HIGHWAY DESIGN AND CONSTRUCTION

through

EXPANSIVE SOILS IN SOUTH DAKOTA

by

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INTRODUCTION

The Materials and Soils Section of the South Dakota Department of Highways has been cognizant of the problems connected with design of road surfaces, through the highly expansive Pierre Shales for many years.

During these years we have made changes in our methods of design and construction procedures which we believed would tend to reduce the expansion of the soils and its resultant effects. We have consulted with several Materials Engineers, from different parts of the country, in an effort to find a design that would reduce if not completely eliminate the rough surface conditions that develop on roads built on highly expansive soil areas.

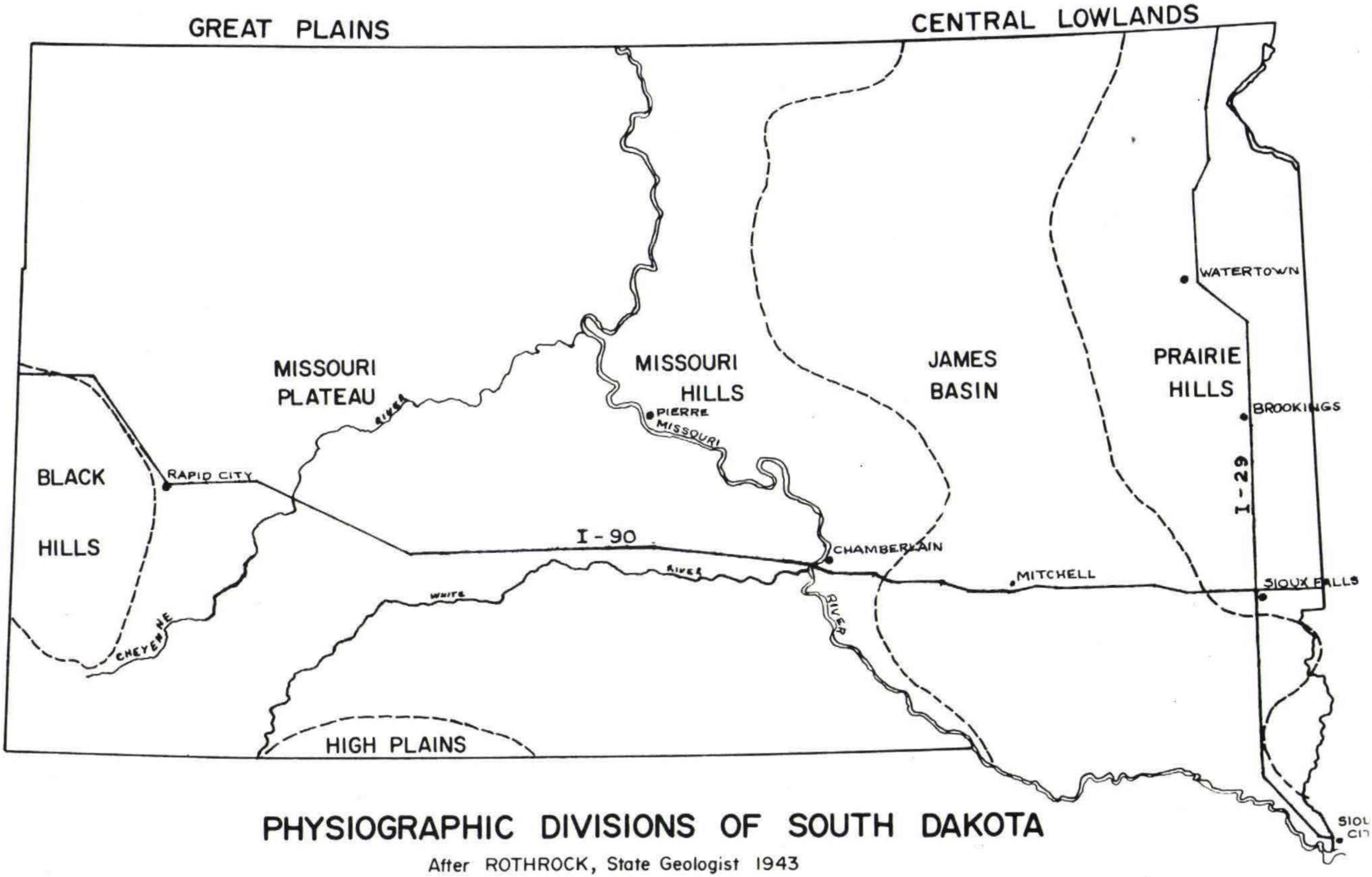
GEOLOGY

The Missouri River almost equally divides South Dakota into two distinct land forms, each half composed of soils having quite different physical characteristics, in regard to Liquid Limits, Plasticity Indices, Volume Changes and Bearing Values. The upper mantle of soil in the eastern half of the state is composed chiefly of Glacial Till, Silt Clays, Clay Silts and Sand Silts. The western half, with the exception of the Black Hills, a small area near the Nebraska border and also an area of sandstone overlay, in the north central portion, is composed of Pierre Shale and weathered Pierre Shale Clay, commonly referred to as "Gumbo Clay". The mineral composition of the bentonitic shale is largely montmorillonite. See Physiography features which are associated with this geology, Fig. 1.

Pierre Shale was laid down West of the Missouri River in South Dakota in the Mesozoic Era, in the upper stage of the Cretaceous, Montana Group, which contains some Fox Hill, Elk Butte, Hell Creek and Mobridge Formations. These shale structures are the results of numerous sea intrusions over a period of millions of years and are composed of layers of interbedded highly plastic, colloidal clay and silts containing nearly pure bentonite layers in some areas. This deposition varies in thickness from several feet to several thousand feet.

SOIL CHARACTERISTICS

The Pierre Shale is composed of layered clay and silts, interspersed with bentonitic layers, having extremely high expansive properties. These layers are differentiated with respect to degree of weathering, volume change and water susceptibility. The upper portion of deposition is usually weathered to a fine homogeneous till-like clay from 1 to 15 feet in thickness. The next portion of deposition is usually weathered to an open jointed condition. This open jointed shale is not homogeneous in texture and therefore readily admits surface water when the upper soil and clay till are removed. The inorganic colloidal clays and bentonitic properties of the Pierre Shale are susceptible to large volume changes when subjected to prolonged alternate dry and wet cycles, such as are prevalent in Western South Dakota. The expansive pressure of the clay derived from Pierre Shale in some areas is nearly 100 pounds per square inch. See Figs. 2 & 3.



