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CLIFTON-HIGHLINE CANAL EXPERIMENTAL PROJECT I 70-1(14)33

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16. Abstract

The swelling characteristic of Mancos Shale in Western Colorado has caused a great deal of maintenance problems ever since highways were paved. In an attempt to find a method to reduce or prevent this swelling, 19 test sections were included in a contract on Interstate 70 near Grand Junction. After eight years of evaluation it has been concluded that the sections which were subexcavated two feet and backfilled with granular material performed worse than all the other sections. These were also the most expensive.

Asphalt membranes on top of the subgrade and subexcavation and backfilling with an A-4 soil are good solutions to the swelling problem.

17. Key Words Swelling, Mancos Shale, aggregates, soil, asphalt membranes, lime, evaluations, moisture content, costs.		18. Distribution Statement	
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IMPLEMENTATION

As a result of this study, it is recommended in Colorado that standard construction design be used in areas of no or low swell potential; subexcavation and backfill with A-4 or A-6 soil be used in cuts of medium swell; and asphalt membrane be applied on top of subgrades with high swell potential. In locations where a water bearing layer occurs in a roadway cut at or slightly below the finished subgrade of a swelling soil it would be advisable to leave the grade unpaved until swelling caused by unloading has nearly stopped.

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INTRODUCTION

After motorists became accustomed to paved roads, they became less tolerant of rough surfaces. In the 1940s and 1950s people in Western Colorado were complaining of rough roads in cut sections located in valley floors. The bumps were mostly caused by swelling in the Mancos Shale formations. What causes this uneven and unpredictable swelling which can raise the road surface several inches over a short distance? This question prompted an experimental project.

This is the final report of that experimental highway project constructed in the Mancos Shale Formation on Interstate 70 in Western Colorado. The grading was completed under one project in 1964. During the grading operation an informal study was being conducted in an attempt to determine the cause of swelling noted in other highways through the same formation. The District Engineer, Planning and Research Division, and the Bureau of Public Roads (now Federal Highway Administration) agreed to design 19 different test sections in the roadway cut sections. These sections were included in the stabilization and paving project which began in the fall of 1964 and was completed in the spring of 1965. Photographs No. 1 and 2 indicate the type of valley floor in which the test sections are located.

MANCOS SHALE CHARACTERISTICS

Mancos Shale formations are generally located in the plateau area of Colorado, Utah, and Wyoming at elevations of 4,000 to 6,500 feet above sea level. This is semi-desert country with annual precipitation of five to twelve inches. Very little vegetation grows in this arid climate as shown in Photographs No. 1 and 2. These massive beds are usually highly foliated with an irregular vertical joint system.

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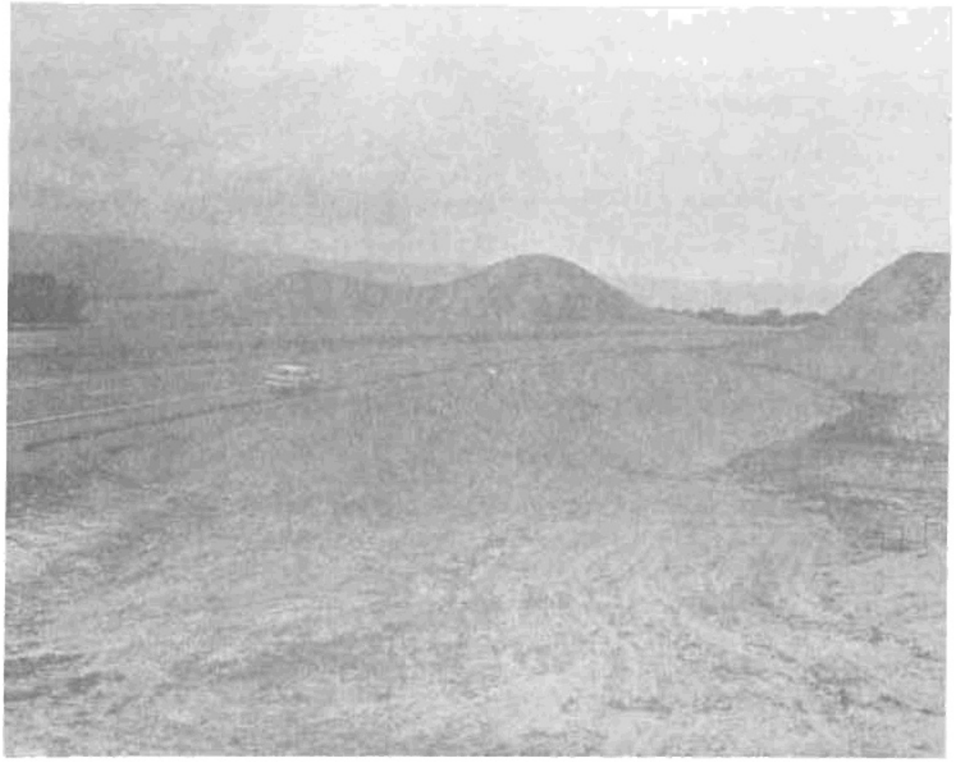

Photograph 1

Photograph 2

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This shale was formed during the Cretaceous Period of the Mesozoic Era 60 to 120 million years ago. It is a highly consolidated material with a dry density of 130 to 150 pounds per cubic foot. The natural moisture content is usually about five percent for the densest shale to eleven percent for the least dense shale.

The material is classified from A-6(12) to A-7-6(40) depending upon the swell potential. The plasticity indices range from 11 to 30. The optimum dry density of the minus No. 4 sieve material is about 110 pounds per cubic foot as determined by AASHO T99, and the optimum moisture is 15 to 20 percent.

X ray defraction analysis of Mancos Shale indicate that it is composed of about 40 percent clay materials. Illite is predominant with mixed layers of montmorillonite and illite and lesser amounts of kaolinite. Seams of bentonite are found occasionally. It was thought that these minerals caused the swelling in the roadway cuts after absorbing moisture.

Chemical tests indicated that varying amounts of calcium sulphate and calcium and magnesium carbonates are present in this shale in amounts of 5 percent to 20 percent. There was no definite correlation between salt content and swelling characteristics.

TEST SECTIONS

The experimental portion of Project No. I 70-1(14) consists of several test sections located as shown in Figure 1. A description of the treatment of the subgrade for each test section is listed.

