plants to our state in increasing numbers. Our roads, already the major transportation system of the state, must meet additional demands in serving these industries and in rendering a greater service to the agricultural sections of our state. It is not a question of this year or next year alone—we must anticipate and build for the future.

I feel that you, representing all phases of the road industry— for it is an industry today—are rendering an invaluable public service; and that you have before you the rendering of an even greater service through your performance of the duties with which you are charged.

This is to me an occasion of more than ordinary significance in the history of Indiana's roads and their administration. Tonight we observe the Silver Anniversary of the Purdue Road School, an occasion when we meet to discuss and work out some of the problems of roads. It is a demonstration of the path which has led Indiana to the forefront in the building and maintaining of a highway transportation system. In this and preceding sessions we combine the practical with the scientific, exchanging experiments of the laboratory with experience in the field—all to the end that we may build better, safer, and more permanent roads for the future.

Again may I express my appreciation of this opportunity to discuss with you some of the problems of Indiana's roads and extend my congratulations on the fine record which you are making toward the solution of those problems.

THE CO-OPERATIVE HIGHWAY RESEARCH PROJECT

W. K. Hatt,
Former Director, Joint Highway Research Project,
Purdue University

A co-operative highway research project was entered into between the State 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.

Dr. H. F. Kriege has been research consultant since the inception of the project and has contributed his mature scientific chemical talent and engineering experience to the staff.

During the first period, from February 20, 1936, to June 30, 1937, a program of research, mainly directed to secondary roads, was formulated. A staff of research workers was employed, and the chemical and physical laboratories were implemented. At the present time substantial progress has been made in the program, which further study has modified.

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 a view to determining, if possible, the causes of failures and to making some recommendations to rectify them. Field inspections were made; and 221 surface samples were collected for laboratory analysis of the various surface treatments, principally those constructed in 1935, in each of the six highway districts. From our field observations and laboratory analysis of these samples, we found the following:

1. That the most prevalent type of failure, exclusive of base failure, was ravelling.
2. That those samples which contained a smaller amount of bitumen ravelled more.
3. That a wide variation existed in the grading of the aggregates and proportions of materials. The percentage of bitumen in the samples varied from 3 to 12 per cent. The surface area of the aggregates in the samples varied from 1000 to 7000 sq. cm. per 100 grams.
4. That apparently there is need for a study of bituminous mixtures composed of various types of bitumens and aggregates, and for consideration of the use of a plant mix.

A study was made of the 100 miles of road surface treated under contract in 1936, and a condition survey was 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 during manipulation and rolling during construction.
2. That there is a gradual breaking down of the aggregate under traffic in these surface treatments with time. For example, we find, from an analysis of 40 samples, that there was an increase, during 10 months of traffic, of approximately 45 per cent 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 by means of chemical tests and by wash tests of the relative adhesion of several bitumens to a variety of aggregates. 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 on a bituminous base. Co-ordinate 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 five- and a ten-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 pounds) 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 was 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 ten-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 ten-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 ten-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 our tests, both abrasion and roller, there appears to be a definite relation between the loss through either the Nos. 8, 10, or 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 ten-ton roller break up aggregate to the same degree as do 100 revolutions of the rattler. Uncrushed gravels tested break up less than crushed gravel.

(9) Under the five-ton roller degradation is more than one-half that under the ten-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 with the Kriegil Minitrack. The project is now well under way.

STABILIZED COUNTY ROADS

Since it is one duty of the Highway Commission to advise the counties on the design of road construction 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 light traffic with the intention of determining how long such experimental base constructions might be used under traffic before a top might be necessary. This test road has been surrounded with the usual careful set of observations of soil and road conditions.

The test road, on University property, was 20 feet wide with side ditches 6 inches deep and 650 feet long, composed of 13 sections each 50 feet in length. They are listed as follows:

Test Road No. 2

Section No.	Composition
17	Soil and 6% portland cement
18	Soil and 10% portland cement
19	Crusher-run stone and 15% soil
20	Crusher-run stone and 15% soil with 15 lb. per sq. yd. screenings on surface
21	Pit-run gravel and 15% soil with 0.5% NaCl
22	Pit-run gravel and 15% soil with 0.5% $CaCl_2$ in top 3 inches
23	Pit-run gravel and 15% soil with 4.4% AES-1
24	Pit-run gravel and 15% soil with 4.4% bitumuls
25	Pit-run gravel and 15% soil with 4.4% TM-2
26	Pit-run gravel and 15% soil with 4.4% SC-3
27	Pit-run gravel and 15% soil
28	Pit-run gravel and 20% soil
29	Soil and 8% portland cement

Except for sections 17 and 18, the materials were weighed, put through a concrete mixer, and deposited loose between steel forms on an accurately struck-off subgrade to a depth of 9 inches, then compacted by a sheepsfoot roller, followed by a surface roller, to a depth of 6 inches. Subsequent surface densities using sand replacement method were as follows:

Test Road No. 2
Density Measurement by Sand-Replacement Method

Section No.	Composition	Density		% Moisture	Density by Gross Wt. and 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

Sections 17 and 18, clay in lumps, rototiller mix.

Section 29, pulverized clay mixed in concrete mixer.

The intermittent controlled traffic on this test road is by trucks of 6,500 pounds weight each, running at fifteen miles per hour and making approximately 1,000 passages of one truck per day. At present, about 10,000 passages between August 30 and December 8, 1938, have shown appreciable failures in only two sections.