PHYSIOGRAPHIC DIVISIONS OF SOUTH DAKOTA

After ROTHROCK, State Geologist 1943

Fig. 1

EXPANSION PRESSURES OF SOUTH DAKOTA SOIL

STANDARD AASHO COMPACTION T - 99

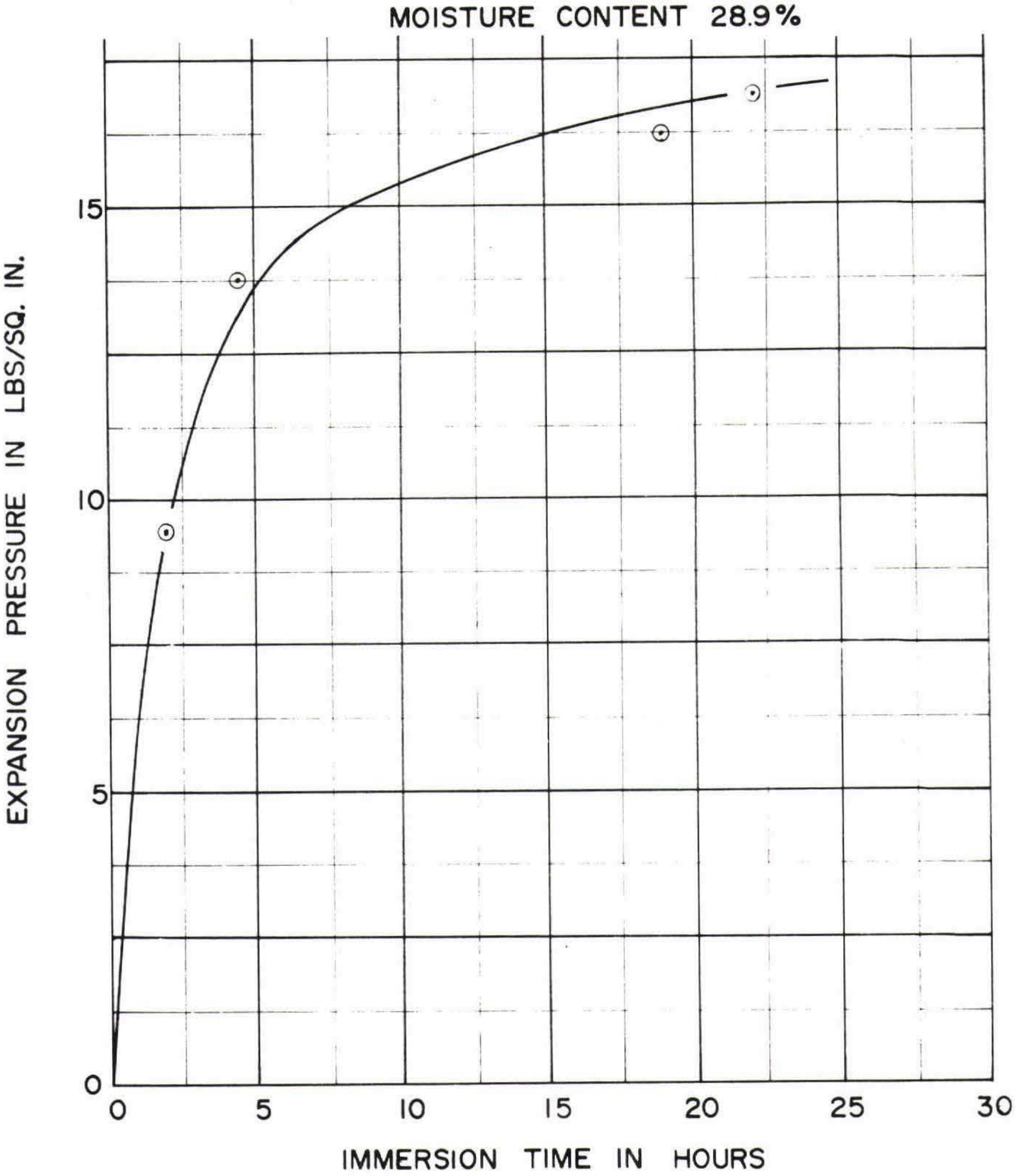


Fig. 2

EXPANSION PRESSURES OF SOUTH DAKOTA SOIL

MODIFIED AASHO COMPACTION T-180

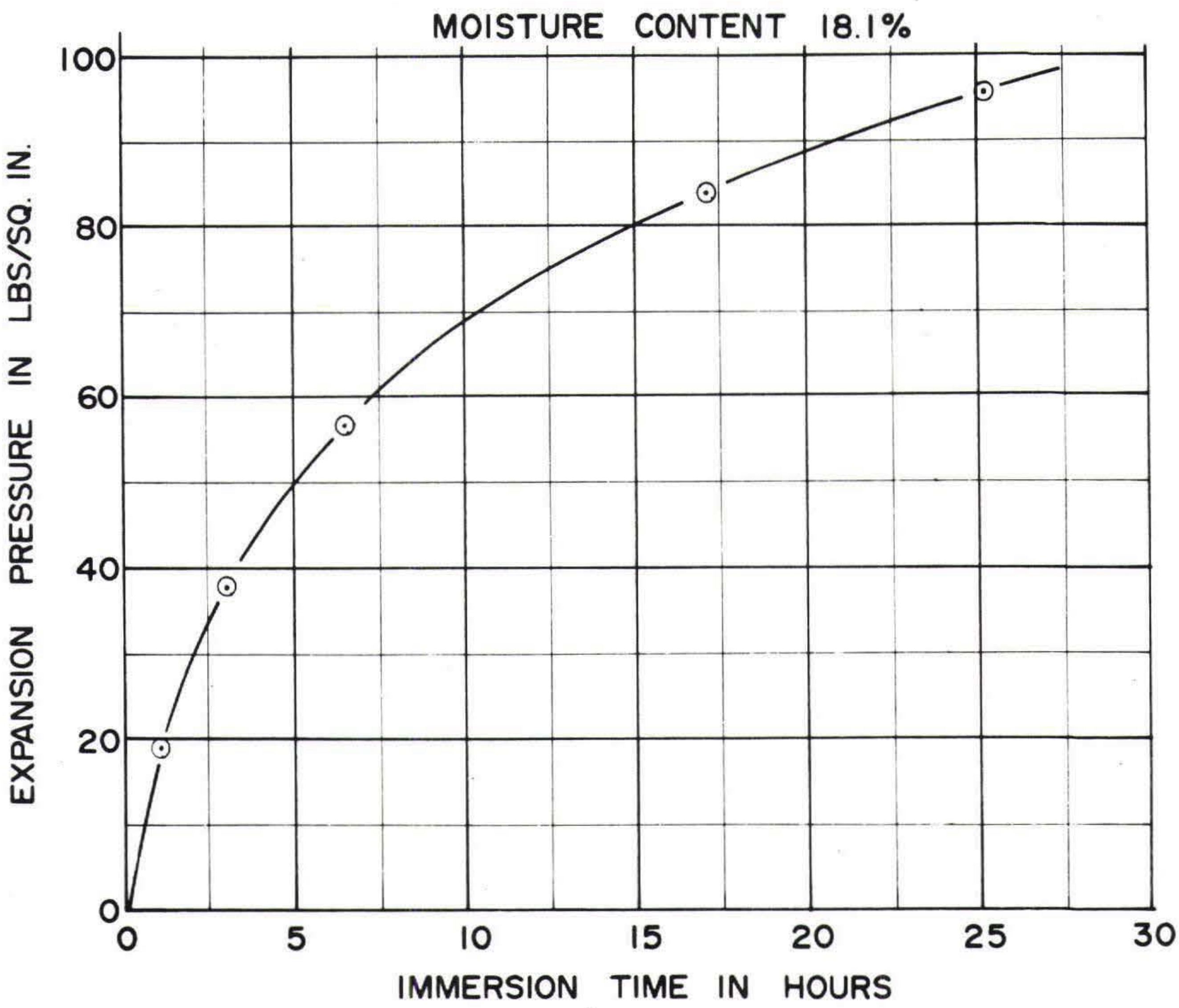


Fig. 3

HISTORY OF HIGHWAY DESIGN & PERFORMANCE

In Pierre Shale

Prior to 1952, asphaltic mats one and one half to two inches thick, in conjunction with base gravel four to six inches thick, were used as a surfacing over the Pierre Shale. Several short sections of plain six inch and eight inch Portland cement concrete pavements were placed on the shale near Pierre, Winner and Chamberlain. Both surfacing types distorted rather badly in a matter of three to five years. Distortion was not due to the traffic but rather to the fact that the expansive soil warped the surfaces to such a degree that traffic was able to finish the job of breakup at an early age.

After observing the poor results of these thinner designs we began to construct thicker pavement surfaces, using three to four inch mats over five to eight inches of base course and six to fifteen inches of subbase. We also inaugurated the practice of subgrade and moisture control, undergrading cut sections twelve inches, scarifying an additional six inches and recompacting the scarified and undercut soil, or replacing the undercut soil with select soil, where possible. In more recent years we have undergraded cut sections to the toe of the inslopes and recompacted the undercut soil or replaced it with select soil.