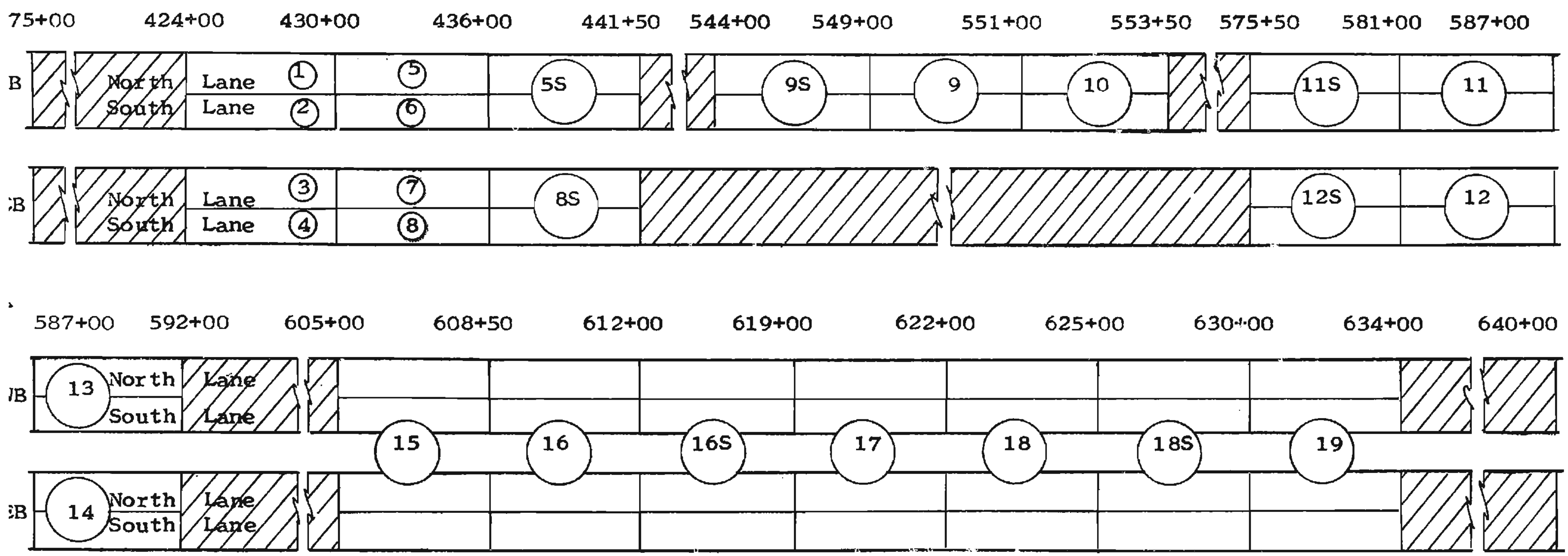
Section Number	Treatment
1.	Subexcavated 2 feet, backfilled with coarse aggregate (3/4" to 1/4")
2.	Subexcavated 2 feet, backfilled with Class 2 subbase
3.	Subexcavated 2 feet, backfilled with A-3(o) material
4.	Subexcavated 2 feet, backfilled with Structure Backfill Material
5.	Subexcavated 2 feet, backfilled with fine sand
6.	Subexcavated 2 feet, backfilled with Structure Backfill Material

FIGURE 1

TEST SECTION LAYOUT

CLIFTON-HIGHLINE CANAL

EXPERIMENTAL BASE PROJECT
PROJECT NO. I 70-1(14)



NOTES
S = Section constructed to Standard Specifications Scale = None

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Section Number	Treatment
7.	Subexcavated 2 feet, backfilled with coarse aggregate (3/4" to 1/4")
8.	Subexcavated 2 feet, backfilled with Class 2 Subbase
9.	Control, standard treatment for bases of cuts
10.	4 percent hydrated lime mixed in top 12" of subgrade
11.	Control, standard treatment for bases of cuts
12.	Lime shafts, 6" diameter filled with hydrated lime paste
13.	1 percent hydrated lime mixed in top three feet of subgrade, sprinkled for three weeks and then compacted
14.	Top 3 feet of subgrade scarified, sprinkled for three weeks and then compacted
15.	Subexcavated 2 feet, backfilled with fine sand
16.	Top of subgrade covered with asphalt membrane and then backfilled with an A-3 material
17.	Subexcavated 2 feet, backfilled with A-4 material
18.	Subexcavated 2 feet, aspahlt membrane applied then backfilled with A-4 material
19.	Subexcavated 2 feet, backfilled with A-3(o) material

The subgrade in the standard sections - 9 and 11 - was loosened to a one foot depth and brought to optimum moisture and 95 percent of laboratory density in accordance with AASHO Method T99.

There are also seven standard sections (5S, 8S, 9S, 11S, 12S, 16S, and 18S) which are all in embankments and used for comparisons.

All sections and the roadway between are covered with 17" of subbase, 4" of base course and 5" of hot bituminous pavement.

For comparison purposes the sections have been grouped as follows:

- A - Asphalt membrane, Sections 16 and 18
- B - Subexcavated 2 feet and backfilled with granular material, Sections 1 through 8, 15 and 19
- C - Standard sections in cuts, 9 and 11
- D - Subexcavated 2 feet and backfilled with A-4 soil, Section 17
- L - Lime treatments, Sections 10, 12 and 13
- S - Standard sections in fills, Sections 5S, 8S, 9S, 11S, 12S, 16S and 18S

See Appendix B, page 21 for Soil Data.

EVALUATIONS

Spring measurements only are included in this narrative because they are the most critical ones in the life of a pavement. The five measurements are Present Serviceability Index, deflections, radius of curvature, elevations and moisture contents. The results are analyzed below.

(a) Present Serviceability Index

The PSI has been determined by the CHLOE Profilometer which measures the slope variance of the roadway surface. Colorado uses the following formula for flexible pavements:

$$PSI = 4.85 - 1.91 \text{ Log } (\overline{SV} - 2) - R - 0.01 \sqrt{C + P} + T_x$$

$\overline{SV}$ = average slope variance from CHLOE readings

$R = 1.38 \text{ (average rut depth)}^2$

$C + P$ = cracking and patching per 1000 square feet

T_x = correction for texture

CHLOE Profilometer is sensitive to surface irregularities and small bumps but registers little effect from the long swells prevalent in Mancos Shale cuts. The test sections where the subgrades was excavated and backfilled with granular material (B line in Figure 2) compare very well in PSI with other sections. The rideability in a passenger car at 60 or 70 mph over these same sections is very uncomfortable to the passengers. The amount of swelling in Figure 6 is a better indicator of the rideability at higher speeds. The section with the least swell give the most comfortable ride.

PSI values for the different types of treatments are plotted in Figure 2. The deterioration can readily be seen, and the trend would indicate that major maintenance will be necessary in about five years. The asphalt membrane sections had a relatively low PSI in the beginning but have not deteriorated as much as the others. The PSI of the standard section in cuts (C in Figure 1) is low partly because of the large amounts of cracking.

(b) Deflections

Surface rebound deflections were measured by a Benkelman Beam corrected for temperature and then graphed in Figure 3. Because of the small amount of deflection in the spring of 1973, no pavement failures are indicated.

