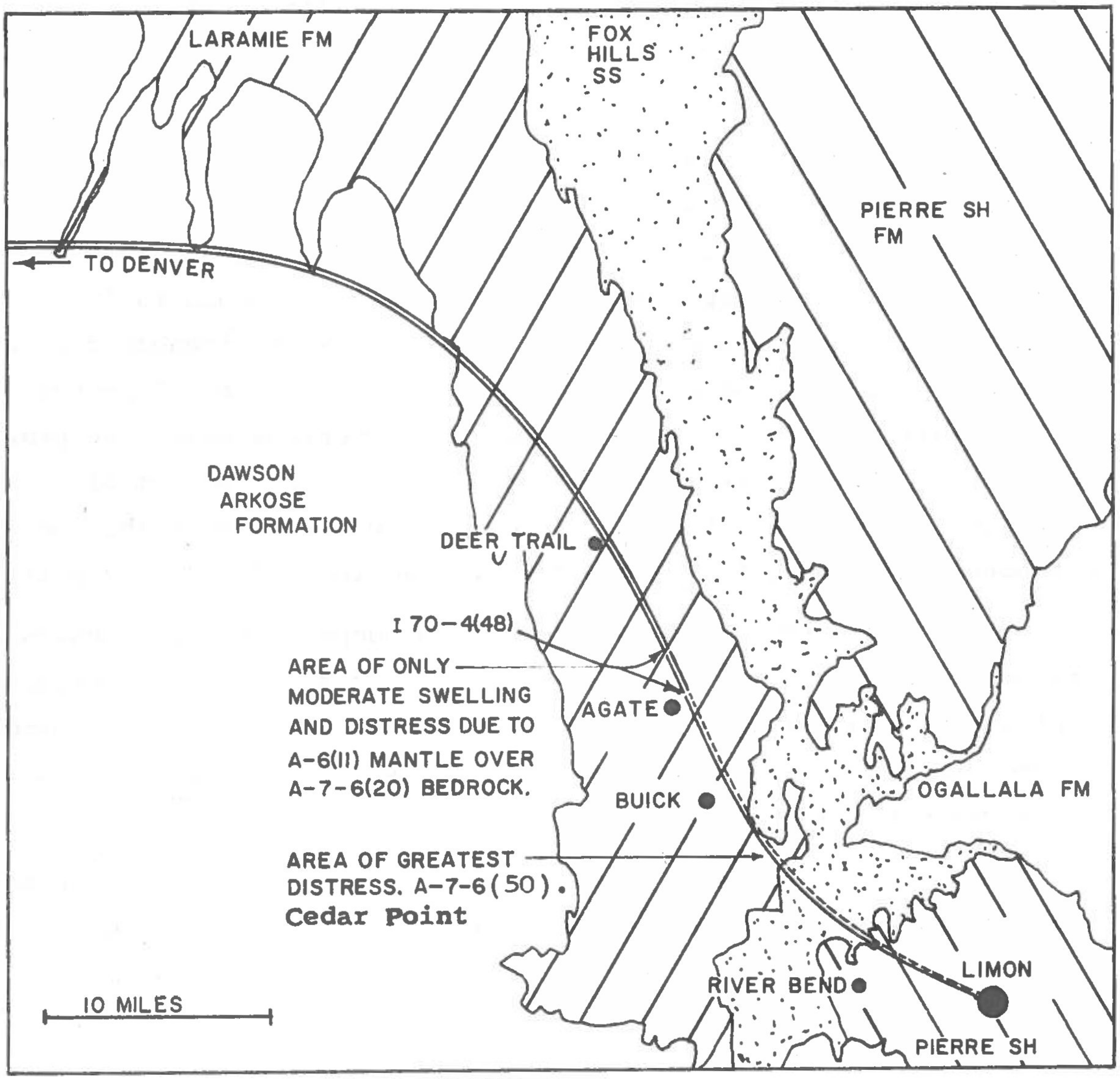


FIGURE I

The alignment traverses soils formed from weathering of the lower stratas of the Laramie formation. Having been an ancient delta or fresh water deposit, it contains carbonaceous debris of all kinds including coal and lignite shale. The clays are exceptionally active, having Liquid Limits as high as 100, and Plasticity Indices as high as 80. Volume change from field condition to saturation may be as high as 15%. The railroad bed required constant maintenance across this geologic formation for the first 60 years of its existence, but the many layers of ballast placed between the R.R. ties and the soil have finally provided a fairly inert foundation.

The former roadbed of US Highway No. 40 was abandoned in the highly distressed area approximately 10 miles east of the I 70-4(48) location, when the eastbound lane of Interstate 70 was opened in 1959. Without traffic and continual maintenance, the asphaltic-mix surface of this old road took on the appearance of a narrow pond with 6" (15 cm) swells or ripples running transversely every 10 or 12 feet (4 meters) down the old highway.

Part of the new Interstate highway is in this badly distressed area east of I 70-4(48), and was surfaced with a 6" (15 cm) cement treated base and 8" (20 cm) of PCC concrete under Project I 70-4(6). Within 2 months after paving, the concrete slabs in some sections began to 'rock' under truck traffic, and within 2 years there was very noticeable distress in the riding surface. In one cut area the slabs were lifted 15 inches (38 cm) by the swelling soil. Several asphalt-mix overlays have been provided to smooth over the faulted slabs for motorists safety and comfort. The study area for this project, however, does not lie directly on the shale, and the eastbound lane which is the pavement placed in 1960, shows very little distress

Under a contract between the Colorado Department of Highways and the University of Colorado, the CU Civil Engineering Department studied the swelling problem in this area and concluded that, "No present prediction scheme can designate a safe treatment thickness; the empirical systems unfortunately are still best."

The Physical Research Laboratory of the Bureau of Public Roads found Montmorillonite to be the principal mineral with small amounts of Kaolinite also present. In four of the six samples submitted to the Bureau of Public Roads, the Montmorillonite appeared to be well crystallized and capable of large volume changes.

Location of the Project

Project I 70-4(48) was for the construction of 2 westbound lanes (driving and passing) for approximately 2.7 miles (4.3 km) in an area of only moderately swelling soils as shown in Figure 1. The two westbound lanes east of this westbound project suffered such heavy distress between 1959 and 1962 that they were rebuilt on a new alignment in 1971. To the west are sands and clays of the Dawson Arkose, and east of this swelling area is the Fox Hills Sandstone which is an excellent subgrade material. Most of the bad Laramie bedrock has a blowsand mantle 5'-10' (3 meters) thick, which, if left undisturbed, will help to protect the Laramie shales from the moisture and temperature changes which bring on volume change.

The eastbound lane of I 70 adjacent to Project I 70-4(48) was completed in 1959. Both cut and fill sections composed the grade. Some distress is apparent in all the cut sections. The fill sections are generally stable since they were constructed with moisture-density control and had a sand or wind-deposited silt layer over the weathered shales. The cuts either exposed or very nearly exposed the weathered shale. Critical areas on Project I 70-4(48) were almost certain to be the cut sections, and the design called for treatment of the cuts to prevent future distress and failure. The three experimental treatments comprising this project are described below.

DESCRIPTION OF MATERIALS

Subgrade Material

Figure 2 is a sketch of the profile for Project I 70-4(48) as it runs southeasterly toward the Interchange at Agate, Colorado for 2.7 miles (4.3 km).

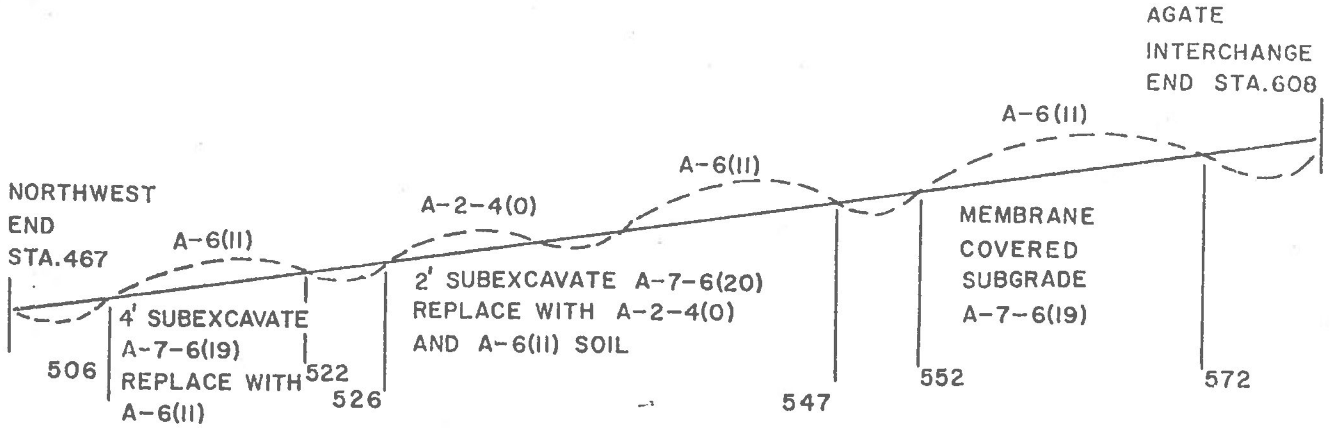


FIGURE 2

Typical characteristics of the mantle soils and the weathered Laramie are shown below:

	Blow Sand A-2-4 (0)	Mantle Soil A-6 (11)	Weathered Laramie A-7-6 (40)
% Pass No. 200 sieve	26 to 50	90%	90%
Liquid Limit	25 to 35	32	65
Plasticity Index	Np to 15	12	40
California Bearing Ratio	25*to 65*	3	2
% Swell (Optimum to Saturated)	0 - 1%	1%	4%
Max Density (AASHO Std.)	115#/cu. ft.	107#/cu. ft.	97#/cu. ft.
Opt Moisture(AASHO Std.)	10 - 17%	18%	25%

*Hveem Stabilometer value in place of CBR.

Base Course Material

The base course material on Project I 70-4(48) consisted of a 6" layer of blended burned shale fragments (Scoria) from an outcrop in the east edge of the Laramie formation. After crushing to 3/4" maximum size and blending 65% to 75% of this material with 35% to 30% sand from a low terrace on East Bijou Creek, the combination made the following average gradation:

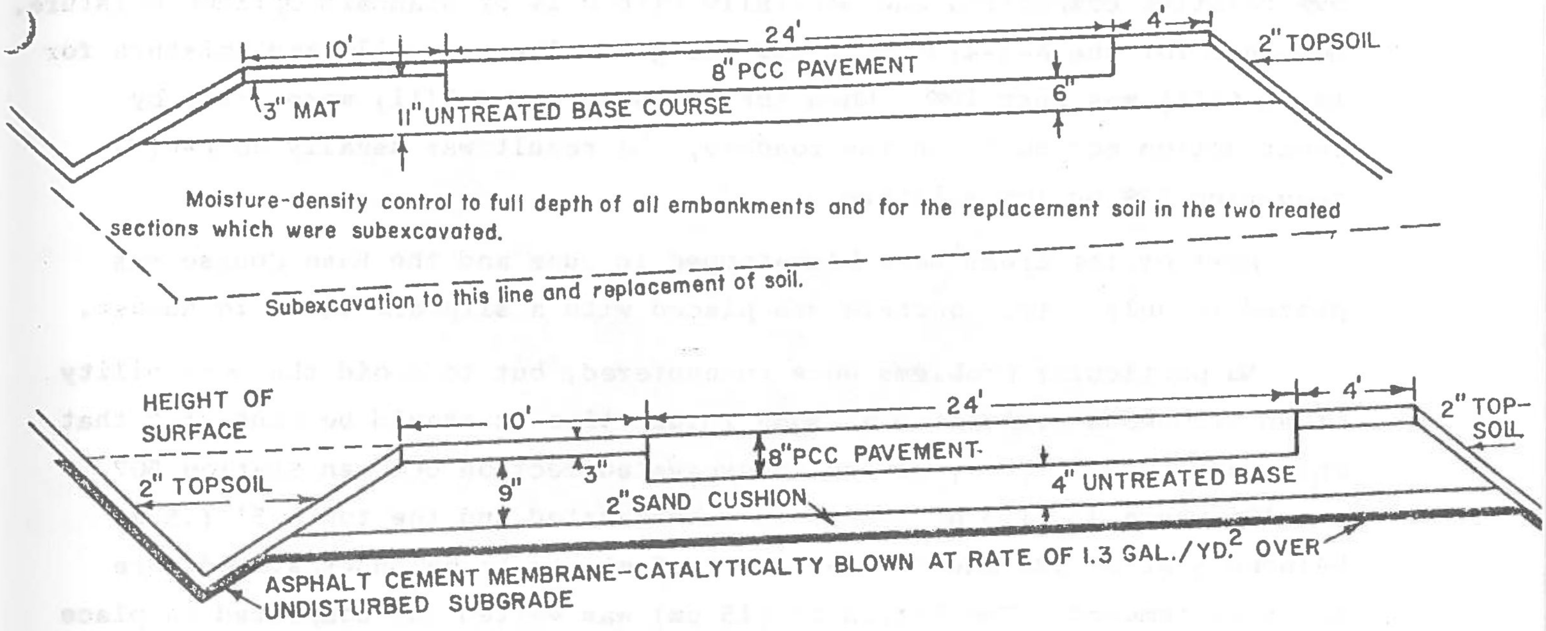
% Passing 3/4 Sieve	98%
% Passing #4 Sieve	50%
% Passing #8 Sieve	40%
% Passing #200 Sieve	8%

The Hveem Stabilometer value on this material was 82 at 111 pounds (50 kg) per cubic foot and 12% moisture. The sand equivalent value was 23.

Paving Material

The typical sections for paving were as shown on the following page:

The typical sections for paving were as shown below:



Sand cushion and topsoil cover placed in such a manner as not tear or disturb the asphalt membrane running across the subgrade, across the ditch and up the backslope.

FIGURE 3

The wearing surface was an 8" (20 cm) thick layer of PCC Class AX having approximately 70% fine aggregate (sand) and 30% coarse aggregate. Entrained air content averaged 5.2%. Seven-day compressive strength averages approximately 3100 psi and 28 day strength averaged 4300 psi (30,000 kPa). The thickness averaged 8 1/8" (20 cm) and the skewed construction joints were sawed every 15' (5 m). The longitudinal centerline joint was formed with a plastic ribbon. Paved shoulders averaged 3 1/4" (8.3 cm) in thickness and were composed of a blend of burned shale, sand, and 7% 85-100 pen asphalt. The result was a Stabilometer value of 23, Rt = 90. Both wet and dry unconfined strength values were approximately 530 psi.

CONSTRUCTION OF THE PROJECT

Subexcavated Treatment

Construction of the project began in the early spring of 1968. The weather was dry and warm until July and August when there were a number of afternoon and overnight showers.

Tests in the subexcavated and recompacted sections showed from 95 to 99% relative compaction and generally within 1% of Standard Optimum Moisture. Moisture for the A-2-4(0) backfill was generally about 11% and moisture for the A-6(11) was near 19%. When the A-2-4(0) and A-6(11) were mixed by construction equipment on the roadway, the result was usually an A-6(7) requiring 17% or 18% moisture.

