FIELD EXPERIMENTS IN SUBGRADE DRAINAGE AND TREATMENT

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SYNOPSIS

A condensed account of that portion of the Cooperative Subgrade Soil Research jointly pursued by the U S Bureau of Public Roads, the Ohio State Highway Department and the Engineering Experiment Station of The Ohio State University, relating to Subgrade Drainage and Treatment in Ohio

More than 42,500 feet of porous or treated subbases beneath paved roads and approximately 25,700 feet of untreated paved roads are compared Some 20 different materials and nearly 50 different combinations and methods were used Four experimental projects beneath concrete pavements and six projects with traffic bound roads are reported The comparisons made in this report are on the basis of crack ratios For pavements with no center joint, slag subbase yielded no longitudinal cracks, sand gave a longitudinal crack ratio of 0 095, gravel of 0 20, a cement-clay mixture of 0 29, while upon the untreated sections the average ratio was 0 60

To prevent confusion the term "porous subbase" used in this paper is defined as. any hard, tough material such as granulated or crushed slag, broken stone, gravel or hard steam cinders, having a maximum size of aggregate not exceeding 1 5 inches and preferably not exceeding one inch, containing sufficient fine material to aid in binding it under the roller, but not enough to prevent free percolation of water through the whole mass A "porous subbase" should always be drained to free outlets at frequent intervals

It is also necessary to call attention to the condition existing when this study was begun

Few center joints or contraction and expansion joints were used at that time Therefore center and longitudinal cracks occurred quite frequently upon concrete pavements It was the intention to explore the field for possible alleviating methods and materials, and having found those showing good results, to compare them at a later time for relative economy and excellence This paper is only concerned with the explorations above mentioned

Eight concrete roads, one bituminous macadam and six stage constructed roads were constructed

Each project consisted of from six to eighteen experimental sections varying from 100 to 400 feet in length In the earlier projects 100 and 200 foot sections were used, later 300 and 400 foot sections were used wherever conditions would permit

The following materials were used in these experimental sections

For porous bases, sand, slag, gravel, stone, and cinders
For chemical treatments, salt, calcium chloride, hydrated lime, soda ash and soda silicate
For bituminous treatments, cold tar, cold oil, Tarvia D, asphalt emulsion, crude oil, kerosene and used crank-case oil
For admixtures, lime, cement, sand, stone dust, slag dust, chemicals and oils

EXPERIMENTAL TREATMENT OF SUBGRADES

CONCRETE ROADS

Only four of the eight projects beneath concrete roads have been under traffic long enough to be of service in showing results

The first one was constructed in the fall of 1924 on U S 50 N about three miles west of Marietta, in Washington County, Ohio It has been through seven winters

These treatments and porous subbases were beneath a 16 foot, 9 by 7 by 9 inch concrete road, widened on curves, reinforced by a $\frac{3}{4}$ inch rod along each edge, but having no center joint nor any transverse joints except at the close of work at noon and at the end of the day It was laid upon a heavy red clay

The materials used were river sand and gravel, granulated slag, and a 5 per cent cement mixture with the subgrade soil The sand, slag, gravel and cement-soil mixture were used in 2, 4 and 6 inch depths beneath the pavement French drains were constructed every 30 feet on each side of the road at staggered intervals

The use of sand as a porous base was found to be quite impractical because trucking could not be done over it after the sand had been placed It was necessary to place it in 12 foot sections, place planks upon it and compact it by running the concrete mixer upon the planks Hand tamping after wetting the sand was required along the sides beyond the ends of the planking

The other materials were used with little or no trouble in placing and compacting, and they remained in position during the trucking of the concrete

Crack surveys were made each year and the relative conditions of the different sections of road were shown by the crack ratios, that is, the feet of crack to the lineal feet of pavement over each kind of subbase

The slag subbase is here shown to be very much better than the other treatments and to have but 40 per cent of the crack ratio shown on the untreated sections

The average crack ratio for all of the treated sections is only 70 per cent of that on the untreated sections after more than six years in service

The depth of porous base in this project does not appear to be of importance Two inch depths seem to give the best results with six inch depths next

The six inch gravel and the four inch cement-soil mixture had considerably more cracks than the average of the results upon the untreated sections The crack survey results are shown in Figure 1.

In comparing the amount of cracking between the various sections in all the cases in this paper the joints have not been included

TABLE I

CRACK RATIOS

U S ROUTE 50 N MARIETTA, OHIO

Material	Subbase Thickness			Average
	2 Ins	4 Ins	6 Ins	
Gravel	0 788	0 923	1 865	1 192
Sand	1 016	1 187	1 055	1 086
Common clay	0 880	2 003	1 174	1 352
Slag	0 610	0 726	0 482	0 606
Average, treated sections	0 824	1 210	1 144	1 059
Earth, average of six untreated sections				1 510

The second project was constructed in September, 1925, beneath an 18-foot, 9 by 7 by 9 inch concrete road on Route 32, three miles west of Marysville, Ohio

This road also has neither center nor transverse joints except at points where concrete laying had to cease for more than 30 minutes It was reinforced by a $\frac{3}{4}$ inch longitudinal bar along each edge

The subgrade soil beneath this road is a heavy yellow clay, tough and plastic when wet The season of construction was very rainy so that the soil was as nearly saturated as it would normally become

Fourteen test sections, mostly 200 feet long, were constructed beneath this road Depths of 2, 4 and 6 inches of compacted No 4 stone and of gravel, and 2, 4 and 6 inch depths of cement-soil and lime-soil mixtures were used

Very little change in the water content of the soil took place for more than a year after construction so that few cracks occurred Crack surveys were made in 1927 and again in 1931