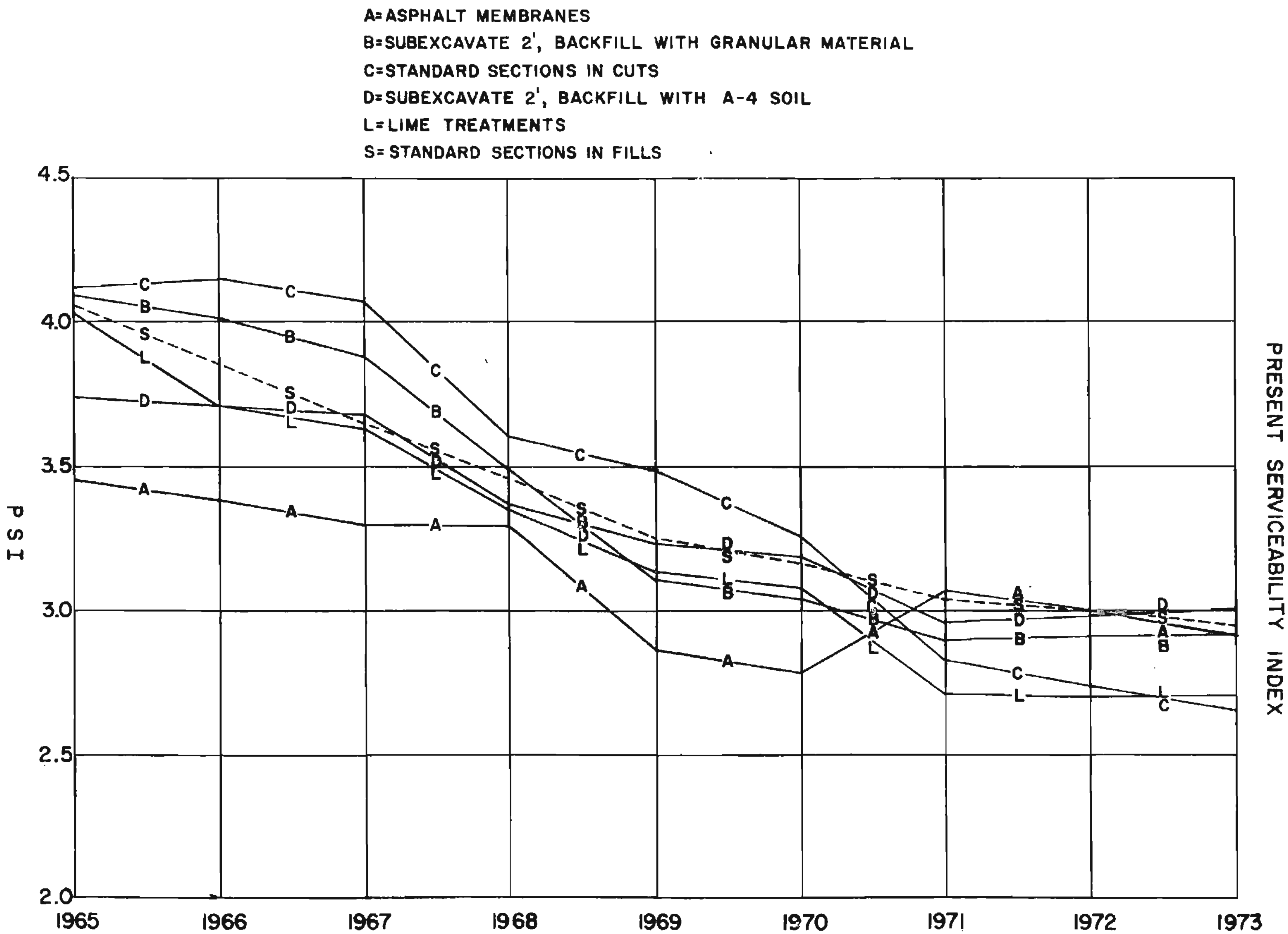

Figure 2

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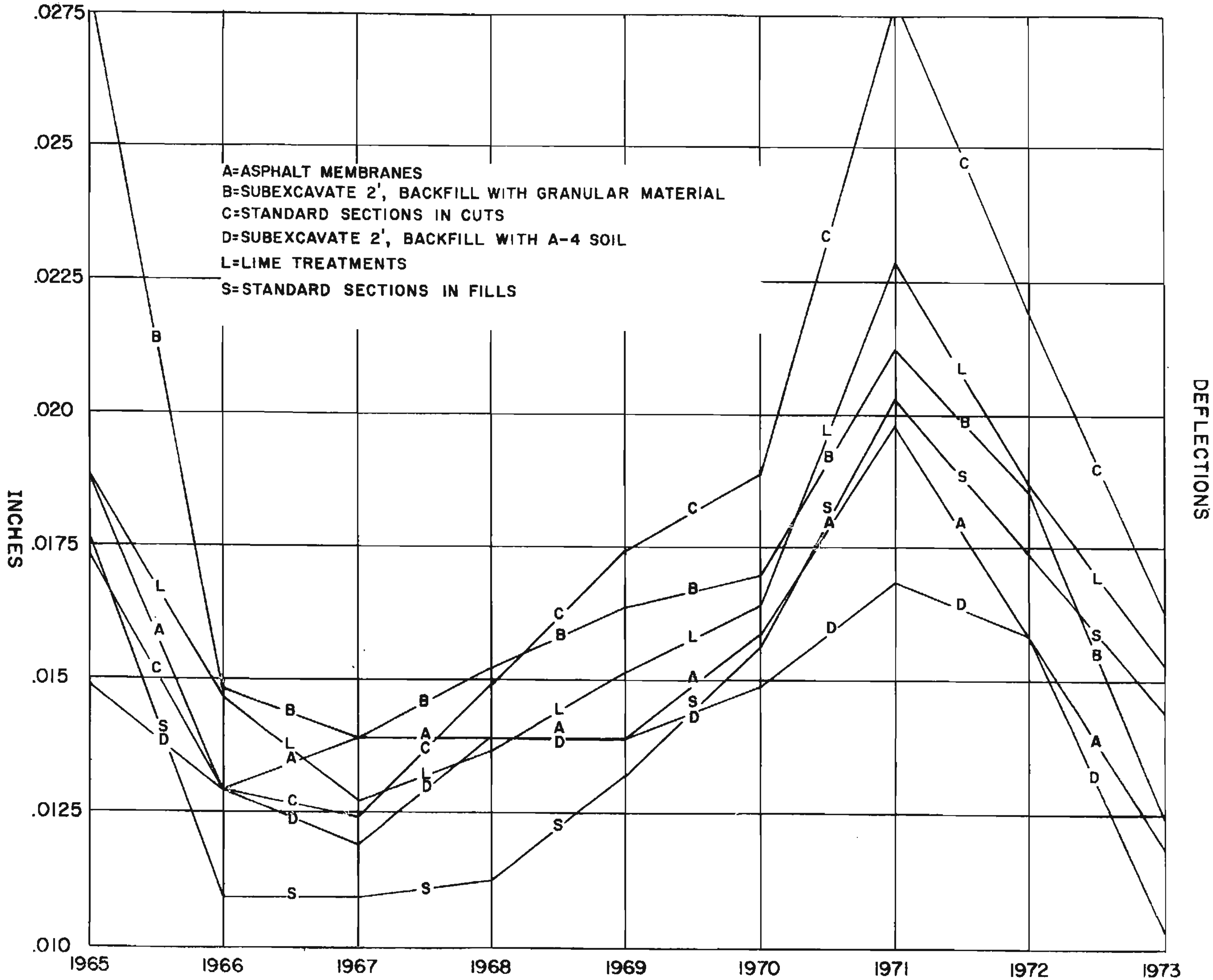

