THE COOPERATIVE HIGHWAY RESEARCH PROJECT

PURDUE UNIVERSITY AND INDIANA HIGHWAY COMMISSION

PROGRESS REPORT

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SYNOPSIS

Progress reports are made on a condition survey and study of the composition of bituminous surfaces, a study of the effects of road rollers on aggregates in place in comparison with the Los Angeles rattler test, two test roads having 28 different sections, a study of freezing and thawing, and wetting and drying tests of soil mixtures, frost action in soils, tests of soils, and characteristics of rock asphalt

A significant observation from the survey of bituminous surface treatments is that there was not only a large amount of degradation of aggregates during construction, but that there was a gradual breaking down of the aggregate under traffic There appeared to be a definite relation between the results of the Los Angeles rattler test and the action of the road roller on the aggregates in place

A cooperative Highway Research Project was entered into between the Highway Commission of Indiana and Purdue University, in February, 1936, with an allowance of $25,000 up to June 30, 1936 The Project was further supported in March, 1937, by an act of the legislature amending a section of the highway law to permit $50,000 a year to be expended from the funds of the Highway Commission for the use and benefit of Purdue University in carrying out a program of highway research and highway extension

An Advisory Board, consisting of three members from the Highway Commission and three from Purdue University was organized to hear reports of progress from the Director of the project, and to advise him upon the special research needs of the Highway Commission as reflected in the research program The Director and the research workers, who are appointed by the University, give full time to the project, which was placed in the Engineering Experiment Station.

STUDY OF BITUMINOUS SURFACE TREATMENTS

The first work started on the Joint Highway Research Project (June 1, 1936) was a study and investigation of bituminous surface treatments, with the view in mind to determine, if possible, the causes of failures and to make some recommendations to rectify the same Field inspections were made and 221 surface samples collected for laboratory analysis of the various surface treatments, principally those constructed in 1935, in each of the six highway districts. From the field observations and laboratory analysis of these samples, it was found that.

1 The most prevalent type of failure, exclusive of base failure, was ravelling

2 Those samples which contained a smaller amount of bitumen ravelled more

3 A wide variation existed in the grading of the aggregates and proportions of materials The bitumen in the samples varied from 3 to 12 percent The surface area of the aggregates in the samples varied from 1000 to 7000 sq. cm per 100 grams

4 Apparently there is need for a study of bituminous mixtures composed of various types of bitumens and aggregates and consideration of the use of a plant mix

A study was made of the 100 miles of roads surface treated under contract in 1936, and a condition survey made of these roads in April, 1937

This survey showed that there is a definite relation between the time of construction, weather conditions and service behavior of these surface treatments In general, those surface treatments completed earlier in the season, during favorable weather conditions and those having a higher bitumen content were better able to resist ravelling Increased ravelling accompanied construction during the fall when weather conditions were unfavorable (low temperature and rain)

Studies were also made of some of the 1937 surface treatments in which two types of bituminous materials and two types of aggregates were used Records were secured of the quantity, type and source of materials used on these jobs Samples for laboratory analysis were taken from these roads at periodic intervals of approximately one month, three months and one year From field observations and laboratory analysis of these samples, we find the following

1 That a large amount of degradation of the aggregates occurs under manipulation and rolling during construction

2 That there is a gradual breaking down of the aggregate under traffic in these surface treatments For example, we find, from an analysis of 40 samples, that there was an increase during 10 months traffic, of approximately 45 percent in surface area of the aggregate

3 That there is slightly more degradation under traffic taking place in the stone surface treatments than in the crushed gravel

This survey led to two related projects (1) a study of the relative adhesion of several bitumens to a variety of aggregates by means of chemical tests and by wash tests. The results of this study have since been published in September, 1938, in a bulletin entitled "Adhesion of Bituminous Films to Aggregates," by Owen R Tyler, Research Chemist in the Joint Highway Research Project, and (2) the degradation of aggregates usually used in Indiana under ten-ton and five-ton rollers on a concrete base and an oil mat base Coordinate tests were made of these same aggregates in the Los Angeles Rattler to determine if the action of the rattler reproduced the action of a roller, and would select the type of aggregate best suited for surface treatment

Degradation of Aggregate

In order to determine how much degradation was occurring under a 5 and a 10-ton roller, a series of tests was set up, using aggregates from various sources throughout the state on both a flexible and a rigid base The grading and amount of aggregate spread per square yard (40 lb) was similar to that used in bituminous surface treatments in Indiana Samples of the same aggregates were also tested in the Los Angeles abrasion machine to determine if there were any correlation between the abrasion loss as determined by this machine and the amount of degradation which occurred under the roller tests