Most of the areas were blue-topped in June and the Base Course was placed in July. The concrete was placed with a slipform paver in August.

No particular problems were encountered, but to avoid the possibility of an erroneous evaluation at some future time it should be mentioned that only the top 3.5' (1 m) of the subexcavated section between Station 507 and 521 where 4' (1.3 m) was to be subexcavated and the top 1.5' (.5 m) between Station 526 and 547 where 2' (.7 m) was to be subexcavated were actually removed. The bottom 6" (15 cm) was wetted and compacted in place to obtain the 4 foot (1.3 m) depth and 2 foot (.7 m) depth of treated subgrade The remaining backfill was placed in horizontal layers of not more than 8" (20 cm) thickness, wetted to optimum moisture and compacted to 95% maximum density as determined by AASHO Designation: T 99-61.

Membrane Treatment

The cut scheduled for membrane treatment was brought to grade and the surface disturbed as little as possible by June 1968. During the first week in June, it was sprayed with 0.1 gal/sq. yd. of SS-1 Emulsified Asphalt to prevent any foaming of the 50-60 AC Catalytically Blown Membrane material. This amount of emulsified asphalt gave the surface a grayish-black appearance as it wetted the surface particles and settled the dust.

On June 11, 1968, the subgrade surface, shoulders, ditch, and back slope (up to the elevation of the finished surface of the roadway) was sprayed with approximately 1.3 gal/sq. yd. (6 liters/m^2) of the membrane material. See Figures 4 and 5 on page 7. The specifications and construction requirements for the asphalt are shown on page 8.

Figure 4. Distributor Applying Asphalt Membrane

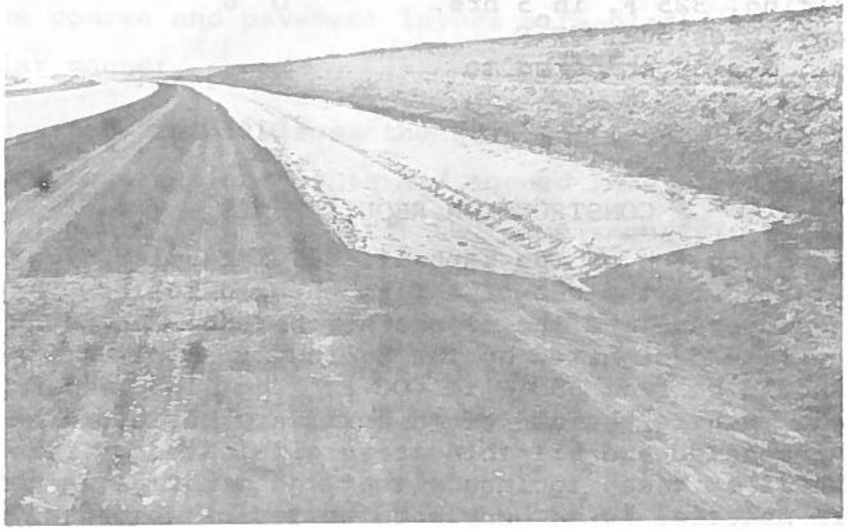


Figure 5. Partially Completed Asphalt Membrane
(Note the asphalt-covered bench in the cut slope at the right edge of the picture)

December 20, 1967

SECTION 411
ASPHALT CEMENT (CATALYTICALLY BLOWN)
COLORADO PROJECT NO. I 70-4(48)347

DESCRIPTION

This work shall consist of furnishing and applying asphalt as a continuous membrane in reasonably close conformity with details shown on plans and this specification.

MATERIAL REQUIREMENTS

Material shall conform to requirements of Item 411 of the Standard Specifications and the following:

Asphalt used as a membrane shall be 50-60 penetration grade. This material shall be prepared by the catalytic blowing of petroleum asphalt. The use of iron chlorides or compounds thereof will not be permitted. The asphalt shall be homogeneous, free of water and shall not foam when heated to 347°F. It shall meet the following specific requirements:

Test Designation	Test Method ASTM	50-60 Penetration Grade
Flash Point	D 92	425°F. Min.
Softening Point	D 36	175°F.-225°F.
Penetration, 77°F., 100 gms., 5 sec.	D 5	50-60
Penetration, 32°F., 200 gms., 60 sec.	D 5	30 Min.
Penetration, 115°F., 50 gms., 5 sec.	D 5	120 Max.
Ductility, 77°F. (5cm per min) cm	D113	3.5 Min.
Loss on Heating, 325°F. in 5 hrs.	D 6	1.0 Max.
Penetration of residue, 77°F (100 gms., 5 sec. compared to original) %		60.0 Min.
Solubility in CCl_4, %	D165	97.0 Min.

CONSTRUCTION REQUIREMENTS

Prior to the application of the asphalt, all irregularities in the subgrade shall be eliminated by the use of a flat wheeled roller. Asphalt shall be applied to the subgrade and the slopes as shown on the plans by a suitable sprayer at the rate designated by the Engineer. Application temperature of the asphalt should be from 350°F to 400°F. The high temperature of the application may require the use of an auxiliary heater. The membrane shall be carefully inspected and all thin areas eliminated by remedial hand-spray work. Care shall be taken to insure that the membrane is not ruptured in sections where material is to be placed on top of membrane.

The membrane material was applied first to the median area, then proceeded toward the back slope leaving an outside pass of the roadway free of asphalt so that the front slope and the back slope of the ditch could be shot prior to the last section of roadway.

The distributor operator was informed at the end of each shot as to what the actual rate of application was so that he could make whatever corrections were necessary to make the proper 1.3 gal. per square yard (6 liter/m^2) application on subsequent shots.

When the sand cushion material was placed on the roadway portion of this project, it was necessary that the contractor (Peter Kiewit Sons' Co.) supply a distributor with 85-100 AC to fortify the weak spots in the ditch sections of the catalytically blown asphalt. This was shot by spray bar extension and hand spray.

A large tear in the membrane occurred 3 feet (1 meter) left of centerline at Station 568+45 when construction equipment began hauling sand cushion material during midday temperatures. When hauling was restricted to the cool early morning hours, the sand layer was placed over the asphalt membrane without difficulty. The tear at Station 568+45 was covered by plastic sheeting and sealed with liquid asphalt.

The base course and pavement layers were placed over the sand cushion in the regular manner.

Shortly after paving across the membrane treated section it was noticed that the sawed contraction joints had opened in a peculiar manner. Instead of each joint opening approximately the same amount (0.0010 to 0.020 inches) (.05 cm), there would be a sawed joint or two which did not open at all, followed by a joint which opened twice or three times as much as normal. Observers attribute this occurrence to the presence of the sand cushion which acts as roller bearings in reducing surface friction between the layers of the roadway section. Where there is a sand cushion, the 2" deep saw cut does not always weaken the concrete slab enough for a contraction joint. Perhaps 1 or 2 slabs will cling together and slide 0.02 to 0.04 (.1 cm) inches before enough friction will develop to open a sawed joint. Of course, when a joint finally does open, it will be a wide one.

INSTRUMENTATION

Moisture Cells

The treatments provided to help suppress the volume change of the subgrade on this project were of two distinct types:

1. Subexcavation and backfill of a soil using moisture-density control.
2. Application of a catalytically blown asphalt membrane over the subgrade to prevent surface moisture and condensate from supplying moisture to the foundation.

The success of the membrane treatment might depend very much on how well the moisture was controlled beneath the pavement. It was also imagined that it might be interesting to know the rate at which moisture collected in the subexcavated sections.

To help supply information on these moisture values without disturbing the roadway surface, a standard SOILTEST MC-300A Moisture Meter and Soil Moisture cells were purchased for installation of sensors under the pavement.

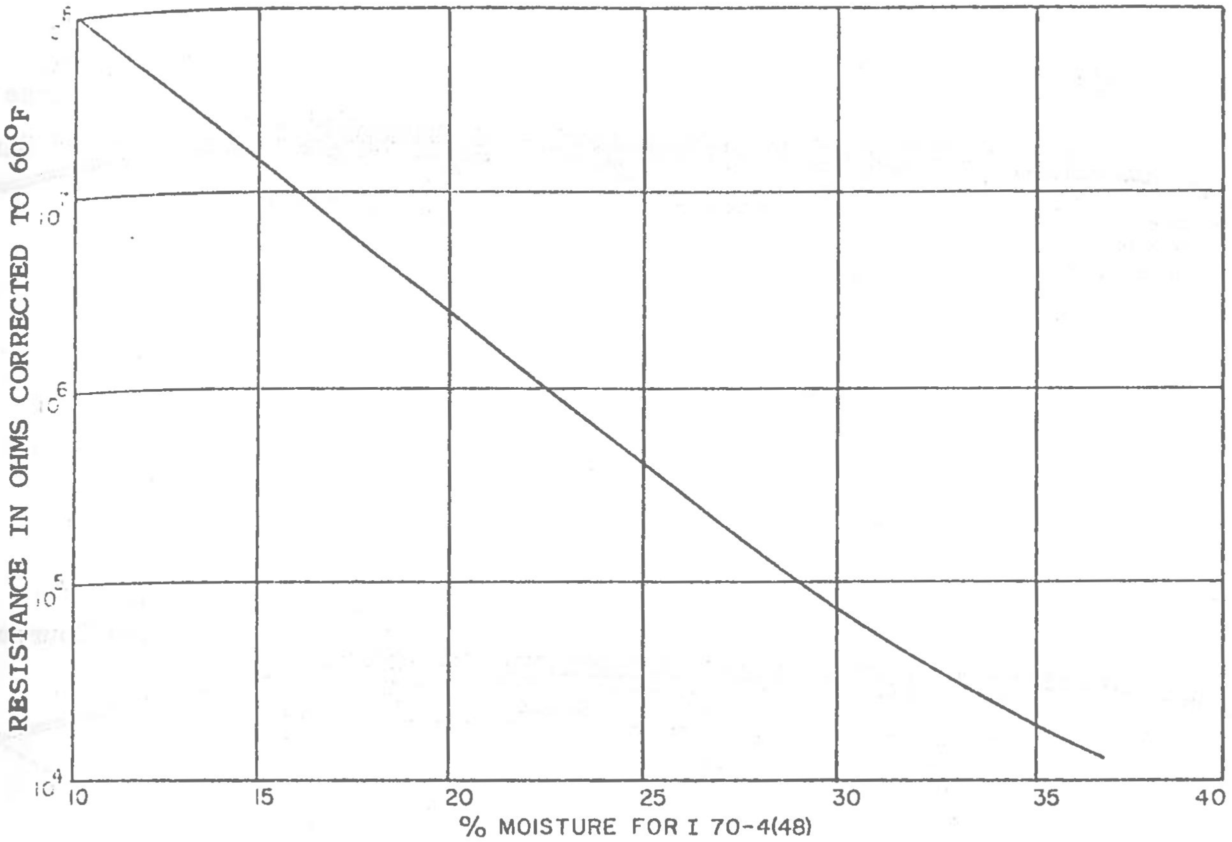
Calibration of the Cells

The moisture cells are made up of two stainless, corrosion resistant plates separated by a processed fiberglass binding which provides a coupling which varies with the moisture content of the surrounding medium. A small thermistor completes this two-circuit, three wire unit. Cells are approximately 1" (2.5 cm) by 1½" (4 cm) by 1/8" (.3 cm) thick. No method has been developed for standardizing the electrode sandwich resistance for moisture readings, even though the manufacturer claims to have made every effort to insure the most uniform materials, construction, and assembly. On the other hand, the thermistor is easily calibrated, and a chart for this purpose accompanies the purchase of the cells.

The procedure then, is to place the individual cells in soil samples of the subgrade material whose moisture content is known. Readings of the resistance of the moisture circuit and the temperature circuits are then made and the resistance of the moisture circuit is corrected for a temperatur of 60°F(16° C). A plot of a number of different moistures against resistance in the moisture circuit (after correction to 60°F) results in a graph that can be used at some later time to determine field moisture.

The graph which was developed with a Simpson Volt-ohm D.C. resistance meter for the soils on I 70-4(48) is shown on Figure 6.

Figure 6

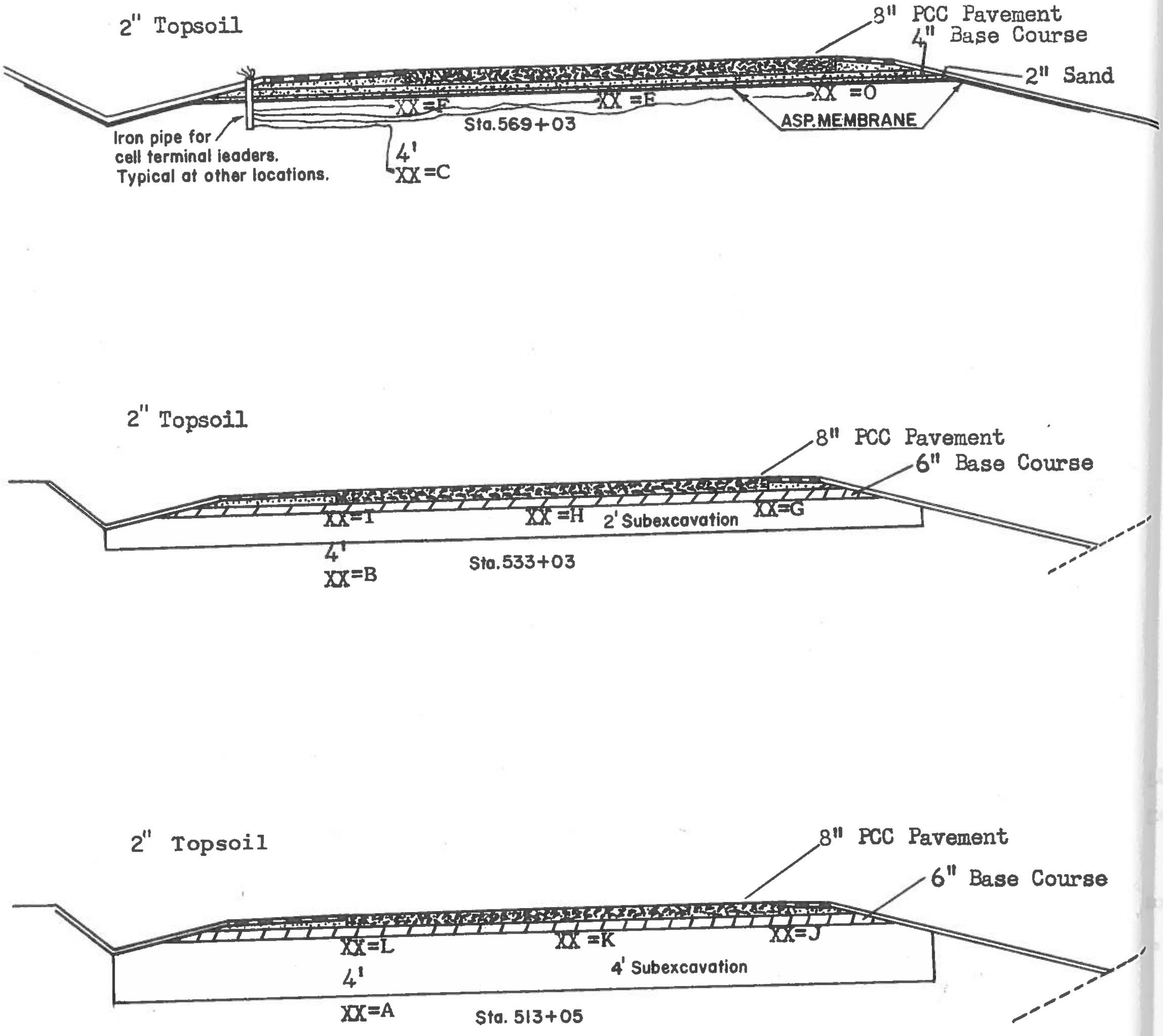


Placement of Moisture Cells

Figure 7 shows the location of the 4 moisture cells placed in each of the 3 areas of treatment. Neoprene covered wire leads were run to 4" (10 cm diameter pipes set vertically with the top end flush with the shoulder surface approximately 12" (30 cm) toward the ditch from the edge of the asphalt shoulder. From terminals in these 12" pipes, the resistance of the moisture cells may be determined at Station 513+05 for the 4' (1.3 m) Subexcavated Section, at Station 533+03 for the 2' (.6 m) Subexcavated Section and at Station 569+03 for the membrane treated Section.