Figure 3

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c. Radius of Curvature

A Dehlen Meter was used to measure the radius of curvature of the pavement surface between the dual tires of 9,000 pound load. The results corrected for temperature are indicated in Figure 4. The graphs indicate no loss of strength in the eight years of the life of the road.

d. Moisture Content of the Subgrade

In order to measure periodically the moisture contents and densities under some of the test sections, 1 5/8" OD x 20' stainless steel pipes were installed vertically through the pavement of Sections 1 through 8. A nuclear depth probe was inserted to record moisture content and densities at many different depths. The tubes rusted through and were of no value after nearly four years.

Subsequent sampling was accomplished by removing a portion of the material by auger and drying it in an oven. The results of the moisture tests are in the Appendix. Figure 5 is a graph of the average moisture content of the top of the subgrade of the various types of sections. The C and L sections show a high initial moisture because they were wetted as part of the requirements for those treatments.

There is good correlation between the increase in subgrade moisture content and the amount of swelling. This will be discussed further in the next subsection.

In the spring of 1973, the moisture content in the shale of Section 18 westbound was 15.7 percent. This indicates that there must be a leak nearby in the asphalt membrane. Thus far the swelling here is the least amount in all the sections but may be expected to increase with an increase in moisture.

e. Swelling

Elevations of pavement surface of each test section (except standard sections in fills) were recorded immediately after construction and each spring thereafter. A dumpy level and self reading rod were used to measure the elevations.

The averages of the maximum amount of swelling in each type

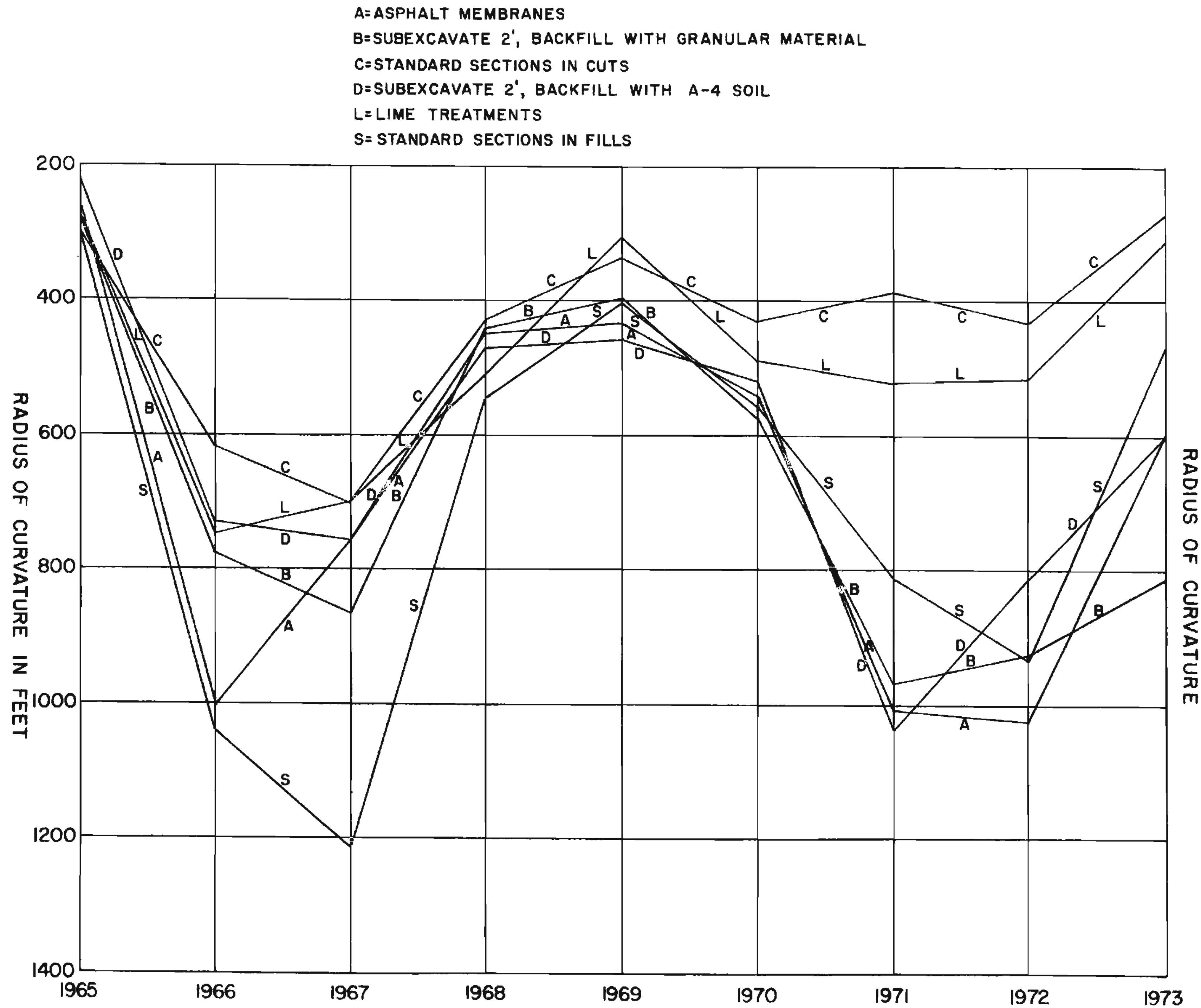
A=ASPHALT MEMBRANES
B=SUBEXCAVATE 2', BACKFILL WITH GRANULAR MATERIAL
C=STANDARD SECTIONS IN CUTS
D=SUBEXCAVATE 2', BACKFILL WITH A-4 SOIL
L=LIME TREATMENTS
S=STANDARD SECTIONS IN FILLS
RADIUS OF CURVATURE IN FEET
RADIUS OF CURVATURE
200
400
600
800
1000
1200
1400
1965
1966
1967
1968
1969
1970
1971
1972
1973