While the sieving of these samples and the analysis of the data are not complete, the following facts appear to be true

(1) There is an increasing amount of degradation occurring under the roller with an increase in the number of trips

(2) The increase in degradation of the aggregates with an increase in number of trips is greater on the rigid base On the flexible base, the increase in amount is slight after four trips of the 10-ton roller

(3) More degradation occurs when these aggregates are rolled on a rigid base than when they are rolled on a flexible base

(4) The amount of degradation of the aggregates under the rear rollers is greater than that under the front roller This difference is greater on the rigid base than on the flexible base

(5) Aggregates from various sources show a difference in their resistance to crushing under a 10-ton roller Those aggregates which showed a low abrasion loss by means of the Los Angeles abrasion machine also showed a small amount of degradation under the roller, and likewise, those showing a high loss in abrasion also showed a high amount of degradation under the roller

(6) The amount of degradation occurring under the rear roller in seven round trips of a 10-ton roller on a rigid base is slightly less than is produced by 100 revolutions in the Los Angeles abrasion machine The roller test shows a greater amount of degradation in the larger particles, but does not produce as many fines as the Los Angeles abrasion machine

(7) From the tests, both abrasion and roller, there appears to be a definite relation between the loss through either the No 8, No 10, or No 12 sieve and the total surface area of the sample

(8) The action of the Los Angeles rattler appears to be that of a stone crusher When the tested material is sieved, the gradation of sizes approximates a Fuller curve Seven trips of the 10-ton roller break up aggregate to the same degree as 100 revolutions of the rattler Uncrushed gravel breaks up less than crushed gravel

(9) Under the 5-ton roller degradation is more than one-half of that under the 10-ton roller

Design of Materials for Surfacing

Design of material for such surface treatments, (including percentages of bitumen and properties of aggregates) involves mixing by pugmill to determine if trial mixtures may be too fat or too lean, and the tests of such mixtures for stability using the Kriegil Minitrack The project is now well under way

STABILIZED COUNTY ROADS

Since one duty of the Highway Commission is to advise the counties on the design of road constructions suitable to such traffic, the program turned to the construction of a short test road, in which some 13 sections of stabilized base construction were represented, using portland cement, salt, bitumens, clay, clay bearing gravel, and crushed stone. The test road has been submitted to a light traffic for the purpose of determining how long such experimental base constructions might be used under traffic before a top would be necessary This test road has been surrounded with the usual careful set of observations of soil and road conditions This is Test Road Number 2 in this report

Account of Road Construction and Compaction

The test road was 20 ft wide with side ditches 6 in deep, and 650 ft long, composed of 13 sections each 50 ft in length, located on University property The sections are described in Table 1

Except for sections 17 and 18, the materials were weighed, put through a concrete mixer, and deposited loose between steel forms on accurately struck-off subgrade to a depth of 9 in , then compacted by a sheepsfoot roller, followed by a surface roller, to a depth of 6 in Table 1 states the density of these bases in the test road compared to the laboratory densities with the Proctor Method Subsequent surface densities using sand replacement method were as in Table 2

The intermittent controlled traffic on this test road is by 6500 pounds weight of trucks each, at 15 miles per hour at the rate of approximately 1000 passages of

TABLE 1

Account of Compacted Densities in Laboratory Proctor Cylinder and by Sheepsfoot Roller Test Road No 2

Section No	Description	Loose Dry Density	Compacted Dry lb per cu ft		Wet Field lb per cu ft	Moisture %
			Lab	Field		
17	Clay + PC 6%	75	106 5 110	113	126	12 1
18	Clay 10%	76	107 0 112	114	126	11 4
29	Clay 8%	67	99 5 102	101	115	13 8
19	Stone + Clay	102	133	154	163	6 2
20	Stone + Clay	103		155	163	6 3
21	Gravel + Clay + Salt	101	119 9 120	152	165	9 0
22 3″ course	Gravel + Clay + CaCl-2	109	124 0 120	164	176	7 1
23	Gravel + Clay + AES-1	100	123 1 128	150	162	8 4
24	Gravel + Clay + Bit Stab	100	125 1 129	150	162	8 0
25	Gravel + Clay + TM-2	99	123 8 127	148	161	9 1
26	Gravel + Clay + SC-3	97	127 0 131	146	158	8 3
27	Gravel + Clay + 85–15	100	120 0 130	150	162	8 0
28	Gravel + Clay + 80–20	99	124 0 131	148	163	9 8