The crack ratios for the various sections are shown in Table II

Note that the crack ratio is materially less upon this pavement than upon Route No 50 This difference may be due to several fac-

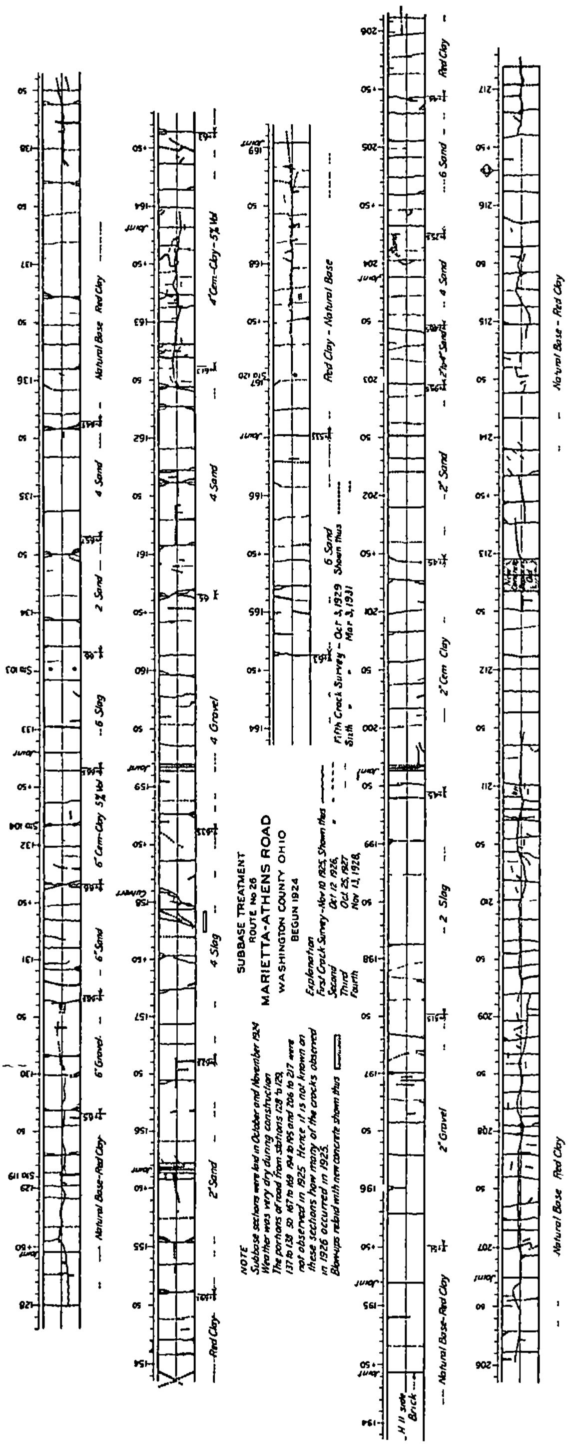
SUBBASE TREATMENT
ROUTE No 26
MARIETTA-ATHENS ROAD
WASHINGTON COUNTY OHIO
BEGUN 1924

Figure 1

tors, but two at least stand out rather prominently, namely, the soil difference and the moisture content of the subgrade soil at the time the roads were constructed No 50 was constructed in a very dry season with the subgrade soil almost in dust dryness, while No 32 was constructed in a rainy season when the soil was plastic with water

The soil on No 32 contains much more clay and nearly double the colloidal content, and therefore changes the moisture content much more slowly and to a much less extent than does the soil on No 50 The variation in soil characteristics is much greater in the soils beneath Route 32

The two inch and the six inch lime-soil mixtures show the least cracking, about 77 and 70 per cent respectively, of the untreated sec-

TABLE II

CRACK RATIOS

STATE ROUTE 32, MARYSVILLE, OHIO

Material	Total Length	Subbase Thickness			Average Crack Ratio
		2 Ins	4 Ins	6 Ins	
Lime-clay	500	0 705	0 945	0 620	0 784
Cement-clay	600	0 845	0 910	0 810	0 855
No 4 stone	580	0 775	0 900	0 810	0 826
Gravel	620	0 945	0 900	0 865	0 875
Tile	400				0 830
Averages	2,700	0 8175	0 914	0 799	0 843
Treated earth	2,430				0 913

tions The average of all the treated sections is 92 5 per cent of the cracking shown by the untreated sections The four inch lime-soil, the four inch cement-soil and the two inch gravel base were all three equal to or greater in cracking results than the average of the untreated sections

Figure 2 shows the cracks upon Project No 2

Project No 3 was constructed in September and October, 1928, beneath an 18 foot, 9 by 7 by 9 inch concrete pavement on Route 14, about 15 miles southeast of Ravenna, Ohio

The pavement was reinforced with $\frac{3}{4}$ inch side bars, and protected by a center joint and transverse joints every 40 feet

The soil is a silty, yellow clay The weather during construction was good

Eleven experimental sections, usually 200 feet long, were built Two, four and six inch compacted porous subbases of granulated slag, No 4 stone, No 46 stone and hard cinders were used.