Observation of the roads that have been built during the past three to eight years, using these methods, indicates that we have been successful to a certain degree, in reducing the severity of warping in the areas containing highly expansive soil. While many of these roads provide an adequate riding surface we are still faced with the problem of undesirable roughness, even on some roads where we have placed extremely thick granular layers. Some of these roads have shown roughness in areas where as much as 30 inches of select material and subbase have been placed under the base and mat. The same condition has also developed where extremely thick subbases were used under concrete surfacing.

Our most recent efforts in trying to control warping in surfacing placed on these expansive soils are discussed more fully further on in this report.

INVESTIGATIONS SHOWING EFFECTS OF CLIMATIC AND SOIL

DIFFERENTIALS ON SUBGRADE STABILITY

We have made extensive and concentrated investigations in several portions of roadbeds over a widely scattered area of the Pierre Shale deposition. By extensive and concentrated, we mean we have bored holes at intervals of 5 to 20 feet, obtained moisture samples and secured materials for testing.

One location of the Interstate route and two others on U.S. #16 adjacent to the Interstate route have been selected to show the nature of the shale in sections where differential heaving has occurred and patching or roughness is pronounced. These sites are located on I 90-2(9) 77, Pennington Co., Sta. 18+92 to 28+77, eastbound lane, on U.S. #16 FI 185(28) Jackson County, 302+50 to 307+50 and on U.S. #16 F 185(24) Jones Co., Sta. 651+66 to 656+76. The Jackson and Jones County projects have been in place for more than twelve years. See Tables 1, 2 and 3.

Tables 1, 2 and 3 indicate tremendous differentials exist in liquid limits and volume changes, over very short distances. It is noted that the differentials exist not only in a longitudinal direction of from 5 to 15 feet, but also in very thin verticle layers of 6 to 18 inches.

Recent investigations of subgrade in the expansive shale areas have been made to determine the seasonal moisture fluctuations.

Figures four through six show that there are considerable moisture differentials throughout the various seasons along with changes in density. These moistures were taken from bituminous surfaced roads, that have been in service at least 8 years. It is apparent these variable moistures are caused by the extreme wet and dry weather cycles in conjunction with variable soil conditions.

The moisture differentials take place over a relatively short period of time, as indicated in the following figures. The time interval can be as short as from the spring of one year to the fall of the next year. As mentioned in the forepart of this report, the shale is weathered in open jointed layers and allows moisture to seep into the lower portions of roadbed. The fact that the shale is not a homogeneous mass allows the moisture to penetrate into these soil layers having differentiated characteristics which result in differential heaving and warping of the road surface.

An investigation of four extremely rough bumps that developed in a bituminous surfaced grade, that was completed only a year ago, was conducted during August of this year.

All of the rough areas were found in cut sections. Since the roadbed was constructed by undercutting toe to toe, the investigations were begun four feet below the surface of the grade. Shelby tubes were used to extract cores of the undisturbed shale to a depth of eight to twelve feet below the mat. These undisturbed cores showed a high amount of oxide staining and large seams of gyp crystals which is indicative of the large amounts of free water which can move through the platy jointed shale. Although no pure bentonite seams were encountered, the liquid limit of the soil averages 81 and the plastic index is 49, which caused considerable expansion to occur when water entered the jointed shale in the newly exposed ditch cuts.

Project I90-2(9)77, Pennington County

October 1963

Section "A", Sta 18+92.3 to 28+77.1 Eastbound Lane

Sample Number	Station		Proctor Density	Percent Optimum Moisture	Field Moisture 12"	P I	L L
1A	19+00	17.5R	______	______	25.2	34.7	63.5
21A	19+29	2R	87.5	29.5	28.5	51.3	82.2
20A	19+50	12.5L	----	----	22.6	43.4	71.1
19A	20+50	12.5L	88.7	28.2	26.8	47.4	74.7
3A	21+00	12.5R	92.1	25.8	29.8	41.1	73.4
27A	22+00	1L	92.1	25.8	22.0	37.3	63.9
17A	22+50	12.5L	88.7	28.2	27.0	45.7	74.9
5A	23+00	12.5R	92.1	25.8	26.3	38.3	65.1
16A	23+50	12.5R	88.7	28.2	31.0	48.9	80.6
6A	24+00	12.5R	88.7	28.2	27.4	47.7	74.7
24A	24+75	2L	88.7	28.2	23.1	53.0	80.0
5R	25+37.8	6L	101.2	20.9	18.0	31.7	52.3
14A	26+50	12.5L	107.1	18.1	14.0	23.6	44.6
6R	26+63	6L	103.5	19.7	15.6	33.4	54.3
9A	27+00	12.5R	----	30.5	27.4	44.0	76.3
13A	27+50	12.5L	92.1	25.8	29.6	50.3	97.1
10A	28+00	12.5R	89.9	27.4	25.7	45.4	74.4
12A	28+50	12.5L	97.4	22.7	22.4	35.6	63.4

Note: All soil classify A7-6(20) Clay

Table No. 1

Project FI 185(28) Jackson Co

Sta 302+50 to 307+50

Sample	Station	Dry Den.	Opt Moist	Field Moist		P.I	L L
				6"	18"		
40	0+60	104.0	19.0	23.3	31.7	28	48
43	1+00	99.0	23	21.6	16.9	43	68
45	1+30	93.0	26	21.9	26.4	51	84
47	1+60	87.0	31	24.0	25.6	64	97
48	2+00	87.0	31	22.8	26.6	71	106
51	2+20	99.0	23	25.9	19.1	44	71
54	2+70	93.0	26	23.8	20.5	53	80
58	3+30	93.0	26	23.8	23.5	50	77
64	4+20	99.0	23	29.7	20.7	47	72
65	4+40	101.0	20	25.8	19.9	45	67
68	4+60	99.0	23	26.3	21.4	44	70
69	5+00	104.0	19	26.7	24.6	36	61

Percent of volume change above optimum moisture content is 15% to 21%.

Absolute volume change from wet to dry is 45% to 66%.

All soil samples classify A7-6(20)

Table No. 2

Project F 185(24) Jones Co

Sta 651+66 to 656+76

Sample	Station	Dry Den	Opt Moist	Field Moist 6"	Field Moist 18"	P I	L L
70	0+00	96	24.0	25.1	24.2	40	71
74	0+60	98	23.0	21.5	23.4	37	64
79	1+30	96	24.0	22.6	17.2	43	71
84	2+10	97	23.6	23.5	19.0	40	66
87	2+50	92	25.0	31.5	27.7	48	76
90	3+00	97	23.6	28.0	28.6	35	66
93	3+40	90	27.0	30.9	30.2	43	80
95	3+70	85	30.5	28.7	54.2	50	93
96	3+90	97	23.6	36.2	26.9	44	74
99	4+30	90	27.0	32.9	30.0	47	80
100	4+50	96	24.0	30.3	30.0	39	71
104	5+10	97	23.6	27.0	31.1	46	74

Percent of volume change above optimum moisture content is 11.0 to 12.5%

Absolute volume change from wet to dry is 55% to 63%.