Figure 4

MOISTURE CONTENT OF TOP OF SUBGRADE

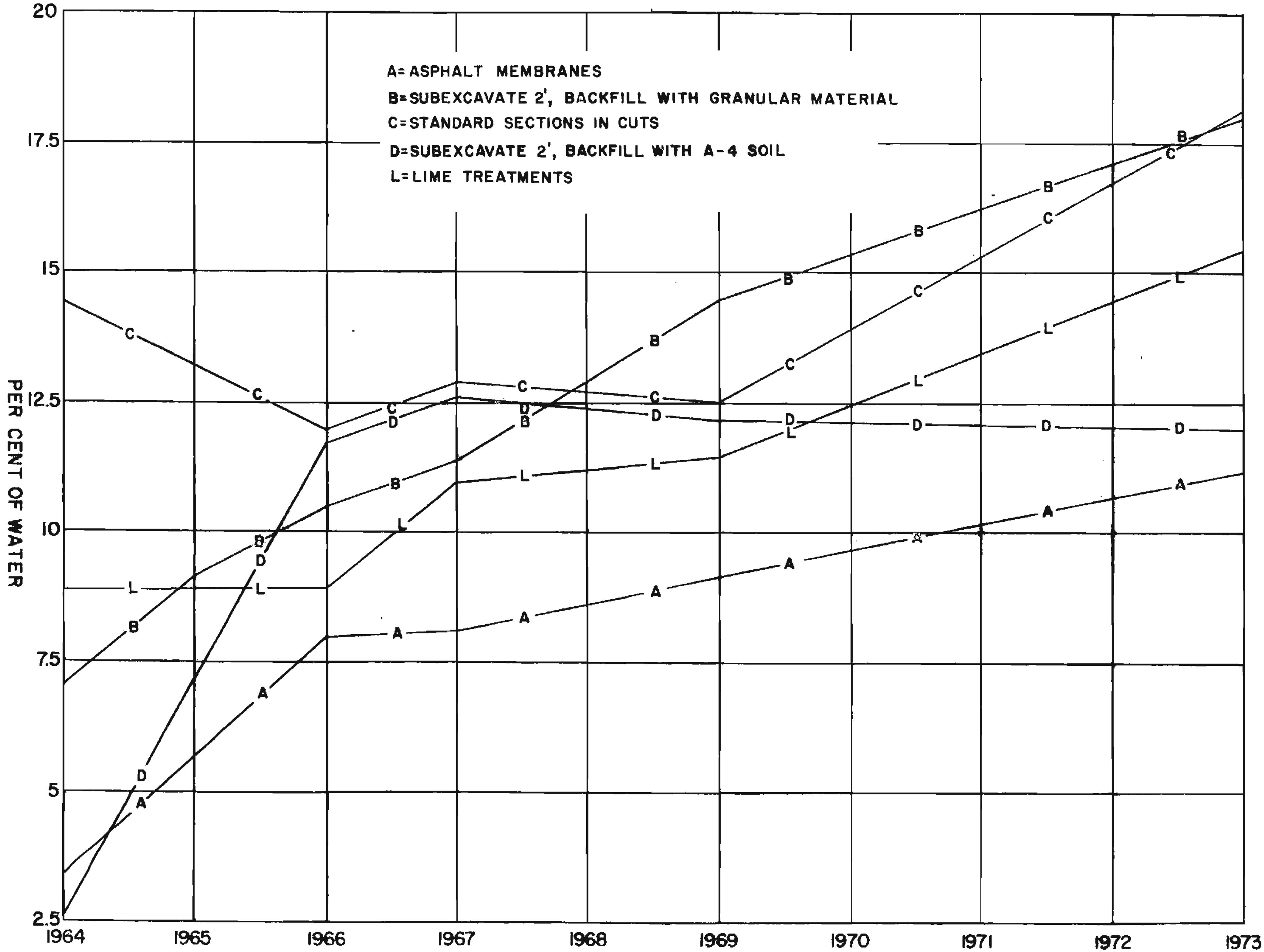

Figure 5

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of treatment are plotted in Figure 6. The sections with the most swelling are those which were subexcavated and backfilled with granular material. The one that was backfilled with A-4 soil had the next to least amount of swelling. Even though there was only one section of this type, we feel that the results are fairly typical for this treatment. The same type of work was done in 1968 on another project, and the results are satisfactory at this time. The asphalt membrane has evidently prevented swelling, also.

Even though the standard sections in cuts had as much water in the subgrade as the ones which were subexcavated and backfilled with granular material (see Figure 5), they had significantly less swelling. This is due to the fact that the subgrade was wetted and compacted in the standard section before the surfacing material was placed.

Figure 7 is a profile of a 200 foot length of two test sections. Section 1 is typical of the greatest amount of swelling, and Section 18 is typical of the least. The differential swelling in Section 1 causes an uncomfortable ride to a person in a vehicle which is traveling at 60 to 70 miles per hour.

Figure 8 is a comparison of the test sections by swelling, longitudinal cracking, deflections and Present Serviceability Index. About two-thirds of the sections have alligator cracking to various extents. Generally, the alligator cracking is greatest in the sections with the greatest longitudinal cracking.

CONSTRUCTION COSTS

Based on Colorado's 1972 Cost Data, the estimated costs of the various treatments are shown on the following page in increasing amounts. These have been calculated for a 100 foot length of a four lane divided highway.