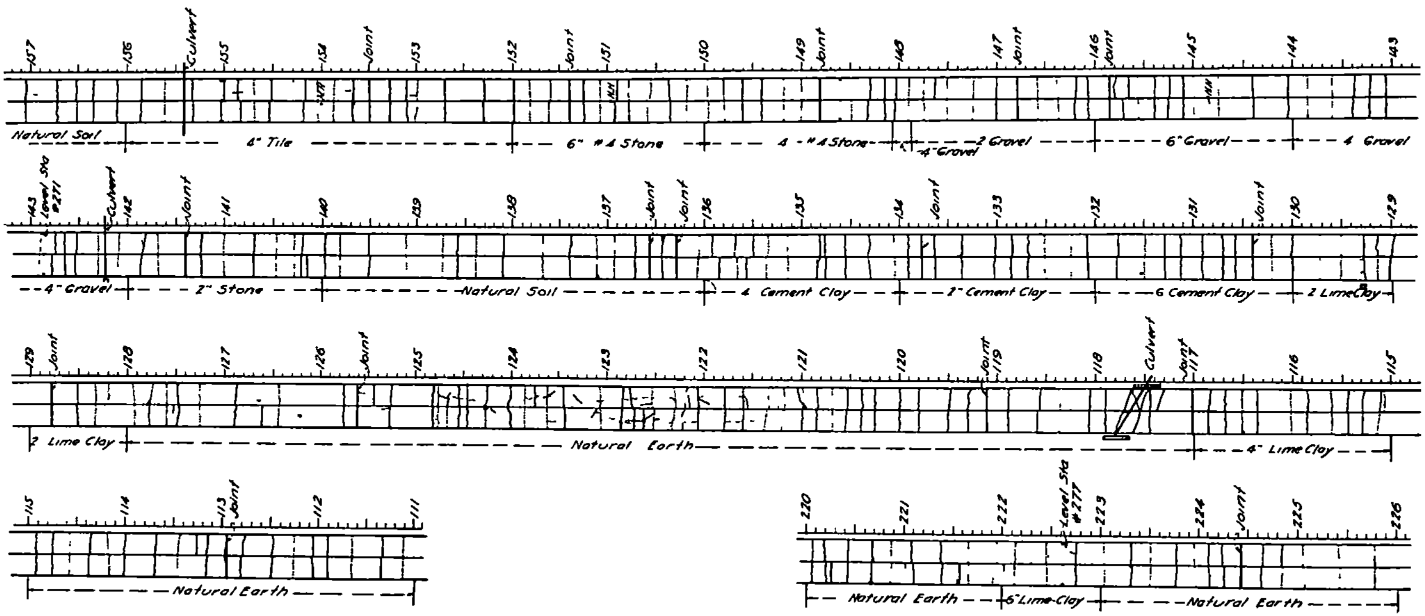

Figure 2 Subbase Treatment Route No 32 Marysville, Union County, Ohio

First Crack Survey, Oct 31, 1927 - - - -
Second Crack Survey, Jan 9, 1931 ~~~~

Note—This Experimental Project Was Constructed in September, 1925, During an Extremely Wet Season The Clay Soil Was Saturated and Remained So for Nearly a Year This May Account for the Fewer Number of Cracks During the First Two Years

Two crack surveys were made, one in the spring of 1929, the other in 1931

The four inches of No 4 stone showed the least cracking having a crack ratio of 0 190, with six inches of granulated slag and two inches of No 4 stone next, having a ratio of 0 270

Six inches of hard cinders showed the worst results with a ratio of 0 675, followed by four inches of granulated slag and two inches of No 46 gravel, each of which had a ratio of 0 540

The average ratio for all treatments was 0 400 against an average ratio of 0 515 for nontreated sections Here as elsewhere no advantage can be shown of one depth of material over another

Table No III and Figure 3 gives the results of the crack survey The specifications called for slab lengths of 40 feet Seventy-seven double slabs or 154 nine-foot width slabs cover the work of this project.

Twenty-nine of these nine-foot width slabs show no cracks, 21 have two cracks each, and 104 have one crack each

Six of the uncracked slabs are upon the untreated sections while 23 are upon the porous base sections Ten of the uncracked sections are upon the 2 and 4 inch stone bases and four upon the 6 inch granulated slag base

Eleven of the slabs having two cracks are upon the untreated sections, four upon slabs 46 to 52 feet long over porous bases, while the remaining six are over porous bases with the normal 40-foot slab

As 125 out of the 154 slabs have transverse cracks, it would seem rather strong evidence that a 40-foot slab length under these conditions is too long

The last project beneath concrete which has been under traffic sufficiently long to give some evidence of value is on Route 2, just east of Toledo Eleven experimental sections were built beneath a 20-foot, 10 by 8 by 10 inch section of this road, in September, 1929 A crack survey was made on January 19, 1931, 16 months later

This pavement is reinforced with $\frac{3}{4}$ inch side bars, also with wire mesh, weighing 46 6 lbs per 100 square feet and with dowel bars across the center joints Transverse contraction and expansion joints alternate every 60 feet

One 360-foot experimental section consists of a surface treatment of the subgrade with $\frac{1}{2}$ gallon of tar per square yard The other ten sections are porous subbases 2, 4 or 6 inches thick of Nos 7, 34 and 46 slag and the same sizes of crushed stone The lengths of these sections were made 180 feet to coincide with the regular spacing of the transverse joints

Table IV and Figure 4 show the results of this project for a term of 16 months

On the 840 feet of untreated base having 30 slabs, 13, three of which were about 33 feet long were unbroken, 16 had one transverse crack and one had two cracks. The total was 167 feet of crack, or a ratio of 199