All soils Samples classify A7-6(20)

TABLE NO. 3

SUBGRADE & MOISTURE DENSITY DATA

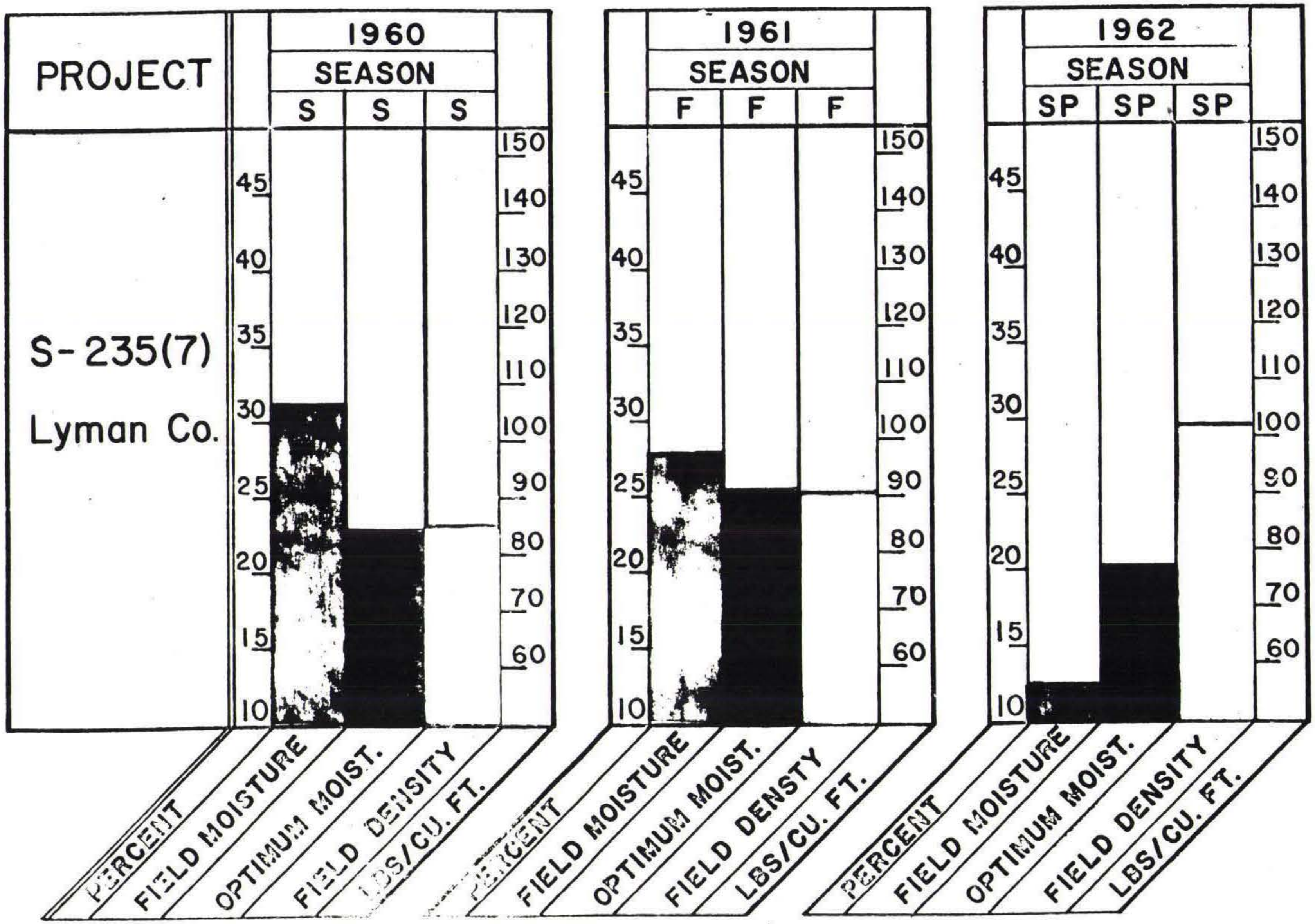


Fig. No. 4

SUBGRADE & MOISTURE

DENSITY DATA

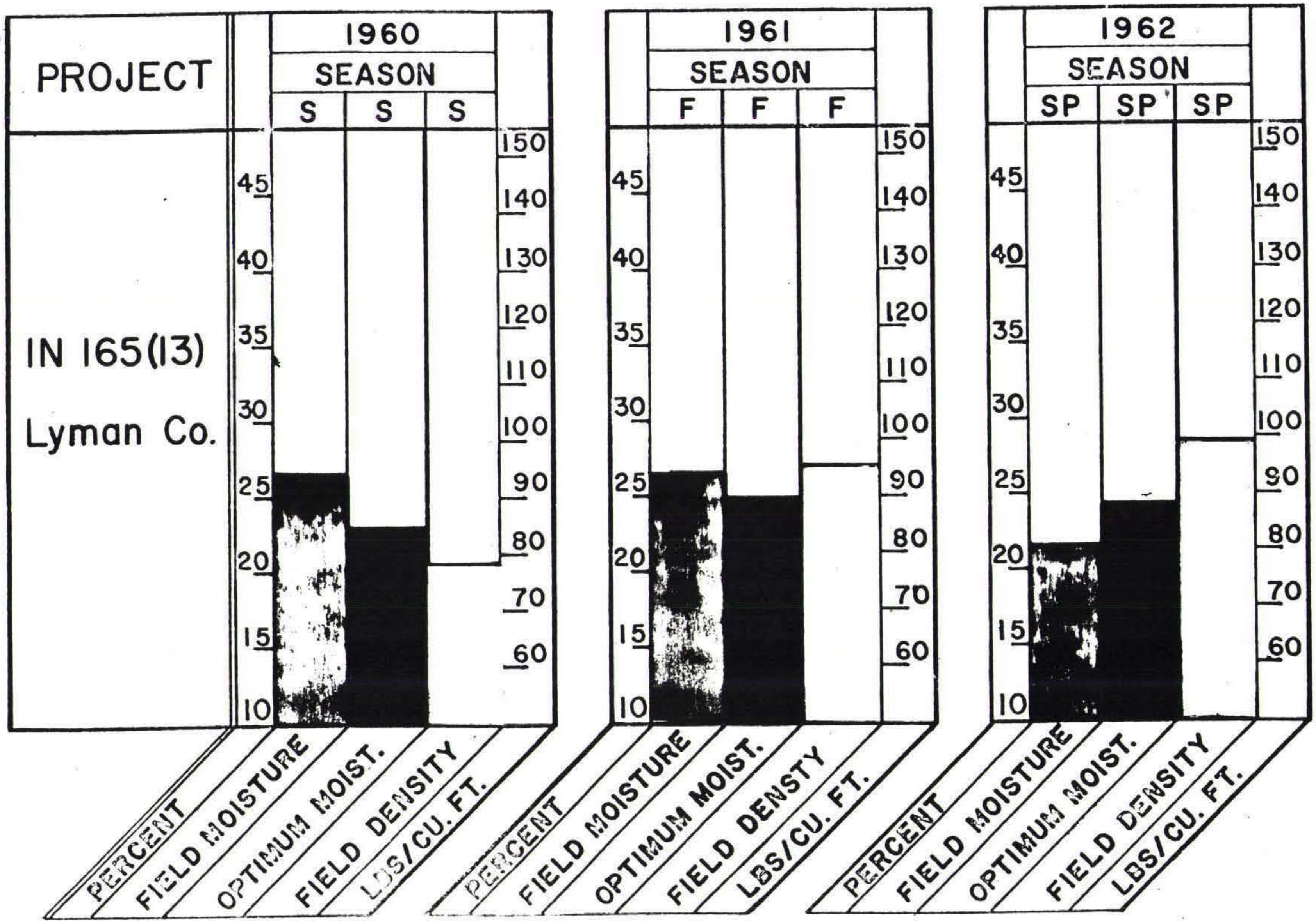


Fig. No. 5

SUBGRADE MOISTURE & DENSITY DATA

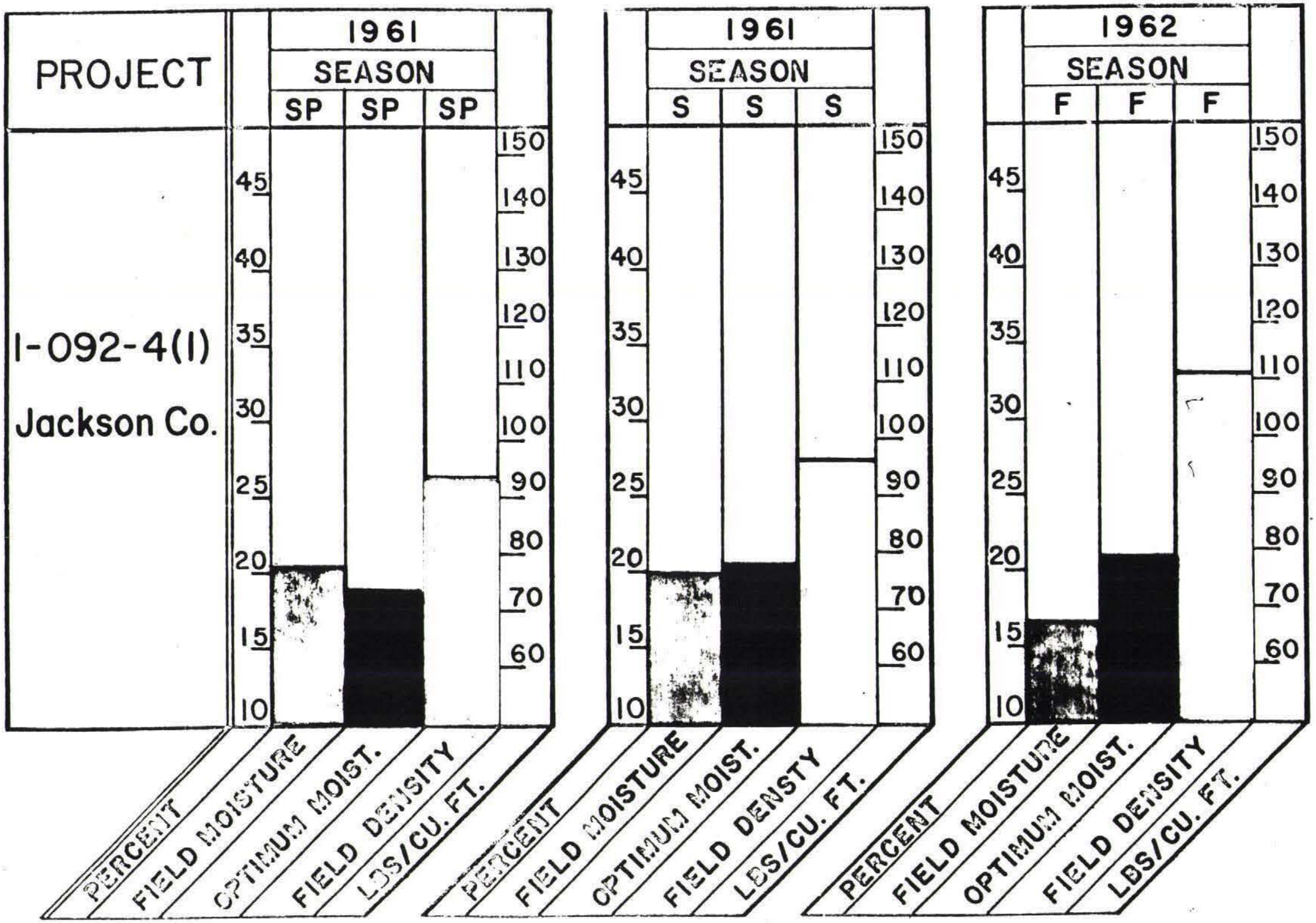


Fig No. 6

Table four is resume' of the test data from the investigation in Butte County.

TEST RESUME'

Heaved Areas U.S. #85 Butte County

Proj.	Station	Depth	L.L.	P.I.	Field Moist.	Opt. Moist.	% Swell	Dry Density
F 011-5(9) Butte County	289+00	4'-8.5'	83	51	21	31	21	84
F 011-5(10)	792+80	4'-8.5'	90	54	24	31	23	84
F 011-5(11)	1227+90	4'-8.0'	75	46	18.5	27	15	90
F 011-5(11)	1273+10	4'-7.5'	77	46	19	30	12	88

Table 4

A similar investigation was conducted on Interstate Route I 90 in Pennington County. Table five is a resume' of this Investigation.

TEST RESUME'

Heaved Areas I 90 Rt. Jackson County

Average	Depth	L.L.	P.I.	Field Moist.	Opt. Moist.	% Swell	Dry Density
15 Holes	0-1'	46	227	15	-	-	102
22 Holes	1'-2'	76	50	26	24	20	93
7 Holes	2'-3'	82	50	22	-	18	98
8 Holes	3'-4'	83	51	23	28	20	96

Table 5

It is noted that the field moisture in most cases is considerably below the optimum moisture, especially at the deeper depths.

MAINTENANCE DATA

The data presented in tables six through nine was gathered from our construction and maintenance records. This data is included merely to show the relative cost of the various types of designs that have been used during the past twelve years. They are indicative of the high cost of maintenance in areas where extremely high expansive soils are encountered. Footnotes on the various tables explain special conditions which are associated with the various projects.

EXPERIMENTAL STABILIZATION

We presently have under study an experimental road near the Big Bend Dam in the Missouri River Hills. The stabilizing agents used are Lime, Lime-Asphalt, Phosphoric Acid plus Ferric Sulphate and a PDC formula. The average liquid limit of the soils in the first 6 miles of test project 91 percent. The last 2.5 miles has an average liquid limit of 61 percent.

The primary objectives of this experimental road are:

1. To determine if it is possible to achieve the degree of stability necessary to prevent warping of road surfacing materials by the addition of chemicals, or other additives, to the highly expansive soils.

2. To determine if additives in the in-place soils are more effective than replacing with non-expansive materials.

3. To determine to a certain degree the economy of using stabilizing agents for the in-place soils, as compared to hauling in non-expansive soil.