The moisture-temperature cells were installed a day or two before PCC paving operations. Good checks of the moisture content were found at that time by comparing the moisture content as determined by resistance readings with the moisture content as determined by drying the soil from the hole in which the cells were placed.

Moisture Cells = XX
Shoulders are Bituminous Pavement



ROADWAY CROSS SECTIONS SHOWING LOCATION OF MOISTURE CELLS

Figure 7

Bench Marks

To make it possible to take future readings of the elevation of the concrete slabs, bench marks were established as follows:

Elevation	
5348.87	USGS Marker 30' W of 2nd Pole W of MP 575, 80'N of RR Trac
5357.97	1"X3' Steel Pipe, Guard and Lath Sta. 465+54 Rt EBL
5360.37	1"X 3' Steel Pipe, Guard and Lath Sta. 471+89 Rt EBL
5362.51	1"X 3' Steel Pipe, Guard and Lath Sta. 475+84 Rt EBL
5364.92	Brass Cap in Hd. Wall Lt. CBC Sta. 478+ WBL
5364.85	1" X 3' Steel Pipe, Guard and Lath Sta. 482+25 Rt EBL
5367.06	1" X 3' Steel Pipe, Guard and Lath Sta. 486+24 Rt EBL
5368.39	1" X 3' Steel Pipe, Guard and Lath Sta. 490+26 Rt EBL
5371.11	1" X 3' Steel Pipe, Guard and Lath Sta. 494+30 Rt EBL
5374.66	1" X 3' Steel Pipe, Guard and Lath Sta. 498+30 Rt EBL
5381.29	1" X 3' Steel Pipe, Guard and Lath Sta. 502+24 Rt EBL
5387.13	1" X 3' Steel Pipe, Guard and Lath Sta. 506+15 Rt EBL
5394.65	1" X 3' Steel Pipe, Guard and Lath Sta. 510+15 Rt EBL
5403.69	1" X 3' Steel Pipe, Guard and Lath Sta. 514+15 Rt EBL
5409.78	1" X 3' Steel Pipe, Guard and Lath Sta. 518+40 Rt EBL
5405.86	1" X 3' Steel Pipe, Guard and Lath Sta. 522+30 Rt EBL
5400.53	Brass Cap in Hd. Wall Lt. CBC Sta 523+85 WBL
5408.53	1" X 3' Steel Pipe, Guard and Lath Sta. 527+94 Rt EBL
5413.37	1" X 3' Steel Pipe, Guard and Lath Sta. 531+97 Rt EBL
5409.09	1" X 3' Steel Pipe, Guard and Lath Sta. 536+10 Rt EBL
5413.39	1" X 3' Steel Pipe, Guard and Lath Sta. 540+18 Rt EBL
5413.02	1" X 3' Steel Pipe, Guard and Lath Sta. 544+30 Rt EBL
5410.96	1" X 3' Steel Pipe, Guard and Lath Sta. 548+25 Rt EBL
5409.16	Brass Cap in Hd. Wall Lt. CBC Sta. 549+ WBL
5414.35	1" X 3' Steel Pipe, Guard and Lath Sta. 553+19 Rt EBL
5414.80	1" X 3' Steel Pipe, Guard and Lath Sta. 557+52 Rt EBL
5414.83	1" X 3' Steel Pipe, Guard and Lath Sta. 561+55 Rt EBL
5414.59	1" X 3' Steel Pipe, Guard and Lath Sta. 565+55 Rt EBL
5414.75	1" X 3' Steel Pipe, Guard and Lath Sta. 569+59 Rt EBL
5410.90	1" X 3' Steel Pipe, Guard and Lath Sta. 573+52 Rt EBL
5413.00	1" X 3' Steel Pipe, Guard and Lath Sta. 577+52 Rt EBL
5414.91	Brass Cap in Curb Bridge Sta. 583+ Rt. EBL
5412.17	1" X 3' Steel Pipe, Guard and Lath Sta. 588+12 Rt EBL
5412.38	1" X 3' Steel Pipe, Guard and Lath Sta. 592+06 Rt EBL
5413.35	1" X 3' Steel Pipe, Guard and Lath Sta. 596+00 Rt EBL
5415.65	1" X 3' Steel Pipe, Guard and Lath Sta. 600+00 Rt EBL
5418.45	1" X 3' Steel Pipe, Guard and Lath Sta. 604+79 Rt EBL
5420.45	1" X 3' Steel Pipe, Guard and Lath Sta. 609+75 Rt EBL

INITIAL CONDITIONS OF THE ROADWAY

Moisture in the Subgrade

Figure 8 presents a record of the moisture in the subgrade as indicated by the moisture cells since the project was paved. Several readings are in doubt, possibly due to malfunction of the insulation on the leads or shorting within the cell itself.

However, the following generalization of moisture content immediately after paving might be made:

	4' (1.2 m) Subexcavated Section	2' (.6 m) Subexcavated Section	Membrane Section
Moisture Content 4' (1.2m) below the Surface	26%	28%	30%
Moisture Content in the top 6" (15 cm) of the Surface	31%	34%	25%

Seven months later (March 1969) the moisture values averaged as follows:

	4' (1.2 m) Subexcavated Section	2' (.6 m) Subexcavated Section	Membrane Section
Moisture Content 4' (1.2 m) below the Surface	25%	26%	26%
Moisture Content in the top 6" (15 cm) of the Surface	27%	27%	23%

Being composed mostly of burned shale particles (Scoria), the base course showed no free moisture although the moisture content was approximatel 12%. During January and February 1969, the weather was unusually warm and d

Deflection of the Pavement

As might be expected for concrete pavement, the Benkelman Beam Deflecti values were quite low, averaging 0.010" (.025 cm) at the center of the slabs, and 0.020" (.05 cm) at the joints for all treated sections.

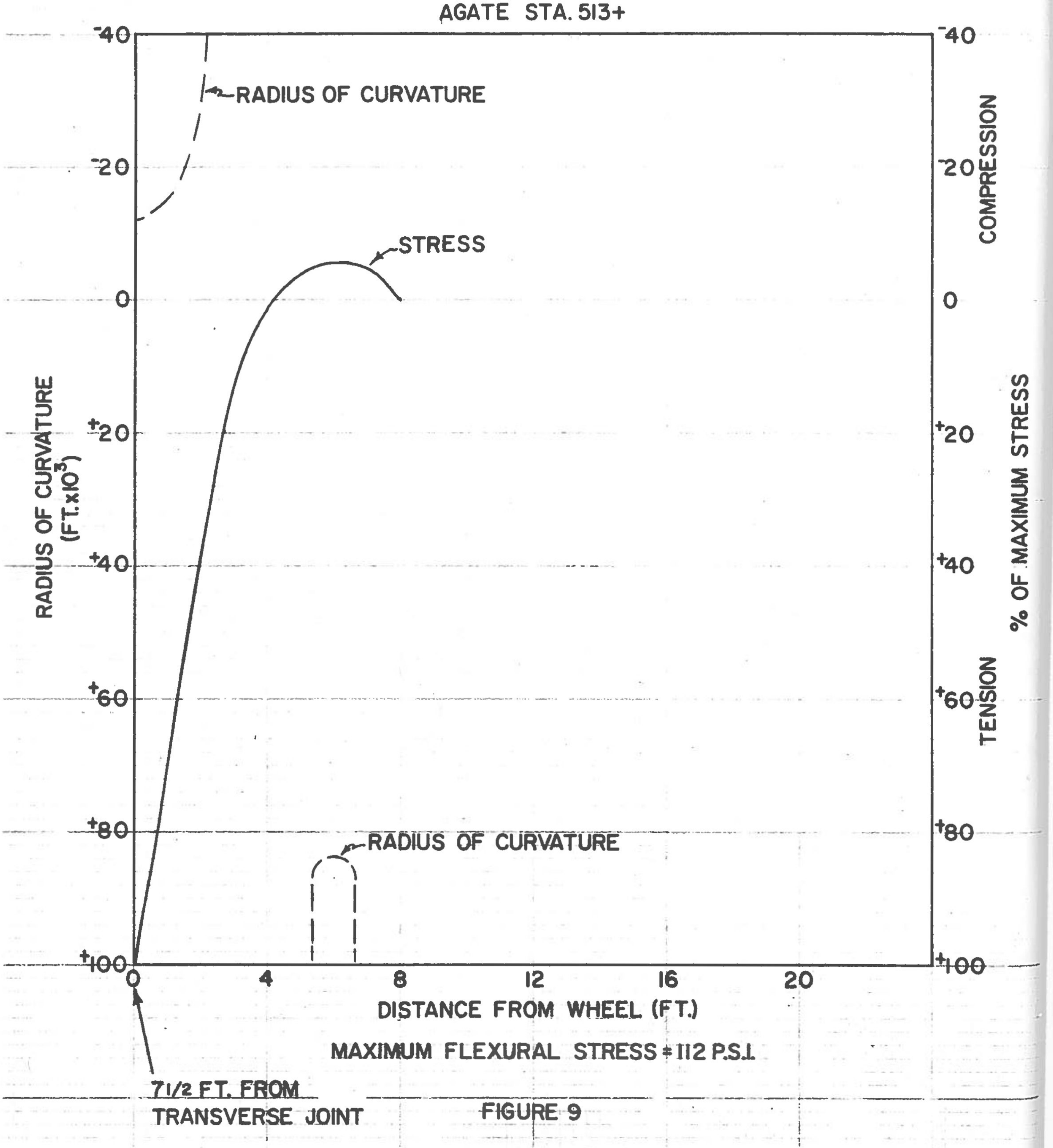
The Texas Basin Beam having a 40" (100 cm) span was also used with a 9000# (4086 kg) wheel load. Deflections were generally 0.0014" within the slabs and 0.0100" (.025 cm) across joints for all treated sections. The results from the Basin Beam measurements were used to calculate the radius o curvature and the flexural stress. Figure 9 is a plot of the radius of curvature and the stress in the concrete pavement at Station 513. Similar curves have been plotted for Station 533 and Station 569.

SUBGRADE MOISTURES AT AGATE I 70-4(48)
DETERMINED BY SOIL MOISTURE CELLS

STATION	CELL NO. AND LOCATION		PERCENTAGE OF MOISTURE					
					1968		1969	
			AUG.	SEPT.	OCT.	DEC.	MARCH	
513+05	A	4' Below Subgrade 12' Lt. of CL	26	27	27	26	25	4' SUBEXCAVATION & BACKFILL
	L	Top of Subgrade 12' Lt. of CL	-	35	32	-	27	
	K	Top of Subgrade Centerline		30	-	38	29	
	J	Top of Subgrade 12' Rt. of CL		31	31	31	25	
533+03	B	4' Below Subgrade 12' Lt. of CL	28	28	28	30	26	2' SUBEXCAVATION & BACKFILL
	I	Top of Subgrade 12' Lt. of CL		35	35	34	26	
	H	Top of Subgrade Centerline		33	34	35	26	
	G	Top of Subgrade 12' Rt. of CL		34	34	34	28	
569+03	C	4' Below Subgrade 12' Lt. of CL	30	32	25?	32	26	(Beneath the Membrane) ASPHALT MEMBRANE (These Cells are) (Beneath the Membrane)
	F	Top of Subgrade 12' Lt. of CL	22	24	24	32?	23	
	E	Top of Subgrade Centerline	22	23	27	27	23	
	D	Top of Subgrade 12' Rt. of CL	23	25	26	33?	22	

Figure 8

TYPICAL CURVES OF STRESS AND RADIUS OF CURVATURE



MAXIMUM FLEXURAL STRESS = 112 P.S.I.

FIGURE 9

Smoothness of the Pavement

The Present Serviceability Index of the Pavement has been determined annually with the CHLOE Profilometer since 1969. The following results were obtained:

Location	1975 Driving Lane RWP	1975 Driving Lane LWP	1968 Driving Lane RWP	1968 Driving Lane LWP
Sta. 522 to 506 - 4' (1.2 m) Subex Section	3.2	3.4	3.9	3.8
Sta. 547 to 526 - 2' (.6 m) Subex Section	3.3	3.4	4.3	3.9
Sta. 572 to 552 - Membrane Section	3.5	3.5	4.0	3.9

The loss in smoothness is due mostly to faulting, since the cracking in the 3 sections is not considered to be severe.

Smoothness at 40 MPH (64 km/h)

The Colorado Accelerometer is a device for measuring the acceleration of the rear axle of a vehicle going 20 or 40 mph (64 km/h). A graph of the acceleration or discomfort imposed upon the occupants in a vehicle traveling westward (since I 70-4(48) was for the construction of the westbound lanes) is shown on page 18. The surface of the membrane section is quite smooth (3.5), but the subexcavated sections show enough roughness to place the Present Serviceability Index in the 3.2 to 3.3 range. In 1968, these sections were in the 3.8 to 3.9 range. In 1975, the smoothness device for Sufficiency Study measurements gave a 3.4 PSI reading for all three sections.

Surface Irregularities

The 20 foot (6 m) reference frame for the CHLOE Profilometer has been modified to support a bicycle wheel which can move up or down according to the irregularities on the surface of the pavement. A graph of this movement (full scale up and down and 1" = 50' (15 m) horizontally) is shown on pages 19 through 21. A comparison of these graphs with the ones made in 1969 shows that considerable faulting has taken place in the last 7 years in all test sections.