TABLE III

CRACK RATIOS

ROUTE 14, PORTAGE COUNTY, OHIO

Built in September, 1928

Material Used	Length Feet	Kind of Crack	April 2, 1929	Mar 18, 1931	Total	Crack Ratio
			Lengths of Cracks			
6 in No 34 slag	120	Transverse		36	36	0 300
6 in Hard cinder	80	Transverse		54	54	0 675
6 in Gran slag	200	Transverse		54	54	0 270
4 in Hard cinders	200	Transverse		90	90	0 450
4 in No 4 stone	200	Transverse		38	38	0 190
4 in No 46 gravel	200	Transverse		78	78	0 390
4 in Gran slag	200	Transverse	18	90	108	0 540
2 in Hard cinder	200	Transverse	18	72	90	0 450
2 in No 4 stone	200	Transverse		54	54	0 270
2 in No 46 gravel	200	Transverse	36	72	108	0 540
2 in Gran slag	200	Transverse	18	72	90	0 450
Earth	1000	Transverse	90	411	501	
4 sections		Longitudinal		4	4	
		Corner	8	2	10	
		All	98	417	515	0 515
All Treated Sections	2000				800	0 400

Material Used	Length Feet	Subbase Thickness			Crack Lengths	Crack Ratio
		2 Ins	4 Ins	6 Ins		
		Crack Ratios				
All stone	400	0 270	0 190		92	0 230
All slag	720	0 450	0 540	0 281	288	0 400
All gravel	400	0 540	0 390		186	0 465
All cinder	480	0 450	0 450	0 675	234	0 487
All earth	1000				515	0 515

The 2, 4 and 6 inch slag sections of 36 slabs, totaling 1,080 feet, had 29 unbroken slabs and 7 slabs having one transverse crack each, or 70 feet of crack The crack ratio for slag was 065

The stone sections had 26 slabs, 21 of which were unbroken, four had one transverse crack and one had two transverse cracks Four of

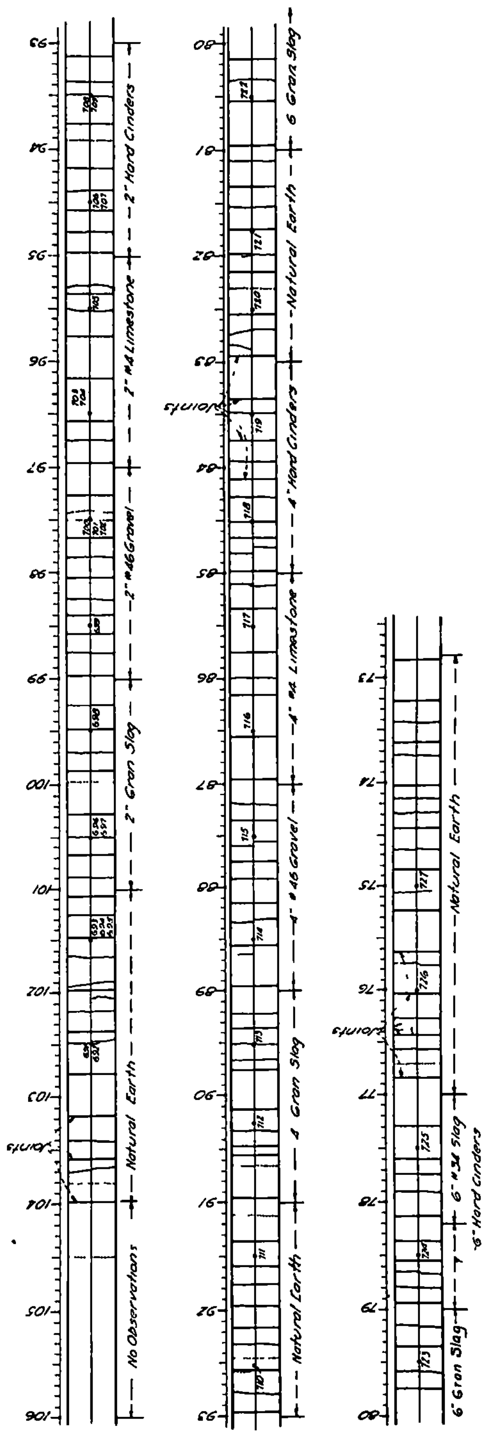

Figure 3 Subbase Treatment. Route No. 14. Portage County, Ohio Built September 27–October 2, 1928

First Crack Survey, Apr 2, 1929 - - - -
Second Crack Survey, Mar 18, 1931 ~~~~

the unbroken slabs were less than 33 feet in length The crack ratio for the 720 feet of stone was 083

The 360 feet treated with cold tar had 6 unbroken slabs, two of which were but 11 feet long, being slabs at the end of the day's work,

TABLE IV

EXPERIMENTAL SUBBASES ON ROUTE 2, SEC C, LUCAS COUNTY, 20 FT CONCRETE

Built in September, 1929

Material Used	Length	Kind of Crack	Crack Length Jan 19, 1931	Crack Ratio	Sta to Sta
Earth	590	Corner Transverse	2 135	0 232	105 to 110+90
2 in No 7 slag	180	Transverse	10	0 056	110+90 to 112+70
4 in No 7 slag	180	Transverse	0	0 0	112+70 to 114+50
6 in No 6 slag	180	Transverse	0	0 0	114+50 to 116+30
2 in No 46 slag	180	Transverse	20	0 111	116+30 to 118+10
4 in No 46 slag	180	Transverse	20	0 111	118+10 to 119+90
4 in No 34 slag	180	Transverse	20	0 111	119+90 to 121+71
2 in No 7 stone	180	Transverse	20	0 111	121+71 to 123+52
4 in No 7 stone	180	Transverse	40	0 222	123+52 to 125+32
3 in No 46 stone	180	Transverse	0	0 0	125+32 to 127+11
4 in No 34 stone	180	Transverse	0	0 0	127+11 to 128+92
Cold tar	360	Transverse	88	0 244	128+92 to 132+52
Earth	250	Transverse	30	0 125	132+52 to 135
Total earth	840		167	0 199	
Total treatment	2160		218	0 101	
Total slag	1080		70	0 065	
Total stone	720		60	0 083	
Total tar	360		88	0 244	