TEST ROAD NO. 1 UNDER CLIMATIC CHANGES

Research into soils and modified soil necessarily occupied the close attention of the staff, first with a view to determining 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.

One 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, was built, 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. 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:

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 3.58% 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% $CaCl_2$

TEST ROAD NO. 1
Field Performance Rating of Materials
(as of 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 and bitumen	4	1	6
Soil and sand and quicklime	3	4	2
Soil and granular material	8	6	3

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.

TEST ROAD NO. 1
Field Performance Rating of Materials
(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

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 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.

The materials in the test road that show the least change of moisture with climate changes will show the least slaking of laboratory specimens in the wetting and drying test in each of the following soil mixtures, but not in the order listed: soil and portland cement or quicklime; soil and sand and bitumen.

A comparison of these freezing and thawing laboratory tests with field measurements indicates that when the number of cycles of freezing and thawing withstood increases, the field penetrometer resistance also increases in 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).

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 following soil mixtures: soil and portland cement or quicklime; soil and salt (NaCl).

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.

(2) Under the wetting and drying test, the soil alone and soil with granular material slake 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 materials listed below, a 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 a study by Mr. H. F. Winn of frost action in stabilized soil mixtures to reduce heaving and the formation of segregated ice conditions which are responsible for the so-called "spring break-up."

It is well known that ice lenses form in bases of road and cause an uplift or heave of the surface, bringing about heavy maintenance charges and interruption of traffic. The frost, working downwards and meeting capillary water from below, forms ice. The total uplift is equal to the combined thickness of the ice layers or lenses, so-called.

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 clay 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 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 conclusions 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 conditions were included in the testing process: (1) materials tested after curing to low moisture content, 2 to 5%, corresponding to conditions after a dry fall, (2) materials tested with initial moisture contents of 40 to 80% 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% saturation.

While the investigation is still in progress, current results may be cited:

(1) In fairly dry (2-5% 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

ALTERNATE METHODS OF LABORATORY TEST

It was also 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, to produce a cylindrical specimen of uniform density with a typical cone fracture and thus give a measure of the 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 calculated 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 in the field 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%	10%
Ultimate strength	277	454
Elastic limit	74	162
Modulus of elasticity	5,000	12,000

(all in pounds per square inch)

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 the bitumen and a study of methods of recovering bitumens from samples taken from construction are proceeding.

The desirable duration of curing action in plant stock piles was first examined in 1937 in 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, and 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 a 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 containing the soft recovered asphalt have 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, and to 16 in 60 days, remained at 16 for the 90-day sample, and increased to 20 in 120 days.

The rock asphalt containing 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.

These observations on curing conditions confirm previous observations on laboratory-cured materials from the same sources. Hubbard-Field stability values for the crust of the stockpile containing the soft asphalt showed increases from 933 pounds for uncured material to 1,517 in 30 days, to 1,942 in 60 days, to 2,050 in 90 days.

Stability values for the stockpile containing hard recovered asphalt increased slightly from 1,542 for fresh material to 1,583 in 30 days, to 1,758 in 60 days, to 1,775 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.

CONCLUSION

It will be seen, therefore, that the program of the Joint Highway Research Project is arranged to aid in the solution of some of the problems of the Highway Commission in Indiana. The staff has been careful to see that the work is conducted under such scientific care that a number of relations of general scientific value will result.

RIDE AND LIVE

Paul G. Hoffman,
President, The Studebaker Corporation,
South Bend, Indiana

Thirty years ago this spring I was the chauffeur on the first long motor trip of the Hoffman family. The car was a 1905 Pope-Toledo purchased second-hand by my father at a cost of approximately $1,500. It was an open car. The chassis would have done credit to Rube Goldberg. Advertisements called it the world's first mile-a-minute automobile. Tires cost from $75 to $90 apiece, were good for about 2,500 miles; punctures were frequent. A steering knuckle cost $30, and a new one was needed every so often. Springs, priced at about $30, broke every time you hit a bad bump. There were seven lugs on each wheel; to change a tire was a major operation. For touring we carried 16 spark plugs, all available inner tubes, two extra casings, tools enough to outfit a small garage. We lived in Western Springs, southwest of Chicago. Our trip, for which we had to wait until spring, had as its destination Sycamore, Illinois, approximately sixty miles away. Preparations were made weeks ahead. We started bright and early on Saturday morning, with five people and an enormous hamper of lunch. Our adventures, briefed, were as follows:

In the first few miles I changed four spark plugs. Otherwise, everything was lovely.

On the far side of the Fox River I tried to shift from third to second gear to climb a hill, and failed. When the car was out of gear there was no service brake. We started to roll backward. My aunt screamed, tossed out the lunch basket, and followed it herself in a flying leap. I stopped the car by backing into the bank.

After trying again and making the grade, we reached a fork in the road. Nobody knew which one to take, and we had no maps. Father said "left," and Grandfather said "right." Grandpa had the more positive manner, and we went right. We should have gone left.

It began to rain. Considerable time was lost putting up the curtains.

The road became a bog in which we finally sank. I cut brush to give the wheels traction. We got out of the first mudhole, went a short way, sank again.

Night came on. I lighted the headlamps. Old-fashioned rock-carbide lamps, they flickered and flickered, went out. No help at all for seeing ahead. We slid into the ditch and were