We have just completed our third year of testing on this project and will run tests during 1968, after which a final report will be written. An interim report was written during 1966, which outlines the procedures of laboratory work and field work, and also includes some of the test data. We could not give definite conclusions in this report but there appears to be some trends developing in regard to warping, crack pattern and rideability. This report is available to those who wish to have a copy.

TABLE 6

I 90-2(9) 77 Sec. 1 & 2

Pennington Co. West of New Underwood to East of Wicksville, length 18.628 miles

Type: Concrete	Thickness Design	Concrete	Subbase	Select Soil
		9" Reinf.	*9" - 12"	**18"

*Upper 6" of subbase treated with lime.
**Select soil used in some shale cuts.

Year of Const. 1961

Construction Cost:

Surfacing, Subbase, Base & Shoulders, only	$5,653,583.00
Cost/lane mile	$151,749.00
Maintenance Cost to date, Full Proj.	$224,491.00
Cost/lane mile/per year	$1,094.00
Total construction & maint. cost/lane mile to date	$157,769.00

Items, Patching Surface, Sealing Joints, Replacement in kind

Patching Shoulders only.

Note: The bulk of the above maintenance expenditure was used on 2.199 miles of extremely rough pavement which is located in areas of highly bentonitic soil.

TABLE 7

I 90-2(17) 96

Pennington Co. East of Wocksville to East of Wasta, length 7.038 miles

Type: Bituminous	Thickness Design	Mat	Hot Mix Base	Base	Subbase	Subgrade
		1-1/2"	4"	4"	9"-12"	6" Lime Treated

Year of Construction, 1964

Construction Cost:

Surfacing, Base, Subbase and Lime Treatment, only	$1,192,548.90
Cost/lane mile	$84,722.10
Maintenance Cost to date, Full Proj.	$6,553.00
Cost/lane mile/per year	$186.00
Cost/lane mile to date	$85,653.00

Note: The above project is to be completed with a 3" overlay mat by 1972 which is estimated to bring the per lane mile cost to $105,000.00. This project is located in an area of highly plastic soil.

TABLE 8

I 90-2(3) 114

Pennington Co. East of Wall to East Pennington Co. Line, length 12.245 miles

Type: Bituminous	Thickness Design	Mat	Brown Base	Base	Subbase
		4"	4"	4"	5"-12"

Year of Construction, 1960

Construction Costs:

Surfacing, Base & Subbase, only	$1,077,400.00
Cost/lane mile	$87,980.00
Maintenance Cost to date, Full Proj.	$9,913.00
Cost/lane mile/per yr.	$124.00

Items: Patching Surface, Sealing Joints

Replacement in kind and Patching Shoulders, only

Total Construction and Maintenance

Cost/lane mile to date $88,789.00

Note: This project is located in areas of lower liquid soils. However, several portions are located in highly bentonitic soil areas and are extremely rough and in need of overlay.