Materials	Subbase Thickness				Average Crack Ratio
	2 Ins	3 Ins	4 Ins	6 Ins	
	Crack Ratios				
Slag	0 083		0 074		0 065
Stone	0 111		0 111		0 083
Tar					0 244

seven slabs had one transverse crack each, and one slab had two cracks The crack ratio for tar was 244

Omitting the tar section the average crack ratio for the other treated sections was 36 3 per cent of the crack ratio for the untreated sections Thirty-seven slabs out of 106 observed slabs have cracked in the first 16 months of service A 35 per cent breakage in 16 months

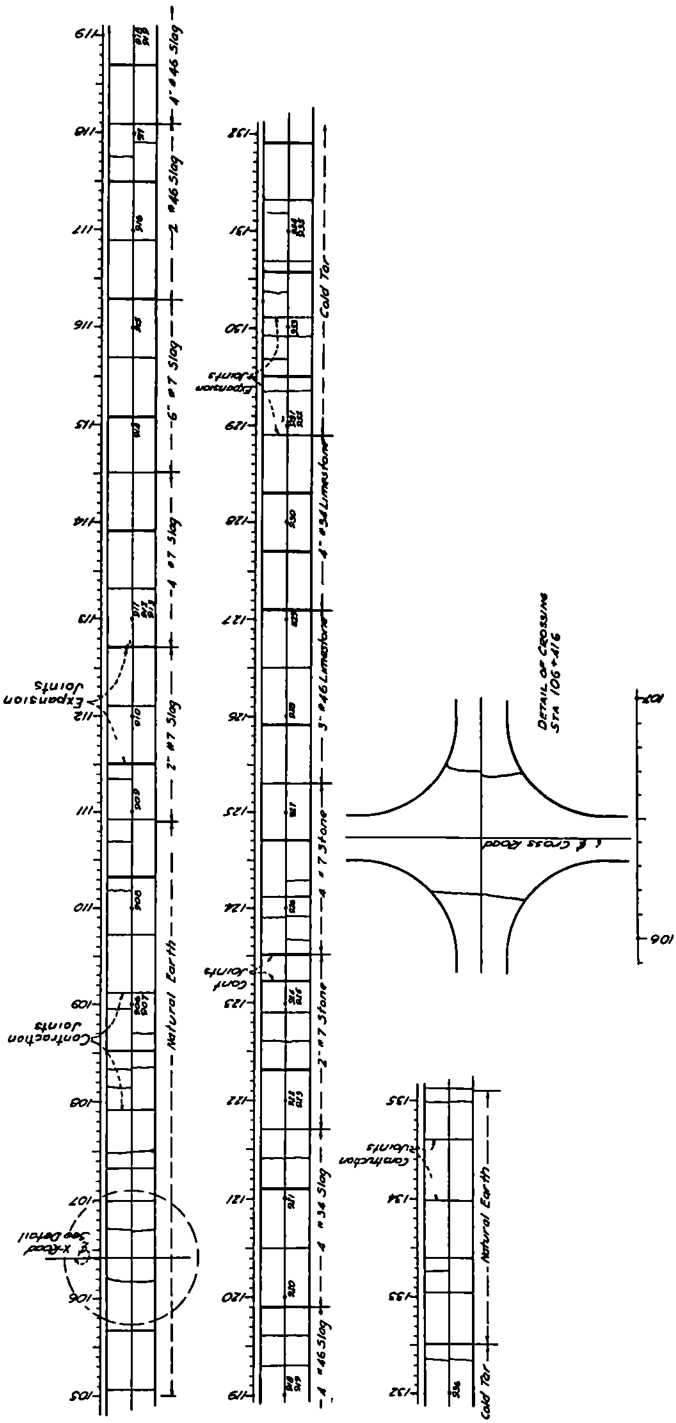

Figure 4. Subbase Treatment. Route No 2. Lucas County, Ohio Built September, 1929

upon a mesh reinforced concrete would seem to indicate that a 60 foot slab length is much too long

A comparison of the soils in these four projects shows some marked differences

The texture of the soil is shown by the average mechanical analyses of the soils from each project in Table V

TABLE V

MECHANICAL ANALYSES

Route No	No of Samples	Gravel Over 2 m m	Per Cent			
			Sand	Silt	Clay	Below 002 m m
U S 50 N	33	5 6	15 8	36 6	42 0	28 8
State R 32	17	0 9	8 3	21 5	69 4	54 4
State R 14	36	3 6	20 3	38 5	37 6	26 8
State R 2	31	0 0	2 1	35 9	62 0	43 7

A comparison of the soil characteristics shows a similar variation as indicated in Table VI

TABLE VI

SOIL CHARACTERISTICS

Route No	No of Samples	Atterberg's Tests			Shrinkage			Moisture Equiv	
		Lower Liquid Limit	Lower Plastic Limit	Plastic Index	Volumetric	Limit	Ratio	Field	Centrifuge
U S 50 N	33	35 6	23 3	12 3	33 2	17 1	1 81	26 7	22 2
State R 32	17	53 8	29 0	24 8	71 2	15 5	1 87	32 4	23 9
State R 14	36	35 5	20 9	14 6	36 4	16 0	1 85	23 1	20 6
State R 2	31	54 1	26 9	27 2	73 1	15 2	1 88	38 2	31 4

In general there is a similarity between the soils on routes 50 and 14 and between routes 32 and 2

The large number of slabs cracked within 16 months upon route 2, when the clay content is 62 per cent, the volumetric change is 73 per cent and the field moisture equivalent is 38 per cent, is strong evidence that the soil must have some effect upon the life of that concrete pavement

From the present data it is not safe to draw positive conclusions regarding the varying effects of the different soil factors

When the various projects have been through six or eight years of service there will be much more evidence from which to draw conclusions

What practical conclusions can be drawn from this bit of evidence from the treatment of the subgrades beneath concrete pavements?