Skid Resistance of the Pavement

Coefficients of friction as determined with the British Portable Tester and the Soiltest Skid Trailer are shown below:

Location	Coef Friction by BPT @ 7 MPH 1969	Coef Friction by BPT @ 7 MPH 1975	Coef by Skid Trailer @ 40 MPH 1969	Coef by Skid Trailer @ 40 MPH 1975
Sta. 522 to 506 - 4' (1.2 m) Subex Section	77	67	71	55
Sta. 547 to 526 - 2' (.6 m) Subex Section	77	67	71	55
Sta. 572 to 552 - Membrane Section	77	67	71	55

In 1975 the skid number for the EB lane constructed in 1960 was 65 by the British Portable tester and 54 by the Skid Trailer.

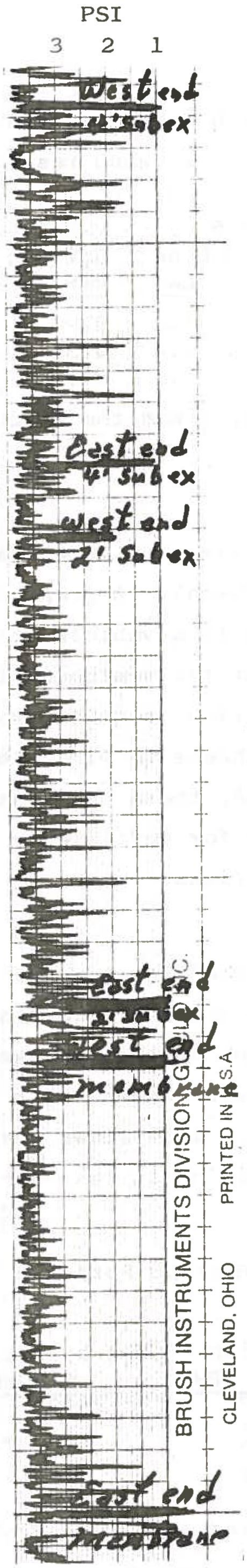
ACCELEROMETER GRAPHS

for

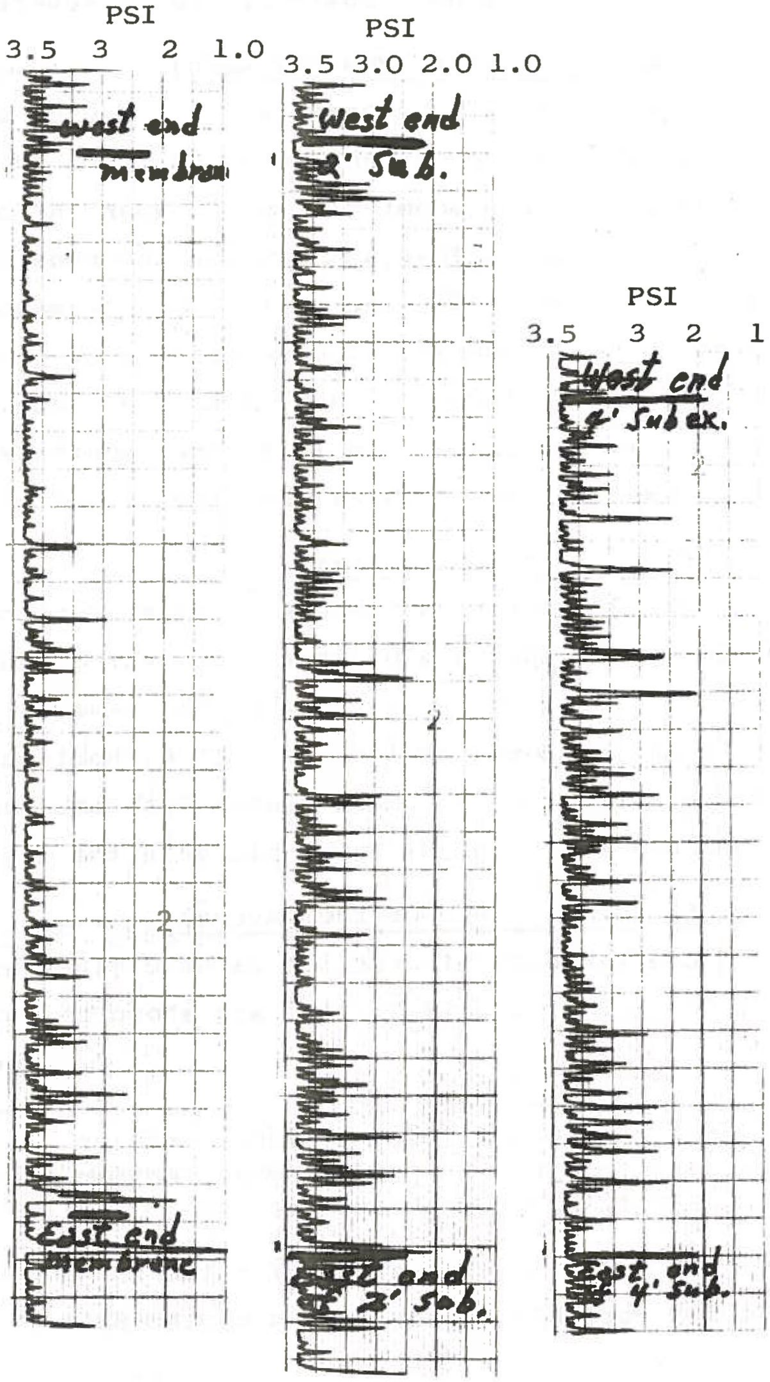
Test Sections West of Agate, Colorado
Taken October 6, 1975

High points (pen throws to the right) represent axle passage over sawed joints spaced 12', 18', 19', and 13' in sequential order.

The concrete placed over the membrane test section Sta. 552 to Sta. 572 appears to be quite smooth (PSI approx 3.5). There is little or no difference between the smoothness sho by the accelerometer on the 4' subexcavated section and the 2' subexcavated section.



40 mph Graph



20 mph Graphs

13'

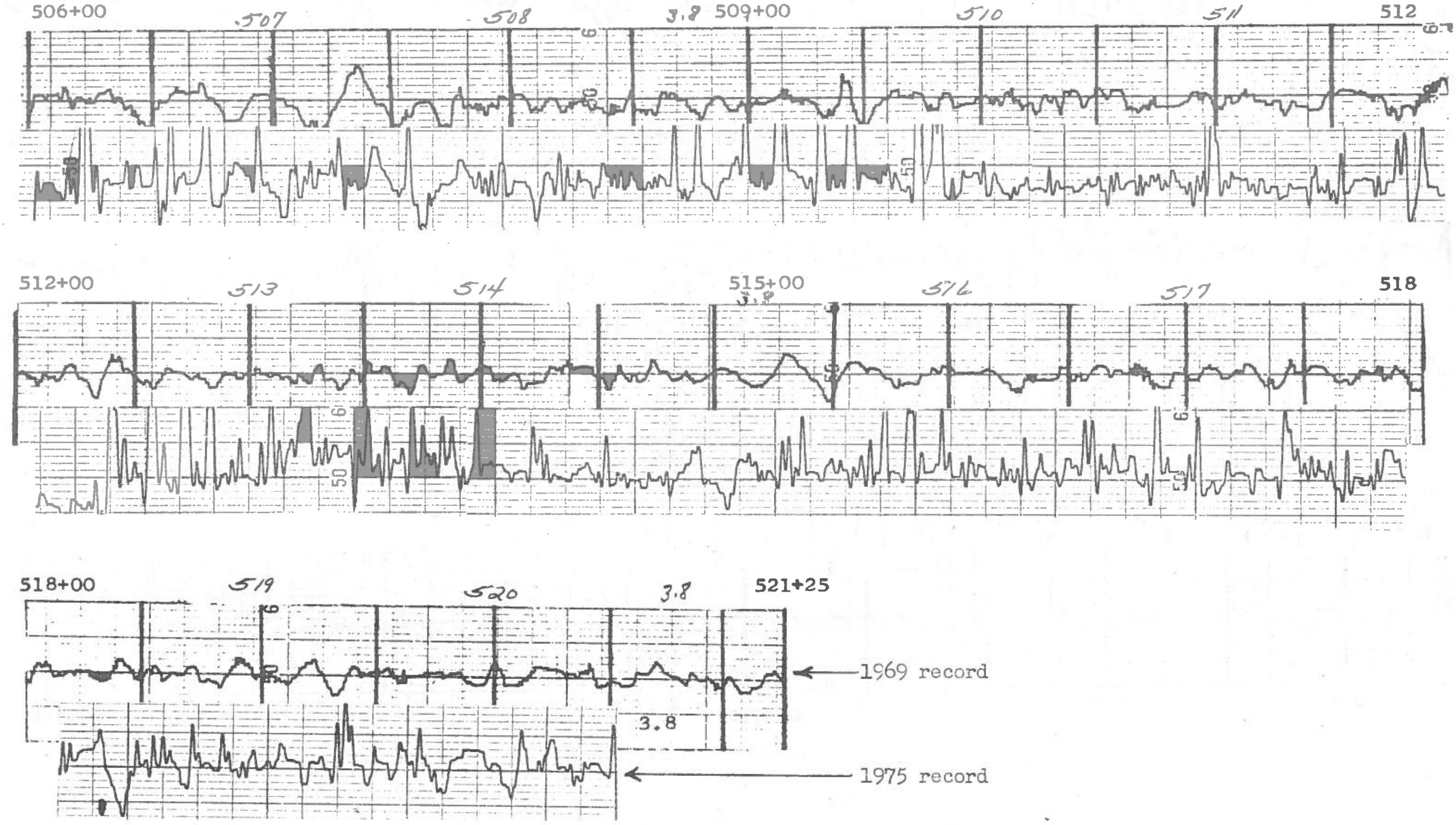
Sta. 552
3.5).
ness sho
and the

PROJECT NO. I 70-4(48)