TABLE 9

FI 185(24) & (23) WPGH 185F

Jones Co. from Stamford to East of Oakaton, length 15.806 miles.

Type: Bituminous	Thickness Design	Mat	Base	Subbase
		1-1/2" + (2" overlay)	5"	7"

Year of Construction: 1952

Construction Cost:	
Surfacing, Subbase, Base	
& Shoulders, only	*$968,224.00
Cost/lane mile	$61,256.00
Maintenance cost to date, Full Proj.	$174,825.00
Cost/lane mile/per year	$762.00
Items: Patching Surface, Filling Cracks,	
Replacement in kind, only.	
Total Construction and Maintenance	
Cost/lane mile to date:	$72,256.00

* Includes cost of Base & Overlay 1957

Note: This project is located in an area of higher liquid limit soils.

METHODS OF DESIGN AND CONSTRUCTION USED ON INTERSTATE 90

Preliminary Field Studies

Preliminary Soils Investigation by the Department of Highways consisted of development of a continuous soils profile from field measurements of existing soil types existing along each project and tests made on samples of the various soil types encountered. In addition a careful performance study was made of existing highway, U.S. 16, which extends the entire length of the route in question. Areas causing considerable maintenance because of differential swell, usually in cut sections, were investigated by digging a series of closely spaced holes and recording the position and extent of in-place soil types. Samples were taken to determine the nature of each layer. Also, in-place moisture and density tests of the upper portion of the subgrade soil, which was covered by asphalt concrete and soil aggregate base course, were taken from the existing road paralleling each project to help determine subgrade density and the natural moisture retention characteristics. An estimate was also made of the quantity of available topsoil (usually the top 6 inches of sodded areas) and of the availability of weathered soil suitable for topping the upper three feet of the entire subgrade; this material is usually found in the upper 3 to 5 feet of the natural terrain.

Prior to preparing grading plans a considerable amount of discussion took place between Department of Highway Engineers, Bureau of Public Roads and the Highway Commission in regard to type of pavement which could economically be placed and maintained on Interstate 90, over the expansive soils west of the Missouri River in South Dakota. Recommendations originally agreed to consisted of from 13 to 14 inches of deep strength asphalt concrete. After further study a proposal was presented to use a composite type surface of pavement consisting of an 8 inch thickness of 2500 psi concrete base course covered by 5 inches of asphalt concrete applied using stage construction, and finally an 8 inch thickness of continuously reinforced concrete pavement on 3 inches of lime stabilized base course was selected for the first five projects having a total length of 42.2 miles from Cactus Flat east to the east Jackson County line.

The Department of Highways during April, 1965 at the suggestion of the Highway Commission employed "Woodward-Clyde-Sherard and Associates" of Denver, Colorado to provide recommendations which would result in the most economical and satisfactory construction procedure, as well as the best type of surfacing to use on Interstate Highway I 90 from Wasta to Chamberlain in South Dakota. They submitted their findings and recommendations in a report entitled "Treatment of Expansive Soils for Interstate Highway I 90, South Dakota", dated May, 1965.

Generally their recommendations for subgrade design and construction consisted of the following:

1. Pre-wetting of the natural subgrade clays to cause expansion prior to construction.

2. Undercutting all subgrade soils (shoulder to shoulder) to a depth of six feet and replacing with the same soils placed under controlled conditions of moisture and density.

3. Density of embankments was recommended to be controlled between 90 and 95 percent of AASHO T-99, using the energy-input method of placement control.

4. The moisture content of embankment soil was recommended to be controlled at optimum plus approximately 3 percent to minimize expansion, yet retain adequate strength to support the required wheel loadings using a normal pavement section.

5. They suggested placing the most expansive soils in the bottom of adjacent deep fills or wasting, and placing the least expansive soils directly beneath pavements in both fill and cut areas. Use of impervious soils in the treated or upper zone to minimize access of water to underlying expansive soils was also recommended.

6. Special methods of field control was recommended to identify and direct placement of the most expansive materials, and to assure uniformity of placement in regard to moisture and density.

7. Recommendations included advice for protection of the surface of the subgrade with lime or asphalt, or replace the moisture in the top 1 to 2 feet of fills just prior to paving to assure proper moisture content.

8. Good construction procedures and proper control by experienced, qualified engineering personnel was recommended. According to the Consultants the type of pavement to be used over expansive soil subgrades should be based upon factors other than the nature of the soil used. In other words, either an Asphalt, a composite or a P.C.C. pavement could be placed on a swelling soil subgrade if constructed as recommended in the report.

Mr. Harold Allen, Consulting Engineer from Bethesda, Maryland, who had recently retired from the Bureau of Public Roads with a lifetime of experience in soil analysis and pavement design, was employed in June, 1965 to review and comment upon the Woodward-Clyde-Sherard and Associates, May, 1965 report. Substantially he concurred with their recommendations and findings.

Design Features (Special Provisions and Undercut Sections)

After review of the May, 1965 report special provisions were written for "Undercutting and Selected Subgrade Topping" and for methods of "Subgrade Construction". Prior to finalizing the special provisions, conferences were held with Department of Highways and Bureau of Public Roads Engineers. Also, a conference was held at Rapid City with all prospective grading contractors prior to advertising the grading work for a letting to discuss the special provisions, the type of work involved and the engineering control proposed on projects to be constructed on Interstate 90 through the expansive soil area. As a result of these conferences several changes in the Special Provision requirements were made.

Copies of these Special Provisions may be obtained by submitting a written request to either of the authors of this paper. An outline of the requirements contained in the Special Provisions appears below

Special Provisions for Undercutting and Selected Subgrade Topping.

1. Selected subgrade topping for the top 3 feet of all roadway embankment friable shall be fine-grained, and sufficiently homogeneous and weathered so as to readily receive water. The moist material shall be capable of being easily broken down by the fingers or hands so 90% (excl. rock or stone) will pass a 1 inch sieve in accordance with Test No. SD 212.

2. Sources of selected topping will be confined to horizons and areas designated on the plans or by the Engineer. Excluded will be the upper 6 inches of sodded areas or other soil high in silt or humus content.

3. The six foot depth of undercut shown on the plans may be reduced to three feet or increased as necessary upon written authorization by the engineer.

4. Undercut or other suitable material which does not contain obvious layers of bentonite shall be used to reconstruct the undercut area below the three foot selected topping zone.

5. Measurement and payment for selected subgrade topping (upper 3 ft.) will be based on plan shown embankment volume plus plan shown shrinkage. Payment for the item of selected subgrade topping is for additional work, involving material selection, necessary blending, extra haul or handling, or for interim stockpiling if necessary.

6. Undercutting will be paid for at the contract price for "Unclassified Excavation".

Special Provisions for Subgrade Construction.

1. Pre-irrigation of all material designated for subgrade construction will be required or other methods may be employed provided satisfactory results are obtained. Contractor is required to provide competent supervisory employees to direct placement of water to avoid waste.

2. Grading construction work will be restricted to daylight hours in accordance with a schedule prepared by the Engineer, based on weekly periods with starting and stopping time established one-half hour before sunrise and one-half hour after sunset.

3. Excavated soil with detrimental amounts of bentonite shall be placed as directed by the Engineer in, (a) lower portion of high fills (below 20 ft.), (b) embankment slopes beyond the subgrade shoulder lines, or (c) waste areas designated by the Engineer within one-half mile haul distance.

4. Soil having a maximum dry weight of less than 88 lbs. per cubic foot will not be restricted from use in the upper 12 inches of the subgrade.

5. Project shall be divided into grading areas not to exceed one mile in length and the Contractor shall develop a plan within each grading area that adequately demonstrates to the Engineer that an adequate quantity of selected topping will be salvaged or reserved for such use. The Contractor is also required to follow this plan to assure availability at time of placing the upper 3 ft. of the subgrade of an adequate quantity of selected subgrade topping soil.