1 Is the crack ratio the best method of measuring the observed results of this investigation?

2 Has the investigation shown any increase in slab length?

3 Is this information applicable throughout the continental United States?

4 Have porous and treated subbases effectively reduced vertical displacements at the cracks and joints?

5 Have they reduced the length of longitudinal cracks sufficiently to indicate a possible elimination of the necessity for longitudinal joints?

Answering these questions in order·

1 The writer believes that there are three or four methods of securing a measure of the results from such a series of experiments

The crack ratio is probably the easiest one to make

Slab lengths will give another picture of the results

Percentage of slab areas above or below an adopted normal area, another

Relative maintenance costs over a lengthy period of time still another

The latter two require much more time and effort to secure reliable data

The first two give much the same picture of the results obtained.

2 Comparing the crack ratio with the slab length method of measuring results upon U S Route 50 N

The crack ratios of the individual treated sections are from 32 to 134 per cent of the crack ratio of the average of the untreated sections The averages for different materials rank as follows the crack ratio for total slag is 40 per cent of the ratio of the untreated sections, for sand, 72 per cent, for gravel, 78 per cent, and for cement-soil mixture, 89 per cent The average crack ratio of the treated sections is 70 per cent of that of the untreated sections

Assuming that the lineal feet of road divided by the number of slabs in any given section will give the average slab length, an analysis yields the results in Table VII for U S Route 50

In the case of Route 32, the crack ratio on the treated sections is 92 3 per cent of the ratio on the untreated The average slab length of all treated sections is 20 1 feet against 23 0 feet on the untreated sections, or the slabs on the untreated sections are nearly 15 per cent longer than on the treated sections The tile section is the only untreated one having longer slabs than the treated sections

3 Regarding the geographic range over which such information might reasonably apply, it must be remembered that, rainfall, tem-

perature (especially frost), soil types, materials both for the concrete and the subbase vary so widely, that the transplanting of conclusions drawn under one set of conditions to another locality with entirely different variables must be done with the greatest care and judgment

4 Whether porous and treated subbases will produce smoother riding surfaces by reducing the vertical displacement at joints and cracks has not been determined by the results obtained from levels taken upon six or eight sections

Two places observed over untreated sections had displacements of 0 040 and 0 049 foot Displacements of pavements over various treated subbases ranged from 0 035 to as much as 0 102 foot

TABLE VII

SLAB LENGTH ON PROJECT NO 1, U S 50 N

Material	Length	No of Slabs	Ave Length Feet	Percentage of Slab Length of Untreated Sections
Untreated	2090	178 5	11 7	100
Slag	494 6	19 9	24 8	212
Gravel	505 5	25 6	19 7	168
Sand	1285	71 3	18 0	154
Cement-soil	502	38 0	13 2	113
Total treated	2787	154 8	18 0	154

5 Porous subbases seem to have a marked effect in reducing longitudinal cracking of concrete pavements that have no longitudinal joints An analysis of the results obtained upon the two roads—U S Route 50 North, and State Route 32—is given in Table VIII The nine feet of longitudinal cracking on Route 32 occurred upon the subbase treated with admixtures of lime and cement with soil No longitudinal cracking occurred on any of the porous subbases on this road

As to whether or not longitudinal joints may safely be omitted where porous subbases have been used, it is unsafe to make any assertion at this time on so few results The increasing width of roadway and weight and speed of traffic suggest the need of further investigation along this line before final conclusions can be drawn It is certain, however, that transverse joints should be used and that under conditions in Ohio they should be less than 40 feet—probably 30 to 35 feet apart

TABLE VIII

LONGITUDINAL CRACKS ON U S ROUTE 50 N

Subbase Material	Length, Feet	Length of Longitudinal Cracks, Feet	Crack Ratio
On U S Route 50 N			
Gravel	505	102	0 20
Sand	1285	132	0 103
Cement-clay, mixed	502	145	0 29
Slag	494	0	0 00
Total treated bases	2787	379	0 136
Total untreated bases	2090	1259	0 60
On State Route 32			
Treated base	2700	9	
Untreated base	2430	140	

EXPERIMENTAL TREATMENT OF SUBGRADES

TRAFFIC BOUND ROADS

The subgrades of six different traffic bound roads were treated by chemicals, oils and various other materials

Due to various reasons and conditions three of these gave no information of value and are therefore omitted from further reference

The very nature of the method of construction of traffic bound or stage construction roads makes comparison of treatments difficult

The best time to observe the effects of treatment is during the late winter and early spring breakup from frost

Project No 6 consisted of thirteen 400-foot sections on Route 80, about 8 miles south of Ravenna in Portage County, Ohio This is an 18-foot traffic bound slag road, built in August, 1929 The treatments were applied after the roadbed had been carefully graded and before the application of the slag

The roadbed was scarified about three inches deep on all sections and rescarified after the application of the materials, on all but the sections treated with limestone dust and the No 7 slag

The lime, salt, calcium chloride and limestone dust were applied with a farm lime distributor The slag was applied by hand The oils were sprayed on from a power distributor

The amount of crushed slag applied by the highway department was about 3 5 inches in depth of the loose material (1,000 cu yds per mile) This was bladed across the road, leaving about two inches to be beaten in by traffic with the surplus stored in windrows on either side

As the material was beaten in or thrown out by traffic the road was re-bladed to keep it smoothed up and to keep excess slag on the surface to supply material for saturating the subgrade soil with aggregate.