Note Loose material weighed into concrete mixer loose, density computed on 9-in depth
Field compaction is from 9 in loose to 6 in compacted, or 1 5 by sheepsfoot roller, in carefully struck-off subgrade between steel forms
Lab upper values are from Winn measurements, on 3 x 7-in cylinder
Lab lower values are from Jackson measurements, on 4 x 5-in cylinder
Nos 17 and 18 clay and cement mixed with rototiller
No 29, clay pulverized, and mixed with cement and water in concrete mixer
No 22 compacted in 3-in layers

TABLE 2

Test Road No 2 Density Measurement by Sand-Replacement Method

Section No	Composition	Density		Moisture %	Density by Gross Wt & Volume
		Wet	Dry		
17	Clay + 6% P C	117	108	7 5	113
29	Clay + 8% P C	113	104	9	101
18	Clay + 10% P C	109	101	8	114

Section 17 and 18, clay in lumps, rototiller mix
Section 29, pulverized clay mixed in concrete mixer

one truck per day. At present, about 10,000 passages between August 30 and December 8, 1938 have shown complete failures in only two sections.

TEST ROAD NO 1 UNDER CLIMATIC CHANGES

Research into soils and modified soil necessarily occupied close attention of the staff, first with respect to relations between several standardized tests in common use, but, principally, with the desire to determine which of the several standard tests now in vogue might be most predictive of what materials would be suitable for service conditions. In the laboratory, materials like those in the test roads were submitted to freezing and thawing tests, wetting and drying tests, and tests on the Kriegil Minitrack

An aim was to study the relation of findings from such laboratory tests to the action of climate on similar materials

Accordingly, another test road, No 1, in which the various combinations of clay, portland cement, salts, bitumens, and other materials were subjected to the action of climate alone, involving change of temperature and change of moisture without traffic, was built From November of 1937 to September of 1938, this test road was observed for changes of moisture, for heaving under frost and moisture, and for stability under a penetrometer. The materials in this test road are given in Table 3

COMPARISON OF STANDARD DURABILITY TEST AND TEST ROAD NO 1

Wetting and Drying Tests Compared to Stability in Test Road No 1

A comparison of these wetting and drying tests with field measurements shows that when the slaking of the laboratory specimen increases, the stability against the penetrometer in the field decreases, in the case of each of the following mixtures, but not in the order listed

Soil and quicklime
Soil and portland cement
Soil and sand
Soil and sand and bitumen
Soil and sand and quicklime

TABLE 3
TEST ROAD NO 1

Section No	Composition
1	Sand
2	Undisturbed Clay
3W	Clay and 6% AES
3C	Clay and 6% TC
3E	Clay and 6% MC-1
4	40–60 Clay-sand and 4% AES
5	40–60 Clay-sand and 4% TC
6	40–60 Clay-sand and 4% MC-1
7W	Clay and 5% Slag
7E	Clay and 40% Slag
8W	Clay and 5% Limestone screenings
8E	Clay and 40% Limestone screenings
9	60–40 Clay-sand
10	60–40 Clay-sand and CaO
11	Clay
12	Clay and 6% CaO
13	Clay and 6% P C
14	Clay
15W	Clay and 1% NaCl
15E	Clay and 6% NaCl
16W	Clay and 1% $CaCl_2$
16E	Clay and 6% $CaCl_2$

TABLE 4
FIELD PERFORMANCE RATING OF MATERIALS IN TEST ROAD NO 1
Rating of Sections December 1938

Materials	South Side		
	Rating According to		
	Ave Max Heave	Ave Moisture Spread	Ave. Penetration
Soil	5	7	5
Soil and Bitumen	7	2	8
Soil and Portland Cement	2	3	1
Soil and Quicklime	6	8	4
Soil and Salts	1	5	7
Soil and Sand & Bitumen	4	1	6
Soil and Sand & Quicklime	3	4	2
Soil and Granular Material	8	6	3

Note The numbers state the best performance—i e the section showing least heave, and therefore rated number 1, is the soil and salts section; the section showing the least moisture spread, and therefore rated number 1, is the soil, sand and bitumen section, and the section showing the least penetration, and therefore rated number 1, is the soil and portland cement section

Wetting and Drying Tests Compared to Resistance to Moisture Change in Test Road No 1