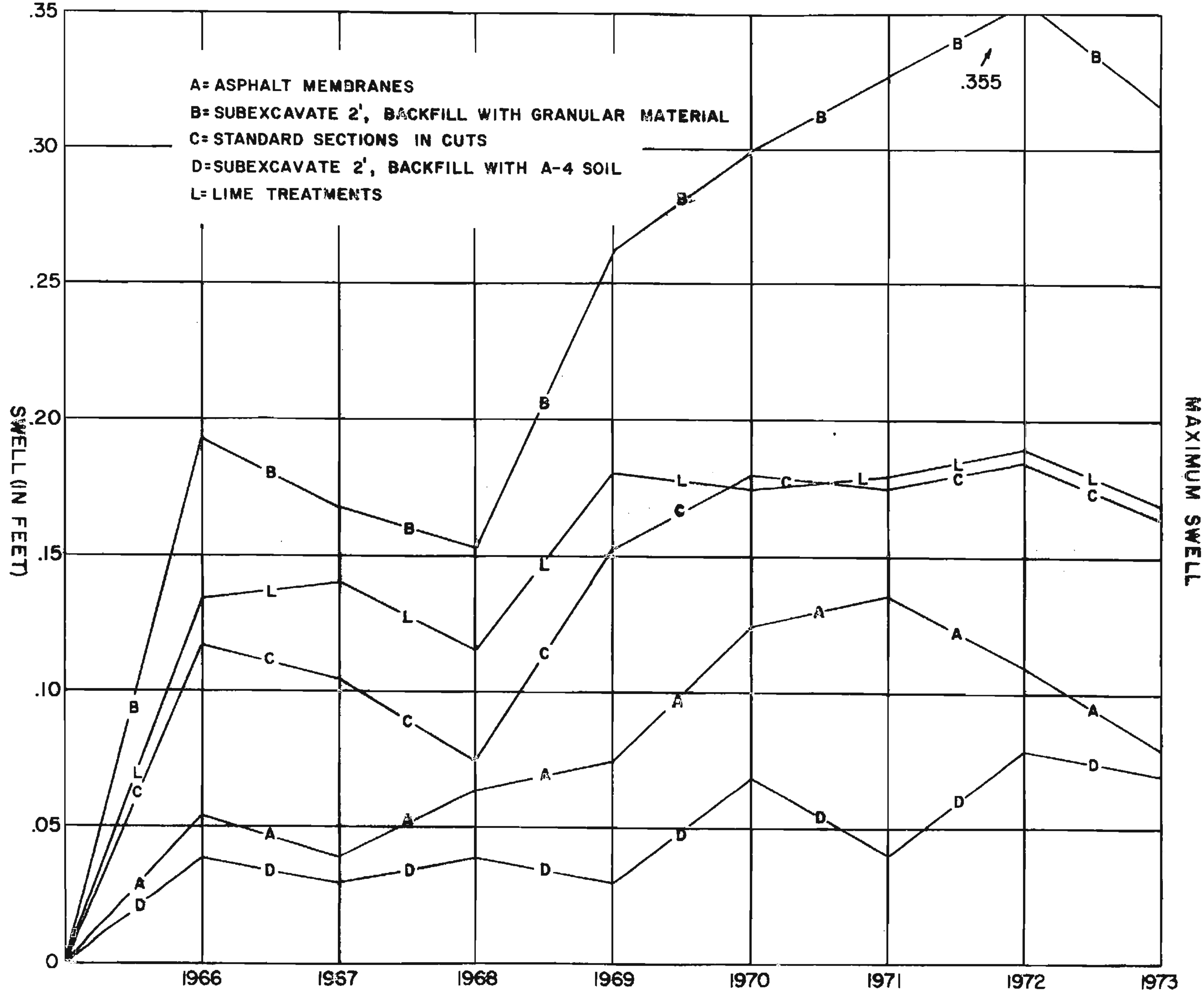

Figure 6

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TYPICAL PAVEMENT PROFILE

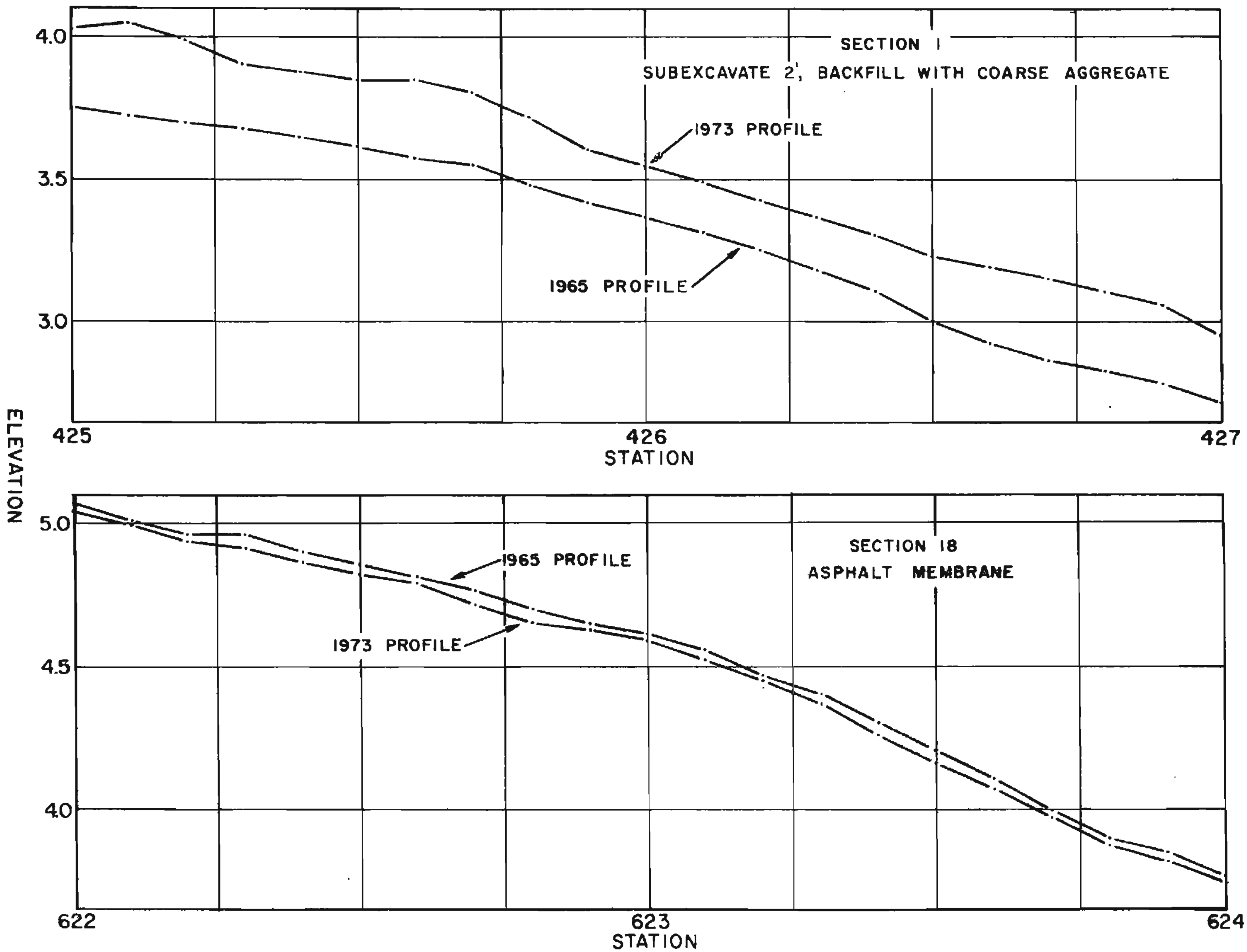

Figure 7

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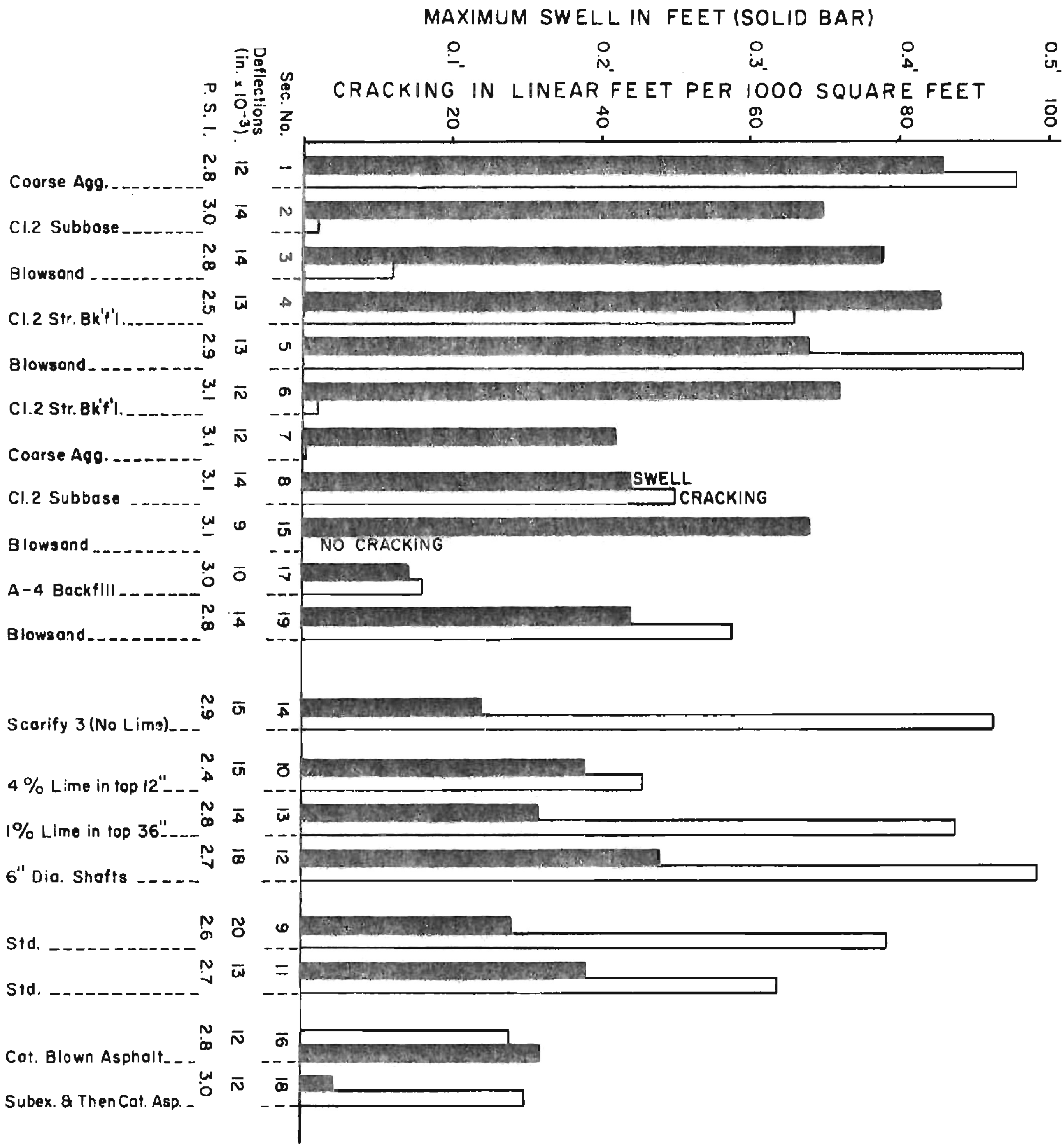
Figure 8

CLIFTON EXP. PROJECT



Section	P. S. I.	Deflections (in. x 10^-3)	Sec. No.
Coarse Agg.	2.8	12	1
Cl.2 Subbase	3.0	14	2
Blowsand	2.8	14	3
Cl.2 Str. Bk'f'l.	2.5	13	4
Blowsand	2.9	13	5
Cl.2 Str. Bk'f'l.	3.1	12	6
Coarse Agg.	3.1	12	7
Cl.2 Subbase	3.1	14	8
Blowsand	3.1	9	15
A-4 Backfill	3.0	10	17
Blowsand	2.8	14	19
Scarify 3 (No Lime)	2.9	15	14
4 % Lime in top 12"	2.4	15	10
1% Lime in top 36"	2.8	14	13
6" Dia. Shafts	2.7	18	12
Std.	2.6	20	9
Std.	2.7	13	11
Cat. Blown Asphalt	2.8	12	16
Subex. & Then Cat. Asp.	3.0	12	18

CRACKING AND SWELL

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Section Numbers	Description	Cost
9 & 11	Control - Standard treatment	$ 50
14	Scarify 3', sprinkle for 3 weeks & compact	540
17	Subexcavate 2', backfill with A-4 soil	960
13	Scarify 3', mix in 1% hydrated lime, sprinkle for 3 weeks and compact	1,240
10	Mix top 12" with 4% hydrated lime, sprinkle and compact	1,660
18	Subexcavate 2', place asphalt membrane and backfill with A-4 or A-6 soil	2,210
3, 5, 15, & 19	Subexcavate 2', backfill with fine sand A-3(o)	2,530
2 & 8	Subexcavate 2', backfill with Class 2 subbase	2,860
4 & 6	Subexcavate 2', backfill with Structure backfill (Class 2)	3,000
12	Lime Shaft	3,310
16	Subexcavate 2', place asphalt membrane and backfill with fine sand A-3(o)	3,780
1 & 7	Subexcavate 2', backfill with coarse aggregate (3/4" to #4)	3,970
	Average -	$2,166

As a general rule, the most expensive sections had the greatest swelling. The control sections were the most economical to construct but were below average in performance. Asphalt membrane sections have been placed in other areas of Colorado without subexcavation and backfilling. This operation has been done at a cost of about $1,250 per station per four lanes of divided highway, and in some instances has reduced the amount of subbase material. When a clay subgrade can be kept below optimum noisture condition, then there is a higher in place R value and a reduced cover requirement.