   Contractor is required to complete the grading work in any area with no undue delay or to replace lost moisture due to such delay, solely at his expense.

   Maximum length of grading allowed to be in progress for each complete grading spread will be 3 miles, with a maximum of 2 miles in the rough grading stage.

   After completion of earth subgrade, lime application shall be completed within ninety-six hours, weather permitting.

6. Requirement for upper six feet of all embankments.

   (a) Place moistened selected subgrade topping (top 3 ft. of subgrade) on the grade in loose lifts generally not to exceed 8 inch thickness, smooth by blading, correct obvious dry or wet spots, disk or otherwise manipulate the material to break-down chunks and remove compaction planes formed by pneumatic tires. Degree of pulverization shall be to the satisfaction of the Engineer. It can be determined by Test No. SD 113.

6. (Continued):

(b) Compaction shall be obtained by sheepsfoot rollers. However, embankment material composed chiefly of granular or silty soil, which will not compact satisfactorily by rolling with a sheepsfoot roller, may be compacted with other types of rollers approved by the Engineer. Also, the unconsolidated surface of the final lift of the subgrade shall be compacted with rubber tired equipment. Four coverages of the sheepsfoot roller is anticipated, minimum of 2 coverages will be required. Work will be accepted upon completion of rolling.

(c) Density tests of the subgrade made to guide the energy-input of subsequent work may extend as deep as three inches into the previously placed lift.

(d) Requirements for top six feet of all embankments (moisture and density).

Density, minimum limit	=	92% AASHO T-99
Density, Target	=	95% AASHO T-99
Moisture, Target	=	3 percentage points over optimum.
Moisture, lower limit	=	Optimum, AASHO T-99. Engineer may approve a lift with moisture not more than 3 percentage points below optimum provided the two consecutive overlaying lifts are placed at or above optimum.

7. Requirements for Subgrade Embankments below the top 6 ft. zone.

(a) Loose lifts when placed shall not exceed 12 inches in depth.

(b) Prior to compaction of each lift the material shall be leveled, and pulverized and mixed by disking or other methods as necessary to condition the soil to receive the required amount of moisture. Additional water needed shall be added during the pulverization and mixing operations.

(c) As compaction planes are not considered detrimental below the 6 ft. zone any type of roller may be used. Coverage must be uniform and adequate to meet minimum density requirements.

7. (Continued):

(d) Subgrade Embankment Requirements Below the Top 6 foot zone.

Density, minimum limit	=	95% of AASHO T-99
Density, minimum on berms	=	100% of AASHO T-99 for all embankments within 100 ft. of bridge or overhead structure ends.
Moisture, Target	=	3 percentage points above optimum.
Moisture, lower limit	=	Not more than two (2) percentage points below optimum as determined by AASHO T-99. Engineer may accept a lift containing adequate moisture when not lower than 4 percentage points below optimum, provided the two consecutive overlaying lifts contain moisture equal to or greater than 2 percentage points below optimum.

8. Moisture tests will normally be made separately from density tests for control of the work.

Density tests of the work will be used as a guide to adjust the compactive effort on subsequent lifts in order to meet or substantially meet contract requirements.

Typical Undercut Sections

Typical Cross-Sections for Main Line Undercutting are attached as Exhibit "A". This exhibit consists of sheet #6 taken from grading plans on I 90-3(22) 151 in Jackson County. Interchange ramps and cross roads are undercut only 3 feet, shoulder slope to shoulder slope, as shown. On this particular project no special undercutting was required on separation cross roads or frontage roads.

Main line undercutting for the top 3 feet of the earth subgrade is full roadbed width, shoulder slope to shoulder slope, and the backfill material for the top 3 feet (including adjacent fill areas) consists of selected subgrade topping. Undercutting below the top 3 feet (to a depth of six feet) is confined to the area between the subgrade shoulder lines. In other words the top 3 feet is undercut 52 ft. wide, shoulder to shoulder, to form a 3 ft. trench.

CONSTRUCTION METHODS

Prior to construction a Pre-Bid Letting Conference was held in the District Four Conference Room, in order to fully acquaint the prospective bidders with the intent of the special provisions and specifications that were set up to control the special features of the moisture control, density control, undercutting of blocky shale and placement of select topping. The contractors were advised specifically in regard to the Department's role in providing inspectors to assist in selection and placement of the selected topping and the removal of bentonite seams and/or extremely high liquid limit shale.

The following items were covered in the Conference discussion:

I. Assignment of Soil Inspectors.

II. Watering, relative to:

   A. Pre-irrigation, time element.
   B. Uniformity.

III. Excavation and Placement of Bentonic Soil Relative to:

   A. Area of placement.
   B. Thickness
   C. Moisture Content
   D. Density

IV. Construction of upper 6 feet of embankment and below the upper 6 feet of embankment relative to:

   A. Manner of placement of lifts.
   B. Thickness of lifts.
   C. Leveling
   D. Additional water.
   E. Pulverization & Mixing.
   F. Density Control, Energy Input.
   G. Moisture Control.

V. Basis of Payments:

   A. Unclassified Excavation paid at Contract unit price.
   B. Undercutting, plan quantity with authorized increase or decrease paid same as contract unit price for Unclassified Excavation.
   C. Select Subgrade topping plan shown quantities paid at contract unit.

SOIL INSPECTOR DUTY ASSIGNMENT

Four Soil Inspectors were chosen from various Districts of the Department who had considerable experience in grade construction. These inspectors were given a course of instruction in the Central Laboratory dealing specifically with the purpose of the soil selection, the special moisture-density control work, project soil identification, special tests and interpretation of the specifications, and special provisions relating to the assignment.

These men work directly under the Resident Engineer and act in an advisory capacity to him regarding the grading operations insofar as it relates to the selection of selected topping - soil and the identification and/or disposal of highly plastic soils. They are responsible for the determination of amounts of undercut that may be necessary, that is in addition to the plan shown quantities, as well as deletion of undercut where it is deemed unnecessary. It is their responsibility to document all such changes. They are required to keep complete daily diaries of all phases of the work within their responsibility.

CONSTRUCTION PROBLEMS

During construction of the I 90-3(14) Jackson County project it was found that it was necessary to modify the interpretation of the density control from strictly a passing or failing density test, as determined by SD 105 or SD 106, to allow the use of Item #7 of the Special Provision for Subgrade Construction. This provision states "To Control the energy input expended during compaction and placement of subgrade embankments the contractor will be required during construction to determine, with the help of the Engineer, the necessary amount of rolling and/or manipulation of the soil after placement by hauling equipment in order to produce the desired degree of compaction".

It was also found that, in addition to the previously pre-irrigated soil, it was necessary to rip and pre-water the cut section excavation material prior to placement on the fills, in order to achieve the desired moisture content.

Large, eight to ten thousand gallon power sprays are also used on the fill to apply additional water during the discing and pulverization phase of the operation. Sheepsfoot rollers are used to apply a specific number of roller passes to achieve the desired density. A minimum of two passes are specified, and in most cases it has not been necessary to apply more than two passes, and rarely more than three passes are needed. An attempt is made to maintain an orderly movement of scrapers, patrols, discs, water tanks and rollers over the entire width of fills in order to achieve the specified thickness, density and moisture in each lift of embankment.

The use of extremely large heavy hauling units has caused some problem in density control. It is necessary many times to rip and redisc a compacted layer due to extreme over compaction. There has also been problems due to the fact that the requirement of a plus three optimum moisture target has caused the equipment to bog down in some areas.

A total of 235 random moisture and density tests were taken from the upper six feet of four completed or nearly completed projects. These samples represent thirty four miles of interstate between seven mile Corner and Belvidere. The average density of the soil represented by these tests is 97.4% of T99. The average optimum moisture is 1 percentage point above optimum. Although the above number of tests represent only a small portion of the total number of tests taken there is an indication that we are generally within the specification limits even though we are on the high side of the density requirement and on the low side of the moisture target.