The materials in the Test Road that show the least change of moisture with climatic changes, will show the least slaking of laboratory specimens in the wetting and drying test in the case of each of the following soil mixtures but not in the order listed

Soil and portland cement or quicklime
Soil and sand and bitumen

TABLE 5

FIELD PERFORMANCE RATING OF MATERIALS IN TEST ROAD NO 1 (SOUTH SIDE)

Material	Combined Rating According to Rating for Heave, Moisture Spread, Penetration
Soil and Portland Cement	1
Soil and Sand and Quicklime	2
Soil and Sand and Bitumen	3
Soil and Salts	4
Soil and Bitumen	5
Soil and Granular Material	5
Soil	5
Soil and Quicklime	6

Freezing and Thawing Tests Compared to Stability in Test Road

A comparison of these freezing and thawing laboratory tests with field measurements, indicates that when the withstood number of cycles of freezing and thawing increases, the field penetrometer resistance also increases in the case of the following soil mixtures, but not in the order listed

Soil and bitumen
Soil and sand and bitumen
Soil and granular materials
Soil and portland cement or quicklime
Soil and salt (NaCl)

Freezing and Thawing Tests Compared to Resistance to Moisture Change in Test Road

Also, the materials in the Test Road that show the least change of moisture with climate changes will show the greatest strength under the freezing and thawing test in the laboratory in the case of the following soil mixtures

Soil and portland cement or quicklime
Soil and salt (NaCl)

COMPARISON OF THE RELATIVE SEVERITY OF FREEZING AND THAWING WITH WETTING AND DRYING TESTS

A comparison of the relative severity of freezing and thawing and wetting and drying tests is complicated, since the several materials behave differently under the two methods of test, thus

(1) Under the freezing and thawing laboratory test, the following materials crack and break up without slaking

a Soil and granular material
b Soil and bitumen
c Soil and granular material and bitumen

While (2) under the wetting and drying test, the soil alone and with granular material slakes immediately upon immersion

The slaking is the more severe in mixtures of soil and granular materials, than in soil alone.

(3) Mixtures of soil and bitumen, and of soil and granular materials and bitumen, do not slake immediately, but suffer material losses under repeated cycles

(4) In the case of the following materials listed, comparison between the severity of the wetting and drying test, and the freezing and thawing test indicates that the wetting and drying test is more severe than the freezing and thawing test Each of the materials listed slakes with loss of material in the wetting and drying test

Soil and quicklime
Soil and sand and quicklime
Soil and portland cement

FROST ACTION

A project of particular interest is that reported by Mr H F. Winn,[1] namely, a

[1] This volume, p 264.

study of frost action in stabilized soil mixtures with the aim to reduce heaving and the formation of segregated ice which are responsible for the so-called "spring break-up"

It is well known that ice lenses form in bases of roads and cause an uplift or heave of the surface, bringing about heavy maintenance charges and interruption of traffic The frost works downwards and meets capillary water from below, forming ice The total uplift is equal to the thickness of the ice layers or lenses, so-called available Specimens under test are formed by a method similar to the Proctor method of compaction

The investigations to date have led to the definite conclusion that the moisture content of the material at the beginning of the freezing period is of fundamental importance, and that decisions as to the extent to which frost action may be expected to occur in any stabilized soil mixture can be made only when the limiting conditions of initial moisture content are known For this reason, various initial moisture content

TABLE 6

(1) In fairly dry (2–5 per cent m c) specimens of sandy clay with no granular material, frost heave was reduced to a minimum by the addition of admixtures as follows

Portland cement	6-8%
NaCl	2-3%
$CaCl_2$	2-3%
Tar (TC)	8%
Cutback asphalt (MC-1)	4%
Emulsified asphalt (AES-1)	8%

(2) When specimens are saturated

	Clay Alone	*Graded Mix*
Portland cement	up to 12%-heave	4%, no heave
Tar (TM-2)	8%, serious heave	4%, no heave
Emul as (AES-1)	8%, serious heave	4%, no heave
RC-3		6%, no heave
SC-3	8%, no heave	2%, no heave
NaCl	2-3%, no heave	1-2%, no heave
$CaCl_2$	2-3%, no heave	1-2%, no heave