Research work with lime shafts which have performed since 1964 indicates that the lime shafts installed on this project were too slender, and the slurry was too thick for maximum effectiveness. This method of treatment is the subject of other reports from the Colorado Division of Highways. See Reference No. 4, page 22.

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CONCLUSIONS AND RECOMMENDATIONS

Based on the amounts of swelling and comfort of ride, the sections subexcavated and backfilled with granular material were the worst performing ones in this project. This treatment is certainly not worth the greater expense involved. The best performing section was the one that was subexcavated two feet and backfilled with an A-4 soil. It was also one of the most economical to construct. The standard sections - which were the most economical - were below average in swelling but above average in cracking.

It is recommended that standard construction design be used in areas of low swelling potential; subexcavation and backfill with A-4 or A-6 soil be used in cuts of medium swell; and asphalt membrane be applied across the full width of roadways and beyond the bottom of ditches in soils of high swell potential. If a water bearing layer occurs in a cut at or slightly below the finished subgrade of swelling soils it would be advisable to leave the grade unsurfaced until the swelling due to unloading has nearly ceased. Lime shafts were not adequately designed for this project. Other research projects have shown that shafts at least 12 inches in diameter are an effective remedy for maintenance personnel to use in badly swelled roadways.

Research may be needed to find an adequate test for determining the differential swell potential of the soils encountered in highway alignments. The Atterburg Limits tests, which are useful in determining swell potential in weathered Pierre Shale and certain other clays, do not seem to indicate the swell potential of Mancos Shale.