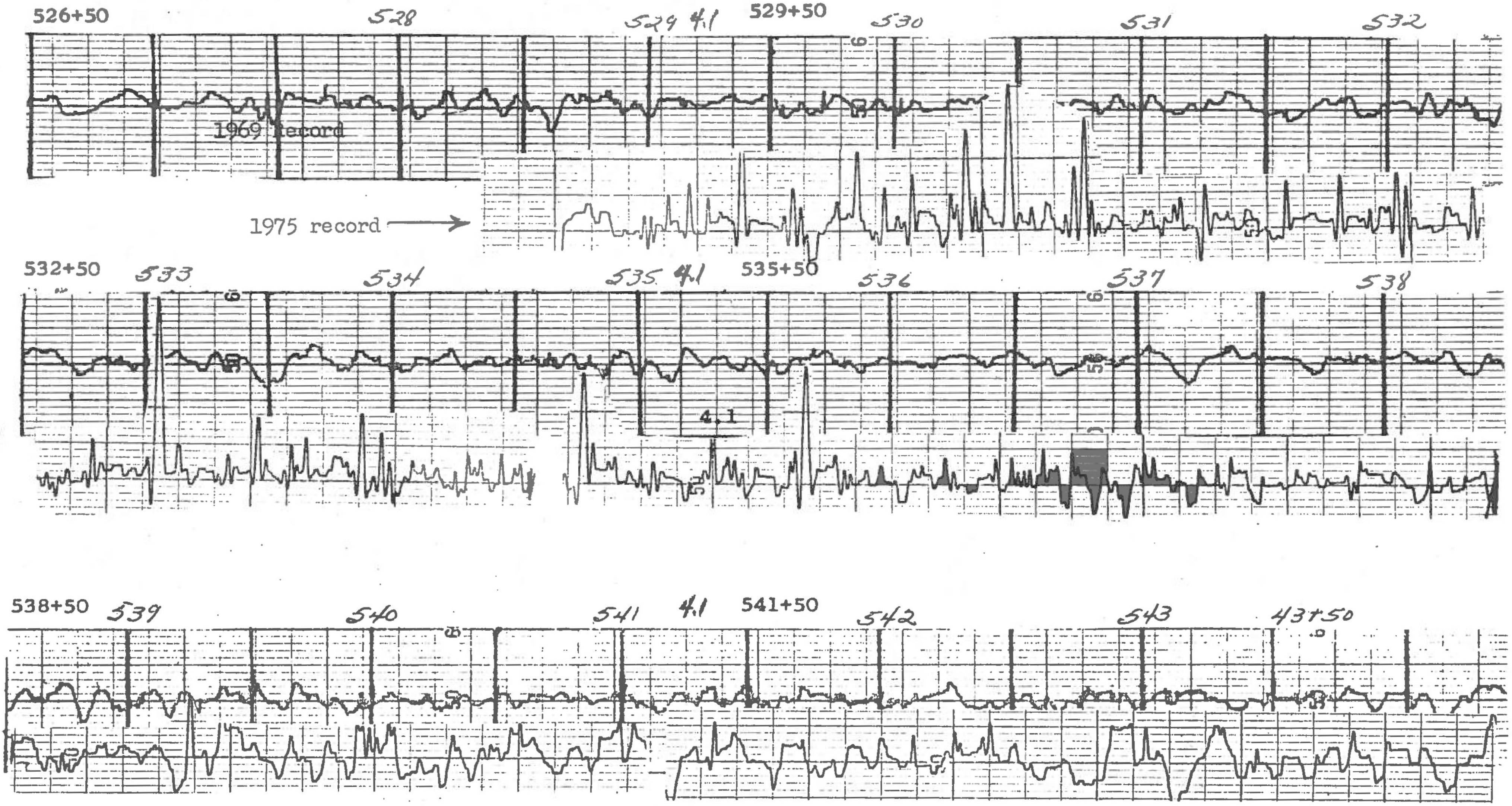
AGATE - WEST

CHLOE PROFILOMETER CHARTS
OCTOBER 2, 1968

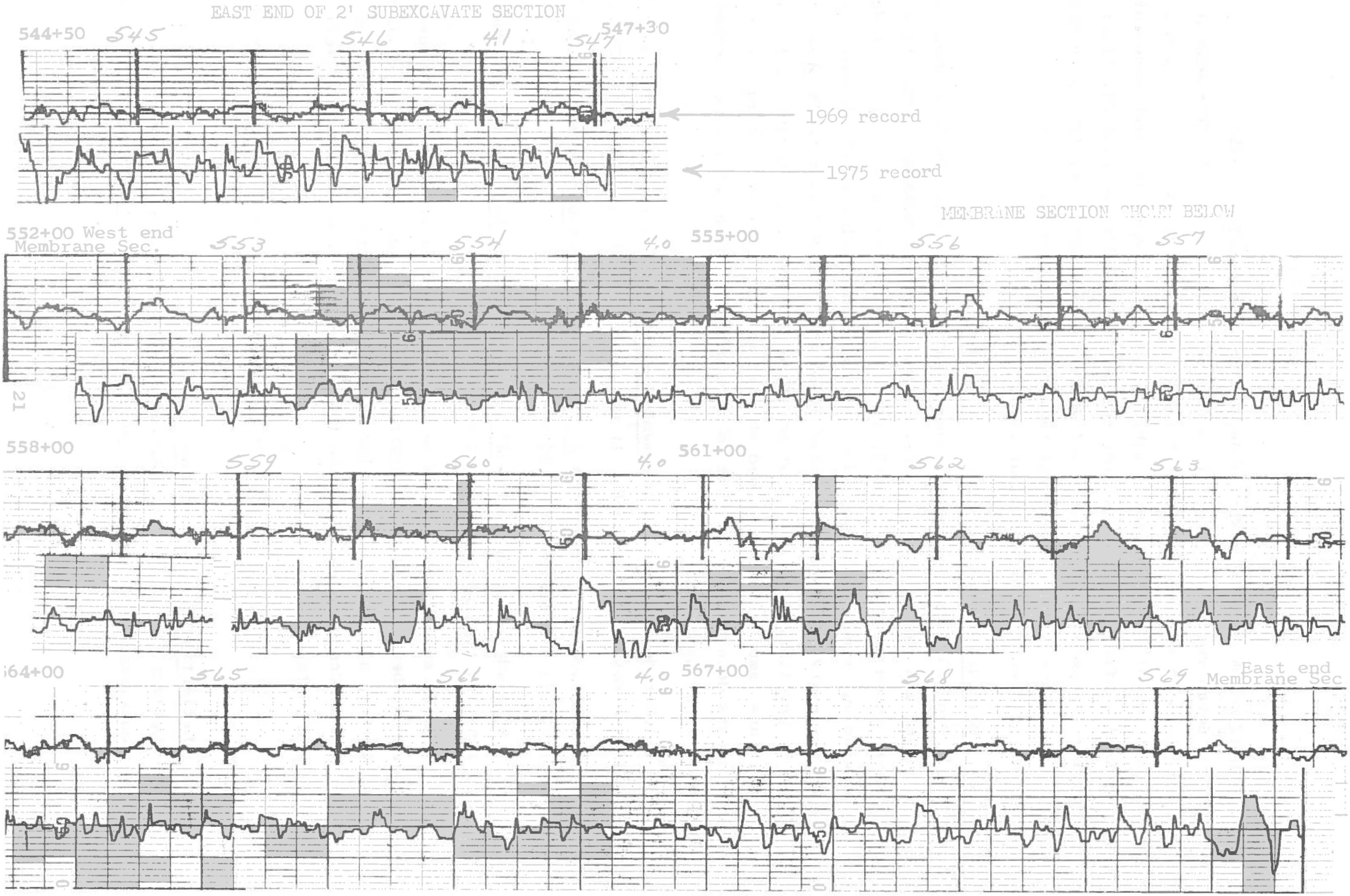
RIGHT WHEEL PATH, WB DRIVING LANE 4 foot Subexcavate Section



2 Foot SUBEXCAVATION SECTION



3


EAST END OF 2' SUBEXCAVATE SECTION
544+50
545
546
4.1
547
547+30
1969 record
1975 record
MEMBRANE SECTION SHOWN BELOW
552+00 West end Membrane Sec.
553
554
4.0
555+00
556
557
21
558+00
559
560
4.0
561+00
562
563
564+00
565
566
4.0
567+00
568
569
East end Membrane Sec

CONDITION OF THE PAVEMENT 7 YEARS AFTER CONSTRUCTION (1975)

Seven years is ordinarily a long enough time for the development of distress in a concrete pavement placed on swelling soils in Colorado. The usual run of events is for slight (almost imperceptible) slab movement or cracking after the first winter season, followed by perceptible distress after the second winter, and definite displacement after the third winter. If there are to be significant failures on the project, they should have been apparent by the spring of 1975.

Moisture in the Subgrade

Page 23 shows moisture values found in 1975 near the locations sampled in 1968 and the following years. Comparing these moisture contents with those shown on pages 14 and 15, it appears that there has been considerable drying out since 1968 instead of moisture absorption which is considered to be necessary for volume increase of soils. The moisture cells were considered to be unreliable indicators of moisture content by the spring of 1970, and moisture samples were obtained thereafter with an auger. Actually, moisture contents determined from 1968 to 1970 with moisture cells were checked by hand auger sampling.

Subgrade moisture in the membrane section was typically 30% when the membrane was placed in 1968. It was nearer to 26% in 1969, and 23% by 1975.

Subgrade moisture in the 2' subexcavated section was 30% in 1968, 26% by 1969 and typically 17% by 1975.

Subgrade moisture in the 4' subexcavated section was 27% in 1968, 25% by 1969 and typically 17% by 1975.

For a subgrade soil with an optimum moisture of 24-25% it appears that there has been considerable drying since 1968, and this gradual drying out instead of additional saturation is no doubt responsible for at least a part of the tendency of the subgrade to show very little cracking or swell in the last 7 years.

The Figure on page 24 shows the moisture trend under the membrane section.

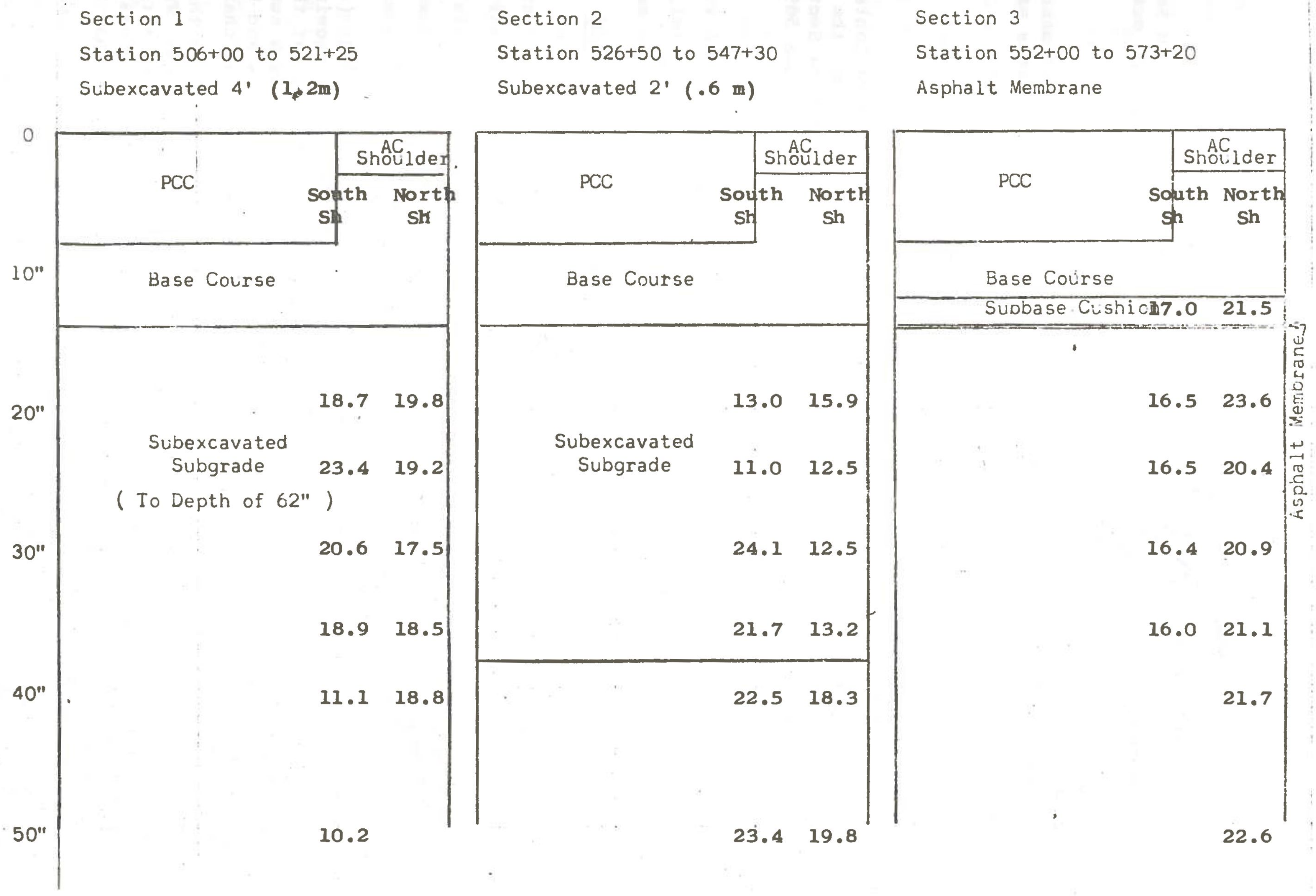
Deflection of the Pavement

Deflection measurements were made each spring since 1969 by means of the Benkelman Beam. They have averaged about .011 in the membrane section

AGATE EXPERIMENTAL PROJECT

MOISTURE PROFILE for Spring of 1975

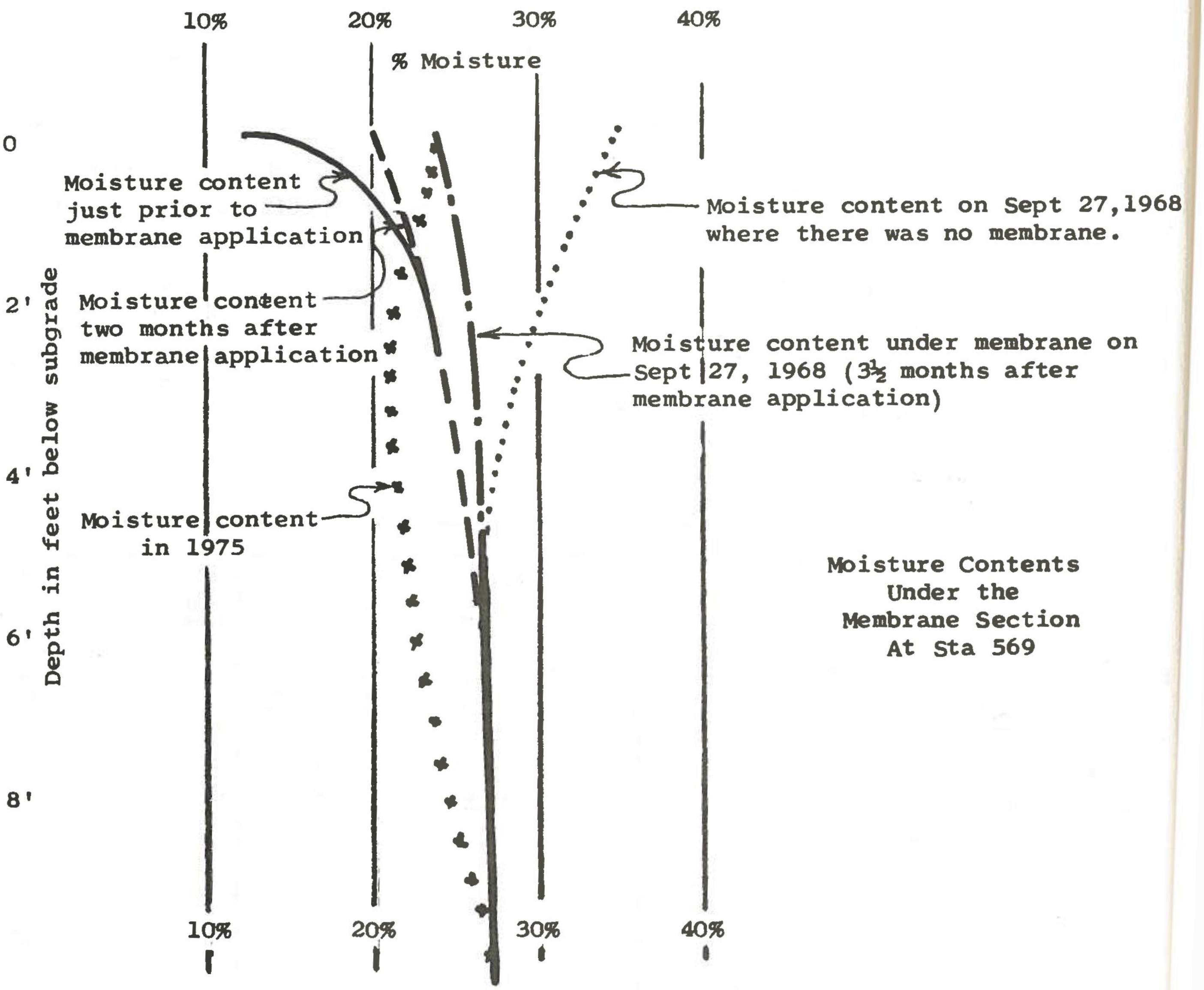
(Values shown are % moisture at depths shown on the left side)


Section 1
Station 506+00 to 521+25
Subexcavated 4' (1.2m)

Section 2
Station 526+50 to 547+30
Subexcavated 2' (.6 m)

Section 3
Station 552+00 to 573+20
Asphalt Membrane

	Section 1		Section 2		Section 3	
	South Sh	North Sh	South Sh	North Sh	South Sh	North Sh
					17.0	21.5
20"	18.7	19.8	13.0	15.9	16.5	23.6
	23.4	19.2	11.0	12.5	16.5	20.4
30"	20.6	17.5	24.1	12.5	16.4	20.9
	18.9	18.5	21.7	13.2	16.0	21.1
40"	11.1	18.8	22.5	18.3		21.7
50"	10.2		23.4	19.8		22.6



Moisture Contents
Under the
Membrane Section
At Sta 569

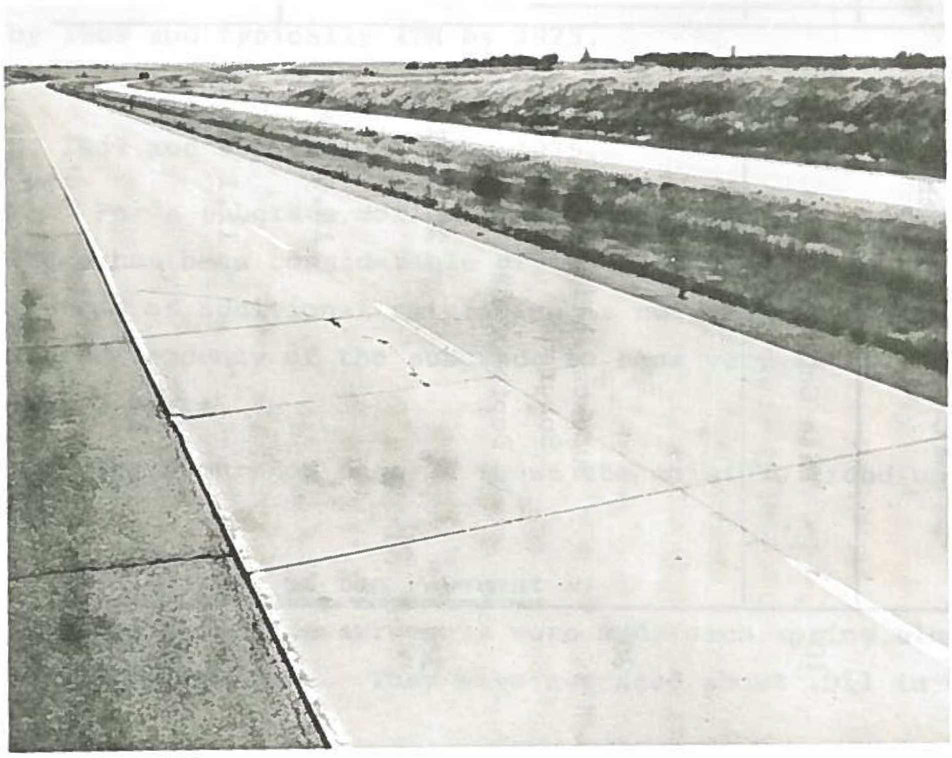


Photo in 2' (.6 m) Sube
Section showing the
cracking at the point
of maximum surface
distress and highest
elevation change.