SUBGRADE SURFACE TREATMENT

The upper six inches of finished earth subgrade is treated with five percent lime. Following the lime treatment the upper three inches of subgrade is treated with an application of four percent RC-1 asphalt. This type of treatment is intended to hold the moisture in the subgrade during the interim period between subgrade finishing and the placement of surfacing. Lime-Asphalt treatment is being done on 42.2 miles of the I-90 route grading from Cactus Flats to Stamford. Samples taken from test holes in the treated finished subgrade on Project I 90-3(14), Jackson County which was completed one year ago in August, showed the moisture below the upper 6 inches of grade to be slightly above optimum. The lime and asphalt treated subgrade also provides a very stable roadbed for the surfacing materials, especially during periods of wet weather when the highly plastic soil would be impassable for heavy equipment.

CONCLUSION

The following Table No. 10 lists a breakdown of items, quantities and cost per mile of the various grading operation and structures for a 42.2 mile portion of the interstate between Cactus Flats and Stamford. An estimated total cost is also given for grading, structures and surfacing. The surfacing cost is listed for only one surfacing project which has been completed out of five projects.

Table No. 10

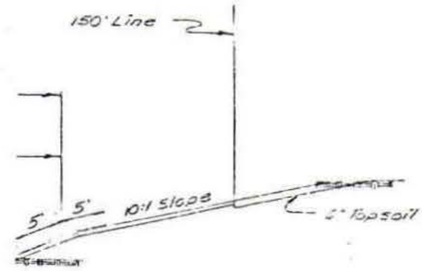
Study of Quantities and Costs Incurred on
42.2 miles of Grading, I-90, Jackson County

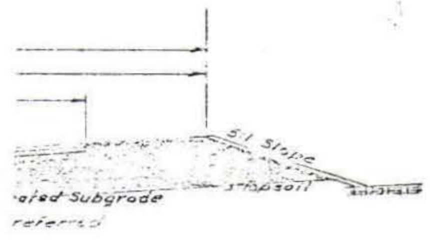
s	Quantity/mile	Cost/mile
ncl. Borrow)	337,480 cu. yd.	$84,213
ade Topping	90,110 cu. yd.	15,585
ng)	9.970 M. Gal.	23,939
ace Top Soil	18,430 cu. yd.	6,330
me (In-Pl.)	622 Tons	31,923
ph. (In-Pl.)	236 Tons	17,250
		179,238
art Grading)	(83.8% of total grading cost)	34,522
Grading Cost	(16.2% of total grading cost)	213,760
ng Cost	(42.2 miles)	33,516
ure Cost	(42.2 miles)	288,766
Paving Cost	(9.869 miles)	$536,042
lete Cost (Based on 9.869 miles)		

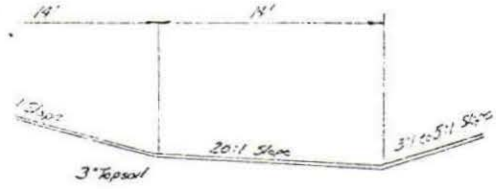
revious experience indicates that extra depth subbase and limited
g and relatively wide moisture and compaction, control limits
equately solve our warping problem.

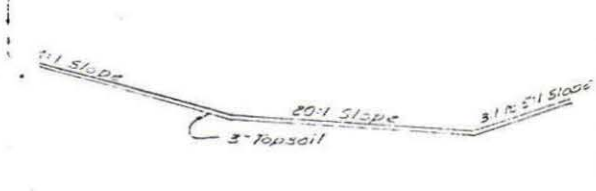
hoped with deeper depth of undercutting, tighter limits on moisture
control and use of selected topping, that we will be able to build
rmity into the subgrade. A uniform subgrade thus constructed
e the effects of the deeper differential soil movements upon the
materials by lowering the seat of movement. Tentative plans are
C pavements for 109 miles (including the 42 miles in Jackson County)
miles of a 14 inch deep-strength asphalt concrete. The asphalt
pavement is planned for use across the Cheyenne and Missouri River
and also through an area between Vivian and Draper, where an
hilly terrain exists.

FED. ROAD DIST. NO.	STATE OF	PROJECT	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
5	S. D.	I-10-5(23)-151		6	45









com

September 27, 1967

Re: Appendix to paper "Highway Design and Construction through Expansive Soils in South Dakota" by A. W. Potter and E. B. McDonald.

The attached graph charts are given as additional information in regard to the use of the selected topping soil as described in the above report.

The graphs illustrate the difference in the degree of swelling potential between the jointed shale and the weathered shale at the various percents of dry density.

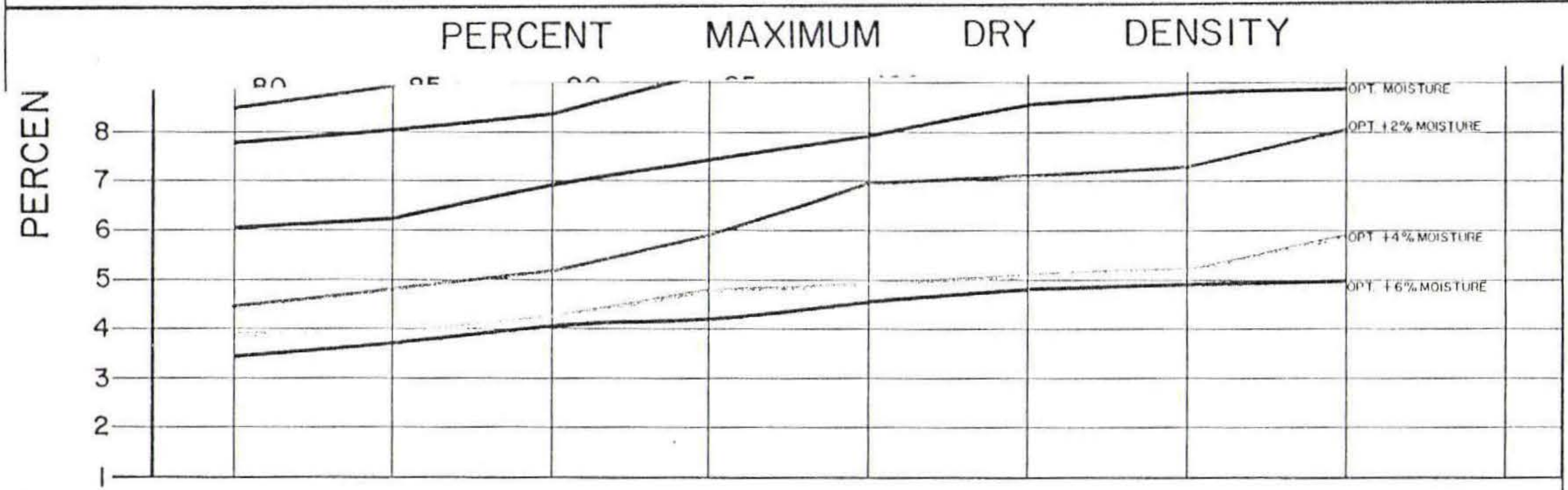
The difference in swell potential between the two soil types was the basic factor in the decision to use the upper weathered shale as select topping in the upper 6 foot of undercut zones as shown in Exhibit "A" of the report.

E. B. McDonald

E. B. McDonald
Materials Engineer

EBMcD:fn
Attach.

SPECIAL SWELL TESTS on JOINTED SHALE



SOIL DATA:

LOCATION – 8 M. SO. FT. PIERRE, S. D.

OPTIMUM MOISTURE – 23.5

MAXIMUM DENSITY – 96.0

LIQUID LIMIT – 49.8

PLASTIC INDEX – 27.4

LEGEND:

- OPTIMUM +6 % MOISTURE
- " +4 % "
- " +2 % "
- OPTIMUM MOISTURE
- OPTIMUM – 6% MOISTURE
- " – 4% "
- " – 2% "