The various materials used in treatment and the amounts are given in Table IX

The division engineer reported that he was over this project early in the spring of 1930 and that while he had little difficulty in getting over the treated section, he had to have his car hauled out from the untreated section

TABLE IX

MATERIALS AND DATA FOR PROJECT NO 6

Sec No	Length in Feet	Materials Used			Remarks
		Kind	Total Amounts	Per Sq Yd	
1	400	Untreated			
2	400	Salt	4000 lbs	5 lbs	
3	400	Hydrated lime	4800 lbs	6 lbs	
4	400	Calcium chloride	2400 lbs	3 lbs	
5	400	Untreated			
6	400	Stone dust	6400 lbs	8 lbs	
7	400	No 7 slag	24 cu yds	0 03 cu yds	1-inch depth
8	400	Kerosene	600 gals	0 75 gal	
9	400	Untreated			
10	400	Cold tar	600 gals	0 75 gal	
11	400	Crude oil	600 gals	0 75 gal	
12	400	Used crankcase oil	600 gals	0 75 gal	
13	400	Untreated			

The writer was over this road in August, 1930 The order of excellence then was about as follows, first being best:

1 Used crank case oil, and sections 1 and 5 of untreated soil.
2 Crude oil and salt
3 No 7 slag and limestone dust
4 Calcium chloride, kerosene, cold tar, and hydrated lime
5 Two untreated sections and much of the portion of the road lying south of the treated sections

Observed again on March 18, 1931, the order was as follows:

1 Used crankcase oil, No 7 slag, and untreated section 1
2 Limestone dust and the two untreated sections Nos. 9 and 13
3 Cold tar, hydrated lime, untreated section No 5
4 Salt, calcium chloride, and kerosene
5 Crude oil and many stretches of the adjoining road south of the treated sections

The soil conditions did not seem to be any worse on the southern untreated end of the road, but drainage conditions appeared to be worse

Project No 8 is located upon Route 76 in Morgan County about 10 miles east of McConnellsville Ten 400-foot sections were built upon this 18-foot slag bound road The treatments were installed similarly to those in Project No 6

The work was done October 8 and 9, 1929

The materials and quantities per square yard were the same as on Project 6 except for hydrated lime, 3 lbs per square yard being used this time Ten pounds of bank sand per square yard was installed on this project

The first observation trip was made February 25, 1930, with the following ratings:

1 No. 7 slag
2 Salt, and crude oil Untreated sections 5, 9, 13 were good upon the grades but not so good upon the level
3 Calcium chloride, hydrated lime, stone dust, bank sand, used crank case oil, and untreated section No 1, cold tar good on grade but badly cut upon level
4 Kerosene, badly cut up

The next observation trip was made March 2, 1931. All sections looked much alike at this time—no marked differences.

Project No 13 was installed upon an 18-foot slag bound road, Route 265 in Guernsey County about 13 miles east of Cambridge. In order to secure as uniform soil conditions as possible this project was divided into two lengths about 3 miles apart Six sections were placed in the western division and nine in the eastern The work was done on August 25 to 30, 1930 The materials and quantities are shown in Table X

The subgrade was scarified about 3 inches deep, the material applied, the subgrade re-scarified, and then rolled

In the case of the sodium silicate it was first diluted with water one part to two parts of silicate before it was applied with an ordinary oil distributor.

For the sand-tar mixture, the sand was first spread upon the subgrade and the cold tar sprayed upon it from an oil distributor at the rate of 1 25 gallons per square yard The two materials were then thoroughly mixed with a disc harrow, and then rolled

The calcium chloride and soda ash were furnished free by The Solvay Process Company of Syracuse, New York, and the sodium silicate was furnished free by the Grasselli Chemical Company of Cleveland, Ohio The work was done by the maintenance forces of the Ohio Highway Department

The road was inspected for results on March 4 and May 12, 1931. The results as judged in the order of excellence were as follows:

Div A

1. Excellent—salt, No 4 stone, calcium chloride
2. Good—Sections 1 and 8, of untreated soil
3. Fair—crude oil, hydrated lime, and Tarvia D

TABLE X

DATA ON PROJECT NO 13

Sec No	Length in Feet	Materials Used			Remarks
		Kind	Total Amount	Am't per Sq Yd	
Div A					
1	1200	Untreated			
2	400	Salt	4200 lbs	5 25 lbs	
3	400	No 4 stone	45 tons	0 056 tons	
4	400	Calcium chloride	2500 lbs	3 13 lbs	
5	400	Crude oil	1076 gals	1 35 gal	
6	400	Portland cement	6000 lbs	7 5 lbs	
7	400	Tarvia D	1000 gals	1 25 gals	"Dust layer"
8	400	Untreated			
Div B					
1	400	Untreated			
2	400	Clacium chloride	3300 lbs	4 12 lbs	
3	400	Sodium silicate	6400 lbs	8 00 lbs	
4	400	Sodium carbonate	4500 lbs	5 63 lbs	
5	400	Untreated			
6	400	No 7 slag	45 cu yds	0 056 cu yd	
7	400	Sand	60 cu yds	0 075 cu yd	
		Tar	1000 gals	1 25 gal	
8	400	Hydrated lime	6000 lbs	7 5 lbs	
9	400	Grade B sand	35 cu yds	0 044 cu yd	1 57 inches
10	400	Limestone dust	44 tons	0 055 tons	
11	400	Stone screenings	75 tons	0 094 tons	
12	400	Untreated			

Div B

1 Excellent—soda ash, sodium silicate, calcium chloride and untreated section No 1

2 Good—sand, stone screenings and untreated sections 5 and 12

3 Fair—No 7 slag, sand and tar, hydrated lime and stone dust

The two best sections seemed to be soda ash and sodium silicate.