Cracks are thin and
localized. Faulting
actually is responsibl
for more loss of ridin
comfort than the crack

each year, .012 in the 2' subexcavation section and .010 in the 4' subexcavation section. These values are very low and almost the same as the deflection values found in 1969 after construction.

Smoothness of the Pavement

As shown in the comparisons on pages 17 and 21, the CHLOE Profilometer has shown that smoothness of the membrane section has gradually fallen from a PSI value of 3.9 in 1969 to an average of about 3.4 in 1975 due mostly to faulting.

Smoothness of the 2' (.6 m) subexcavation section dropped from 4.0 to 3.3, and smoothness of the 4' (1.2 m) subexcavation section dropped from 3.9 to 3.3.

The accelerometer tests showed the same results.

Skid Resistance of the Pavement

Page 17 also shows that the skid resistance has been gradually falling since 1969. The British Portable tester showed values of 77 and the skid trailer showed values of 71 just after construction. In the Spring of 1975, those values had fallen to 70 and 55 respectively.

Elevation of the Pavement

Pages 26 through 32 show elevations of the north and south edges of the concrete in the westbound lane in 1969. Above these elevations in parenthes are the last three digits of the elevations measured in the spring of 1975. The elevations start at the west end of the project where the 4' (1.2 m) subexcavation section is located and proceed eastward through the 2' (.6 m) subexcavation section and finally through the membrane test section.

For the most part, there has been very little change in elevation since 1969, compared to the elevation changes observed farther east in the Cedar Point area, at least. Even in the 2' subexcavation section where the elevation increased approximately 0.20' (.06 m) the cracking is only on the order of 10 to 20 feet (3 to 7 meters) per 1000 ft^2. See photo on page 24 of this report. This amount is considered to be inconsequential since the cracks are narrow and they have not increased in size or length in the last 5 years. Actually, the maximum swell in the 4' (.6 m) subexcavation and in the membrane sections is 0.1' (3 cm) and in the 2' (1.2 m) subexcavation section is 0.2' (6 cm).

ELEVATIONS AT LEFT AND RIGHT EDGES OF SAWED JOINTS (Feet above SL)
Original elevations found in 1969 are shown with the
1975 elevations shown in parenthesis above

NW end of 4' Subexcavate Sec

Station 506

Slight Swell - Looks OK

Slight Swell - Looks OK

Slight Swell - OK

(4.41) 5394.40	(4.70) 5394.66	(8.96) 5398.92	(9.36) 5399.32	(3.37) 5403.34	(3.77) 5403.71
(4.69) 5394.64	(5.03) 5394.95	(9.19) 5399.16	(9.60) 5399.57	(3.68) 5403.56	(4.01) 5403.96
(4.97) 5394.88	(5.34) 5395.21	(9.40) 5399.36	(9.85) 5399.81	(3.87) 5403.84	(4.16) 5404.19
(5.21) 5395.11	(5.55) 5395.44	(9.66) 5399.64	(0.10) 5400.06	(4.01) 5404.07	(4.49) 5404.42
(5.46) 5395.36	(5.77) 5395.68	(9.93) 5399.89	(0.37) 5400.31	(4.32) 5404.30	(4.75) 5404.78
(5.71) 5395.62	(6.03) 5395.92	(0.16) 5400.12	(0.60) 5400.53	(4.56) 5404.54	(4.99) 5404.92
(5.95) 5395.83	(6.22) 5396.12	(0.42) 5400.39	(0.88) 5400.83	(4.79) 5404.76	(5.26) 5405.14
(6.21) 5396.05	(6.49) 5396.38	(0.69) 5400.65	(1.10) 5401.05	(5.02) 5404.98	(5.44) 5405.38
(6.34) 5396.26	(6.74) 5396.63	Station 510+09		(5.25) 5405.22	(5.66) 5405.60
(6.54) 5396.48	(6.99) 5396.88	(0.93) 5400.90	(1.35) 5401.30	(5.45) 5405.44	(5.86) 5405.81
(6.77) 5396.78	(7.14) 5397.10	(1.19) 5401.15	(1.60) 5401.55	(5.66) 5405.64	(6.07) 5406.02
(7.01) 5396.98	(7.37) 5397.34	(1.41) 5401.37	(1.82) 5401.78	(5.90) 5405.87	(6.29) 5406.24
(7.24) 5397.21	(7.63) 5397.59	(1.68) 5401.64	(2.06) 5402.01	(6.10) 5406.06	(6.50) 5406.44
(7.47) 5397.45	(7.90) 5397.84	(1.93) 5401.88	(2.31) 5402.25	(6.35) 5406.29	(6.72) 5406.66
(7.75) 5397.71	(8.14) 5398.08	(2.16) 5402.14	(2.56) 5402.49	(6.59) 5406.49	(6.94) 5406.87
(8.01) 5397.96	(8.37) 5398.33	(2.38) 5402.35	(2.79) 5402.72	(6.82) 5406.70	(7.16) 5407.09
(8.25) 5398.19	(8.62) 5398.60	(2.62) 5402.60	(3.02) 5402.96	(6.99) 5406.88	(7.37) 5407.26
(8.49) 5398.44	(8.85) 5398.82	(2.87) 5402.84	(3.30) 5403.23	(7.17) 5407.06	(7.56) 5407.44
(8.71) 5398.66	(9.12) 5399.08	(3.12) 5403.10	(3.50) 5403.45	(7.37) 5407.26	(7.75) 5407.64

ELEVATIONS AT LEFT AND RIGHT EDGES OF SAWED JOINTS
Original elevations found in 1969 are shown with the
1975 elevations shown in parenthesis above

Station 510+09 (continued)

(7.54)	(7.91)
5407.45	5407.83
(7.90)	(7.27)
5407.82	5407.20
(8.07)	(8.45)
5408.02	5408.36

Station 515+07

Slight Swell - Looks OK

(8.24)	(8.63)
5408.18	5408.54
(8.40)	(8.79)
5408.33	5408.70
(8.57)	(8.98)
5408.51	5408.90
(8.75)	(9.13)
5408.68	5409.04
(8.92)	(9.31)
5408.84	5409.23
(9.10)	(9.46)
5409.01	5409.39
(9.25)	(9.61)
5409.18	5409.54
(9.40)	(9.77)
5409.33	5409.68
(9.54)	(9.92)
5409.47	5409.84
(9.68)	(0.05)
5409.61	5409.97
(9.83)	(0.20)
5409.76	5410.11
(9.98)	(0.33)
5409.91	5410.25
(0.13)	(0.46)
5410.07	5410.39
(0.26)	(0.60)
5410.20	5410.52
(0.38)	(0.74)
5410.32	5410.68
(0.50)	(0.86)
5410.45	5410.80

Slight Swell

(0.63)	(0.98)
5410.56	5410.91
(0.74)	(1.10)
5410.67	5411.04
(1.84)	(1.23)
5410.79	5411.13
(0.94)	(1.31)
5410.88	5411.24
(1.02)	(1.38)
5410.99	5411.32
(1.13)	(1.49)
5411.08	5411.43
(1.24)	(1.60)
5411.19	5411.53
(1.30)	(1.63)
5411.30	5411.64
(1.36)	(1.70)
5411.39	5411.73
(1.43)	(1.78)
5411.48	5411.81
(1.52)	(1.85)
5411.54	5411.91
(1.62)	(1.98)
5411.62	5411.98
(1.69)	(2.05)
5411.70	5412.02
(1.75)	(2.13)
5411.76	5412.12
(1.79)	(2.17)
5411.82	5412.21
(1.87)	(2.28)
5411.90	5412.30
(1.94)	(2.35)
5411.96	5412.36

Station 520+03

(2.01)	(2.42)
5412.04	5412.43
(2.08)	(2.47)
5412.10	5412.49
(2.15)	(2.53)
5412.15	5412.54
(2.18)	(2.57)
5412.21	5412.59
(2.24)	(2.63)
5412.28	5412.64
(2.30)	(2.67)
5412.32	5412.69
(2.36)	(2.72)
5412.37	5412.73
(2.39)	(2.77)
5412.39	5412.76
(2.41)	(2.80)
5412.45	5412.82

Station 521+19

(2.48)	(2.84)
5412.47	5412.82

Construction Joint

(2.49)	(2.87)
5412.46	5412.84
(2.51)	(2.89)
5412.49	5412.87
(2.51)	(2.90)
5412.50	5412.87
(2.52)	(2.92)
5412.52	5412.89

Station 521+97

(2.52)	(2.92)
5412.52	5412.90

SE end of 4' Subexcavate

Station 526+00

NW end of 2' Subexcavate

5413.03	5413.38

ELEVATIONS AT LEFT AND RIGHT EDGES OF SAWED JOINTS
Original elevations found in 1969 are shown with the
1975 elevations shown in parenthesis above

Station 527+09					
(3.02)	(3.42)	(3.25)	(3.64)	(3.55)	(3.91)
5413.05	5413.40	5413.28	5413.64	5413.58	5413.94
(3.02)	(3.42)	(3.23)	(3.63)	(3.59)	(3.92)
5413.06	5413.41	5413.28	5413.65	5413.59	5413.95
(3.03)	(3.41)	(3.24)	(3.65)	(3.60)	(3.93)
5413.06	5413.42	5413.28	5413.65	5413.62	5413.95
5413.08	5413.43				
5413.10	5413.47				
(3.05)	(3.48)	(3.25)	(3.67)	(3.60)	(3.94)
5413.10	5413.48	5413.29	5413.65	5413.63	5413.97
(3.05)	(3.55)	(3.28)	(3.69)	(3.60)	(3.96)
5413.09	5413.49	5413.31	5413.68	5413.64	5413.99
(3.08)	(3.59)	(3.32)	(3.72)	(3.60)	(3.95)
5413.11	5413.49	5413.33	5413.70	5413.64	5414.00
(3.10)	(3.56)	(3.35)	(3.75)	(3.56)	(3.97)
5413.12	5413.49	5413.36	5413.73	5413.65	5414.01
(3.12)	(3.56)	(3.36)	(3.77)	(3.60)	(3.98)
5413.14	5413.51	5413.39	5413.75	5413.65	5414.01
(3.13)	(3.51)	(3.39)	(3.79)	(3.63)	(4.00)
5413.16	5413.52	5413.40	5413.77	5413.63	5414.02
(3.14)	(3.52)	(3.40)	(3.82)	(3.65)	(4.00)
5413.17	5413.53	5413.42	5413.79	5413.67	5414.03
(3.17)	(3.54)	(3.43)	(3.84)	(3.66)	(4.02)
5413.18	5413.54	5413.44	5413.83	5413.70	5414.05
(3.18)	(3.56)	(3.43)	(3.84)	(3.67)	(4.05)
5413.20	5413.56	5413.44	5413.84	5413.72	5414.04
(3.19)	(3.58)	(3.45)	(3.86)	(3.68)	(4.05)
5413.21	5413.58	5413.45	5413.84	5413.72	5414.06
(3.21)	(3.60)	(3.43)	(3.87)	(3.68)	(4.06)
5413.22	5413.59	5413.50	5413.87	5413.74	5414.10
(3.22)	(3.62)	(3.46)	(3.87)		
5413.24	5413.60	5413.48	5413.89	Station 534+97	
(3.23)	(3.64)	(3.50)	(3.87)	(3.70)	(4.09)
5413.22	5413.62	5413.50	5413.90	5413.75	5414.10
(3.25)	(3.63)	(3.56)	(3.89)	(3.69)	(4.09)
5413.26	5413.64	5413.54	5413.92	5413.75	5414.11
Station 530+03					
(3.24)	(3.64)	(3.54)	(3.91)	(3.70)	(4.11)
5413.27	5413.64	5413.56	5413.92	5413.76	5414.12

91) 94
92) 95
93) 95
94) 97
96) 99
95) 00
97) 01
98) 01
00) 02
00) 03
02) 05
05) 04
05) 06
06) 10
09) 10
09) 11
11) 12

ELEVATIONS AT LEFT AND RIGHT EDGES OF SAWED JOINTS
Original elevations found in 1969 are shown with the
1975 elevations shown in parenthesis above

Station 534+97 (continued)

(3.74) 5413.77	(4.16) 5414.13
(3.77) 5413.78	(4.16) 5414.15
(3.81) 5413.80	(4.18) 5414.19
(3.84) 5413.84	(4.21) 5414.20
5413.87	5414.22

Moderate Swell

(3.93) 5413.90	(4.29) 5414.22
(3.97) 5413.90	(4.31) 5414.25
(4.01) 5413.94	(4.36) 5414.30
(4.01) 5413.98	(4.36) 5414.32
(4.01) 5414.00	(4.40) 5414.35
(4.04) 5414.01	(4.42) 5414.36
(4.07) 5414.01	(4.44) 5414.38
(4.07) 5414.04	(4.45) 5414.41
(4.09) 5414.07	(4.46) 5414.42
(4.13) 5414.07	(4.49) 5414.43
(4.15) 5414.08	(4.53) 5414.45
(4.17) 5414.12	(4.62) 5414.48
(4.21) 5414.13	(4.65) 5414.49
(4.22) 5414.14	(4.64) 5414.51
(4.20) 5414.16	(4.66) 5414.51

Moderate Swell

10 ft of random cracking/1000 ft^2

(4.20) 5414.17	(4.69) 5414.52
(4.22) 5414.16	(4.64) 5414.53
(4.24) 5414.17	(4.62) 5414.54
(4.23) 5414.19	(4.63) 5414.56
(4.26) 5414.20	(4.65) 5414.56
(4.34) 5414.20	(4.64) 5414.58
(4.43) 5414.22	(4.68) 5414.60
(4.45) 5414.24	(4.72) 5414.60
(4.46) 5414.26	(4.76) 5414.62
(4.48) 5414.28	(4.80) 5414.64
(4.50) 5414.28	(4.77) 5414.64

Station 540+05

High Swell

(4.42) 5414.28	(4.76) 5414.63
(4.47) 5414.29	(4.76) 5414.64
(4.53) 5414.31	(4.85) 5414.66
(4.54) 5414.32	(4.88) 5414.67
(4.56) 5414.34	(4.87) 5414.69
(5.56) 5414.36	(4.84) 5414.71
(4.59) 5414.38	(4.90) 5414.72
(4.60) 5414.40	(4.89) 5414.74

20 ft of random cracking/1000 ft^2

High Swell

(4.61) 5414.41	(4.89) 5414.76
(4.63) 5414.42	(4.92) 5414.78
(4.64) 5414.44	(4.99) 5414.81
(4.61) 5414.45	(4.96) 5414.82
(4.58) 5414.46	(4.93) 5414.84
(4.58) 5414.46	(4.92) 5414.84
(4.64) 5414.46	(5.02) 5414.85
(4.66) 5414.48	(5.04) 5414.85
(4.67) 5414.47	(5.00) 5414.86
(4.64) 5414.48	(4.97) 5414.87
(4.73) 5414.51	(5.06) 5414.88
(4.73) 5414.54	(5.12) 5414.90
(4.75) 5414.56	(5.13) 5414.92
(4.77) 5414.58	(5.13) 5414.93
(4.79) 5414.58	(5.12) 5414.94
(4.80) 5414.60	(5.10) 5414.95
(4.78) 5414.61	(5.11) 5414.97
(4.77) 5414.62	(5.09) 5414.99

Station 543+95

(4.78) 5414.62	(5.13) 5414.99

ELEVATIONS AT LEFT AND RIGHT EDGES OF SAWED JOINTS
Original elevations found in 1969 are shown with the
1975 elevations shown in parenthesis above

Station 543+95 (continued)

(4.69) (5.08)
5414.61 5414.98

5414.62 5415.00
5415.65 5415.02
5414.64 5415.03

(4.71) (5.10)
5414.66 5415.06

(4.72) (5.12)
5414.68 5415.05

Station 545+01

Slight Swell - Looks OK

(4.71) (5.12)
5414.67 5415.04

(4.71) (5.14)
5414.67 5415.06

(4.75) (5.17)
5414.70 5415.09

(4.75) (5.19)
5414.72 5415.11

(4.76) (5.20)
5414.74 5415.13

(4.81) (5.22)
5414.76 5415.14

(4.82) (5.24)
5414.79 5415.15

(4.83) (5.23)
5414.80 5415.17

(4.85) (5.25)
5414.83 5415.18

(4.85) (5.25)
5414.84 5415.20

(4.87) (4.24)
5414.85 5415.21

(4.90) (5.25)
5414.87 5415.23

(4.91) (5.26)
5414.88 5415.23

(4.90) (5.26)
5414.89 5415.24

(4.90) (5.28)
5414.90 5415.26

SE end of 2' Subexcavate

Station 548+00

(4.93) (5.34)
5415.00 5415.35

Station 550+00

(5.32) (5.59)
5415.28 5415.60

NW end of Membrane Sec.