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APPENDIX A

Location	Moisture Content Percent						
Section 1	1964	1965	1966	1967	1969	1971	1973
Subbase		5.9	5.5		3.4		
Coarse Aggregate		2.8	2.7		1.4		3.2
Shale (top)	8.4	9.1			14.1		19.9 (12.9 1.8' lower)
Section 2							
Subbase		6.2	6.0	6.2	3.8		
Subbase (Class 2)		5.2	5.1	4.8	4.3		
Shale (top)	8.3	10.4	12.4	13.7	16.9		
Section 3							
Subbase		5.9	5.5	5.7	4.0		
Sand (A-3(o))		8.3	6.3	6.3	4.6		
Shale (top)	8.6	9.3	11.2	13.1	16.6		
Section 4							
Subbase		5.6	4.9	6.2	4.2		
Str. Backfill		6.4	4.1	3.8	4.5		9.5
Shale (top)	8.9	9.6	12.2	12.1	18.1		20.2 (13.5 2'lower)
Section 5							
Subbase		6.2	6.0	6.7	3.7	4.1	
Sand		13.5	7.8	14.4	4.5	14.7	17.8
Shale (top)	7.8	8.4	10.0	11.5	15.8	17.6	19.2 (11.4 1.7' lower)
Section 6							
Subbase		5.2	4.8	4.8	3.9		
Str. Backfill		4.2	3.3	3.4	3.0		
Shale (top)	7.7	7.3	8.2	9.0	13.3		
Section 7							
Subbase		6.3	5.5	5.3	3.4		
Coarse Aggregate		2.3	2.3	2.2	3.5		
Shale (top)	7.4	10.0	10.0	10.1	14.2		
Section 8							
Subbase		7.1	7.0	7.4	3.8		
Subbase (Class 2)		6.8	6.3	5.8	5.3		5.7
Shale (top)	8.5	9.8	10.2	10.2	12.9		20.0 (10.3 1.4' lower)
Section 9							
Subbase					7.0		6.6
Shale (top)					13.2)		19.6 (8.5 1.7' lower)

APPENDIX A

Location			Moisture Content Percent				
Section 10	1964	1965	1966	1967	1969	1971	1973
Subbase			4.4	4.5	5.6		
Lime Till			29.5	32.2	29.5		27.5
Shale (top)			11.4	11.2	12.5		
Section 11							
Subbase			5.0	5.6	6.0		4.8
Shale (top)	14.4		12.0	12.9	11.8		16.8 (9.6 2.8' lower)
Section 12							
Subbase			5.2	4.5	5.9		6.1
Lime Shaft					61.1		
Shale (top)	8.9		10.2	12.8	10.2		15.5 (11.4 0.5' lower)
Section 13							
Subbase			3.2	5.4	5.0		
Lime Till	13.8		9.5	19.2	18.8		30.2
Shale (top)			4.4				
Section 14							
Subbase			7.6	5.1	3.7		
Shale Till	12.9		14.3	16.7	14.7		
Shale (top)	2.8		11.9	12.8	12.0		16.6 (12.3 0.5' lower)
Section 15 Eastbound							
Subbase			5.3	3.7	3.5		
Sand	7.1		5.1	6.1	6.4		10.8
Shale (top)	3.3		12.3	14.4	14.6		16.2 (10.5 1' lower)
Section 15 Westbound							
Subbase			7.8	4.2	4.3		
Sand	5.8		8.8	14.0	12.2		20.3
Shale (top)			10.2	12.3	10.8		14.7 (6.6 0.8' lower)
Section 16 Eastbound							
Subbase			5.5	4.8	4.0		
Sand	7.1		7.9	10.9	6.6		15.1
Asphalt Membrane							
Shale (top)			5.8	5.0	6.0		6.7 (6.9 1' lower)

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APPENDIX A

Location	Moisture Content Percent						
Section 16 Westbound	1964	1965	1966	1967	1969	1971	1973
Subbase			4.7	5.5	4.4	4.0	
Sand	6.0		12.0	16.7	13.3	6.7	20.9
Asphalt Membrane							
Shale (top)	3.6		8.8	7.5	9.6	5.9	12.0
							(5.5 0.3' lower)
Section 17 Eastbound							
Subbase			3.8	4.0	4.0		
Soil Backfill	9.7		10.9	9.0	7.8		7.4
Shale (top)			10.4	10.6	10.4		8.8
							(13.9 0.4' lower)
Section 17 Westbound							
Subbase			7.2	5.3	6.3		
Soil Backfill			12.0	14.6	13.8		16.6
Shale (top)	2.6		13.3	14.6	14.1		15.3
							(9.6 0.7' lower)
Section 18 Eastbound							
Subbase			4.2	4.2	3.6		
Soil Backfill	10.0		10.2	8.9	7.8		5.8
Asphalt Membrane							
Shale (top)	3.3		10.2	12.2	12.8		15.7
							(9.5 0.8' lower)
Section 18 Westbound							
Subbase			4.7	4.6	5.6		
Soil Backfill	11.0		7.5	15.4	10.8		14.7
Asphalt Membrane							
Shale (top)			7.4	7.8	8.4		10.2
							(7.6 0.7' lower)
Section 19 Eastbound							
Subbase			6.0	6.1	5.7		
Sand	6.9		7.8	16.4	10.2		13.2
Shale (top)	2.4		13.4	12.8	11.1		13.0
							(9.1 0.8' lower)
Section 19 Westbound							
Subbase			4.5	4.0	4.8	2.7	
Sand	7.0		12.6	15.7	12.6	12.5	18.3
Shale (top)			5.2	6.8	9.8	14.3	13.5
							(5.0 0.8' lower)

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APPENDIX B

SOIL DATA

Section Number	Soil Classification	Liquid Limit	Plastic Index	Percent Passing #200 Sieve	Percent Optimum Moisture
1.	A-6(13)	40	15.7	82	17
2.	A-6(13)	40	15.7	82	17
3.	A-6(13)	40	15.7	82	17
4.	A-6(13)	40	15.7	82	17
5.	A-6(13)	40	15.7	82	17
6.	A-6(13)	40	15.7	82	17
7.	A-6(13)	40	15.7	82	17
8.	A-6(13)	40	15.7	82	17
9.	A-7-6(21)	42	18.6	99	19
10.	A-7-6(21)	42	18.6	99	19
11.	A-7-6(21)	42	18.6	99	19
12.	A-7-6(21)	42	18.6	99	19
13.	A-7-6(21)	42	18.6	99	19
14.	A-7-6(21)	42	18.6	99	19
15.	A-6(11)	34	14.3	81	15
16.	A-6(11)	34	14.3	81	15
17.	A-6(11)	34	14.3	81	15
18.	A-6(11)	34	14.3	81	15
19.	A-6(11)	34	14.3	81	15

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