The superintendent of maintenance said he had the most trouble in maintaining the sand-tar and the crude oil sections

It was noted that in nearly all cases except the crude oil and the No 4 slag, which were partly in a cut, less of the road metal slag used for surfacing, was beaten into the road bed, than was needed on the untreated sections In the case of the crude oil and No 4 slag, the cut carried the roadbed into a water carrying stratum of soil that required excess metal to solidify the road bed

The same thing was true of all untreated sections in cuts and in many reaches of the road where no cuts existed

The average soil characteristics for the three projects upon traffic bound roads are shown in Tables XI and XII

TABLE XI

AVERAGE MECHANICAL ANALYSIS OF SOILS ON PROJECTS NOS 6, 8, AND 13

Project No	Number of Samples	Fractions of Soils in Percentage					Route No
		Gravel	Sand	Silt	Clay	Below 002 M M	
6	28	6 4	23 0	34 3	36 6	27 0	80
8	15	1 2	7 9	43 2	47 5	32 8	76
13	14	2 2	13 2	40 2	44 2	31 1	265

TABLE XII

CHARACTERISTICS OF SOILS FROM PROJECTS, NOS 6, 8, AND 13

Project No	Number of Samples	Atterberg Tests			Shrinkage			Moisture Equivalent	
		Lower Liquid Limit	Lower Plastic Limit	Plasticity Index	Vol	Limit	Ratio	Field	Centrifuge
6	28	34 0	21 2	12 8	30 5	16 8	1 81	25 5	19 4
8	15	43 2	24 5	18 7	54 3	15 0	1 88	30 1	25 6
13	14	40 9	25 5	15 4	41 0	18 2	1 81	27 4	24 0

It is difficult to point definitely to advantages obtained by treatment upon traffic bound roads, yet evidently benefits are there

One explanation of the results appearing in the three cases cited is that they are probably due to the methods of handling the treatments Scarifying the subgrade and mixing the materials with it prepared the subgrade to assimilate more quickly the road metal applied later This preparation with the subsequent blading and traffic would probably secure stability of surface much quicker than otherwise That this is worth the additional cost I believe will generally be granted

The indications are, from these experimental field tests, that stone screenings, fine slag and agricultural limestone dust, if mixed with the top three or four inches of the subgrade by scarifying, just preceding the application of the road metal, will hasten the binding process and secure a stable surface more quickly than when the road metal is applied directly upon the prepared subgrade which has been hardened by intervening traffic The indication was unmistakable on Project 13 that less road metal was required to stabilize the road bed

Soda ash, sodium silicate, calcium chloride and salt seem to show some beneficial results, but the number of cases and varieties of soils where they have been used are too few to warrant any positive conclusions

CONCLUSIONS AND INDICATIONS

1 The evidence strongly favors the conclusion that a porous subbase of slag or broken stone of material finer than 1 inch in diameter improves the subbase and prevents many cracks in the overlying concrete pavement that would otherwise have occurred.

2. The depth necessary for such a treatment has not been determined, but the indications point to 2 to 4 inches after compacting as being sufficient for ordinary heavy clay soils Saturated soils would undoubtedly require much greater depths

3 A few treatments with lime, soda ash, sodium silicate and salt and others with crank case oil and crude oil have given indications of improved subbase conditions upon traffic bound slag roads

4. Only 9 of 51 treated sections beneath concrete pavements have shown worse results than the untreated sections compared with them

DISCUSSION ON SUBGRADE DRAINAGE AND TREATMENT

ABSTRACTED

MR MARK MORRIS, *Research Assistant, Iowa State Highway Commission* In Professor Eno's report there is one possible comparison of data from the concrete pavement projects to which he made no reference. Table I from data in the report shows a comparison of the crack ratios on the different projects subjected to various treatments.

In this table the best treatment, and the untreated earth have been compared each year, and then a comparison made between the values obtained for these two treatments each year. It will be noted that the crack ratio for the earth treatment shows a great decrease from the first project constructed in 1924 to the project constructed in 1929.

The best method of treatment on each project shows a similar reduction The last column in the table shows the crack ratio for all treatments used on each project This also shows a reduction in the crack ratio. The conditions or factors causing this reduction for the period of years is greater than the reduction for the best method of treatment in any one year Perhaps the reduction in crack ratio was due to the use of expansion joints and contraction joints in the later projects If this be true, then the crack ratio would not appear to be a common term for comparing the results between projects In this case, it is suggested that the method of comparison make use of slab length, rather than crack length as reported in the paper

TABLE I

Comparison of Crack Ratios

Project No	County	Year Built	Type Pavement Section	Spacing Expansion Joints	Center Joint	Crack Ratio		
						Earth	Best Treatment	All Treatment
1	Washington	1924	16′, 9–7– 9″	None	None	1 510	0 606 (Slag)	1 052
2	Union	1925	18′, 9–7– 9″	None	None	913	0 784 (Cement)	0 843
3	Portage	1928		40′		515	0 230 (Slag)	0 400
7	Lucas	1929	20′, 10–8–10″	60′	Yes	199	0 065 (Slag)	0 101