Station 551+00

(5.77) (5.84)
5415.71 5415.79

(5.85) (5.86)
5415.78 5415.83

(5.91) (5.90)
5415.84 5415.85

(5.95) (5.91)
5415.88 5415.86

(6.01) (5.96)
5415.94 5415.89

(6.03) (5.98)
5416.01 5415.92

(6.09) (5.98)
5416.07 5415.93

(6.13) (6.01)
5416.13 5415.96

(6.18) (6.08)
5416.18 5416.04

(6.27) (6.07)
5416.24 5416.07

(6.30) (6.09)
5416.28 5416.11

(6.36) (6.19)
5416.35 5416.16

Slight Swell - Looks OK

(6.43) (6.20)
5416.41 5416.17

(6.46) (6.22)
5416.44 5416.18

(6.54) (6.22)
5416.50 5416.19

(6.56) (6.23)
5416.52 5416.20

(6.56) (6.26)
5416.52 5416.23

(6.56) (6.28)
5416.52 5416.25

(6.59) (6.30)
5416.54 5416.25

(6.60) (6.31)
5416.55 5416.27

(6.61) (6.32)
5416.56 5416.26

(6.63) (6.33)
5416.59 5416.28

(6.65) (6.36)
5416.61 5416.30

(6.67) (6.38)
5416.62 5416.32

(6.70) (6.40)
5416.66 5416.34

(6.72) (6.41)
5416.68 5416.35

Station 554+97

(6.73) (6.44)
5416.68 5416.37

(6.78) (6.47)
5416.71 5416.40

(6.80) (6.51)
5416.75 5416.43

(6.82) (6.53)
5416.75 5416.45

ELEVATIONS AT LEFT AND RIGHT EDGES OF SAWED JOINTS

Original elevations found in 1969 are shown with the
1975 elevations shown in parenthesis above

Station 554+97 (continued)

Slight Swell	(6.83)	(6.53)
	5416.76	5416.47
	(6.85)	(6.57)
	5416.79	5416.50
	(6.90)	(6.60)
	5416.81	5416.52
	(6.88)	(6.61)
	5416.82	5416.54

Construction Joint

(6.96)	(6.61)
5416.86	5416.53
(6.95)	(6.60)
5416.89	5416.54
(6.95)	(6.63)
5416.90	5416.54
(6.90)	(6.58)
5416.90	5416.56
(6.94)	(6.61)
5416.92	5416.59
(6.94)	(6.60)
5416.94	5416.60
(6.94)	(6.61)
5416.93	5416.61
(6.94)	(6.66)
5416.94	5416.61
(7.00)	(6.67)
5416.96	5416.64
(7.03)	(6.67)
5417.00	5416.66
(7.04)	(6.67)
5417.04	5416.67
(7.05)	(6.70)
5417.03	5416.66
(7.05)	(6.71)
5417.02	5416.69
(7.04)	(6.72)
5417.02	5416.71
(7.05)	(6.74)
5417.04	5416.73

(7.06)	(6.75)
5417.05	5416.73
(7.07)	(6.77)
5417.06	5416.75
(7.09)	(6.79)
5417.08	5416.76
(7.10)	(6.81)
5417.10	5416.79
(7.10)	(6.80)
5417.10	5416.80
(7.11)	(6.82)
5417.11	5416.80
(7.14)	(6.83)
5417.13	5416.82
(7.13)	(6.84)
5417.13	5416.82
(7.14)	(6.89)
5417.13	5416.82
(7.15)	(6.90)
5417.14	5416.82
(7.16)	(6.98)
5417.16	5416.84

Station 559+98

(7.14)	(6.90)
5417.16	5416.85
(7.18)	(6.87)
5417.18	5416.86
(7.22)	(6.90)
5417.21	5416.88
(7.19)	(6.95)
5417.18	5416.90
(7.21)	(7.03)
5417.18	5416.90
(7.24)	(7.03)
5417.21	5416.93
(7.24)	(7.06)
5417.24	5416.94
(7.32)	(7.10)
5417.26	5416.95

(7.30)	(7.08)
5417.30	5416.96
(7.23)	(7.03)
5417.28	5417.01
(7.31)	(7.06)
5417.30	5417.02
(7.36)	(7.07)
5417.36	5417.05
(7.39)	(7.09)
5417.37	5417.06

Station 561+95

(7.40)	(7.11)
5417.37	5417.05
(7.42)	(7.09)
5417.38	5417.06
(7.44)	(7.09)
5417.42	5417.08
(7.42)	(7.10)
5417.40	5417.08
(7.45)	(7.09)
5417.40	5417.08
(7.45)	(7.08)
5417.42	5417.06
(7.49)	(7.09)
5417.46	5417.08
(7.47)	(7.11)
5417.45	5417.09
(7.50)	(7.12)
5417.49	5417.11
(7.56)	(7.15)
5417.54	5417.14
(7.58)	(7.22)
5417.55	5417.20
(7.61)	(7.25)
5417.58	5417.23
(7.64)	(7.29)
5417.60	5417.26
(7.63)	(7.32)
5417.60	5417.27

ELEVATIONS AT LEFT AND RIGHT EDGES OF SAWED JOINTS
Original elevations found in 1969 are shown with the
1975 elevations shown in parenthesis above

Station 564+00

(7.64) 5417.61	(7.35) 5417.29
(7.67) 5417.64	(7.36) 5417.31
(7.71) 5417.67	(7.36) 5417.32
(7.69) 5417.68	(7.35) 5417.33
(7.70) 5417.68	(7.36) 5417.34
(7.73) 5417.70	(7.37) 5417.35
(7.73) 5417.70	(7.38) 5417.36

Station 565+05

(7.71) 5417.70	(7.40) 5417.38
(7.72) 5417.72	(7.41) 5417.40
(7.73) 5417.72	(7.44) 5417.41
(7.75) 5417.72	(7.46) 5417.42
(7.75) 5417.74	(7.46) 5417.42
(7.76) 5417.75	(7.48) 5417.44
(7.76) 5417.75	(7.46) 5417.44
(7.79) 5417.77	(7.47) 5417.45
(7.82) 5417.80	(7.49) 5417.47
(7.85) 5417.84	(7.50) 5417.48
(7.88) 5417.83	(7.51) 5417.48
(7.91) 5417.90	(7.55) 5417.51
(7.91) 5417.88	(7.56) 5417.52
(7.89) 5417.86	(7.55) 5417.52
(7.89) 5417.87	(7.58) 5417.52
(7.91) 5417.88	(7.58) 5417.54
(7.92) 5417.88	(7.60) 5417.56
(7.92) 5417.89	(7.62) 5417.58
(7.96) 5417.92	(7.62) 5417.60
(7.95) 5417.92	(7.64) 5417.62
(7.95) 5417.93	(7.66) 5417.64
(7.94) 5417.96	(7.68) 5417.65
(7.97) 5417.98	(7.69) 5417.66
(7.98) 5417.98	(7.70) 5417.66
(8.00) 5418.00	(7.68) 5417.67
(8.01) 5418.02	(7.75) 5417.69
(8.05) 5418.02	(7.74) 5417.72
(8.07) 5418.03	(7.76) 5417.73
(8.11) 5418.06	(7.85) 5417.74
(8.11) 5418.07	(7.84) 5417.76
(8.12) 5418.07	(7.81) 5417.77
(8.12) 5418.11	(7.81) 5417.81
(8.15) 5418.14	(7.82) 5417.82

Station 569+99

(8.14) 5418.13	(7.85) 5417.84
(8.19) 5418.17	(7.91) 5417.85
(8.18) 5418.18	(7.92) 5417.86
(8.18) 5418.18	(7.90) 5417.87
(8.19) 5418.19	(7.90) 5417.88
(8.20) 5418.20	(7.92) 5417.89
(8.21) 5418.20	(7.89) 5417.90
(8.22) 5418.21	(7.92) 5417.91
(8.25) 5418.22	(7.95) 5417.92
(8.27) 5418.25	(7.94) 5417.94
(8.26) 5418.25	(7.96) 5417.94
(8.28) 5418.25	(7.96) 5417.93
(8.28) 5418.26	(7.94) 5417.94
(8.34) 5418.29	(7.98) 5417.96

Station 572+00

(8.33) 5418.28	(7.95) 5418.00

SE end of membrane covered Sec
Station 574+00

(8.74) 5418.50	(8.32) 5418.22

CONCLUSIONS

Regarding the difference between the performance of the three types of treatments

This project did not provide a good opportunity to get a good comparison between the 3 types of treatment because in all three treatments the moisture content of the upper 2 meters of the subgrade was 4 to 5 percentage points above optimum when the concrete pavement was placed. This feature by itself nullified most of the swell potential for all three treatments. If subgrade soils could always be placed 5% above optimum AASHO T-99 moisture content, there would probably be little if any problem with swell, but there might be some problem with poor support and possibly with maneuverability during construction. There were no problems along this line with this project where there was a 6" (15 cm) treated base over the stiff clay.

On the basis of faulting of the slabs, there is nothing to favor any one of the treatments. Faulting is 1/4" to 3/8" (.9 cm) in all sections.

There are more cracks and more elevation changes in the 2' (.6 m) subexcavation section than in the other two sections. Probably, it could be said that 2 feet (.6 m) of subexcavation is not quite enough treatment for an A-7-6(40) subgrade having a plasticity index over 30.

Regarding the difference between the performance of the treated sections and the eastbound roadway placed in 1960

The eastbound roadway was 15 years old in 1975, and it is in remarkably good shape in the area adjacent to these test sections even though it is in 6' to 10' (3 m) cut. Further to the east, this EB lane was badly deformed by the swelling subgrade in 1961 and 1962. The only clue to the relatively good performance of this old section is the moisture content. In 1975 it was approximately 26%. Records of the moisture content in this area in 1960 are not available, but it may be that like conditions for the test sections in 1968, the subgrade in 1960 was 2 or 3% above optimum T-99 moisture.

Actually, there is less faulting in this old pavement with its 6" (15 cm) of cement treated base. It averages 1/4" (.64 cm) and the few cracks are thin and very unobjectionable.

It would have to be admitted that in this particular area, the 15 year old pavement in the EB lane is in as good condition as the 7 year old concrete in the westbound lane.

Regarding suggestions made by FHWA personnel upon receipt of the FIRST INTERIM REPORT

In 1969, it was suggested that an untreated control section should have been included in this project. There were two reasons why this was not done: 1) The project only contained 3 major cut sections. One of the treated sections would have had to be reduced in size by at least 1000' (305 m) and it was felt by the District personnel that the test sections were too short as it was. 2) On the basis of past experience, District personnel felt that an untreated section would certainly result in badly cracked and disrupted slabs which would look bad and require excessive maintenance. This argument should have been countered with a reference to the eastbound lane which was in good condition in 1969 and had no special treatment. However, this EB lane might be considered as an untreated control section, and if so, it would certainly have to be admitted that for some reason (possibly the relatively low PI of 35-38 and 4% above optimum moisture) it performed as well as the treated sections.

It was requested in 1969 that some explanation be given as to how each treatment was intended to solve the swelling soil problem. The 2' and 4' subexcavated sections were intended to illustrate the effect of breaking up nature's strata containing well crystallized montmorillonite capable of large volume changes. Colorado Department of Highways Memo 323 called for subexcavation to a depth commensurate with the plasticity index of the subgrade soil. The 2' subexcavation section and the 4' subexcavation section were designated to check the validity of this memo. It has always been felt that this memo neglected to take into account the moisture in the subgrade at the time that the pavement structure was placed. As a result of this project and numerous observations of other projects over swelling soils in Colorado, CDOH Memo 323 has been revised and is included here on page 38 for consideration.

The 50-60 AC Catalytically Blown Membrane section was included in this project to test the effectiveness of this kind of treatment over the swelling soils in this area. This type of treatment had been used with some success on I 70-4(53) and at Elk Springs in Western Colorado, but little was known about the durability and actual waterproofing capability. This treatment attempts to solve the swelling soil problem by restricting the evaporation of moisture from the subgrade before the pavement structure is placed, and by preventing the intrusion of surface moisture into the subgrade after the surface structure is placed.

The rainstorms during construction as mentioned on page 5 of this report and in the interim report apparently had a very pronounced effect on the performance of the roadways. By saturating the subgrade, it assisted in bringing the moisture content above the optimum level in a very uniform manner and holding it there until after the pavement was placed. If it had not been for these showers, in all probability the surface of the subgrade would have dried out in a very irregular manner between the time of final grading and placement of the pavement. This subgrade in the dry condition (typically 15% moisture) has a much greater swell potential than it has at 27% moisture. Uneven swelling has been found to contribute the most to cracking and distressed pavement surfaces. If these showers had not come, considerably more information regarding the differences in performance of each treated section might have been determined. The rain tended to make all sections appear the same.

The field construction procedure for the subexcavated sections mentioned on page 6 whereby the lower 0.5 (.15 m) foot of the subexcavation was disturbed and wetted in places was really not a change of plan. It is much more convenient, and just as effective to work the lower lift <u>on</u> the roadway as somewhere else, if that lower layer is ripped and pulverized well. It is doubtful if this procedure had an effect on the final performance of either the 2' subexcavation section or the 4' subexcavation section.