Mr Winn, of the research staff, has investigated this action in a cold room built in the laboratory for this purpose, wherein specimens of clay, clay with sand and with stabilizing admixtures are subjected to freezing temperatures from above, and with a water supply from below the specimens Specimens are completely surrounded by dry sand so that the frost enters the specimen from the top only The temperature of the cabinet is gradually lowered from +30°F to −10°F during a period of 21 days One cycle of freezing has been used Temperatures of 20° below zero are conditions were included in the testing process (1) materials tested after curing to low moisture content, 2 to 5 per cent, corresponding to conditions after a dry fall, (2) materials tested with initial moisture contents of 40 to 80 per cent saturation resulting from curing and then immersing in water for several days, and (3) materials tested when all of the voids are filled with water or at 100 per cent saturation

While the investigation is still in progress, current results may be cited as in Table 6

ALTERNATE METHODS OF LABORATORY TEST

It was evident that the routine laboratory tests were expensive in time. Some simpler test might be found, such as a plain compression test of a cylinder or a ball test, wherein a ball penetrates the surface of the material either under static or impact condition. Naturally, a correlation of these results needs an extended analysis Mr Mayo, of the staff, has been working on a standardization of the compression cylinder test, with an aim to producing a cylindrical specimen of uniform density with a typical cone fracture which will thus give a measure of shearing strength of the soil or soil mixture He has found that by simultaneous pressure on the top and the bottom of the specimen which forces the loose material into a mould, uniform compaction results and the density of the finished specimen is the same as that which he calculates from the material of which the specimen is to be composed Thus far, the materials experimented with have been clay alone, and clay mixed with portland cement, the latter with percentages of 6, 8, and 10 in a series contemplating 2, 4, 6, 8, 10, and 12 per cent. Stress-strain diagrams are drawn from a simple compression test The results of the compression test will be compared with the behavior of the materials in the two test roads. For example, with 10 per cent of moisture in specimens and with 6 and 10 per cent of portland cement in silty clay, the following results were obtained

	6% lb per sq in	10% lb per sq in
Ultimate strength	277	454
Elastic limit	74	162
Modulus of Elasticity	5000	12,000

ROCK ASPHALT

Experience with the service supplied by rock asphalt surfacing led to a prolonged study of that product from Kentucky, starting with the quarry, through the mill, to the use of the material in construction and its service under traffic. Research work on the characteristics of bitumen and a study of methods of recovering bitumens from samples taken from construction is proceeding.

Stockpile Curing of Rock Asphalt from Two Different Sources

The desirable duration of curing action in plant stock piles was first examined in 1937 in the case of two deposits, one with a soft asphalt and one with a hard asphalt Samples were taken from these stock piles and cured in the laboratory

In 1938 fresh material was secured from these deposits and cured in stock piles at the laboratory

One stockpile, containing rock asphalt with a high penetration of the recovered asphalt, has shown a gradual increase in hardness from the original uncured material to 90-day cured material. The penetration on the original material was 166, which dropped to 86 in 30 days, to 61 in 60 days, and to 47 in 90 days. Samples from the interior of this same stockpile have shown less hardening and have a penetration of 126 after 90 days of curing

The other stockpile, containing a hard recovered asphalt, has shown only slight increase in hardness after 90 days of curing The crust of the stockpile has decreased in penetration from 23 for the original material to 17 in 90 days The interior of this pile has shown no appreciable difference in penetration after 90 days

Minitrack Tests on Rock Asphalt Samples

Rock asphalt containing the soft recovered asphalt has shown an increase in stability with curing and consequent hardening of the asphalt. The failure position of the uncured material was 8 and increased to 12 in 30 days; to 16 in 60 days, remained at 16 for the 90-day sample; and increased to 20 in 120 days.

The rock asphalt with the hard asphalt has also shown an increase in stability from failure position 4 for the uncured material; to 8 for 30 days; to 8 for 60 days; to 9 for 90 days; and to 10 for 120 days

Hubbard-Field Stability Tests for Comparison

These observations on curing conditions confirm previous observations on laboratory cured materials from the same sources Stability values for the crust of the stockpile containing the soft asphalt, showed increases from 933 lb for uncured material to 1517 lb in 30 days, to 1942 lb. in 60 days, to 2050 lb in 90 days.

Stability values for the stockpile containing hard recovered asphalt increased slightly from 1542 for fresh material to 1583 in 30 days, to 1758 in 60 days; to 1775 in 90 days

In this series of investigations, the increase in stability seems to vary directly with the percentage drop in penetration with curing. The soft asphalt has decreased in penetration in a comparatively straight line relationship from 166 to 47 in 90 days. The hard asphalt has shown very little change in penetration in 90 days, i e , from 23 to 17