Checks on the elevation of the edges of the pavement were made each spring after the original readings in 1969. The figures have been plotted on graph paper for display, but because of the very small and gradual change, the large unwieldy graphs do not appear to be worth their inclusion here. The elevation changes are shown on pages 26 through 32.

A breakdown on the cost of the treated sections is shown below:

For the 4' subexcavated section from Station 506 to 522 there were

$\frac{48 \times 4 \times 1600}{27}$ = 11378 cubic yards involved

Excavation = 11378 x .28/16 = $200 per Sta.
Wetting = 11378 x .051/16= 36 per Sta.
Haul = 11378 x .02/16 = 14 per Sta.
$250 per Sta. in 1968 or approximately
250 x 2.5 = $625 in 1975

(2.5 = increase in cost index since 1968)

For the 2' subexcavation section from Station 526 to 547

$$\frac{48 \times 2 \times 2100}{27} = 7466 \text{ cubic yards involved}$$

Excavation = 7466 x .28/21 = $100

Wetting = 7466 x .051/21 = 18

Haul = 7466 x .02/21 = 7

$125 per Sta. in 1968 or approximately
125 x 2.5 = $312 in 1975

For the membrane treated section from Station 552 to 572 approximately 75' wide

$$\frac{2000 \times 75}{9} = 16{,}700 \text{ square yard @ } 1.5 \text{ gal/yd}^2 = 25{,}000 \text{ gallon}$$

25,000 gal = 25,000 x 8 = 200,000 lbs = 100 tons

100 tons @ $60/ton = $6000 or 6000/20 = $300/station in 1968
or approximately $750/Station in 1975

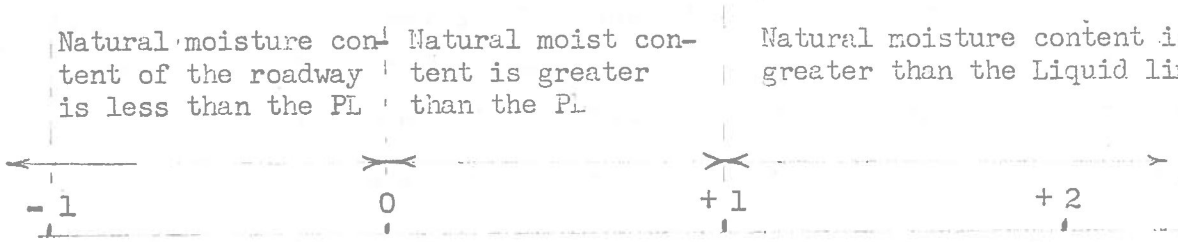
CONCLUSIONS

Regarding an attempt to devise a new method of identifying the the need for swelling soil treatment

The Liquidity Index described below has been suggested as a means of identifying the need for swelling soil treatment.

$$\text{Liquidity Index} = \frac{\text{Natural water content} - \text{Plastic Limit}}{\text{Liquid Limit} - \text{Plastic Limit}}$$

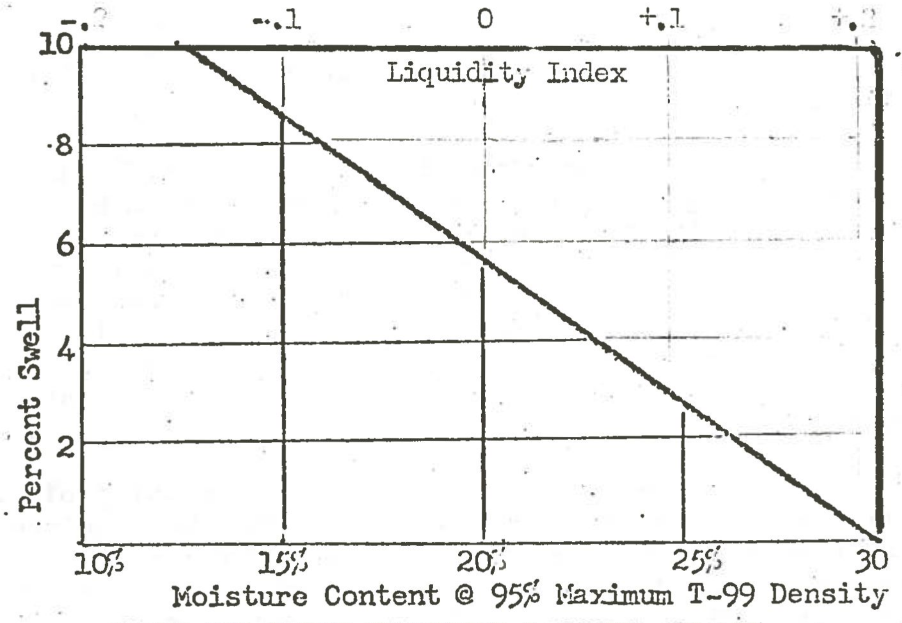
$$= \frac{W_{\text{natural}} - PL}{PI}$$



The Liquidity Index appears to be difficult to use for construction, however, since the natural moist content can change over such a great range during construction. For instance, during the 1960 construction season in the Agate area the natural moisture content tended to dry out to 15% despite the wetting operations to place subgrade soils at 25%. These values would result in a Liquidity Index of $\frac{15 - 20}{65 - 20} = \frac{-5}{45} = -.11$ and according to the graph below, the subgrade would swell approximately 8.5%.

In the 1968 construction season the same material would have been placed during the rainy season, and with a natural moisture content of 29, the Liquidity Index would have been $\frac{29 - 20}{45} = \frac{9}{45} = +.2$ which calls for no special treatment for volume changes. Although these climatic changes taken for illustration were 8 years apart, in Colorado they could have been only 8 days or even 8 hours apart. It would be impossible to change the design of the roadway to counteract this swell potential in such a short period of time.

VARIATION IN THE % SWELL WITH THE COMPACTED MOISTURE CONTENT



GRAPH FOR BADLY WEATHERED LARAMIE SHALES, etc.

PROPOSED GUIDELINES FOR
TREATMENT OF EXPANSIVE SOILS

DOH Memo #323
(Construction-Swelling Soils)

DIVISION OF HIGHWAYS
STATE OF COLORADO
4201 E. Arkansas
Denver, Colorado 80222

Problems due to expansive soils usually occur in cut areas and in transitions from cut to fill areas.

These soils are usually identified by the liquid limit, plasticity index, volume change test and expansion pressure test. Laboratory tests, however, have shown that the Third Cycle Expansion Pressure test as performed by Colorado requires less cover than is actually needed over swelling soils in Colorado. This memo and preceding Memo Nos. 323 call for more cover than the standard Third Cycle expansion pressure test. The liquid limit and plasticity index usually correlate with swell potential in the laboratory, but may not be related to the swell potential in the field due to moisture content, density and chemicals in the insitu soil. Many potential high swelling soils in areas of high ground water have taken on enough moisture so that additional swelling is not a problem. But certain dry, dense, and often unweathered soils must be treated to prevent distortion.

Remedial measures for cut areas in swelling soil will normally consist of one of the following:

1. Placement of 1.30 gal./sq.yd. of catalytically blown asphalt membrane or plastic impregnated polypropylene membrane, directly on the finished subgrade, throughout the entire cut and through transitions from cut to fill until the depth of the fill is a minimum of three feet. The membrane should extend over the ditch section and up the backslope to an elevation approximately equal to that of the wearing course. This method has a good performance record in areas of deep water tables.

2. Full depth asphalt pavement (quite impermeable) placed directly on the subgrade. Membranes may be required in the ditch section in cuts and at the edge of pavement on fills to prevent changes in moisture content under the edge of the pavement and subsequent longitudinal cracking of pavement. When the full depth asphalt pavement to be placed is known to be permeable the membrane should also be placed under the pavement.

3. Subexcavation of potential expansive soil (dry dense unweathered shales and dry dense clays) and backfilling with impermeable soil at 95 percent of maximum dry density and at optimum moisture in accordance with AASHTO Designation

continued . . .

T 99. This treatment should carry through the cut area and transitions from cut to fill until the depth of fill is approximately equal to the depth of treatment. Soil with a plasticity index of over 50 should be placed in the bottom of the fills of less than 50 feet in height or wasted. The backfill soil should be uniform and all lenses or pockets of very high swelling soil should be removed and replaced with the predominant type of soil which has a plasticity index under 50. Drainage ditches must be below the subgrade level in the cut areas and must have enough grade to allow rapid runoff of surface water.

The following tables are to be used as a guide to determine the depth of treatment:

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

* Excavate and waste, replace with better impermeable material.

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

*Excavate and waste, replace with better impermeable material.

The type of treatment should be based on a thorough investigation. When a choice of treatments is available the most economical treatment should be used. Depth of subgrading may be reduced by having a trained soil technician or engineer check the soil as it is being excavated. The zones or pockets containing the worst material would be excavated according to the above table and replaced with a material similar to the better surrounding material which required less depth of treatment.

9/19/75

PUBLICATIONS

State Department of Highways
Division of Highways-State of Colorado

66-1	Final Report - Denver SE Pavement Study I 25-3(20)
66-2	Interim Reports on the Experimental Base Project At Ordway, Colorado #1
66-3	Interim Report on the Clifton-Highline Canal Experimental Project I 70-1(14)33 #1
66-4	Final Report on Statistical Research Project - Quality Control Study on Asphalt Pavement
66-5	Final Report on the Automatic "Icy Road" Sign Study
66-6	Interim Report on Crawford-South Experimental Project S 0125(9) #1
66-7	Final Report on the Strasburg E & W Pavement Study I 70-4(30)
66-8	ASCE Report on High Altitude Multiple Vehicle Emission Tests
66-9	Final Report on Photo and Engineering Geology Along Interstate Route 70 from Dotsero to Rifle, Colorado
66-10	Interim Report on the Reflective Traffic Bead Study #1
66-11	Rock Slope Stability in the Precambrian Metamorphic Rocks of the Front Range, Colorado
67-1	Interim Report on Experimental Base Project at Ordway, Colorado #2
67-2	Second Interim Report on Crawford-South Experimental Project S 0125(9)
67-3	Interim Report on Clifton-Highline Canal Experimental Project I 70-1(14)33 #2
67-4	Reflective Traffic Bead Study #2
67-5	Density-Temperature-Roller Data from Asphalt Paving Projects in Colorado
67-6	Skid Resistance in Colorado
67-7	Swelling Soils Study at Cedar Point, Colorado
67-8	Lime Shaft and Lime Till Stabilization of Subgrades on Colorado Highways
67-9	Embankment Construction Without Moisture-Density Control
67-10	Study of Preformed Open Cell Neoprene Joint Sealer
67-11	Dielectric Measurements of Asphalt Content
67-12	Revision of Colorado CHLOE Profilometer
67-13	Performance of Box Beam Guard Rail Having Vertical Post Mounted in Sand
67-14	Scaling on Concrete Bridge Decks
68-1	Rock Rippability Study
68-2	Equilibrium Moisture and Density Study of Subgrades in Colorado
68-3	Grooving of Concrete Pavement Surfaces in Colorado to Prevent Hydroplaning
68-4	A Statistical Study of Rock Slopes in Jointed Gneiss with Reference to Highway Rock Slope Design
68-5	Reflective Traffic Bead Study -Interim #3
68-6	Use of a Microwave Oven for Rapid Drying of Aggregate Samples
68-7	Means for Measuring Surface Smoothness
68-8	Culvert Performance at Test Sites in Colorado
68-9	Colorado's Reflective Bead Study
68-10	Dielectric Measurements of Asphalt Content - Final Report

PUBLICATIONS

State Department of Highways
Division of Highways-State of Colorado

69-1	Treatment of Swelling Soils, West of Agate, Colorado
69-2	The Whitewater Experimental Project - First Interim Report
69-3	Evaluation of Dielectric Measurement Apparatus for Determining Pavement Density
69-4	Pavement Marking Materials Tested in Colorado
69-5	Study of Preformed Open Cell Neoprene Joint Sealer for Use in Transverse Weakened Plane Sawed Joints - Final Report
69-6	Use of Microwave Oven for Rapid Drying of Aggregate Samples - Final Report
69-7	Follow Up Report, Colorado's Reflective Bead Study
69-8	Rock Rippability Study - Final Report
69-9	Ordway Experimental Project, Post Construction Field Measurements - Interim Report
70-1	State-of-the-Art - Automatic Controls on Construction Equipment
70-2	Action Program to Promote Highway Safety
70-3	Reflective Traffic Bead Study - Final Report
70-4	Asphalt Membrane Project at Elk Springs - First Interim Report
70-5	Evaluation of Colorado's Flexible Pavement Base Design Methods - Final Report
70-6	The Effect of Vibration on the Durability of Concrete Pavement - First Interim Report
70-7	Crawford - South Experimental Project S 0125(9) - Third Interim Repor
70-8	The Whitewater Experimental Project: An Instrumented Roadway Test Section to Study Hydrogenesis - Final Report
70-9	Clifton-Highline Canal Experimental Project - Third Interim Report
71-1	The Effect of Good Vibration on the Durability of Concrete Pavement #2
71-2	Effect of Vibration on Durability of Concrete
71-3	Lighted Deer Crossing Signs and Vehicular Speed
72-1	Reflection Cracking in Bituminous Overlays - Interim Report
72-2	Evaluation of Dielectric Measurement Apparatus for Determining Pavement Density
72-3	Skid Testing in Colorado
72-4	Development of Dwarf Ground Cover for Erosion Control in Colorado
72-5	Corrugated Metal Arch Barrier, Phase 1, Scale Model Study
72-6	Styrofoam Highway Insulation on Colorado Mountain Passes
72-7	Colorado Tunnel Ventilation Study - Interim Report
72-8	Effectiveness of Absorptive Form Liner for Horizontal Surfaces
72-9	Partially Beaded Centerline Markings
72-10	Field Study of Erosion Control Agents in Colorado
72-11	Soil Modification Highway Projects in Colorado
72-12	Calibration of Colorado's Texturemeter - Final Report
72-13	Air Pollution at High Altitude Construction Sites

PUBLICATIONS

State Department of Highways
Division of Highways-State of Colorado

73-1	Thermoplastics - Performance in Denver
73-2	The Ordway Colorado Experimental Base Project
73-3	Noise Levels Associated with Plant Mix Seals
73-4	Accelerated Concrete Strength Study
73-5	Colorado Tunnel Ventilation Study
73-6	Clifton-Highline Canal Experimental Report
73-7	Seibert Experimental Project
74-1	Implementation Package for Swelling Soils in Colorado
74-2	Embankments With and Without Moisture Density Control
75-1	Erosion Control and Revegetation on Vail Pass
75-2	The Effects of Vibration on Durability of Concrete Pavement
75-3	Infrared Heating to Prevent Preferential Icing of Concrete Box Girder Bridges
75-4	Asphalt Membrane Project at Elk Springs, Colorado
75-5	Treatment of Swelling Soils - West of Agate, Colorado, Project I 70-4(48)347